JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GEOTECHINICAL ENGINEERING CHAIR

Investigation of Dynamic behaviors of soils of Shashemene Town

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Geotechnical Engineering)

By: -Yeabsira Mesfin

January, 2018

Jimma, Ethiopia

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By: -Yeabsira Mesfin

Advisors:

Main Advisor: Dr.Siraj Mulugeta (PhD)

Co Advisor: -Mr. Jemal Jibril (PhD fellow)

January,2018

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Declaration

This thesis is my original work and has not been presented for degree in any other university.

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Name Signature Date

This thesis has been submitted for examination with my approval with university supervisors

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Co-Advisor Signature Date

3. _________________________ ___________ _____/______/_____

External -Examiner Signature Date

4. _________________________ ___________ _____/______/____

Internal-Examiner Signature Date

5. _________________________ __________ _____/______/_____

Chair- Person Signature Date

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Also I would like to thank to my beloved family members and friends.

Table of Contents

List of Symbols and Abbreviations

JIT	Jimma institute of Technology
ASTM	American Society for Testing Materials
Aloop	Loop area
Cu	Uniformity Coefficient
D	Damping ratio
e	Void ratio
G	Dynamic shear modulus
Gmax	Maximum Dynamic shear modulus
Gs	Specific gravity of soil
Ko	Coefficient of lateral earth pressure at rest
LL	Liquid limit
Pc	Pre-consolidation pressure
PI	Plastic index
PL	Plastic Limit
OCR	Over consolidation ratio
SM	Silty sand
TP	Test pit
WD	Dissipated energy stored
Wn	Field moisture content
Ws	Maximum strain energy
Vs	Shear wave velocity
ɣ	Shear strain
ρ	Density of soil

σ	Normal stress
$\sigma'o$	Effective confining stress
$\sigma'v$	Effective vertical stress
τ	Shear stress

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ABSTRACT

The nature and distribution of earthquake damage is strongly influenced by the response of soils to cyclic loading. The better understanding of the dynamic properties of some particular natural soil such as the Mexico City clays or the San Francisco Bay mud, together with the actual ground motion measurements during the Michoacan-1985 and the Loma-Prieta earthquakes, have been greatly contribute to show off the importance of local site conditions and dynamic properties of natural soils. Of those dynamic properties, the shear modulus and damping characteristics of cyclically loaded soils are critical to the evaluation of geotechnical engineering problems. Generally, soil is a nonlinear material which causes nonlinear seismic loading responses of grounds especially for earthquake ground motions corresponding to strain level ($\gamma \geq 0.01\%$).

The general objective of this research is to investigate the dynamic properties of soils found in Shashemene town.

In this thesis, the shear modulus and damping ratio values of soils commonly found in Shashemene were determined using cyclic simple shear testing machine on remolded samples. The tests were conducted as a function of cyclic strain amplitude of 0.01 %, 0.1 %, 1 %, 2.5 %, and 5% under the axial pressures of 100kPa, 200kPa,300kPa and 400kPa. The test results revealed that the shear modulus reduction values are in good agreement with curves of local soils but slightly lower than other established literature value at the highest strain level (γ >0.1 %). The damping ratio value of the tests are generally in acceptable range with curves of local soils but slightly lower than the other literature values. This indicates that, the testing conditions appear to have significant effect on the damping ratio values but little effect on the shear modulus reduction values. The cyclic simple shear test machine, currently functional in the laboratory, is capable of reproducing earthquake stress condition accurately. Moreover, the index properties of the soil are determined for characterization of the soil in the town to setup schedules of dynamic property investigations in this research.

Key words : *Shear modulus (G), Damping ratio(D), Shear stress (τ) ,Shear strain (γ)*

CHAPTER ONE

INTRODUCTION

1.1. Back Ground

The behavior of soils when they are subjected to dynamic loading is investigated in this research. In Soil Dynamics and Earthquake Engineering that deformation characteristics of soils, expressed in terms of shear stiffness and damping ratio are the fundamental parameters describing soil behavior. These parameters are required for the estimation of the response of soil and soil-structure systems, when subjected to cyclic and dynamic loadings, i.e., earthquakes, vehicular traffic, machine vibration, pile-driving, blasting, etc. The potential damage caused by Earthquake phenomena includes: loss of bearing capacity, excessive settlement, lateral spreading, flow failure, and ground oscillation.

Vibrations are generated by manmade and natural disasters. The factors affecting the shaking due to an earthquake at a site are soil structure interaction, local soil conditions, path of the wave and location of the source. Soil acts like a dynamic oscillator and affects the ground motion of the structures constructed on top of it to a great extent. The soil structure interaction has two main parts which comprises of kinematic effect and inertial effect, in the former one the flexibility of the soil will influence the response of the soil structure system, and in the latter one the mass of the structure influences the response of the soil structure system. [5]

The type of dynamic loading in soil and foundation of a structure depends on the nature of the source producing it. Dynamic loads vary in their magnitude, direction and position with time.

The dynamic properties of soil in Shashemene have not been investigated so far. In this thesis, the shear modulus and damping ratio values of soils commonly found in Shashemene are to be investigated in the laboratory using the cyclic simple shear testing machine on remolded samples. In addition, some important properties of the soil tests have been determined for better characterization of soils.

This thesis presents results of cyclic simple shear tests, performed for the investigation of the dynamic properties of natural silty sand soils from Shashemene. The behavior of soils is described and the implications of the test results for seismic site response are discussed.

There are two reported earthquakes with epicenters fitting to the area of the Shashemene sub-sheet. The earthquake from September 6th 1944 is likely to have taken place in the south-western corner of the sub-sheet, but the location and even the occurrence of this event is very uncertain. There was, however, another earthquake (magnitude 5.1) on December 2nd 1983 most likely in the area between the Lake Cheleleka basin and the Wendo Genet scarp to the south of Wendo Genet. [Geological Survey of Ethiopia]

The methods used commonly to determine the parameters of dynamic properties of soils are cyclic simple shear test, cyclic torsional simple shear test, cyclic triaxial test and resonant column test.

The dynamic behaviors parameters (Shear modulus and Damping ratio) are used in the design and evaluation of the behaviors of earthen, earth-supported and earth-retaining structures.

Factors affecting the shear modulus and damping ratio of soils have been studied by Hardin and Drnevich; (1972a; 1972b) these factors are strain amplitude, void ratio, effective confining pressure, frequency of loading, number of loading cycles, over consolidation ratio, degree of saturation, grain characteristics and time.

1.2 Statement of the Problem

Investigation of dynamic properties of soils is one of the most important geotechnical investigations in order to know the ground response under seismic loading which can lead to severe geotechnical problems such as permanent settlement, tilting of structures, liquefaction and so on.

The Shashemene area is located to the east of the active volcanoes of the Corbetti volcanic system. Such a position is vulnerable in the zone of predominating western winds. Southern Ethiopia reveals seismic activity, which combines several types of earthquakes.

Developing cities like Shashemene needs proper and detail investigation of the dynamic properties of soils for design of any civil structures which was built and to be built in the town. In addition, Shashemene is classified as zone 4 of seismic zones in Ethiopia which in deed needs a special attention for the proposed case. Therefore, knowing and determining the dynamics properties of soils of Shashemene town will prevent the town from damages and lose of human lives caused by problems related to earthquake by designing structures with seismic consideration.

1.3 Objectives

1.3.1 General Objective

The general objective of this research is to investigate the dynamic properties of soils found in Shashemene town.

1.3.2 Specific Objectives

The specific objectives of this research are;

- To identify the soil type found in the area
- To determine shear modulus and damping ratio of soil specimens
- To compare the results of the findings with similar researches of Adama and Ziway town of Ethiopia.

1.4. Scope of the Investigation

This thesis is limited to routine cyclic simple shear test and index properties test for the soils found in Shashemene with coverage area 130 $km^2$and also limited to parameters of dynamic properties of soils (damping ratio and shear modulus). The transportation problem and the soil character make the retrieval of undisturbed soil samples for laboratory test difficult. Hence, disturbed soil samples will be collected from the test pits.

Soil samples are taken from five test pits and Samples were taken from a depth 3m natural ground surface depending on the soil profile found in the study area.

1.5. Organization of the Thesis

This research is organized in five chapters. The first Chapter gives a brief description of the thesis background, objectives, scope, and the methodology employed. Chapter 2 of this research gives review on dynamic soil characteristics of soils, and stiffness and damping values of soils. Chapter 3 presents details about the research methodology used. Chapter 4 explains the results obtained from laboratory tests and Chapter 5 presents the conclusions, recommendations, and possibility of extension of this study for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Even though the study of earthquake dates back many centuries, the analysis of earthquake effect on structures based on the dynamic soil property is a recent phenomenon. The nature and distribution of earthquake damage is strongly affected by response of soil deposits and earth structures under seismic loading conditions. The evaluation of the dynamic properties of natural soil deposits is of prior importance in order to solve problems involving soil -structure interactions, to study the site response, to predict the ground motion and to proceed to seismic zonation [16]. Ground motion under earthquake loading is influenced by the soil condition, but the non-linearity of the soil behavior makes it difficult to estimate the site response. The values of dynamic properties of soils; shear modulus and damping ratio are influenced by plasticity index, void ratio, relative density, number of cycles, grain size distribution, type of soils, over burden pressure, location of ground water and amplitude of earthquake (amplitude of cyclic loading). The shear modulus and damping ratio are obtained from laboratory and field tests. In literature review basic physical properties of soils and soil response under cyclic loading are examined.

2.2. Some important properties of Soil

2.2.1. Physical States and Index Properties of soil

Soils are aggregates of mineral particles, and together with air and/or water in the void spaces, they form three-phase systems. A large portion of the earth's surface is covered by soils, and they are widely used as construction and foundation materials [4]. Index Properties are properties of a soil which help to classify the soil to assess the engineering behavior of the soil under study. The physical properties which show the state of the soil are soil color, soil structure, texture, particle shape, grain specific gravity, water content, density index, in-situ unit weight, consistency limits, and particle size distribution, and related indices [27].

2.2.1.1 Particle Shape and Size

The particle shape of coarse-grained soils may be described as 'angular', 'sub-angular', 'sub-rounded', 'rounded' and 'well-rounded'. Silt and clay constitute the finer fractions of the soil and one grain of this fraction generally consists of only one mineral. Microscopic studies of clay and silt soil indicates that the particles are angular, flake shaped or sometimes needle-like shape [4].

2.2.1.2 Specific Gravity

The specific gravity of soil (Gs) is defined as the ratio of the mass in air of a given volume of soil particles to the mass in air of an equal volume of gas free distilled water at a stated temperature (20°C). The specific gravity is determined by means of a calibrated pycnometer, by which the mass and temperature of a de-aired soil/distilled water sample is measured [16]. The specific gravity of the soil grains has value in computing the void ratio, degree of saturation and particle size by wet analysis when the unit weight and water content are known. Typical values of specific gravity are presented in Table 2.1 below.

Table 2. 1 Specific gravity value of some soil types

S.No	Soil type	Grain specific gravity
1	Quartz sand	2.64 - 2.65
2	Silt	2.68-2.72
3	Silt with organic matter	2.40 - 2.50
4	Clay	2.44-2.92
5	Bentonite	2.34
6	Loess	2.65-2.75
7	Lime	2.7
8	Peat	1.26 - 1.80

2.2.1.3 Moisture Content

Moisture content of a soil has a direct bearing on strength and stability of fine-grained soils. The knowledge of water content is necessary for classification, for correlation studies and for the calculation of stability of all kinds of earth works [26]. The water content of soil can influence the behavior of cyclically loaded soil specimen, as it controls grain to grain slippage and pore water pressure development.

2.2.1.4 In-situ Unit Weight

The in-situ unit weight refers to the unit weight of a soil in the undisturbed condition. The in-situ unit weight can be determined using either a sand-replacement or drive cylinder method. According to ASTM-D 2937-94, drive-cylinder method is used to determine the in-place density of natural, inorganic soils which do not contain significant amount of particles coarser than 4.75 mm, and which can be readily retained in the drive cylinder. For this research, the Drive-cylinder method has been used to determine the field density of the soils in each test pits.

2.2.1.5 Grain Size Distribution

For a basic understanding of the nature of soil, the distribution of the grain size in a given soil mass should be known. The distribution of particle sizes larger than 75 µm is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer [26]. The grain-size distribution can be used to determine some of the basic soil parameters, such as the effective size, the uniformity coefficient, and the coefficient of gradation. Grain size distribution affects the seismic response in soil deposit [21].

2.2.1.6 Soil Classification

A soil classification should permit the engineer to easily relate the soil description to its behavior characteristics. All soils are normally classified according to one of the following two systems. **Unified Soil Classification System (USCS):** This system is used primarily for engineering purposes and is particularly useful to the Geotechnical Engineer.

Therefore, they should be used for all structural-related projects; such as bridges, retaining walls, buildings, etc. Precise classification requires that a grain size analysis and Atterberg Limits tests be performed on the sample.

AASHTO Classification System: This system is used generally to classify soils for highway construction purposes and therefore will most often be used in conjunction with roadway soil surveys. Like the Unified System, this system requires grain size analysis and Atterberg Limit tests for precise classification.

2.3. Dynamic Soil Properties

2.3.1 Shear Modulus

Soil stiffness is represented by either shear-wave velocity or shear modulus. Because most soils have curvilinear stress-strain relationships, the tangent shear modulus (Gtan) varies through a cycle of loading but, its average value over the entire loop can be approximated by the secant shear modulus, Gsec, which is commonly called equivalent shear modulus (G) [4]. The relationship between maximum shear modulus (Gmax), secant shear modulus (Gsec), shear strain (ɤ), and shear stress (τ) is illustrated in Figure 2.1. In addition, the figure shows the relationship between the stress–strain hysteresis loop for one cycle of loading and the material damping ratio. Using the equivalent linear analysis method, the secant shear modulus can be determined by the extreme points on the hysteresis loop.

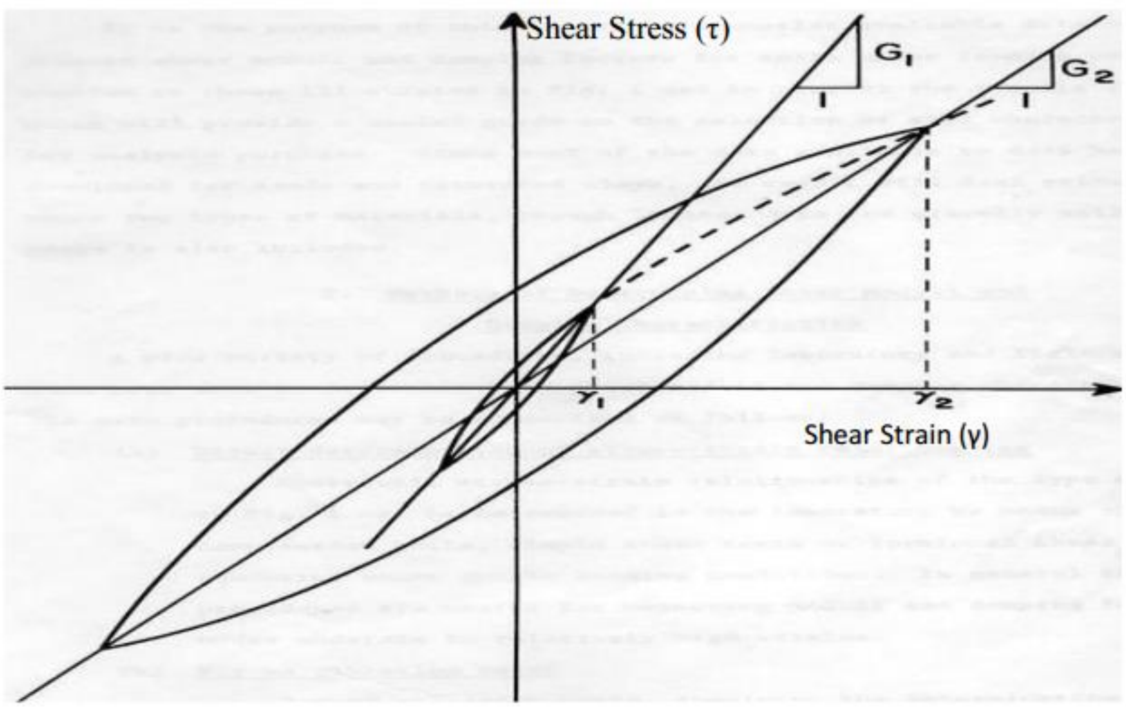

Figure 2-1 Hysteretic Stress-strain Relations at Different Strain Amplitudes [13]

2.3.2 Damping Ratio

The second key dynamic parameter for soils is damping. Two fundamentally different damping phenomena are associated with soils, namely material damping and radiation damping.

(I) Material damping

Material damping (or internal damping) in a soil occurs when any vibration wave passes through the soil. It can be thought of as a measure of the loss of vibration energy resulting primarily from hysteresis in the soil. Mechanisms that contribute to material damping are friction between soil particles, strain rate effect, and nonlinear soil behavior. As the soil elements loose stiffness with the amplitude of strain, its ability to dampen dynamic forces increases and damping decreases with confining pressure, void ratio, geologic age, and plasticity index and sometimes with cementation. [7]. The hysteretic damping ratio can be calculated by

$$D = \frac{Wd}{4\pi Ws} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.1)$$

Where Wd = energy dissipated in one cycle of loading, and Ws=maximum strain energy stored during the cycle. As noted in Fig.2.1, the area inside the hysteresis loop is Wd, and the area of the triangle is Ws. Theoretically, there should be no dissipation of energy in the linear elastic range for the hysteretic damping model. However, even at very low strain levels, there is always some energy dissipation measured in laboratory specimens. The damping ratio at very low strain levels is a constant value and is referred to as the small-strain damping ratio (Dmin). At higher strains, nonlinearity in the stress–strain relationship leads to an increase in material damping ratio with increasing strain amplitude [18].

(II) Radiation damping

Radiation damping is a measure of the energy loss from the structure through radiation of waves and it is a purely geometrical effect. The theory for the elastic half-space has been used to provide estimates for the magnitude of radiation damping, Whitman and Richart (1967) [2]. Radiation damping is frequency independent and only theoretical values for a particular type of footing and its usefulness may be for qualitative rather than quantitative assessments [2].

2.2.3. Normalized Shear Modulus

The current state of practice for determining shear modulus (G) and material damping (D) for ground response analysis involves: (1) estimating or measuring shear wave velocity (V_S) in the field and (2) estimating or measuring the variation of G and D with the strain γ, primarily in the laboratory. It is a common practice to normalize G by dividing it by Gmax. A plot of the variation of G/Gmax with γ is called a normalized modulus reduction curve. Since most seismic geophysical tests induce shear strains lower than about $3*10^{-4}$%, the measured shear wave velocities can be used to compute Gmax as suggested by Luna, R., and Jadi, H. [7]:

$$Gmax=\rho*(V_S)^2 \qquad (2)\ [17]$$

Where: ρ is the density of the soil deposit and V_S is shear wave velocity.

The use of measured shear wave velocities is generally the most reliable means of evaluating the in situ value of Gmax for a particular soil deposit. When shear wave velocity measurement is not available Gmax can be estimated in different ways. Hardin and Drnevich [13] developed a particular relationship with Gmax for an isotropic state of stress:

$$Gmax = 3.23 * \frac{((2.97 - e)^2)}{1 + e} * (OCR)^K * (\sigma'_0)^{0.5} \qquad (2.3)$$

$$\sigma'_0 = \frac{(\sigma'_v + 2K_0\sigma'_v)}{3} \qquad (2.4)$$

Where: e = void ratio

OCR = over consolidation ratio

σ'_o = Effective confining stress

σ'_v = Effective vertical stress

K_o =coefficient of lateral earth pressure at rest

k =dimensionless quantity which is a function of PI.

Although developed for cohesive soils, this equation was found to be applicable to cohesion less soils simply by setting k equal to 0 (PI is equal to 0) [8].

Table 2-2 Empirical Values of Exponential Parameter (k) Proposed by Hardin and Drnevich [13]

PI	k
0	0
20	0.18
40	0.30
60	0.41
80	0.48
≥100	0.50

2.4. Methods of Determining Shear Moduli and Damping Characteristics

A wide variety of procedures, including laboratory and field tests have been used to determine both shear modulus and damping characteristics. The main procedures can be summarized as follows:

2.4.1. Direct Determination of Stress-Strain Relationships

Hysteretic stress-strain relationship of which is shown in Figure 2-1 can be determined in the laboratory by means of triaxial compression tests, simple shear tests or tensional shear tests conducted under cyclic loading conditions. In general, these procedures are useful for measuring shear modules and damping factors under moderate to relatively high strains ($0.01<\gamma<5\%$).

2.4.2. Forced Vibration tests

Forced vibration tests, involving the determination of resonant frequencies and measurement of response with different frequencies have been used to determine both shear modules and damping factors. Test conditions in the laboratory have included the application of longitudinal vibrations and tensional vibrations to cylindrical samples or shear vibrations to layers of soil placed on a shaking table. In general, these procedures are useful for determining properties at relatively low to moderate strain levels ($10^{-4}< \gamma <10^{-2}\%$).

2.4.3. Free Vibration Tests

Free vibration tests, in which measurements are made of the decay in response of a soil sample or soil deposit, have been used to measure both shear modules and damping factors for soils. Methods of excitation are essentially similar to those used for forced vibration tests, but the procedures can be used for measurement of soil characteristics at relatively low to moderately high strain levels ($10^{-3} < \gamma < 1\%$).

2.4.4. Field Measurement of Wave Velocities

Field tests have been used to measure the velocity of propagation of compression waves, shear waves, and Rayleigh waves from which values of soil modulus can readily be determined for low strain ($\gamma \leq 10^{-4}\%$) conditions. These procedures have not provided values of damping factors. The different test procedures for measuring 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 procedure	Test condition	Approximate strain range	Properties can be determined
Determination of hysteretic stress-strain relationships	Triaxial compression	$10^{-2} to\ 5\%$	Modulus : damping
	Simple shear	$\mathbf{10^{-2} to\ 5\%}$	**Modulus : damping**
	Torsional shear	$10^{-2} to\ 5\%$	Modulus : damping
Forced vibration	Longitudinal vibrations	$10^{-4} to\ 10^{-2}\%$	Modulus : damping
	Torsional vibrations	$10^{-4} to\ 10^{-2}\%$	Modulus : damping
	Shear vibration -Lab	$10^{-4} to\ 10^{-2}\%$	Modulus : damping
	Shear vibration -field	$10^{-4} to\ 10^{-2}\%$	Modulus : damping
Free vibration tests	Longitudinal vibrations	$10^{-3} to\ 1\%$	Modulus : damping
	Torsional vibrations	$10^{-3} to\ 1\%$	Modulus : damping
	Shear vibration -Lab	$10^{-3} to\ 1\%$	Modulus : damping
	Shear vibration -field	$10^{-3} to\ 1\%$	modulus
Field wave velocity measurements	Compression waves	$5x10^{-4}\%$	modulus
	Shear waves	$5x10^{-4}\%$	modulus

2.5. Factors Affecting Shear Modulus and Damping Ratio

When a soil is subjected to earthquake or cyclic loading, the shear modulus and damping ratio of the soil are influenced by many factors. Those factors affecting the shear modulus and damping ratio of soils have been studied by Hardin and Drnevich [13]. These factors are:

- ✓ Strain amplitude, c
- ✓ Void ratio, e
- ✓ Effective confining stress, σ'o
- ✓ Frequency of loading
- ✓ Effective stress strength parameters, c' and Φ'
- ✓ Number of loading cycles, N
- ✓ Over consolidation ratio, OCR
- ✓ Degree of saturation, and grain characteristics,
- ✓ Time effects

2.5.1. Shearing Strain Amplitude

Strain has an extreme influence on dynamic properties of soil; therefore, tests should be carried out at definite strain amplitude. For small-strain tests, the shearing strain amplitude is controlled below 0.001% for any test. For the nonlinear dynamic properties tests, the shearing strain amplitude is increased from possible low level to possible high level, ($0.001\% < \gamma < 0.1\%$) and for higher strain tests, the shearing strain amplitude is controlled larger than 0.1%. Figure 2-2 show at low strain amplitude, the shear modulus is high, but it decreases as the strain amplitude increases.

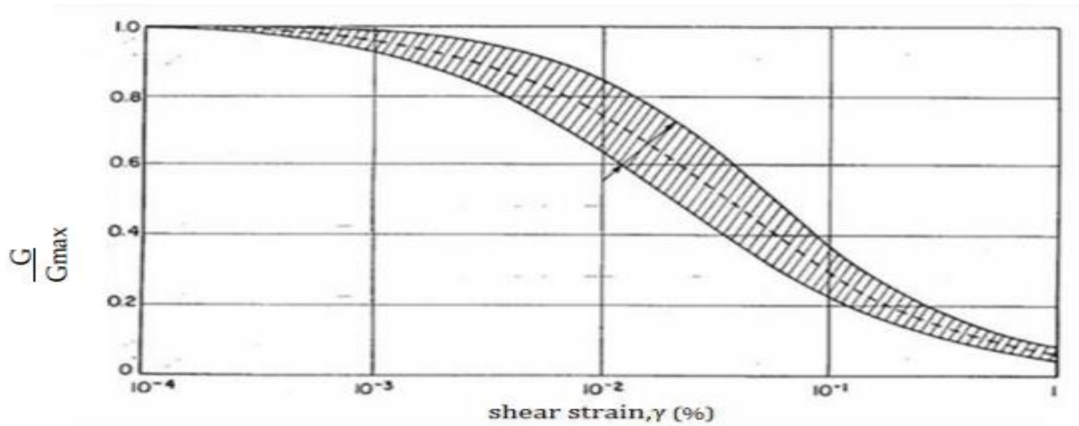

Figure 2-2: Variation of shear modulus with shear strain for sand [19]

Approximate upper and lower bound relationships between damping ratio and shear strain are shown by the dashed lines in Figure 2-3 and a representative average relationship is shown by the solid line. It also observed that the value of damping ratio increases with shear strain.

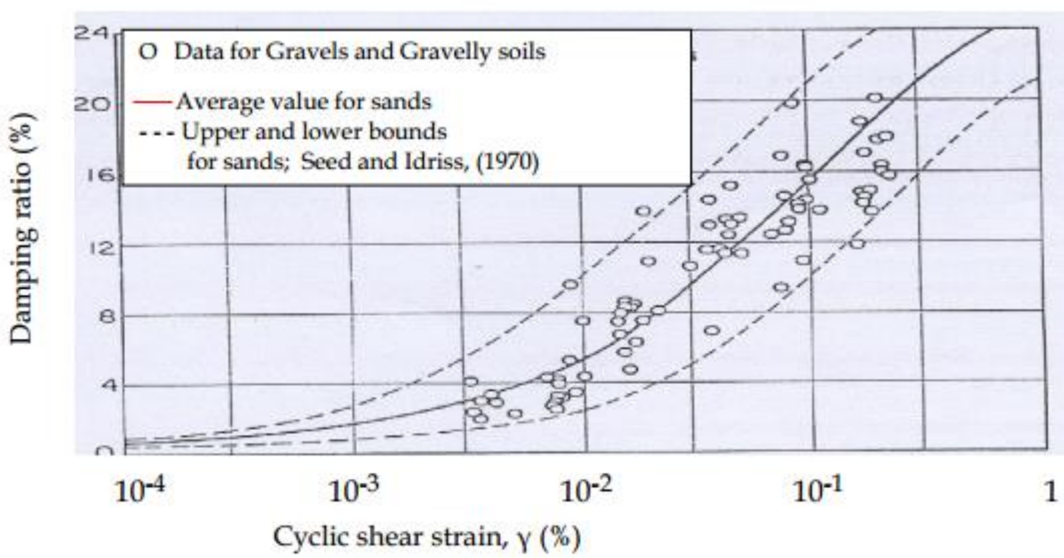

Figure2-3: Damping ratio curve for sand [19]

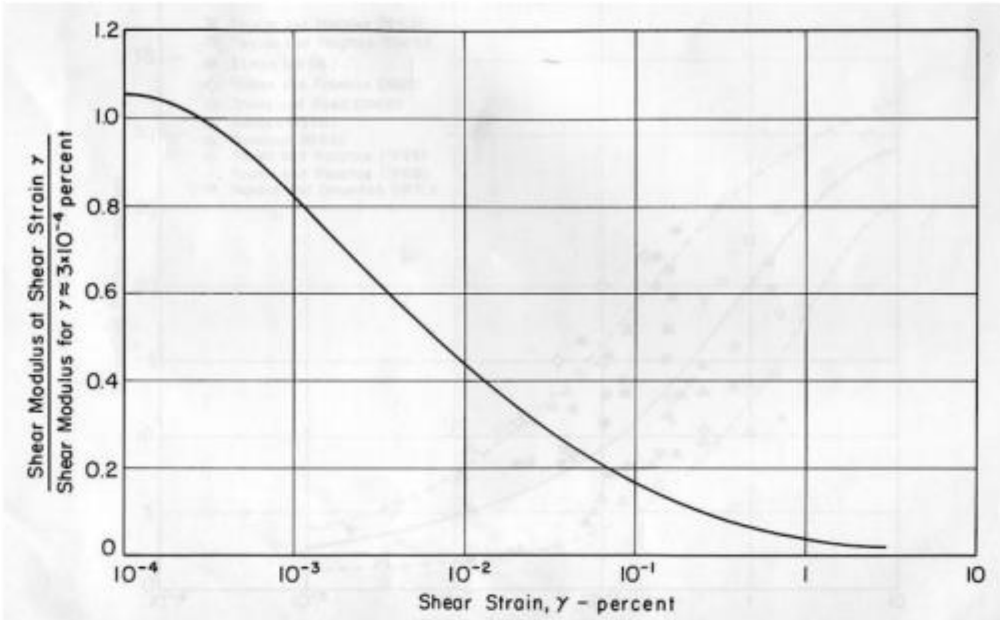

Figure 2.4 Typical reduction of shear modulus with shear strain for saturated clays [13]

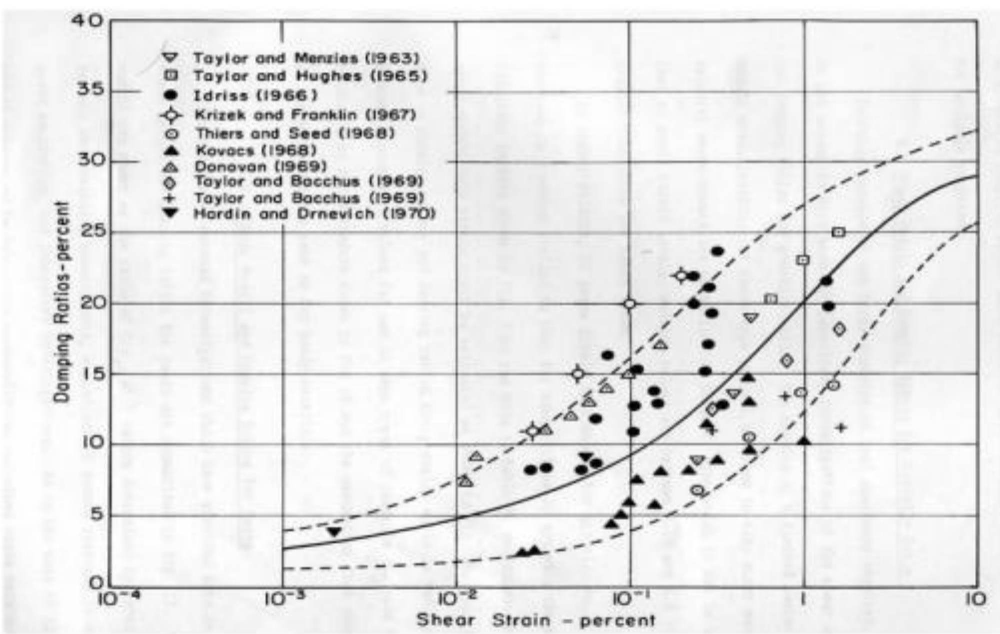

Figure. 2.5 Damping ratio for saturated clays [13]

2.5.2. Void ratio

Void ratio is a very important factor that influences small-strain shear modulus. Hardin and Richart [11] evaluated the shear wave velocity of granular soils, and drew the conclusions that the small strain shear modulus decreases with increasing void ratio.

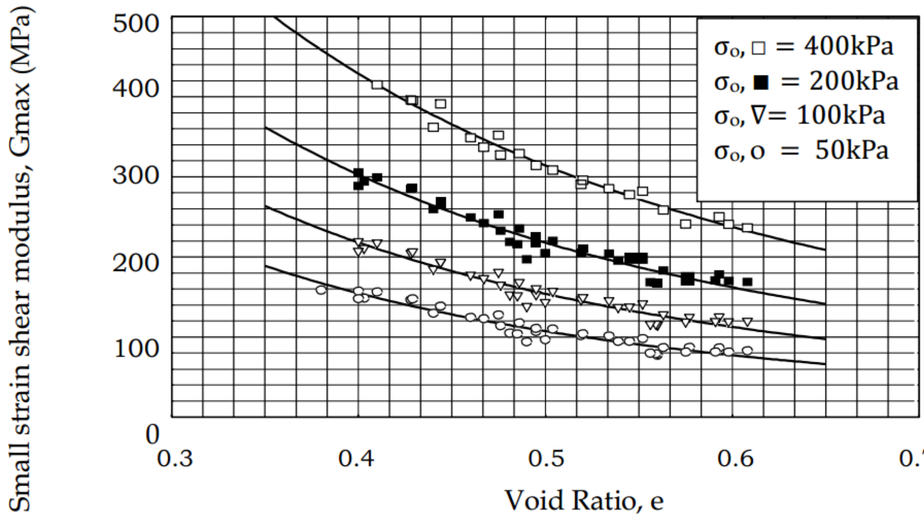

Figure 2-6: Variation of Small-strain shear modulus with void ratio under different confining pressures. [18]

However, effect of void ratio has no significant influence on damping ratio at any shearing strain amplitude under all confining pressures. [18]

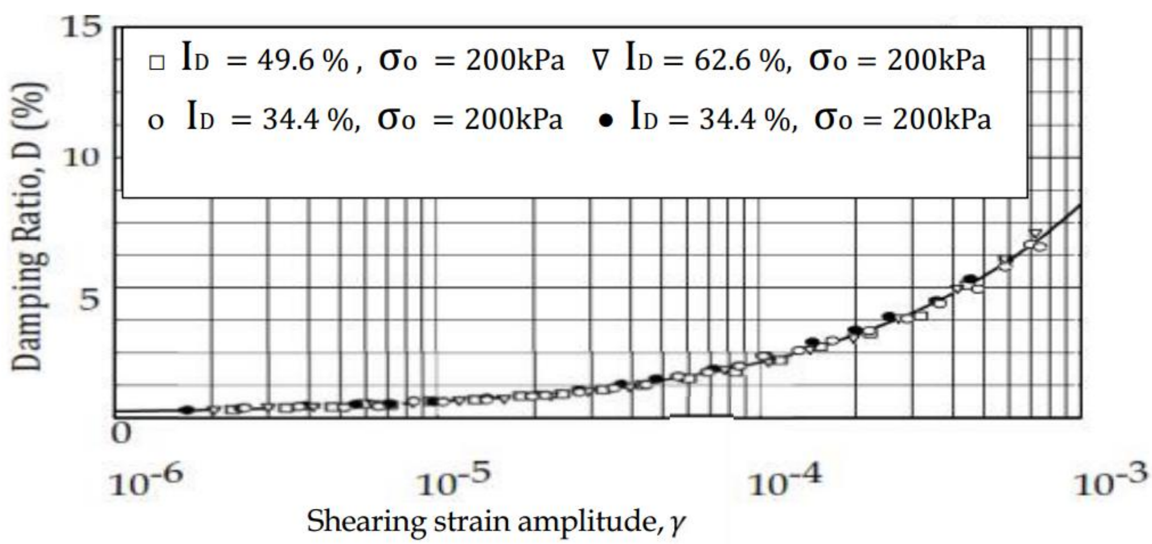

Figure 2-6: Variation of damping ratio with shearing strain amplitude under confining pressure of 200 kPa. [18]

2.5.3. Confining Pressure

The effects of confining pressure on small-strain shear modulus were studied in the past few decades. 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 and clayey soils [13]. Confining pressure (or mean principal effective stress) together with void ratio are recognized as the very important parameters which influence the small-strain shear modulus of soil. [13] Figure 2-6 illustrates the small-strain shear modulus of Ottawa 20-30 sands almost linearly increases with an increase in mean confining pressure.

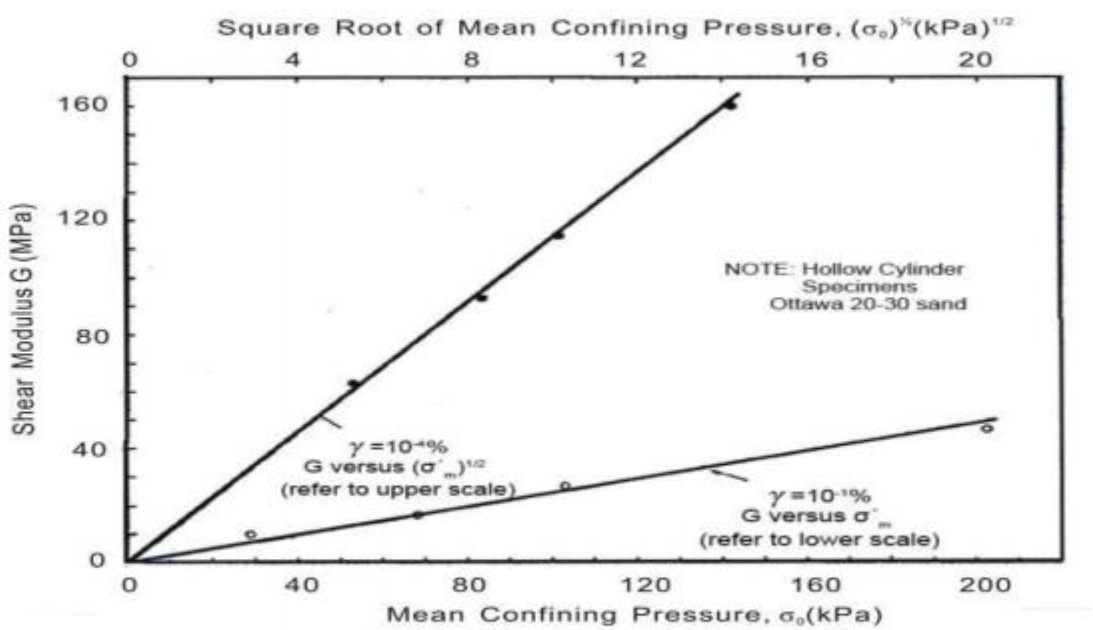

Figure 2-8 Relation between shear modulus with mean confining pressure [2]

2.5.4. Degree of Saturation

Hardin and Richart [11] and Lawrence [16] reported that the degree of saturation had only small effect on small-strain shear modulus for sand at low pressures. Hardin and Drnevich [13] classified degree of saturation as the very important parameter for cohesive soils but unimportant parameter for cohesion less soils.

2.5.5. Frequency of Loading

It is very important to assess the shear modulus and hysteretic damping of soils when predicting or back analyzing the response of ground or soil structures subjected to various types of cyclic loading. The frequency of transient loadings from wave, seismic, traffic and machine loadings may range from 0.01 to 100 Hz. [21]. Several investigations had revealed that loading frequency or strain rate had only small or no influence on small-strain shear modulus for cohesion less soils [11]. It is therefore common practice to carry out laboratory cyclic tests at a frequency range of 0.1 to 2 Hz. Mostly The frequency of 1 Hz preferred [3].

2.5.6. Number of loading cycles

Silver and Seed [22] measured the shear modulus and damping ratio of dry sands at the1st, 10th, and 300th cycles of loading, and indicated that the shear modulus slightly increases and damping ratio significantly decreases with increasing number of loading cycles. Similarly, Li and Cai [14] also reported that in general, the shear modulus moderately increases and the damping ratio decreases with the number of loading cycles as shown in Figure 2-7.

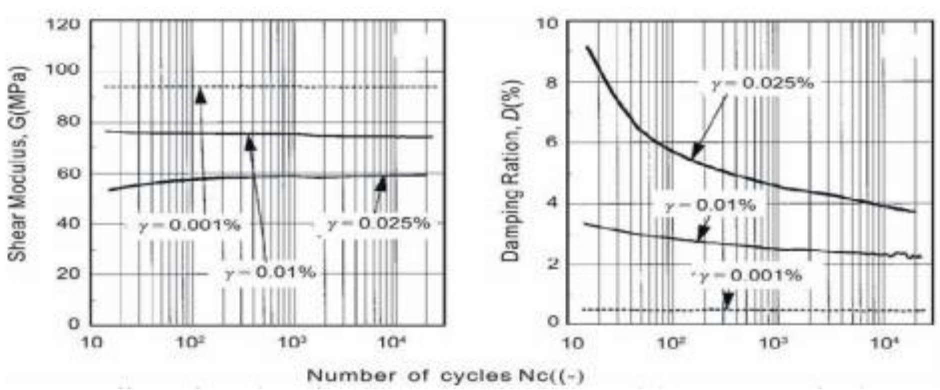

Fig.2-9: Effects of number of cycles on shear modulus and damping ratio for dry sand [14]

In general, the shear modulus increases slightly while damping ratio significantly decreases with increasing number of loading cycles. The primary increase in shear modulus and decrease in damping ratio occurs within the first 10 cycles of loading.

2.5.7. Effect of Stress history

It is recognized that small-strain shear moduli of soils increase with over consolidation ratio (OCR), especially for clayey soils. Hardin and Richart [11], Hardin and Black [12] reported that the OCR had only small or no effect on the small-strain shear modulus for sand. In theory, as soil is loaded to higher stress, the relative movements between particles occur resulting in soil having higher density, resulting in an increase in Gmax.

2.5.8. Effect of non-plastic fine materials

Figure 2-8 demonstrates that soil deposited in the loose state will have silt grains at or near the contact points between the larger grains. If the soil only has a moderate amount of fines, initial shearing causes the finer particles to fill the voids between the larger grains and the contacts of the larger particles dominates the behavior of the soil. This response continues until the voids of the larger particles are completely filled with finer material. Additional fines push the larger particles apart and the contacts of the fines increasingly dominate the behavior of the soil. Initial shearing of silty sand may push the fines into the void spaces of the sand, leading to a high initial contractive tendency which may cause static liquefaction at low confining pressures. Higher confining pressures push the sand particles into better contact, increasing the dilative tendencies of the soil and leading to higher liquefaction resistance. [27]

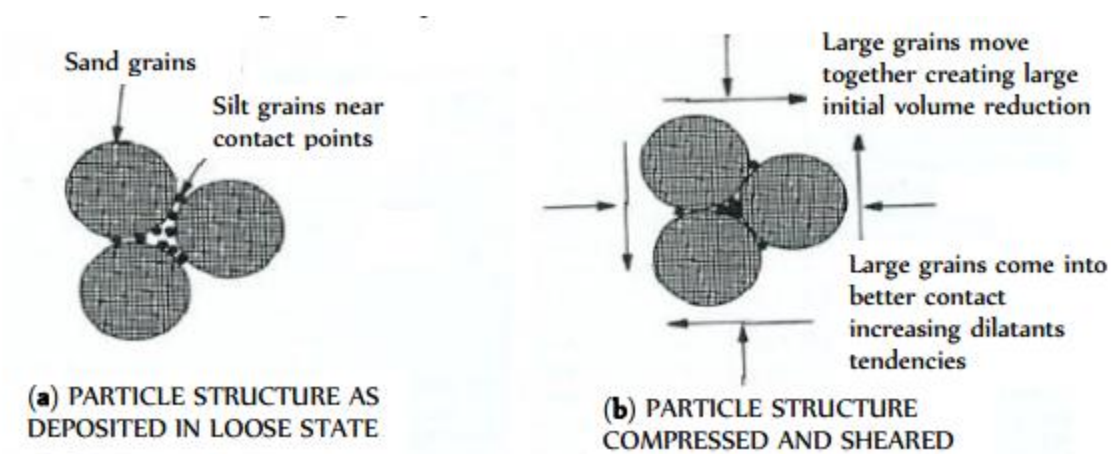

Figure 2-10: Hypothetical particle structure of loose silty sand with low silt content: (a)as deposited and (b) after densification due to shearing (Yamamuro and Lade,1997)

Thevanayagam [24] used a similar framework to describe particles of two different diameters in a mixture. At low fine content, the smaller particles fill the voids of the sand skeleton but the behavior of the sand skeleton dominates the mechanical behavior. As more fines are added, the sand skeleton still dominates, but some fine particles begin to separate the coarse particles. This change continues up to some threshold value defined as the threshold fines content at which the voids of the larger particles are completely filled. Above this threshold fines content, the coarse particles become increasingly dispersed in the matrix of the finer particles, and since most inter-particle contacts are now transmitted through the finer particles, the mechanical behavior of the fine material increasingly governs the mechanical behavior of the mixture. An important corollary result of these studies is that relative density may be an insufficient indicator of the liquefaction potential of a silty sand deposit. The fines in such sand will not contribute to the strength of the soil because only the contacts between the larger particles are carrying the load. The addition of fines, however, increases the relative density of the soil because the fines are filling the voids in the larger particles and reduce the overall void ratio. At higher fines content, the fines may start to fill between the contact points of the larger particles. Even though the addition of fines may increase the relative density of a soil, the stiffness may decrease as a result of fines filling the contact points.

It was also found that non plastic fines can reduce the small-strain shear modulus of a soil and increase the small-strain damping ratio, but this effect decreases with increasing uniformity coefficient (Cu). The reason for this relationship is thought to be because, in uniform soils (low Cu), the fines separate the larger particles of the soil skeleton and act as “rollers, decreasing the stiffness. In well-graded (high Cu) soils, on-plastic fines fill the void between large particles and increase the number of particle contacts. [7]

The primary impact of non-plastic fines is thought to be on the inter particle contacts of the larger particles. At high values of uniformity coefficient, the addition of fines to the soil is thought to be equivalent to the effect of increasing the uniformity coefficient of soil. At lower values of uniformity coefficient, the addition of fines is thought to push apart the larger particles in the soils, increasing the number but reducing the area of particle contacts, resulting in decreasing Gmax. The influence of fines is therefore more pronounced for more uniform soils. [7]

2.6. Liquefaction

During earthquakes, major destruction of various types of structures occurs due to the creation of fissures, abnormal and/or unequal movement, and loss of strength or stiffness of the ground. The loss of strength or stiffness of the ground results in the settlement of buildings, failure of earth dams, landslides and other hazards. The process by which loss of strength occurs in soil is called soil liquefaction. The phenomenon of soil liquefaction is primarily associated with medium – to fine-grained saturated cohesion less soils.

One of the first attempts to explain the liquefaction phenomenon in sandy soils was made by Casagrande (1936) and is based on the concept of critical void ratio. Dense sand, when subjected to shear, tends to dilate; loose sand, under similar conditions, tends to decrease in volume. The void ratio at which sand does not change in volume when subjected to shear is referred to as the critical void ratio. Casagrande explained that deposits of sand that have a void ratio larger than the critical void ratio tend to decrease in volume when subjected to vibration by a seismic effect. If drainage is unable to occur, the pore water pressure increases. Based on the effective stress principles, at any depth of a soil deposit.

$$\sigma' = \sigma - u$$

Where σ': effective stress

σ: total stress

u: pore water pressure

If the magnitude of σ remains practically constant, and the pore water pressure gradually increases, a time may come when σ will be equal to u. At that time, σ' will be equal to zero. Under this condition, the sand does not possess any shear strength, and it transforms into a liquefied state. [3]

The factors that affect liquefaction characteristics of sand are the grainsize distribution of sand, density of deposit, vibration characteristics, location of drainage and dimensions of deposit, magnitude and nature of super imposed loads, method of soil-structure, period under sustained load, previous strain history and entrapped.

Grain size distribution affects the behavior of sand masses during vibrations. Fine and uniform sands are believed to be more prone to liquefaction than the coarse sands under otherwise identical conditions since the permeability of a coarse sand is greater than that of a fine sand, the pore pressure developed during vibrations dissipates mare easily in coarse sand than in fine sand. Hence, the chance of liquefaction is reduced with coarseness of the sand grains. Also, uniformly graded sands are more susceptible to liquefaction than well-graded sands. [7]

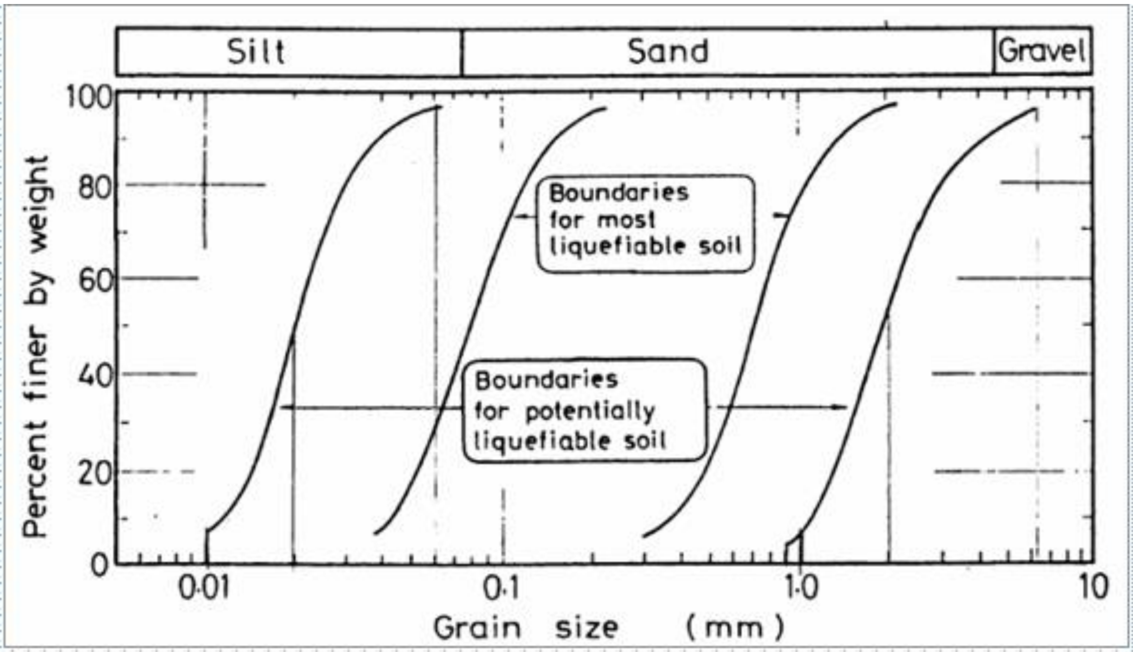

Figure 2-11: Limits in the gradation curves separating liquefiable and non-liquefiable soil(Tsuchida,1970)

CHAPTER THREE

RESEARCH METHDOLOGY

3.1. Introduction

Before selecting sampling areas, visual site investigation and information from construction firms were collected to consider the different soil types and to take sample evenly in the whole town. Accordingly, five representative sampling areas were selected randomly from different locations of the town as shown in Figure 3-1. Pits were excavated to the maximum depth of three meters. Only disturbed samples were taken because of the silt nature of the soil which makes recovering of undisturbed sample difficult. For each test pit field tests were conducted to determine bulk density using core cutter method. In the field visual soil description was made (see appendix-A for soil profiles of each test pits). To conduct the different laboratory tests, about 40kg of disturbed soil sample was collected in bulk randomly from each site.

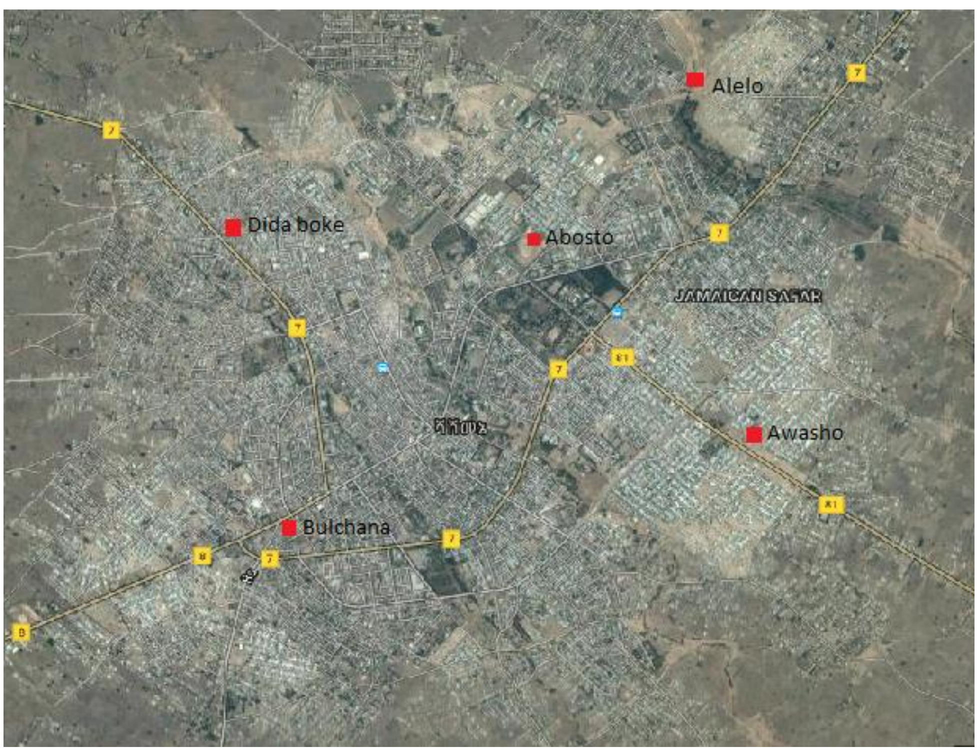

Figure 3.1 Locations of the test pits

3.2. Study Area

Shashemene is a city found in West Arsi Zone, Oromia Region, Ethiopia. It is located 7.20 latitude and 38.60 longitudes and it is situated at 1924 meters above sea level. Shashemene has a population of 85,871 making it the 4th biggest city in Oromia.

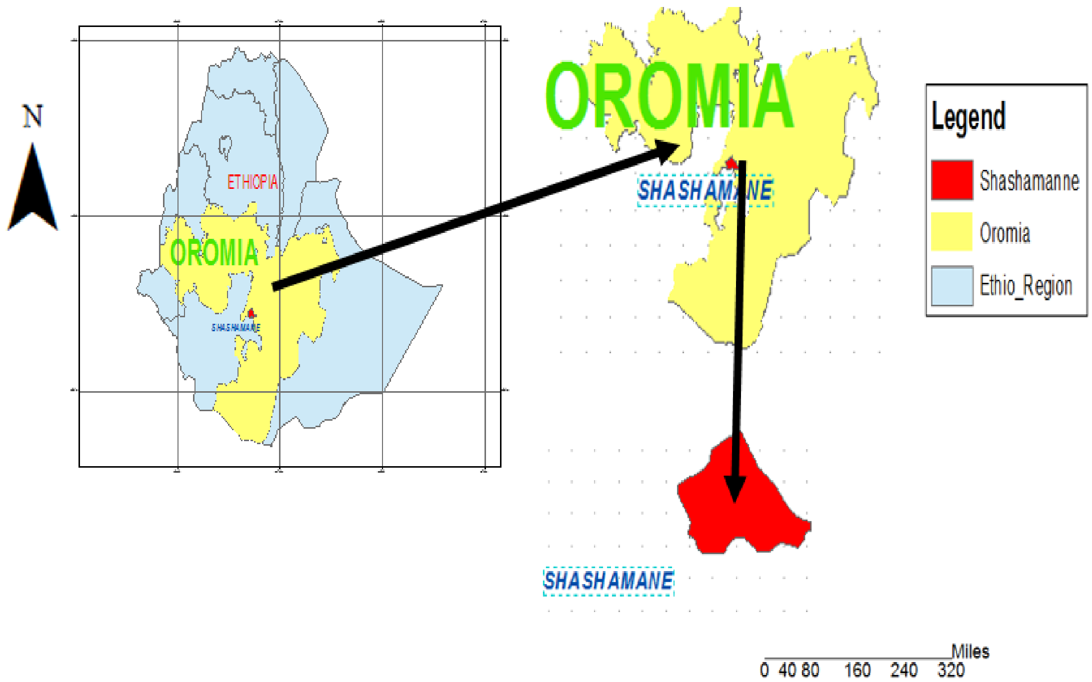

Figure 3.2 Map of Shashemene

3.2 Geology

The area of the Shashemene sub-sheet is located within the central part and the eastern edge of the Main Ethiopian Rift and is dominated by the eastern part of the Lower Pleistocene Hawasa caldera. Upper Miocene to Pliocene volcanic rocks of the Nazret Group composed by prevailing rhyolitic ignimbrites with intercalated basaltic units form the basement of the wider area of the Main Ethiopian Rift. The Nazret Group ignimbrites do not crop out in the mapped area and are covered by younger volcanic sequences of Lower Pleistocene to Holoceneage; however basaltic units of the Nazret Group were documented. Lower Pleistocene volcanic rocks of the Dino Formation composed of rhyolitic ignimbrites, crystal-rich rhyolite, rhyodacite and trachyandesite, belonging to the volcanic activity of the Hawasa caldera are present in the central part of the mapped area, whereas in the majority of the studied territory, these rocks are also hidden below younger volcanic sequences. The subsequent volcanic sequence of the Middle Pleistocene age - Corbetti ignimbrites - is exposed in the eastern half of the map, whereas to the west it is covered by Holocene pyroclastic deposits. Basaltic lavas and pyroclastics erupted in the Hawasa basaltic belt in the south-western part of the sub-sheet most likely also during the middle Pleistocene, and possibly lasted until the upper Pleistocene. The youngest deposits of the Upper Pleistocene to Holocene show generally low thicknesses, mostly below 10 m but cover a significant area of the western part of the sub-sheet. The north-western corner of the sub-sheet is covered by phreatomagmatic tuff of an unclear source and pumice from the Wendo Koshe Volcano. Extensive cover of colluvial and polygenetic to lacustrine sediments is developed in the south-western corner of the sub-sheet. The dominant tectonic strikes are those of a NW-SE and NE-SW direction. [Geological Survey of Ethiopia]

3.2. Cyclic Simple Shear Testing System

3.2.1. Introduction

In this study, the dynamic properties of soils were investigated using cyclic simple shear equipment. The cyclic simple shear apparatus is generally used for research into the dynamic of soil behavior. Nowadays there are different types of cyclic simple shear apparatuses in use. In this research the type of apparatus used is 31 -WF7500 cyclic simple shear machine which is developed by the Controls Group. The complete system is controlled by the UTS004 software application program. In the cyclic simple shear device, the shear strain is induced by horizontal movement at the bottom of the sample relative to the top. The horizontal diameter of the sample remains constant [26]. The system as in Figure 3-4 is designed to allow a sample to be consolidated, drained and then sheared.

Figure 3-3: 31-WF7500 cyclic simple shear machine [26]

3.2.2. Elements of Cyclic Simple Shear Apparatus

The sample is set up in the machine, which has a rigidly fixed top half and a moving bottom half. The top half houses the vertical ram. This is housed in a linear bearing to allow vertical movement and prevent horizontal movement. The bottom half is mounted on roller bearings as in a standard shear box. The sample is supported by a stack of close fitting-polished stainless steel rings. The rings provide lateral confinement and produce a Ko condition during consolidation and also maintain a constant diameter throughout the test.

During shear the rings slide across each other as shown in Figure 3-1. During the shearing stage of the test the vertical height of the sample is maintained at a constant height by the vertical actuator in a closed control loop with the vertical displacement transducer. The rings maintain a constant sample diameter.

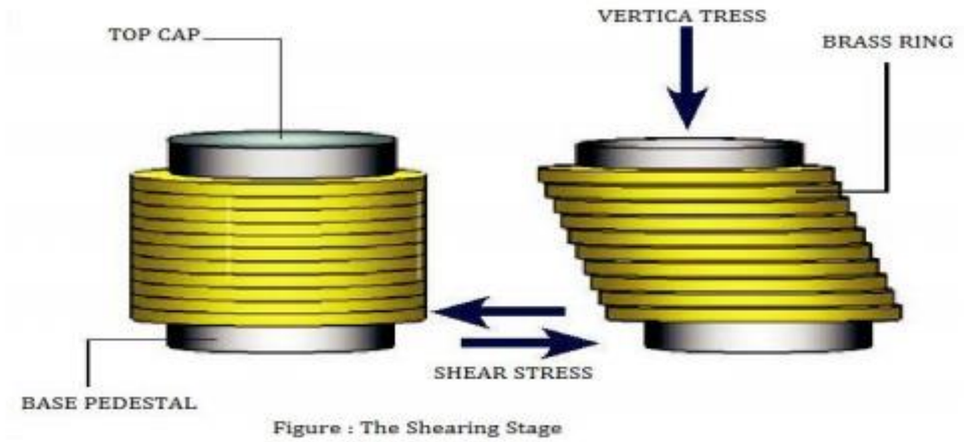

Figure 3-4: Simplified view of laterally constrained sample under cyclic simple shear conditions [26]

3.3.3. Sample Preparation

In order to conduct the cyclic simple shear test, the disturbed soil samples were remolded to field condition (at field density and water content) to replicate the natural state. The specimen is cylindrical in shape with 20 mm height and 70 mm diameter. Once the specimen was prepared, it would be mounted on the cyclic simple shear test machine for testing. The samples were prepared using ASTM test standard method.

3.3.4. Consolidation Stage

The consolidation stage is simply the application of a static axial loading stress to the specimen while the lateral loading (shear) axis is held stationary. Axial stress and specimen displacements (axial and lateral) are measured over time and logged by the system. Logged data is also displayed to the operator in the form of charts and tables as the test stage proceeds. The consolidation stage is manually terminated by the operator once the rate of vertical strain becomes less than 0.05% per hour [20].

The effective pressure applied during consolidation stage of cyclic simple shear test is taken to be100kPa, 200kPa,300kPa and 400kPa. The reason behind to select 100kPa, 200kPa,300kPa and 400kPa effective pressures is to account the stress history of the soil (normally consolidated, pre-consolidated and partially-reconsolidated) and to compare with the previous study results.

3.3.5. Cyclic Simple Shear Stage

This stage of the test applies a lateral cyclic shear force, or optionally a displacement, to the specimen, while the vertical force is either maintained at the specified stress, or optionally, the specimen height is maintained. Both axial and lateral force and specimen displacements are measured for each loading cycle. Measured data are obtained from 50 sample points captured over the cycle period [25]. This data is displayed to the operator in the form of wave shapes, charts and tables and also logged by the system to an archive data file. The loading cycle shape is operator selectable from predefined functions but may also be a user generated shape.

3.4 Presentation of Cyclic Shear Test results

3.4.1 Axial loads and Shear Strain Levels used

The cyclic simple shear testing machine enables one to conduct cyclic shear test within the strain levels of 0.01 to 5 percent. This test is also being conducted with different axial stress, which enables one to see its effect on the values of shear modulus and damping ratio. In this study, axial loads of 100 kPa, 200 kPa, 300kPa and 400 kPa were used. Table 3.5 below summarizes the axial stress and shear strain values used in this thesis. It should be noted here that, preparations of specimens and testing have been done for each strain level and axial load for all samples of representative test pits.

Table 3-1: Axial stress and shear strain values used in this thesis

Test pits	Sample type	Axial stress (kPa)	Shear strain (%),ɤ				
Awasho	Remolded to field condition	100	0.01	0.1	1	2.5	5
		200	0.01	0.1	1	2.5	5
		300	0.01	0.1	1	2.5	5
		400	0.01	0.1	1	2.5	5
Bulchana	Remolded to field Condition	100	0.01	0.1	1	2.5	5
		200	0.01	0.1	1	2.5	5
		300	0.01	0.1	1	2.5	5
		400	0.01	0.1	1	2.5	5
Dida boke	Remolded to field Condition	100	0.01	0.1	1	2.5	5
		200	0.01	0.1	1	2.5	5
		300	0.01	0.1	1	2.5	5
		400	0.01	0.1	1	2.5	5
Alelo	Remolded to field Condition	100	0.01	0.1	1	2.5	5
		200	0.01	0.1	1	2.5	5
		300	0.01	0.1	1	2.5	5
		400	0.01	0.1	1	2.5	5

3.4.2 Shear Stress and Strain Parameters

During the cyclic shear stage of the test both lateral force and specimen displacements are measured for each loading cycle with time. Measured data can be displayed to the operator on Microsoft Excel spreadsheet. From the lateral force and displacement recorded data, one can calculate the shear stress (τ) and shear strain (ɤ) values. Using the specimen height after consolidation (< 20 mm) and its diameter, 70 mm, the shear stress and shear strain of the specimen can be calculated based on the following equation.

$$\tau = \frac{Force}{Area} = \frac{Shear\ force}{\pi * 35^2} * 10^3 MPa$$

$$ɤ = \frac{\Delta L}{L} = \frac{Displacement}{Height\ after\ consolidation}$$

Table 3.4 below shows sample tabulation of shear strain and shear stress from the lateral force and specimen displacement taken from the 5^{th} cycle test result of silty sand soil with peak-to-peak cyclic strain amplitude of 2.5%. The loading frequency used in this study is 1 Hz, which is commonly used in laboratory tests. From the predefined shear shape option such as, sinusoidal, triangular etc., the loading cycle shape has been selected to be sinusoidal (see Figure 3.5) as it is the most common type of seismic wave shape for analysis [2]. In most seismic events, the number of significant cycles is likely to be less than 20, so the specimen was cyclically loaded through 40 cycles [3] using a uniform sinusoidal load at a frequency of 1.0 Hz, which is commonly used in laboratory tests. For all practical purposes the values determined at fifth cycles is likely to provide reasonable values [6].

3.4.3 Computation of Shear Modulus and Damping Ratio Values

The hysteresis loop is achieved by plotting shear stress against shear strain. It is used for the calculation of shear modulus and damping ratio for each cycle. In order to illustrate this, cyclic shear test results of one specimen consolidated to a pressure of 200kPa and cyclically loaded to maximum single displacement amplitude of 0.5 mm (corresponding to maximum single strain amplitude of 2.5%) is shown in Fig. 4-5 to 4-7. Additional cyclic shear test results are shown in appendix G.

The shear stress is calculated simply by dividing the shear force by the area of the specimen base (0.003848m2), and the shear strain is calculated by dividing the shear displacement by the specimen height after consolidation (<20mm).

Shear modulus and damping ratio of hysteresis loop are calculated using the following equations:

$$\boldsymbol{G} = \frac{\tau max - \tau min}{\gamma max - \gamma min} \quad \text{and} \quad \boldsymbol{D} = \frac{(\boldsymbol{Area\ of\ loop})}{(4 * \pi * \boldsymbol{Area\ of\ triangle})}$$

with variables as described in Figure 4-8. To obtain these two values from the hysteresis loop the recommendations of standard ASTM D3999 are followed. Since, in most seismic events, the number of significant cycles is likely to be less than 20, the values determined at 5^{th} cycles are likely to provide reasonable values for all practical purposes. [6]

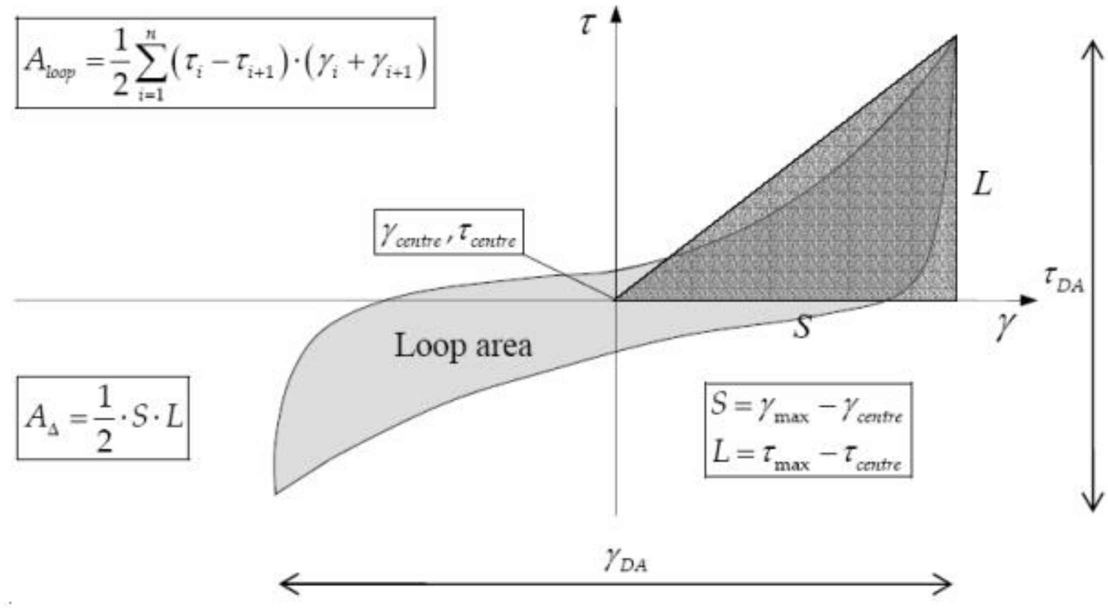

Figure 3.5 Hysteresis loop with triangle area

CHAPTER 4

RESULTS AND DISCUSSION OF TEST RESULTS

4.1 Laboratory Tests for Index Properties

The following laboratory tests were conducted and the results are presented:

- ✓ In-situ density and moisture content
- ✓ Particle size analysis
- ✓ Specific gravity test
- ✓ Atterberg's limits

4.1.1. In-situ Density and Moisture Content Tests

The in-situ bulk density test was carried out at field and used to determine bulk densities for all samples. From the test results, it is observed that the bulk density varies from 1.1 to 1.45gm/cc and moisture content varies from 12.78 to 18.42%.

Table 4.1: In-situ Density and Moisture Content Tests

	Depth (m)	Bulk density (gm/cm^{3})	Field moisture content (%)	Specific gravity, Gs
Awasho	3	1.24	14.52	2.17
Abosto	3	1.102	12.78	2.38
Bulchana	3	1.43	16.67	2.27
Dida boke	3	1.45	18.42	2.08
Alelo	3	1.445	13.87	2.271

In this thesis the specific gravities test results are shown in Table 4-1. From this table the values of specific gravities are more reasonable values for silty sand soils.

4.1.2. Particle Size Analysis

Particle size analysis is widely used in engineering classification of soils. The purpose of this test is to determine the distribution of grain sizes in a given soil sample. The result of particle size analysis performed on each sample is shown in Appendix-C.

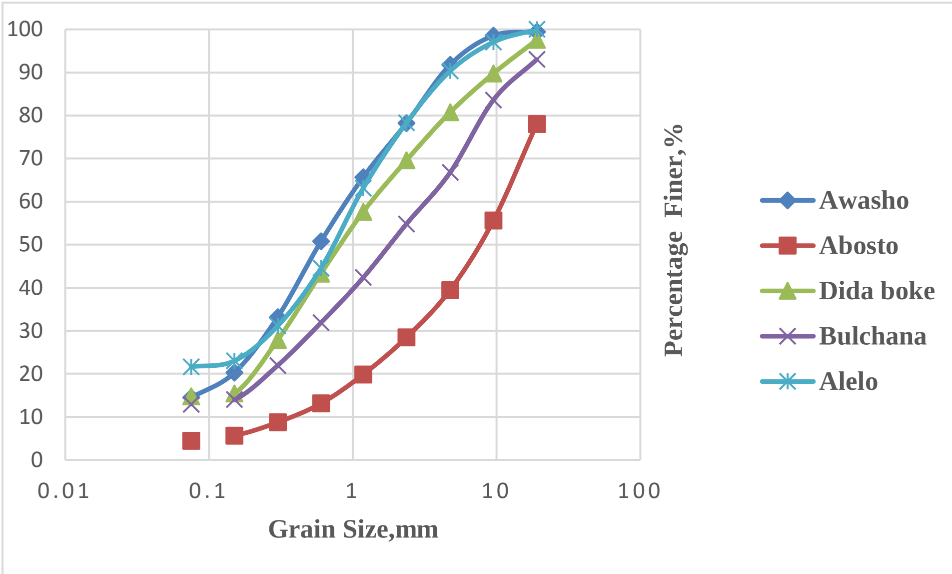

Figure 4.1: Particle size distribution curve

4.1.3. Atterberg's Limits Test

Atterberg's Limits tests were carried out on silty soil passing 425-micron sieve. Liquid limit was determined using Casagrande's liquid limit device and plastic limit was determined by rolling wet soil paste in to 3 mm threads and determining the moisture content when thread just started crumbling. The tests were performed as per ASTM code (IS: 2720 (Part-IV)). The Liquid Limit, Plastic Limit and Plasticity Index of the study area is summarized in Table 4-2. From the test results the Liquid Limit varies from 27.78% to 43.47%, Plastic Limit varies from 20% to 33.3% and Plasticity Index varies from 1 to 12.0 for all the specimens tested. [Appendix-D]

4.1.4. Specific Gravity

The specific gravity of solid matter in a soil particle may be defined as the ratio of the unit weight of solid matter to the unit weight of water [23]. The specific gravity was determined in the laboratory according to ASTM D854-92. According to ASTM D854-92, specific gravity of soils is determined by means of a pycnometer. The results of the test are shown in Table 4-2. The specific gravity of the sample is found to vary between 2.08 to 2.38. [Appendix-E]

4.1.5. Soil Classification

According to ASTM D 2487, Standard Test Method for Classification of soils for Engineering Purposes, which is based on the Unified Soil Classification System [3] as shown in Fig.4-3, the soil sample is classified as gravel and silty sand. The test results are presented in Table 4-2.

Table 4-2: Engineering Properties of Tested Soils

Test pit name	Awasho	Abosto	Dida boke	Bulchana	Alelo
Liquid limit (%)	27.78	32	39.4	43.47	34.7
Plastic limit (%)	26.67	20	33.3	38.88	29.4
Plasticity index	1	12	6	4.59	5.3
Water content (%)	12.78	13.34	14.23	18.42	13.4
% gravel	8.25	60.55	19.27	33.25	9.67
% sand	91.75	39.45	80.73	66.75	90.33
% fines	14.45	4.38	14.48	12.93	21.63
USCS classification	Silty sand (SM)	Gravel	Silty sand (SM)	Silty sand (SM)	Silty sand (SM)

4.2. Hysteresis loops of test results

The hysteresis loop of each cycle can be plotted using the results of shear strains and shear stresses that can be computed and presented with excel program. In most seismic events, the number of significant cycles is likely to be less than 20 [2]. For all practical purposes, the values determined at 5th cycles likely to provide reasonable values [3]. Figure 4.2 shows the hysteresis loops of the 5th cycle plotted for each strain level of silty sand soil tested under 400 KPa axial stresses. In this study, the number of cycles used in a test is 40 cycles and Figure 4.2 shows the hysteresis loops of 40 cycles together in each strain levels of silty sand soil tested with 400 KPa. It has been shown that the deformation characteristics of soils vary to a large extent depending upon the magnitude of shear strains to which the soils are subjected. And also the values of shear modulus and damping ratio will depend on the magnitude of the strain for which the hysteresis loop is determined. Figure 4.2 shows the hysteresis loops of the 5th cycles for each strain level test together and it shows how the value of shear strain affects the shape and size of the hysteresis loops. As the shear strain increases, the line connecting the tips of the hysteresis loop rotate clockwise implying a decrease shear modulus decreases. The width of the hysteresis loop becomes wider as the shear strain value increases. As a result, the damping effect of the soil increases.

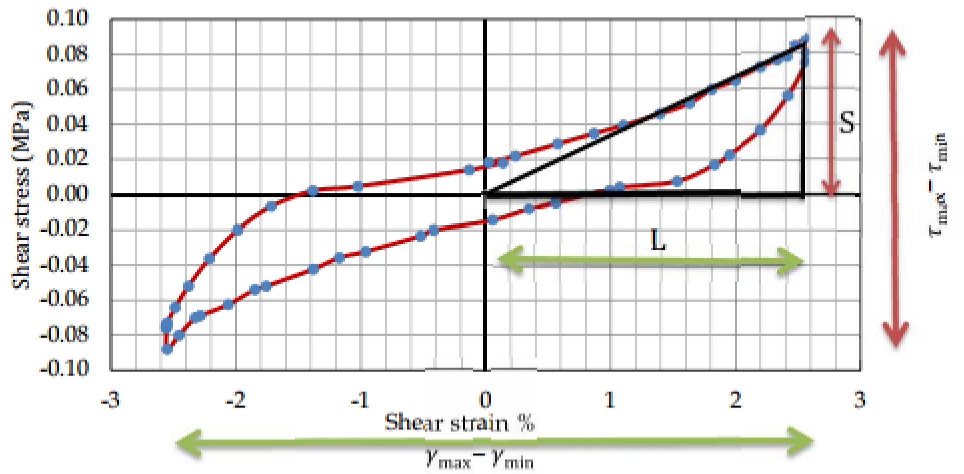

Figure 4.2 Hysteresis loops of the 5th cycle of silty sand soil tested under 400 KPa axial stresses for Awasho test pit.

4.3 Computed Shear stress and strain parameters

Table 4.3 Shear stress and shear strain values of the 5th cycle test result of silty sand soil with 2.5 % strain and 100 kPa axial loads.

Lateral Displacement (mm)	Lateral Force (kN)	Area (mm^2)	$\tau = \frac{shear\ force}{area} * 10^3$ (KN/mm^2)	$\gamma = \frac{displacement\ (mm)}{19.6}$
0.31385	-0.26321	3848.45	-0.068393769	0.016012755
0.32913	-0.2273	3848.45	-0.05906274	0.016792347
0.3503	-0.1811	3848.45	-0.047057906	0.017872449
0.37796	-0.12702	3848.45	-0.033005496	0.019283673
0.41341	-0.06743	3848.45	-0.01752134	0.021092347
0.46068	-0.00898	3848.45	-0.002333407	0.023504082
0.55458	0.02597	3848.45	0.006748171	0.028294898
0.63048	0.064	3848.45	0.016630072	0.032167347
0.68306	0.10889	3848.45	0.028294508	0.03485
0.73345	0.15029	3848.45	0.039052086	0.037420918
0.78775	0.18554	3848.45	0.048211618	0.040191327
0.84388	0.21451	3848.45	0.055739324	0.043055102
0.89595	0.23917	3848.45	0.062147098	0.045711735
0.9425	0.25916	3848.45	0.067341397	0.048086735

0.98393	0.27438	3848.45	0.071296236	0.05020051
1.01861	0.28626	3848.45	0.074383193	0.051969898
1.03786	0.29806	3848.45	0.077449363	0.052952041
1.05374	0.30597	3848.45	0.079504736	0.053762245
1.07989	0.30394	3848.45	0.078977251	0.055096429
1.08684	0.30666	3848.45	0.079684029	0.05545102
1.0923	0.30708	3848.45	0.079793163	0.055729592
1.09597	0.30586	3848.45	0.079476153	0.055916837
1.0968	0.302	3848.45	0.078473152	0.055959184
1.09671	0.29689	3848.45	0.077145344	0.055954592
1.09525	0.28964	3848.45	0.075261469	0.055880102
1.09099	0.27778	3848.45	0.072179709	0.055662755
1.08401	0.25647	3848.45	0.066642414	0.055306633
1.07145	0.22395	3848.45	0.058192259	0.054665816
1.05317	0.18039	3848.45	0.046873417	0.053733163
1.02785	0.1271	3848.45	0.033026283	0.052441327
0.99446	0.06789	3848.45	0.017640868	0.050737755
0.95237	0.00593	3848.45	0.00154088	0.048590306
0.8583	-0.02865	3848.45	-0.007444556	0.043790816
0.77004	-0.0723	3848.45	-0.018786784	0.039287755
0.71917	-0.11812	3848.45	-0.030692876	0.036692347
0.67251	-0.15917	3848.45	-0.041359508	0.034311735
0.61883	-0.19725	3848.45	-0.051254401	0.031572959
0.55569	-0.22877	3848.45	-0.059444712	0.028351531
0.4951	-0.25123	3848.45	-0.065280827	0.025260204
0.44425	-0.27048	3848.45	-0.070282841	0.022665816
0.40208	-0.28589	3848.45	-0.074287051	0.020514286
0.36852	-0.29817	3848.45	-0.077477946	0.018802041
0.34681	-0.3091	3848.45	-0.08031805	0.017694388
0.32206	-0.31252	3848.45	-0.08120672	0.016431633
0.31176	-0.31712	3848.45	-0.082402006	0.015906122
0.30492	-0.31891	3848.45	-0.082867128	0.015557143
0.30069	-0.31869	3848.45	-0.082809962	0.015341327
0.29817	-0.31695	3848.45	-0.082357832	0.015212755
0.29723	-0.3142	3848.45	-0.081643259	0.015164796
0.29768	-0.31027	3848.45	-0.080622069	0.015187755

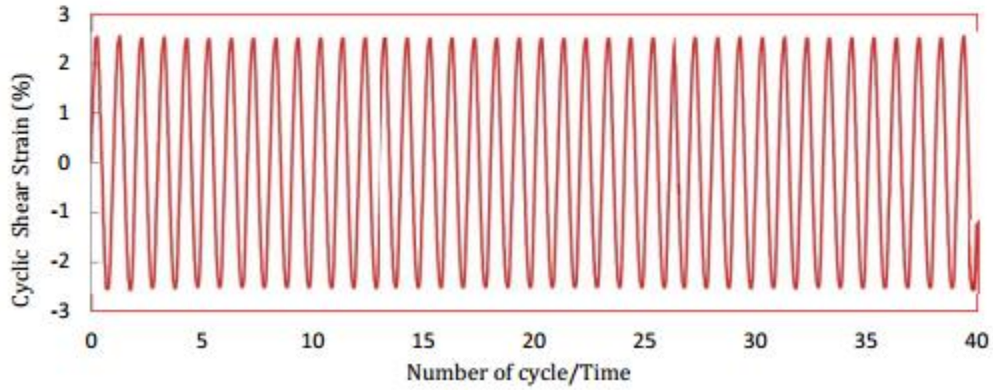

Figure 4.3: Graph of cyclic shear strain versus Number of cycle/Time.

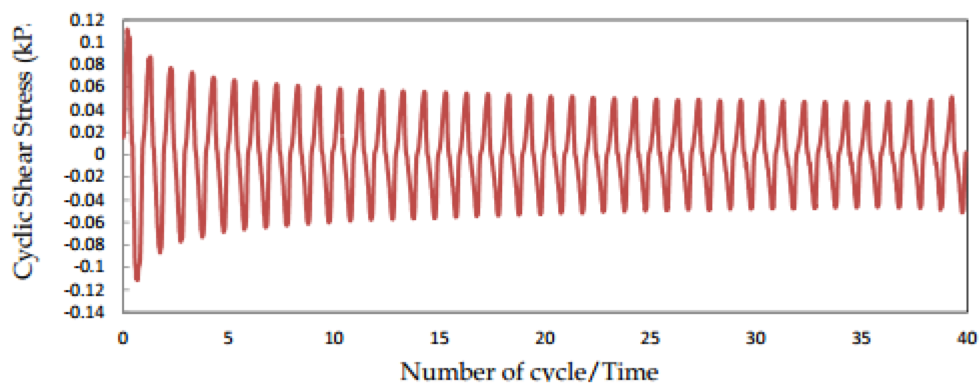

Figure 4-4: Graph of cyclic shear stress versus Number of cycle/Time for Awasho test pit

4.4. Computation of Shear Modulus and Damping Ratio Values

Table 4-4: Typical calculation for shear modulus and damping ratio using Figure 4-2

Calculation of shear modulus		Calculation of damping ratio	
τ_{max}	0.04425	Area of the hysteresis loop =0.5*$\sum(\tau_i-\tau_{i+1})*(\gamma+\gamma_{i+1})$	0.016
τ_{min}	-0.04425		
$\tau_{max}-\tau_{min}=2S$	0.0885		
γ_{max}	0.0244475	Area of triangle=0.5*S*L	0.005
γ_{min}	-0.0244475		
$\gamma_{max}-\gamma_{min}=2L$	0.048895	$D=\frac{area\ of\ loop}{4*\pi*area\ of\ triangle}*100\%$	**25.01**
$G=\frac{\tau max-\tau min}{\gamma max-\gamma min}$	**1.81** MPa		

In similar manner with Table 4.4, the values of shear modulus and damping ratio of each cycle in test can be determined. In this study, a single specimen was tested up to 40 cycles and Table 4-5 shows shear modulus and damping ratio values of each cycle for Awasho test pit under an axial stress of 200kPa. Additional test results are shown in appendix G.

Table 4-5: Shear modulus and damping ratio values for Awasho test pit under an axial stress of 200kPa.

Strain %	0.01	0.10	1.00	2.50	5.00		0.01	0.10	1.00	2.50	5.00
Cycle no.	**Shear modulus, G**						**Damping ratio ,D**				
1	4.15	2.94	2.30	1.91	**1.81**		17.46	19.56	22.70	23.82	**25.01**
2	4.10	2.89	2.25	1.85	1.76		17.27	19.37	22.51	23.63	24.81
3	4.01	2.88	2.24	1.84	1.75		16.46	18.56	21.71	22.62	23.75
4	4.07	2.87	2.23	1.83	1.74		16.09	18.19	21.34	22.45	23.58
5	4.16	2.87	2.17	1.97	1.87		15.60	17.71	20.85	21.96	23.06
6	3.84	2.63	2.00	1.60	1.52		14.46	16.57	19.71	20.43	21.45
7	3.81	2.61	1.97	1.58	1.50		14.37	16.48	19.62	20.74	21.77
8	3.79	2.59	1.95	1.55	1.48		14.03	16.14	19.28	18.76	19.70
9	3.77	2.57	1.93	1.53	1.46		12.95	15.05	18.19	19.31	20.28
10	3.75	2.55	1.91	1.51	1.43		11.61	13.72	16.86	17.97	18.87
11	3.73	2.52	1.89	1.49	1.41		12.11	14.21	17.36	18.47	19.40
12	3.70	2.50	1.86	1.47	1.39		11.78	13.89	17.03	17.36	18.22
13	3.48	2.28	1.64	1.25	1.18		11.40	13.51	16.65	17.77	18.65
14	3.46	2.26	1.62	1.22	1.16		11.28	13.39	16.53	16.86	17.70
15	3.44	2.24	1.60	1.20	1.14		10.92	13.03	16.17	17.29	18.15
16	3.42	2.22	1.58	1.18	1.12		11.75	13.86	17.00	18.11	19.02
17	3.33	2.13	1.49	1.09	1.04		10.48	12.59	15.73	16.85	17.69
18	3.31	2.11	1.47	1.07	1.02		11.24	13.35	16.49	17.61	18.49
19	3.29	2.08	1.44	1.05	1.00		10.17	12.28	15.42	16.54	17.37
20	3.26	2.06	1.42	1.03	0.97		10.92	13.03	16.17	17.29	18.15
21	3.24	2.04	1.40	1.00	0.95		9.99	12.10	15.24	16.36	17.18
22	3.22	2.02	1.38	0.98	0.93		10.48	12.59	15.73	16.85	17.69
23	3.20	2.00	1.36	0.96	0.91		9.65	11.75	14.89	16.01	16.81
24	3.18	1.97	1.33	0.94	0.89		10.22	12.33	15.47	16.59	17.42
25	3.15	1.95	1.31	0.92	0.87		9.49	11.59	14.73	15.85	16.64
26	2.93	1.73	1.09	0.69	0.66		9.89	11.99	15.13	16.25	17.06
27	2.91	1.71	1.07	0.67	0.64		10.76	12.87	16.01	17.13	17.98
28	2.89	1.69	1.05	0.65	0.62		9.70	11.80	14.94	16.06	16.86
29	2.87	1.66	1.03	0.63	0.60		10.47	12.58	15.72	16.84	17.68

30	2.84	1.64	1.00	0.61	0.58		9.44	11.54	14.68	15.80	16.59
31	2.82	1.62	0.98	0.58	0.56		10.14	12.25	15.39	16.51	17.33
32	2.80	1.60	0.96	0.56	0.53		9.37	11.47	14.61	15.73	16.52
33	2.78	1.58	0.94	0.54	0.51		9.83	11.93	15.07	16.19	17.00
34	2.76	1.55	0.92	0.52	0.49		9.07	11.17	14.31	15.43	16.20
35	2.73	1.53	0.89	0.50	0.47		9.54	11.64	14.78	15.90	16.70
36	2.71	1.51	0.87	0.47	0.45		8.93	11.03	14.17	15.29	16.06
37	2.69	1.49	0.85	0.45	0.43		9.27	11.37	14.51	15.63	16.41
38	2.67	1.47	0.83	0.43	0.41		10.04	12.15	15.29	16.41	17.23
39	2.65	1.44	0.80	0.41	0.39		9.06	11.16	14.30	15.42	16.19
40	2.62	1.42	0.78	0.39	0.37		9.79	11.89	15.03	16.15	16.96

Using the values of shear modulus and damping ratio, the shear modulus and damping ratio curves can be plotted.

4.5 Effect of Number of Cycles

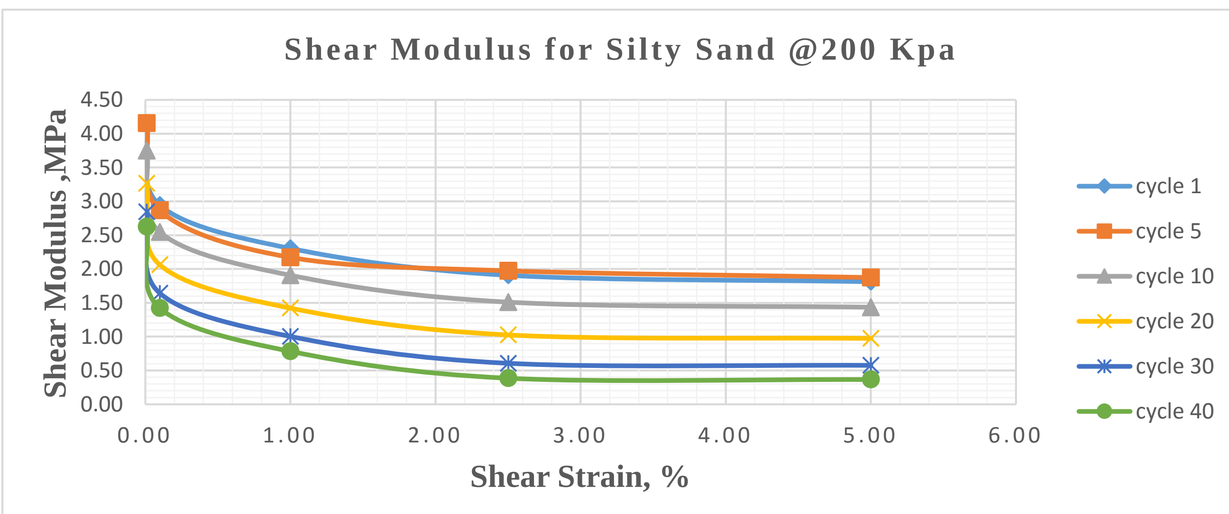

Figure 4.5 Effect of Number of Cycles Shear Modulus curves of silty sand soil for 200Kpa

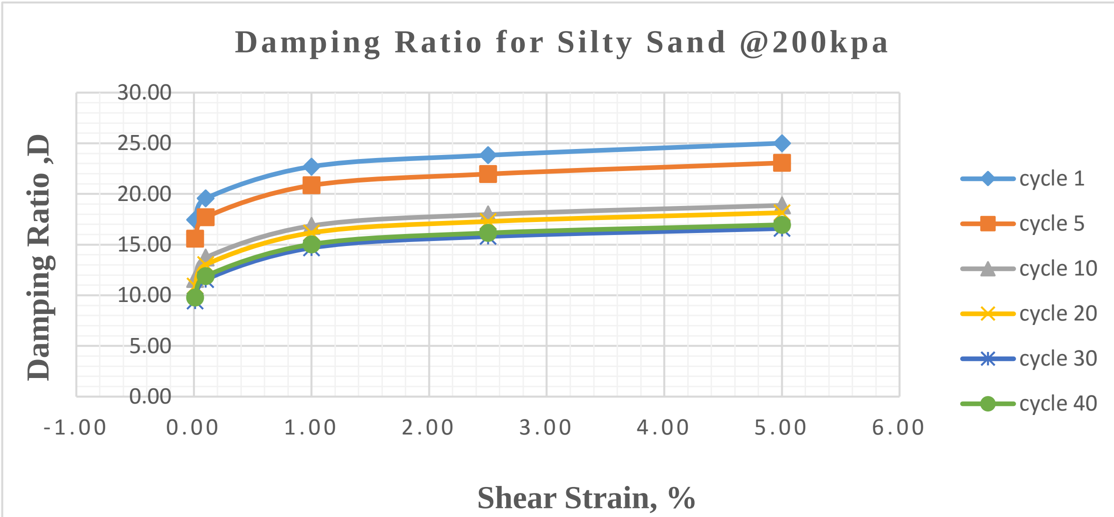

Figure 4.6 Effect of Number of Cycles of Damping Ratio curves of silty sand soil for 200 KPa

From the above figure, it can be seen that the shear modulus moderately increases while the damping ratio decreases with increasing number of loading cycle. During cyclic shearing the soil specimen contracted, as a result the void ratio will be decreases with number of cycles. This reduction in void ratio of soils leads to increases the cyclic shear modulus. The primary increase in shear modulus occurred within the first 20 cycles of loading.

4.6 Effect of Strain Amplitude

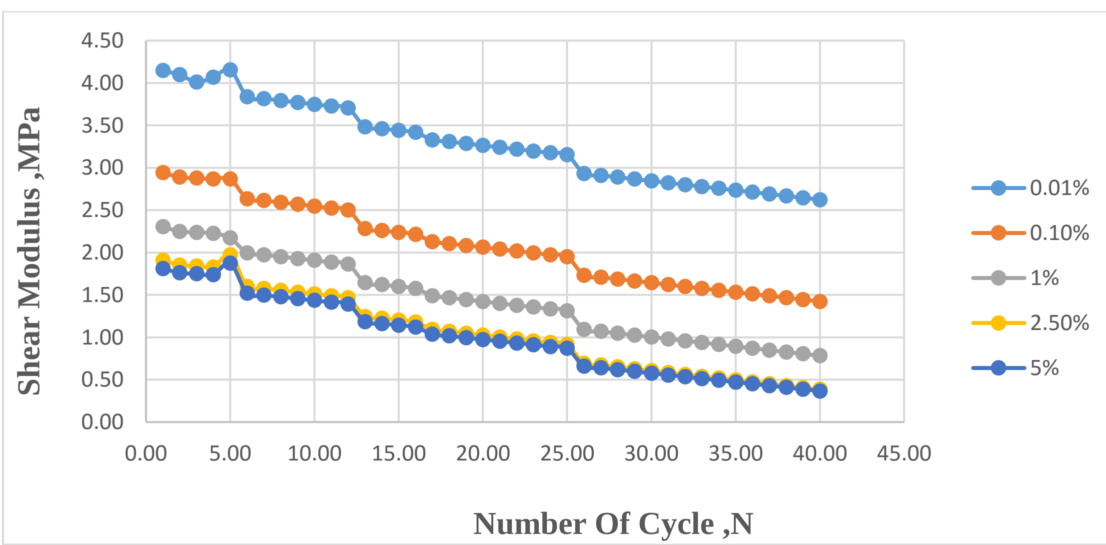

Figure 4-7: Effects of Strain amplitude on the Location of Shear Modulus Curves for Silty Sand (For Awasho Test Pit) Soil Under an Axial Stress of 200KPa

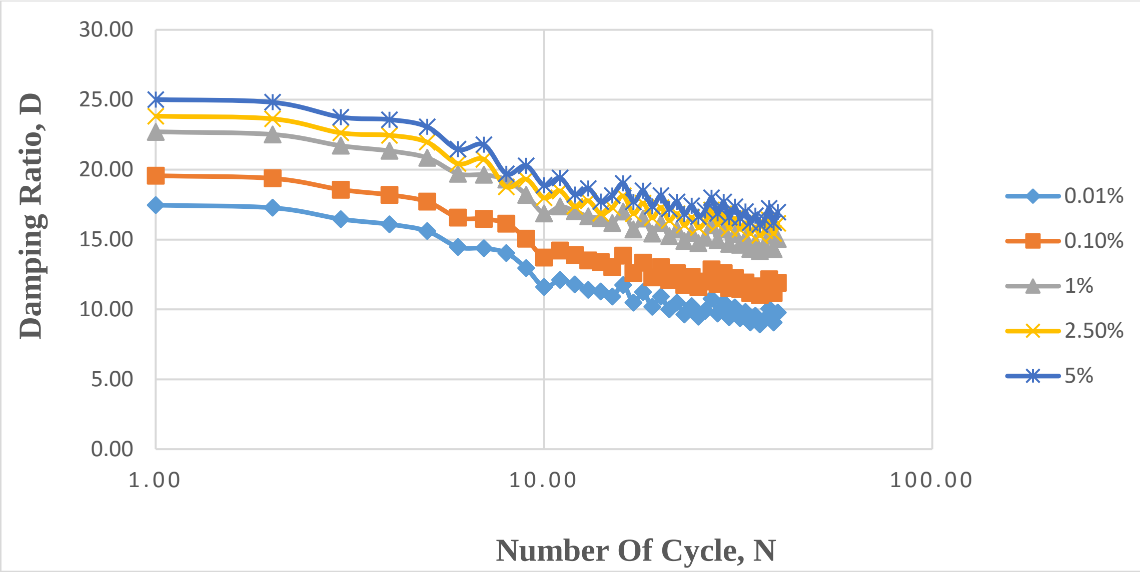

Figure 4:8 Effects of Strain amplitude on the Location of Damping Ratio Curves for Silty Sand (Awasho Test Pit) Soil Under an Axial Stress of 200kpa

It is well known that the deformation characteristics of soils are highly nonlinear and this is manifested by the shear modulus and damping ratio which vary significantly with the amplitude of shear strain under cyclic loading. Figure 4.7 and 4.8 shows the variation of shear modulus and damping ratio with shear strain.

4.7. Effect of Axial Loads

Previous study shows strength degradation would occur from cycle to cycle as cycling loading continues. As indicated in figures 4.5 and figure 4.6 the variation of both shear modulus and damping ratio for different cycles are nearly the same. The effect of number of cycles with increase axial loads shows slight difference on the shear modulus and damping ratio values. As mentioned in the previous sections it is the consolidation stress which has a significant influence on shear modulus and damping values. In this research samples were consolidated under an axial stress of 100, 200,300and 400KPa in order to evaluate the influence of consolidation stress. The variation of both shear modulus and damping ratio at different axial stress showed in figures 4.9 to 4.10.

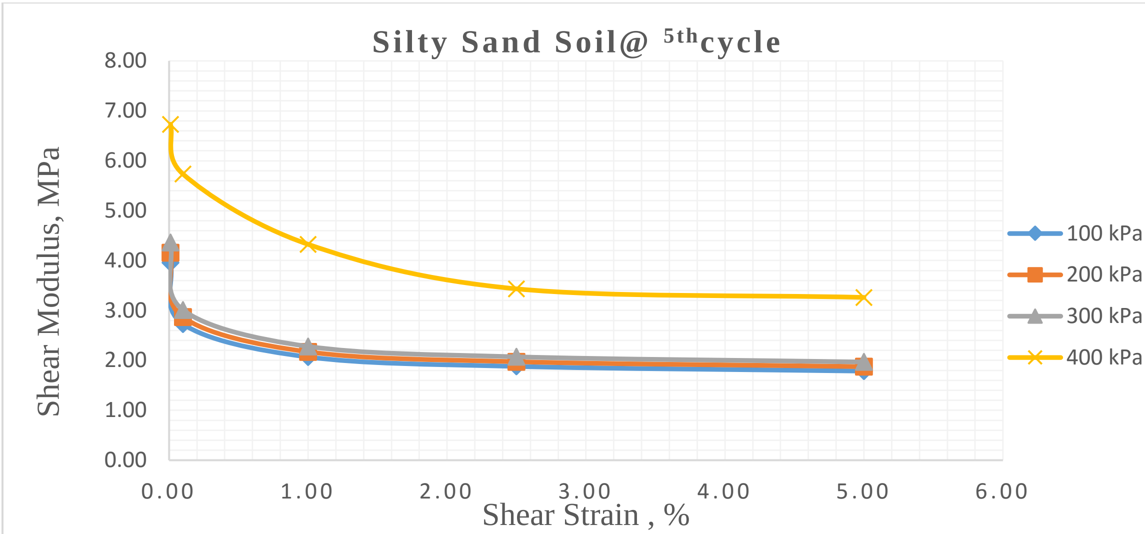

Figure 4. 9 Effect of Axial Loads on Shear Modulus of the Silty Sand Soil Sample from Awasho Test Pit

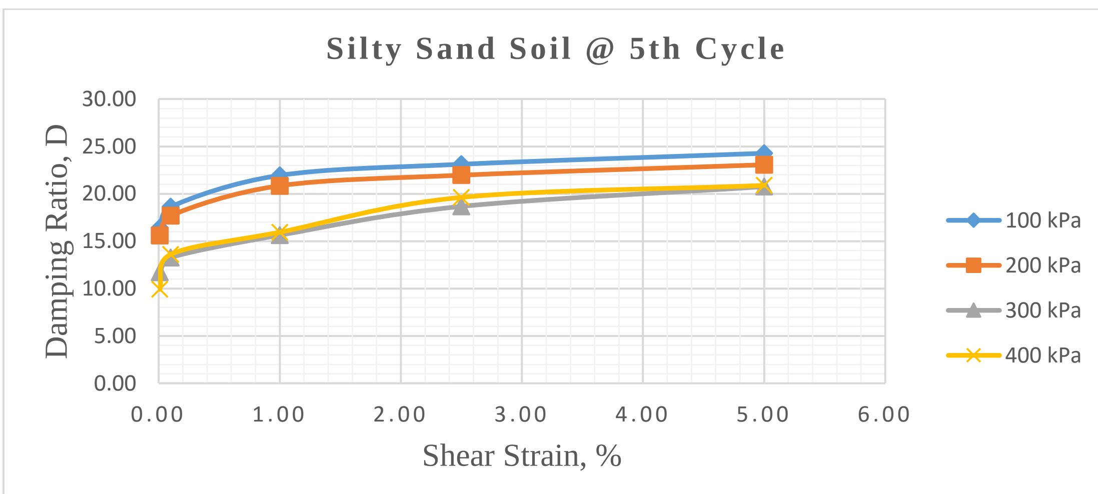

Figure 4 .10 Effect of Axial Loads on Damping Ratio of Silty Sand Soil Sample from Awasho Test Pit

4.8. Computation of maximum Shear Modulus

The small strain shear modulus Gmax describes soil response in the initial, elastic stress strain range and is a function of the stress state and degree of compactness of the soil. Since cyclic simple shear tests are high strain tests (0.01 to 5%) one cannot measure shear modulus and damping values at low strain levels. So, the maximum shear modulus, Gmax which corresponds to very low strain levels cannot be determined from such tests. For the sake of comparison, the maximum shear modulus, Gmax of each specimen is determined using Eq.2-1written below, and the calculated max is used to obtain the normalized shear modulus which is then compared with those obtained from literature. [12]

$$G_{max} = 14760\,\frac{(2.973-e)^2}{1+e}(OCR)^a(\sigma'_m)^{0.5}$$

…………… (4.1)

Where: e = void ratio

OCR = Over-consolidation ratio =Pc/Po

Pc = Pre consolidation pressure of a specimen

Po = Present effective vertical pressure

σ'_o = Effective confining stress

σ_v' = Effective vertical stress

K = Coefficient of lateral earth pressure at rest

K = Dimensionless quantity which is a function of PI, it can be obtained from Table 2-1.

K_o= is the coefficient of lateral pressure at rest. For cohesion less soils K = 0.43 to 0.67, with a value of 0.5 often used. [5]

The maximum shear modulus, modulus of reduction and damping ratio of the soil are important parameters for dynamic analysis of the soil. The maximum shear modulus can be obtained from low strain seismic geophysical test which involves the measurements of body wave velocities which can be easily related to low-strain soil moduli or by using empirical correlations with index properties of soil. The maximum shear modulus, Gmax which corresponds to very low strain levels cannot be determined using cyclic simple shear tests. Therefore, for the sake of comparison in this study, computation of Gmax is done using the expression in Equation (4.1) and presented below.

$$G_{max} = 14760\,\frac{(2.973-e)^2}{1+e}(OCR)^a(\sigma'_m)^{0.5}$$

Where Gmaxis the maximum shear modulus (lb/ft^2) and e is void ratio of the soil

$$e = \frac{Gs\gamma w}{\gamma d} - 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

Where; a is a parameter that depend on the plasticity index of the soil and determined using Table 4.5.

PI	**a**
0	0
20	0.18
40	0.30
60	0.41
80	0.48
≥100	0.50

The overconsolidation ratio (OCR) of soil is expressed as:

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

Where σ'_c is pre-consolidation pressure of a specimen

σ'_p is present effective vertical pressure

σ'_m is mean principal effective stress (lb/ft^2)

$$\sigma_m = \frac{\rho_1 + \sigma_2 + \sigma_3}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

Where $\sigma_1$is the axial stress and $\sigma_2 = \sigma_3$are the lateral confining stresses

K_0 is coefficient of earth pressure at rest and estimated reasonably to 0.5 for these silt soils. From Table 4.5, the value of a range from 0 to 0.41as the PI value goes from 0 to 60. Linear interpolation was used for the determinations of a for each test pit (see Table 4.8). Table 4.6 Values of the parameters PI, a and e for all test pits.

Parameter	Awasho test pit
PI	1
a	0.009
e	1.315

Computation of Gmax has been made for both silt and clay soil using the above procedures and tabulated in Table 4.7. For the sake of comparison Gmax values for different soil types are presented in Table 4.8.

Table 4. 6 Typical Gmax values of soils [9]

Type of soil	Intial shear modulus (kPa)
Soft clays	2750-13750
Firm clays	6900-34500
Silty sand	27600-138000
Dense sand and gravel	69000-345000

Over-consolidation ratio (OCR) for a soil can be defined as

$$OCR = \frac{preconsolidation\ pressure, \sigma c}{present\ effective\ vertical\ pressure, \sigma p}$$

Pre-consolidation stress is calculated the following equation (Nagaraj and Murti, 1996).

$$\log Pc = \frac{1.322\frac{eo}{el} - 0.0463 log\sigma}{0.188} \quad \ldots\ldots 4.4$$

And the void ratio at the liquid limit is calculated by the following equation (Nagaraj and Murti,1996).

$$el = \frac{LL}{100} * Gs$$

Table 4.7 Computation of Maximum Shear Modulus

Parameters	Sample from pit			
	Awasho	Bulchana	Alelo	Dida boke
Effective vertical pressure	100kPa			
Specific gravity,G	2.17	2.27	2.27	2.08
Void ratio of effective overburden pressure,e_o	1.315	1.38	1.31	1.28
Void ratio @ liquid limit,e_L	1.101	0.98	0.88	0.82
Over consolidation ratio,OCR	0.5	0.5	0.5	0.5
a	0.009	0.09	0.084	0.054
Mean pricipal effective stess	1392.37	1392.37	1392.37	1392.37
Maximum shear modulus,Gmax in lb/ft^2	498,866.93	1,549,323.581	1,195,459.93	664,357.283
Maximum shear modulus, Gmax in kPa	31,767.63	44,183.56	37,240.12	31,810.26

Parameters	Sample from pit			
	Awasho	Bulchana	Alelo	Dida boke
Effective vertical pressure	200kPa			
Specific gravity,G	2.17	2.27	2.27	2.08
Void ratio of effective overburden pressure,e_o	1.315	1.38	1.31	1.28
Void ratio @ liquid limit,e_L	1.101	0.98	0.88	0.82
Over consolidation ratio,OCR	0.5	0.5	0.5	0.5
a	0.009	0.09	0.084	0.054
Mean pricipal effective stess	2784.74	2784.74	2784.74	2784.74
Maximum shear modulus,Gmax in lb/ft^2	915,291.365	780,474.123	879,183.026	1,267,401.99
Maximum shear	43,825.3	37,370.08	42,096.38	60,684.79

modulus, Gmax in kPa				

Parameters	Sample from pit			
	Awasho	Bulchana	Alelo	Dida boke
Effective vertical pressure	300kPa			
Specific gravity,G	2.17	2.27	2.27	2.08
Void ratio of effective overburden pressure,e_o	1.315	1.38	1.31	1.28
Void ratio @ liquid limit,e_L	1.101	0.98	0.88	0.82
Over consolidation ratio,OCR	0.5	0.5	0.5	0.5
a	0.009	0.09	0.084	0.054
Mean pricipal effective stess	4177.11	4177.11	4177.11	4177.11
Maximum shear modulus,Gmax in lb/ft^2	1,121,002.1	955,884.85	1,076,778.45	1,052,249.25
Maximum shear modulus, Gmax in kPa	53,674.98	45,768.96	51,557.5	54,323.64

Parameters	Sample from pit			
	Awasho	Bulchana	Alelo	Dida boke
Effective vertical pressure	400kPa			
Specific gravity,G	2.17	2.27	2.27	2.08
Void ratio of effective overburden pressure,e_o	1.315	1.38	1.31	1.28
Void ratio @ liquid limit,e_L	1.101	0.98	0.88	0.82
Over consolidation ratio,OCR	0.5	0.5	0.5	0.5
a	0.009	0.09	0.084	0.054
Mean pricipal effective stess	5569.48	5569.48	5569.48	5569.48
Maximum shear modulus,Gmax in lb/ft^2	1,294,451.29	1,103,785.94	1,243,385.05	792,423.94
Maximum shear modulus, Gmax in kPa	61,979.95	52,850.65	59,534.836	35,823.5

4.9. Modulus reduction (G/Gmax) values

The modulus reduction curves are the most widely used way of characterizing the modulus of soil under cyclic loading. Table 4.8 shows the modulus reduction values determined using the G values of 5th cycle and the calculated Gmaxvalues of table 4.8.The value of Gmax is used to obtain the normalized shear modulus which is then compared with those obtained from literature.

Table 4.8 Modulus Ratio (G/Gmax) Values

Axial load =100 kPa					
Shear strain, %	0.01	0.1	1	2.5	5
G/Gmax					
Awasho	0.61	0.43	0.32	0.27	0.26

Axial load =200 kPa					
Shear strain, %	0.01	0.1	1	2.5	5
G/Gmax					
Awasho	0.95	0.65	0.5	0.45	0.4

Axial load =300 kPa					
Shear strain, %	0.01	0.1	1	2.5	5
G/Gmax					
Awasho	0.77	0.53	0.4	0.36	0.34

Axial load =400 kPa					
Shear strain, %	0.01	0.1	1	2.5	5
G/Gmax					
Awasho	0.67	0.46	0.35	0.31	0.3

4.10. Comparison of Test Results with Previous Findings

4.10.1 Introduction

Previously, some researchers developed different modulus reduction and damping ratio for different soil types at different places of Ethiopia. Modulus reduction and damping ratio curves of silty sand developed by Abraham Mengistu and Abu Gemechu are used to compare the test results of soils under study.

4.10.2 Shear Modulus Reduction

The computed shear modulus reduction values from Table 4.8 are plotted on the curves. Regarding local soils a comparsion is made with the curve done by Abraham Mengistu and Abu Gemechu (figure 4.11 -4.14) .

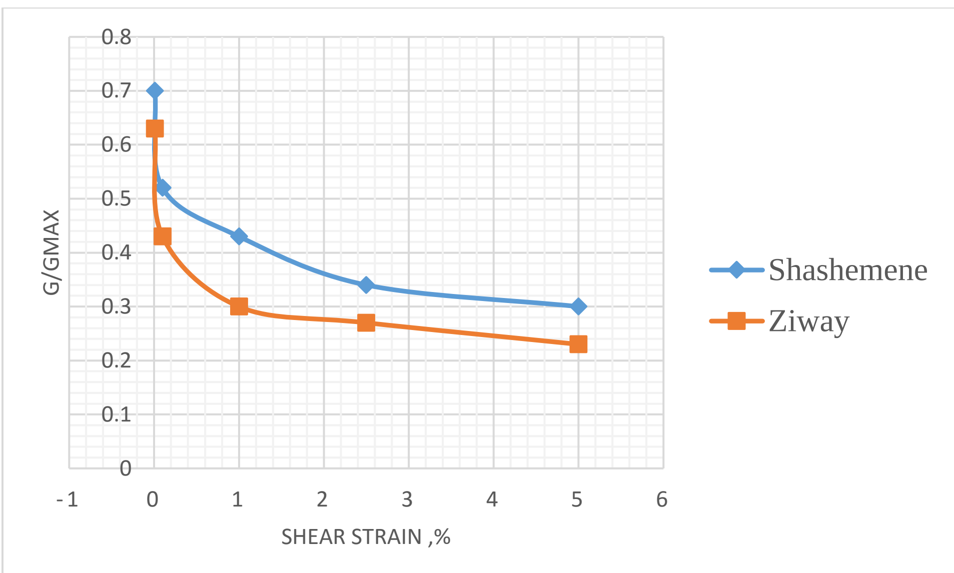

Figure 4.11 Comparison of G/Gmax values with Ziway silty sand soil (Abraham Mengistu) @ 400kPa

As shown in the figure 4.11 the G/Gmax value for Ziway silty sand soil @ 400kPa axial load is almost comparable to that of the Shashemene silty sand at similar axial load.

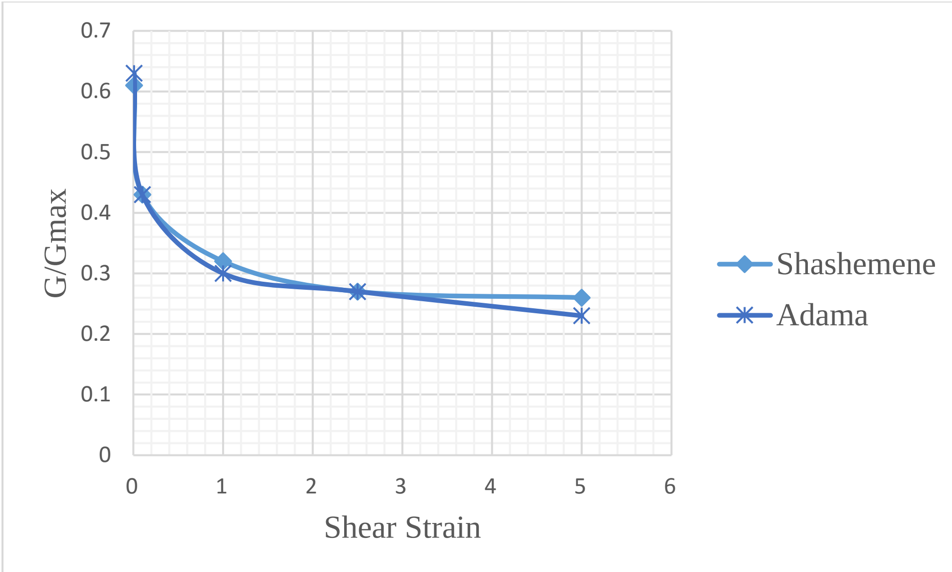

Figure 4.12 Comparison of G/Gmax values with Adama silty sand soil @ 100kPa

Figure 4.12 shows that the G/Gmax value of Adama silty sand soil by Abu G. comparable to Shashemene silty sand soil under the same axial load.

4.10.3 Damping ratio

The computed damping ratio values of silty sand soil (Tables 4.3 - 4.4) can be plotted and compared with different damping ratio curves from literatures. Figures 4.13 - 4.14 show location of damping ratio test results as compared with different literature curves.

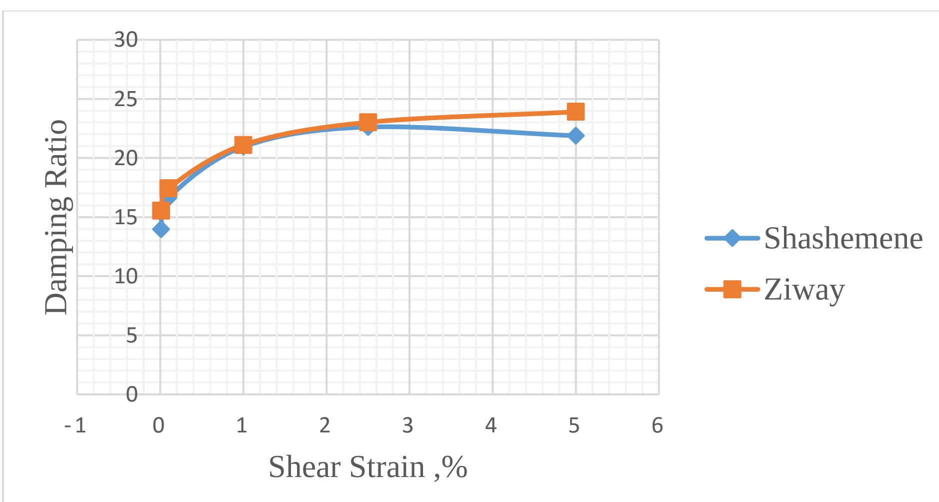

Figure 4.13 Comparison of damping ratio damping ratio values with Ziway silty sand soil (by Abraham Mengistu)@ 400 kPa

As shown in the figure 4.13 the Damping ratio value for Ziway silty sand soil @ 400kPa axial load is decreases as compared to that of the Sha shemene silty sand at similar axial load.

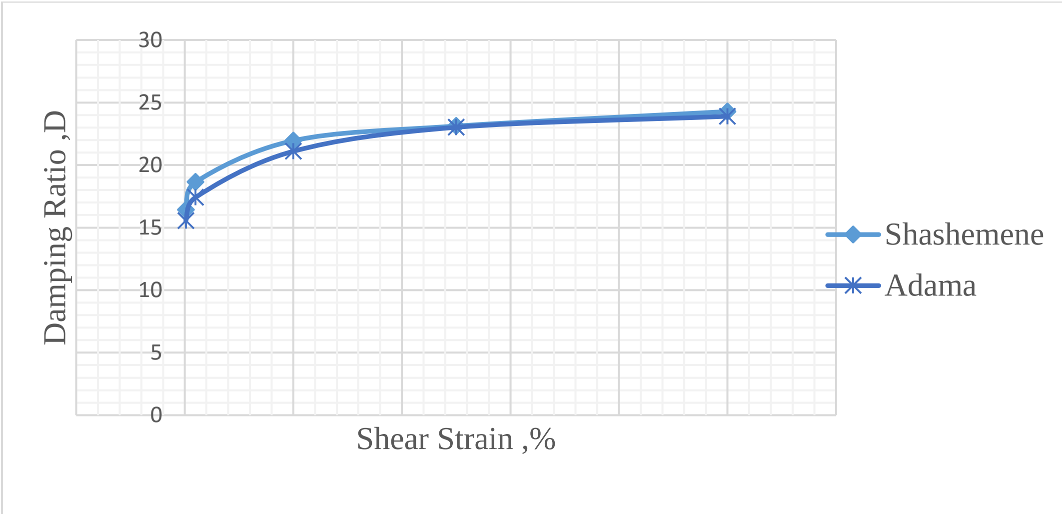

Figure 4.14 Comparison of Damping ratio values with Adama silty sand soil @ 100kPa

Figure 4.14 shows us the Damping ratio value for Adama silty sand soil @ 400kPa axial load is in the range of the Shashemene silty sand at similar axial load.

4.11. Liquefaction Susceptibility analysis

According to USCS classification system (table 4.2) the area has loose sandy silt. So the liquefaction susceptibility of the soil is checked in figure 4.13

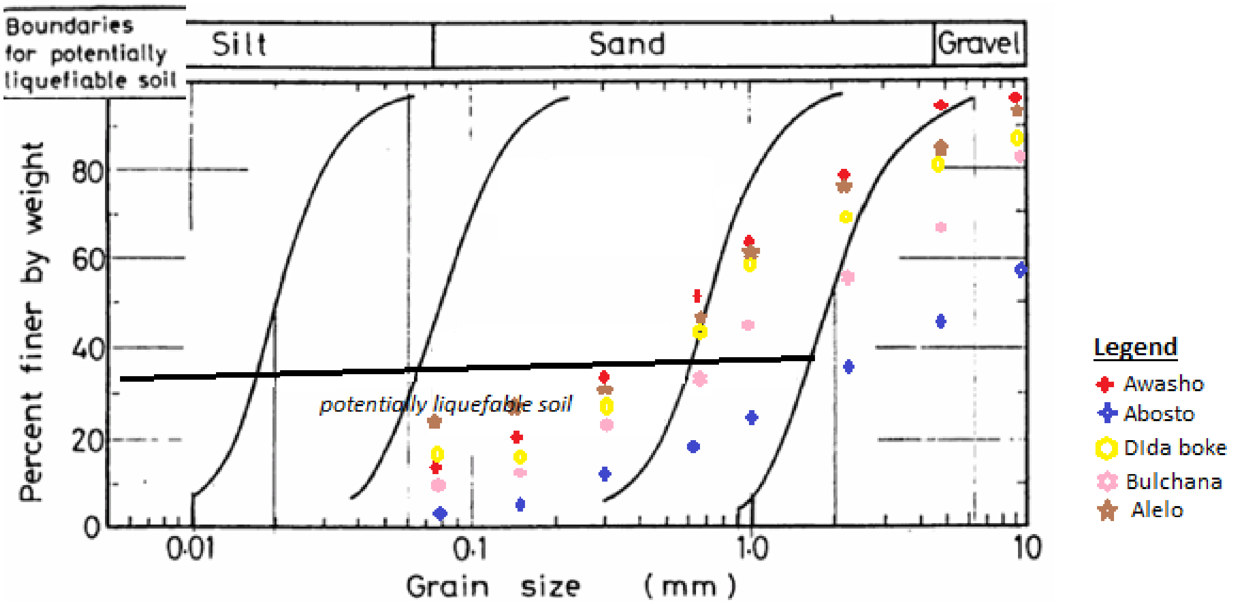

Figure 4.15 Liquefaction susceptibility chart (Tsuchida,1970)

The figure above shows us the soils found in the area are potentially susceptible to liquefaction according to the grain size distriburion criteria.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The dynamic properties (G and D) of Shashemene soils are addressed based on cyclic simple shear tests on four silty sand soil samples.

From the results of this study, the following can be stated:

- The type soil found in the study area is commonly silty sand soil.
- The value of shear modulus is in the range of 0.3 to 4MPa for medium strain level (γ<0.1 %) and 3.0 to 7MPa for higher strain level (γ >0.1 %).The damping ratio values range between 10 to 18% for medium strain level (γ <0.1%) and 18 to 27.0% for higher strain level (γ >0.1 %).
- As it was expected the shear modulus increases moderately while the damping ratio decreases as the number of cycle increases, this property was observed within the first 20 cycles of loading.
- The damping ratio values for silty sand soils under the same axial loads are almost in the range of silty sand soil curves developed by Abraham M. and Abu G.
- The G/Gmax value for Ziway silty sand soil under similar axial load is almost comparable to that of the Shashemene silty sand at similar axial load.
- The soils type found in the study are in the range of potentially susceptible to liquefaction in accordance of grain size distribution.

5.2. Recommendations for Practical Implications

In this thesis strain based approach was used to determine shear modulus and damping ratio of silty sand soils found in Shashemene town. Those values can be used as input parameters: design of foundations for machinery and vibrating equipment, analysis of slope stability of embankments under earthquake loading conditions and also used to model soil behavior under dynamic loading.

5.3. Recommendation for future studies

For future studies:-

- The test should be repeated using cyclic triaxial testing machine to have a better understanding and characterization of the dynamic properties of the soils by comparing with the literature.
- Conducting field tests like standard penetration test helps to see the consistency of laboratory test results with field condition and estimate the potential sample disturbance effect on results of laboratory shear strength tests values.
- Studies should be done on liquefaction suscepitibilty in boarder way.

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APPENDICES

Appendix A

(Field density and Water content of soils)

Table A.1 Determination of field density and water content of all test pits

Determination number	Awasho	Abosto	Dida boke	Bulchana	Alelo
Mass of cylinder before pouring	7884.5	7690	7450	7399.5	7758
Mass of cylinder after pouring	4469	4432	4325	4356	4549
Mass of sand in the cone	1440	1440	1440	1440	1440
Mass of sand in the hole	1975.5	1818	1685	1603.5	1769
Density of sand	1.42	1.42	1.42	1.42	1.42
Volume of hole	1391.2	1280.2	1186.5	1129.2	1245.77
Mass of soil from the hole	2018	1411	1471	1614	1801
Bulk density of the soil	1.45	1.102	1.24	1.43	1.445
Mass of wet soil	135	150	131	146	156
Mass of dry soil	114	133	112	128	137
Mass of water	21	17	15	18	19
Water content	18.42	12.78	16.67	14.06	13.87
Dry density	1.22	0.977	1.11	1.25	1.27

Appendix B

(Specific gravity test results for samples)

Table B.1 Determination of specific gravity of all test pits

Sample number	Awasho	Abosto	Dida boke	Bulchana	Alelo
Weight of pyconometer +water (Wpw), gm	362.5	346	362.5	362	346
Weight of pyconometer +water + soil sample (Wpws), gm	376	360.5	376.5	375	360
Weight of oven dry soil (Ws) ,gm	25	25	25	25	25
Temperature, ^{o}C	22	22	22	23	23
Temperature correction (K)	0.9996	0.9996	0.9996	0.9996	0.9996
Specific gravity, G_s =(K*Ws)/Ws+Wpw-Wpws)	2.173	2.38	2.272	2.082	2.271

Appendix C

(Grain size analysis test result for samples)

Mass of Total Sample = 2000gm)							
S. No	**Sieve Size (mm)**	**weight of sieve**	**weight of sieve with soil retained**	**Mass of Retained Soil (gm)**	**Percentage Retained (%)**	**% cumulative retained**	**Percentage Passing (%)**
1	19	735	747	12	0.6	0.6	99.4
2	9.5	614	631	17	0.85	1.45	98.55
3	4.75	413.5	549	135.5	6.775	8.225	91.775
4	2.36	503	774	271	13.55	21.775	78.225
5	1.18	455.5	707	251.5	12.575	34.35	65.65
6	0.6	439.5	738	298.5	14.925	49.275	50.725
7	0.3	394.5	746	351.5	17.575	66.85	33.15
8	0.15	382	640	258	12.9	79.75	20.25
9	0.075	361	477	116	5.8	85.55	14.45
10	0	363.5	652.5	289	14.45	100	0

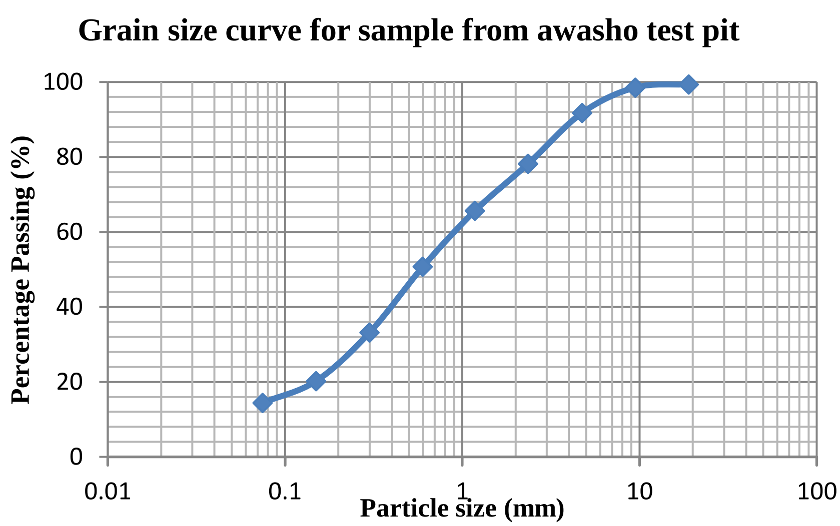


Figure C.1 Grain size curve for Awasho test pit

(Mass of Total Sample = 2000gm)							
S. No	**Sieve Size (mm)**	**weight of sieve**	**weight of sieve with soil retained**	**Mass of Retained Soil (gm)**	**Percentage Retained (%)**	**%tage cumulative retained**	**Percentage Passing (%)**
1	**19**	**735**	**1175**	**440**	**22**	**22**	**78**
2	**9.5**	**614**	**1062.5**	**448.5**	**22.425**	**44.425**	**55.575**
3	**4.75**	**413.5**	**736**	**322.5**	**16.125**	**60.55**	**39.45**
4	**2.36**	**503**	**723**	**220**	**11**	**71.55**	**28.45**
5	**1.18**	**455.5**	**628**	**172.5**	**8.625**	**80.175**	**19.825**
6	**0.6**	**439.5**	**574**	**134.5**	**6.725**	**86.9**	**13.1**
7	**0.3**	**394.5**	**482**	**87.5**	**4.375**	**91.275**	**8.725**
8	**0.15**	**382**	**444**	**62**	**3.1**	**94.375**	**5.625**
9	**0.075**	**361**	**386**	**25**	**1.25**	**95.625**	**4.375**
10	**0**	**363.5**	**451**	**87.5**	**4.375**	**100**	**0**

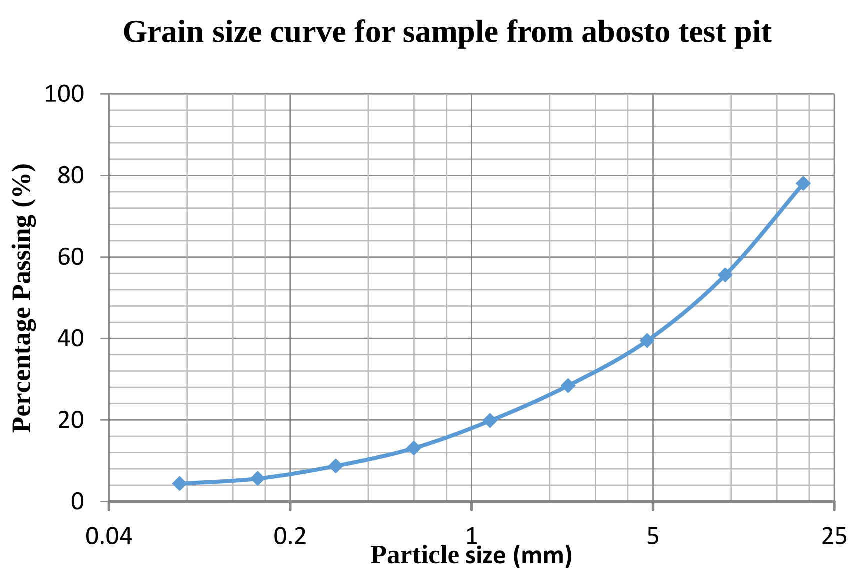


Figure C.2 Grain size curve for Aposto test pit

(Mass of Total Sample = 2000gm)							
S. N o	**Sieve Size (mm)**	**weight of sieve**	**weight of sieve with soil retained**	**Mass of Retained Soil (gm)**	**Percentage Retained (%)**	**%tage cumulative retained**	**Percentage Passing (%)**
1	**19**	**735**	**784**	**49**	**2.45**	**2.45**	**97.55**
2	**9.5**	**614**	**770**	**156**	**7.8**	**10.25**	**89.75**
3	**4.75**	**413.5**	**594**	**180.5**	**9.025**	**19.275**	**80.725**
4	**2.36**	**503**	**726**	**223**	**11.15**	**30.425**	**69.575**
5	**1.18**	**455.5**	**695**	**239.5**	**11.975**	**42.4**	**57.6**
6	**0.6**	**439.5**	**726**	**286.5**	**14.325**	**56.725**	**43.275**
7	**0.3**	**394.5**	**703.5**	**309**	**15.45**	**72.175**	**27.825**
8	**0.15**	**382**	**630**	**248**	**12.4**	**84.575**	**15.425**
9	**0.075**	**361**	**375**	**14**	**0.7**	**85.275**	**14.725**
10	**0**	**363.5**	**658**	**294.5**	**14.725**	**100**	**0**

Grain size curve for sample from dida boke test pit

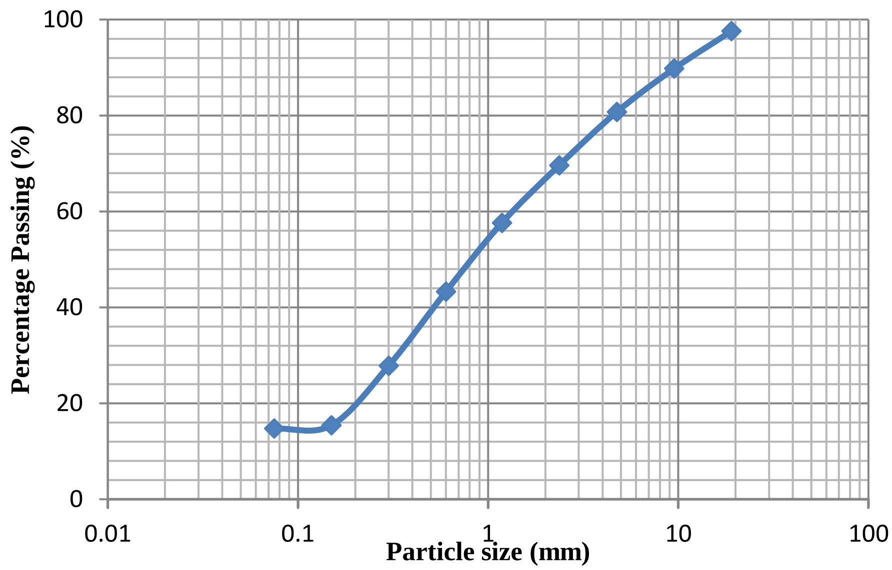


Figure C.3 Grain size curve for Dida boke test pit

(Mass of Total Sample = 2000gm)							
S. N o	**Sieve Size (mm)**	**weight of sieve**	**weight of sieve with soil retained**	**Mass of Retained Soil (gm)**	**Percentage Retained (%)**	**%tage cumulative retained**	**Percentage Passing (%)**
1	19	**735**	**875**	**140**	**7**	**7**	93
2	9.5	**614**	**802**	**188**	**9.4**	**16.4**	83.6
3	4.75	**413.5**	**750.5**	**337**	**16.85**	**33.25**	66.75
4	2.36	**503**	**742**	**239**	**11.95**	**45.2**	54.8
5	1.18	**455.5**	**705**	**249.5**	**12.475**	**57.675**	42.325
6	0.6	**439.5**	**649**	**209.5**	**10.475**	**68.15**	31.85
7	0.3	**394.5**	**593**	**198.5**	**9.925**	**78.075**	21.925
8	0.15	**382**	**541**	**159**	**7.95**	**86.025**	13.975
9	0.075	**361**	**382**	**21**	**1.05**	**87.075**	12.925
10	0	**363.5**	622	**258.5**	**12.925**	**100**	0

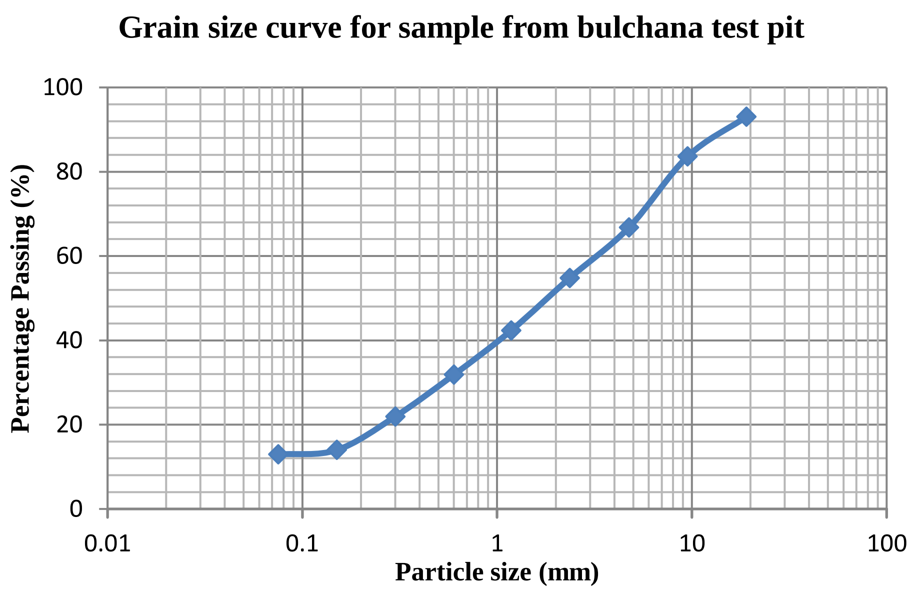


Figure C.3 Grain size curve for Bulchana test pit

(Mass of Total Sample = 2000gm)							
S. No	**Sieve Size (mm)**	**weight of sieve**	**weight of sieve with soil retained**	**Mass of Retained Soil (gm)**	**Percentage Retained (%)**	**%tage cumulative retained**	**Percentage Passing (%)**
1	19	735	735	0	0	0	100
2	9.5	614	673	59	2.95	2.95	97.05
3	4.75	413.5	548	134.5	6.725	9.675	90.325
4	2.36	503	744	241	12.05	21.725	78.275
5	1.18	455.5	759	303.5	15.175	36.9	63.1
6	0.6	439.5	811.5	372	18.6	55.5	44.5
7	0.3	394.5	662.5	268	13.4	68.9	31.1
8	0.15	382	544	162	8.1	77	23
9	0.075	361	388.5	27.5	1.375	78.375	21.625
10	0	363.5	796	432.5	21.625	100	0

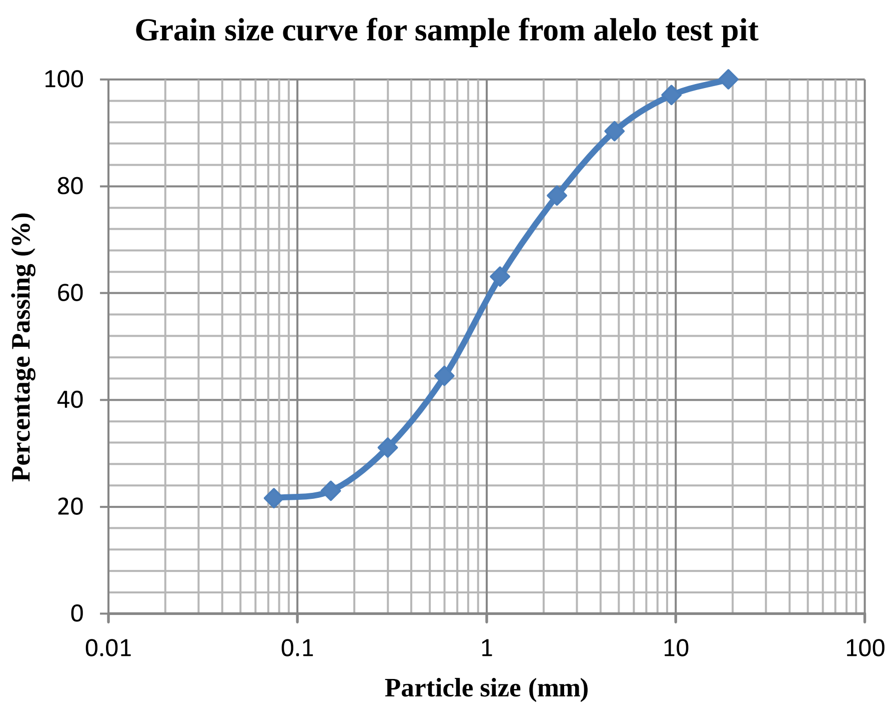


Figure C.3 Grain size curve for Alelo test pit

Appendix D

(Atterberg's limit -test results for sample)

Table D-1: Determination of Liquid Limit, Plastic Limit and Plastic Index (for Awasho)

	Liquid limit				Plastic limit
Trial number	1	2	3	4	
Can no.	B2	DV 5	DC1	AC2	G1
Mass of can (gm)	20.5	20	19.5	20	20
Mass of can +wet soil (gm)	32	31.5	30	30	29.5
Mass of can +dry soil (gm)	30	29	26.5	28.5	27.5
Mass of water (gm)	2	2.5	3.5	1.5	2
Mass of dry soil (gm)	9.5	9	7.5	8.5	7.5
Water content %	39	27.78	26	10	26.67
No. of blows	12	25	30	35	

Liquid limit ,LL=27.78 Plastic limit, PL =26.67 Plastic index,PI= 1%

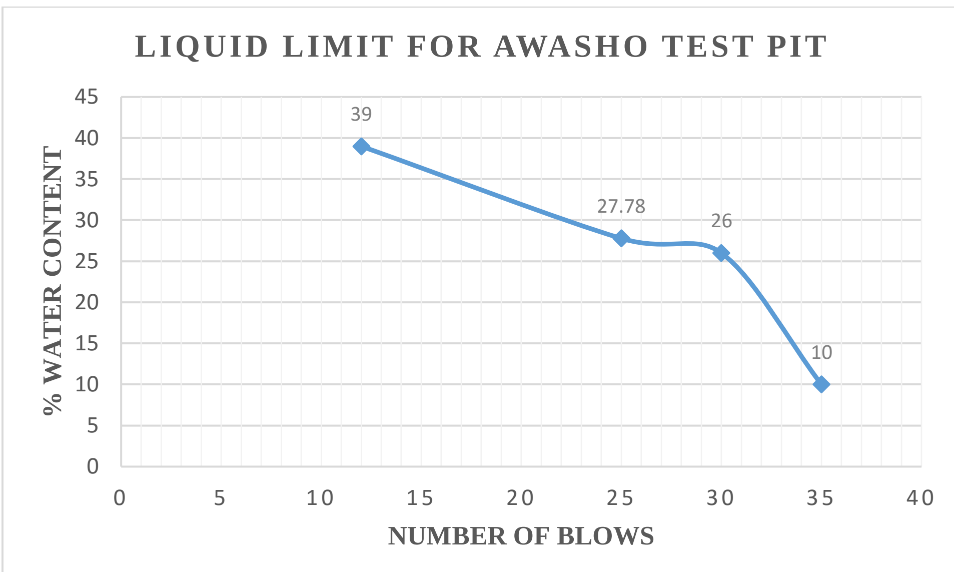


Figure D.1 Water content versus Number of blows of Awasho test pit

Table D-2: Determination of Liquid Limit, Plastic Limit and Plastic Index (for Abosto)

	Liquid limit			Plastic limit
Trial number	1	2	3	
Can no.	D2	V10- 5	G2	B5
Mass of can (gm)	20.5	20	21	20
Mass of can +wet soil (gm)	33	31.5	37.5	28.5
Mass of can +dry soil (gm)	28	29	33.5	27
Mass of water (gm)	5	2.5	4	1.5
Mass of dry soil (gm)	7.5	9	12.5	7.5
Water content %	41	23	32	20
No. of blows	21	33	25	

Liquid limit ,LL=32 Plastic limit, PL =20 Plastic index,PI= 12%

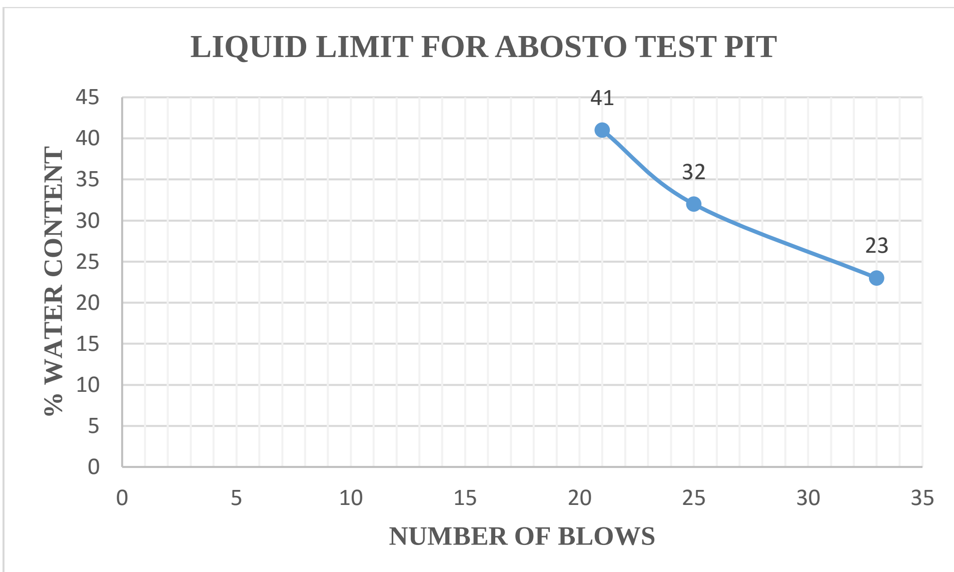


Figure D.2 Water content versus Number of blows of Abosto test pit

Table D-3: Determination of Liquid Limit, Plastic Limit and Plastic Index (for Dida boke)

	Liquid limit			Plastic limit
Trial number	1	2	3	
Can no.	C2	V5	B16	VI-10
Mass of can (gm)	19.5	20	21	17
Mass of can +wet soil (gm)	31	31.5	43.5	23
Mass of can +dry soil (gm)	28.5	29	37.5	17
Mass of water (gm)	2.5	2.5	4	2
Mass of dry soil (gm)	8	9	12.5	6
Water content %	30	44	32	33.33
No. of blows	35	14	25	

Liquid limit ,LL=39.4 Plastic limit, PL =33.33 Plastic index,PI= 6.07%

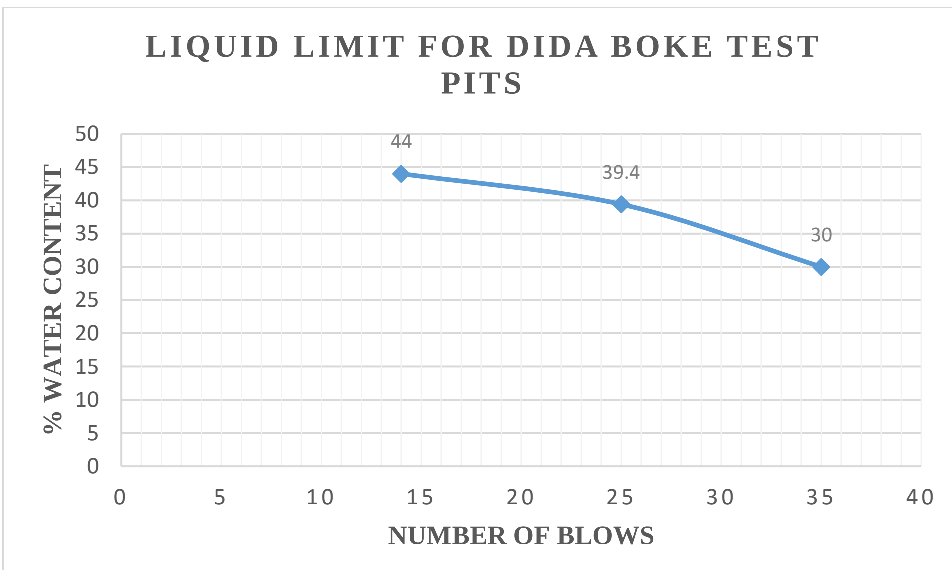


Figure D.3 Water content versus Number of blows of Dida boke test pit

Table D-4: Determination of Liquid Limit, Plastic Limit and Plastic Index (for Bulchana)

	Liquid limit			Plastic limit
Trial number	1	2	3	
Can no.	Z2	C4	TV4	G8
Mass of can (gm)	21	20	20.5	20
Mass of can +wet soil (gm)	33.5	31.5	37	28
Mass of can +dry soil (gm)	30.5	29	32	26
Mass of water (gm)	3	2.5	5	2
Mass of dry soil (gm)	9.5	9	11.5	6
Water content %	51	35	43.47	33.33
No. of blows	10	38	25	

Liquid limit ,LL=43.47 Plastic limit, PL =33.33 Plastic index,PI= 10%

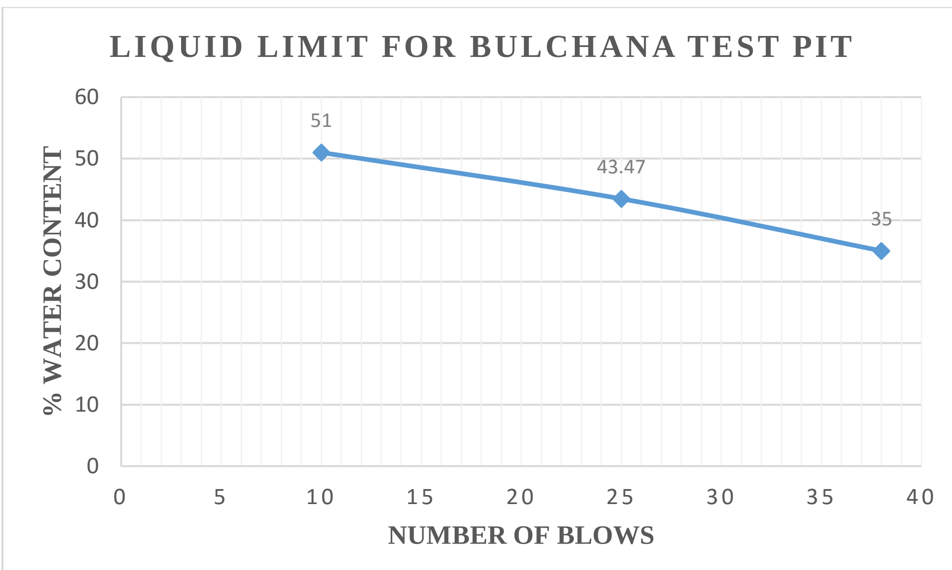


Figure D.4 Water content versus Number of blows of Bulchana test pit

Table D-5: Determination of Liquid Limit, Plastic Limit and Plastic Index (for Alelo test pit)

	Liquid limit			Plastic limit
Trial number	1	2	3	
Can no.	F2	A5	CA5	G3
Mass of can (gm)	20.5	20	19.5	20
Mass of can +wet soil (gm)	35	31.5	41	31
Mass of can +dry soil (gm)	31	29	35	28.5
Mass of water (gm)	4	2.5	6	2.5
Mass of dry soil (gm)	10.5	9	15.5	8.5
Water content %	42	29	38.7	29.4
No. of blows	16	35	25	

Liquid limit ,LL=38.7 Plastic limit, PL =29.4 Plastic index,PI= 9.3%

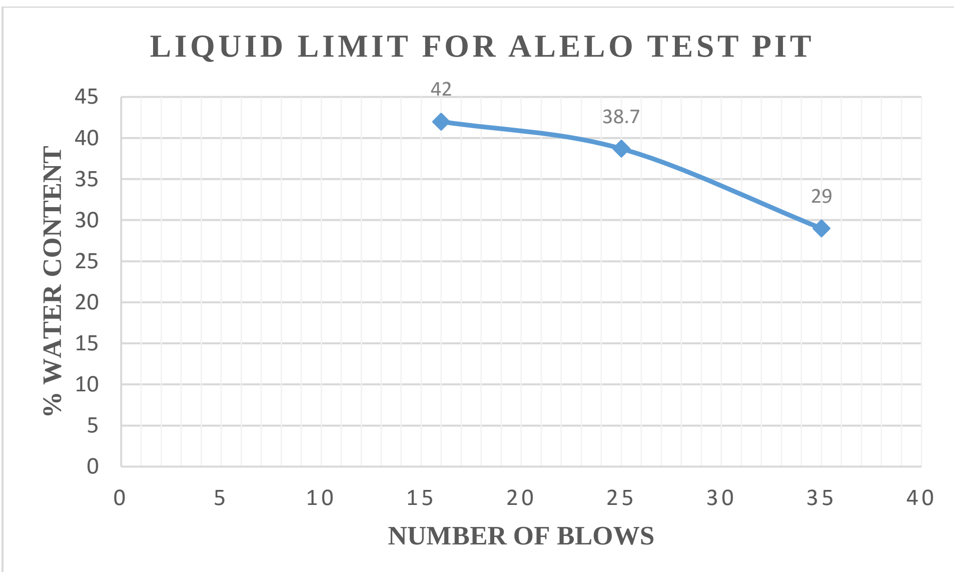


Figure D.5 Water content versus Number of blows of Alelo test pit

Appendix E Cyclic Simple Shear test Result (Shear stress and Shear strain)

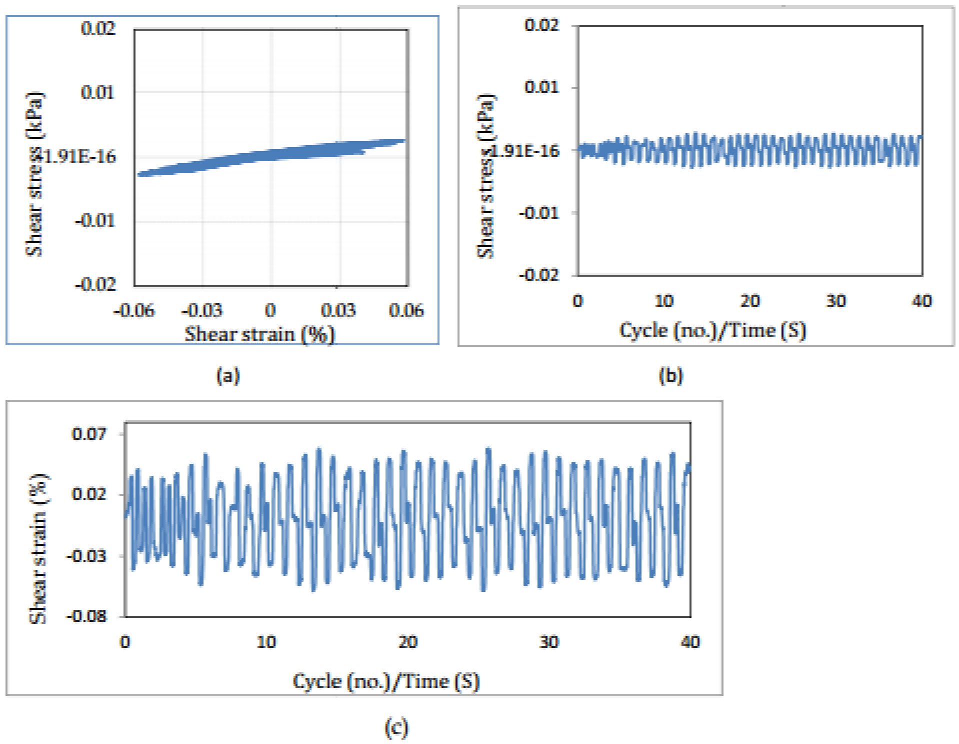
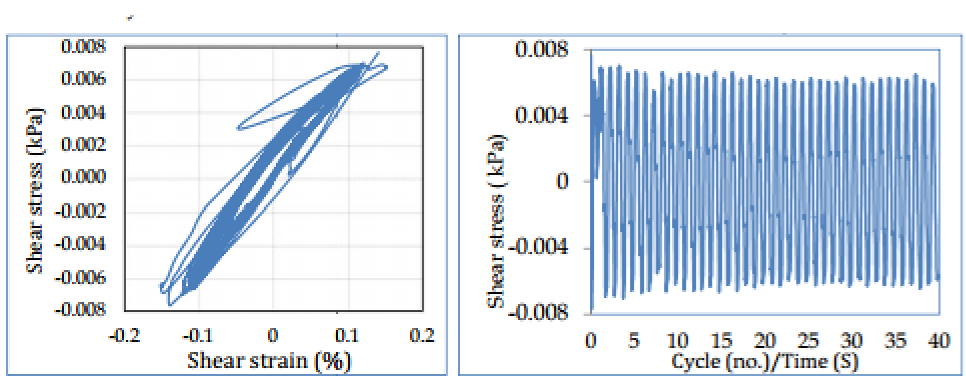
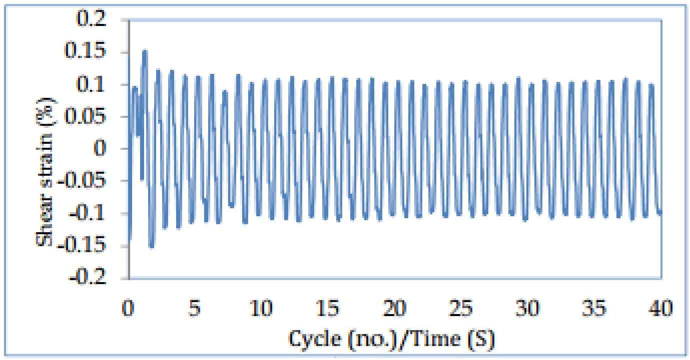


Figure E-1: Results of a strain controlled test (γ=0.05%, frequency =1Hz, σ'v=200 kPa): (a) shear stress versus shear strain; (b) shear stress versus number of cycles; (c)shear strain versus number of cycles.

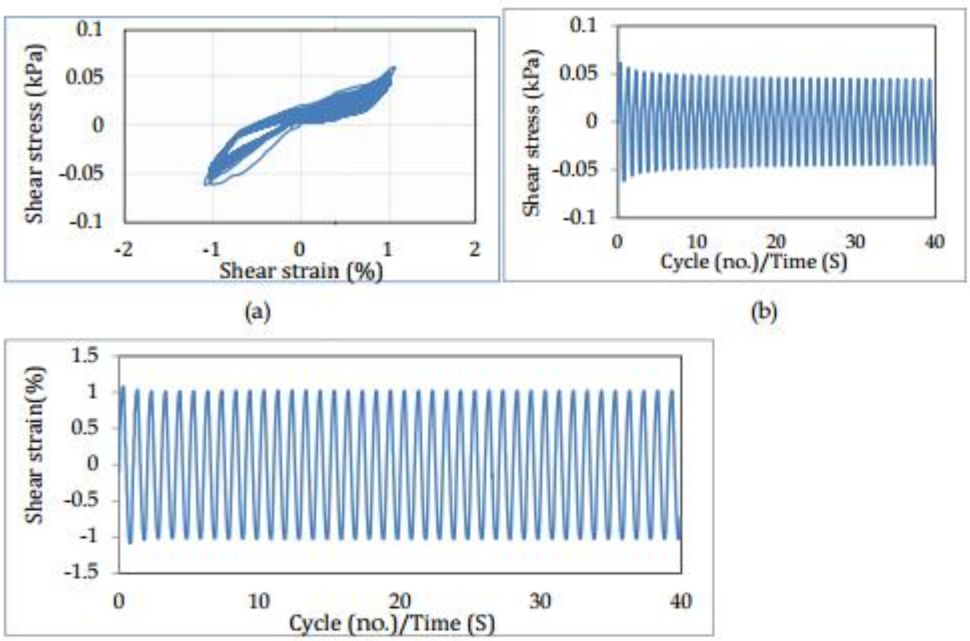


(a) (b)



(c)

Figure E-2: Results of a strain controlled test (γ=0.1%, frequency =1Hz, σ'v =200 kPa): (a) shear stress versus shear strain; (b) shear stress versus number of cycles; (c)shear strain versus number of cycles.



(a) (b)

(c)

Figure E-3: Results of a strain controlled test (γ =1%, frequency =1Hz, σ'v =200 kPa): (a) shear stress versus shear strain; (b) shear stress versus number of cycles; (c)shear strain versus number of cycles.

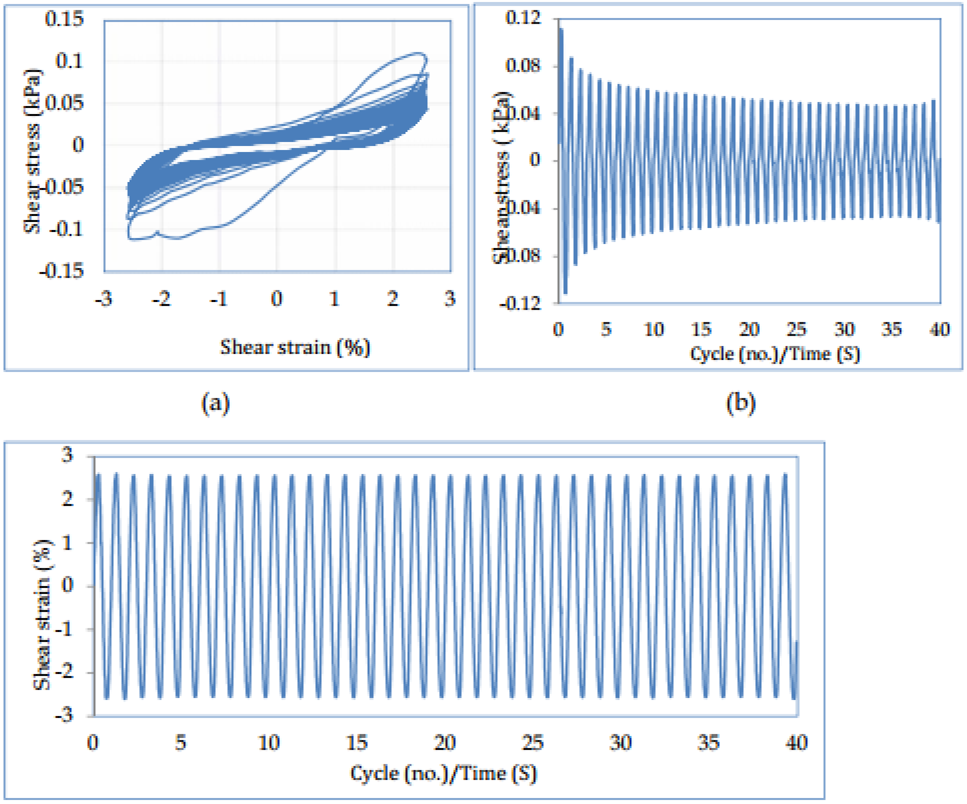
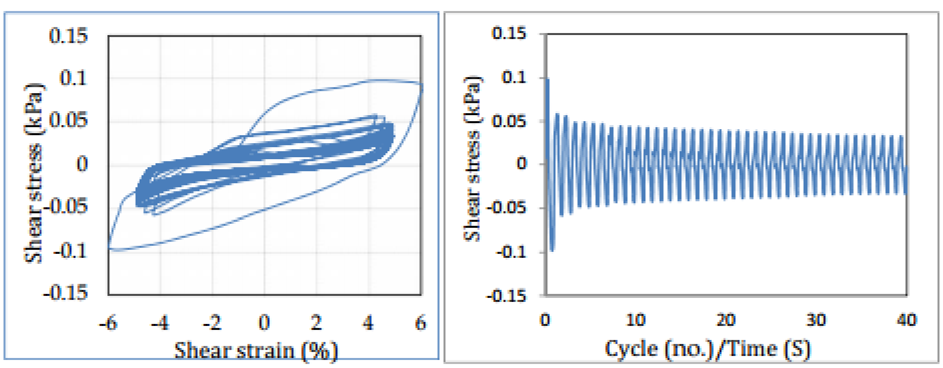
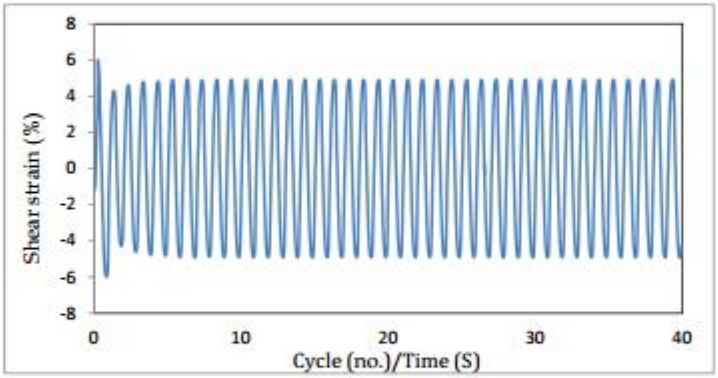


Figure E-4: Results of a strain controlled test (γ =2.5%, frequency =1Hz, σ'v =200 kPa): (a)shear stress versus shear strain; (b) shear stress versus number of cycles; (c)shear strain versus number of cycles.



(a) (b)



(c)

Figure E-5: Results of a strain controlled test (γ =5%, frequency =1Hz, σ'v=200 kPa): (a) shear stress versus shear strain; (b) shear stress versus number of cycles; (c)shear strain versus number of cycles

APPENDIX F Values of shear modulus and damping ratio

awasho-1	Shear modulus for 100kpa					Damping ratio for 100kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	3.95	2.80	2.19	1.82	1.73	18.38	20.59	23.90	25.07	26.33
2.00	3.90	2.75	2.14	1.76	1.68	18.18	20.39	23.70	24.87	26.12
3.00	3.82	2.74	2.13	1.75	1.67	17.33	19.54	22.85	23.81	25.00
4.00	3.87	2.73	2.12	1.74	1.66	16.94	19.15	22.46	23.64	24.82
5.00	3.96	2.73	2.07	1.88	1.79	16.42	18.64	21.95	23.12	24.28
6.00	3.65	2.51	1.90	1.52	1.45	15.23	17.44	20.75	21.50	22.58
7.00	3.63	2.49	1.88	1.50	1.43	15.13	17.35	20.65	21.83	22.92
8.00	3.61	2.47	1.86	1.48	1.41	14.77	16.99	20.30	19.75	20.74
9.00	3.59	2.45	1.84	1.46	1.39	13.63	15.84	19.15	20.33	21.34
10.00	3.57	2.43	1.82	1.44	1.37	12.22	14.44	17.75	18.92	19.87
11.00	3.55	2.40	1.80	1.42	1.35	12.75	14.96	18.27	19.45	20.42
12.00	3.53	2.38	1.77	1.40	1.33	12.40	14.62	17.92	18.27	19.18
13.00	3.32	2.17	1.56	1.19	1.13	12.00	14.22	17.52	18.70	19.64
14.00	3.30	2.15	1.54	1.17	1.11	11.88	14.09	17.40	17.75	18.63
15.00	3.28	2.13	1.52	1.14	1.09	11.50	13.71	17.02	18.20	19.11
16.00	3.26	2.11	1.50	1.12	1.07	12.37	14.58	17.89	19.07	20.02
17.00	3.17	2.03	1.42	1.04	0.99	11.04	13.25	16.56	17.73	18.62
18.00	3.15	2.01	1.40	1.02	0.97	11.83	14.05	17.36	18.53	19.46
19.00	3.13	1.98	1.38	1.00	0.95	10.71	12.93	16.23	17.41	18.28
20.00	3.11	1.96	1.35	0.98	0.93	11.50	13.71	17.02	18.20	19.11
21.00	3.09	1.94	1.33	0.96	0.91	10.52	12.74	16.04	17.22	18.08
22.00	3.07	1.92	1.31	0.93	0.89	11.04	13.25	16.56	17.73	18.62
23.00	3.05	1.90	1.29	0.91	0.87	10.15	12.37	15.68	16.85	17.70
24.00	3.02	1.88	1.27	0.89	0.85	10.76	12.98	16.29	17.46	18.33
25.00	3.00	1.86	1.25	0.87	0.83	9.99	12.20	15.51	16.68	17.52
26.00	2.79	1.65	1.04	0.66	0.63	10.41	12.62	15.93	17.10	17.96
27.00	2.77	1.63	1.02	0.64	0.61	11.33	13.55	16.85	18.03	18.93
28.00	2.75	1.61	1.00	0.62	0.59	10.21	12.42	15.73	16.91	17.75
29.00	2.73	1.59	0.98	0.60	0.57	11.03	13.24	16.55	17.72	18.61
30.00	2.71	1.56	0.96	0.58	0.55	9.93	12.15	15.46	16.63	17.46
31.00	2.69	1.54	0.93	0.56	0.53	10.68	12.89	16.20	17.38	18.25
32.00	2.67	1.52	0.91	0.54	0.51	9.86	12.08	15.38	16.56	17.39
33.00	2.65	1.50	0.89	0.51	0.49	10.34	12.56	15.87	17.04	17.89
34.00	2.63	1.48	0.87	0.49	0.47	9.54	11.76	15.07	16.24	17.06
35.00	2.60	1.46	0.85	0.47	0.45	10.04	12.25	15.56	16.74	17.57
36.00	2.58	1.44	0.83	0.45	0.43	9.40	11.61	14.92	16.10	16.90
37.00	2.56	1.42	0.81	0.43	0.41	9.75	11.97	15.28	16.45	17.28
38.00	2.54	1.40	0.79	0.41	0.39	10.57	12.79	16.10	17.27	18.14
39.00	2.52	1.38	0.77	0.39	0.37	9.53	11.75	15.06	16.23	17.04
40.00	2.50	1.35	0.75	0.37	0.35	10.30	12.52	15.82	17.00	17.85

awasho	Shear modulus for 200kpa					Damping ratio for 200kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.15	2.94	2.30	1.91	1.81	17.46	19.56	22.70	23.82	25.01
2.00	4.10	2.89	2.25	1.85	1.76	17.27	19.37	22.51	23.63	24.81
3.00	4.01	2.88	2.24	1.84	1.75	16.46	18.56	21.71	22.62	23.75
4.00	4.07	2.87	2.23	1.83	1.74	16.09	18.19	21.34	22.45	23.58
5.00	4.16	2.87	2.17	1.97	1.87	15.60	17.71	20.85	21.96	23.06
6.00	3.84	2.63	2.00	1.60	1.52	14.46	16.57	19.71	20.43	21.45
7.00	3.81	2.61	1.97	1.58	1.50	14.37	16.48	19.62	20.74	21.77
8.00	3.79	2.59	1.95	1.55	1.48	14.03	16.14	19.28	18.76	19.70
9.00	3.77	2.57	1.93	1.53	1.46	12.95	15.05	18.19	19.31	20.28
10.00	3.75	2.55	1.91	1.51	1.43	11.61	13.72	16.86	17.97	18.87
11.00	3.73	2.52	1.89	1.49	1.41	12.11	14.21	17.36	18.47	19.40
12.00	3.70	2.50	1.86	1.47	1.39	11.78	13.89	17.03	17.36	18.22
13.00	3.48	2.28	1.64	1.25	1.18	11.40	13.51	16.65	17.77	18.65
14.00	3.46	2.26	1.62	1.22	1.16	11.28	13.39	16.53	16.86	17.70
15.00	3.44	2.24	1.60	1.20	1.14	10.92	13.03	16.17	17.29	18.15
16.00	3.42	2.22	1.58	1.18	1.12	11.75	13.86	17.00	18.11	19.02
17.00	3.33	2.13	1.49	1.09	1.04	10.48	12.59	15.73	16.85	17.69
18.00	3.31	2.11	1.47	1.07	1.02	11.24	13.35	16.49	17.61	18.49
19.00	3.29	2.08	1.44	1.05	1.00	10.17	12.28	15.42	16.54	17.37
20.00	3.26	2.06	1.42	1.03	0.97	10.92	13.03	16.17	17.29	18.15
21.00	3.24	2.04	1.40	1.00	0.95	9.99	12.10	15.24	16.36	17.18
22.00	3.22	2.02	1.38	0.98	0.93	10.48	12.59	15.73	16.85	17.69
23.00	3.20	2.00	1.36	0.96	0.91	9.65	11.75	14.89	16.01	16.81
24.00	3.18	1.97	1.33	0.94	0.89	10.22	12.33	15.47	16.59	17.42
25.00	3.15	1.95	1.31	0.92	0.87	9.49	11.59	14.73	15.85	16.64
26.00	2.93	1.73	1.09	0.69	0.66	9.89	11.99	15.13	16.25	17.06
27.00	2.91	1.71	1.07	0.67	0.64	10.76	12.87	16.01	17.13	17.98
28.00	2.89	1.69	1.05	0.65	0.62	9.70	11.80	14.94	16.06	16.86
29.00	2.87	1.66	1.03	0.63	0.60	10.47	12.58	15.72	16.84	17.68
30.00	2.84	1.64	1.00	0.61	0.58	9.44	11.54	14.68	15.80	16.59
31.00	2.82	1.62	0.98	0.58	0.56	10.14	12.25	15.39	16.51	17.33
32.00	2.80	1.60	0.96	0.56	0.53	9.37	11.47	14.61	15.73	16.52
33.00	2.78	1.58	0.94	0.54	0.51	9.83	11.93	15.07	16.19	17.00
34.00	2.76	1.55	0.92	0.52	0.49	9.07	11.17	14.31	15.43	16.20
35.00	2.73	1.53	0.89	0.50	0.47	9.54	11.64	14.78	15.90	16.70
36.00	2.71	1.51	0.87	0.47	0.45	8.93	11.03	14.17	15.29	16.06
37.00	2.69	1.49	0.85	0.45	0.43	9.27	11.37	14.51	15.63	16.41
38.00	2.67	1.47	0.83	0.43	0.41	10.04	12.15	15.29	16.41	17.23
39.00	2.65	1.44	0.80	0.41	0.39	9.06	11.16	14.30	15.42	16.19
40.00	2.62	1.42	0.78	0.39	0.37	9.79	11.89	15.03	16.15	16.96

awasho	Shear modulus for 300kpa					Damping ratio for 300kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.35	3.09	2.42	2.00	1.90	13.09	14.67	17.03	20.25	22.51
2.00	4.30	3.03	2.36	1.94	1.85	12.95	14.53	16.89	20.09	22.33
3.00	4.21	3.02	2.35	1.93	1.84	12.34	13.92	16.28	19.23	21.38
4.00	4.27	3.01	2.34	1.92	1.83	12.07	13.65	16.00	19.09	21.22
5.00	4.36	3.01	2.28	2.07	1.97	11.70	13.28	15.64	18.67	20.76
6.00	4.03	2.77	2.10	1.68	1.59	10.85	12.43	14.78	17.36	19.31
7.00	4.01	2.74	2.07	1.66	1.57	10.78	12.36	14.72	17.63	19.60
8.00	3.98	2.72	2.05	1.63	1.55	10.53	12.10	14.46	15.95	17.73
9.00	3.96	2.70	2.03	1.61	1.53	9.71	11.29	13.65	16.41	18.25
10.00	3.94	2.67	2.00	1.59	1.51	8.71	10.29	12.64	15.28	16.99
11.00	3.91	2.65	1.98	1.56	1.48	9.08	10.66	13.02	15.70	17.46
12.00	3.89	2.63	1.96	1.54	1.46	8.84	10.41	12.77	14.75	16.40
13.00	3.66	2.40	1.72	1.31	1.24	8.55	10.13	12.49	15.10	16.79
14.00	3.63	2.37	1.70	1.28	1.22	8.46	10.04	12.40	14.33	15.93
15.00	3.61	2.35	1.68	1.26	1.20	8.19	9.77	12.13	14.69	16.34
16.00	3.59	2.33	1.66	1.24	1.18	8.81	10.39	12.75	15.40	17.12
17.00	3.50	2.23	1.56	1.15	1.09	7.86	9.44	11.80	14.32	15.92
18.00	3.47	2.21	1.54	1.12	1.07	8.43	10.01	12.37	14.96	16.64
19.00	3.45	2.19	1.52	1.10	1.04	7.63	9.21	11.57	14.06	15.63
20.00	3.43	2.16	1.49	1.08	1.02	8.19	9.77	12.13	14.69	16.34
21.00	3.40	2.14	1.47	1.05	1.00	7.50	9.07	11.43	13.91	15.46
22.00	3.38	2.12	1.45	1.03	0.98	7.86	9.44	11.80	14.32	15.92
23.00	3.36	2.10	1.42	1.01	0.96	7.23	8.81	11.17	13.61	15.13
24.00	3.33	2.07	1.40	0.98	0.93	7.67	9.25	11.60	14.10	15.68
25.00	3.31	2.05	1.38	0.96	0.91	7.11	8.69	11.05	13.47	14.98
26.00	3.08	1.82	1.15	0.73	0.69	7.41	8.99	11.35	13.81	15.36
27.00	3.06	1.79	1.12	0.71	0.67	8.07	9.65	12.01	14.56	16.19
28.00	3.03	1.77	1.10	0.68	0.65	7.27	8.85	11.21	13.65	15.18
29.00	3.01	1.75	1.08	0.66	0.63	7.86	9.43	11.79	14.31	15.91
30.00	2.99	1.72	1.05	0.64	0.60	7.08	8.66	11.01	13.43	14.93
31.00	2.96	1.70	1.03	0.61	0.58	7.61	9.19	11.54	14.03	15.60
32.00	2.94	1.68	1.01	0.59	0.56	7.02	8.60	10.96	13.37	14.87
33.00	2.92	1.66	0.98	0.57	0.54	7.37	8.95	11.30	13.76	15.30
34.00	2.89	1.63	0.96	0.54	0.52	6.80	8.38	10.74	13.12	14.58
35.00	2.87	1.61	0.94	0.52	0.49	7.15	8.73	11.09	13.52	15.03
36.00	2.85	1.59	0.91	0.50	0.47	6.70	8.27	10.63	13.00	14.45
37.00	2.82	1.56	0.89	0.47	0.45	6.95	8.53	10.89	13.29	14.77
38.00	2.80	1.54	0.87	0.45	0.43	7.53	9.11	11.47	13.95	15.51
39.00	2.78	1.52	0.85	0.43	0.41	6.79	8.37	10.73	13.11	14.57
40.00	2.76	1.49	0.82	0.41	0.38	7.34	8.92	11.27	13.73	15.26

awasho-1	Shear modulus for 400kpa				Damping ratio for 400kpa					
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	6.67	5.72	4.40	3.56	3.38	11.87	15.56	17.90	21.58	22.84
2.00	6.60	5.68	4.35	3.51	3.33	11.67	15.36	17.70	21.38	22.64
3.00	6.54	5.60	4.34	3.50	3.32	10.82	14.51	16.85	20.53	21.58
4.00	6.52	5.65	4.33	3.49	3.31	10.43	14.12	16.46	20.14	21.40
5.00	6.73	5.73	4.33	3.43	3.26	9.91	13.61	15.95	19.62	20.88
6.00	6.57	5.43	4.11	3.27	3.10	8.72	12.41	14.75	18.43	19.27
7.00	6.26	5.41	4.08	3.24	3.08	8.62	12.32	14.66	18.33	19.59
8.00	6.33	5.39	4.06	3.22	3.06	8.26	11.96	14.30	17.98	17.51
9.00	6.32	5.37	4.04	3.20	3.04	7.12	10.82	13.16	16.83	18.09
10.00	6.29	5.34	4.02	3.18	3.02	5.71	9.41	11.75	15.42	16.68
11.00	6.16	5.32	4.00	3.16	3.00	6.24	9.93	12.27	15.95	17.21
12.00	6.25	5.30	3.98	3.14	2.98	5.89	9.59	11.93	15.60	16.03
13.00	6.04	5.09	3.77	2.93	2.78	5.49	9.19	11.53	15.20	16.46
14.00	6.02	5.07	3.75	2.91	2.76	5.37	9.06	11.40	15.08	15.51
15.00	6.00	5.05	3.73	2.89	2.74	4.99	8.68	11.03	14.70	15.96
16.00	5.97	5.03	3.71	2.87	2.72	5.86	9.56	11.90	15.57	16.83
17.00	5.89	4.95	3.62	2.78	2.64	4.53	8.22	10.56	14.24	15.50
18.00	5.87	4.92	3.60	2.76	2.62	5.32	9.02	11.36	15.04	16.30
19.00	5.85	4.90	3.58	2.74	2.60	4.20	7.90	10.24	13.91	15.17
20.00	5.83	4.88	3.56	2.72	2.58	4.99	8.68	11.03	14.70	15.96
21.00	5.81	4.86	3.54	2.70	2.56	4.01	7.71	10.05	13.72	14.98
22.00	5.79	4.84	3.52	2.68	2.54	4.53	8.22	10.56	14.24	15.50
23.00	5.76	4.82	3.50	2.66	2.52	3.64	7.34	9.68	13.36	14.62
24.00	5.74	4.80	3.48	2.64	2.50	4.25	7.95	10.29	13.97	15.23
25.00	5.72	4.78	3.45	2.61	2.48	3.48	7.17	9.51	13.19	14.45
26.00	5.51	4.57	3.24	2.40	2.28	3.90	7.59	9.93	13.61	14.87
27.00	5.49	4.55	3.22	2.38	2.26	4.82	8.52	10.86	14.53	15.79
28.00	5.47	4.53	3.20	2.36	2.24	3.70	7.39	9.73	13.41	14.67
29.00	5.45	4.50	3.18	2.34	2.22	4.52	8.21	10.55	14.23	15.49
30.00	5.43	4.48	3.16	2.32	2.20	3.42	7.12	9.46	13.14	14.40
31.00	5.41	4.46	3.14	2.30	2.18	4.17	7.86	10.21	13.88	15.14
32.00	5.39	4.44	3.12	2.28	2.16	3.35	7.05	9.39	13.06	14.32
33.00	5.37	4.42	3.10	2.26	2.14	3.83	7.53	9.87	13.55	14.81
34.00	5.34	4.40	3.08	2.24	2.12	3.03	6.73	9.07	12.75	14.01
35.00	5.32	4.38	3.06	2.22	2.10	3.53	7.22	9.57	13.24	14.50
36.00	5.30	4.36	3.03	2.19	2.08	2.89	6.58	8.93	12.60	13.86
37.00	5.28	4.34	3.01	2.17	2.06	3.24	6.94	9.28	12.96	14.22
38.00	5.26	4.32	2.99	2.15	2.04	4.06	7.76	10.10	13.78	15.04
39.00	5.24	4.29	2.97	2.13	2.02	3.02	6.72	9.06	12.74	14.00
40.00	5.22	4.27	2.95	2.11	2.00	3.79	7.49	9.83	13.50	14.76

bulchana	Shear modulus for 100kpa					Damping ratio for 100kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.97	3.53	2.77	2.29	2.17	13.09	14.67	17.03	17.87	18.76
2.00	4.92	3.47	2.70	2.22	2.11	12.95	14.53	16.89	17.72	18.61
3.00	4.82	3.45	2.69	2.21	2.10	12.34	13.92	16.28	16.97	17.82
4.00	4.88	3.44	2.67	2.20	2.09	12.07	13.65	16.00	16.84	17.68
5.00	4.99	3.44	2.61	2.37	2.25	11.70	13.28	15.64	16.47	17.30
6.00	4.60	3.16	2.39	1.92	1.82	10.85	12.43	14.78	15.32	16.09
7.00	4.58	3.14	2.37	1.89	1.80	10.78	12.36	14.72	15.55	16.33
8.00	4.55	3.11	2.34	1.87	1.77	10.53	12.10	14.46	14.07	14.78
9.00	4.52	3.08	2.32	1.84	1.75	9.71	11.29	13.65	14.48	15.21
10.00	4.50	3.06	2.29	1.81	1.72	8.71	10.29	12.64	13.48	14.16
11.00	4.47	3.03	2.26	1.79	1.70	9.08	10.66	13.02	13.86	14.55
12.00	4.45	3.00	2.24	1.76	1.67	8.84	10.41	12.77	13.02	13.67
13.00	4.18	2.74	1.97	1.49	1.42	8.55	10.13	12.49	13.32	13.99
14.00	4.15	2.71	1.94	1.47	1.40	8.46	10.04	12.40	12.64	13.28
15.00	4.13	2.69	1.92	1.44	1.37	8.19	9.77	12.13	12.97	13.61
16.00	4.10	2.66	1.89	1.42	1.34	8.81	10.39	12.75	13.59	14.27
17.00	4.00	2.55	1.79	1.31	1.24	7.86	9.44	11.80	12.64	13.27
18.00	3.97	2.53	1.76	1.28	1.22	8.43	10.01	12.37	13.20	13.86
19.00	3.94	2.50	1.73	1.26	1.19	7.63	9.21	11.57	12.40	13.02
20.00	3.92	2.47	1.71	1.23	1.17	8.19	9.77	12.13	12.97	13.61
21.00	3.89	2.45	1.68	1.20	1.14	7.50	9.07	11.43	12.27	12.88
22.00	3.86	2.42	1.65	1.18	1.12	7.86	9.44	11.80	12.64	13.27
23.00	3.84	2.39	1.63	1.15	1.09	7.23	8.81	11.17	12.01	12.61
24.00	3.81	2.37	1.60	1.12	1.07	7.67	9.25	11.60	12.44	13.06
25.00	3.78	2.34	1.57	1.10	1.04	7.11	8.69	11.05	11.89	12.48
26.00	3.52	2.08	1.31	0.83	0.79	7.41	8.99	11.35	12.19	12.80
27.00	3.49	2.05	1.28	0.81	0.77	8.07	9.65	12.01	12.85	13.49
28.00	3.47	2.02	1.26	0.78	0.74	7.27	8.85	11.21	12.04	12.65
29.00	3.44	2.00	1.23	0.75	0.72	7.86	9.43	11.79	12.63	13.26
30.00	3.41	1.97	1.20	0.73	0.69	7.08	8.66	11.01	11.85	12.44
31.00	3.39	1.94	1.18	0.70	0.67	7.61	9.19	11.54	12.38	13.00
32.00	3.36	1.92	1.15	0.67	0.64	7.02	8.60	10.96	11.80	12.39
33.00	3.33	1.89	1.12	0.65	0.62	7.37	8.95	11.30	12.14	12.75
34.00	3.31	1.87	1.10	0.62	0.59	6.80	8.38	10.74	11.57	12.15
35.00	3.28	1.84	1.07	0.60	0.57	7.15	8.73	11.09	11.93	12.52
36.00	3.25	1.81	1.05	0.57	0.54	6.70	8.27	10.63	11.47	12.04
37.00	3.23	1.79	1.02	0.54	0.52	6.95	8.53	10.89	11.72	12.31
38.00	3.20	1.76	0.99	0.52	0.49	7.53	9.11	11.47	12.31	12.92
39.00	3.18	1.73	0.97	0.49	0.47	6.79	8.37	10.73	11.57	12.14
40.00	3.15	1.71	0.94	0.46	0.44	7.34	8.92	11.27	12.11	12.72

bulchana	Shear modulus for 200kpa				Damping ratio for 200kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	5.22	3.71	2.90	2.40	2.28	12.44	13.94	16.18	16.97	17.82
2.00	5.16	3.64	2.83	2.33	2.22	12.30	13.80	16.04	16.84	17.68
3.00	5.06	3.63	2.82	2.32	2.20	11.73	13.23	15.47	16.12	16.93
4.00	5.13	3.61	2.81	2.31	2.19	11.46	12.96	15.20	16.00	16.80
5.00	5.24	3.61	2.74	2.49	2.36	11.12	12.62	14.85	15.65	16.43
6.00	4.83	3.32	2.51	2.01	1.91	10.31	11.81	14.04	14.56	15.28
7.00	4.81	3.29	2.49	1.99	1.89	10.24	11.74	13.98	14.78	15.51
8.00	4.78	3.26	2.46	1.96	1.86	10.00	11.50	13.74	13.37	14.04
9.00	4.75	3.24	2.43	1.93	1.83	9.23	10.72	12.96	13.76	14.45
10.00	4.72	3.21	2.40	1.90	1.81	8.27	9.77	12.01	12.81	13.45
11.00	4.70	3.18	2.38	1.88	1.78	8.63	10.13	12.37	13.16	13.82
12.00	4.67	3.15	2.35	1.85	1.76	8.39	9.89	12.13	12.37	12.98
13.00	4.39	2.88	2.07	1.57	1.49	8.12	9.62	11.86	12.66	13.29
14.00	4.36	2.85	2.04	1.54	1.46	8.04	9.54	11.78	12.01	12.61
15.00	4.33	2.82	2.01	1.51	1.44	7.78	9.28	11.52	12.32	12.93
16.00	4.31	2.79	1.99	1.49	1.41	8.37	9.87	12.11	12.91	13.55
17.00	4.20	2.68	1.88	1.38	1.31	7.47	8.97	11.21	12.00	12.60
18.00	4.17	2.65	1.85	1.35	1.28	8.01	9.51	11.75	12.54	13.17
19.00	4.14	2.63	1.82	1.32	1.25	7.25	8.75	10.99	11.78	12.37
20.00	4.11	2.60	1.79	1.29	1.23	7.78	9.28	11.52	12.32	12.93
21.00	4.08	2.57	1.76	1.26	1.20	7.12	8.62	10.86	11.66	12.24
22.00	4.06	2.54	1.74	1.24	1.17	7.47	8.97	11.21	12.00	12.60
23.00	4.03	2.51	1.71	1.21	1.15	6.87	8.37	10.61	11.41	11.98
24.00	4.00	2.49	1.68	1.18	1.12	7.28	8.78	11.02	11.82	12.41
25.00	3.97	2.46	1.65	1.15	1.10	6.76	8.26	10.50	11.29	11.86
26.00	3.70	2.18	1.38	0.88	0.83	7.04	8.54	10.78	11.58	12.16
27.00	3.67	2.15	1.35	0.85	0.81	7.67	9.17	11.41	12.20	12.81
28.00	3.64	2.13	1.32	0.82	0.78	6.91	8.41	10.65	11.44	12.01
29.00	3.61	2.10	1.29	0.79	0.75	7.46	8.96	11.20	12.00	12.60
30.00	3.58	2.07	1.26	0.76	0.73	6.72	8.22	10.46	11.26	11.82
31.00	3.56	2.04	1.24	0.74	0.70	7.23	8.73	10.97	11.76	12.35
32.00	3.53	2.01	1.21	0.71	0.67	6.67	8.17	10.41	11.21	11.77
33.00	3.50	1.99	1.18	0.68	0.65	7.00	8.50	10.74	11.53	12.11
34.00	3.47	1.96	1.15	0.65	0.62	6.46	7.96	10.20	10.99	11.54
35.00	3.45	1.93	1.13	0.63	0.59	6.79	8.29	10.53	11.33	11.90
36.00	3.42	1.90	1.10	0.60	0.57	6.36	7.86	10.10	10.90	11.44
37.00	3.39	1.88	1.07	0.57	0.54	6.60	8.10	10.34	11.14	11.69
38.00	3.36	1.85	1.04	0.54	0.51	7.16	8.66	10.90	11.69	12.28
39.00	3.33	1.82	1.01	0.51	0.49	6.45	7.95	10.19	10.99	11.54
40.00	3.31	1.79	0.99	0.49	0.46	6.97	8.47	10.71	11.51	12.08

bulchana	Shear modulus for 300kpa				Damping ratio for 300kpa					
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	5.48	3.89	3.05	2.52	2.40	11.82	13.24	15.37	16.12	16.93
2.00	5.42	3.82	2.98	2.45	2.33	11.69	13.11	15.24	16.00	16.79
3.00	5.31	3.81	2.96	2.44	2.31	11.14	12.57	14.69	15.31	16.08
4.00	5.38	3.79	2.95	2.42	2.30	10.89	12.32	14.44	15.20	15.96
5.00	5.50	3.79	2.87	2.61	2.48	10.56	11.98	14.11	14.87	15.61
6.00	5.08	3.49	2.64	2.11	2.01	9.79	11.21	13.34	13.83	14.52
7.00	5.05	3.46	2.61	2.09	1.98	9.73	11.15	13.28	14.04	14.74
8.00	5.02	3.43	2.58	2.06	1.95	9.50	10.92	13.05	12.70	13.34
9.00	4.99	3.40	2.55	2.03	1.93	8.76	10.19	12.32	13.07	13.73
10.00	4.96	3.37	2.52	2.00	1.90	7.86	9.28	11.41	12.17	12.78
11.00	4.93	3.34	2.49	1.97	1.87	8.20	9.62	11.75	12.50	13.13
12.00	4.90	3.31	2.47	1.94	1.84	7.97	9.40	11.53	11.75	12.34
13.00	4.61	3.02	2.17	1.65	1.57	7.72	9.14	11.27	12.03	12.63
14.00	4.58	2.99	2.14	1.62	1.54	7.64	9.06	11.19	11.41	11.98
15.00	4.55	2.96	2.11	1.59	1.51	7.39	8.82	10.94	11.70	12.29
16.00	4.52	2.93	2.09	1.56	1.48	7.95	9.38	11.51	12.26	12.87
17.00	4.40	2.82	1.97	1.44	1.37	7.10	8.52	10.65	11.40	11.97
18.00	4.38	2.79	1.94	1.41	1.34	7.61	9.03	11.16	11.92	12.51
19.00	4.35	2.76	1.91	1.39	1.32	6.89	8.31	10.44	11.19	11.75
20.00	4.32	2.73	1.88	1.36	1.29	7.39	8.82	10.94	11.70	12.29
21.00	4.29	2.70	1.85	1.33	1.26	6.77	8.19	10.32	11.07	11.63
22.00	4.26	2.67	1.82	1.30	1.23	7.10	8.52	10.65	11.40	11.97
23.00	4.23	2.64	1.79	1.27	1.21	6.53	7.95	10.08	10.84	11.38
24.00	4.20	2.61	1.76	1.24	1.18	6.92	8.35	10.47	11.23	11.79
25.00	4.17	2.58	1.74	1.21	1.15	6.42	7.85	9.97	10.73	11.27
26.00	3.88	2.29	1.44	0.92	0.87	6.69	8.12	10.24	11.00	11.55
27.00	3.85	2.26	1.41	0.89	0.85	7.29	8.71	10.84	11.59	12.17
28.00	3.82	2.23	1.39	0.86	0.82	6.56	7.99	10.11	10.87	11.41
29.00	3.79	2.20	1.36	0.83	0.79	7.09	8.51	10.64	11.40	11.97
30.00	3.76	2.17	1.33	0.80	0.76	6.39	7.81	9.94	10.69	11.23
31.00	3.73	2.14	1.30	0.77	0.73	6.87	8.29	10.42	11.17	11.73
32.00	3.70	2.11	1.27	0.74	0.71	6.34	7.76	9.89	10.65	11.18
33.00	3.68	2.09	1.24	0.71	0.68	6.65	8.08	10.20	10.96	11.51
34.00	3.65	2.06	1.21	0.69	0.65	6.14	7.56	9.69	10.45	10.97
35.00	3.62	2.03	1.18	0.66	0.62	6.45	7.88	10.01	10.76	11.30
36.00	3.59	2.00	1.15	0.63	0.60	6.04	7.47	9.59	10.35	10.87
37.00	3.56	1.97	1.12	0.60	0.57	6.27	7.70	9.82	10.58	11.11
38.00	3.53	1.94	1.09	0.57	0.54	6.80	8.22	10.35	11.11	11.66
39.00	3.50	1.91	1.06	0.54	0.51	6.13	7.56	9.68	10.44	10.96
40.00	3.47	1.88	1.04	0.51	0.48	6.62	8.05	10.18	10.93	11.48

bulchana	Shear modulus for 400kpa				Damping ratio for 400kpa					
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	5.76	4.09	3.20	2.65	2.52	11.22	12.58	14.60	15.32	16.08
2.00	5.69	4.01	3.12	2.57	2.44	11.10	12.46	14.48	15.20	15.96
3.00	5.57	4.00	3.11	2.56	2.43	10.58	11.94	13.96	14.55	15.27
4.00	5.65	3.98	3.09	2.54	2.42	10.35	11.70	13.72	14.44	15.16
5.00	5.77	3.98	3.02	2.74	2.60	10.03	11.39	13.41	14.12	14.83
6.00	5.33	3.66	2.77	2.22	2.11	9.30	10.65	12.67	13.14	13.79
7.00	5.30	3.63	2.74	2.19	2.08	9.24	10.60	12.62	13.34	14.00
8.00	5.27	3.60	2.71	2.16	2.05	9.02	10.38	12.40	12.07	12.67
9.00	5.24	3.57	2.68	2.13	2.02	8.33	9.68	11.70	12.42	13.04
10.00	5.21	3.54	2.65	2.10	1.99	7.47	8.82	10.84	11.56	12.14
11.00	5.18	3.51	2.62	2.07	1.96	7.79	9.14	11.16	11.88	12.47
12.00	5.15	3.48	2.59	2.04	1.94	7.58	8.93	10.95	11.16	11.72
13.00	4.84	3.17	2.28	1.73	1.64	7.33	8.68	10.71	11.42	11.99
14.00	4.81	3.14	2.25	1.70	1.62	7.25	8.61	10.63	10.84	11.38
15.00	4.78	3.11	2.22	1.67	1.59	7.02	8.38	10.40	11.12	11.67
16.00	4.75	3.08	2.19	1.64	1.56	7.56	8.91	10.93	11.65	12.23
17.00	4.63	2.96	2.07	1.52	1.44	6.74	8.09	10.12	10.83	11.38
18.00	4.59	2.93	2.04	1.49	1.41	7.23	8.58	10.60	11.32	11.89
19.00	4.56	2.89	2.01	1.45	1.38	6.54	7.90	9.92	10.63	11.17
20.00	4.53	2.86	1.98	1.42	1.35	7.02	8.38	10.40	11.12	11.67
21.00	4.50	2.83	1.95	1.39	1.32	6.43	7.78	9.80	10.52	11.05
22.00	4.47	2.80	1.91	1.36	1.29	6.74	8.09	10.12	10.83	11.38
23.00	4.44	2.77	1.88	1.33	1.27	6.20	7.56	9.58	10.29	10.81
24.00	4.41	2.74	1.85	1.30	1.24	6.57	7.93	9.95	10.67	11.20
25.00	4.38	2.71	1.82	1.27	1.21	6.10	7.45	9.47	10.19	10.70
26.00	4.07	2.40	1.52	0.96	0.92	6.36	7.71	9.73	10.45	10.97
27.00	4.04	2.37	1.49	0.93	0.89	6.92	8.27	10.29	11.01	11.56
28.00	4.01	2.34	1.45	0.90	0.86	6.23	7.59	9.61	10.33	10.84
29.00	3.98	2.31	1.42	0.87	0.83	6.73	8.09	10.11	10.83	11.37
30.00	3.95	2.28	1.39	0.84	0.80	6.07	7.42	9.44	10.16	10.67
31.00	3.92	2.25	1.36	0.81	0.77	6.52	7.88	9.90	10.62	11.15
32.00	3.89	2.22	1.33	0.78	0.74	6.02	7.38	9.40	10.12	10.62
33.00	3.86	2.19	1.30	0.75	0.71	6.32	7.67	9.69	10.41	10.93
34.00	3.83	2.16	1.27	0.72	0.68	5.83	7.18	9.20	9.92	10.42
35.00	3.80	2.13	1.24	0.69	0.65	6.13	7.49	9.51	10.22	10.74
36.00	3.77	2.10	1.21	0.66	0.63	5.74	7.09	9.11	9.83	10.32
37.00	3.74	2.07	1.18	0.63	0.60	5.96	7.31	9.33	10.05	10.55
38.00	3.71	2.04	1.15	0.60	0.57	6.46	7.81	9.83	10.55	11.08
39.00	3.68	2.01	1.12	0.57	0.54	5.82	7.18	9.20	9.92	10.41
40.00	3.65	1.98	1.09	0.54	0.51	6.29	7.65	9.67	10.38	10.90

Dida boke	Shear modulus for 100kpa					Damping ratio for 100kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.49	3.19	2.50	2.07	1.96	14.43	16.17	18.77	19.70	20.68
2.00	4.44	3.13	2.44	2.01	1.91	14.28	16.02	18.62	19.54	20.52
3.00	4.35	3.12	2.42	1.99	1.89	13.61	15.35	17.95	18.71	19.64
4.00	4.41	3.10	2.41	1.98	1.88	13.30	15.04	17.64	18.57	19.49
5.00	4.50	3.10	2.35	2.14	2.03	12.90	14.64	17.24	18.16	19.07
6.00	4.16	2.85	2.16	1.73	1.64	11.96	13.70	16.30	16.89	17.74
7.00	4.13	2.83	2.14	1.71	1.62	11.89	13.63	16.22	17.15	18.01
8.00	4.11	2.81	2.11	1.68	1.60	11.61	13.35	15.94	15.51	16.29
9.00	4.08	2.78	2.09	1.66	1.58	10.71	12.45	15.04	15.97	16.77
10.00	4.06	2.76	2.07	1.64	1.55	9.60	11.34	13.94	14.86	15.61
11.00	4.04	2.73	2.04	1.61	1.53	10.01	11.75	14.35	15.28	16.04
12.00	4.01	2.71	2.02	1.59	1.51	9.74	11.48	14.08	14.35	15.07
13.00	3.77	2.47	1.78	1.35	1.28	9.43	11.17	13.77	14.69	15.42
14.00	3.75	2.45	1.76	1.33	1.26	9.33	11.07	13.67	13.94	14.64
15.00	3.73	2.42	1.73	1.30	1.24	9.03	10.77	13.37	14.29	15.01
16.00	3.70	2.40	1.71	1.28	1.21	9.72	11.46	14.05	14.98	15.73
17.00	3.61	2.30	1.61	1.18	1.12	8.67	10.41	13.01	13.93	14.63
18.00	3.58	2.28	1.59	1.16	1.10	9.30	11.04	13.63	14.56	15.29
19.00	3.56	2.26	1.56	1.13	1.08	8.41	10.15	12.75	13.68	14.36
20.00	3.53	2.23	1.54	1.11	1.05	9.03	10.77	13.37	14.29	15.01
21.00	3.51	2.21	1.52	1.09	1.03	8.26	10.00	12.60	13.53	14.20
22.00	3.49	2.19	1.49	1.06	1.01	8.67	10.41	13.01	13.93	14.63
23.00	3.46	2.16	1.47	1.04	0.99	7.98	9.72	12.31	13.24	13.90
24.00	3.44	2.14	1.44	1.01	0.96	8.45	10.19	12.79	13.72	14.40
25.00	3.41	2.11	1.42	0.99	0.94	7.84	9.58	12.18	13.11	13.76
26.00	3.18	1.87	1.18	0.75	0.71	8.17	9.91	12.51	13.44	14.11
27.00	3.15	1.85	1.16	0.73	0.69	8.90	10.64	13.24	14.16	14.87
28.00	3.13	1.83	1.13	0.70	0.67	8.02	9.76	12.36	13.28	13.94
29.00	3.10	1.80	1.11	0.68	0.65	8.66	10.40	13.00	13.92	14.62
30.00	3.08	1.78	1.09	0.66	0.62	7.80	9.54	12.14	13.06	13.72
31.00	3.06	1.76	1.06	0.63	0.60	8.39	10.13	12.73	13.65	14.33
32.00	3.03	1.73	1.04	0.61	0.58	7.74	9.49	12.08	13.01	13.66
33.00	3.01	1.71	1.01	0.59	0.56	8.12	9.86	12.46	13.39	14.06
34.00	2.99	1.68	0.99	0.56	0.53	7.50	9.24	11.84	12.76	13.40
35.00	2.96	1.66	0.97	0.54	0.51	7.89	9.63	12.22	13.15	13.80
36.00	2.94	1.64	0.94	0.51	0.49	7.38	9.12	11.72	12.64	13.28
37.00	2.91	1.61	0.92	0.49	0.47	7.66	9.40	12.00	12.92	13.57
38.00	2.89	1.59	0.90	0.47	0.44	8.31	10.05	12.64	13.57	14.25
39.00	2.87	1.56	0.87	0.44	0.42	7.49	9.23	11.83	12.75	13.39
40.00	2.84	1.54	0.85	0.42	0.40	8.09	9.83	12.43	13.35	14.02

Dida boke	Shear modulus for 200kpa				Damping ratio for 200kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.71	3.35	2.62	2.17	2.06	13.71	15.37	17.83	18.71	19.65
2.00	4.66	3.28	2.56	2.11	2.00	13.56	15.22	17.69	18.56	19.49
3.00	4.56	3.27	2.55	2.09	1.99	12.93	14.58	17.05	17.77	18.66
4.00	4.63	3.26	2.53	2.08	1.98	12.64	14.29	16.76	17.64	18.52
5.00	4.73	3.26	2.47	2.24	2.13	12.25	13.91	16.38	17.25	18.12
6.00	4.36	3.00	2.27	1.82	1.73	11.36	13.02	15.48	16.05	16.85
7.00	4.34	2.97	2.24	1.79	1.70	11.29	12.94	15.41	16.29	17.10
8.00	4.31	2.95	2.22	1.77	1.68	11.02	12.68	15.15	14.74	15.48
9.00	4.29	2.92	2.19	1.74	1.66	10.17	11.82	14.29	15.17	15.93
10.00	4.26	2.90	2.17	1.72	1.63	9.12	10.77	13.24	14.12	14.83
11.00	4.24	2.87	2.14	1.69	1.61	9.51	11.17	13.63	14.51	15.24
12.00	4.21	2.85	2.12	1.67	1.58	9.25	10.91	13.38	13.63	14.32
13.00	3.96	2.60	1.87	1.42	1.35	8.96	10.61	13.08	13.96	14.65
14.00	3.94	2.57	1.84	1.39	1.32	8.86	10.52	12.98	13.24	13.90
15.00	3.91	2.55	1.82	1.37	1.30	8.58	10.23	12.70	13.58	14.26
16.00	3.89	2.52	1.79	1.34	1.27	9.23	10.88	13.35	14.23	14.94
17.00	3.79	2.42	1.69	1.24	1.18	8.24	9.89	12.36	13.23	13.90
18.00	3.76	2.39	1.67	1.22	1.16	8.83	10.48	12.95	13.83	14.52
19.00	3.74	2.37	1.64	1.19	1.13	7.99	9.65	12.11	12.99	13.64
20.00	3.71	2.34	1.62	1.17	1.11	8.58	10.23	12.70	13.58	14.26
21.00	3.69	2.32	1.59	1.14	1.08	7.85	9.50	11.97	12.85	13.49
22.00	3.66	2.29	1.57	1.12	1.06	8.24	9.89	12.36	13.23	13.90
23.00	3.64	2.27	1.54	1.09	1.04	7.58	9.23	11.70	12.58	13.21
24.00	3.61	2.24	1.52	1.07	1.01	8.03	9.68	12.15	13.03	13.68
25.00	3.59	2.22	1.49	1.04	0.99	7.45	9.11	11.57	12.45	13.07
26.00	3.33	1.97	1.24	0.79	0.75	7.77	9.42	11.89	12.76	13.40
27.00	3.31	1.94	1.22	0.76	0.73	8.45	10.11	12.58	13.45	14.13
28.00	3.28	1.92	1.19	0.74	0.70	7.62	9.27	11.74	12.62	13.25
29.00	3.26	1.89	1.17	0.71	0.68	8.23	9.88	12.35	13.23	13.89
30.00	3.23	1.87	1.14	0.69	0.66	7.41	9.07	11.53	12.41	13.03
31.00	3.21	1.84	1.12	0.66	0.63	7.97	9.62	12.09	12.97	13.62
32.00	3.18	1.82	1.09	0.64	0.61	7.36	9.01	11.48	12.36	12.97
33.00	3.16	1.79	1.07	0.61	0.58	7.72	9.37	11.84	12.72	13.35
34.00	3.13	1.77	1.04	0.59	0.56	7.12	8.78	11.24	12.12	12.73
35.00	3.11	1.74	1.02	0.56	0.54	7.49	9.14	11.61	12.49	13.11
36.00	3.08	1.72	0.99	0.54	0.51	7.01	8.67	11.13	12.01	12.61
37.00	3.06	1.69	0.97	0.51	0.49	7.28	8.93	11.40	12.28	12.89
38.00	3.03	1.67	0.94	0.49	0.46	7.89	9.54	12.01	12.89	13.53
39.00	3.01	1.64	0.92	0.46	0.44	7.11	8.77	11.24	12.11	12.72
40.00	2.98	1.62	0.89	0.44	0.42	7.69	9.34	11.81	12.69	13.32

Dida boke	Shear modulus for 300kpa					Damping ratio for 300kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.95	3.51	2.75	2.28	2.16	13.03	14.60	16.94	17.78	18.66
2.00	4.89	3.45	2.69	2.21	2.10	12.89	14.46	16.80	17.63	18.52
3.00	4.79	3.44	2.67	2.20	2.09	12.28	13.85	16.20	16.88	17.73
4.00	4.86	3.42	2.66	2.19	2.08	12.01	13.58	15.92	16.76	17.59
5.00	4.96	3.42	2.59	2.36	2.24	11.64	13.21	15.56	16.39	17.21
6.00	4.58	3.15	2.38	1.91	1.81	10.79	12.36	14.71	15.25	16.01
7.00	4.55	3.12	2.36	1.88	1.79	10.73	12.30	14.64	15.48	16.25
8.00	4.53	3.09	2.33	1.86	1.76	10.47	12.04	14.39	14.00	14.70
9.00	4.50	3.07	2.30	1.83	1.74	9.66	11.23	13.58	14.41	15.13
10.00	4.48	3.04	2.28	1.80	1.71	8.66	10.24	12.58	13.41	14.08
11.00	4.45	3.01	2.25	1.78	1.69	9.04	10.61	12.95	13.79	14.48
12.00	4.42	2.99	2.22	1.75	1.66	8.79	10.36	12.71	12.95	13.60
13.00	4.16	2.72	1.96	1.49	1.41	8.51	10.08	12.42	13.26	13.92
14.00	4.13	2.70	1.94	1.46	1.39	8.42	9.99	12.33	12.58	13.21
15.00	4.11	2.67	1.91	1.43	1.36	8.15	9.72	12.07	12.90	13.55
16.00	4.08	2.65	1.88	1.41	1.34	8.77	10.34	12.68	13.52	14.19
17.00	3.98	2.54	1.78	1.30	1.24	7.82	9.39	11.74	12.57	13.20
18.00	3.95	2.51	1.75	1.28	1.21	8.39	9.96	12.30	13.14	13.80
19.00	3.92	2.49	1.72	1.25	1.19	7.59	9.16	11.51	12.34	12.96
20.00	3.90	2.46	1.70	1.22	1.16	8.15	9.72	12.07	12.90	13.55
21.00	3.87	2.44	1.67	1.20	1.14	7.46	9.03	11.37	12.21	12.82
22.00	3.84	2.41	1.65	1.17	1.11	7.82	9.39	11.74	12.57	13.20
23.00	3.82	2.38	1.62	1.15	1.09	7.20	8.77	11.11	11.95	12.54
24.00	3.79	2.36	1.59	1.12	1.06	7.63	9.20	11.55	12.38	13.00
25.00	3.76	2.33	1.57	1.09	1.04	7.08	8.65	10.99	11.83	12.42
26.00	3.50	2.07	1.30	0.83	0.79	7.38	8.95	11.29	12.13	12.73
27.00	3.48	2.04	1.28	0.80	0.76	8.03	9.60	11.95	12.78	13.42
28.00	3.45	2.01	1.25	0.78	0.74	7.24	8.81	11.15	11.98	12.58
29.00	3.42	1.99	1.22	0.75	0.71	7.82	9.39	11.73	12.57	13.19
30.00	3.40	1.96	1.20	0.72	0.69	7.04	8.61	10.96	11.79	12.38
31.00	3.37	1.94	1.17	0.70	0.66	7.57	9.14	11.49	12.32	12.94
32.00	3.34	1.91	1.15	0.67	0.64	6.99	8.56	10.91	11.74	12.33
33.00	3.32	1.88	1.12	0.65	0.61	7.33	8.90	11.25	12.08	12.69
34.00	3.29	1.86	1.09	0.62	0.59	6.77	8.34	10.68	11.52	12.09
35.00	3.26	1.83	1.07	0.59	0.56	7.12	8.69	11.03	11.87	12.46
36.00	3.24	1.80	1.04	0.57	0.54	6.66	8.23	10.58	11.41	11.98
37.00	3.21	1.78	1.01	0.54	0.51	6.92	8.49	10.83	11.66	12.25
38.00	3.19	1.75	0.99	0.51	0.49	7.50	9.07	11.41	12.25	12.86
39.00	3.16	1.72	0.96	0.49	0.46	6.76	8.33	10.67	11.51	12.08
40.00	3.13	1.70	0.93	0.46	0.44	7.30	8.87	11.22	12.05	12.65

Dida boke	Shear modulus for 400kpa					Damping ratio for 400kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	5.20	3.69	2.89	2.39	2.27	12.38	13.87	16.10	16.89	17.73
2.00	5.14	3.62	2.82	2.32	2.21	12.24	13.73	15.96	16.75	17.59
3.00	5.03	3.61	2.81	2.31	2.19	11.67	13.16	15.39	16.04	16.84
4.00	5.10	3.59	2.79	2.29	2.18	11.41	12.90	15.13	15.92	16.71
5.00	5.21	3.59	2.72	2.47	2.35	11.06	12.55	14.78	15.57	16.35
6.00	4.81	3.30	2.50	2.00	1.90	10.25	11.75	13.97	14.48	15.21
7.00	4.78	3.28	2.47	1.98	1.88	10.19	11.68	13.91	14.70	15.44
8.00	4.75	3.25	2.45	1.95	1.85	9.95	11.44	13.67	13.30	13.97
9.00	4.73	3.22	2.42	1.92	1.83	9.18	10.67	12.90	13.69	14.38
10.00	4.70	3.19	2.39	1.89	1.80	8.23	9.72	11.95	12.74	13.38
11.00	4.67	3.17	2.36	1.87	1.77	8.59	10.08	12.30	13.10	13.75
12.00	4.64	3.14	2.34	1.84	1.75	8.35	9.84	12.07	12.30	12.92
13.00	4.37	2.86	2.06	1.56	1.48	8.08	9.58	11.80	12.59	13.22
14.00	4.34	2.83	2.03	1.53	1.46	8.00	9.49	11.72	11.95	12.55
15.00	4.31	2.81	2.00	1.51	1.43	7.74	9.24	11.46	12.26	12.87
16.00	4.28	2.78	1.98	1.48	1.41	8.33	9.82	12.05	12.84	13.48
17.00	4.17	2.67	1.87	1.37	1.30	7.43	8.92	11.15	11.94	12.54
18.00	4.15	2.64	1.84	1.34	1.27	7.97	9.46	11.69	12.48	13.11
19.00	4.12	2.61	1.81	1.31	1.25	7.21	8.71	10.93	11.72	12.31
20.00	4.09	2.58	1.78	1.29	1.22	7.74	9.24	11.46	12.26	12.87
21.00	4.06	2.56	1.76	1.26	1.19	7.09	8.58	10.81	11.60	12.18
22.00	4.04	2.53	1.73	1.23	1.17	7.43	8.92	11.15	11.94	12.54
23.00	4.01	2.50	1.70	1.20	1.14	6.84	8.33	10.56	11.35	11.92
24.00	3.98	2.47	1.67	1.17	1.12	7.25	8.74	10.97	11.76	12.35
25.00	3.95	2.45	1.64	1.15	1.09	6.73	8.22	10.44	11.24	11.80
26.00	3.68	2.17	1.37	0.87	0.83	7.01	8.50	10.73	11.52	12.10
27.00	3.65	2.14	1.34	0.84	0.80	7.63	9.12	11.35	12.14	12.75
28.00	3.62	2.11	1.31	0.82	0.77	6.87	8.37	10.59	11.39	11.95
29.00	3.59	2.09	1.29	0.79	0.75	7.43	8.92	11.14	11.94	12.53
30.00	3.57	2.06	1.26	0.76	0.72	6.69	8.18	10.41	11.20	11.76
31.00	3.54	2.03	1.23	0.73	0.70	7.19	8.68	10.91	11.70	12.29
32.00	3.51	2.00	1.20	0.70	0.67	6.64	8.13	10.36	11.15	11.71
33.00	3.48	1.98	1.17	0.68	0.64	6.97	8.46	10.69	11.48	12.05
34.00	3.46	1.95	1.15	0.65	0.62	6.43	7.92	10.15	10.94	11.49
35.00	3.43	1.92	1.12	0.62	0.59	6.76	8.25	10.48	11.27	11.84
36.00	3.40	1.89	1.09	0.59	0.56	6.33	7.82	10.05	10.84	11.38
37.00	3.37	1.87	1.06	0.57	0.54	6.57	8.06	10.29	11.08	11.64
38.00	3.34	1.84	1.04	0.54	0.51	7.12	8.61	10.84	11.63	12.21
39.00	3.32	1.81	1.01	0.51	0.49	6.42	7.91	10.14	10.93	11.48
40.00	3.29	1.78	0.98	0.48	0.46	6.94	8.43	10.66	11.45	12.02

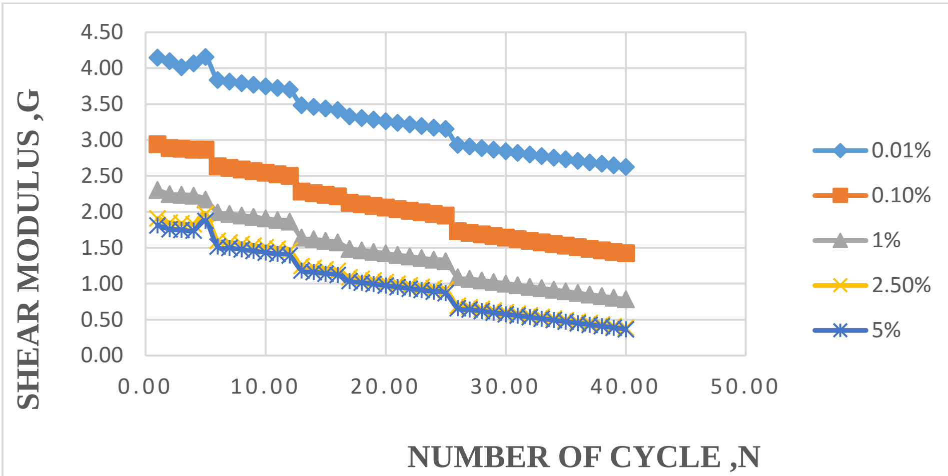
alelo	Shear modulus for 100kpa					Damping ratio for 100kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.73	3.36	2.63	2.17	2.07	13.75	15.40	17.88	18.76	19.70
2.00	4.67	3.29	2.56	2.11	2.01	13.60	15.26	17.73	18.61	19.54
3.00	4.57	3.28	2.55	2.10	1.99	12.96	14.62	17.09	17.82	18.71
4.00	4.64	3.27	2.54	2.09	1.98	12.67	14.33	16.80	17.68	18.57
5.00	4.74	3.27	2.48	2.25	2.14	12.29	13.94	16.42	17.30	18.16
6.00	4.37	3.00	2.27	1.82	1.73	11.39	13.05	15.52	16.09	16.89
7.00	4.35	2.98	2.25	1.80	1.71	11.32	12.98	15.45	16.33	17.15
8.00	4.32	2.95	2.22	1.77	1.68	11.05	12.71	15.18	14.78	15.51
9.00	4.30	2.93	2.20	1.75	1.66	10.20	11.85	14.33	15.21	15.97
10.00	4.27	2.90	2.17	1.72	1.64	9.14	10.80	13.28	14.16	14.86
11.00	4.25	2.88	2.15	1.70	1.61	9.54	11.19	13.67	14.55	15.28
12.00	4.22	2.85	2.12	1.67	1.59	9.28	10.93	13.41	13.67	14.35
13.00	3.97	2.60	1.87	1.42	1.35	8.98	10.64	13.11	13.99	14.69
14.00	3.95	2.58	1.85	1.40	1.33	8.88	10.54	13.02	13.28	13.94
15.00	3.92	2.55	1.82	1.37	1.30	8.60	10.26	12.73	13.61	14.29
16.00	3.90	2.53	1.80	1.34	1.28	9.25	10.91	13.39	14.27	14.98
17.00	3.80	2.43	1.70	1.24	1.18	8.26	9.91	12.39	13.27	13.93
18.00	3.77	2.40	1.67	1.22	1.16	8.85	10.51	12.98	13.86	14.56
19.00	3.75	2.38	1.65	1.19	1.13	8.01	9.67	12.14	13.02	13.68
20.00	3.72	2.35	1.62	1.17	1.11	8.60	10.26	12.73	13.61	14.29
21.00	3.70	2.33	1.60	1.14	1.09	7.87	9.53	12.00	12.88	13.53
22.00	3.67	2.30	1.57	1.12	1.06	8.26	9.91	12.39	13.27	13.93
23.00	3.64	2.27	1.55	1.09	1.04	7.60	9.25	11.73	12.61	13.24
24.00	3.62	2.25	1.52	1.07	1.01	8.05	9.71	12.18	13.06	13.72
25.00	3.59	2.22	1.50	1.04	0.99	7.47	9.13	11.60	12.48	13.11
26.00	3.34	1.97	1.24	0.79	0.75	7.78	9.44	11.92	12.80	13.44
27.00	3.32	1.95	1.22	0.77	0.73	8.48	10.13	12.61	13.49	14.16
28.00	3.29	1.92	1.19	0.74	0.70	7.64	9.29	11.77	12.65	13.28
29.00	3.27	1.90	1.17	0.72	0.68	8.25	9.91	12.38	13.26	13.92
30.00	3.24	1.87	1.14	0.69	0.66	7.43	9.09	11.56	12.44	13.06
31.00	3.22	1.85	1.12	0.67	0.63	7.99	9.65	12.12	13.00	13.65
32.00	3.19	1.82	1.09	0.64	0.61	7.38	9.03	11.51	12.39	13.01
33.00	3.17	1.80	1.07	0.62	0.59	7.74	9.39	11.87	12.75	13.39
34.00	3.14	1.77	1.04	0.59	0.56	7.14	8.80	11.27	12.15	12.76
35.00	3.12	1.75	1.02	0.57	0.54	7.51	9.17	11.64	12.52	13.15
36.00	3.09	1.72	0.99	0.54	0.51	7.03	8.69	11.16	12.04	12.64
37.00	3.07	1.70	0.97	0.52	0.49	7.30	8.96	11.43	12.31	12.92
38.00	3.04	1.67	0.94	0.49	0.47	7.91	9.57	12.04	12.92	13.57
39.00	3.02	1.65	0.92	0.47	0.44	7.13	8.79	11.26	12.14	12.75
40.00	2.99	1.62	0.89	0.44	0.42	7.71	9.36	11.84	12.72	13.35

alelo	Shear modulus for 200kpa					Damping ratio for 200kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	4.96	3.52	2.76	2.28	2.17	13.06	14.63	16.98	17.82	18.71
2.00	4.90	3.46	2.69	2.22	2.11	12.92	14.49	16.84	17.68	18.56
3.00	4.80	3.44	2.68	2.20	2.09	12.31	13.89	16.24	16.93	17.77
4.00	4.87	3.43	2.67	2.19	2.08	12.04	13.61	15.96	16.80	17.64
5.00	4.98	3.43	2.60	2.36	2.24	11.67	13.25	15.60	16.43	17.25
6.00	4.59	3.15	2.39	1.91	1.82	10.82	12.40	14.75	15.28	16.05
7.00	4.57	3.13	2.36	1.89	1.79	10.75	12.33	14.68	15.51	16.29
8.00	4.54	3.10	2.34	1.86	1.77	10.50	12.07	14.43	14.04	14.74
9.00	4.51	3.07	2.31	1.83	1.74	9.69	11.26	13.61	14.45	15.17
10.00	4.49	3.05	2.28	1.81	1.72	8.69	10.26	12.61	13.45	14.12
11.00	4.46	3.02	2.26	1.78	1.69	9.06	10.63	12.98	13.82	14.51
12.00	4.43	3.00	2.23	1.76	1.67	8.81	10.39	12.74	12.98	13.63
13.00	4.17	2.73	1.97	1.49	1.42	8.53	10.10	12.45	13.29	13.96
14.00	4.14	2.71	1.94	1.46	1.39	8.44	10.01	12.37	12.61	13.24
15.00	4.12	2.68	1.91	1.44	1.37	8.17	9.75	12.10	12.93	13.58
16.00	4.09	2.65	1.89	1.41	1.34	8.79	10.37	12.72	13.55	14.23
17.00	3.99	2.55	1.78	1.31	1.24	7.84	9.42	11.77	12.60	13.23
18.00	3.96	2.52	1.76	1.28	1.22	8.41	9.98	12.34	13.17	13.83
19.00	3.93	2.49	1.73	1.25	1.19	7.61	9.19	11.54	12.37	12.99
20.00	3.91	2.47	1.70	1.23	1.17	8.17	9.75	12.10	12.93	13.58
21.00	3.88	2.44	1.68	1.20	1.14	7.48	9.05	11.40	12.24	12.85
22.00	3.85	2.42	1.65	1.17	1.12	7.84	9.42	11.77	12.60	13.23
23.00	3.83	2.39	1.62	1.15	1.09	7.22	8.79	11.14	11.98	12.58
24.00	3.80	2.36	1.60	1.12	1.07	7.65	9.22	11.57	12.41	13.03
25.00	3.77	2.34	1.57	1.10	1.04	7.10	8.67	11.02	11.86	12.45
26.00	3.51	2.07	1.31	0.83	0.79	7.40	8.97	11.32	12.16	12.76
27.00	3.48	2.05	1.28	0.81	0.76	8.05	9.63	11.98	12.81	13.45
28.00	3.46	2.02	1.25	0.78	0.74	7.25	8.83	11.18	12.01	12.62
29.00	3.43	1.99	1.23	0.75	0.71	7.84	9.41	11.76	12.60	13.23
30.00	3.40	1.97	1.20	0.73	0.69	7.06	8.63	10.98	11.82	12.41
31.00	3.38	1.94	1.17	0.70	0.66	7.59	9.16	11.51	12.35	12.97
32.00	3.35	1.91	1.15	0.67	0.64	7.01	8.58	10.93	11.77	12.36
33.00	3.33	1.89	1.12	0.65	0.61	7.35	8.93	11.28	12.11	12.72
34.00	3.30	1.86	1.10	0.62	0.59	6.78	8.36	10.71	11.54	12.12
35.00	3.27	1.83	1.07	0.59	0.56	7.13	8.71	11.06	11.90	12.49
36.00	3.25	1.81	1.04	0.57	0.54	6.68	8.25	10.60	11.44	12.01
37.00	3.22	1.78	1.02	0.54	0.51	6.93	8.51	10.86	11.69	12.28
38.00	3.19	1.76	0.99	0.51	0.49	7.51	9.09	11.44	12.28	12.89
39.00	3.17	1.73	0.96	0.49	0.46	6.78	8.35	10.70	11.54	12.11
40.00	3.14	1.70	0.94	0.46	0.44	7.32	8.90	11.25	12.08	12.69

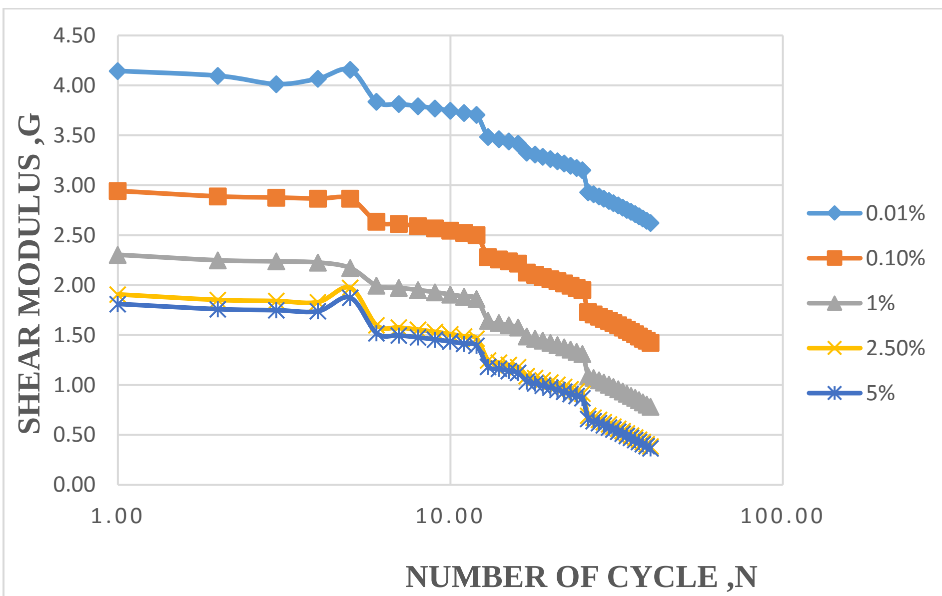
alelo	Shear modulus for 300kpa					Damping ratio for 300kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	5.21	3.70	2.90	2.40	2.28	12.41	13.90	16.14	16.93	17.78
2.00	5.15	3.63	2.83	2.33	2.21	12.27	13.77	16.00	16.79	17.63
3.00	5.04	3.62	2.81	2.31	2.20	11.70	13.19	15.43	16.08	16.88
4.00	5.11	3.60	2.80	2.30	2.19	11.44	12.93	15.16	15.96	16.76
5.00	5.22	3.60	2.73	2.48	2.36	11.09	12.58	14.82	15.61	16.39
6.00	4.82	3.31	2.51	2.01	1.91	10.28	11.78	14.01	14.52	15.25
7.00	4.79	3.28	2.48	1.98	1.88	10.22	11.71	13.94	14.74	15.48
8.00	4.77	3.26	2.45	1.95	1.86	9.97	11.47	13.70	13.34	14.00
9.00	4.74	3.23	2.42	1.93	1.83	9.20	10.70	12.93	13.73	14.41
10.00	4.71	3.20	2.40	1.90	1.80	8.25	9.75	11.98	12.78	13.41
11.00	4.68	3.17	2.37	1.87	1.78	8.61	10.10	12.34	13.13	13.79
12.00	4.66	3.15	2.34	1.84	1.75	8.37	9.87	12.10	12.34	12.95
13.00	4.38	2.87	2.06	1.57	1.49	8.10	9.60	11.83	12.63	13.26
14.00	4.35	2.84	2.04	1.54	1.46	8.02	9.51	11.75	11.98	12.58
15.00	4.32	2.81	2.01	1.51	1.43	7.76	9.26	11.49	12.29	12.90
16.00	4.30	2.79	1.98	1.48	1.41	8.35	9.85	12.08	12.87	13.52
17.00	4.18	2.67	1.87	1.37	1.30	7.45	8.95	11.18	11.97	12.57
18.00	4.16	2.65	1.84	1.34	1.28	7.99	9.49	11.72	12.51	13.14
19.00	4.13	2.62	1.82	1.32	1.25	7.23	8.73	10.96	11.75	12.34
20.00	4.10	2.59	1.79	1.29	1.22	7.76	9.26	11.49	12.29	12.90
21.00	4.07	2.56	1.76	1.26	1.20	7.10	8.60	10.83	11.63	12.21
22.00	4.05	2.54	1.73	1.23	1.17	7.45	8.95	11.18	11.97	12.57
23.00	4.02	2.51	1.70	1.21	1.15	6.86	8.35	10.58	11.38	11.95
24.00	3.99	2.48	1.68	1.18	1.12	7.27	8.76	11.00	11.79	12.38
25.00	3.96	2.45	1.65	1.15	1.09	6.74	8.24	10.47	11.27	11.83
26.00	3.69	2.18	1.37	0.87	0.83	7.03	8.52	10.75	11.55	12.13
27.00	3.66	2.15	1.34	0.85	0.80	7.65	9.15	11.38	12.17	12.78
28.00	3.63	2.12	1.32	0.82	0.78	6.89	8.39	10.62	11.41	11.98
29.00	3.60	2.09	1.29	0.79	0.75	7.44	8.94	11.17	11.97	12.57
30.00	3.58	2.06	1.26	0.76	0.72	6.71	8.20	10.44	11.23	11.79
31.00	3.55	2.04	1.23	0.73	0.70	7.21	8.71	10.94	11.73	12.32
32.00	3.52	2.01	1.21	0.71	0.67	6.66	8.15	10.39	11.18	11.74
33.00	3.49	1.98	1.18	0.68	0.65	6.98	8.48	10.71	11.51	12.08
34.00	3.46	1.95	1.15	0.65	0.62	6.44	7.94	10.17	10.97	11.52
35.00	3.44	1.93	1.12	0.62	0.59	6.78	8.27	10.51	11.30	11.87
36.00	3.41	1.90	1.09	0.60	0.57	6.35	7.84	10.07	10.87	11.41
37.00	3.38	1.87	1.07	0.57	0.54	6.59	8.08	10.32	11.11	11.66
38.00	3.35	1.84	1.04	0.54	0.51	7.14	8.63	10.87	11.66	12.25
39.00	3.33	1.82	1.01	0.51	0.49	6.44	7.93	10.17	10.96	11.51
40.00	3.30	1.79	0.98	0.48	0.46	6.95	8.45	10.68	11.48	12.05

alelo	Shear modulus for 400kpa					Damping ratio for 400kpa				
strain %	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
No of cycle										
1.00	5.47	3.88	3.04	2.52	2.39	11.79	13.21	15.33	16.08	16.89
2.00	5.41	3.81	2.97	2.44	2.32	11.66	13.08	15.20	15.96	16.75
3.00	5.30	3.80	2.95	2.43	2.31	11.11	12.53	14.66	15.27	16.04
4.00	5.37	3.78	2.94	2.42	2.29	10.86	12.28	14.41	15.16	15.92
5.00	5.49	3.78	2.87	2.60	2.47	10.53	11.95	14.08	14.83	15.57
6.00	5.06	3.48	2.63	2.11	2.00	9.77	11.19	13.31	13.79	14.48
7.00	5.03	3.45	2.60	2.08	1.98	9.71	11.13	13.25	14.00	14.70
8.00	5.01	3.42	2.58	2.05	1.95	9.48	10.90	13.02	12.67	13.30
9.00	4.98	3.39	2.55	2.02	1.92	8.74	10.16	12.28	13.04	13.69
10.00	4.95	3.36	2.52	1.99	1.89	7.84	9.26	11.38	12.14	12.74
11.00	4.92	3.33	2.49	1.96	1.87	8.18	9.60	11.72	12.47	13.10
12.00	4.89	3.30	2.46	1.94	1.84	7.95	9.38	11.50	11.72	12.30
13.00	4.60	3.01	2.17	1.64	1.56	7.70	9.12	11.24	11.99	12.59
14.00	4.57	2.98	2.14	1.62	1.53	7.62	9.04	11.16	11.38	11.95
15.00	4.54	2.95	2.11	1.59	1.51	7.37	8.80	10.92	11.67	12.26
16.00	4.51	2.92	2.08	1.56	1.48	7.93	9.35	11.48	12.23	12.84
17.00	4.39	2.81	1.96	1.44	1.37	7.08	8.50	10.62	11.38	11.94
18.00	4.36	2.78	1.94	1.41	1.34	7.59	9.01	11.13	11.89	12.48
19.00	4.34	2.75	1.91	1.38	1.31	6.87	8.29	10.41	11.17	11.72
20.00	4.31	2.72	1.88	1.35	1.29	7.37	8.80	10.92	11.67	12.26
21.00	4.28	2.69	1.85	1.32	1.26	6.75	8.17	10.29	11.05	11.60
22.00	4.25	2.66	1.82	1.29	1.23	7.08	8.50	10.62	11.38	11.94
23.00	4.22	2.63	1.79	1.27	1.20	6.51	7.93	10.06	10.81	11.35
24.00	4.19	2.60	1.76	1.24	1.17	6.90	8.32	10.45	11.20	11.76
25.00	4.16	2.58	1.73	1.21	1.15	6.40	7.83	9.95	10.70	11.24
26.00	3.87	2.28	1.44	0.92	0.87	6.67	8.10	10.22	10.97	11.52
27.00	3.84	2.26	1.41	0.89	0.84	7.27	8.69	10.81	11.56	12.14
28.00	3.81	2.23	1.38	0.86	0.82	6.55	7.97	10.09	10.84	11.39
29.00	3.78	2.20	1.35	0.83	0.79	7.07	8.49	10.61	11.37	11.94
30.00	3.75	2.17	1.32	0.80	0.76	6.37	7.79	9.91	10.67	11.20
31.00	3.72	2.14	1.29	0.77	0.73	6.85	8.27	10.39	11.15	11.70
32.00	3.70	2.11	1.27	0.74	0.70	6.32	7.75	9.87	10.62	11.15
33.00	3.67	2.08	1.24	0.71	0.68	6.63	8.05	10.18	10.93	11.48
34.00	3.64	2.05	1.21	0.68	0.65	6.12	7.54	9.66	10.42	10.94
35.00	3.61	2.02	1.18	0.65	0.62	6.44	7.86	9.98	10.74	11.27
36.00	3.58	1.99	1.15	0.63	0.59	6.03	7.45	9.57	10.32	10.84
37.00	3.55	1.96	1.12	0.60	0.57	6.26	7.68	9.80	10.55	11.08
38.00	3.52	1.94	1.09	0.57	0.54	6.78	8.20	10.32	11.08	11.63
39.00	3.49	1.91	1.06	0.54	0.51	6.12	7.54	9.66	10.41	10.93
40.00	3.46	1.88	1.03	0.51	0.48	6.61	8.03	10.15	10.90	11.45

Appendix F Shear modulus and Damping ratio curves under different axial loads and number of cycles

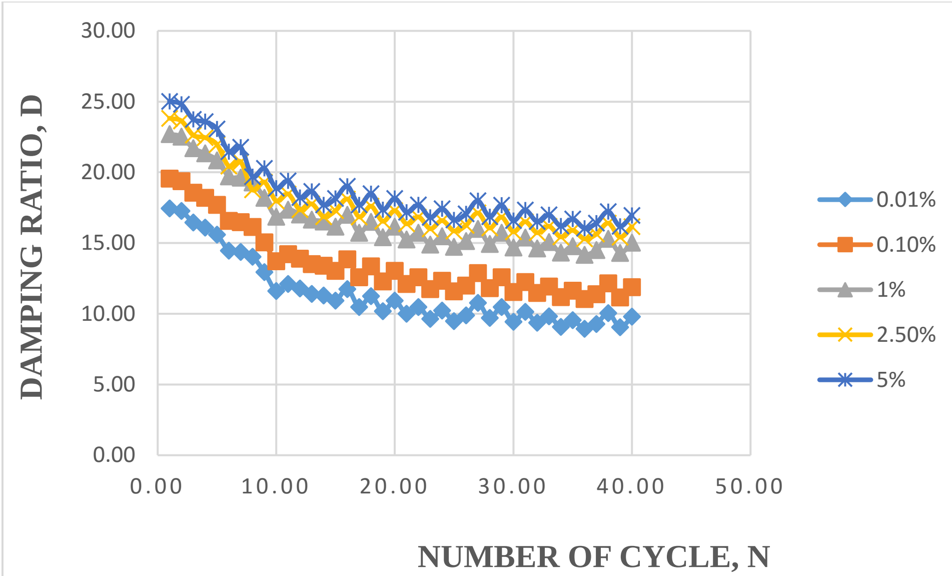


(a)

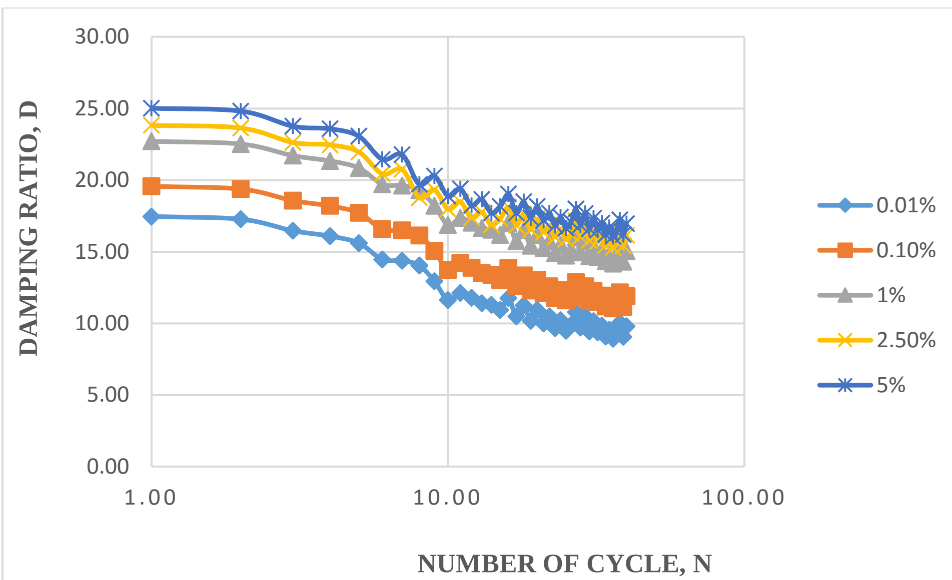


(b)

Figure F.1: Effects of number of cycles on the location of shear modulus curves for silty sand (Awasho test pit) soil under an axial stress of 200kPa: (a) in logarithmic scale; (b) innormal scale

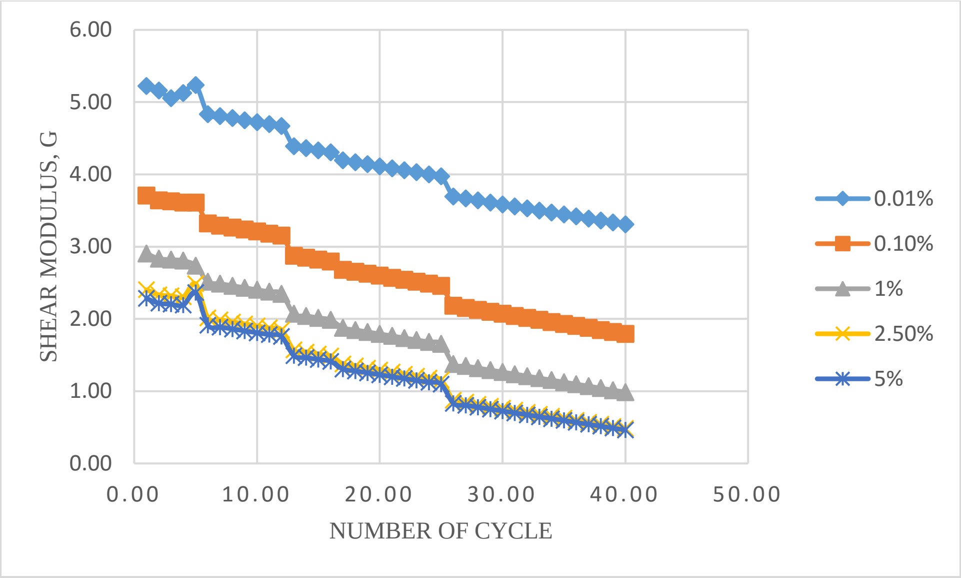


(a)

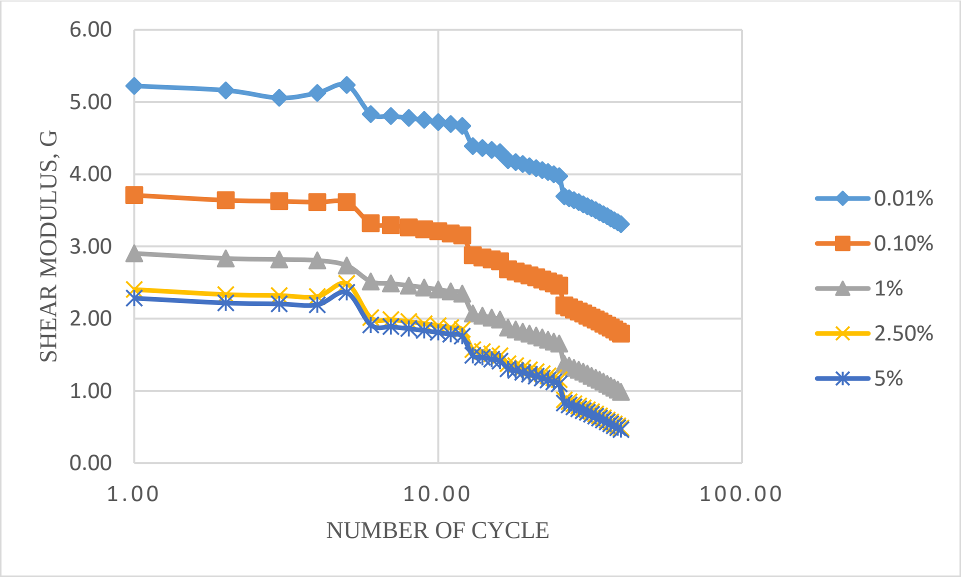


(b)

Figure F: 2Effects of number of cycles on the location of damping curves for silty sand (Awasho test pit) soil under an axial stress of 200kPa: (a) in logarithmic scale; (b)in normal scale.

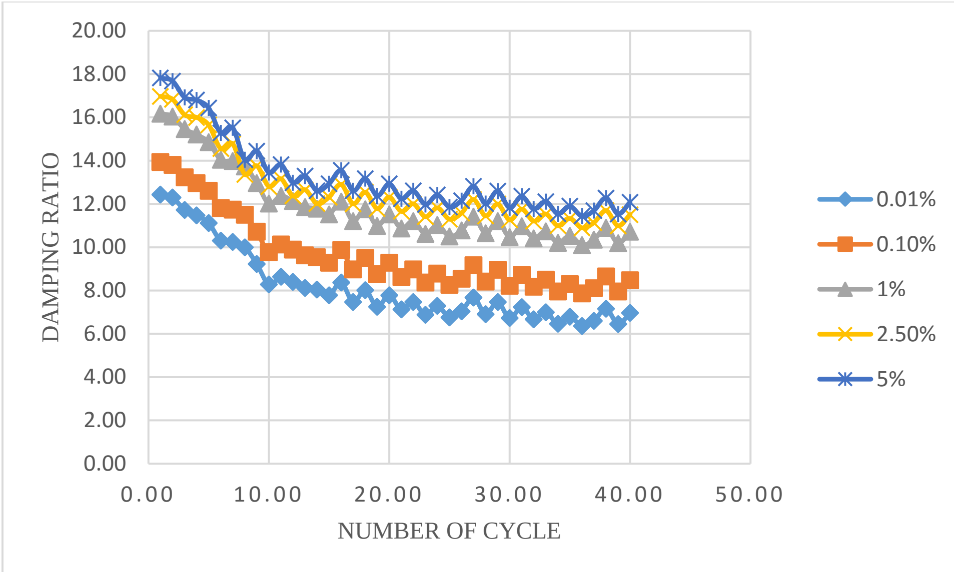


(a)

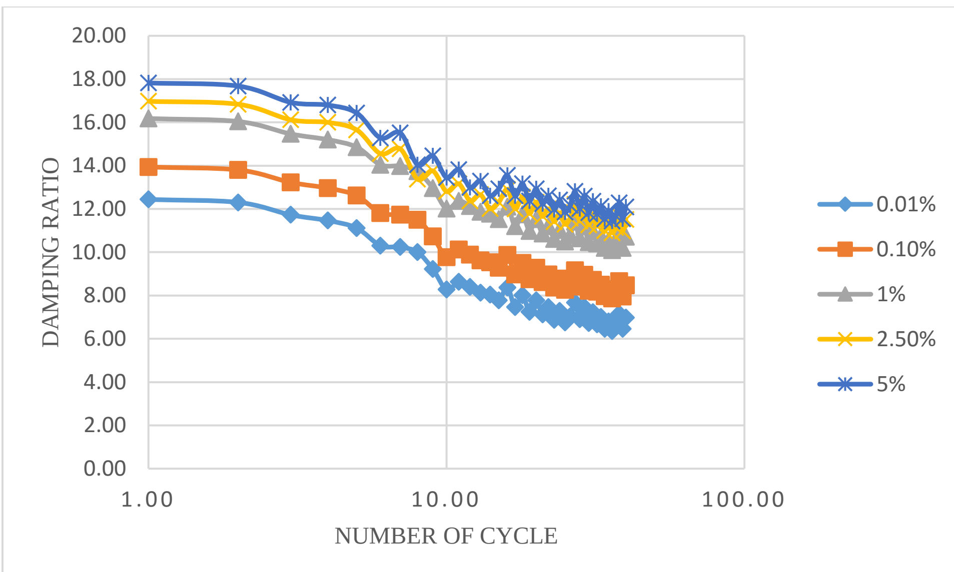


(b)

Figure F.3: Effects of number of cycles on the location of shear modulus curves for silty sand (Bulchana test pit) soil under an axial stress of 200kPa: (a) in logarithmic scale; (b) in normal scale



(a)



(b)

Figure F.4: Effects of number of cycles on the location of damping curves for silty sand (bulchana test pit) soil under an axial stress of 200kPa: (a) in logarithmic scale; (b)in normal scale.

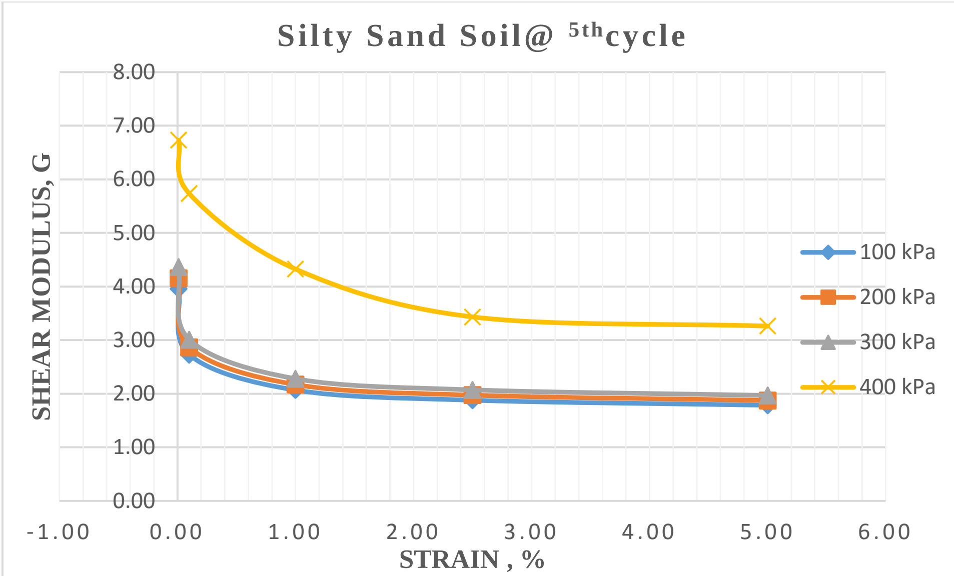


Figure F.5 Effect of axial loads on shear modulus of the Silty sand soil sample from awasho test pit

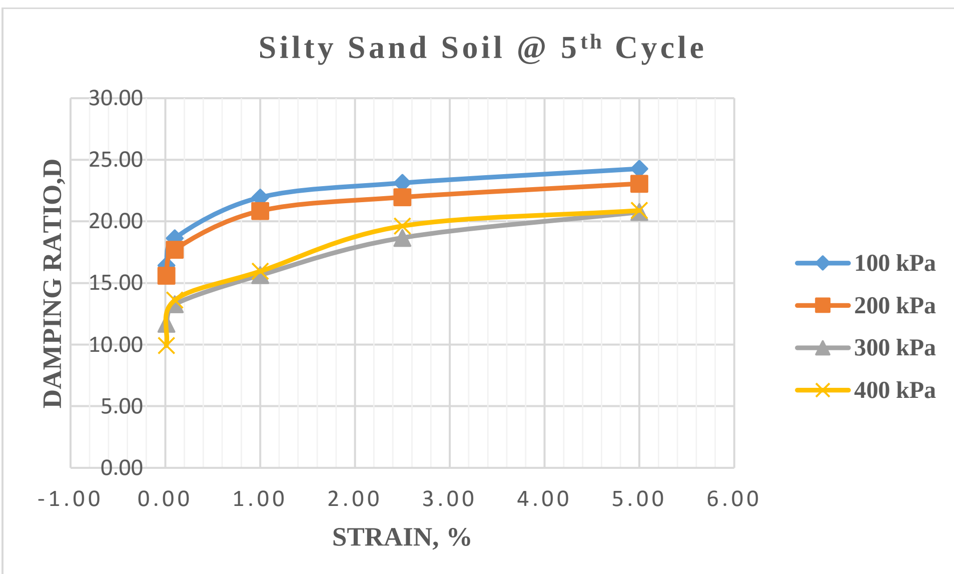


Figure F.6 Effect of axial loads on damping ratio of the Silty sand soil sample from awasho test pit

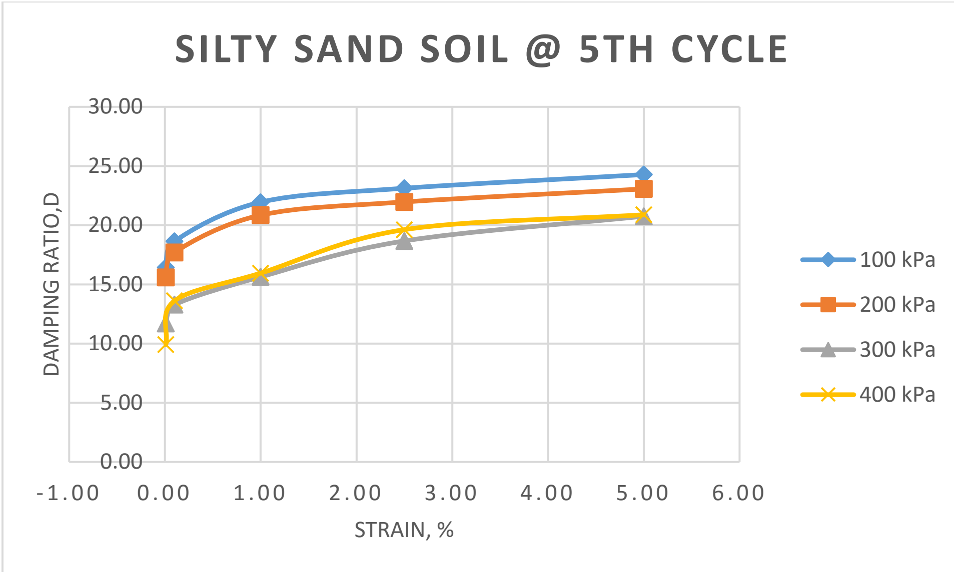


Figure F.6 Effect of axial loads on damping ratio of the Silty sand soil sample from awash test pit