

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY



SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

CIVIL ENGINEERING DEPARTMENT

THE STUDY OF DYNAMIC PROPERTIES OF SOILS IN BISHOFTU AREA

A thesis submitted to the school of graduate studies of Adama science and Technology University in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Geotechnical Engineering)

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SCHOOL OF GRADUATE STUDIES

STUDY ON DYNAMIC PROPERTIES OF SOILS FOUND IN BISHOFTU TOWN

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LIST OF ABBREVIATIONS AND NOTES

AAIT	Addis Ababa University Institute Of Technology;
ASTU	Adama Science And Technology University;
A_{loop}	Loop Area;
D	Damping Ratio;
E	Void Ratio;
G	Dynamic Shear Modulus
G_{max}	Maximum Dynamics Hear Modulus;
K_o	Coefficient Of Lateral Earth Pressure At Rest;
LL	Liquid Limit;
PI	Plastic Index;
PL	Plastic Limit;
ML	Inorganic Silt;
OCR	Over Consolidation Ratio;
TP	Test Pit;
W_D	Dissipated Energy;
W_s	Stored Energy;
W	Field Moisture Content;
V_s	Shear Wave Velocity;
Γ	Shear Strain;
P	Density Of Soil;
Σ	Normal Stress;
Σ'_O	Effective Confining Stress;
Σ'_v	Effective Vertical Stress And
τ	Shear Stress

ABSTRACT

The responses of soils to earth quake is influenced by the dynamic properties of soils namely: shear modulus and damping ratio, site response of soil deposits under cyclic loading and soil-structure interaction. In this study, an attempt has been made to determine the shear modulus and damping ratio of Bishoftu town soils. The soil samples were collected from Bishoftu town at four different locations, namely; Adis Safar (Keble 01), Around TVET (Keble 02), Babugaya (Keble 09) and Babugaya (Keble 15).

The grain size analysis test result showed dominant proportion of soil particle in the research area is low to high plasticity silt soil. 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 value of shear modulus was in the range of 0.51 to 16.78MPa and damping ratio values range between 6.05 to 29.35 %.

The influences of some important factors on dynamic soil properties were also discussed. As number of loading cycles and confining pressure increase, the shear modulus increases and damping ratio decreases. Shear modulus decreases and damping ratio increases with increase in cyclic shear strain amplitude. The values of maximum shear modulus, G_{max} , ranges from 13.47 to 47.21 MPa, normalized shear modulus, G/G_{max} , ranges from 0.04 to 0.48 and the specimen having high void ratio have lower maximum shear modulus, G_{max} , and the void ratio has no significance influenced on damping ratio at any strain amplitude levels. The normalized shear modulus and damping ratio values of the investigated soils found to be similar with those previously developed in the literature. [3], [5], [30] & [31].

Key words: - Shear modulus, damping ratio, cyclic simple shear test.

CHAPTER ONE

1. INTRODUCTION

1.1 General back ground

The town of Bishoftu is located in the Main Ethiopian Rift Valley zone which is prone to an Earthquake activity. It has a latitude $8^{\circ}45'0''$ N and longitude $38^{\circ}58'60''$ E with the average elevation 2006 meter above sea level [8].

The ground motion due to earthquake may lead to permanent settlement, tilting of footing and, thus, failure of the structure supported by them. The nature and distribution of earthquake damage is strongly influenced by the response of soils to cyclic loading. Different soil properties influence the behavior of the soil for different problems. The behavior of soils subjected to dynamic loading is influenced by dynamic soil properties [1]. The measurement of dynamic soil properties is a critical task in the solution of geotechnical earthquake engineering problems. A wide variety of field and laboratory techniques are available, each with different advantages and limitations with respect to different problems. Many are oriented towards measurement of low-strain properties and others towards properties mobilized at large strains. The selection of testing techniques for measurement of dynamic soil properties requires careful consideration and understanding of the specific problem at hand.

The shear modulus and damping characteristics of cyclically loaded soils are critical to the evaluation of many geotechnical earthquake engineering problems due to the fact that soils are nonlinear materials not only at low-strains but, also at intermediate and high strains [4]. Therefore, they could be tested under a wide range of strain. It is possible to test the soils using cyclic simple shear test as it is classified under large strain range. Even though Bishoftu is susceptible to earthquake, no experiment done in the determination of the shear modulus and damping ratio of the soils in the town, therefore, the objective of this thesis is to determine the dynamic soil properties namely shear modulus and damping ratio of soils in Bishoftu town.

1.2 Objective of the Study

- To determine the dynamic soil properties, namely shear modulus and damping ratio of soil in Bishoftu town using cyclic simple shear test;
- To determine the index properties and classify the soils and
- To provide additional useful guide in the selection of soil characteristics for analysis properties.

1.3 Materials and methods

To meet the objectives, field densities were determined using core cutter. Samples are collected from 1.5m and 3m depth for characterization of the soil. The following tests have been conducted to characterize the soils: Atterberg limit, specific gravity, compaction, particle size analysis, one-dimensional consolidation and free swell. In the laboratory, samples have been remolded to field condition for cyclic loading.

1.4 Scope of the study

This study is limited to the determination of dynamic properties of the soil namely shear modulus and damping ratio of Bishoftu town. The method used in the determination of these parameters is limited to the cyclic simple shear test.

1.5 Organization of the Study

This thesis consists of six chapters and nine appendices. The background information is presented under chapter one which mainly focus on introduction, objective, scope and limitation of the thesis. Literature review is mainly presented in second chapter which includes index and dynamic properties of soils. In third chapter description of study area and experimental techniques, sample location, cyclic simple shear testing system, elements of cyclic simple shear apparatus are presented. The fourth chapter consists of field and laboratory test results with their analysis. Comparison of test results with literatures is presented under fifth chapter. The sixth chapter is conclusion and recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Dynamic soil properties

Even though the study of earthquake dates back many centuries, the analysis of earthquake effect on structures based on the dynamic soil properties 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 [7]. The evaluation of dynamic properties of soil deposit is of utmost importance in studying site response, predict ground motion and probability of seismic hazards[23]. The response of soils to cyclic loading is controlled by the mechanical properties associated with dynamic loading including shear wave velocity, modulus, damping ratio and Poisson ratio [34].

Design of geotechnical engineering problems that involve dynamic loading of soils and soil–structure interaction systems requires the determination of two important parameters, the shear modulus and the damping ratio value of the soils [3]. The 1985 earthquake that inflicted great damage to Mexico City sited on soft soil foundations greatly attracted attention of researchers and engineers and moved them to study the dynamic properties of soft soils[7]. Many researchers have been dedicated to the study of dynamic properties of soft soils. The dynamic properties of different kinds of soils have been reported in literature. Idriss and Seed (1968) studied the effect of strain and load cycles on the parameters of the hyperbola model with San Francisco Bay mud. Based on a large number of tests, Hardin and Black (1968; 1969), and Hardin and Drnevich (1972a; 1972b) presented some empirical equations to evaluate the dynamic modulus and damping ratio of soft clay.

Basic and important physical (index) properties, which are necessary in the determination of the dynamic soil properties are; field density and moisture content, specific gravity, Atterberg's limits, grain size distribution and compaction tests. Basically, when a soil is subjected to earthquake or cyclic loading, the shear modulus and damping ratio of the soil are influenced by the above properties [8]. Thus, determination of the cyclic soil properties requires consideration of the above mentioned influencing parameter.

2.1.2 Water content of the soil

The moisture or water content of a soil sample is an indicator of the amount of water present in soil, the water content of soil can influence the behavior of cyclically loaded soil specimen, as it controls grain to grain slippage pore water pressure development [13]. The moisture or water content of a soil sample is an indicator of the amount of water present in soil. It is the ratio of the weight of water contained in the sample to the weight of solids in the sample, expressed in percentage.

$$\omega = \frac{W_w}{W_s} * 100 \text{ ----- 2.1}$$

Where:

ω – moisture content of soil (expressed as percentage)

W_w = weight of water in soil sample

W_s = weight of soil solids in sample ,

2.1.3 Specific gravity test

The specific gravity of a given material is defined as the ratio of the weight of a given volume of the material to the weight of an equal volume of distilled water. This test was done by means of a water pycnometer using ASTM D 854-02 for oven dried soil specimens that pass the 4.75mm (No.4) sieve [12]. Clean and dry volumetric flask and vacuum pump to remove the air from the soil-water mixture was used. Typical value of Specific gravity is presented in table 2.1 below.

Table 2-1:- Specific gravity value of some soil types [33].

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

2.1.4 Atterberg limits test

The Atterberg limits and related indices have proved to be very useful for soil identification and classification. The limits are often used: - directly for controlling soil quality, for use in fills and in semi empirical methods of design Soils [15]. In 1911, Atterberg developed a method for describing the limit consistency of fine-grained soils on the basis of moisture content. These limits are liquid limit, plastic limit, and shrinkage limit [15]. The numerical difference between the liquid limit and the plastic limit termed as plasticity index indicates the magnitude of the range of moisture content over which the soil remains plastic. A quantitative classification is given in table 2.2.

Table 2-2:- Range of plasticity index with its consistency [15]

Plasticity index	Plasticity
0	Non –plastic
1 to 5	Slight
5 to 10	Low
10 to 20	Medium
20 to 40	High
> 40	Very high

2.1.5 Grain size analysis

For a basic understanding of the nature of soil, the distribution of the grain size in a given soil mass should be known. In order to classify a soil for engineering purposes, it needs to know the distribution of the size of grains in a given soil mass. The grain-size analysis is done using sieve analysis on the coarse portion of the soil (> 0.075 mm in diameter), and using hydrometer analysis on the fine portion of the soil (< 0.075 mm in diameter). As a soil mass may contain the particles of both types of soils, a combined analysis comprising both sieve analysis and sedimentation analysis may be required for such soils [15]. This test was done according to ASTM D 422-98.

2.1.6 Soil classification

Geotechnical engineers, classify soils according to their engineering properties. Modern engineering classification systems are designed to allow an easy transition from field observation to basic predictions of soils engineering properties and behaviors.

A classification scheme provides a method of identifying soils in a particular group that would likely exhibit similar characteristics. Soil classification is used to specify a certain soil type that is best suitable for a given application. 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.

2.1.7 Compaction

Compaction is the process of densification of soil by reducing air voids. The degree of compaction of a given soil is measured in terms of its dry density. The dry density is Maximum at the optimum water content. To obtain the maximum dry density and the optimum water content, a graph is drawn with axes of dry density and water content.

Geotechnical engineers regularly recommend the highest practical soil compaction based on data correlating soil density by removal of air with increased mechanical strength [4]. Foundations of heavy buildings, highway roadbeds, and airport runways all require considerable levels of soil compaction for satisfactory performance [16].

2.1.8 One-dimensional consolidation

Consolidation is the time-dependent settlement of soils resulting from the expulsion of water from the soil pores. According to Karl von Terzaghi “consolidation is any process which involves a decrease in water content of saturated soil without replacement of water by air”. In general it is the process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to soil particles to pack together more tightly, therefore reducing its bulk volume. When these occur in a soil that is saturated with water, water will be squeezed out of the soil. When stress is removed from a consolidated soil, the soil will rebound, regaining some of the volume it had lost in the consolidation process.

If the stress is reapplied, the soil will consolidated again along a recompression curve, defined by recompression index. The soil which had its load removed is considered to be over consolidated. The highest stress that it has been subjected to is termed the preconsolidation stress. When a soil layer is subjected to a compressive stress during the construction of a structure, it will exhibit a certain amount of compression. This compression is achieved through a number of ways, including rearrangement of the soil solids or extrusion of water [17]. The most often used method of consolidation testing is the one dimensional consolidation test. In this study, the test specimens have been consolidated to determine the pre- consolidation pressure, to use for simple cyclic shear test.

2.2 Cyclic loading and soil response

The response of soil subjected to cyclic loads will be governed by the cyclic soil properties. The responses obtained for different cyclic loadings need to be back analyzed to determine the cyclic soil properties. A typical soil subjected to cyclic loading exhibits hysteresis response, which is the result of shear stress and shear strain. The shear modulus and damping ratio will be determined from the hysteresis loop. Appropriate evaluation of shear modulus and damping characteristics of soils subjected to cyclic loadings is the basic element to accurate seismic response analysis and soil modeling programs. Parameters describing the cyclic soil properties required for a dynamic analysis include the initial (small strain) damping ratio, D , the initial shear modulus at small shear strain, G_{max} and the modulus reduction and damping curves for the soil [13].

2.2.1 Shear modulus and damping ratio

Shear modulus, G , is generally defined as the slope of the line connecting two extreme points on the hysteresis loop at a certain shear strain (Fig 2.1). The stiffness of the soil degrades dramatically as the level of strain amplitude increases above 10^{-5} different kinds of soils behave differently but all follows similar rule and their nonlinear behavior can be formulized [3].

Hyperbolic models have been widely used to describe nonlinear soil behavior under cyclic loading. Generally, the cyclic nonlinear behavior of the soil is defined by a loading unloading curve, which is governed by Masing's rule [9]. The damping ratio, D , is a measure of the dissipated energy (W_D) versus elastic strain energy (W_S) through one cycle of loading-unloading.

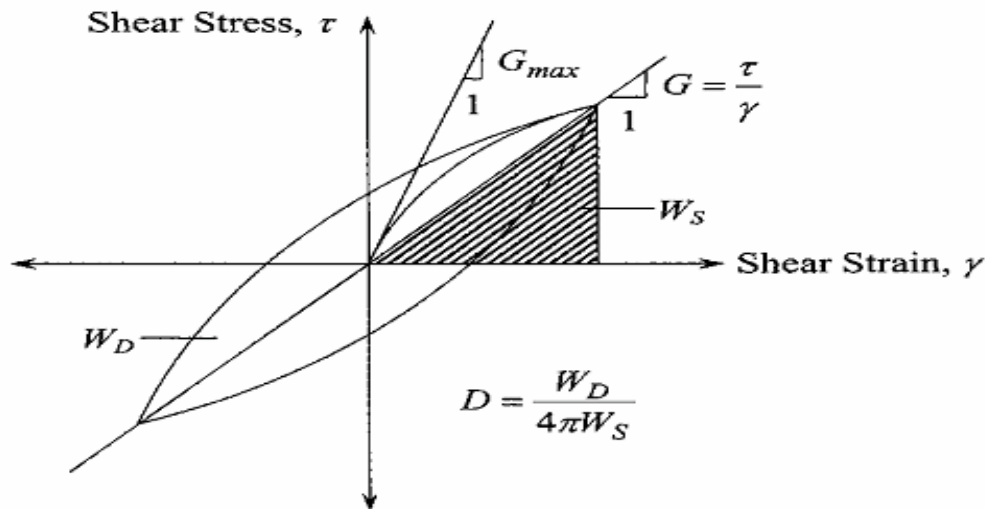


Figure 2.1:- Hysteresis loop for one cycle of loading showing G , D [3].

2.2.2:- Shear modulus and damping ratio of sand

The shear modulus of sand determined by a number of investigators using different laboratory testing procedures under different factors is given in figure 2.2 [13]. Aria, Amhara, Siver and Seed studied the effect of confining pressure for dry sand, Hardin and Drenvich for saturated sand [6]. In addition to confining pressure, other factors such as void ratio, degree of saturation and angle of friction were studied by a number of researchers. Based on these studies, Bolton and Idriss presented the range of values of damping ratios as shown on fig. 2.3,[13].

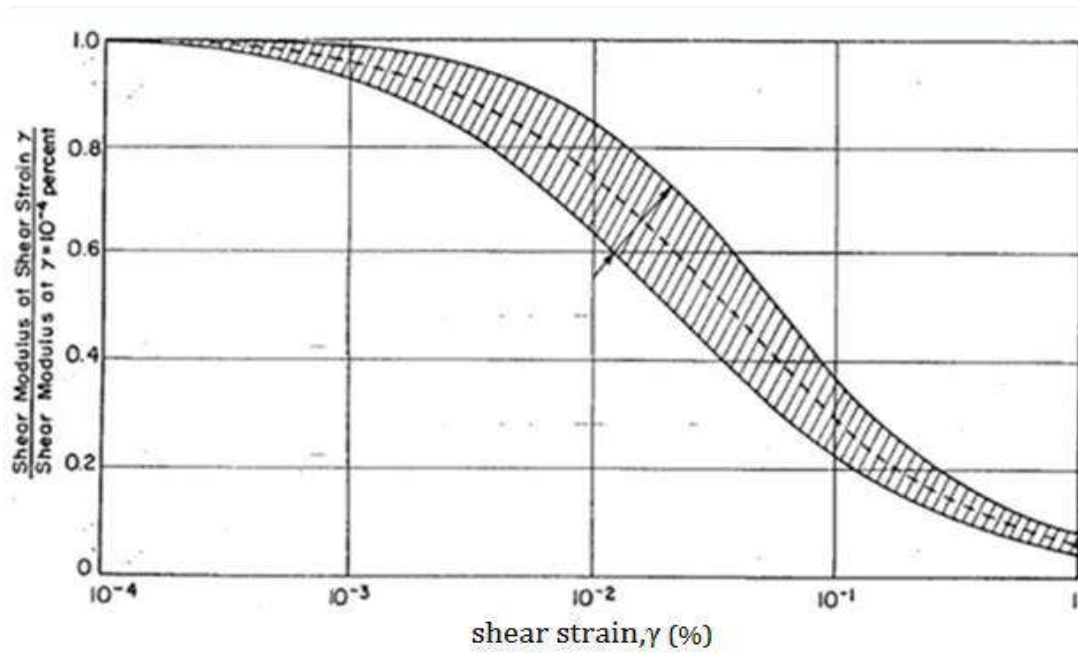


Figure.2.2:- Variation of shear modulus with shear strain for sand [13]

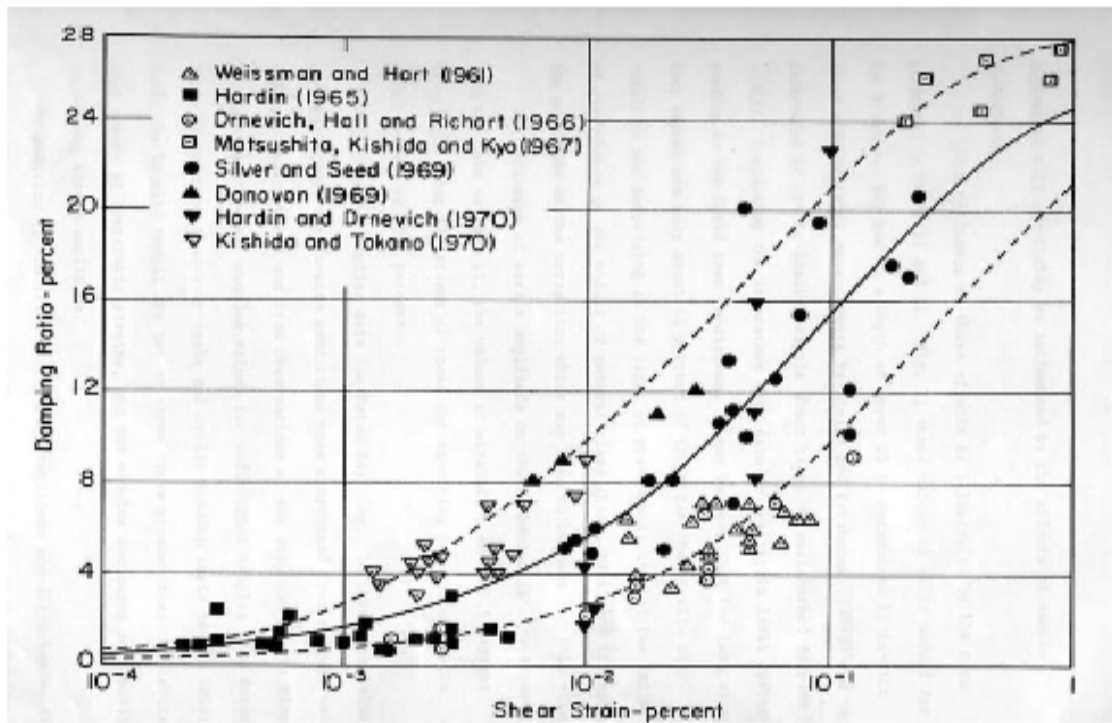


Figure 2.3:- Variation of damping ratios with shear strain for sand [13]

2.2.3 Shear modulus and damping ratio of clay

The value of shear modulus of clay is strongly influenced by strain amplitude and disturbance of sample. Even though the in-situ measurement eliminates the problems of sample disturbance of specimen, no techniques have been developed for including large controlled strain amplitude. For this reason, the shear modulus is determined at very small strain level. In laboratory, samples may be tested under wide range of strain but for test specimens from natural deposits, the shear modulus determined will be inevitably be influenced by the effect of sample disturbance [6]. In addition to sample disturbance and effect of large strain amplitude, the shear modulus is influenced by effective mean principal stress, void ratio, over consolidation ratio and effective stress strength parameters. Figure 2.4, shows the typical values of normalized shear modulus of saturated clay soils tested under different ranges of shear strain amplitude [6].

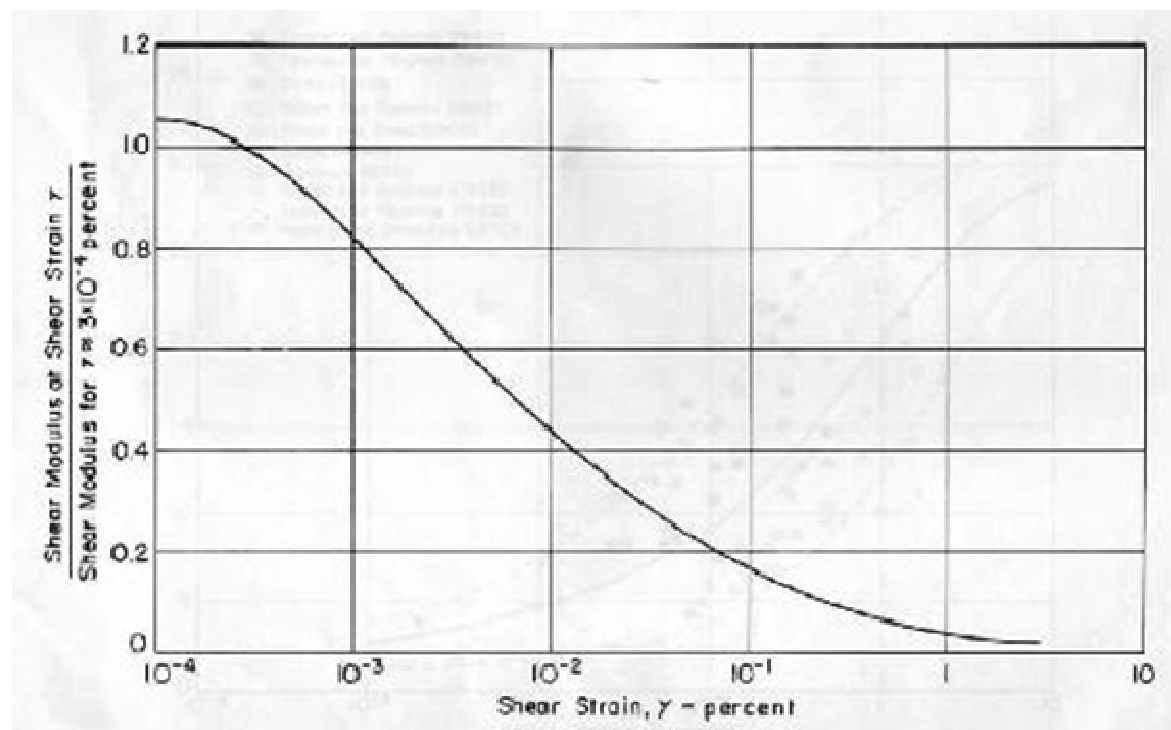


Figure 2.4:- Typical reduction of shear modulus with shear strain for saturated clays [6]

Damping ratio of saturated clay soils is difficult to determine the main influencing factors as there is limitation of test data and variation of results. Figure 2.5 below shows the approximate upper and lower bound relationships (dashed line) between damping ratio and shear strain and representative average relationships (solid line). This average relationship may well provide values of damping ratio with sufficient accuracy for many practical purposes.

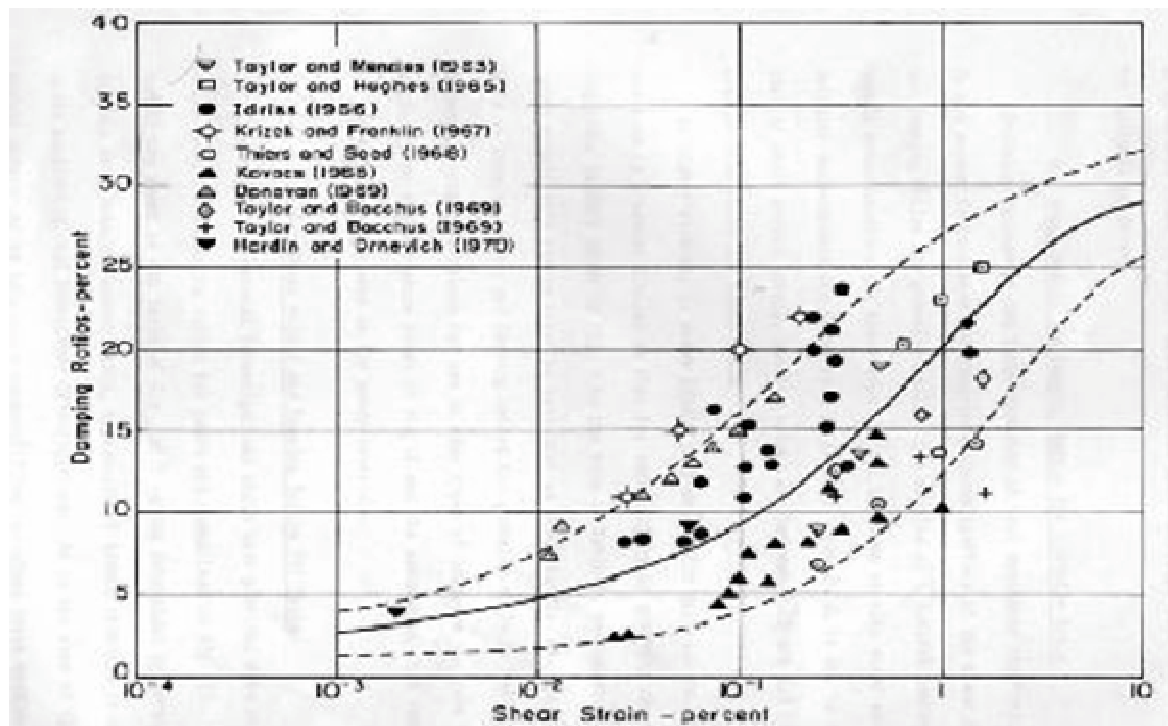


Figure.2.5:- Damping ratio for saturated clays [6]

2.2.4 Values of shear modulus and damping ratio of clay and sand

Both response and ground failure are strongly influenced by properties of soil. Site response is primarily influenced by the properties that control wave propagation, particularly stiffness and damping. Ground failure is influenced by those properties but also by the shear strength of the soil. The properties of soil are influenced by types of soils namely; clay, sand, silt soil. But also dynamic properties of soils such as; modulus reduction behavior is strongly dependent upon shear strain amplitude and plastic index; for cohesion less soils (clay and silt clay) and low plasticity soils (sandy soils) its also influenced by mean effective stress. The influence of effective confining pressure is decreased with increasing plasticity index (PI).

2.2.5 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 G_{max} . A plot of the variation of G/G_{max} with shear strain is called a normalized modulus reduction curve. Since most seismic geophysical tests induce shear strain lower about $3 \times 10^{-4}\%$, the measured shear wave velocities can be used to compute G_{max} as suggested by Luna, R, and Jidi, H [19].

$$G_{max} = \rho V_s^2 \quad (2.2) [19].$$

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 G_{max} for a particular soil deposit. When shear wave velocity measurement are not available G_{max} can be estimated in different ways. Hardin and Drnevich [20] developed a particular relationship with for an isotropic state of stress. The curve G/G_{max} vs shear strain developed for Ethiopia silt soil was decreased with increased shear strain and increased with decreased shear strain while the curve of damping ratio vs. shear strain is decreased with decreased shear strain, Abu.G [5], Abraham.M [30] & Yohanis .H [31].

$$G_{max} = 3.23 * \frac{((2.973 - e)^2)}{1 + e} * OCR^K * (\sigma_o')^{0.5} \quad \text{----- 2.3}$$

$$\sigma_o' = \frac{(\sigma_v' + 2K_o \sigma_v')}{3} \quad \text{----- 2.4}$$

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) [21]

Table 2-3:- Empirical values of exponential parameter (k) proposed by Hardin and Drnevich [20]

PI	K
0	0
20	0.18
40	0.3
60	0.41
80	0.48
>100	0.5

2.3 Methods of determining of shear modulus and damping ratios

The selection of testing techniques for measurement of the shear modulus and damping ratio requires careful consideration and understanding of the specified parameters. There are various procedures, including laboratory and field tests that have been used to determine shear modulus and damping characteristics of soils. A summary of the procedure and the approximate range of strain within which they have been used are presented in the table 2.4 [32]. The main procedures are [32]:

1. Direct determination of stress strain relationships
2. Forced vibration tests
3. Free vibration tests
4. Field measurement of wave velocities
5. Analysis of ground response during earthquake

The approximate strain range is presented in table 2.4.

In this study, direct determination of stress-strain relationships was used for shear modulus and damping ratio determination from cyclic simple shear test. The dynamic properties of soil can be determined in field and laboratory investigation methods. The different methods used for dynamic soil properties investigation are shown in the Fig. 2.4 [32].

Table 2.4 Test procedures for measuring shear modulus and damping ratio [32]

General Procedure	Test condition	Approximate strain range (γ)	Properties that may be determined
Determination of Hysteretic stress-strain relationships	Triaxial compression	10^{-2} to 5%	Shear Modulus; Damping
	Simple shear	10^{-2} to 5%	Shear Modulus; Damping
	Torsional shear	10^{-2} to 5%	Shear Modulus; Damping
Forced vibration	Longitudinal	10^{-4} to $10^{-2}\%$	Shear Modulus; Damping
	Torsional vibrations	10^{-4} to $10^{-2}\%$	Shear Modulus; Damping
	Shear vibrations-lab	10^{-4} to $10^{-2}\%$	Shear Modulus; Damping
	Shear vibrations-field	10^{-4} to $10^{-2}\%$	Shear Modulus
Free vibration tests	Longitudinal	10^{-3} to 1%	Shear Modulus; Damping
	Torsional vibrations	10^{-3} to 1%	Shear Modulus; Damping
	Shear vibrations-lab	10^{-3} to 1%	Shear Modulus; Damping
	Shear vibrations-field	10^{-3} to 1%	Shear Modulus
Field wave velocity Measurements	Compression waves	$\sim 5 \times 10^{-4}\%$	Shear Modulus
	Shear waves	$\sim 5 \times 10^{-4}\%$	Shear Modulus

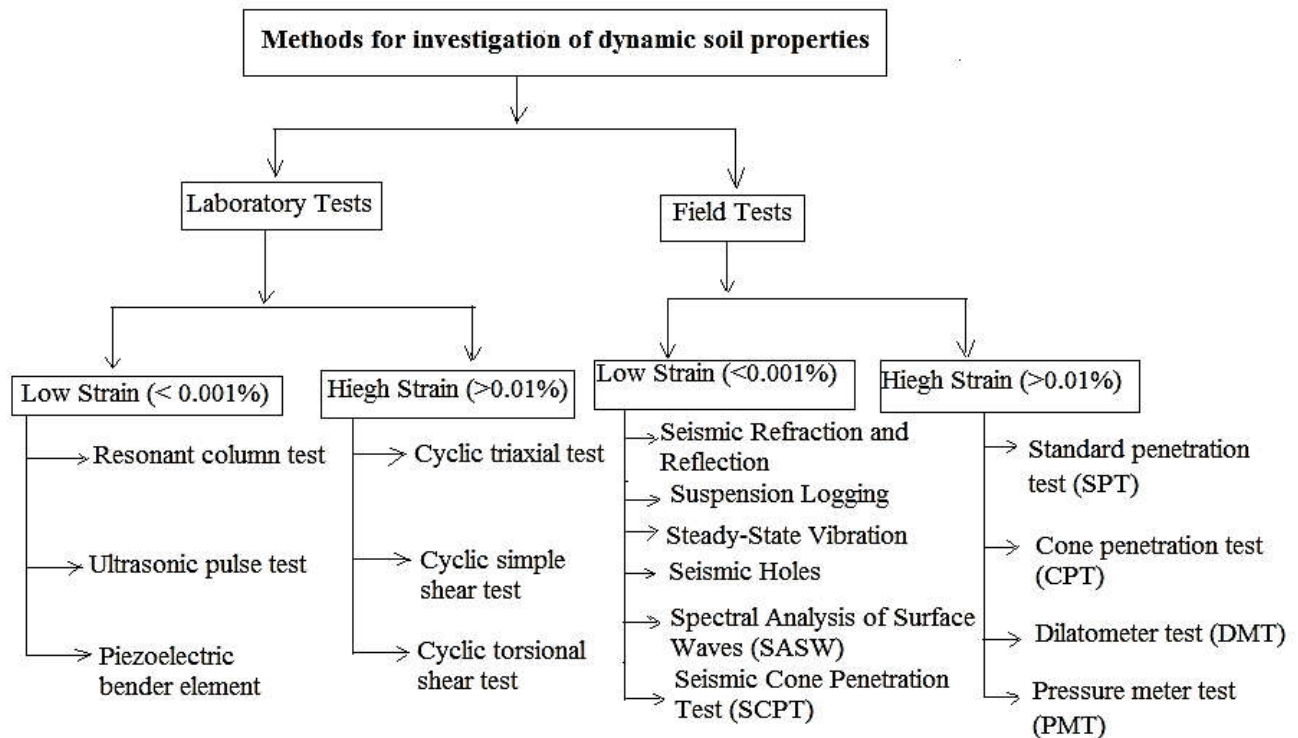


Figure 2.4 Methods of investigation of dynamic soil properties [32]

2.4 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 [20].

These factors are:

- strain amplitude, γ ,
- void ratio, e ,
- effective confining stress, σ'_o
- frequency of loading,
- effective stress strength parameters, c' and ϕ' ,
- number of loading, N ,
- over consolidation ratio, OCR,
- degree of saturation and grain characteristics,
- time effects.

2.4.1 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 high level, for higher strain tests, the shearing strain amplitude is controlled larger than 0.1%. Stress-strain behavior of soil exhibit nonlinearity effect and result in high damping ratio values. Therefore, the shear modulus of soil decreases with an increase in strain amplitude and damping ratio increases with strain amplitude. This is because at higher values of shear strain, the soils strength becomes smaller to resist deformation and more energy released to yield high deformation [31]. Approximate upper and lower bound relationships between damping ratio and shear strain are shown by the dashed lines in Fig. 2-6 and a representative average relationship is shown by the solid line. It also observed that the value of damping ratio increases with shear strain amplitude.

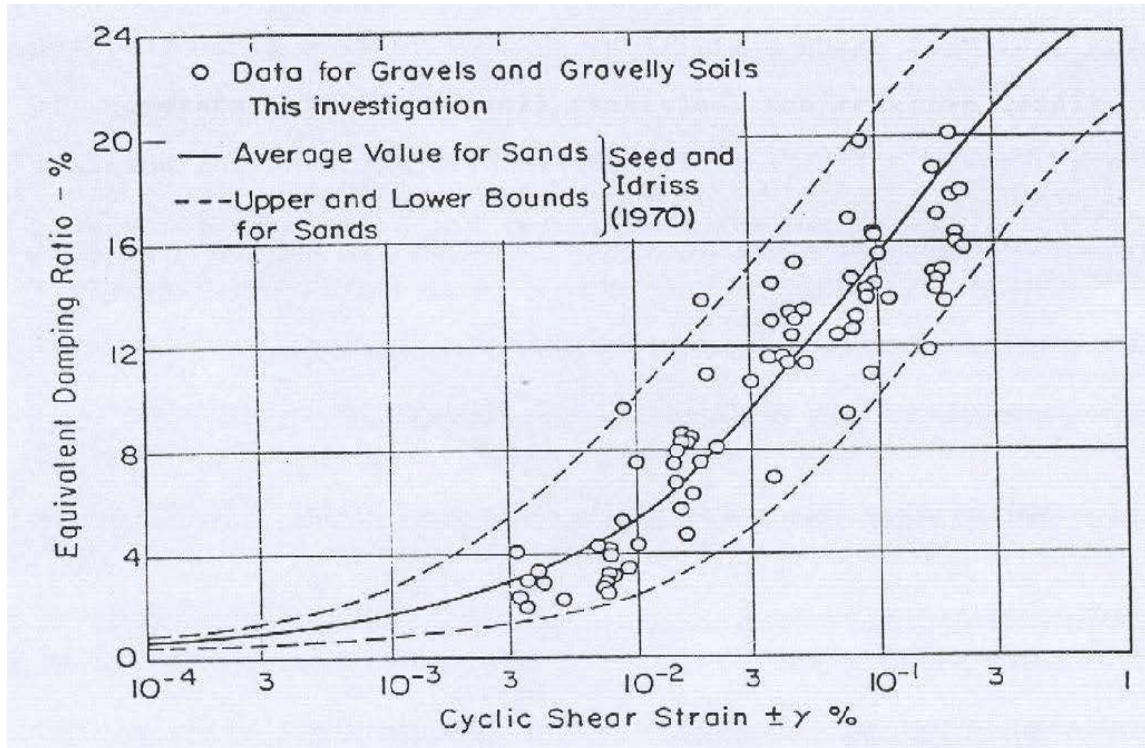


Figure 2-6:- Damping ratio curve for sand [3]

2.4.2. Void ratio

Void ratio is very important factor, which influences small-strain shear modulus. Hardin and Richart [20] evaluated the shear wave velocity of granular soils, and drew the conclusions that the small strains shear modulus decreases with increasing void ratio. However effect of void ratio has no significant influence on damping ratio at any shearing strain amplitude under all confining pressures [20].

2.4.3 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. Confining pressure (or mean principal effective stress) together with void ratio is recognized as the very important parameters, which influence the small-strain shear modulus of soil. [20] Figure 2-7 illustrates the small-strain shear modulus of Ottawa 20-30 sands almost linearly increases with an increase in mean confining pressure.

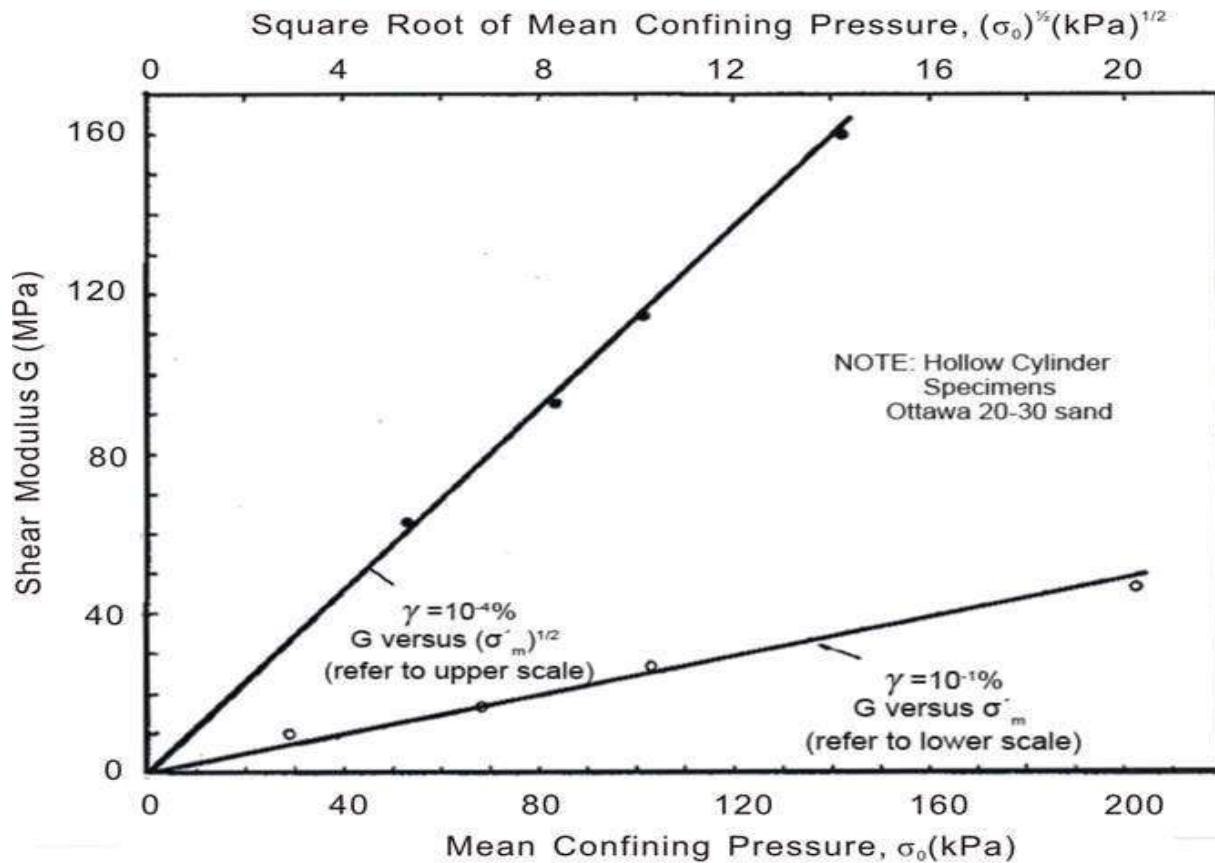


Figure 2-7 Relation between shear modulus with mean confining pressure [25]

2.4.4 Degree of saturation

Hardin and Richart [24] and Lawrence [26] reported that the degree of saturation had only small effect on small-strain shear modulus for sand at low pressures. Hardin and Drnevich [20] classified degree of saturation as the very important parameter for cohesive soils but unimportant parameter for cohesion less soils.

2.4.5 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. 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 [24]. 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].

2.4.6. Number of loading cycles

Silver and Seed [3] measured the shear modulus and damping ratio of dry sands at the 1, 10, and 300 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 [27] also reported that in general, the shear modulus moderately increases and the damping ratio decreases with the number of loading cycles. 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 cycles as shown in fig 2-8.

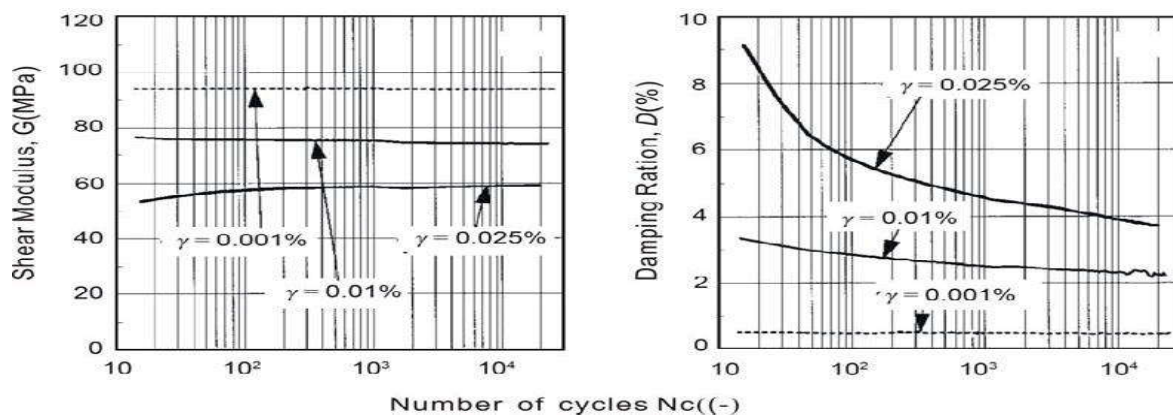


Figure.2-8:- Effects of number of cycles on shear modulus and damping ratio for dry sand [27]

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.

2.4.7 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 [24], Hardin and Black [20] 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 movement between particles occurs resulting in soil having higher density, resulting in an increase in shear modulus.

2.4.8 Effect of non-plastic fine materials

Figure 2-9 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]

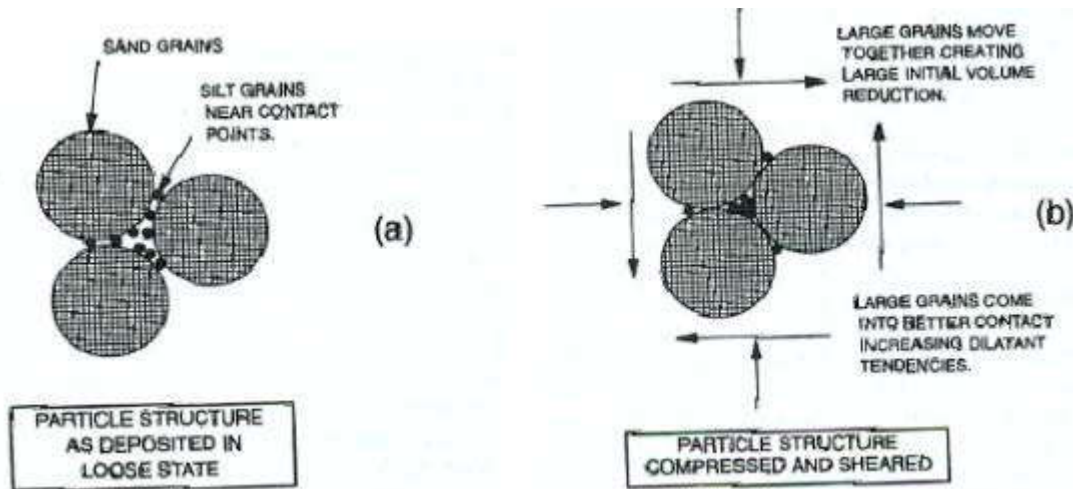


Figure 2.9:- Hypothetical particle structure of loose silty sand with low silt content:

(a) As deposited and (b) after densification due to shearing (Yamamuro and Lade, 1997)

CHAPTER THREE

3. DESCRIPTION OF STUDY AREA AND EXPERIMENTAL TECHNIQUES

3.1 Area of study

Bishoftu is a town and separate district located in the East Shewa zone at 47 kilometers south of, Addis Ababa, on the main road to Adama. According to the population and housing censuses of 2007, the total population of the town was 100,114, of whom 52.1% were women. The central location of Bishoftu is 8°45'N latitude and 38°59'E longitude. From geographical evidences it is located in the great Rift Valley zone of Ethiopia which is prone to an earthquake activity and classified as seismic zone four [6]. Topographically the city is located in tepid to cool sub-moist mid highland at an altitude of about 2006 meters above sea level with moderate weather condition. The temperature of the area falls within a range of 16°C to 24°C. Bishoftu is truly a resort town, known for five crater lakes: Lake Bishoftu, Lake Hora, Lake Bishoftu Guda, Lake Koriftu and the seasonal Lake Cheleklaka.



Figure 3.1:- Location of Test pits.

Table 3.1:- Location of test pits and their designation

S. No	Keble	Test pit	Local name	Latitude(N)	longitude,(E)
4	15	4	Babugaya	8°46'40.24"	38°59'34.52"
3	9	3	Babugaya	8°47'28.12"	38°58'51.56"
2	2	2	TVET	8°44'6.86"	38°58'31.63"
1	1	1	Adis safar	8°45'32.37"	38°56'57.99"

All soil samples were taken from four selected test pits which are located in Keble 01, 02, 09, and 15 Keble. The field density was determined using core cutter and about 30kg of disturbed soil samples from each layer were collected in bulk randomly for the index and dynamic tests. To study the response of the soil at natural condition the field density is preferable to maximum dry density. The dynamic test is performed by compacting sample at field density and natural moisture content. Grain size distribution and index property of soil are determined.

3.2. Cyclic simple shear testing system

Nowadays there are different types of cyclic simple shear apparatuses in use. In this research, the type of apparatus used was 31-WF7500 cyclic simple shear machine which is developed by the controls group. The complete system is controlled by the UTS004 software application program [3]. 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 [3]. The system (Fig 3-2) is designed to allow a sample to be consolidated, drained and then sheared.

3.2.1 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 confinement and produce a K_0 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.

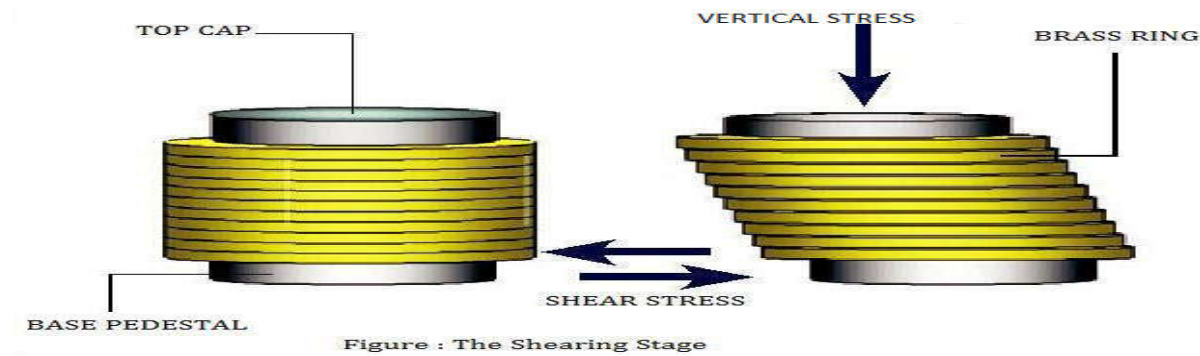


Figure 3.2:- Simplified view of laterally constrained sample under cyclic simple shear conditions [28]

3.2.2 Sample preparation

The general procedures of ASTM D6528 were used to prepare and test samples of soil in cyclic simple shear. In this experimental work, the tamping specimen preparation technique was used for the cyclic testing programs. Sample diameter is 70mm and height is varied from 20 mm to maintain height to diameter ratio less than 0.4, in order to fulfill the ASTM D6528-07 criteria.



Figure 3.3:- 31-WF7500 cyclic simple shear machine [28]

3.2.3 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 [28].

3.2.4 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 [12]. 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.

CHAPTER FOUR

4. LABORATORY TEST RESULTS AND DISCUSSION

4.1. Introduction

Field and laboratory tests such as field density, moisture content, free swell, Atterberg limit, sieve analysis, specific gravity, compaction, consolidations, are conducted to gain a better understanding on important properties of soils under consideration, and how the dynamic shear modulus and damping ratio is influenced by plasticity index, stress history, void ratio and grain distribution. Summary of part of laboratory result of Bishoftu town is presented.

The test results of water content determination for all pits are presented in Appendix-A. The minimum value of water content is 12.09% in pit 3 and the maximum value of water content is 33.67% found in pit 1.

The in-situ bulk density test is 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 1.44 to 1.57gm/cc. (See App B).

For the determination of values of Atterberg limits the soil samples were performed in accordance with ASTM D4318–840. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a pat of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13mm (1/2in.), when subjected to 25 shocks from the cup being dropped 10mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling in to 3.2mm (1/8in.) diameter thread without crumbling. The detail of the test result is presented in Appendix-C.

The amount of swelling and the magnitude of swelling are determined in the laboratory

$$\text{Free swell} = \frac{\text{Final volume} - \text{Initial volume of the soil}}{\text{Initial volume}} * 100 \text{ --- --- --- --- --- 4.1}$$

Based on the test result presented the value of free swelling of all pits are showed in table 4.1, and the detail test results for all pits are showed in Appendix- D.

The result of particle size analysis performed on each sample is shown in appendix-E and the summary of particle size distribution curve is shown in figure 4-1.

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass

of the same volume of gas-free distilled water at a stated temperature (20°C). The details of test results of specific gravity test for all pits are showed in Appendix- F. from test result the specific gravity of the sample is found to vary between 2.67 to 2.7.

The laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. In this study, test specimens have been compacted to field density and moisture content for cyclic shear testing to replicate the natural state of the soil samples. From the test results, it is observed that the maximum dry density varies from 1.44 to 1.57gm/cc and optimum moisture content varies from 12.09 to 33.67%. The test results of compaction test for all pits are presented in Appendix- G.

The main purpose of one dimensional odometer test is to get better understanding on stress history of the soil under study. The tests are based on ASTM D2435 - Standard test method for one-dimensional consolidation. Detailed calculation of test result is shown in table H-1 and H-2 in the appendix H. The preconsolidation pressure is obtained from the graph of figure H-1& H-2 and is found to be 100kPa and 80kPa.

Table 4.1:- Field test, specific gravity, compaction & free swell.

Sample pit	Keble	Depth (m)	Field density – bulk (g/cm ³)	Field density- dry (g/cm ³)	Natural water content (%)	Specific Gravity	MDD	OMC (%)	Free Swell
1	Adis safar	1.50	1.55	1.16	32.84				
		3.00	1.57	1.18	33.67	2.70	1.27	38.50	55.00
2	TVET	1.50	1.47	1.30	12.91				
		3.00	1.50	1.33	13.24	2.67	1.53	22.10	27.00
3	Babugaya	1.50	1.44	1.25	14.84				
		3.00	1.48	1.32	12.09	2.68	1.61	22.00	30.00
4	Babugaya	1.50	1.48	1.30	13.51				
	15 (BG15)	3.00	1.46	1.28	14.20	2.68	1.35	32.50	35.00

Table 4.2:- Atterberg limit and soil classification.

Sample from	% of particle passing- No200	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Type of Soil	Characteristics of soil			On plasticity Chart	Soil type
							LL	PL	PI		
Pit 1	88.4	0.60	11.04	69.96	18.44	Fine Grained	61.00	46.60	14.40	Above A-line	Silt
Pit 2	72.6	1.70	25.73	62.50	10.08	Fine Grained	36.00	30.00	6.00	Below A-line	Silt (ML)
Pit 3	89.8	0.64	9.53	68.60	21.2	Fine Grained	36.00	30.90	5.10	Below A-line	Silt (ML)
Pit 4	72.6	1.70	25.7	51.5	21.1	Fine Grained	26.00	21.00	5.00	Below A-line	Silt (ML)

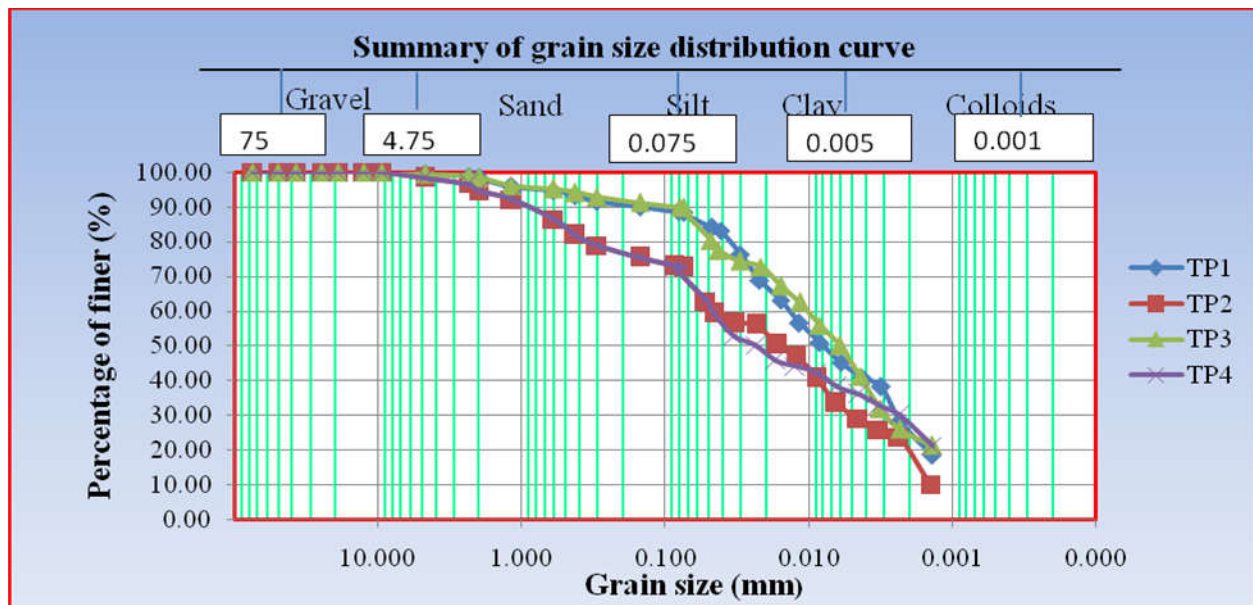


Figure 4.1:- Grain size distributions of all pits

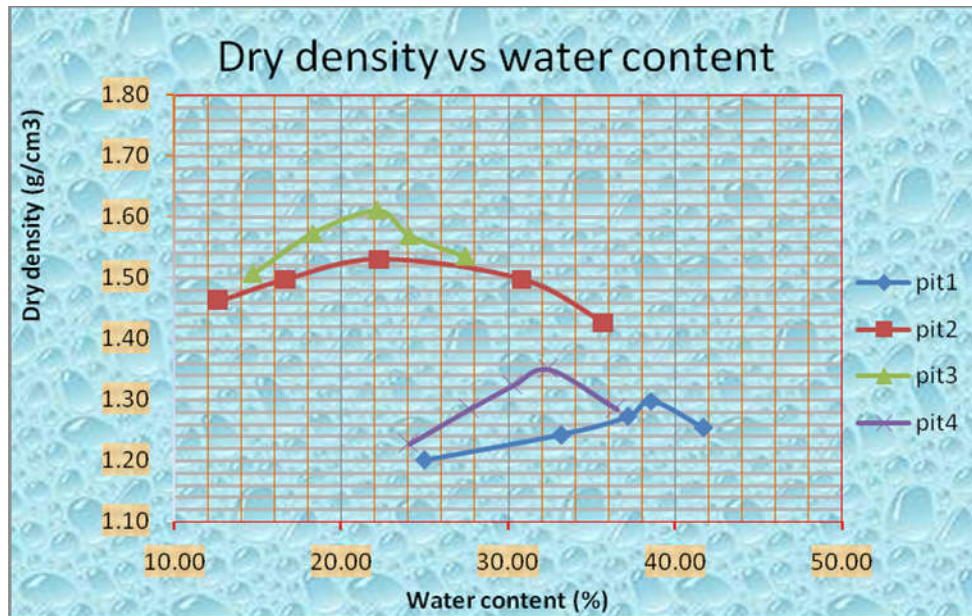


Figure 4.2 Dry densities V_s . Water content of all pits

4.2 Test result from cyclic simple shear test

The data obtained from Cyclic simple shear test gives simply raw data from 50 data points and 40 numbers of cycles for single cyclic loading in the form of Microsoft excel. Hence, for complete test of any selected pressure and amplitude, 2000 data points were recorded. From lateral Lvdt and lateral force test results, shear stresses and shear strains are evaluated, and then dynamic soil parameters are calculated. Once shear modulus and damping ratio are calculated, shear modulus and damping ratio versus shear strain can be drawn.

4.2.1 Determination of shear modulus and damping ratio

The hysteresis loop is produced 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 100kPa and cyclically loaded to maximum single displacement amplitude of 1mm (corresponding to maximum single strain amplitude of 5%). The shear stress is calculated simply by dividing the shear force by the area of the specimen base (0.003848m^2), and the shear strain is calculated by dividing the shear displacement by the specimen height after consolidation ($<20\text{mm}$).

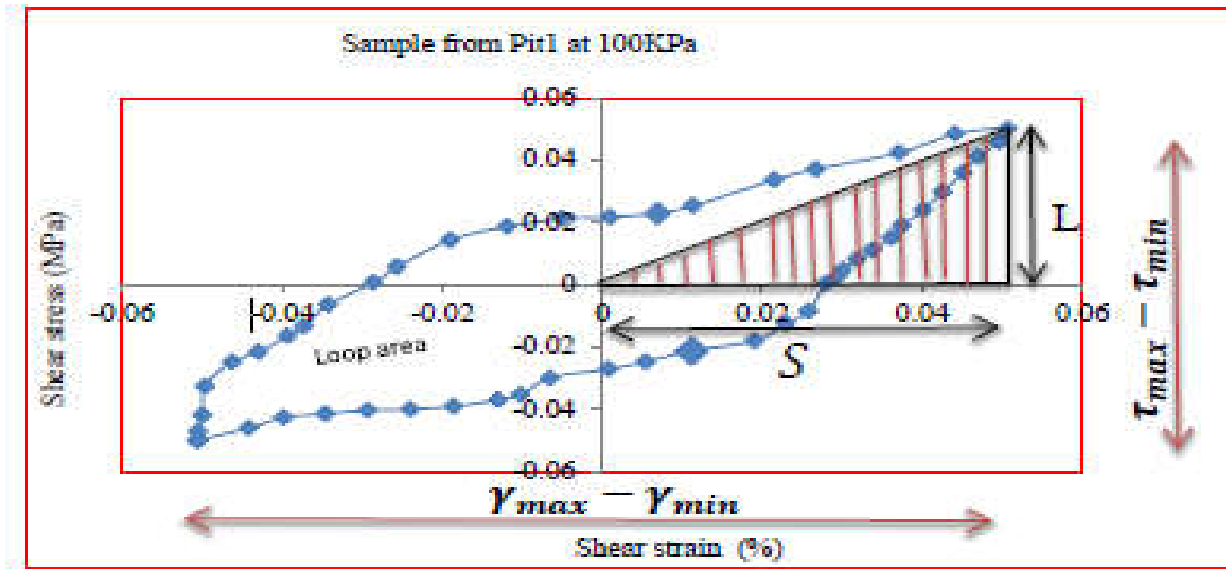


Figure 4.3:- Hysteresis loop and triangle using stress strain values at 5th cycle

4.2.2 Hysteresis loops

The hysteresis loop produced from the cyclic loading of a typical soil can be described by the path of the loop it self or by two parameters that describe its general shape. These parameters are the inclination and the breath of the hysteresis loop, shear modulus and damping, respectively.

To determine the dynamic properties of soils, the graphs of shear stress versus shear strain commonly known as hysteresis loop is plotted. Fig 4.4 shows the hysteresis loop of sample from pit 1 at axial pressure of 100kPa for 0.01%, 0.1%, 1%, 2.5% and 5% shear strains.

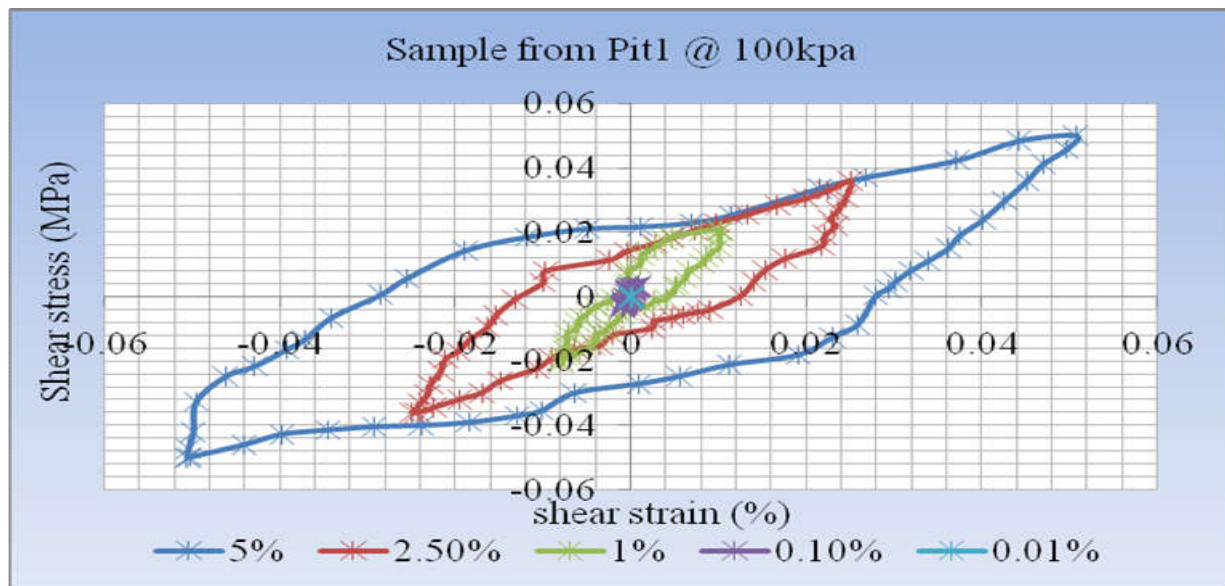


Figure 4-4:- Hysteresis loop showing the effect of shear strain amplitude on the hysteresis loop at 100kPa of axial stress.

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

$$G = \frac{(\tau_{\max} - \tau_{\min})}{(\gamma_{\max} - \gamma_{\min})} \text{ in MPa} \quad \text{--- 4.2}$$

$$D = \frac{\text{Area of loop}}{4 * \pi * \text{Area of Triangle}} * 100 \quad \text{--- 4.3}$$

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 5th cycles are likely to provide reasonable values for all practical purpose [4].

Calculation is based on shear stress and shear strain that obtain from shear force and cyclic amplitude which are the results of cyclic simple shear test. Normally there are 40 cycle for single amplitude (cyclic shear strain) and similar calculation is applied to obtain dynamic soil parameters, shear modulus and damping ratio of soil.

$$\tau = \frac{\text{Shear force}}{\text{Area of sample}} = \frac{F}{A} \text{-----} 4.4$$

$$\text{Area of sample (A)} = \pi * 35^2 = 3848.45\text{cm}^2$$

$$\gamma = \frac{\text{Lateral lvdt}}{\text{Height of sample}} \text{-----} 4.5$$

$$\text{Height of the sample} = 20\text{mm}$$

$$\text{Diameter of the sample} = 70\text{mm}$$

$$G = \frac{\tau_n}{\gamma_n} \text{-----} 4.6$$

τ_n = The difference between the maximum and the minimum values of shear stress

γ_n = The difference between the maximum and the minimum values of shear strain

$$D = \frac{A_{\text{Loop}}}{4\pi A_{\Delta}} * 100 \text{-----} 4.7$$

$$A_{\text{Loop}} = 0.5 * \sum (\tau_i - \tau_{i+1}) * (\gamma_i + \gamma_{i+1})$$

$$A_{\Delta} = 0.5 * L * S$$

A_{Δ} = Triangular area

Table 4-4:- Typical calculation for shear modulus and damping ratio.

Calculation of shear modulus		Calculation of Damping Ratio	
$\tau_{\max}$	0.05013222	$A_{loop} = 0.5 \sum_{i=1}^n (\tau_i - \tau_{i+1}) * (\gamma_i + \gamma_{i+1})$	0.003853
$\tau_{\min}$	-0.05010151		
$\tau_{\max} - \tau_{\min} = \Delta\tau = 2L$	0.10023373	$A_{\Delta} = 0.5 * (S * L)$	0.00127
$\gamma_{\max}$	0.050702227	$D(\%) = \frac{A_{loop}}{A_{\Delta}} * 100$	24.14246
$\gamma_{\min}$	-0.05065653		
$\gamma_{\max} - \gamma_{\min} = \Delta\gamma = 2S$	0.101358755		
$G = \frac{\Delta\tau}{\Delta\gamma} \text{MPa}$	0.988900573		
S	0.050116865		
L	0.050679377		
$0.5 * S * L$	0.001269946		

In this study, a single specimen is tested up to 40 cycles and table 4-5 shows shear modulus and damping ratio values of each cycle for pit 3 under an axial stress of 100kPa. Additional test results are shown in appendix I.

Table 4-5:- Shear modulus and damping ratio of pit3 at 100kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, D (%)				
1	4.10	3.09	2.04	1.30	0.81	14.15	18.25	18.58	19.10	25.91
2	4.18	3.12	2.08	1.50	0.75	14.53	18.21	18.13	19.05	25.28
3	4.22	3.15	2.10	1.35	0.86	14.78	17.73	17.84	18.76	25.99
4	4.42	3.30	2.20	1.39	0.90	14.01	17.36	17.25	18.61	24.24
5	4.51	3.59	2.27	1.44	0.99	14.53	16.00	16.74	18.18	24.14
6	4.37	2.99	2.30	1.42	1.20	14.51	15.85	16.37	18.18	24.20
7	4.75	3.25	2.50	1.54	1.04	14.40	15.78	16.26	18.21	22.96
8	4.94	3.38	2.60	1.37	1.05	14.35	15.73	16.34	16.73	23.66
9	4.75	3.25	2.50	1.47	1.18	14.90	15.30	16.25	16.80	23.53
10	4.51	3.51	2.70	1.32	1.19	15.50	15.25	16.12	16.93	23.33
11	4.94	3.38	2.60	1.44	1.20	15.30	15.14	16.03	16.93	23.65
12	4.13	3.58	2.75	1.53	1.21	14.80	15.08	16.13	16.76	23.51
13	4.14	3.59	2.76	1.59	1.27	14.70	15.01	15.75	16.73	23.83
14	4.16	3.60	2.77	1.59	1.22	14.60	14.89	15.40	16.75	23.07
15	4.26	3.69	2.84	1.62	1.18	14.30	14.56	15.48	16.93	23.27
16	4.25	3.68	2.83	1.66	1.21	13.80	14.38	14.94	16.67	23.00
17	4.31	3.73	2.87	1.69	1.12	13.50	14.24	14.45	17.44	21.74
18	4.37	3.78	2.91	1.69	1.14	13.30	14.15	14.29	16.64	21.57
19	4.49	3.89	2.99	1.74	1.10	12.99	13.50	14.24	16.09	21.72
20	4.96	4.17	3.21	1.90	1.45	12.50	13.60	14.16	16.24	21.36
21	4.76	3.96	3.33	1.92	1.32	12.80	13.55	14.08	16.24	22.73
22	4.48	3.74	3.14	1.93	1.40	12.90	13.33	14.54	16.69	22.68
23	4.93	4.11	3.45	1.98	1.35	13.90	13.25	14.19	16.48	22.61
24	5.06	4.21	3.54	1.95	1.25	12.50	13.21	14.22	16.19	22.40
25	5.14	4.28	3.60	2.01	1.16	12.60	13.56	14.12	15.97	22.31
26	4.93	4.11	3.45	2.25	1.13	12.40	13.45	14.10	16.51	22.24
27	5.06	4.21	3.54	2.19	1.32	12.40	13.21	13.71	15.48	22.25
28	5.51	4.59	3.86	2.32	1.19	13.80	13.20	13.91	15.35	22.79
29	5.57	4.64	3.90	2.35	1.24	12.90	13.10	13.86	15.55	22.16
30	5.28	4.40	3.70	2.34	1.22	12.60	12.98	13.68	15.66	22.09
31	5.43	4.52	3.80	2.36	1.13	12.50	12.87	13.54	15.55	20.58
32	5.43	4.52	3.80	2.34	1.10	12.40	12.75	13.32	15.41	20.30
33	5.58	4.65	3.91	2.40	1.23	12.80	12.65	13.26	15.41	21.88
34	5.61	4.68	3.93	2.34	1.20	12.60	12.53	13.41	15.41	22.85
35	5.43	4.52	3.80	2.38	1.25	12.50	12.45	13.59	15.38	22.41
36	5.68	4.74	3.98	2.41	1.40	12.40	12.41	13.45	15.32	22.24
37	5.67	4.72	3.97	2.42	1.23	12.25	12.31	13.66	15.48	22.48
38	5.70	4.75	3.99	2.45	1.52	12.14	13.50	14.28	15.30	22.30
39	5.73	4.77	4.01	2.18	1.61	11.58	12.50	14.67	15.00	22.15
40	5.86	5.22	4.17	2.42	1.72	11.90	12.90	14.21	15.26	22.38

4.3:- Influence of number of cycle, confining pressure & shear strain amplitude on shear modulus and damping ratio

ASTM D3999 indicates that the values determined at 5th cycle are likely to provide reasonable values for all practical purposes [4]. Thus, in this research, the value determined at 5th cycle is considered for analysis purpose. Table 4.6 contains the values of shear modulus and damping ratio of all pits for strain 0.01%, 0.1%, 1%, 2.5% and 5% under axial consolidation pressures of 100kPa, 200kPa, 300kPa and 400kPa.

Table 4.6:- Values of shear modulus and damping ratio at 5th cycle of all pits

Shear strain (%)	0.01	0.1	1	2.5	5	0.01	0.1	1	2.5	5
Axial load	Shear modulus, G (MPa) of pit 1					Damping ratio, D (%) of pit 1				
100KPa	4.38	3.25	2.26	1.19	1.01	16.00	17.08	18.02	19.00	24.00
200KPa	8.03	6.94	4.39	2.59	1.63	18.83	19.54	22.58	23.47	24.36
300KPa	9.56	8.98	6.34	4.03	3.56	10.48	14.30	15.48	17.72	19.42
400KPa	10.70	9.29	7.32	4.48	3.65	10.67	11.69	13.74	14.42	17.54
Axial load	Shear modulus, G (MPa) of pit 2					Damping ratio, D(%) of pit 2				
100KPa	5.32	3.79	2.66	1.87	1.50	12.42	16.59	18.91	20.82	24.47
200KPa	7.59	4.89	2.81	1.76	1.20	9.30	15.54	20.03	23.30	24.00
300KPa	11.53	8.28	6.32	3.73	3.23	8.79	13.40	18.42	22.75	23.04
400KPa	15.09	12.14	7.90	4.80	3.95	6.67	9.53	15.45	17.95	19.86
Axial load	Shear modulus, G (MPa) of pit 3					Damping ratio, D(%) of pit 3				
100KPa	4.51	3.59	2.27	1.44	0.99	14.53	16.00	16.74	18.18	24.14
200KPa	4.86	3.66	3.10	1.77	1.61	14.11	15.26	15.70	17.80	21.53
300KPa	6.81	4.96	4.11	2.11	1.84	10.14	11.29	13.45	15.12	18.49
400KPa	8.23	6.80	4.13	2.96	2.19	12.43	13.35	14.32	15.59	18.66

4.3 Dependency of shear modulus and damping ratio on axial stresses

As mentioned in the previous sections, the confining stress which has a major influence on shear modulus and damping values. In this research, samples were consolidated under an axial stress of 100, 200, 300 and 400kPa in order to evaluate the influence of confining stress. From Fig., 4.5 to 4.10, it can be seen that samples confined to a higher stress have higher shear modulus values. Since, as the confining stress increases the soil particles become closer to each other, resulting in densification of soil sample. Densification causes an increase in density which further results in the increment of shear modulus.

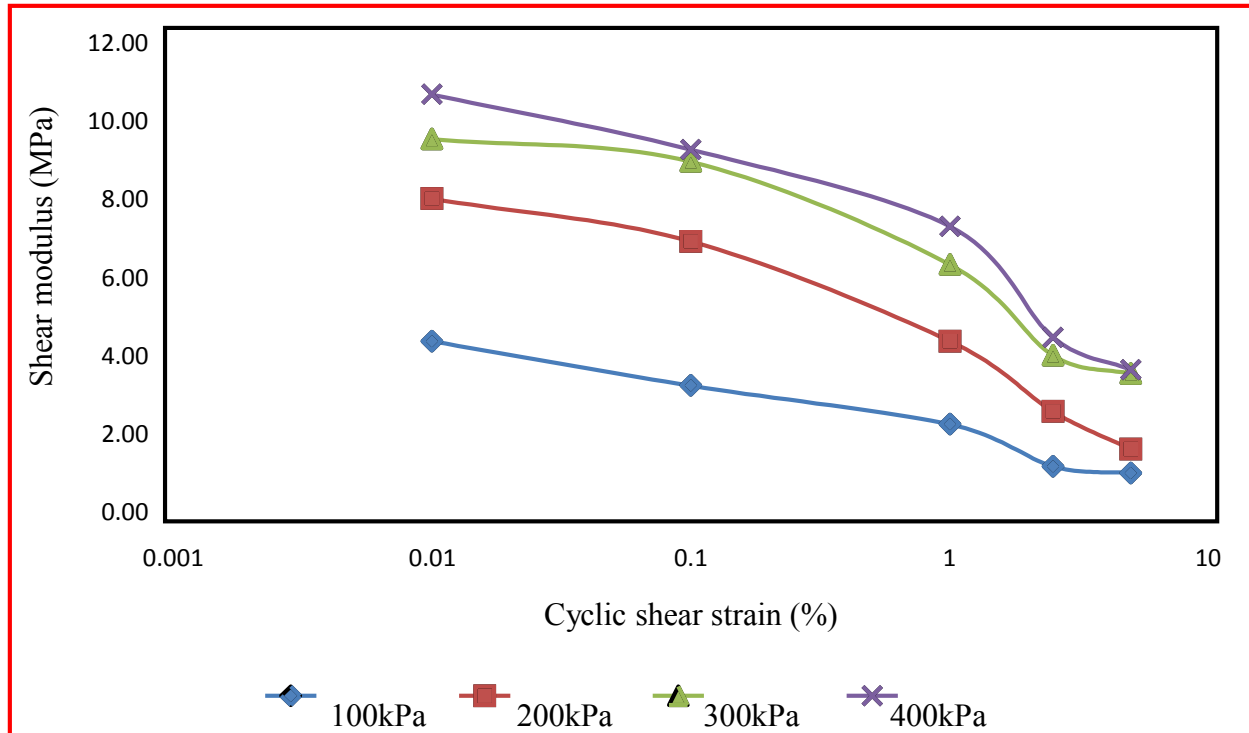


Figure 4-5:- Effect of confining pressure on shear modulus of pit1.

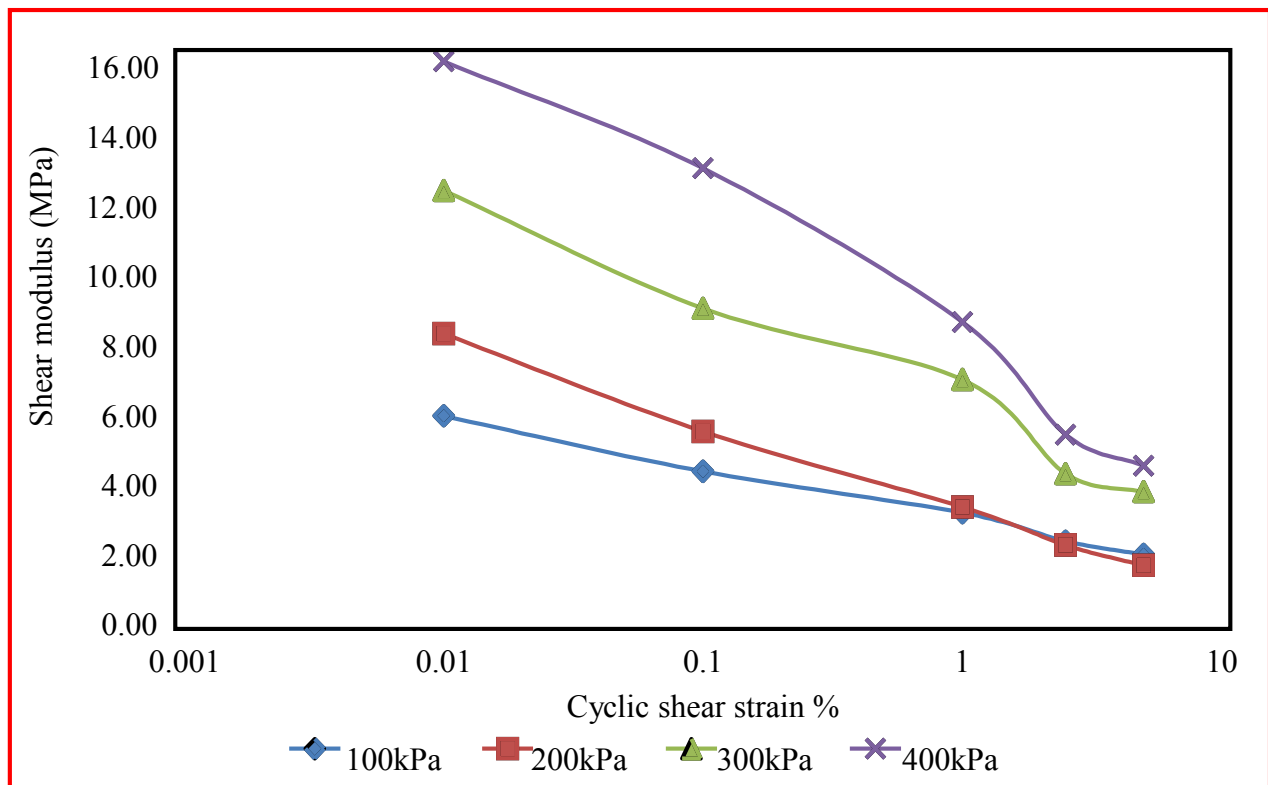


Figure 4-6:- Effect of confining pressure on shear modulus of pit2.

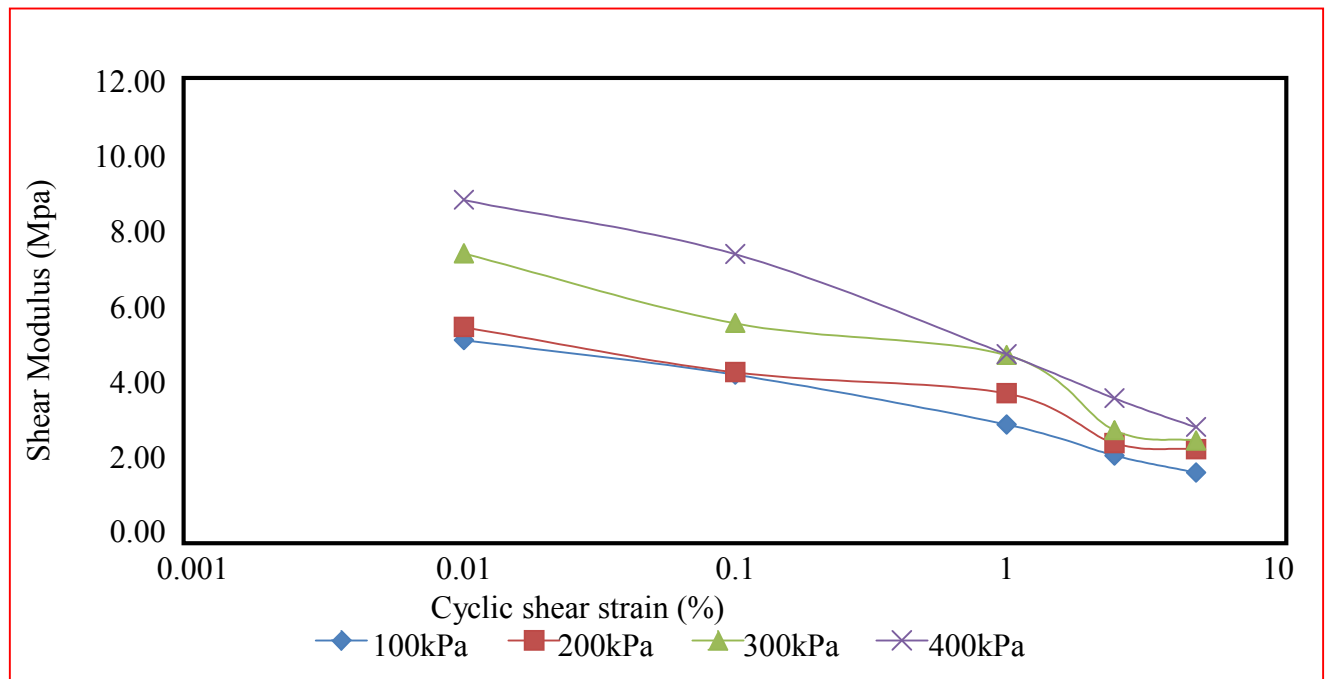


Figure 4-7:- Effect of confining pressure on shear modulus of pit 3

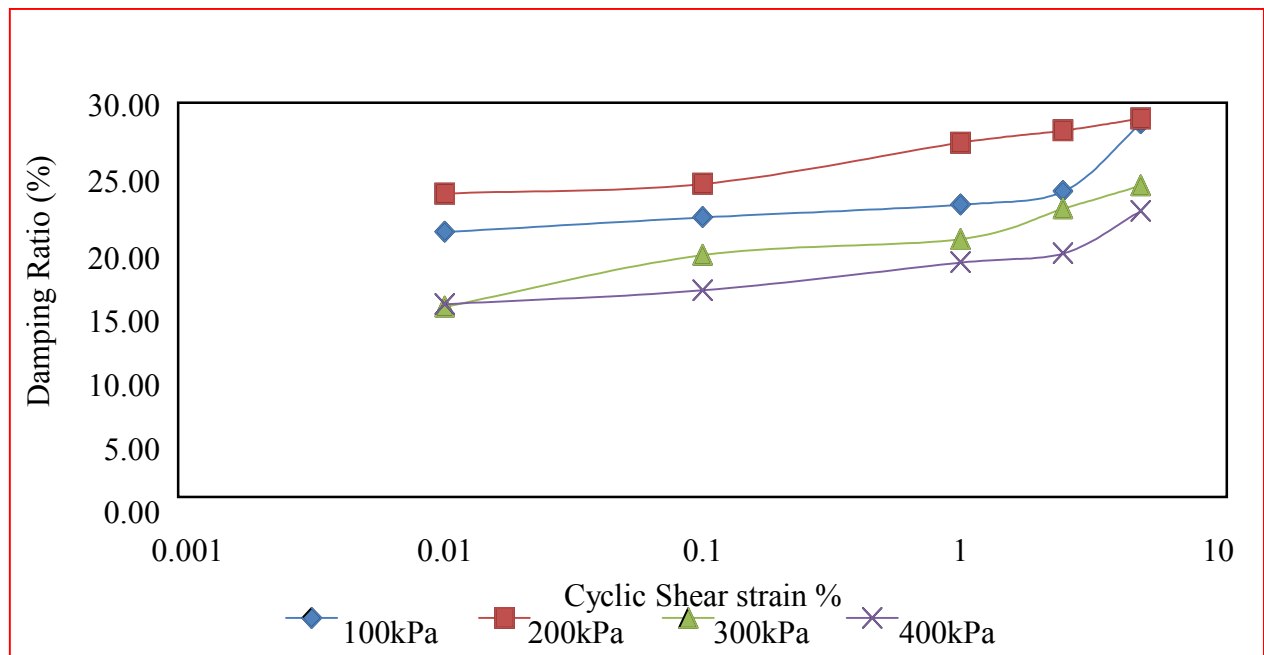


Figure 4-8:- Effect of confining pressure on damping ratio of pit1.

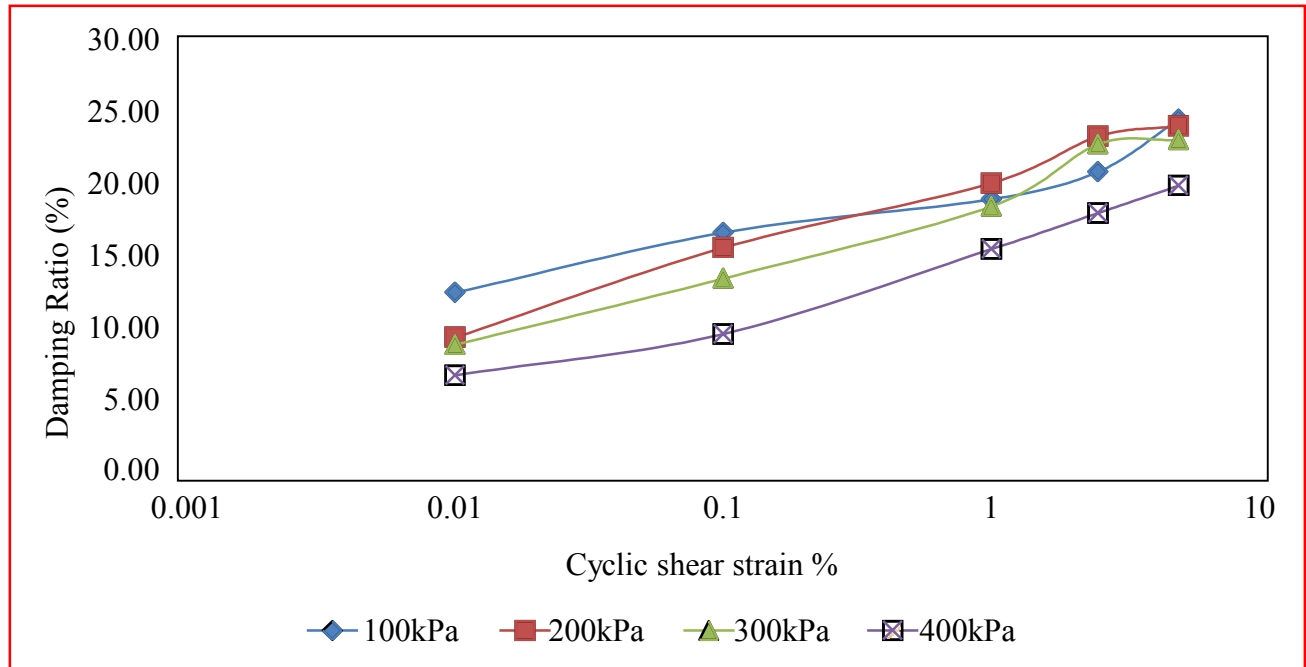


Figure 4-9:- Effect of confining pressure on damping ratio of pit2.

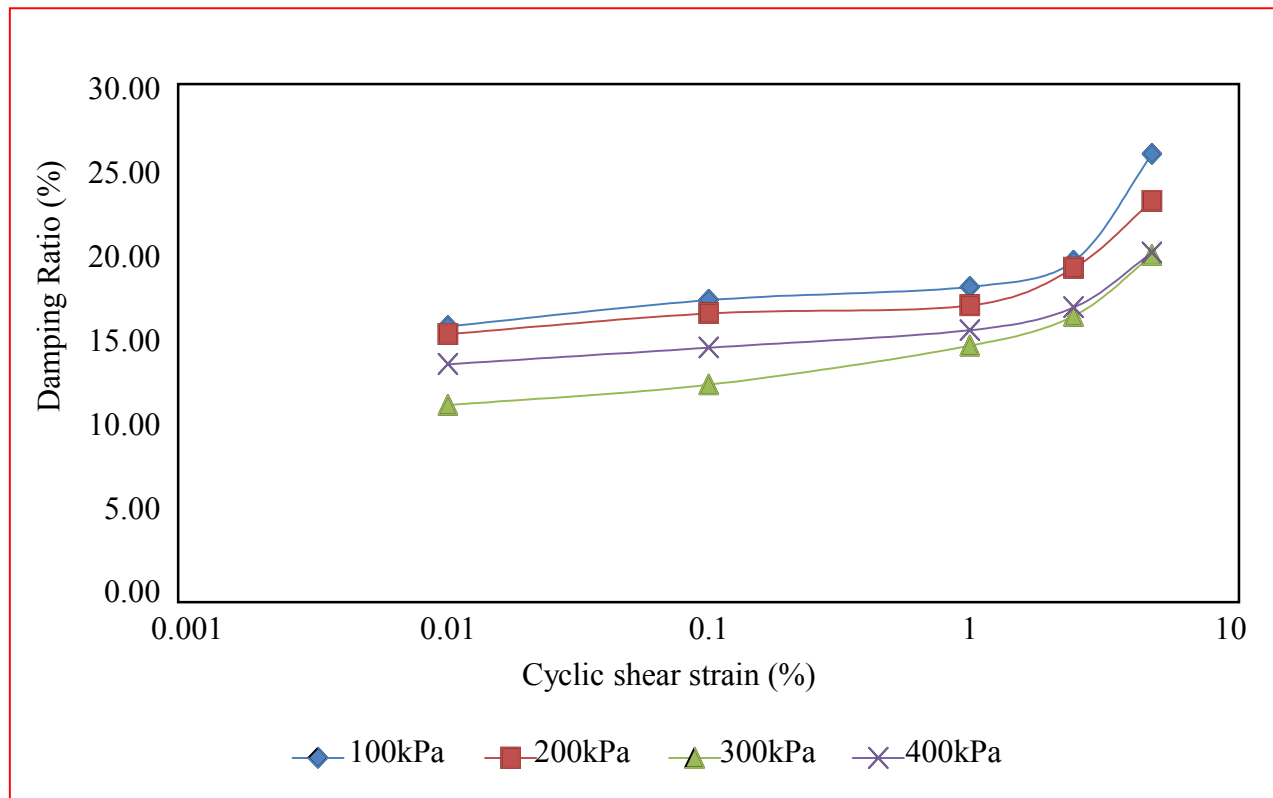


Figure 4-10:- Effect of confining pressure on damping ratio of pit3.

4.4:- Dependency of shear modulus and damping ratio on number of cycle

The effect of number of cycles with increase axial loads shows, slight difference on the shear modulus and damping ratio values. Figure 4.11 to 4.15; indicate the variation of the values of Shear modulus and damping ratio with the number of cycles.

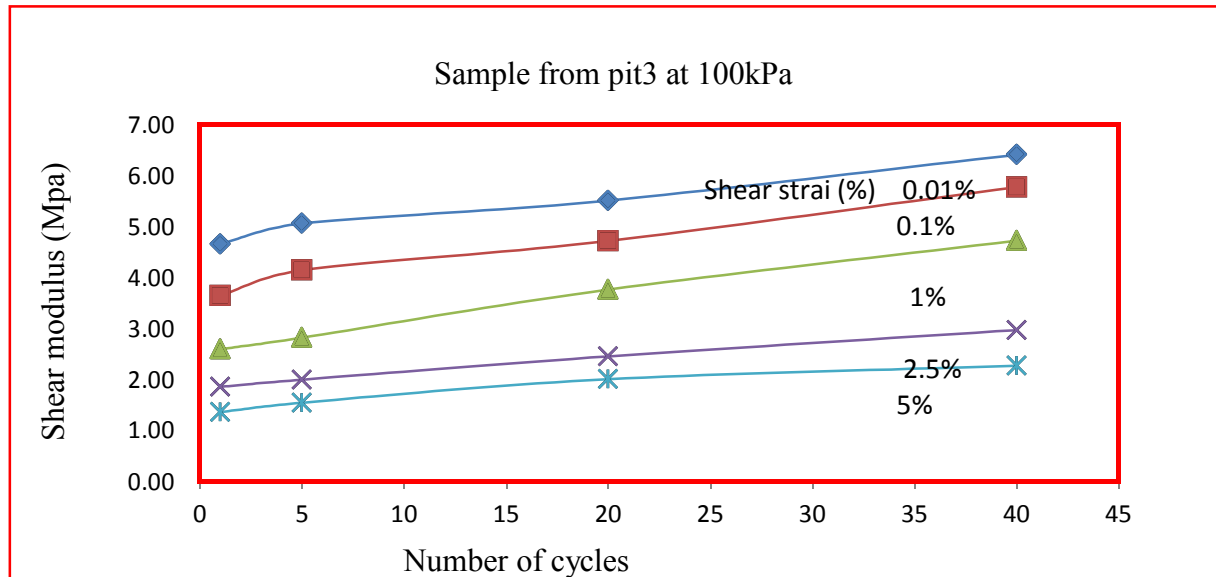


Figure 4-11:- Effect of number of cycle on shear modulus of pit3 at 100kPa.

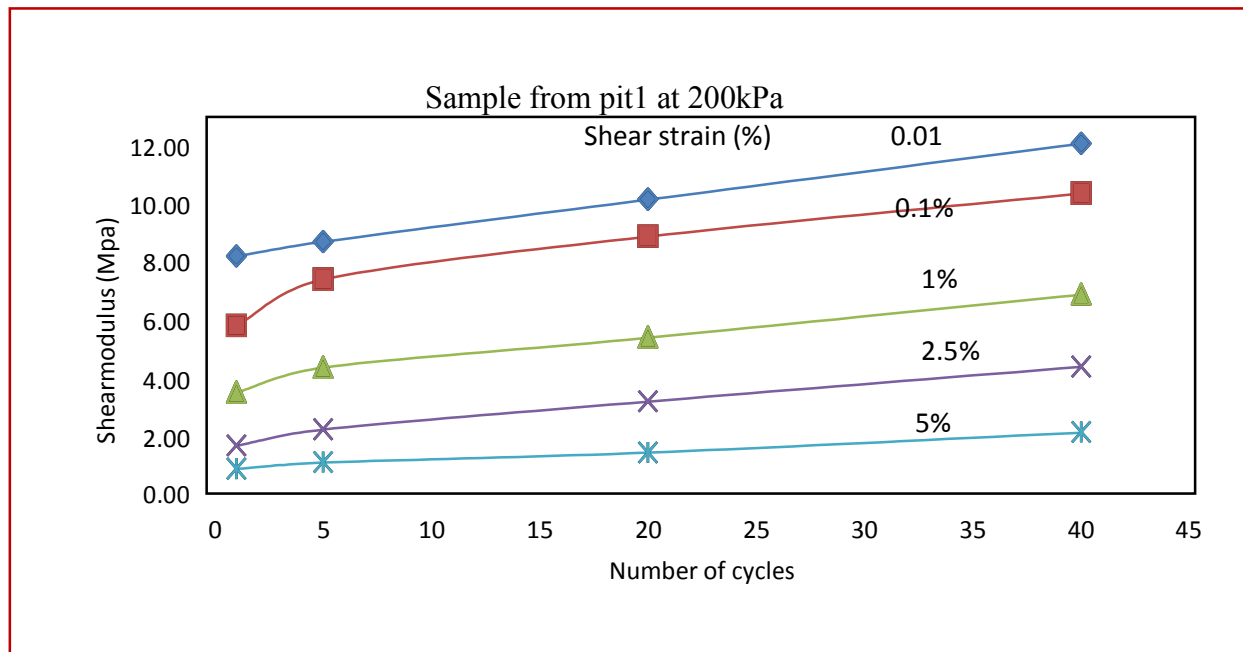


Figure 4-12:- Effect of number of cycle on shear modulus of pit1 at 200kPa.

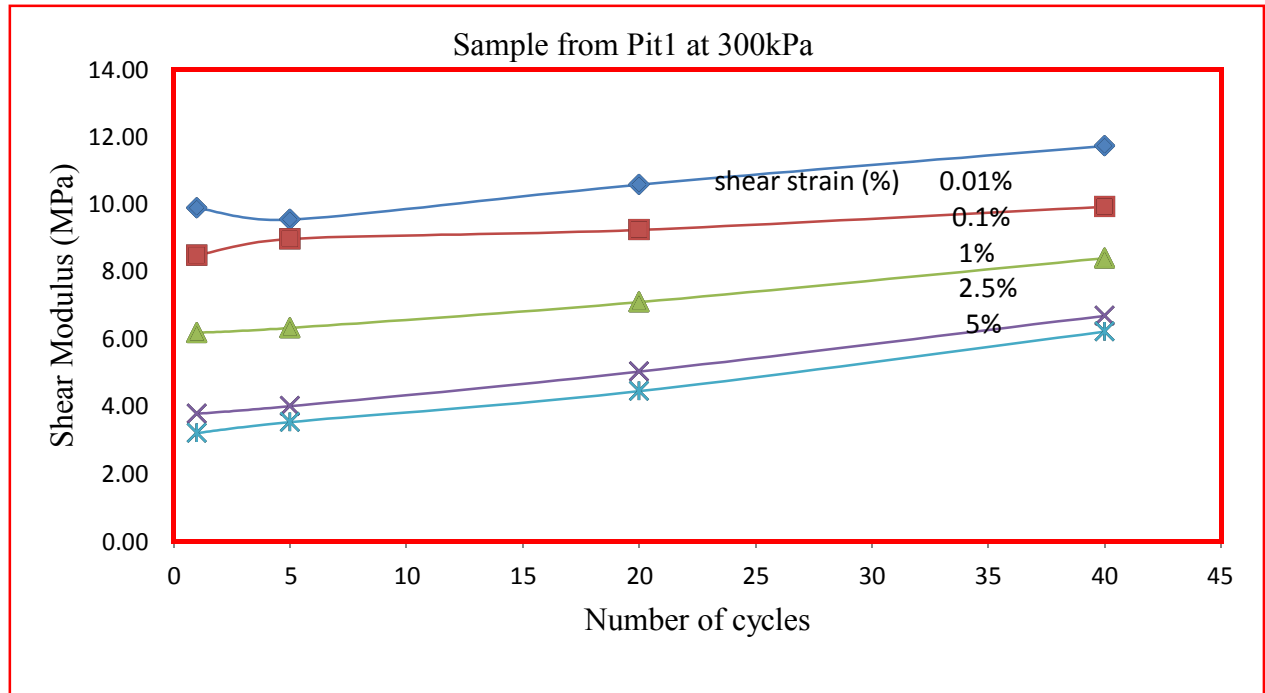


Figure 4-12:- Effect of number of cycle on shear modulus of pit1 at 300kPa.

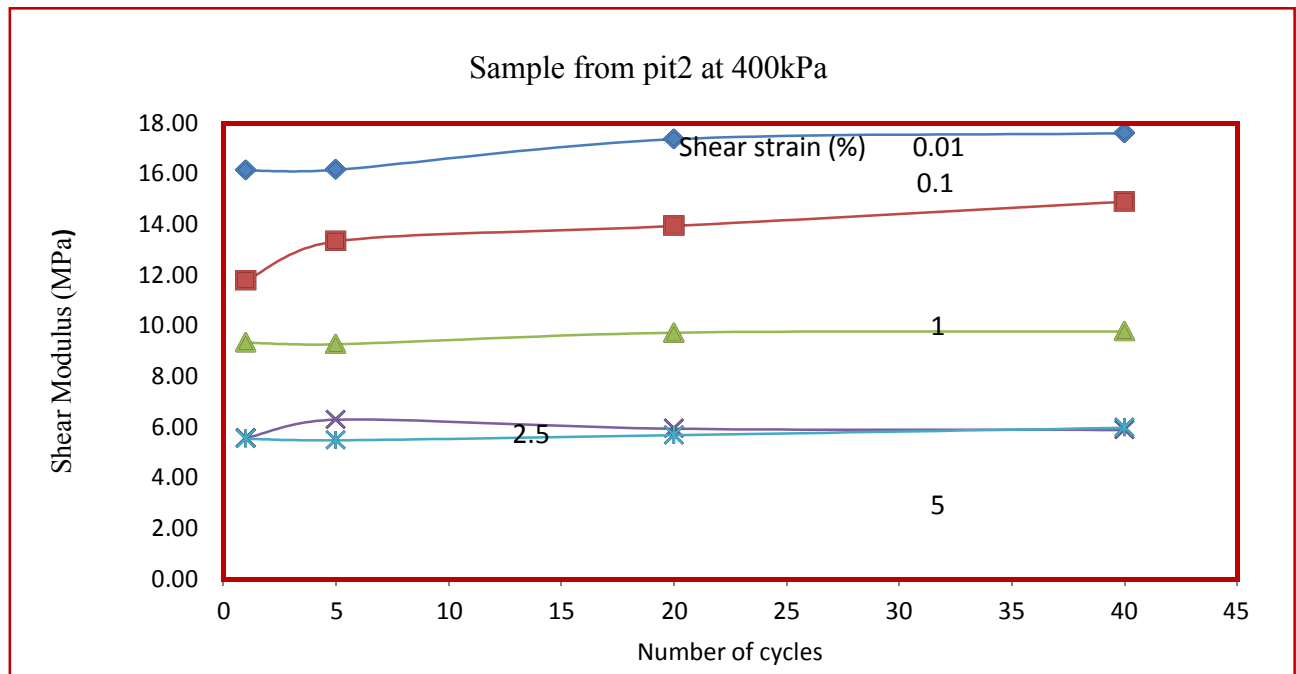


Figure 4-13:- Effect of number of cycle on shear modulus of pit 2 at 400kPa.

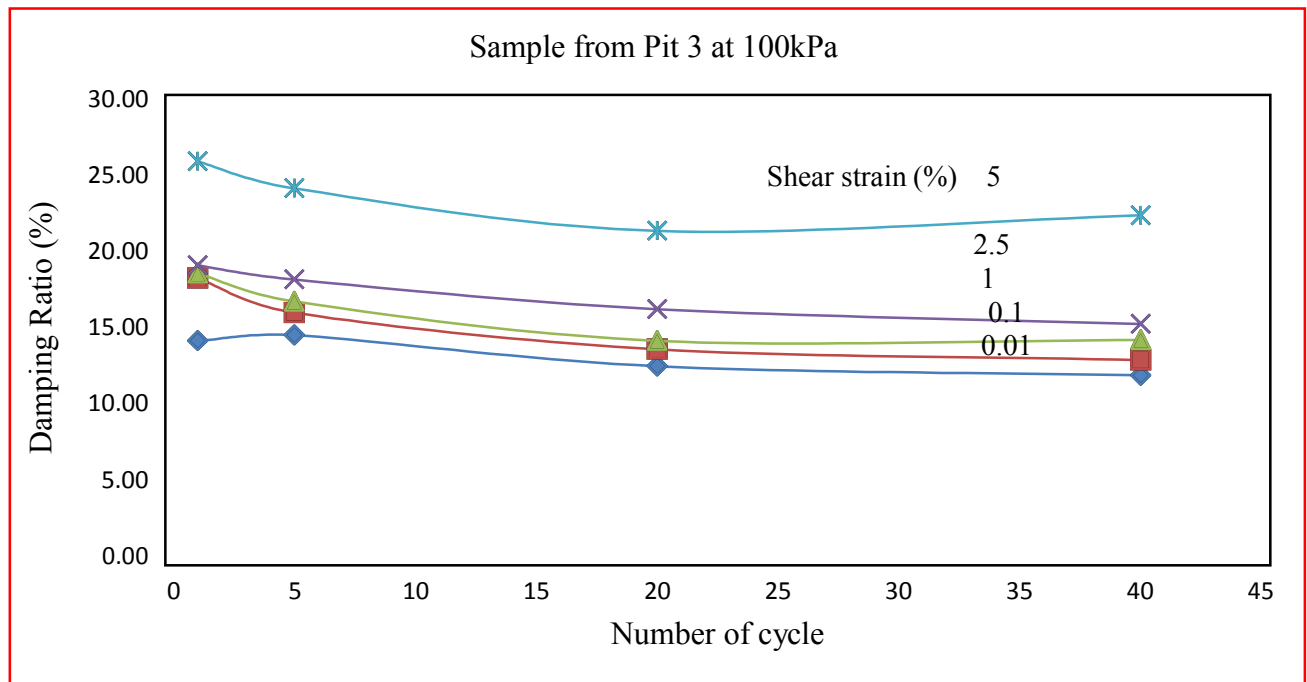


Figure 4-14:- Effect of number of cycle on damping ratio of pit 3 at 100kPa.

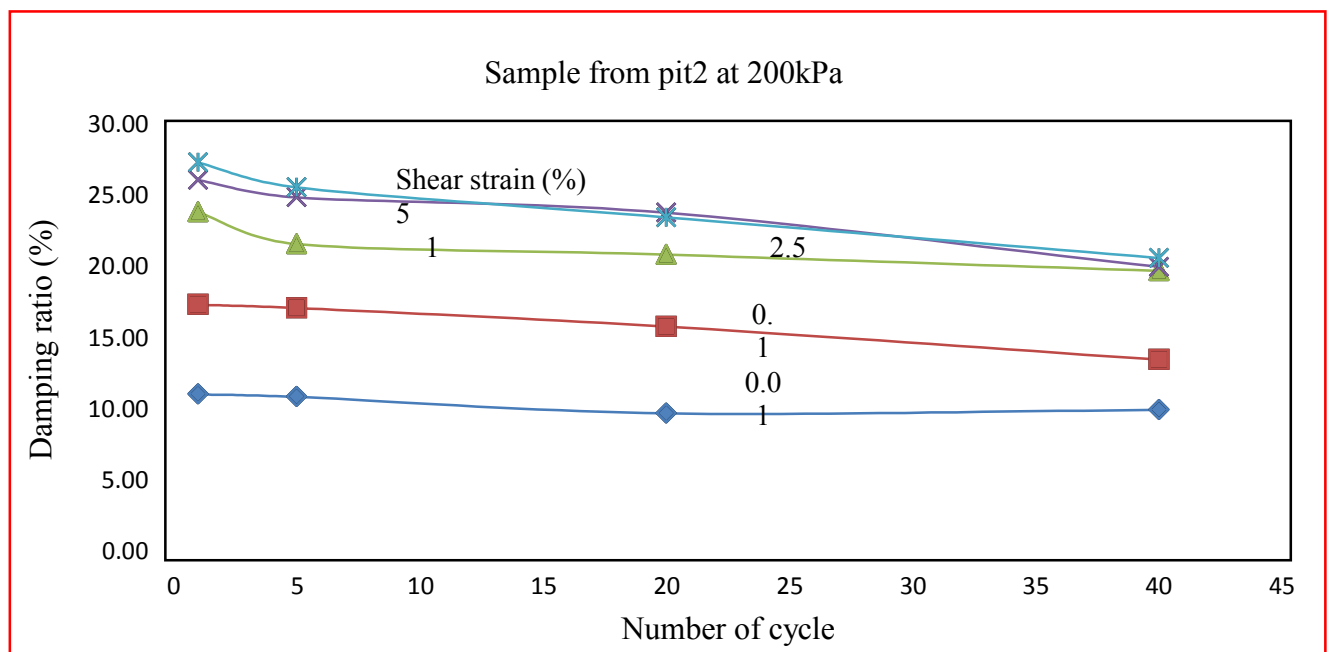


Figure 4-15:- Effect of number of cycle on damping ratio of pit 2 at 200kPa

4.5:- Dependency of shear modulus on shear strain amplitude

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 4.16 to 4.18, shows the variation of shear modulus and damping ratio with shear strain.

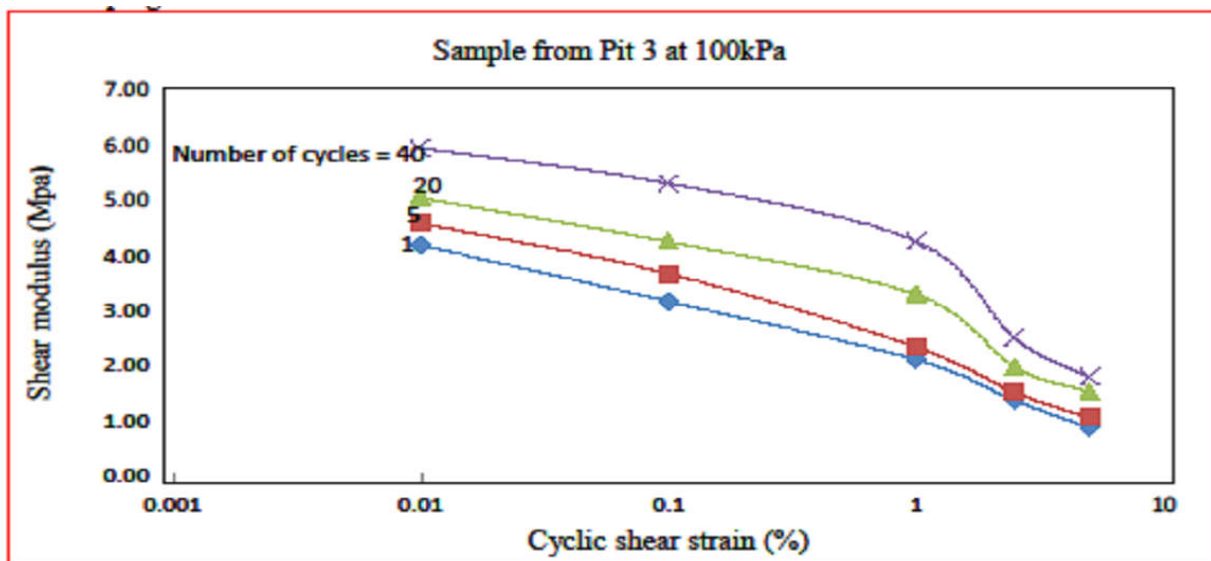


Figure 4-16:- Effect of number of shear strain on shear modulus of pit3 at 100kPa

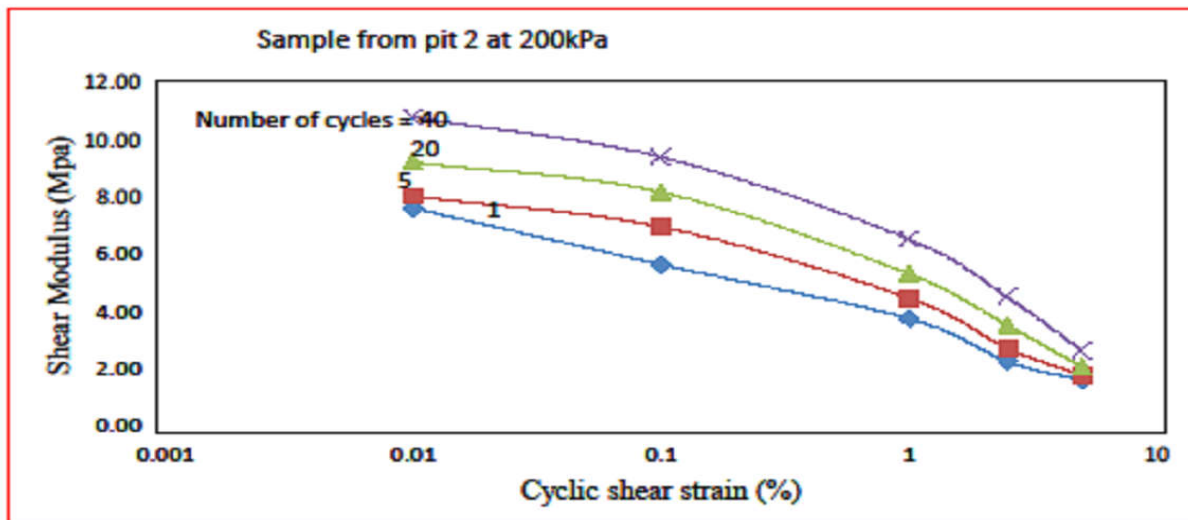


Figure 4-17:- Effect of number of shear strain on shear modulus of pit 2 at 200kPa

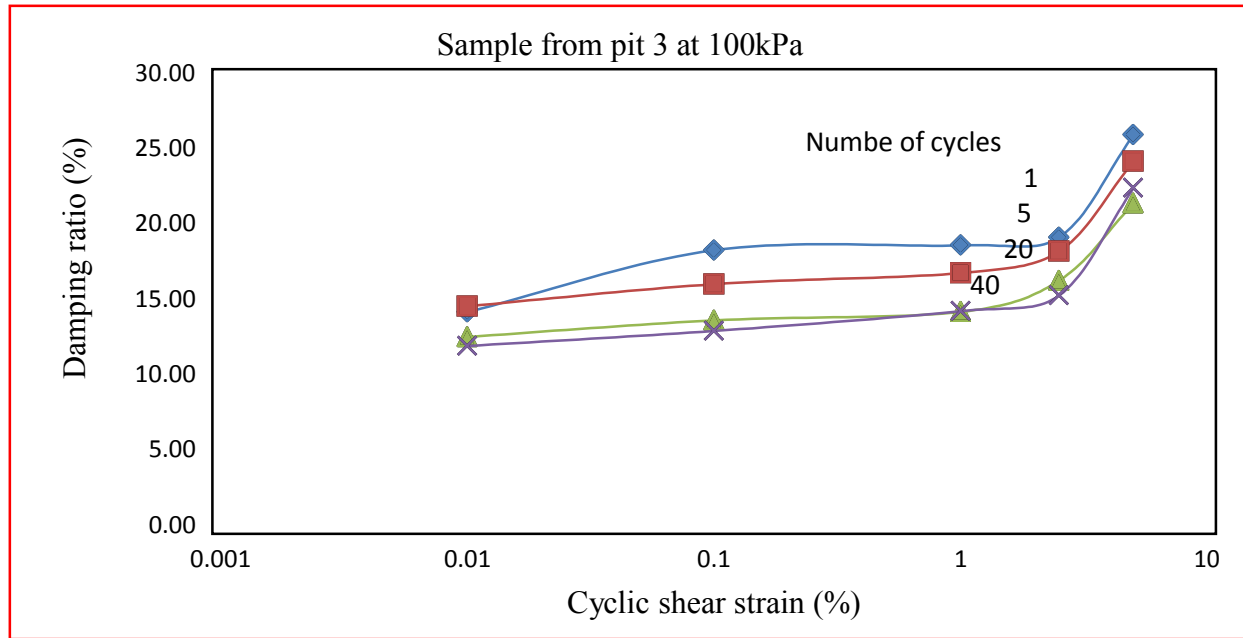


Figure 4-18:- Effect of number of shear strain on damping ratio of pit3 at 100kPa

4.6 Variation of shear modulus with of soil plasticity

Plasticity has effects on both the shear modulus and damping ratio of soil. As shown in the Fig.4.19, the normalized shear modulus increase as the soil plasticity increase with same axial stress.

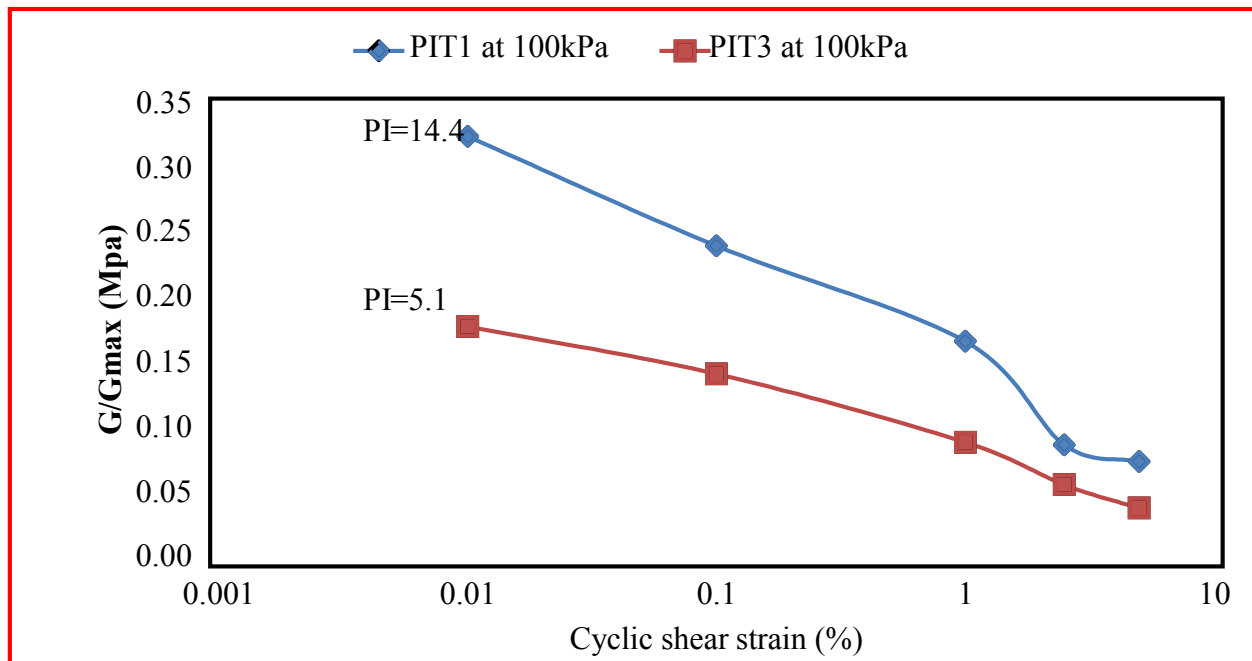


Figure 4-19: Variation of normalized shear modulus of Bishoftu soil with soil plasticit

4.7 Variation of shear modulus and damping ratio with void ratio

Void ratio is one of the mechanical properties of soil, which is mainly influenced by the static or dynamic actions of loading. As the void ratio increases the area of contact between soil particles decreases. This decrement of area of contact leads to decreases the shear modulus. The variation of initial shear modulus with void ratio was observed by plotting Bishoftu soil results as shown in the figure 4.20. As the void ratio increase, the initial shear modulus decreases and has no significant influence on damping ratio at any shearing strain amplitude under all confining pressures. Figure 5.21 and 5.22; show the influence of void ratio on the shear modulus.

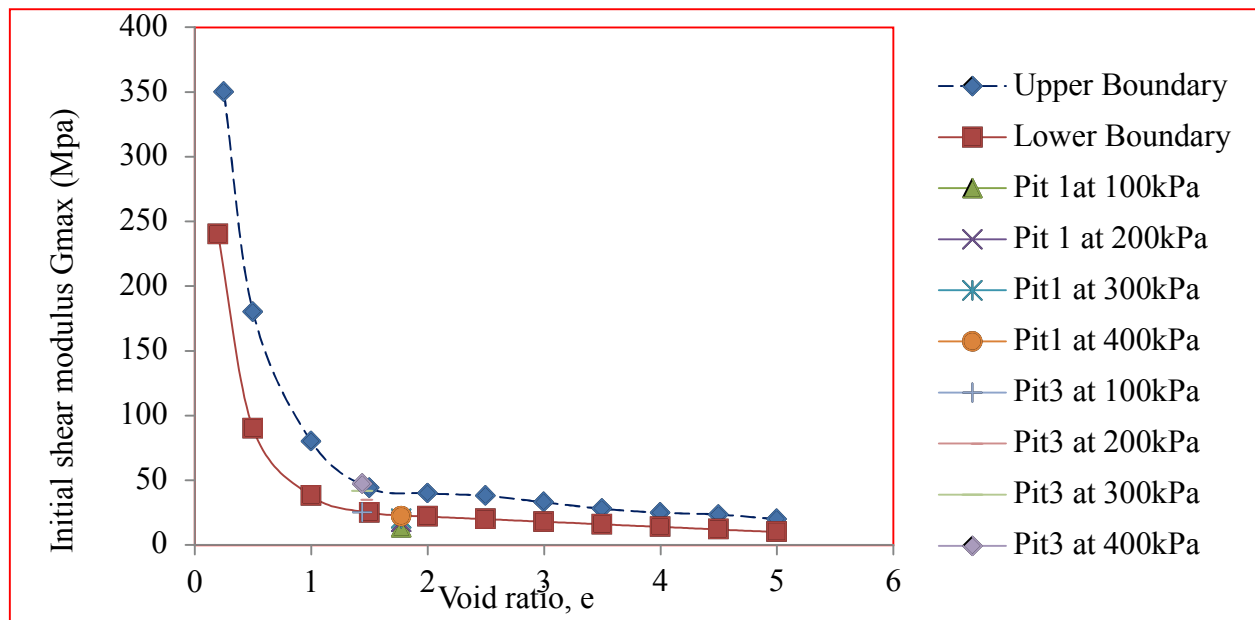


Figure 4-20:- Variation of initial shear modulus of Bishoftu soil with void ratio

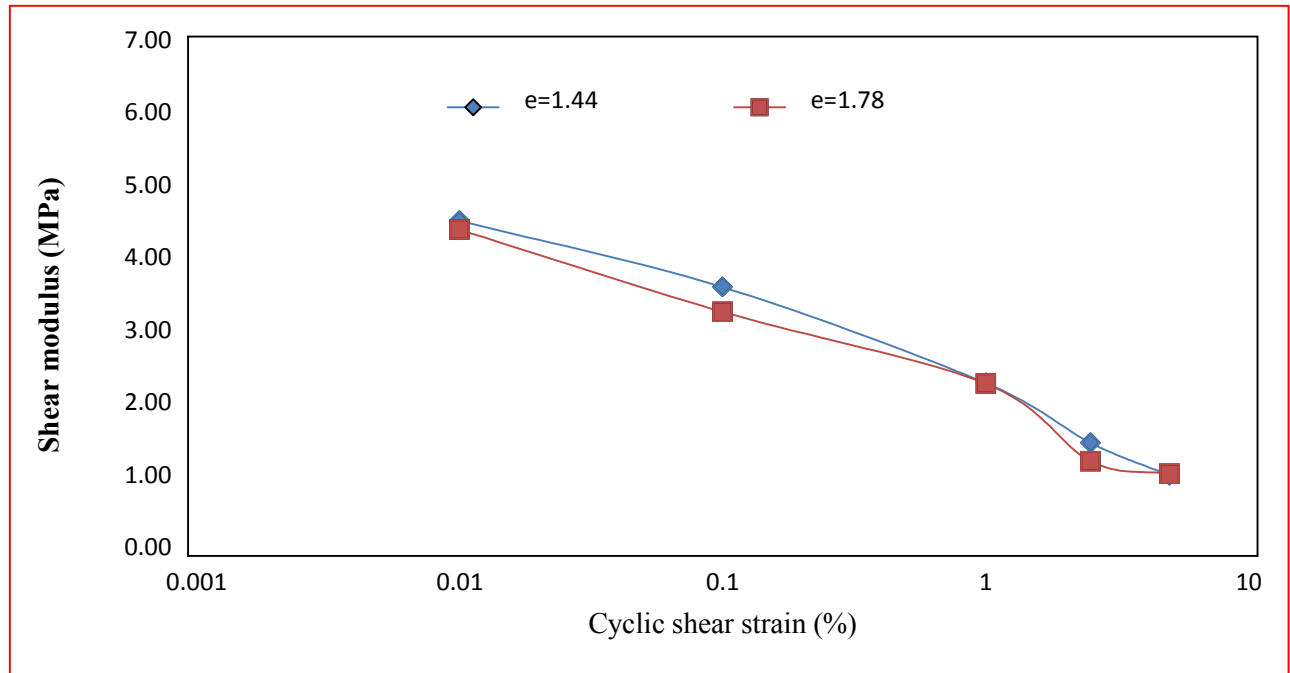


Figure 4-21:- Influence of void ratio on shear modulus versus cyclic shear strain, under an axial-stress of 100kPa.

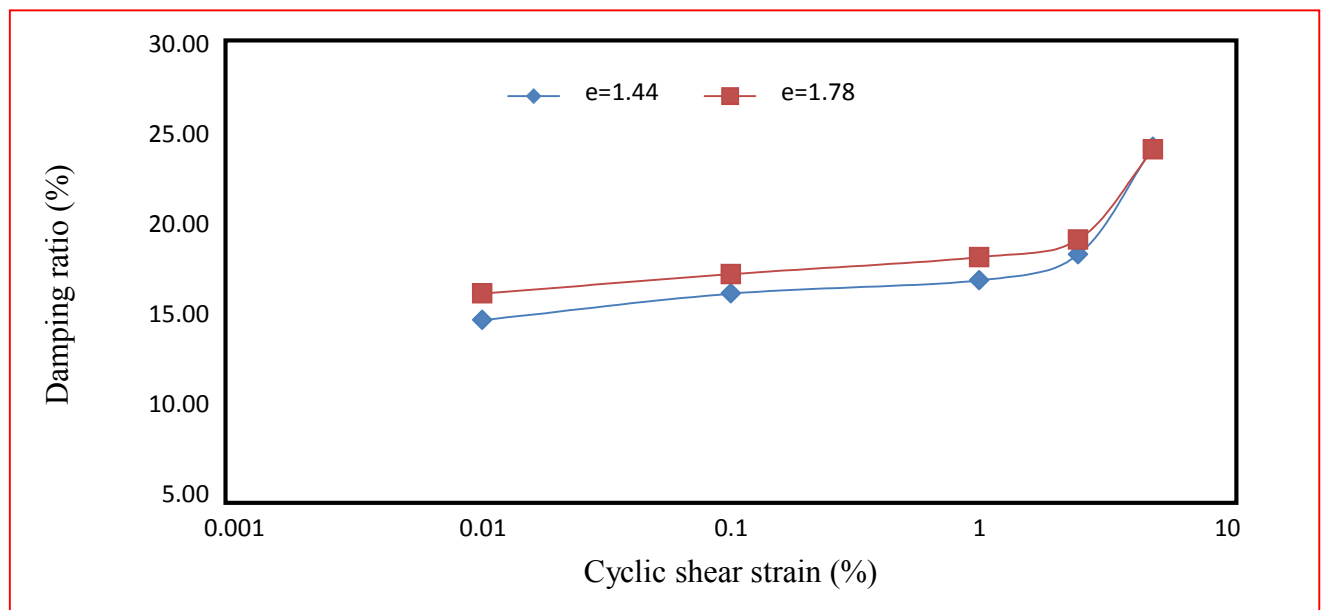


Figure 4-22:- Influence of void ratio on damping ratio versus cyclic shear strain under an axial stress of 100kPa.

CHAPTER FIVE

5. COMPARISON OF TEST RESULTS WITH LITERATURES

5.1 INTRODUCTION

The small strain shear modulus, $G_{\max}$, describes a 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 ratio values at low strain levels. So, the maximum shear modulus, $G_{\max}$, which corresponds to very low shear strain levels, can not be determined from such tests. For the sake of comparison the maximum shear modulus, $G_{\max}$, of each specimen is determined using Eq. 5.1 written below, and the calculated maximum shear modulus, $G_{\max}$, is used to obtain normalized shear modulus, which is then compared with those obtained from literature.

$$G_{\max} = 3.23 * \frac{((2.973 - e)^2)}{1 + e} * OCR^K * (\sigma_o')^{0.5} \text{ ----- 5.1}$$

$$\sigma_o' = \frac{(\sigma_v' + 2K_o \sigma_v')}{3} \text{ ----- 5.2}$$

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

From table 2.3, for cohesion less soils $K=0.43$ to 0.67 , with a value of 0.5 often used. Although Eq.5.1 is 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). For example, for the specimen mentioned in section 4.4, a specimen having a PI of 14.4 , from table 2-3, by interpolation $K=0.01296$ and the value of void ratio at the natural state of the soil is 1.78 . And also from consolidation test result the value of pre-consolidation pressure, $PC=100\text{kPa}$. (see Appendix H.)

$$\sigma_0' = \frac{(100 + 2 * 0.5 + 100)}{3} = 66.67\text{kPa}$$

$$G_{\max} = 3.23 * \frac{((2.973 - e)^2)}{1 + e} * OCR^K * (\sigma_0')^{0.5}$$

$$G_{\max} = 3.23 * \frac{((2.973 - 1.78)^2)}{1 + 1.78} * OCR^{0.01296} * (\sigma_0')^{0.5} \text{ ----- 5.3}$$

Thus, $G_{\max} = 13,470.30\text{kPa}$ For this specimen the fifth cycle cyclic shear modulus is $1,012.18\text{kPa}$

$$\text{So, } G/G_{\max} = \frac{1012.18\text{KPa}}{13470.30\text{KPa}} = 0.08\text{kPa}.$$

Table 5-1:- Maximum shear modulus and normalized shear modulus values

Confining Pressure	Shear Strain (%)	Pit 3			Pit 1		
		$G_{\max}$ (MPa)	$G/G_{\max}$	D (%)	$G_{\max}$ (MPa)	$G/G_{\max}$	D (%)
100kPa	0.01	25.16	0.18	14.53	13.47	0.33	16.00
	0.1		0.14	16.00		0.24	17.08
	1		0.09	16.74		0.17	18.02
	2.5		0.06	18.18		0.09	19.00
	5		0.04	24.14		0.08	24.00
200kPa	0.01	34.46	0.14	14.11	17.41	0.46	18.83
	0.1		0.11	15.26		0.40	19.54
	1		0.09	15.70		0.25	22.58
	2.5		0.05	17.80		0.15	23.47
	5		0.05	21.53		0.09	24.36
300kPa	0.01	41.43	0.16	10.14	20.23	0.47	10.48
	0.1		0.12	11.29		0.44	14.30
	1		0.10	13.45		0.31	15.48
	2.5		0.05	15.12		0.20	17.72
	5		0.04	18.49		0.18	19.42
400kPa	0.01	47.21	0.17	12.43	22.51	0.48	10.67
	0.1		0.14	13.35		0.41	11.69
	1		0.09	14.32		0.33	13.74
	2.5		0.06	15.59		0.20	14.42
	5		0.05	18.66		0.16	17.54

Previously, some researchers developed different modulus reduction and damping ratio for different soil types. Modulus reduction and damping ratio curves of sand and saturated clay developed by Seed and Idriss (1970), modulus reduction and damping ratio curves of different PI soil developed by Vucetic and Dobry (1991) and normalized shear modulus and damping ratio curves of Adama silt soil developed by Abu Gemech (2011), Ziway silt soil developed by Abraham Mengistu (2015) and Modjo silt soil developed by Yohannes Hailemariam (2015). Once the values of $G_{\max}$ are calculated, one can calculate $(G/G_{\max})$. Depending on the values of $(G/G_{\max})$ and shear strain amplitude, one can draw normalized shear modulus reduction curves to indicate the influence of confining pressure and types of soils (Plasticity index).

Figure 5.1 to 5.6, shows that the influence of normalized shear modulus VS cyclic shear strains at different axial consolidation pressure.

The computed normalized shear modulus, ($G/G_{\max}$), and damping ratio values from table 5.1 are plotted against shear strain on the curves developed by Seed H.B and Idriss [3]. Figure 5.7 to 5.10, shows comparison of normalized shear modulus values of Bishoftu silt soil with the curves developed by Seed and Idriss [3].

The computed normalized shear modulus, ($G/G_{\max}$), and damping ratio values of Bishoftu silt soil are also plotted against shear strain for local silt soils. Figure 5.11 to 5.14, shows comparison of normalized shear modulus values of Bishoftu silt soil with the along result from Abu, Abraham & Yohannes. (2015). [5], [30] & [31]

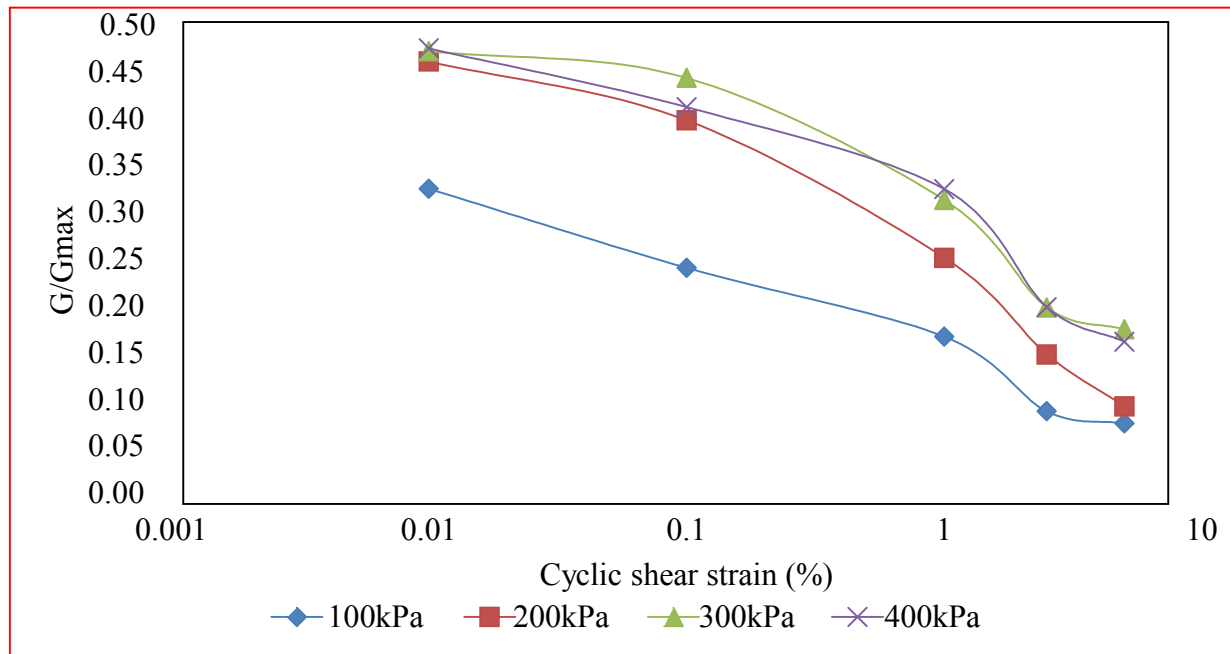


Figure 5.1:- $G/G_{\max}$ Vs shear strain amplitude at different axial consolidation pressure of pit1

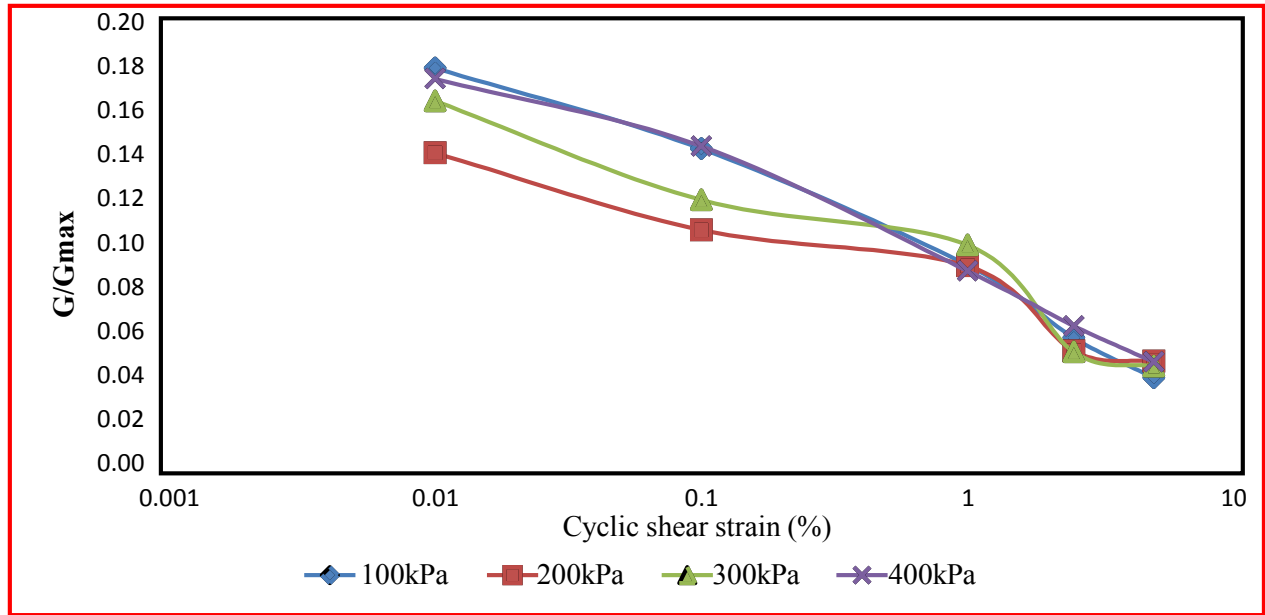


Figure 5.2:- $G/G_{\max}$ V_s : shear strain amplitude at different axial consolidation pressure of pit3

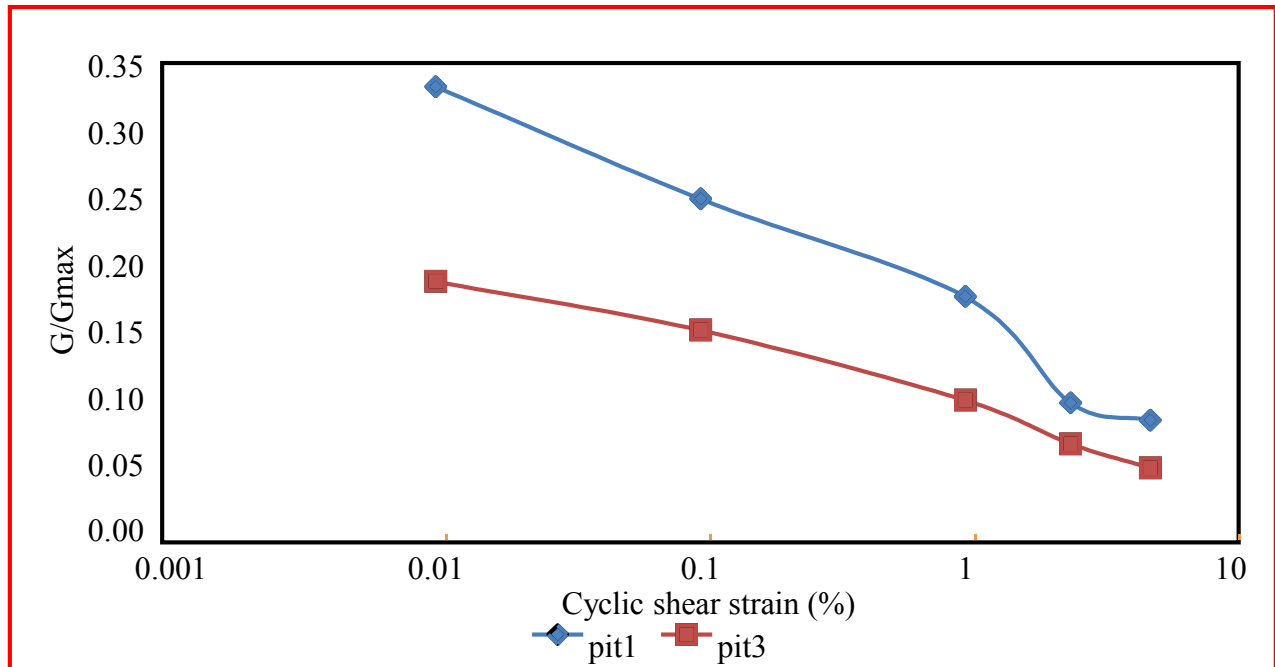


Figure 5-3:- $G/G_{\max}$ V_s shear strain amplitude of pit 1&3 at 100kPa

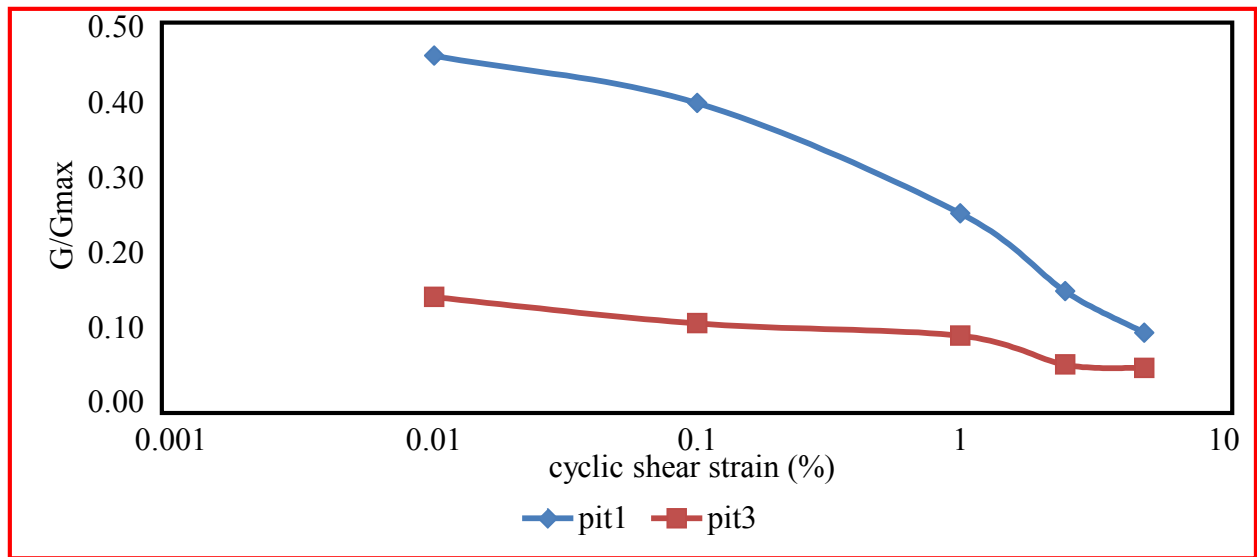


Figure 5-4:- G/G_{max} V_s shear strain amplitude of pit 1&3 at 200kPa

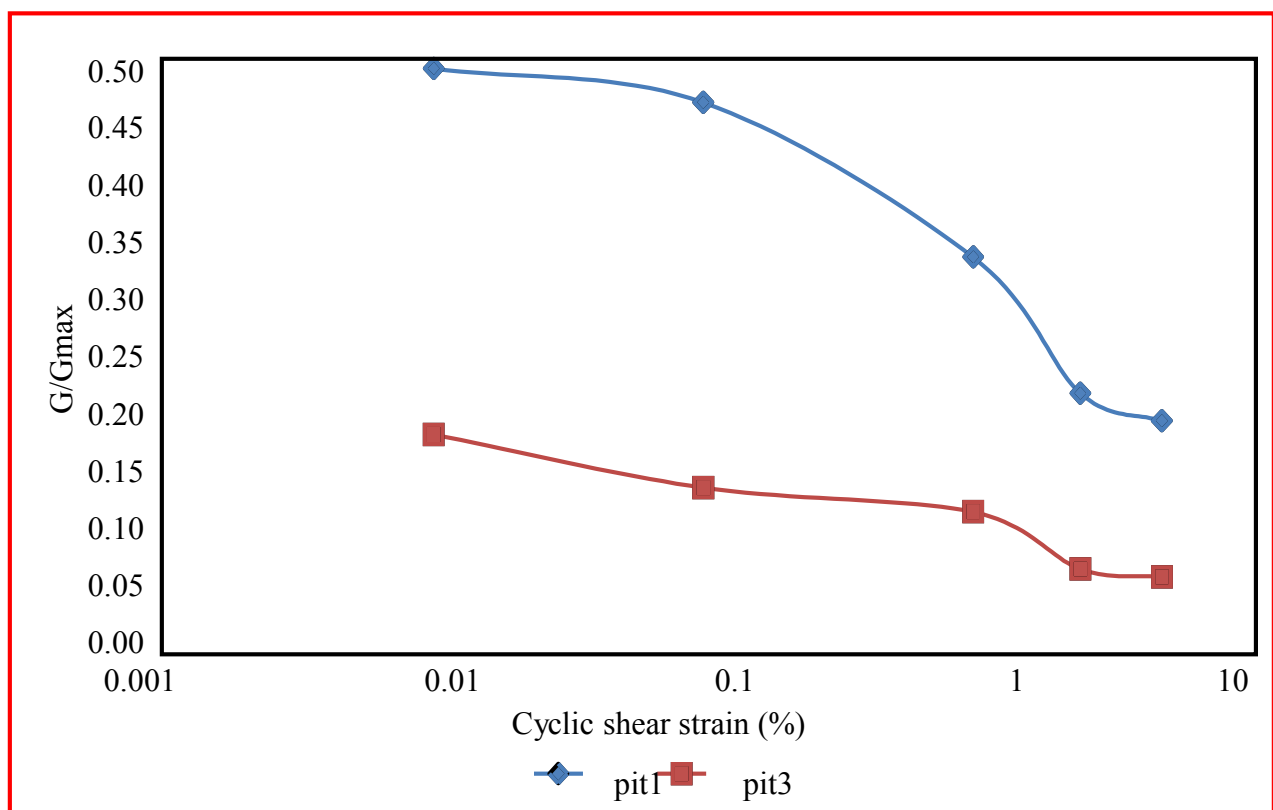


Figure 5-5:- G/G_{max} V_s shear strain amplitude of pit 1&3 at 300kPa

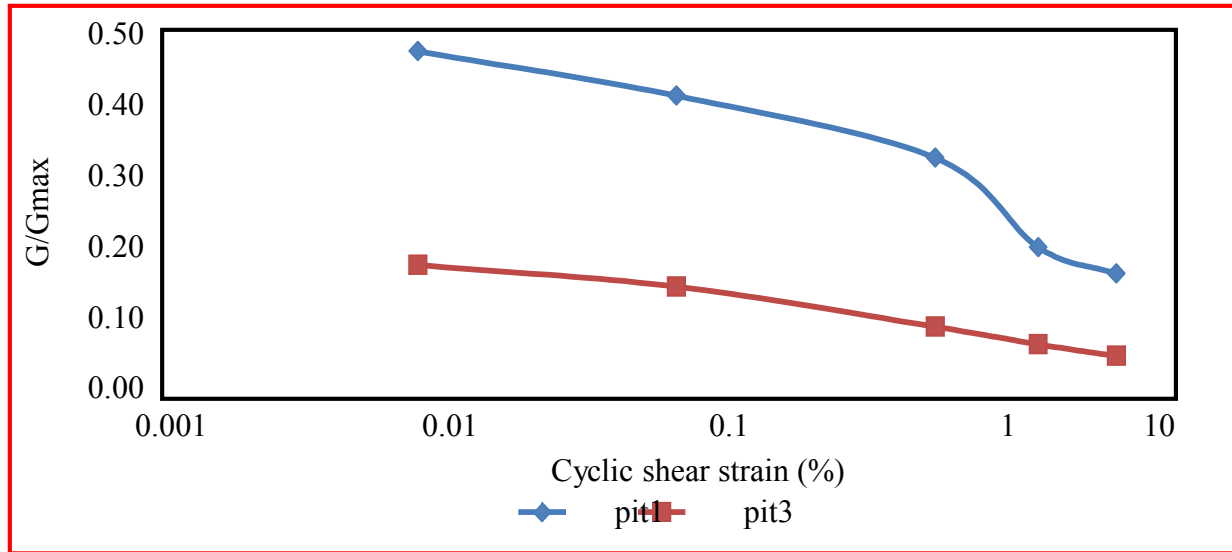


Figure 5.6:- G/G_{max} V_s shear strain amplitude of pit 1&3 at 400kPa

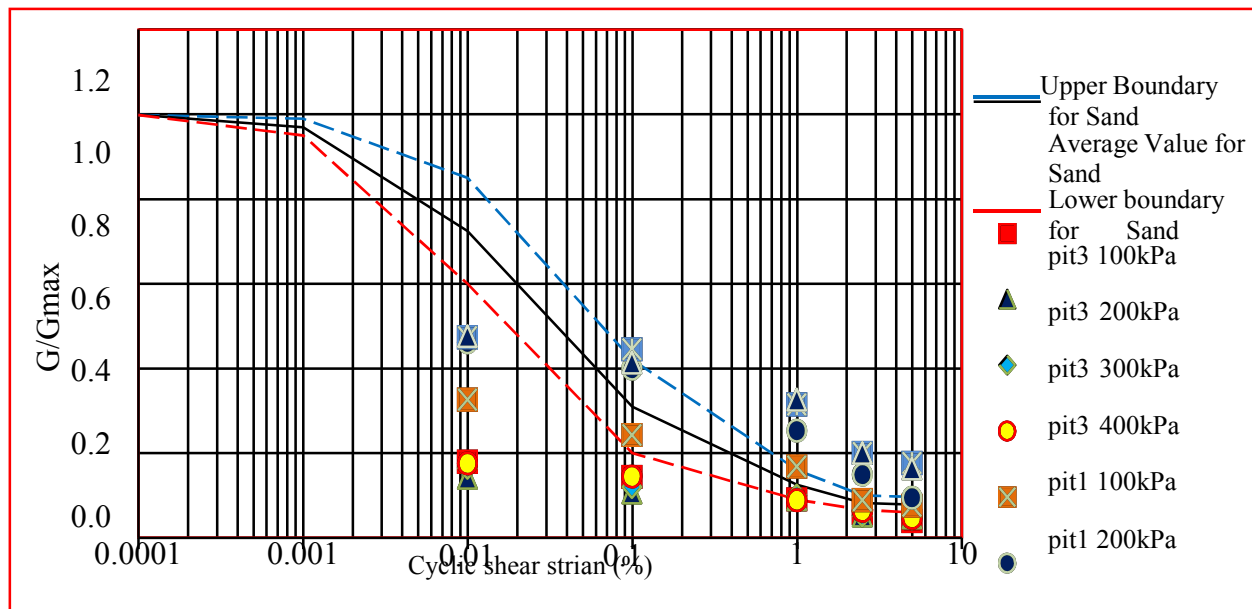


Figure 5-7:- Comparison of normalized shear modulus values of Bishoftu silt soil with the curves developed for sand by Seed and Idriss [3].

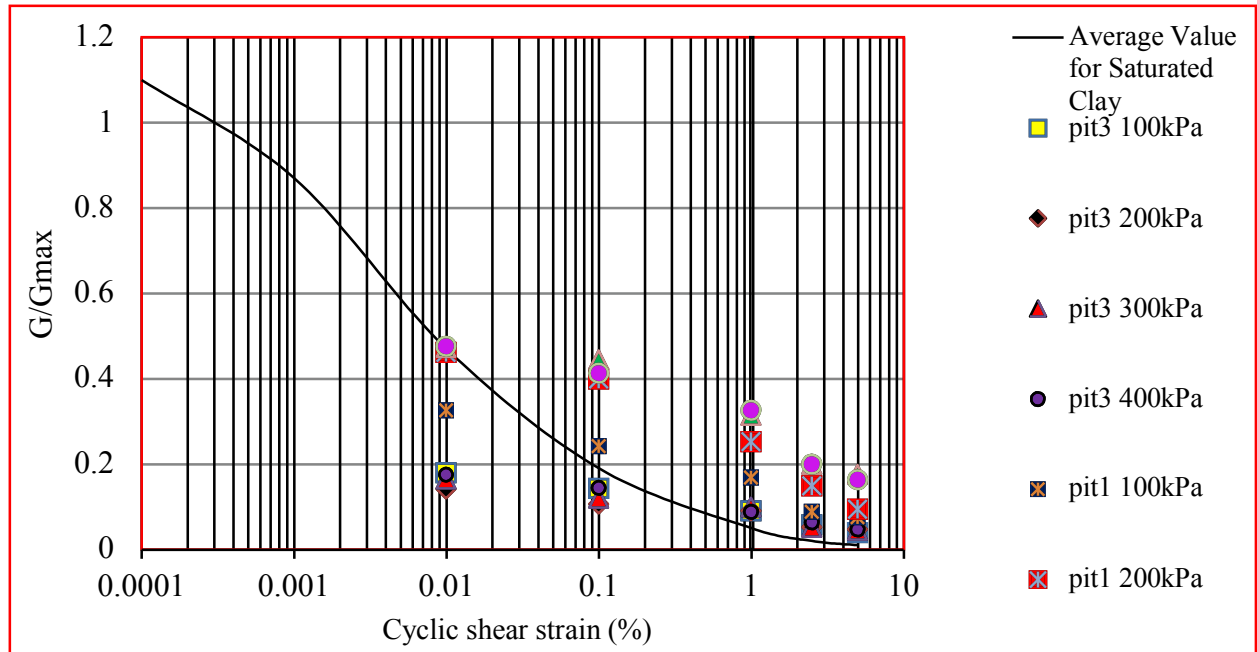


Figure 5-8:- Comparison of normalized shear modulus values of Bishoftu silt soil with the curve developed for saturated clay by Seed and Idriss [3].

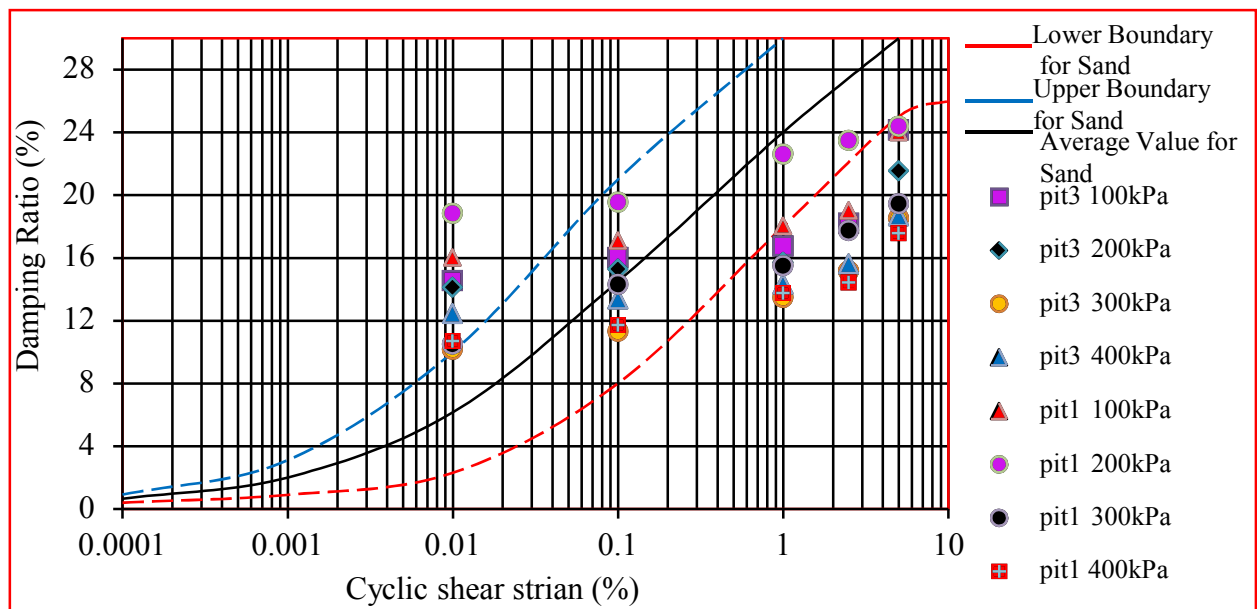


Figure 5-9:- Comparison of damping values of Bishoftu silt soil with the curve developed for sand by Seed and Idriss [3].

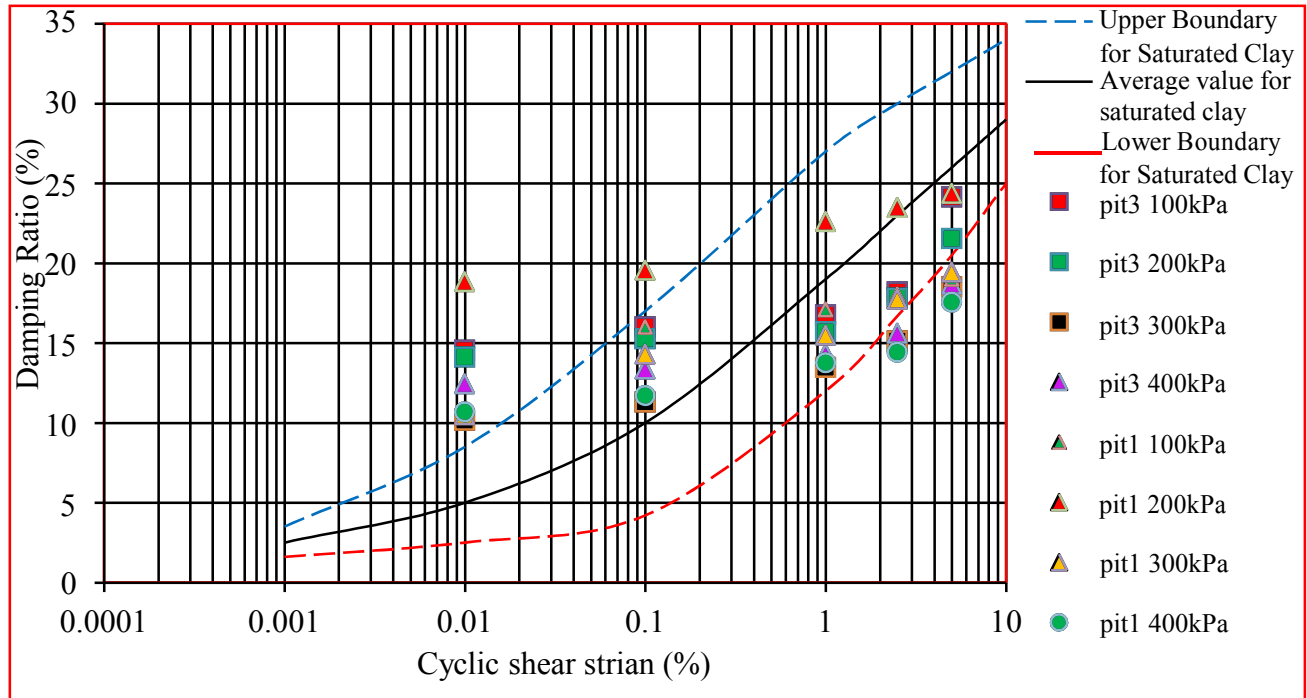


Figure 5-10:- Comparison of damping values of Bishoftu silt soil with the curves developed for saturated clay by Seed and Idriss [3].

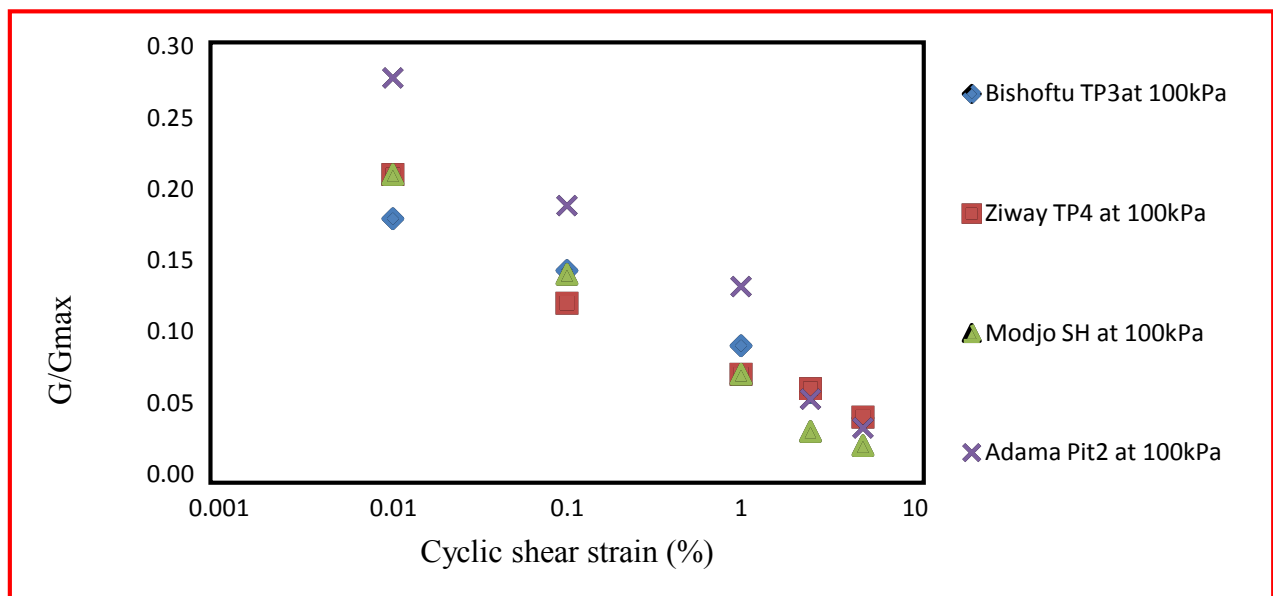


Figure 5-11:- Comparison of Normalized shear modulus values of Bishoftu silt soil with silt soil curves [5],[30],[31].

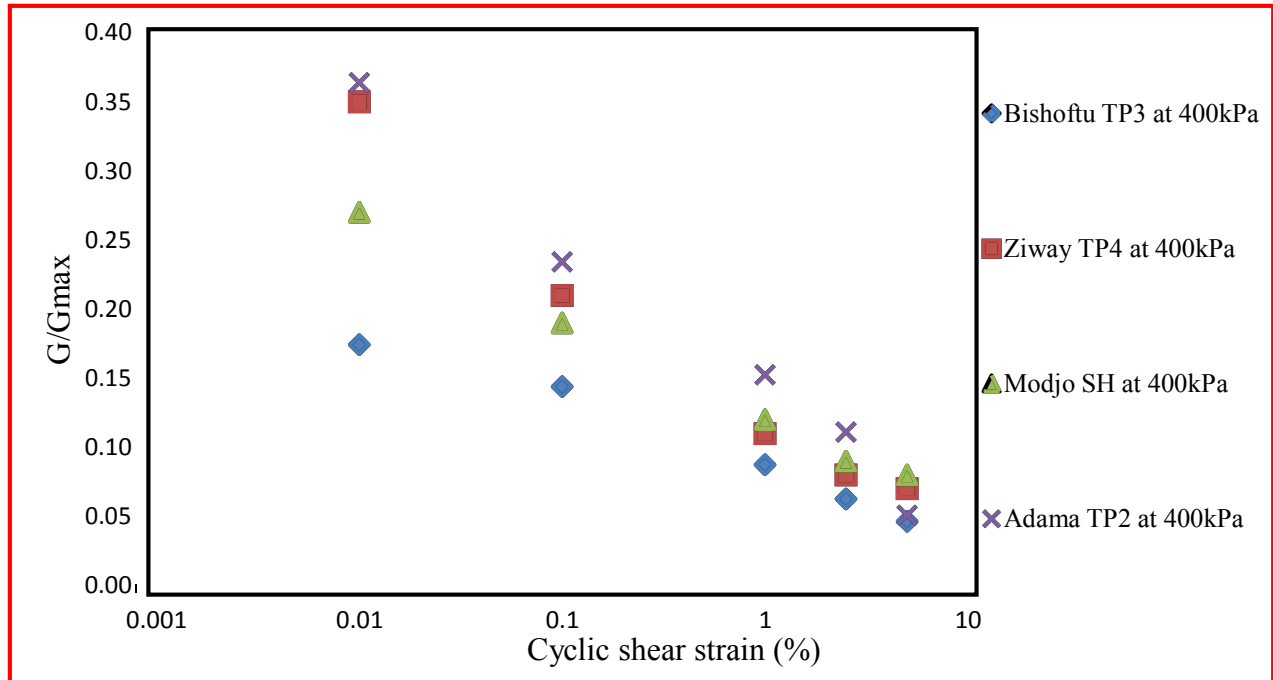


Figure 5-12:- Comparison of Normalized shear modulus values of Bishoftu silt soil with silt soil curves [5],[30],[31].

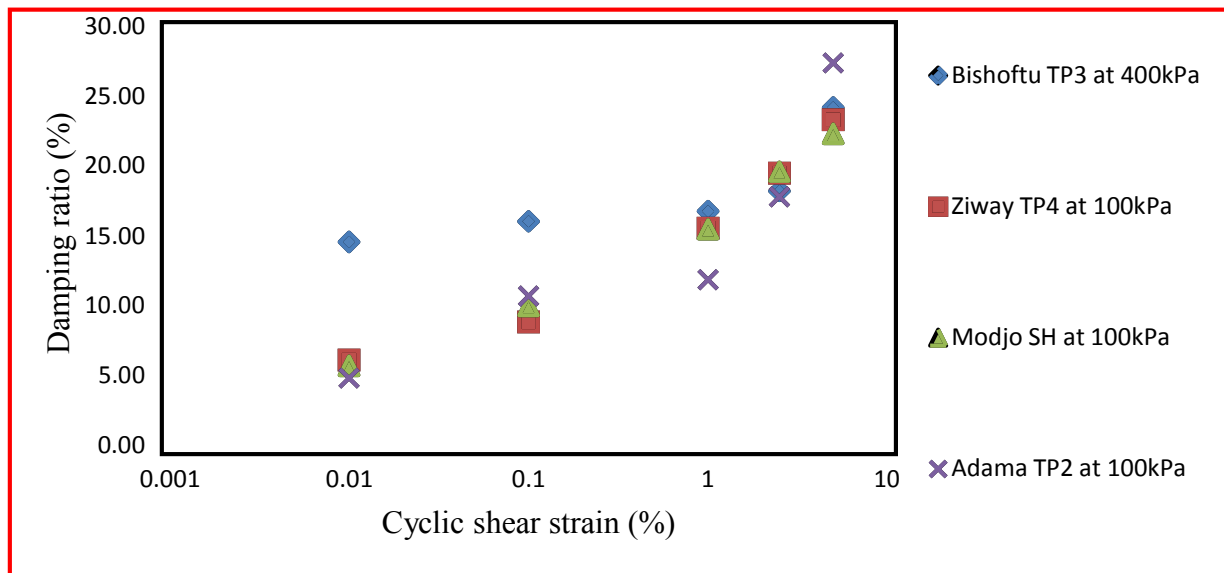


Figure 5-13:- Comparison of damping ratio values of Bishoftu silt soil with silt soil curves [5],[30],[31].

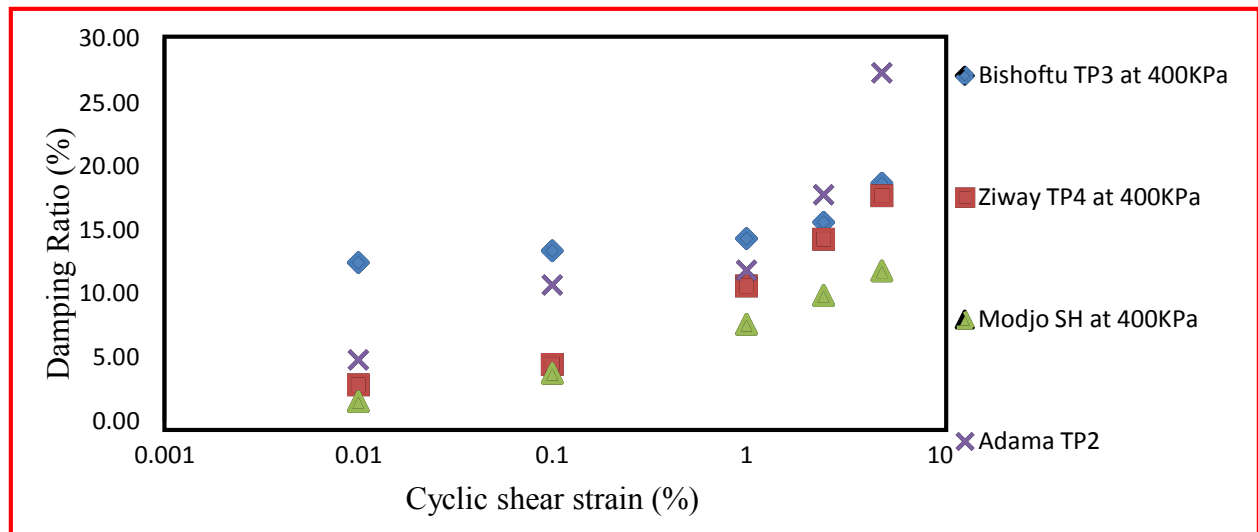


Figure 5-14:- Comparison of damping ratio values of bishoftu silt soil with silt soil curves [5],[30],[31].

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This study has investigated dynamic soil properties, namely shear modulus and damping ratio of soils from Bishoftu town using cyclic simple shear test. The influence of some important factors on the shear modulus and damping ratio of soils are also discussed. In addition, the shear modulus values of normalized to compare with previously developed values for silt soils by seed and Idriss, Abu .G, Abraham. M & Yohannes.H.

Based on the investigation the following salient features are drawn:

1. The value of shear modules is in the range of 2.99 to 16.78MPa for medium strain level ($0.01 \% < \gamma < 0.1\%$) and 0.51 to 8.99MPa for higher strain level ($\gamma > 0.1\%$). The damping ratio values range between 6.05 to 21.88 % for medium strain level ($0.01 \% < \gamma < 0.1\%$) and 9.84 to 29.35 % for higher strain level ($\gamma > 0.1\%$).
2. Shear modulus increased with increased confining pressure and decreased with increased shear strain, but the damping ratio decreased with increased confining pressure and increased with increased shear strain.
3. The values of maximum shear modulus, G_{max} , ranges from 13.47 to 47.21 MPa and normalized shear modulus, G/G_{max} , are ranges from 0.04 to 0.48.
4. Maximum shear modulus, G_{max} , increased with increased confining pressure and normalized shear modulus, G/G_{max} , decreased with increased strain amplitude.
5. The specimen having high void ratio have lower maximum shear modulus, G_{max} , and the void ratio has no significance influenced on damping ratio at any strain amplitude levels.
6. The normalized shear modulus and damping ratio values of the investigated soils are similar with those suggested by Seed and Idriss, Abu G, Abraham M and Yohannes H.
7. The grain size analysis test result showed that the dominant proportion of soil particle in the research area is low to high plasticity silt soils.

6.2. Recommendations

In this research an attempt was made to determine the values of shear modulus and damping ratio of soils found in Bishoftu town. Based on this investigation the following recommendations are made.

1. The values of shear modulus and damping ratio were obtained from disturbed soil samples only. For better dynamic characterization it is important to supplement these results from undisturbed soil.
2. Samples of soil were collected only from four test pits at depth of 3m, by increasing the number of sampling pits with depth, detail investigation should be done.
3. The dynamic test was done by cyclic simple shear apparatus only. For comparisons and better understanding of test results, the test should be repeated using cyclic triaxial testing machine.

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Appendix A:-Water content determination

Table A-1:- Water content determination for pit 1

Test pit : 1		Sample depth : 1.5m		
Specimen number		1	2	3
Moisture can number		D2	16	T13
M _c	Mass of empty, clean can + lid, (g)	15.6	16	15.8
M _{clm}	Mass of can, lid, and moist soil,(g)	61.5	64.3	64
M _{cld}	Mass of can, lid, and dry soil, (g)	50.3	51.8	52.5
M _s	Mass of soil solids, (g)	34.7	35.8	36.7
M _p	Mass of pore water, (g)	11.2	12.5	11.5
W	Water content, (%)	32.28	34.92	31.34
W _{avg}	Water content average, (%)	32.84		

Table A-2:- Water content determination for pit 1

Test pit : 1		Sample depth : 3m		
Specimen number		1	2	3
Moisture can number		MT2	T1	19
M _c	Mass of empty, clean can + lid, (g)	15.9	15.7	15.5
M _{clm}	Mass of can, lid, and moist soil, (g)	59.7	60.7	61.3
M _{cld}	Mass of can, lid, and dry soil, (g)	48.9	49.8	49.1
M _s	Mass of soil solids, (g)	33	34.1	33.6
M _p	Mass of pore water,(g)	10.8	10.9	12.2
W	Water content, (%)	32.73	31.96	36.31
W _{avg}	Water content average, (%)	33.67		

Table A-3:- Water content determination for pit 2

Test pit : 2		Sample depth : 1.5m		
Specimen number		1	2	3
Moisture can number		T1	HY	62
M _c	Mass of empty, clean can + lid, (g)	15.8	29.1	15.4
M _{clm}	Mass of can, lid, and moist soil, (g)	89	107	103
M _{cld}	Mass of can, lid, and dry soil, (g)	80.4	98.5	92.8
M _s	Mass of soil solids, (g)	64.6	69.4	77.4
M _p	Mass of pore water, (g)	8.6	8.5	10.2
W	Water content, (%)	13.31	12.25	13.18
W _{avg}	Water content average, (%)	12.91		

Table A-4:- Water content determination for pit 2

Test pit : 2		Sample depth : 3m		
Specimen number		1	2	3
Moisture can number		B7	25	MT4
M _c	Mass of empty, clean can + lid, (g)	15.1	15.9	15.8
M _{clm}	Mass of can, lid, and moist soil, (g)	78	82	72.8
M _{cld}	Mass of can, lid, and dry soil, (g)	70.3	74.1	66.6
M _s	Mass of soil solids, (g)	55.2	58.2	50.8
M _p	Mass of pore water, (g)	7.7	7.9	6.2
w	Water content, (%)	13.95	13.57	12.20
W _{avg}	Water content average, (%)	13.24		

Table A-5:- Water content determination for pit3

Test pit : 3		Sample depth : 1.5m		
Specimen number		1	2	3
Moisture can number		AP1	T20	9
M _c	Mass of empty, clean can + lid, (g)	15.2	15.35	15.1
M _{clm}	Mass of can, lid, and moist soil, (g)	66.1	68.8	67
M _{cld}	Mass of can, lid, and dry soil, (g)	59	62.5	60.25
M _s	Mass of soil, (g)	43.8	47.15	45.15
M _p	Mass of pore water, (g)	7.1	6.3	6.75
W	Water content, (%)	16.21	13.36	14.95
W _{avg}	Water content average, (%)	14.84		

Table A-6:- Water content determination for pit3

Test Pit : 3		Sample depth : 3m		
Specimen number		1	2	3
Moisture can number		A-1	TP4	CR
M _c	Mass of empty, clean can + lid, (g)	15.5	15.5	15.3
M _{clm}	Mass of can, lid, and moist soil, (g)	63.1	64.8	62
M _{cld}	Mass of can, lid, and dry soil, (g)	58.3	59	57.1
M _s	Mass of soil solids, (g)	42.8	43.5	41.8
M _p	Mass of pore water, (g)	4.8	5.8	4.9
W	Water content, w (%)	11.21	13.33	11.72
W _{avg}	Water content average, w (%)	12.09		

Table A-7:-Water content determination for pit 4

Test pit : 4		Sample depth : 1.5m		
Specimen number		1	2	3
Moisture can number		MT+4	A63	A300
M _c	Mass of empty, clean can + lid, (g)	15.7	14	15.6
M _{clm}	Mass of can, lid, and moist soil, (g)	60	55.5	53.9
M _{cld}	Mass of can, lid, and dry soil, (g)	54.5	50.6	49.5
M _s	Mass of soil solids, (g)	38.8	36.6	33.9
M _p	Mass of pore water, (g)	5.5	4.9	4.4
W	Water content, (%)	14.18	13.39	12.98
W _{avg}	Water content average, (%)	13.51		

Table A-8:- Water content determination for pit4

Test pit : 4		Sample depth : 3m		
Specimen number		1	2	3
Moisture can number		P3	MT9	SM1
M _c	Mass of empty, clean can + lid, (g)	15.8	15.8	16.5
M _{clm}	Mass of can, lid, and moist soil, (g)	61.7	63.8	65
M _{cld}	Mass of can, lid, and dry soil, (g)	56	57.7	59.1
M _s	Mass of soil solids, (g)	40.2	41.9	42.6
M _p	Mass of pore water, (g)	5.7	6.1	5.9
W	Water content, (%)	14.18	14.56	13.85
W _{avg}	Water content average, (%)	14.20		

Appendix B:-Bulk density determination

Table B-1:- Soil bulk density determination of Bishoftu soil at 1.5m depth

Soil field density					
Sample depth : 1.5m					
Test pit		3	2	1	4
M_c	Mass of cone, (g)	1303	1303	1303	1303
M_{sc}	Mass of moist soil & cone, (g)	3334	3385	3489	3391
M_s	Mass of moist soil, (g)	2031	2082	2186	2088
H_c	Height of cone, (cm)	18	18	18	18
D_c	Diameter of cone, (cm)	10	10	10	10
A_c	Area of cone, (cm ²)	78.54	78.54	78.54	78.54
V_c	volume of cone, (cm ³)	1413.72	1413.72	1413.72	1413.72
ρ_{bulk}	Field density bulk, (g/cm ³)	1.44	1.47	1.55	1.48
ρ_{dry}	Field density dry, (g/cm ³)	1.25	1.30	1.16	1.30
W	Natural water content, (%)	14.84	12.91	32.84	13.51

Table B-2:- Soil bulk density determination of Bishoftu soil at 3m depth

Soil field density					
Sample depth		3m	3m	3m	3m
Test pit		3	2	1	4
M_c	Mass of cone, (g)	1303	1303	1303	1303
M_{sc}	Mass of moist soil & cone,(g)	3395	3425	3525	3373
M_s	Mass of moist soil, (g)	2092	2122	2222	2070
H_c	Height of cone, (cm)	18	18	18	18
D_c	Diameter of cone, (cm)	10	10	10	10
A_c	Area of cone, (cm ²)	78.54	78.54	78.54	78.54
V_c	volume of cone ,(cm ³)	1413.72	1413.72	1413.72	1413.72
P_{bulk}	Field density bulk, (g/cm ³)	1.48	1.50	1.57	1.46
P_{dry}	Field density dry, (g/cm ³)	1.32	1.33	1.18	1.28
W	Natural water content, (%)	12.09	13.24	33.67	14.20

Appendix C :-(Atterberg limit test results)

Table C-1:- Determination of liquid limit, plastic limit and plastic Index for pit1 at 3.0m

LL of pit1 at 3m						PL of pit1 at 3m	
Trial number	1	2	3	4	5	1	2
Can number	A27	IL6	HY	W9	T1	A1	22
Number of blows	37	32	29	24	20		
Mass of can, M_c (g)	22	15.8	29.1	15.4	15.7	15.5	15.4
Mass of can + mass of wet soil, M_{cws} (g)	34	39	42	39.5	37	30	31
Mass of can + mass of dry soil, M_{cds} (g)	31	31.7	37.5	30	28	25.06	26.43
Mass f dry soil, M_{ds} (g)	9	15.9	8.4	14.6	12.3	9.56	11.03
Mass of moisture, M_m (g)	3	7.3	4.5	9.5	9	4.94	4.57
Water content, W (%)	33.3	45.9	53.6	65.1	73.2	51.7	41.4
Liquid limit & plastic limit, (%)	LL=61.00					46.6	

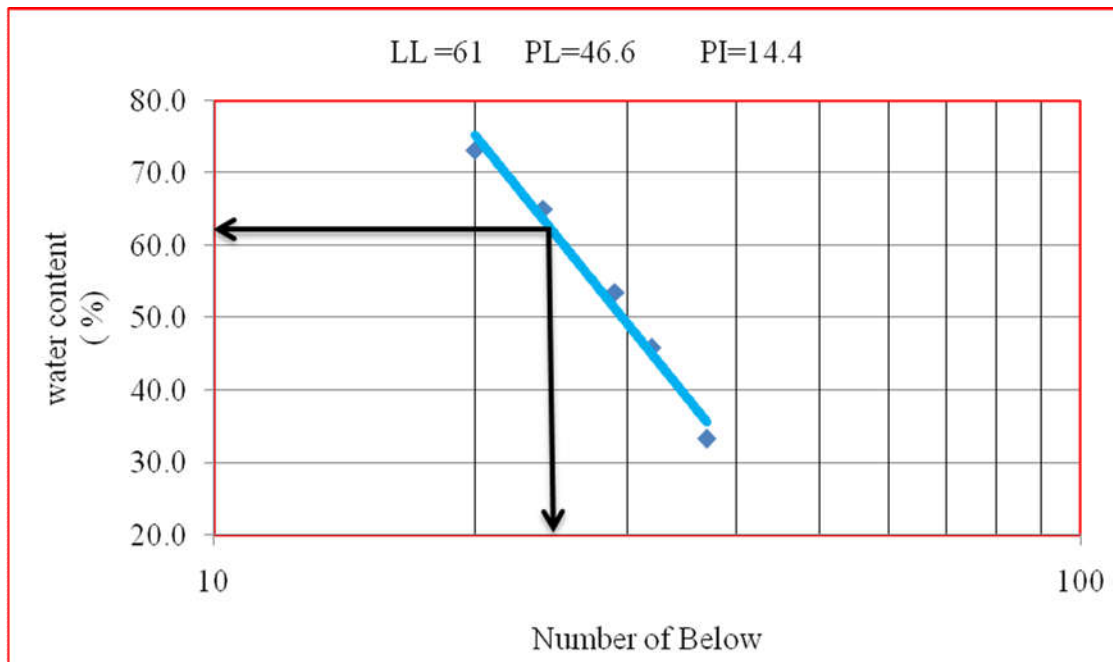


Figure C-1:- Water content versus no. blows of pit 1

Table C-2:- Determination of liquid limit, plastic limit and plastic index for pit 2 at 3.0m

LL of pit 2 at 3m						PL of pit 2 at 3m	
Trial number	1	2	3	4	5	1	2
Can number	M10	GA	PL2	T3	T4	60	24
Number of blows	32	29	24	20	18		
Mass of can , M_c (g)	11	15.6	15.7	15.7	10.7	15.5	15.9
Mass of can + mass of wet Soil, M_{cws} (g)	31.9	38	40	37	35	35	36
Mass of can + mass of dry soil , M_{cds} (g)	26.9	32.4	33.5	31	27.9	30.37	31.5
Mass f dry soil, M_{ds} (g)	15.9	16.8	17.8	15.3	17.2	14.87	15.6
Mass of moisture, (g)	5	5.6	6.5	6	7.1	4.63	4.5
Water content, W (%)	31.447	33.333	36.517	39.216	41.279	31.137	28.846
LL=36						30.0	

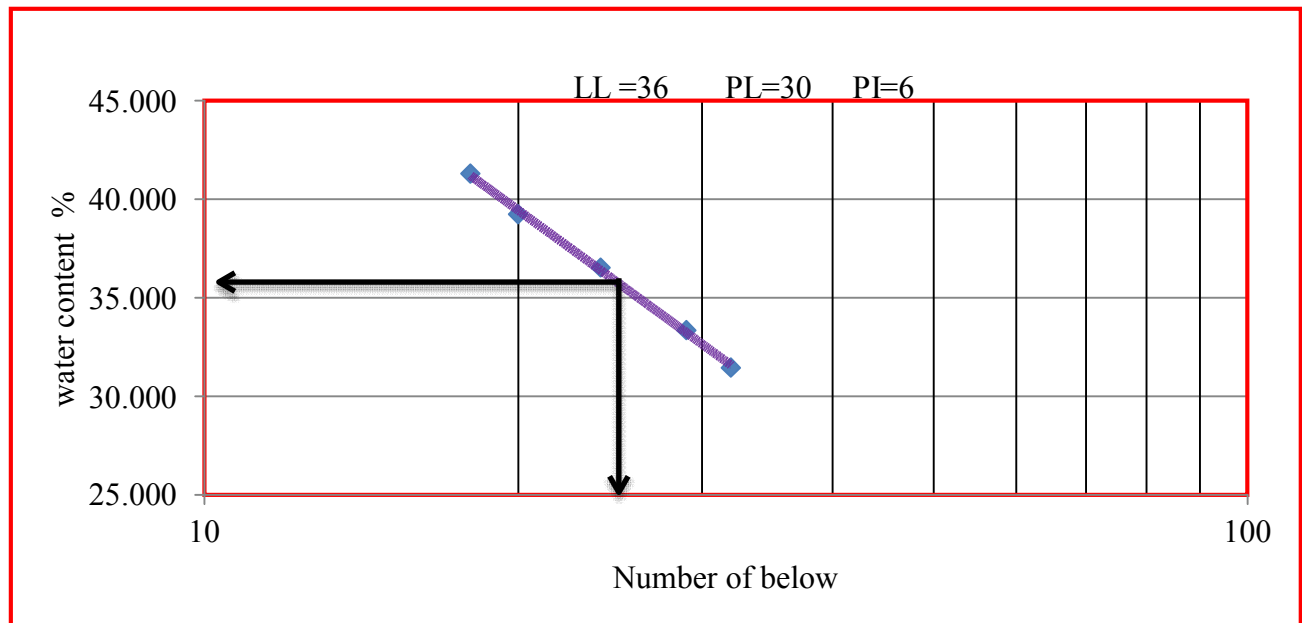


Figure C-2:- Water content versus no. blows of pit 2

Table C-3:- Determination of liquid limit, plastic limit and plastic index for pit 3 at 3.0m

LL of pit 3 at 3m						PL of pit 3 at 3m	
Trial number	1	2	3	4	5	1	2
Can number	30	W3	25	22	A1	W9	IL6
Number of blows	32	29	24	21	17		
Mass of can , M_c (g)	15.6	15.6	15.9	15.4	15.5	15.4	15.8
Mass of can + mass of wet Soil, M_{cws} (g)	30.5	38	40	37	33	31	32
Mass of can + mass of dry soil, M_{cds} (g)	26.9	32.4	33.5	31	27.9	27.5	28
Mass f dry soil, M_{ds} (g)	11.3	16.8	17.6	15.6	12.4	12.1	12.2
Mass of moisture, M_m (g)	3.6	5.6	6.5	6	5.1	3.5	4
Water content, W (%)	31.858	33.333	36.932	38.462	41.129	28.926	32.787
LL=36						PL=30.9	

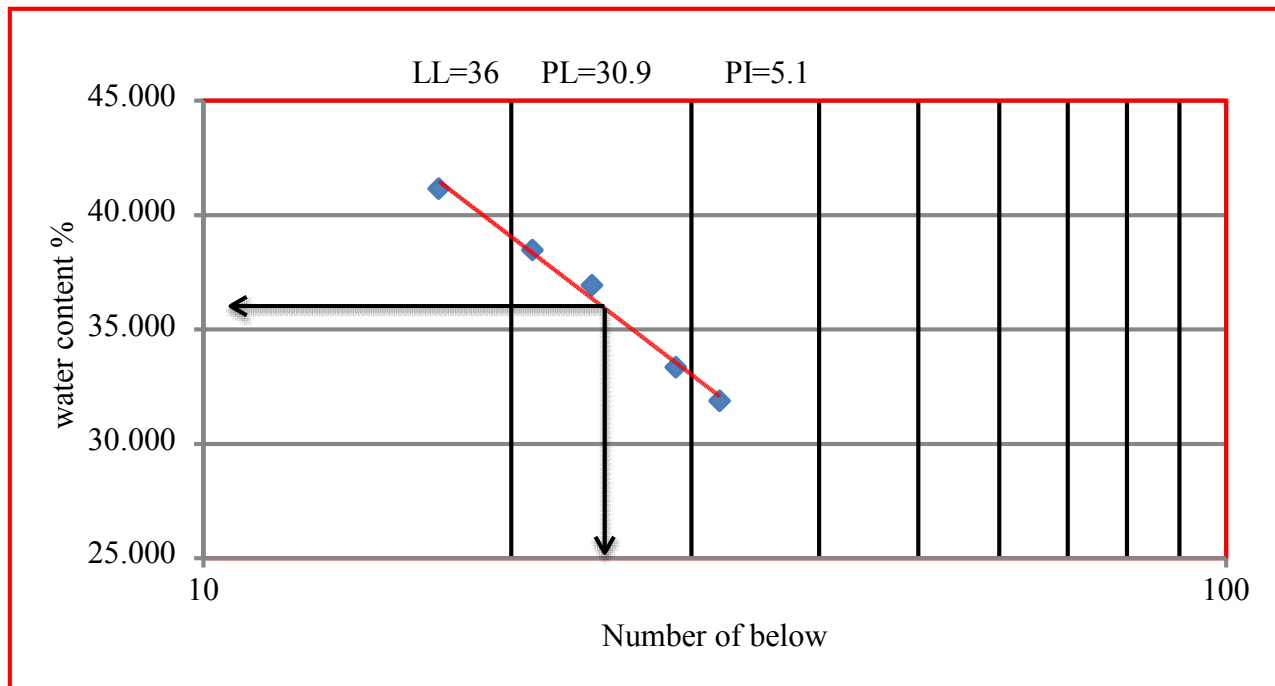


Figure C-3:- Water content versus no. blows of pit 3

Table C-4:- Determination of liquid limit, plastic limit and plastic index for pit 4 at 3.0m

LL of pit 4 at 3m						PL of pit 4 at 3m	
Trial number	1	2	3	4	5		
Can number	60	24	MT8	MT9	A27	W9	IL6
Number of blows	38	35	26	23	18		
Mass of can, M_c (g)	15.50	15.90	15.50	15.70	22.20	15.40	15.80
Mass of can + mass of wet Soil, M_{cws} (g)	29.50	29.70	39.50	36.00	33.00	32.00	33.00
Mass of can + mass of dry soil, M_{cds} (grams)	26.80	27.00	34.50	31.70	30.60	29.15	30.00
Mass f dry soil, M_{ds} (g)	11.30	11.10	19.00	16.00	8.40	13.75	14.20
Mass of moisture, M_m (g)	2.70	2.70	5.00	4.30	2.40	2.85	3.00
Water content, W (%)	23.89	24.32	26.32	26.88	28.57	20.73	21.13
LL=26.00						PL=21	

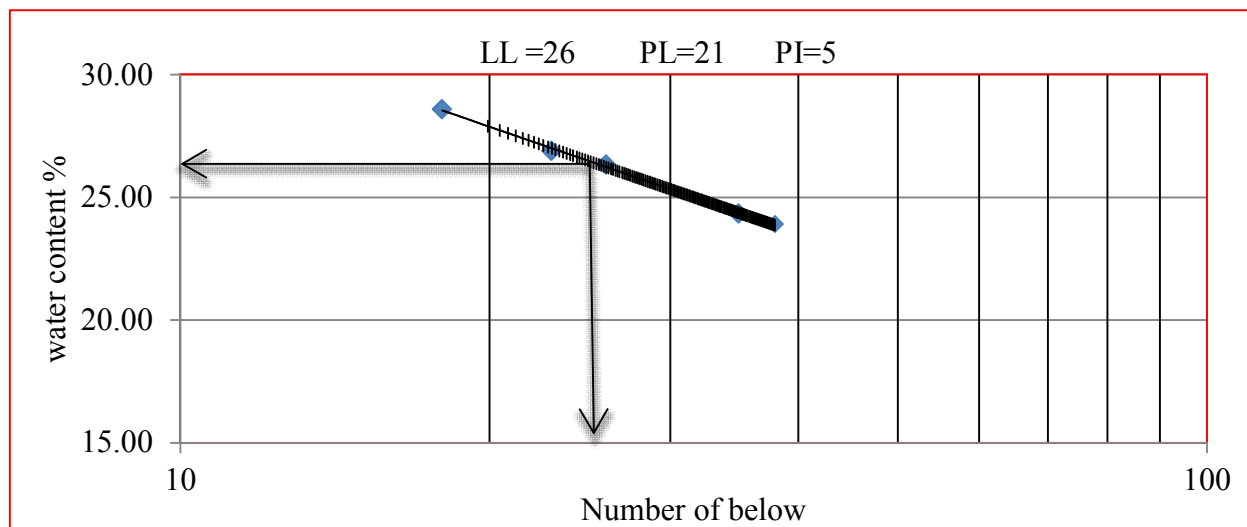


Figure C-4:- Water content versus no. blows of pit4

Appendix D: - Determination of free swelling

Table D.1:- Determination of free swelling for pit1

Test pit 1			Depth = 3m	
Initial volume (cc)	Final volume (cc)		Average final volume (cc)	Free swell index (%)
	Sample No.1	Sample No.2		
10.0	15.0	16.0	15.5	55

Table D.2:- Determination of free swelling for pit2

Test pit 2			Depth = 3m	
Initial volume (cc)	Final volume (cc)		Average final volume (cc)	Free swell index (%)
	Sample No.1	Sample No.2		
10.0	12.6	12.8	12.7	27

Table D-3:- Determination of free swelling for pit3

Test pit 3			Depth = 3m	
Initial volume (cc)	Final volume (cc)		Average final volume (cc)	Free swell index (%)
	Sample No.1	sample No.2		
10.0	12.8	13.2	13.0	30

Table D-4:- Determination of free swelling for pit4

Test pit 4			Depth = 3m	
Initial Volume (cc)	Final volume (cc)		Average final volume (cc)	Free swell index (%)
	Sample No.1	Sample No.2		
10.0	13.6	13.4	13.5	35

Appendix E: - Grain size analysis

Table E-1:- dry sieve analysis for pit1

Dry sieve analysis for pit 1 at 3m				Total mass of sample, 1050gm			
ASTM standard sieve	Sieve opening (mm)	Weight of Sieve, W_s (g)	Weight of sieve +soil, W_{ss} (g)	Weight Retained soil, W_{rs} (g)	%age of wt. retained	Cumulative %age retained	% age of Passing
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1194.6	1194.6	0.0	0.0	0.0	100.0
1/2"	12.5	1216.5	1216.5	0.0	0.0	0.0	100.0
3.8"	9.5	1090.9	1090.9	0.0	0.0	0.0	100.0
No 4	4.75	1263.1	1269.0	5.9	0.6	0.6	99.4
No 8	2.36	990.0	995.0	5.0	0.5	1.0	99.0
No 10	2	944.0	950.0	6.0	0.6	1.6	98.4
No 16	1.18	894.6	920.5	25.9	2.5	4.1	95.9
No 30	0.6	831.0	844.5	13.5	1.3	5.4	94.6
No 40	0.425	789.4	805.0	15.6	1.5	6.8	93.2
No. 50	0.3	750.5	767.5	17.0	1.6	8.5	91.5
No. 100	0.15	778.8	795.0	16.2	1.5	10.0	90.0
No. 200	0.075	767.9	784.6	16.7	1.6	11.6	88.4
Pan	-----	737.1	1664.0	926.9	88.3	99.9	0.0
Total		16836.4	17885.1	1050	99.6		

Table E-2:- Wet sieve analysis for pit 1

Wet sieve analysis of pit 1 at 3m									
Temperature, T (°C)	Elapsed Time, T (min)	Actual hydrometer reading, R_a (cm)	Composite correction	Corrected hydrometer reading, R_c (cm)	Effective Depth, L (cm)	Coefficient, K	Grain Size, D (mm)	Percentage Finer, P (%)	Percentage Finer combined, C_p (%)
22.7	0.25	1.0306	0.0022	1.0284	8.21	0.01397	0.0800	90.21	88.76
22.4	0.75	1.0291	0.0022	1.0269	8.60	0.01397	0.0473	85.45	84.07
22.3	1	1.0288	0.0022	1.0266	8.68	0.01397	0.0412	84.49	83.13
22.6	2	1.0266	0.0022	1.0244	9.26	0.01397	0.0301	77.51	76.26
22.5	4	1.0242	0.0022	1.0220	9.90	0.01397	0.0220	69.88	68.76
22.5	8	1.0222	0.0020	1.0202	10.43	0.01381	0.0158	64.16	63.13
23.3	15	1.0211	0.0020	1.0191	10.73	0.01381	0.0117	60.51	59.54
23	30	1.0200	0.0021	1.0179	11.01	0.01381	0.0084	56.86	55.94
23.3	60	1.0187	0.0020	1.0167	11.35	0.01381	0.0060	53.05	52.19
24.4	120	1.0171	0.0018	1.0153	11.78	0.01365	0.0043	48.60	47.82
24.5	240	1.0140	0.0018	1.0122	12.60	0.01365	0.0031	38.75	38.13
23.2	480	1.0110	0.0020	1.0090	13.39	0.01381	0.0023	28.59	28.13
22	1440	1.0082	0.0023	1.0059	14.13	0.01397	0.0014	18.74	18.44

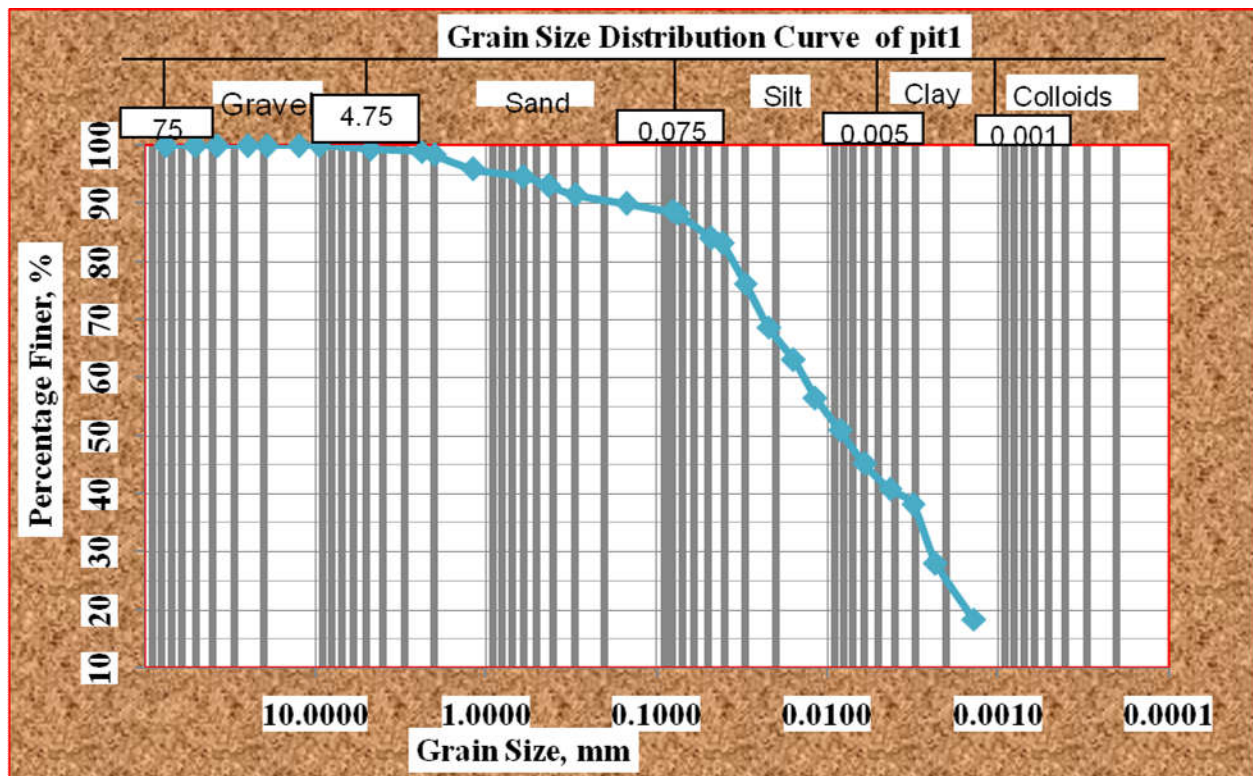


Figure E-1:- Grain size distribution curve of pit1

Table E-3:- dry sieve analysis for pit 2

Dry sieve analysis for pit 2 at 3m				Total mass of sample, 1000gm			
ASTM standard sieve	Sieve opening (mm)	Weight of Sieve, $W_s(g)$	Weight of sieve + soil $W_{ss}(g)$	Weight retained soil, $W_{rs} (g)$	Percentage wt. retained, $P_r(\%)$	Cumulative percentage retained, $C_{pr}(\%)$	Percentage passing, $P_p(\%)$
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1194.6	1194.6	0.0	0.0	0.0	100.0
1/2"	12.5	1216.5	1216.5	0.0	0.0	0.0	100.0
3.8"	9.5	1164.4	1164.4	0.0	0.0	0.0	100.0
No 4	4.75	1263.1	1280.0	16.9	1.7	1.7	98.3
No 8	2.36	990.0	1008.0	18.0	1.8	3.5	96.5
No 10	2	944.0	964.0	20.0	2.0	5.5	94.5
No 16	1.18	894.8	919.0	24.2	2.4	7.9	92.1
No 30	0.6	831.0	888.0	57.0	5.7	13.6	86.4
No 40	0.425	787.0	833.0	46.0	4.6	18.2	81.8
No. 50	0.3	750.4	780.0	29.6	3.0	21.2	78.8
No. 100	0.15	778.6	812.0	33.4	3.3	24.5	75.5
No. 200	0.075	769.9	799.0	29.1	2.9	27.4	72.6
Pan	-----	734.5	755.0	725.2	72.5	99.9	0.0
Total		16906.8	17201.5	1000	99.9		

Table E-4:- Wet sieve analysis for pit 2

Wet sieve analysis of pit 2 at 3m									
Temperature, T(°C)	Elapsed time, T (min)	Actual hydrometer reading, R_a (cm)	Composite correction	Corrected hydrometer reading, R_c (cm)	Effective depth L (cm)	Coefficient, K	Grain Size, D (mm)	Percentage finer, P (%)	Percentage finer combined, C_p (%)
22.7	0.25	1.0253	0.0022	1.0231	9.60	0.01397	0.866	77.13	72.90
22.4	0.75	1.0221	0.0022	1.0199	10.45	0.01397	0.0522	66.33	62.69
22.3	1	1.0210	0.0022	1.0188	10.75	0.01397	0.0458	62.67	59.23
22.6	2	1.0201	0.0022	1.0179	10.98	0.01397	0.0327	59.67	56.39
22.5	4	1.0200	0.0022	1.0178	11.01	0.01397	0.0232	59.33	56.08
23.1	8	1.0180	0.0020	1.0160	11.54	0.01381	0.0166	53.33	50.41
23.3	15	1.0170	0.0020	1.0150	11.80	0.01381	0.0123	50.00	47.25
23	30	1.0150	0.0021	1.0129	12.33	0.01381	0.0089	43.00	40.64
23.3	60	1.0126	0.0020	1.0106	12.96	0.01381	0.0064	35.37	33.43
24.4	120	1.0110	0.0018	1.0092	13.39	0.01365	0.0046	30.67	28.98
24.5	240	1.0100	0.0018	1.0082	13.65	0.01365	0.0033	27.33	25.83
23.2	480	1.0095	0.0020	1.0075	13.79	0.01381	0.0023	25.00	23.63
22	1440	1.0055	0.0023	1.0032	14.85	0.01397	0.0014	10.67	10.08

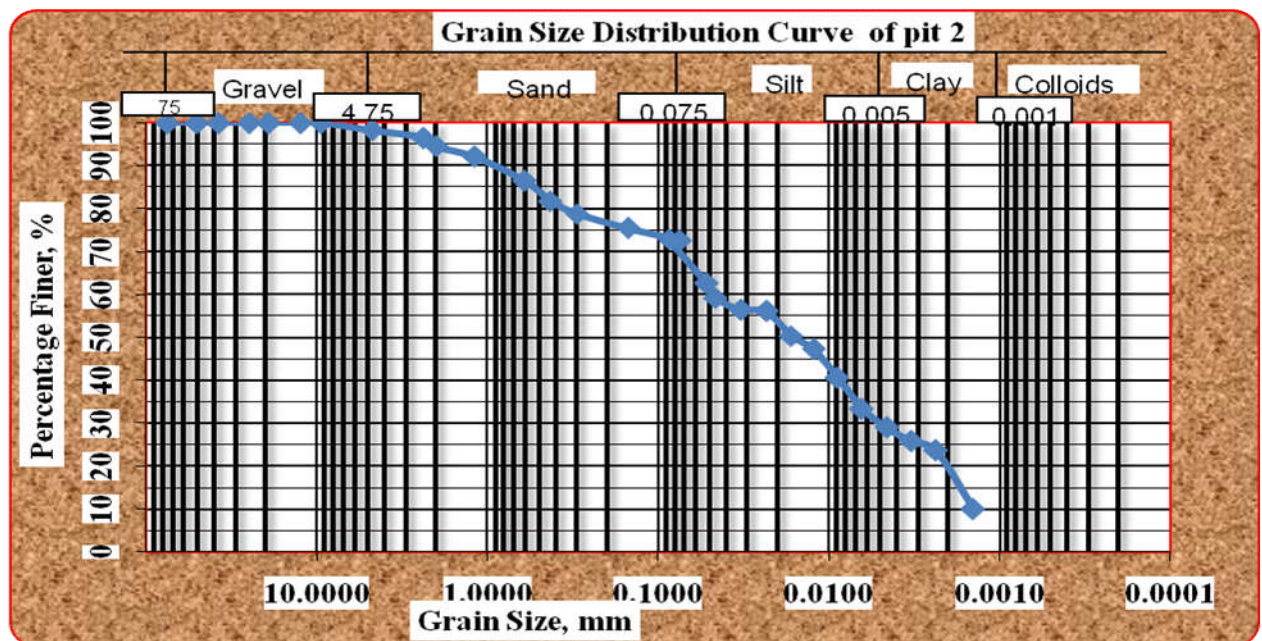


Figure E-2:- Grain size distribution curve of pit 2

Table E-5:- dry sieve analysis for pit 3 at 3m

Dry sieve analysis for pit 3 at 3m				Total mass of sample, 1000gm			
ASTM standard sieve	Sieve Opening, (mm)	Weight of sieve ,W _S (g)	Weight of sieve + soil, W _{SS} (g)	Weight retained soil, W _{rs} (g)	Percentage wt. retained, P _r (%)	Cumulative percentage retained, C _{pr} (%)	Percentage Passing, P _p (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1194.6	1194.6	0.0	0.0	0.0	100.0
1/2"	12.5	1216.5	1216.5	0.0	0.0	0.0	100.0
3.8"	9.5	1090.9	1090.9	0.0	0.0	0.0	100.0
No 4	4.75	1263.1	1269.5	6.4	0.6	0.6	99.4
No 8	2.36	990.0	994.3	4.3	0.4	1.1	98.9
No 10	2	944.0	948.8	4.8	0.5	1.6	98.5
No 16	1.18	894.6	918.0	23.4	2.3	3.9	96.1
No 30	0.6	831.0	840.0	9.0	0.9	4.8	95.2
No 40	0.425	789.4	800.0	10.6	1.1	5.9	94.2
No. 50	0.3	750.5	764.5	14.0	1.4	7.3	92.8
No. 100	0.15	778.8	794.0	15.2	1.5	8.8	91.2
No. 200	0.075	767.9	781.9	14.0	1.4	10.2	89.8
Pan	-----	737.1	1635.0	897.9	89.8	100.0	0.0
Total		16836.4	17836.0	1000	100.0		

Table E-6:- Wet sieve analysis for pit 3

Wet sieve analysis of pit 3 at 3m									
Tempera Ture, T (°C)	Elapse d time, T (min)	Actual hydrome- ter read- ing, R _a (cm)	Compo- site Correc- tion	Corrected hydro- mete r reading, R _c (cm)	Effective Depth, L (cm)	Coeffi- cien t, K	Grain Size, D (mm)	Percen- tage Finer, P _p (%)	Percent age finer combin ed, C _p (%)
22.7	0.25	1.0310	0.0022	1.0288	8.10	0.01397	0.0795	91.48	89.94
22.4	0.75	1.0279	0.0022	1.0257	8.92	0.01397	0.0482	81.64	80.26
22.3	1	1.0270	0.0022	1.0248	9.16	0.01397	0.0423	78.78	77.45
22.6	2	1.0260	0.0022	1.0238	9.42	0.01397	0.0303	75.60	74.32
22.5	4	1.0255	0.0022	1.0233	9.55	0.01397	0.0216	74.01	72.76
22.5	8	1.0235	0.0020	1.0215	10.08	0.01381	0.0155	68.29	67.14
23.3	15	1.0220	0.0020	1.0200	10.48	0.01381	0.0115	63.53	62.46
23	30	1.0200	0.0021	1.0179	11.01	0.01381	0.0084	56.86	55.90
23.3	60	1.0180	0.0020	1.0160	11.54	0.01381	0.0061	50.82	49.96
24.4	120	1.0150	0.0018	1.0132	12.33	0.01365	0.0044	41.93	41.22
24.5	240	1.0120	0.0018	1.0102	13.13	0.01365	0.0032	32.40	31.85
23.2	480	1.0103	0.0020	1.0083	13.58	0.01381	0.0023	26.36	25.92
22	1440	1.0091	0.0023	1.0068	13.89	0.01397	0.0014	21.60	21.23

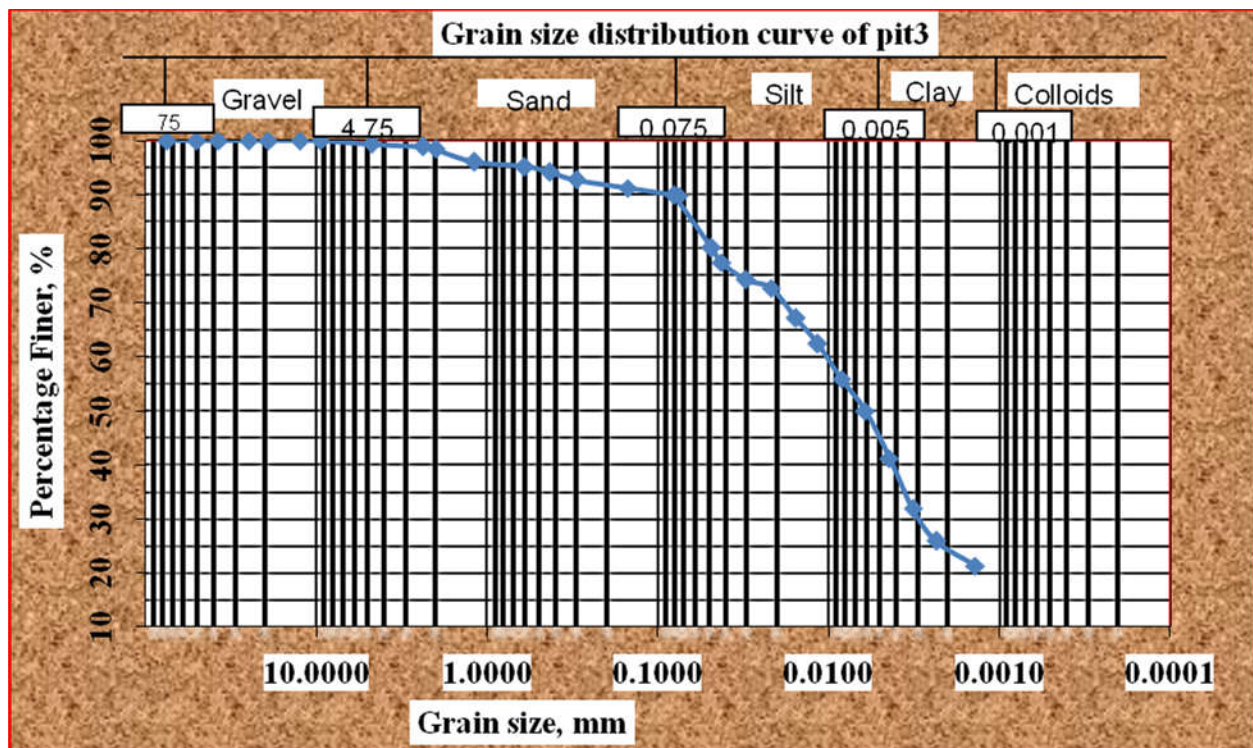


Figure E-3:- Grain size distribution curve of pit 3

Table E-7:- dry sieve analysis for pit 4

Dry sieve analysis for pit 4 at 3m				Total mass of sample, 1000gm			
ASTM standard sieve	Sieve Opening, (mm)	Weight of Sieve, W_S (g)	Weight of sieve + soil, W_{SS} (g)	Weight retained soil, W_{rs} (g)	Percentage wt. retained $P_R(\%)$	Cumulative percentage retained, $C_{pr}(\%)$	Percentage Passing, $P_P(\%)$
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1194.6	1194.6	0.0	0.0	0.0	100.0
1/2"	12.5	1216.5	1216.5	0.0	0.0	0.0	100.0
3.8"	9.5	1164.4	1164.4	0.0	0.0	0.0	100.0
No 4	4.75	1263.1	1280.0	16.9	1.7	1.7	98.3
No 8	2.36	990.0	1008.0	18.0	1.8	3.5	96.5
No 10	2	944.0	964.0	20.0	2.0	5.5	94.5
No 16	1.18	894.8	919.0	24.2	2.4	7.9	92.1
No 30	0.6	831.0	888.0	57.0	5.7	13.6	86.4
No 40	0.425	787.0	833.0	46.0	4.6	18.2	81.8
No. 50	0.3	750.4	780.0	29.6	3.0	21.2	78.8
No. 100	0.15	778.6	812.0	33.4	3.3	24.5	75.5
No. 200	0.075	769.9	799.0	29.1	2.9	27.4	72.6
Pan	--	734.5	1460.0	725.5	72.6	100.0	0.0
Total		16906.8	17906.5	1000	100.0		

Table E-8:- Wet sieve analysis for pit 4 at 3m

Wet sieve analysis of pit 4 at 3m									
Temp eratur e , T (°C)	Elaps ed time, T (min)	Actual hydrome- ter read- ing, R _a (cm)	Compo- site Correc- tion	Corrected hydrome- ter read- ing, R _c (cm)	Effective Depth, L (cm)	Coeffi- cien t, K	Grain Size, D (mm)	Percen- tage finer P	Percen- tage finer combined, C _P (%)
22.7	0.25	1.0253	0.0022	1.0231	9.61	0.01397	0.0866	77.00	72.77
22.4	0.75	1.0222	0.0022	1.0200	10.43	0.01397	0.0521	66.67	63.01
22.3	1	1.0210	0.0022	1.0188	10.75	0.01397	0.0458	62.67	59.23
22.6	2	1.0189	0.0022	1.0167	11.30	0.01397	0.0332	55.67	52.61
22.5	4	1.0181	0.0022	1.0159	11.51	0.01397	0.0237	53.00	50.09
23.1	8	1.0165	0.0020	1.0145	11.94	0.01381	0.0169	48.33	45.68
23.3	15	1.0160	0.0020	1.0140	12.07	0.01381	0.0124	46.67	44.10
23	30	1.0155	0.0021	1.0134	12.20	0.01381	0.0088	44.67	42.21
23.3	60	1.0141	0.0020	1.0121	12.57	0.01381	0.0063	40.33	38.12
24.4	120	1.0132	0.0018	1.0114	12.81	0.01365	0.0045	38.00	35.91
24.5	240	1.0122	0.0018	1.0104	13.07	0.01365	0.0032	34.67	32.76
23.2	480	1.0115	0.0020	1.0095	13.26	0.01381	0.0023	31.67	29.93
22	1440	1.0090	0.0023	1.0067	13.92	0.01397	0.0014	22.33	21.11

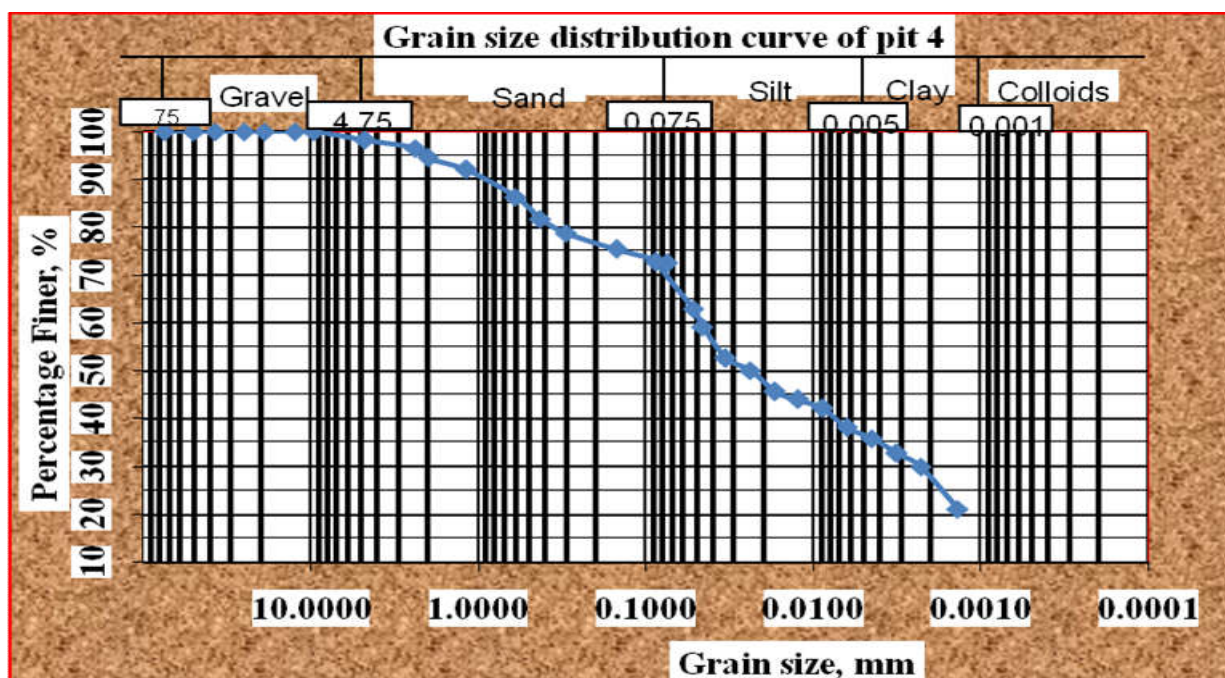


Figure E-4:- Grain size distribution curve of pit 4

Appendix F: - Specific gravity determination

Table F-1:- Specific gravity determination for pit1

Test pit1	Depth: 3m		
[A] Calibration of pycnometer			
Pycnometer number	P ₁	P ₂	P ₃
Weight of dry, clean pycnometer, W _p (g)	65.3	48.1	65.3
Weight of pycnometer + water, W _{pw} (g)	161.8	147.4	161.8
Observed temperature of water, T _i (°C)	22.7	23.2	22.5
[B] Specific gravity determination			
Determination number	1	2	3
Pycnometer number	P ₁	P ₂	P ₃
Weight of pycnometer + soil + water, W _{psw} (g)	177.4	163.5	177.3
Temperature, T _x (°C)	22.8	23.2	22.7
Weight of pycnometer + water at T _x , W _{pw} (g)	161.80	147.40	161.80
Weight of dry soil ,W _S (g)	25	25	25
Conversion factor , K	0.9991	0.9993	0.9993
Specific gravity of soil at 20°c, (G _S)	2.66	2.81	2.63
Average specific gravity of soil, (G _S)	2.70		

Table F-2:- Specific gravity determination for pit2

Test Pit 2	Depth:3m		
[A] Calibration of pycnometer			
Pycnometer number	P ₁	P ₂	P ₃
Weight of dry, clean pycnometer, W _P (g)	65.7	48.1	65.7
Weight of pycnometer + water, W _{pw} (g)	162.8	147.1	162.8
Observed temperature of water, T _i (°C)	22.7	23.2	22.7
[B] Specific gravity determination			
Determination number	1	2	3
Pycnometer number	P ₁	P ₂	P ₃
Weight of pycnometer + soil + water, W _{psw} (g)	178.3	162.8	178.5
Temperature, T _x (°C)	22.8	23.2	22.8
Weight of pycnometer + water at T _x , W _{pw} (g)	162.80	147.10	162.80
Weight of dry soil,W _s (g)	25	25	25
Conversion factor, K	0.9993	0.9993	0.9993
Specific gravity of soil at 20°c. (G _S)	2.63	2.69	2.69
Average specific gravity of soil. (G _S)	2.67		

Table F-3:- Specific gravity determination for pit3

Test Pit3	Depth:3m		
[A] Calibration of pycnometer			
Pycnometer number	P ₁	P ₁	P ₁
Weight of dry, clean pycnometer, W _p (g)	65.8	49.8	47.6
Weight of pycnometer + water, W _{PW} (g)	162.7	147.4	146.9
Observed temperature of water, T _i (°C)	23.8	24	24.3
[B] Specific gravity determination			
Determination number	1	2	3
Pycnometer number	P ₁	P ₁	P ₁
Weight of pycnometer + soil + water, W _{psw} (g)	178.4	163.3	162.3
Temperature, T _x (°C)	24.5	24.6	24.6
Weight of pycnometer + water at T _x , W _{PW} (g)	162.70	147.40	146.90
Weight of dry soil, W _s (g)	25	25	25
Conversion factor, K	0.9989	0.9989	0.9989
Specific gravity of soil at 20°C, (G _S)	2.69	2.74	2.60
Average specific gravity of soil, (G _S)	2.68		

Table F-4:- Specific gravity determination for pit 4

Test Pit: 4	Depth:3m		
[A] Calibration of pycnometer			
Pycnometer number	P ₁	P ₂	P ₃
Weight of dry, clean pycnometer, W _p (g)	63.6	47.9	45.4
Weight of pycnometer + water, W _{pw} (g)	162.5	147.2	144.6
Observed temperature of water, T _i (°C)	23.3	23.4	18.6
[B] Specific gravity determination			
Determination number	1	2	3
Pycnometer number	P ₁	P ₂	P ₃
Weight of pycnometer + soil + water, W _{psw} (g)	178	163.3	160
Temperature, T _x (°C)	23.5	23.6	20.5
Weight of pycnometer + water at T _x , W _{pw} (g)	162.50	147.20	144.56
Weight of dry soil ,W _s (g)	25	25	25
Conversion factor , K	0.9991	0.9991	0.9998
Specific gravity of soil at 20°c,(G _S)	2.63	2.81	2.61
Average specific gravity of soil, (G _S)	2.68		

Appendix G: - Compaction test result

Table G-1:- Compaction test results determination of pit 1

Moisture content V_s dry density					
Test pit: 1			Depth : 3m		
Determination number	1	2	3	4	5
Mass of mold, M_m (g)	1733	1733	1733	1733	1733
Mass of mold+ compacted soil, M_{ms} (g)	3150	3295	3380	3430	3410
Mass of compacted soil, M_{cs} (g)	1417	1562	1647	1697	1677
Volume of mold, V_m (cm ³)	944	944	944	944	944
Bulk density, ρ_b (g/cm ³)	1.50	1.65	1.74	1.80	1.78
Water content, w (%)	24.97	33.21	37.15	38.56	41.74
Dry density, ρ_d (g/cm ³)	1.20	1.24	1.27	1.30	1.25

Water content of pit 1 at 3m									
Test trial	1		2		3		4		5
Container number	60	24	MT9	A27	HY	W9	T1	30	W3 25
Mass of container, M_c (grams)	15.5	15.9	15.7	22.2	29.1	15.4	15.7	15.6	15.5 16
Mass of container + wet soil, M_{cws} (g)	57	56	51.7	58	57	59.7	68	67.5	69 69
Mass of container + dry soil, M_{cds} (g)	52.2	45.2	42.6	49.2	50.8	45.8	53.4	53.1	52.1 54.6
Mass of water, M_w (g)	4.8	10.8	9.1	8.8	6.2	13.9	14.6	14.4	16.9 14.4
Mass of dry soil, M_{ds} (g)	36.7	29.3	26.9	27	21.7	30.4	37.7	37.5	36.6 38.6
Water content, W (%)	13.08	36.86	33.83	32.59	28.57	45.72	38.73	38.40	46.17 37.31
Average water content, W_{avg} (%)	24.97		33.21		37.15		38.56		41.74
Dry density, ρ_d (g/cm ³)	1.20		1.24		1.27		1.30		1.25

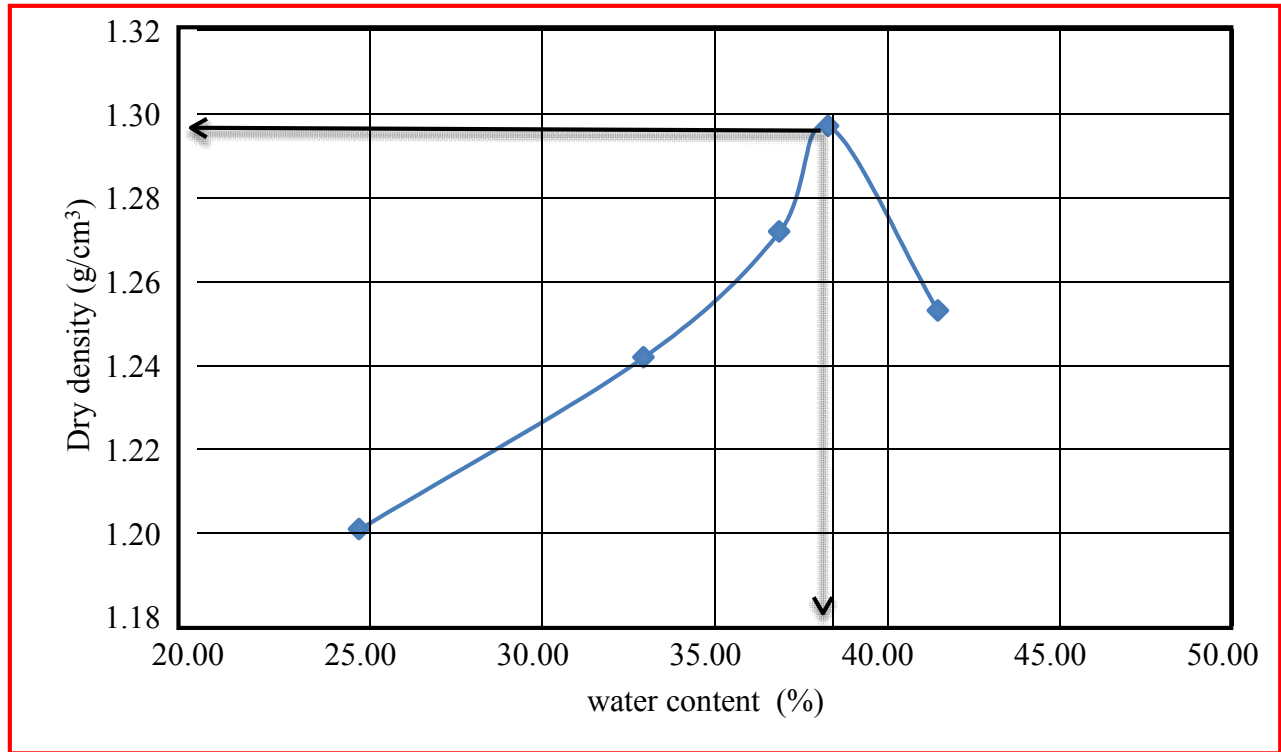


Figure G-1: Dry density V_s water content for pit 1

Table G-2: Compaction test results determination of pit 2

Moisture content V_s dry density					
Test pit 2	Depth :3m				
Determination number	1	2	3	4	5
Mass of mold, M_m (g)	1733	1733	1733	1733	1733
Mass of mold+ compacted soil, M_{ms} (g)	3288	3383	3500	3582	3560
Mass of compacted soil, M_{cs} (g)	1555	1650	1767	1849	1827
Volume of mold, V_m (cm^3)	944	944	944	944	944
Bulk density, ρ_b (g/cm^3)	1.65	1.75	1.87	1.96	1.94
Water content, w (%)	12.66	16.72	22.31	30.78	35.72
Dry density, ρ_d (g/cm^3)	1.46	1.50	1.53	1.50	1.43

Water content at 3m										
Test trial	1		2		3		4		5	
Container number	26	G2	H10	IL6	P3L3	B29	A49	L3	50	25
Mass of container, M_c	15.6	15.7	15.8	15.8	11	15.2	16	15.6	15.8	15.9
Mass of container + wet soil, M_{cws} (g)	50.6	54.4	64.2	60	51.9	57.1	72.3	73.6	66.5	58.7
Mass of container + dry soil, M_{cds} (g)	47.02	49.67	56.6	54.3	44.3	49.6	59.8	59.2	54.2	46.6
Mass of water, M_w (g)	3.58	4.73	7.6	5.7	7.6	7.5	12.5	14.4	12.3	12.1
Mass of dry soil, M_{ds} (g)	31.42	33.97	40.8	38.5	33.3	34.4	43.8	43.6	38.4	30.7
Water content, W (%)	11.39	13.92	18.63	14.81	22.82	21.80	28.54	33.03	32.03	39.41
Average water content, W_{avg} (%)	12.66		16.72		22.31		30.78		35.72	
Dry density, ρ_d (g/cm ³)	1.46		1.50		1.53		1.50		1.43	

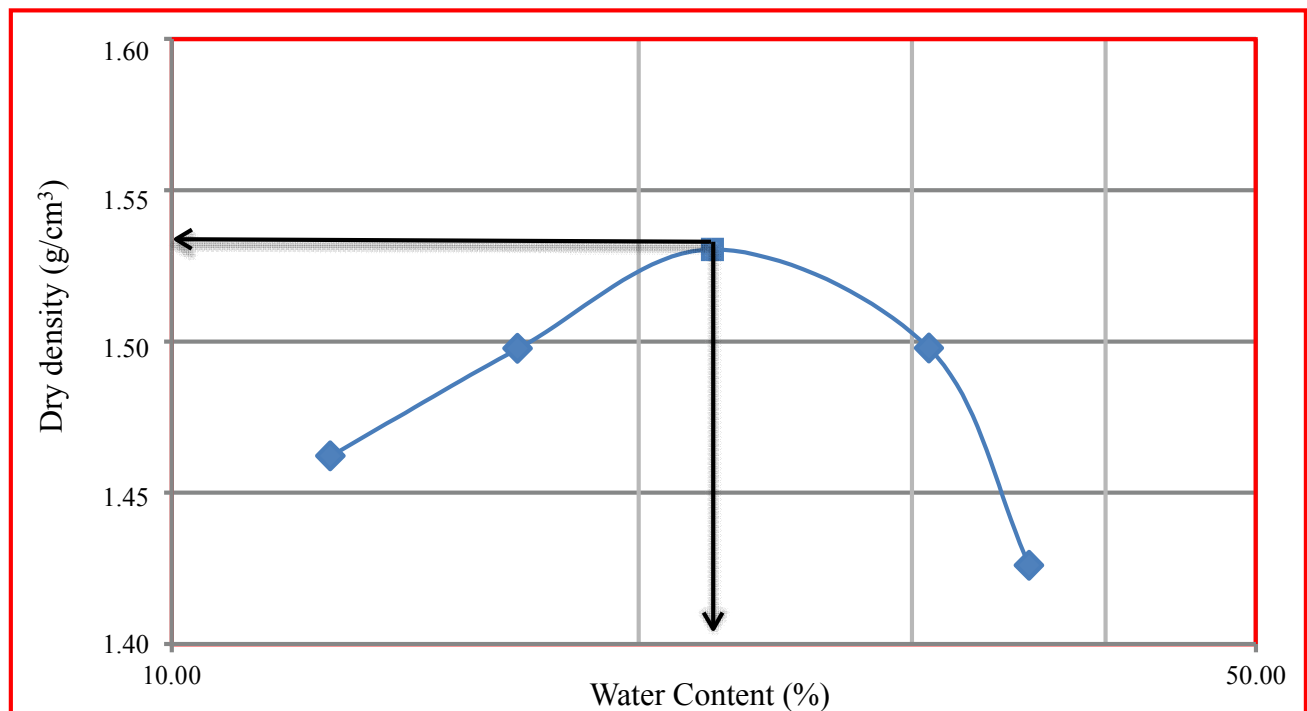


Figure G-2: Dry density Vs water content for pit

Table G-3: Compaction test results determination of pit 3

Moisture content VS dry density					
Test pit 3	Depth=3m				
Determination number	1	2	3	4	5
Mass of mold, M_m (g)	1733	1733	1733	1733	1733
Mass of mold+ compacted soil, M_{ms} (g)	3365	3490	3590	3571	3580.4
Mass of compacted soil, M_{cs} (g)	1632	1757	1857	1838	1847.4
Volume of mold, V_m (cm ³)	944	944	944	944	944
Bulk density, ρ_b (g/cm ³)	1.73	1.86	1.97	1.95	1.96
Water content, w (%)	14.73	18.32	22.14	24.06	27.43
Dry density, ρ_d (g/cm ³)	1.51	1.57	1.61	1.57	1.54

Water content of pit 3 at 3m										
Test trial	1		2		3		4		5	
Container number	T1	P1	P3	TP3	G2	12	62	FL105	9W5	7
Mass of container, M_c (g)	15.4	15.7	15.8	15.8	15.7	15.7	15.3	15.3	15.8	10.8
Mass of container + wetsoil, M_{cws} (g)	77.9	83.3	67.4	52.2	41.5	41.2	76.2	66.8	52.8	54.2
Mass of container + dry soil, M_{cds} (g)	69.8	74.7	59.5	46.5	36.7	36.7	64.4	56.8	44.8	44.9
Mass of water, M_w (g)	8.1	8.6	7.9	5.7	4.8	4.5	11.8	10	8	9.3
Mass of dry soil, M_{ds} (g)	54.4	59	43.7	30.7	21	21	49.1	41.5	29	34.1
Water content, W (%)	14.89	14.58	18.08	18.57	22.86	21.43	24.03	24.10	27.59	27.27
Average water content, W_{avg} (%)	14.73		18.32		22.14		24.06		27.43	
Dry density, ρ_d (g/cm ³)	1.51		1.57		1.61		1.57		1.54	

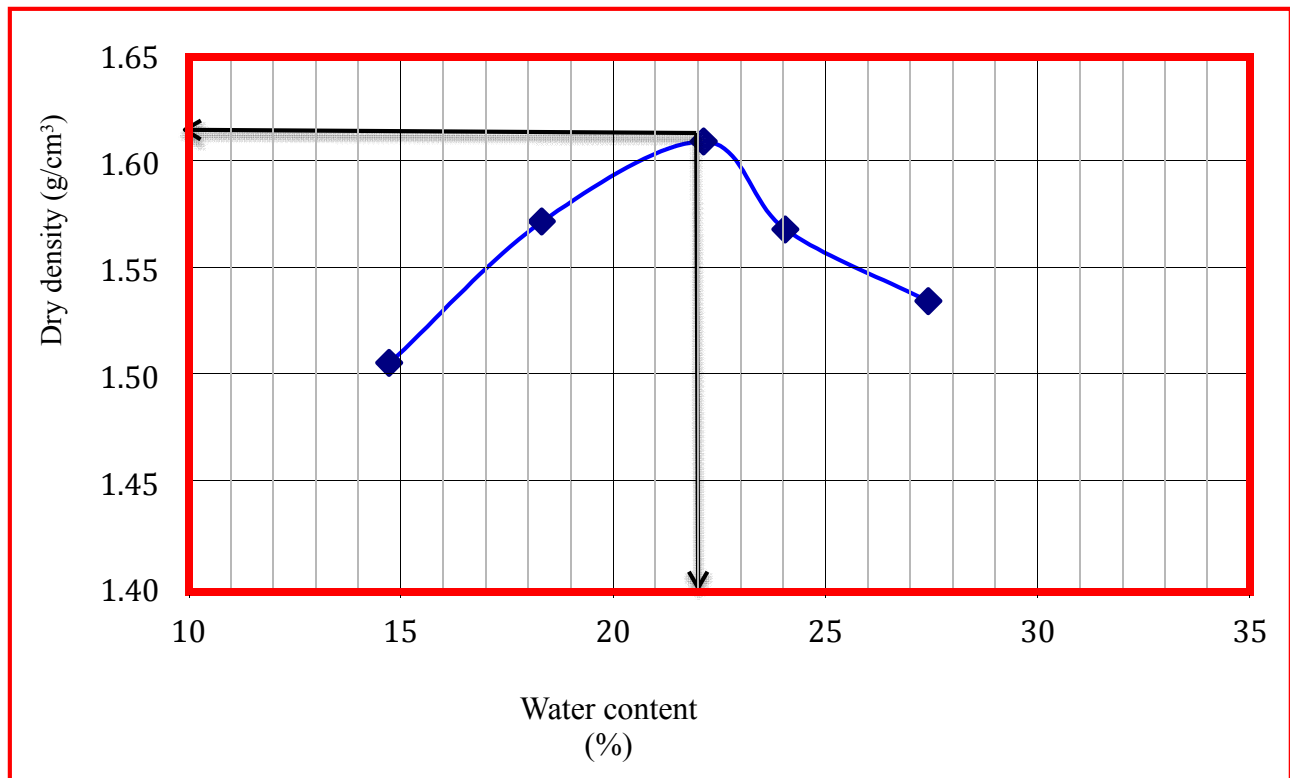


Figure G-3:- Dry density Vs water content for pit 3

Table G-4:- Compaction test results determination of pit 4

Moisture content VS dry density					
Test pit 4	Depth: 3m				
Determination number	1	2	3	4	5
Mass of mold, M_m (g)	1733	1733	1733	1733	1733
Mass of mold+ compacted soil, M_{ms} (g)	3170	3281	3360	3420	3388
Mass of compacted soil, M_{cs} (g)	1437	1548	1627	1687	1655
Volume of mold, V_m (cm ³)	944	944	944	944	944
Bulk density, ρ_b (g/cm ³)	1.52	1.64	1.72	1.79	1.75
Water content, w (%)	24.09	27.70	30.29	32.45	36.52
Dry density, ρ_d (g/cm ³)	1.23	1.28	1.32	1.35	1.28

Water content of pit 4 @ 3m										
Test trial	1		2		3		4		5	
Container number	50	30	12	18	20	15	HM	10	W3	25
Mass of container, M_c (g)	16.2	15.9	15.7	22.2	28	15.3	29.1	15.1	15.5	16
Mass of container + wet soil, M_{cws} (g)	53.9	52.5	52	55	55	57	62	59.8	66	69
Mass of container + dry soil, M_{cds} (g)	47	45	44	48	48.6	47.5	53.9	48.9	53	54.3
Mass of water, M_w (g)	6.9	7.5	8	7	6.4	9.5	8.1	10.9	13	14.7
Mass of dry soil, M_{ds} (g)	30.8	29.1	28.3	25.8	20.6	32.2	24.8	33.8	37.5	38.3
Water content, W (%)	22.40	25.77	28.27	27.13	31.07	29.50	32.66	32.25	34.67	38.38
Average water content, W_{avg} (%)	24.09		27.70		30.29		32.45		36.52	
Dry density, ρ_d (g/cm ³)	1.23		1.28		1.32		1.35		1.28	

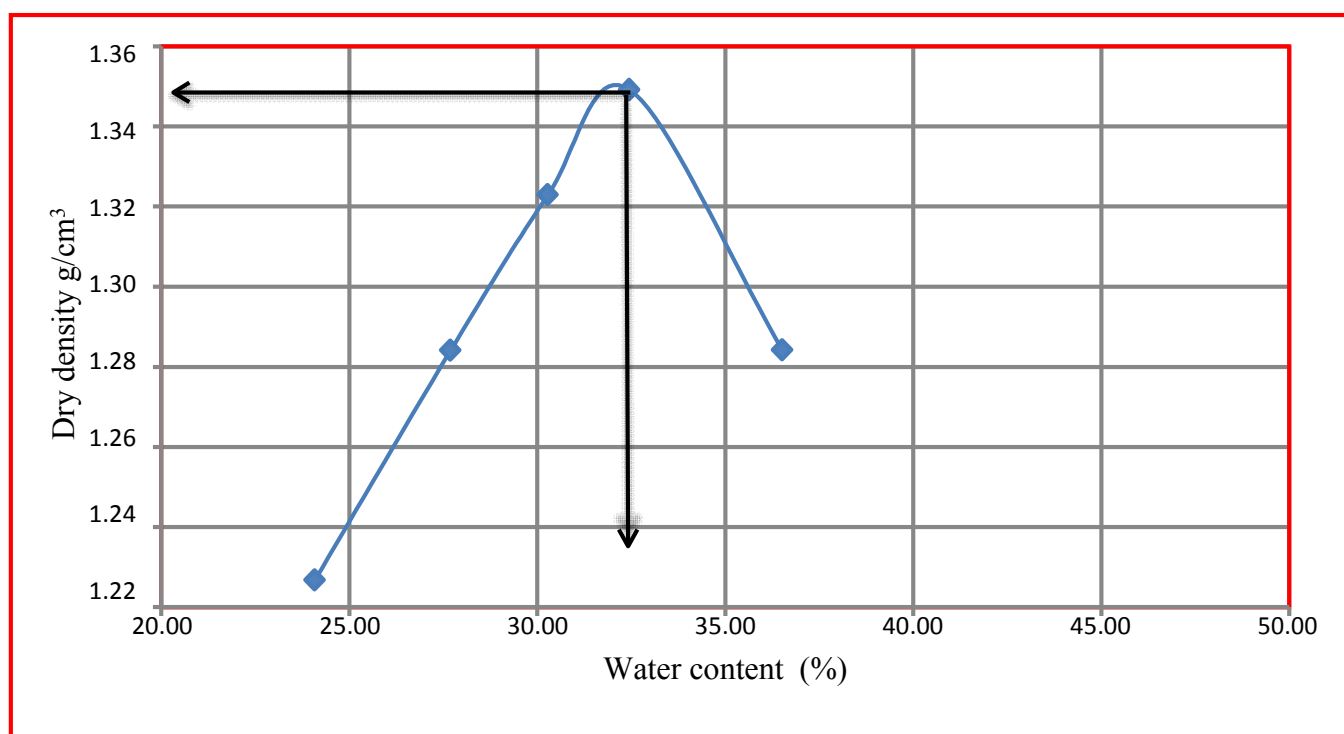


Figure G-4:- Dry density Vs water content for pit 4

Appendix H:-Consolidation test results

Table H-1:- Determination of pre-consolidation pressure for pit1

Test Pit 1	
[A] In the beginning of the test	
Depth : 3m	
Sample type :	Disturbed
Ring area, A (cm ²)	19.625
Height of sample, H _s (mm)	20
Seating load, kPa	7
Initial void ratio, e _o	1.78
Initial moisture content, W _i (%)	32
Specific gravity, G _s	2.7
Wet density, ρ _{wet} (g/cm ³)	1.57
[B] In the end of the test	
Final moisture content, W _f (%)	33.5
Dry specimen weight , w _{ds} (g)	38.15
Dry density, ρ _d (g/cm ³)	1.31
Height of solids, H _s (mm)	7.20
Final void Ratio, e _f :	1.52

[C]Calculation table:					
Applied pressure (kPa)	Final dial reading (mm)	Change in specimen	Final specimen	Void height, H _v (mm)	Void ratio, e
Loading					
7	6.514	0.00	20.00	12.80	1.78
25	6.519	0.00	20.00	12.80	1.78
50	6.624	0.11	19.89	12.69	1.76
100	6.814	0.30	19.70	12.50	1.74
200	7.114	0.60	19.40	12.20	1.69
400	7.503	0.99	19.01	11.81	1.64
800	7.921	1.41	18.59	11.39	1.58
1600	8.344	1.83	18.17	10.97	1.52
Unloading					
1600	8.344	1.83	18.17	10.97	1.52

Table H-2: Determination of pre-consolidation pressure for pit3

Test pit 3	
Depth 3m	
[A] In the beginning of the test	
Sample type :	Disturbed
Ring area, A (cm ²)	19.625
Height of sample, H _s (mm)	20
Seating load, kPa	7
Initial void ratio, e _o	1.44
Initial moisture content, W _i (%)	12.2
Specific gravity, G _s	2.67
Wet density, ρ _{wet} (g/cm ³)	1.46
[B] In the end of the test	
Final moisture content, W _f (%)	13.22
Dry specimen weight , w _{ds} (g)	43.50
Dry density, ρ _d (g/cm ³)	1.26
Height of solids, H _s (mm)	8.21
Final void Ratio, e _f :	1.14

[C]Calculation table:					
Applied pressure (kPa)	Final dial reading (mm)	Change in specimen	Final specimen	Void Height, H _v (mm)	Void Ratio, e
Loading					
7	9.514	0.00	20.00	11.79	1.44
25	9.519	0.01	20.00	11.79	1.44
50	9.624	0.11	19.89	11.68	1.42
100	10.101	0.59	19.41	11.20	1.36
200	10.514	1.00	19.00	10.79	1.31
400	10.903	1.39	18.61	10.40	1.27
800	11.421	1.91	18.09	9.88	1.20
1600	11.932	2.42	17.58	9.37	1.14
Unloading					
1600	11.932	2.42	17.58	9.37	1.14

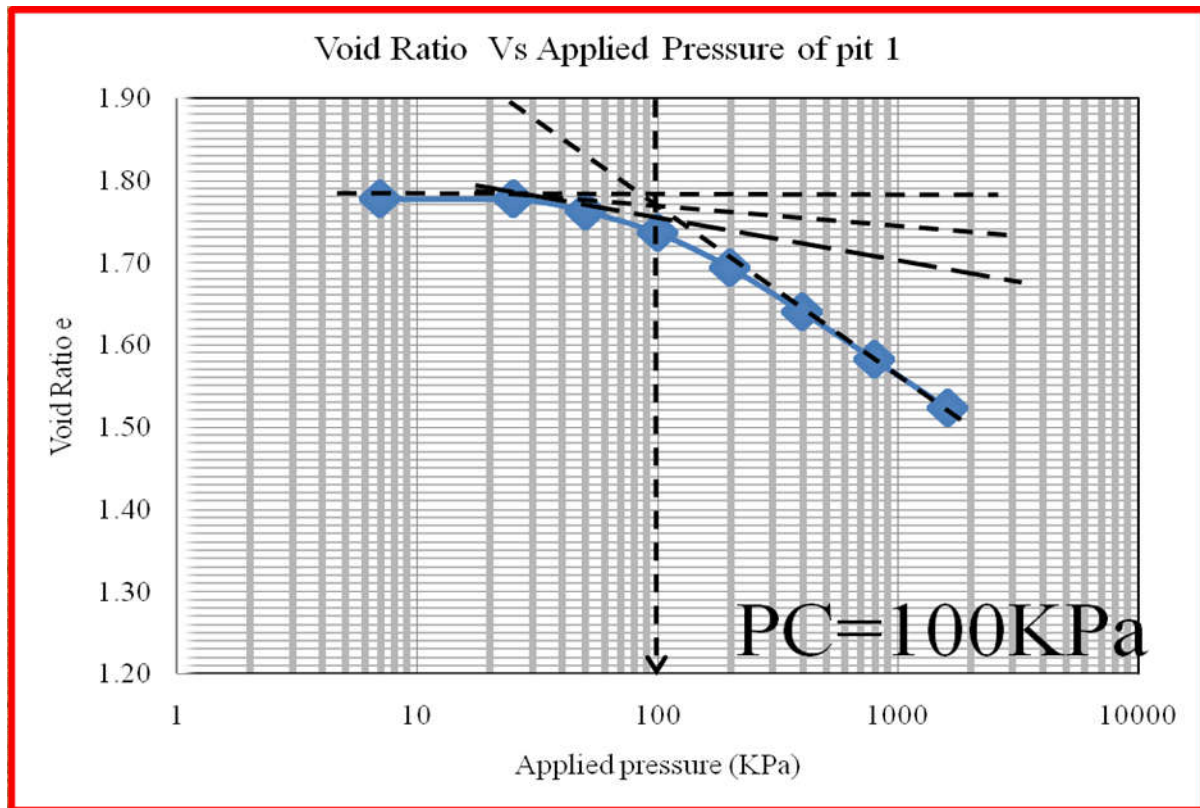


Figure H-1:- Void ratio V_s Pressure for pit 1

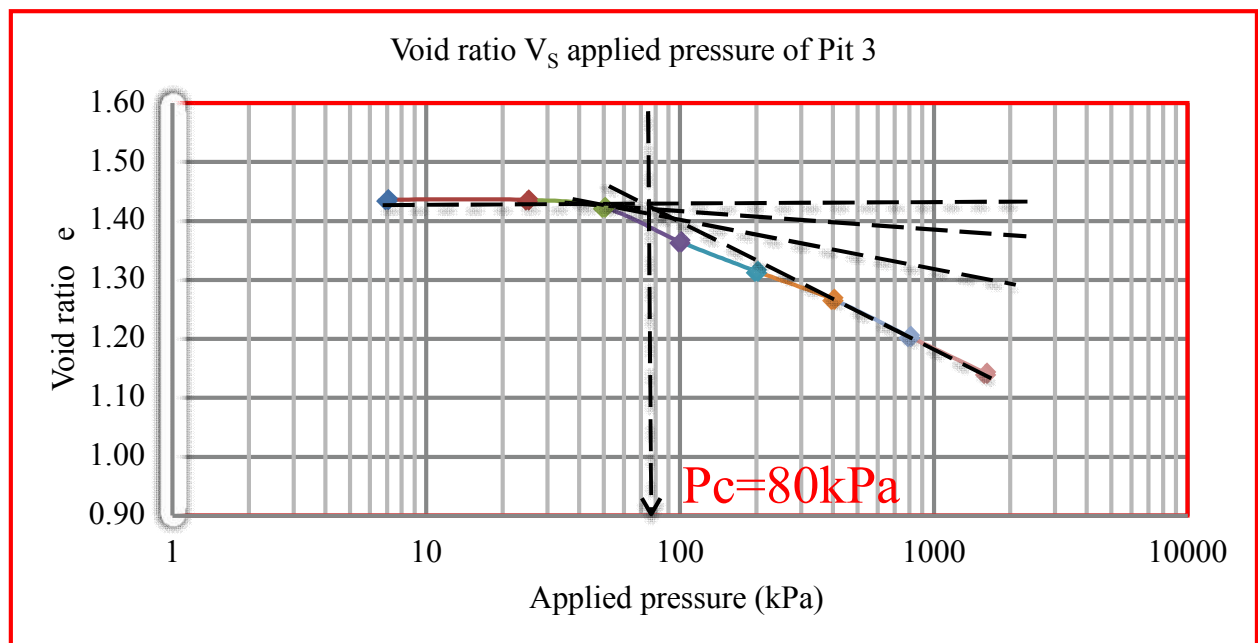


Figure H-2:- Void ratio V_s Pressure for pit 3

Appendix I: - Shear modulus and damping ratio values

Table I-1:- Shear modulus and damping ratio of pit1 at 100kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	4.15	3.15	2.04	0.79	0.51	19.64	21.88	21.25	22.01	25.20
2	4.24	3.18	2.42	0.82	0.68	19.48	21.70	22.06	22.00	25.34
3	4.38	3.17	2.52	0.87	0.81	19.41	21.70	21.81	21.50	25.35
4	4.32	3.27	2.59	0.83	0.93	19.45	21.69	21.73	19.50	25.60
5	4.38	3.25	2.26	1.19	1.01	19.52	17.08	18.02	19.00	25.80
6	4.39	3.34	2.62	1.18	1.05	19.64	20.01	21.54	19.00	26.93
7	4.54	3.35	2.64	1.19	1.07	19.39	21.57	21.53	19.64	26.87
8	4.61	3.46	2.69	1.37	1.14	19.27	21.57	21.45	19.34	26.80
9	4.71	3.48	2.67	1.39	1.16	19.21	21.47	21.23	19.48	26.58
10	4.74	3.51	2.70	1.49	1.19	19.13	21.22	21.27	18.77	27.86
11	4.83	3.58	2.71	1.51	1.16	18.94	21.15	21.17	18.77	26.54
12	4.82	3.60	2.67	1.55	1.18	18.84	19.83	21.84	18.45	26.52
13	4.90	3.67	2.66	1.51	1.14	18.82	20.80	21.54	18.36	26.65
14	5.05	3.69	2.78	1.53	1.16	18.58	20.75	21.57	18.23	26.14
15	5.14	3.78	2.79	1.48	1.32	18.43	20.65	21.51	18.06	25.96
16	5.17	3.77	2.67	1.51	1.36	18.32	20.55	21.31	18.06	25.87
17	5.19	3.80	2.80	1.71	1.26	18.22	19.30	20.31	17.87	25.81
18	5.25	3.91	2.81	1.77	1.33	18.03	20.21	21.17	17.62	25.67
19	5.35	3.99	2.84	1.64	1.24	18.17	19.94	20.89	17.60	25.59
20	5.40	4.02	2.85	1.72	1.40	15.15	16.08	16.42	18.50	26.00
21	5.46	4.02	2.88	1.61	1.41	17.89	19.74	20.62	18.50	25.49
22	5.57	3.90	2.95	1.82	1.41	17.93	16.08	20.58	17.28	25.40
23	5.47	4.03	2.93	1.83	1.43	17.93	19.65	20.51	17.11	25.28
24	5.59	4.09	2.76	1.83	1.47	17.60	19.59	20.50	17.19	25.04
25	5.70	4.22	3.03	1.87	1.46	17.57	19.31	20.48	17.10	25.00
26	5.69	4.29	3.11	2.10	1.51	17.38	19.20	20.41	16.96	24.92
27	5.65	4.33	3.11	1.95	1.40	17.30	19.08	20.40	16.96	24.87
28	5.74	4.08	3.20	2.05	1.47	17.13	19.06	20.35	16.94	24.32
29	5.74	4.37	3.22	2.14	1.54	17.12	19.07	20.36	16.85	24.36
30	5.65	4.42	3.24	2.26	1.62	17.03	19.04	20.34	16.74	24.67
31	5.88	4.43	3.27	2.30	1.66	17.00	19.00	20.33	16.70	24.27
32	5.82	4.37	3.30	2.44	1.75	16.99	19.00	20.33	16.79	23.90
33	5.86	4.53	3.27	2.28	1.64	16.96	18.95	20.31	16.64	22.46
34	5.97	4.55	3.34	2.42	1.74	16.83	18.82	20.27	16.64	22.89
35	6.04	4.58	3.38	2.51	1.80	16.78	18.63	20.12	16.55	23.36
36	6.08	4.61	3.38	2.52	1.82	16.69	18.64	19.94	16.43	22.46
37	6.24	4.61	3.39	2.34	1.69	16.67	18.52	19.98	16.50	22.29
38	6.33	4.67	3.43	2.51	1.80	16.65	18.41	19.66	16.52	22.42
39	6.40	4.69	3.43	2.33	1.68	16.55	18.01	19.81	16.42	21.74
40	6.54	4.74	3.39	2.62	1.89	13.89	14.99	15.24	16.52	22.50

Table I-2:- Shear modulus and damping ratio of pit1 at 200kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	7.61	5.60	3.66	2.11	1.44	17.11	18.03	22.61	23.11	22.07
2	7.79	6.68	4.36	2.43	1.60	18.88	20.06	22.97	23.59	24.75
3	7.87	6.75	4.38	2.51	1.60	18.73	19.95	22.83	23.53	24.67
4	7.97	6.82	4.38	2.63	1.61	18.44	19.54	22.68	23.63	24.48
5	8.03	6.94	4.39	2.59	1.63	18.83	19.54	22.58	23.47	24.36
6	8.11	7.02	4.41	2.49	1.63	18.14	19.54	22.42	23.50	24.26
7	8.02	7.16	4.46	2.59	1.64	18.19	19.55	22.42	23.45	24.22
8	8.22	7.26	4.49	2.81	1.70	18.34	19.55	22.39	23.32	24.19
9	8.40	7.33	4.50	2.91	1.75	18.63	19.34	22.27	23.31	24.16
10	8.49	7.48	4.59	3.11	1.81	18.20	19.70	22.16	23.29	24.07
11	8.64	7.50	4.62	3.01	1.81	18.87	19.08	21.94	23.31	24.03
12	8.68	7.63	4.73	3.11	1.82	18.61	19.08	22.16	23.19	24.03
13	8.64	7.50	4.80	3.30	1.83	18.89	18.99	21.67	23.16	23.96
14	8.77	7.62	4.78	2.94	1.84	17.95	18.82	21.53	22.91	23.90
15	8.82	7.72	4.90	3.34	1.85	17.98	18.28	21.47	22.73	23.90
16	8.96	7.86	4.98	3.21	1.87	17.31	19.60	22.67	22.69	23.93
17	9.03	7.97	5.15	3.33	1.86	17.03	18.34	22.44	22.53	23.81
18	9.15	8.12	5.13	3.00	1.87	16.97	17.95	22.16	23.50	23.65
19	9.21	8.15	5.12	3.10	1.88	16.75	17.91	22.34	22.50	23.60
20	9.26	8.18	5.25	3.40	1.92	14.86	16.06	22.79	22.00	20.88
21	9.28	8.14	5.26	3.63	1.95	15.84	17.95	20.52	21.50	23.30
22	9.30	8.16	5.38	3.56	1.95	15.89	17.99	20.70	19.90	23.26
23	9.36	8.27	5.33	3.45	2.04	15.30	17.46	20.25	22.30	23.25
24	9.48	8.30	5.47	4.03	2.08	15.19	16.96	20.00	21.89	23.22
25	9.57	8.24	5.61	3.66	2.16	15.08	18.51	19.73	21.85	23.17
26	9.59	8.30	5.71	3.41	2.16	14.91	17.21	19.91	21.75	23.10
27	9.65	8.56	5.86	3.69	2.17	14.91	16.78	19.73	21.22	23.01
28	9.73	8.57	5.96	3.55	2.16	14.91	16.47	19.51	21.12	22.98
29	9.73	8.58	6.08	3.65	2.18	14.79	17.83	20.54	20.95	22.94
30	9.86	8.63	6.12	3.91	2.22	14.97	17.54	19.54	20.95	22.88
31	10.19	8.67	6.20	3.45	2.23	14.76	16.46	20.89	20.98	22.60
32	10.19	8.87	6.18	3.94	2.26	14.32	16.04	21.13	20.93	22.66
33	10.33	8.93	6.23	3.83	2.28	14.60	15.89	18.94	20.87	22.55
34	10.34	9.02	6.27	3.92	2.31	14.55	15.92	19.74	20.78	22.59
35	10.38	9.19	6.22	4.05	2.34	14.01	16.40	19.49	20.84	22.38
36	10.36	9.21	6.36	4.41	2.35	13.90	15.92	18.50	20.65	22.36
37	10.60	9.26	6.42	3.55	2.43	13.81	16.02	18.48	20.54	22.20
38	10.74	9.36	6.33	4.45	2.42	14.51	15.06	18.45	20.45	22.14
39	10.77	9.35	6.47	4.60	2.46	13.02	15.80	18.30	20.35	22.13
40	10.87	9.44	6.50	4.41	2.50	12.16	13.80	18.62	20.22	19.26

Table I-3:- Shear modulus and damping ratio of pit1 at 300kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	9.90	8.50	6.20	3.80	3.23	11.24	14.87	16.04	18.72	20.59
2	10.00	8.50	6.30	3.82	3.25	11.04	14.67	16.02	17.96	19.75
3	10.00	8.64	6.31	3.83	3.36	11.00	14.50	15.61	17.86	19.65
4	10.05	8.66	6.34	3.91	3.44	11.03	14.48	15.74	17.79	19.57
5	9.56	8.98	6.34	4.03	3.56	10.48	14.30	15.48	17.72	19.42
6	10.12	8.93	6.44	4.15	3.68	10.58	14.45	15.68	17.62	19.38
7	10.14	8.94	6.48	4.12	3.65	10.48	14.31	15.61	17.78	19.56
8	10.13	9.04	6.50	4.22	3.75	10.25	14.31	15.63	17.67	19.44
9	10.18	9.07	6.69	4.27	3.80	10.04	14.39	15.05	17.32	19.05
10	10.31	9.09	6.70	4.37	3.90	9.76	14.22	14.85	17.79	19.57
11	10.21	9.04	6.71	4.46	3.99	9.73	14.21	15.04	17.86	19.65
12	10.09	9.09	6.72	4.52	4.05	9.68	14.07	14.75	17.15	18.87
13	10.24	9.08	6.75	4.50	3.92	9.54	13.91	14.70	17.18	18.90
14	10.33	9.12	6.79	4.49	3.91	9.51	13.90	14.52	17.80	19.58
15	10.37	9.19	6.80	4.66	4.08	9.32	13.78	14.42	17.24	18.97
16	10.54	9.04	6.86	4.74	4.16	8.84	13.69	14.30	17.47	19.22
17	10.63	9.16	6.89	4.87	4.29	8.84	13.62	14.18	17.46	19.20
18	10.66	9.00	6.93	4.95	4.37	8.67	13.50	14.46	17.34	19.07
19	10.65	9.23	7.06	4.97	4.39	8.48	13.47	14.33	16.99	18.69
20	10.59	9.25	7.11	5.05	4.47	8.46	13.27	14.59	16.77	18.45
21	10.63	9.27	7.26	5.01	4.43	8.36	13.13	14.44	16.88	18.57
22	10.53	9.36	7.28	5.12	4.54	8.11	13.18	13.93	16.30	17.93
23	10.62	9.36	7.16	5.24	4.66	8.03	13.12	14.72	15.86	17.44
24	10.73	9.36	7.32	5.39	4.92	8.09	13.05	14.45	15.59	17.15
25	10.75	9.46	7.36	5.43	4.96	7.89	13.07	14.10	15.85	17.43
26	10.68	9.47	7.41	5.55	5.08	7.54	12.93	13.93	15.25	16.78
27	10.81	9.45	7.47	5.64	5.17	7.61	12.98	13.78	15.01	16.51
28	10.73	9.53	7.55	5.85	5.38	7.50	12.71	13.90	14.65	16.11
29	10.73	9.09	7.51	5.90	5.43	7.40	12.40	13.46	14.77	16.25
30	10.89	9.58	7.66	5.96	5.49	7.26	12.31	13.49	14.56	16.02
31	11.08	9.59	7.62	6.10	5.63	7.28	12.18	13.36	14.53	15.99
32	11.15	9.68	7.64	6.18	5.71	6.97	12.02	13.20	14.35	15.79
33	11.18	9.66	7.83	6.28	5.81	6.78	11.99	13.67	14.31	15.74
34	11.28	9.77	7.87	6.23	5.76	6.66	11.69	13.12	14.31	15.74
35	11.31	9.77	7.96	6.34	5.87	6.60	11.49	13.01	14.04	15.44
36	11.40	9.69	8.06	6.37	5.90	6.40	11.32	13.22	14.18	15.60
37	11.61	9.82	8.22	6.53	6.06	6.38	11.15	12.48	13.58	14.94
38	11.66	9.93	8.40	6.68	6.21	6.29	10.78	12.52	14.05	15.45
39	11.74	9.88	8.31	6.57	6.10	6.14	10.37	12.34	13.13	14.44
40	11.74	9.93	8.41	6.71	6.24	6.05	10.37	12.36	13.13	14.44

Table I-4:- Shear modulus and damping ratio of pit1 at 400kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	10.84	8.51	6.48	3.85	3.32	11.26	12.16	13.86	15.03	18.47
2	10.95	8.76	6.94	4.37	3.37	11.09	12.02	13.79	14.97	18.19
3	10.82	8.89	6.93	4.60	3.35	10.99	11.97	13.72	14.94	17.99
4	10.85	8.64	6.89	4.40	3.40	10.99	11.92	13.75	14.90	17.92
5	10.70	9.29	7.32	4.48	3.65	10.67	11.69	13.74	14.42	17.54
6	11.46	9.60	7.62	4.55	3.54	10.64	11.34	13.60	14.88	17.71
7	11.53	9.97	7.64	4.52	3.52	10.29	11.46	13.40	14.81	17.83
8	10.88	9.77	7.68	4.49	3.50	10.15	11.46	13.41	14.80	17.77
9	11.52	9.88	7.71	4.46	3.49	10.97	11.37	13.32	14.79	17.74
10	11.34	8.99	7.74	4.21	3.56	10.61	10.77	13.29	14.77	17.69
11	11.11	9.40	7.73	4.44	3.83	10.10	11.31	13.22	14.72	17.32
12	11.48	10.11	7.76	4.43	3.81	10.44	10.77	13.18	14.66	17.61
13	11.27	9.69	7.77	4.40	3.80	9.93	10.52	13.08	14.61	17.58
14	11.28	10.11	7.78	4.39	3.79	10.13	10.27	13.18	14.54	17.52
15	11.31	10.28	7.78	4.21	3.60	9.85	10.05	13.13	14.38	17.31
16	11.54	9.98	7.81	4.36	3.77	9.85	10.17	12.89	14.34	17.30
17	11.29	10.09	7.80	4.35	3.76	9.52	10.05	12.68	14.33	17.26
18	11.46	10.01	7.81	4.34	3.75	9.55	9.86	12.72	14.29	17.19
19	11.61	10.28	7.85	4.33	3.74	9.48	9.82	12.50	14.15	17.14
20	11.40	9.88	7.86	4.32	3.62	9.51	9.70	12.69	14.16	17.14
21	11.63	9.60	7.94	4.31	3.73	9.31	9.63	12.98	14.19	17.01
22	11.55	10.20	7.99	4.30	3.73	9.32	9.70	12.39	14.07	16.90
23	11.22	9.98	7.81	4.30	3.72	9.22	9.61	12.37	13.97	16.89
24	11.39	10.01	8.25	4.29	3.71	9.25	10.07	12.36	13.91	16.87
25	11.46	10.26	8.35	4.28	3.71	9.19	9.59	12.36	13.86	16.83
26	11.58	10.02	8.00	4.27	3.70	9.25	9.63	12.26	13.77	16.75
27	11.38	10.27	8.01	4.26	3.70	9.17	9.54	12.30	13.67	16.74
28	11.55	10.14	8.02	4.25	3.69	9.09	9.48	12.15	13.59	16.68
29	11.55	10.20	8.12	4.25	3.69	9.19	9.56	12.17	13.55	16.67
30	11.43	10.22	8.25	4.25	3.68	8.48	9.16	12.12	13.45	16.65
31	11.48	10.14	8.35	4.24	3.68	8.43	9.03	12.07	13.44	16.59
32	11.38	10.31	8.18	4.24	3.67	8.44	8.91	12.16	13.29	16.54
33	11.33	9.92	8.25	4.23	3.67	8.45	8.97	12.04	13.23	16.56
34	11.34	10.29	8.35	4.22	3.67	9.52	8.71	11.90	13.23	16.47
35	11.51	10.27	8.65	4.27	3.75	8.92	9.08	11.87	13.12	16.48
36	11.51	10.33	8.55	4.21	3.66	9.15	8.71	11.87	13.12	16.46
37	11.41	10.33	8.56	4.21	3.66	8.41	8.70	11.86	13.07	16.40
38	11.42	10.33	8.69	4.21	3.65	8.38	8.50	12.01	12.94	16.40
39	11.37	10.33	8.78	4.20	3.65	8.11	8.28	11.87	12.76	16.43
40	11.38	10.33	8.99	4.28	3.78	8.27	8.54	11.66	12.76	16.37

Table I-5:- Shear modulus and damping ratio of pit 2 at 100kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	5.18	3.21	2.40	1.56	1.15	12.36	16.38	22.85	24.57	27.74
2	5.19	3.31	2.45	1.37	1.39	12.35	16.37	18.13	23.23	27.78
3	5.25	3.61	2.48	1.49	1.43	12.33	16.14	18.09	23.20	26.02
4	5.30	3.73	2.50	1.59	1.44	12.32	16.01	18.05	24.17	27.62
5	5.32	3.79	2.66	1.87	1.50	12.42	16.59	18.91	20.82	24.47
6	5.33	3.86	2.13	1.82	1.58	12.16	15.94	17.94	24.02	27.67
7	5.35	4.35	2.40	1.90	1.62	12.11	15.92	17.93	23.03	27.70
8	5.36	4.29	2.37	1.93	1.68	12.01	15.92	17.83	23.02	23.66
9	5.37	4.16	2.29	1.96	1.43	11.99	15.91	17.88	23.00	27.63
10	5.38	4.60	2.54	1.77	1.64	11.90	15.90	17.70	22.95	29.35
11	5.39	3.82	2.11	1.99	1.67	11.88	15.86	17.61	22.85	27.50
12	5.42	4.64	2.56	2.03	1.15	11.74	15.79	17.62	22.72	27.42
13	5.45	4.46	2.46	2.00	1.58	11.73	15.76	17.59	22.89	27.46
14	5.49	4.26	2.35	1.94	1.63	11.60	15.71	17.40	22.72	27.44
15	5.48	4.62	2.54	1.91	1.60	11.56	15.70	17.20	22.71	27.42
16	5.24	4.12	2.27	1.93	1.56	11.47	15.63	17.13	22.61	27.35
17	5.35	4.59	2.53	1.94	1.60	11.38	15.59	16.97	22.41	27.22
18	5.39	4.73	2.61	1.91	1.02	11.36	15.56	16.95	22.42	27.25
19	5.45	4.01	2.21	1.90	1.54	11.31	15.55	16.92	22.32	27.24
20	5.54	4.64	2.56	1.90	1.67	11.28	15.53	16.91	22.50	27.15
21	5.65	4.58	2.53	1.91	1.52	11.20	15.52	16.86	22.40	27.02
22	5.68	4.08	2.25	1.91	1.52	11.03	15.50	16.73	22.41	27.01
23	5.69	4.47	2.47	1.88	1.44	11.01	15.46	16.72	22.30	26.96
24	5.70	4.31	2.38	1.87	1.30	11.00	15.35	16.67	21.96	26.90
25	5.72	4.41	2.43	1.90	1.67	11.01	15.33	16.67	21.89	26.89
26	5.71	4.40	2.42	1.88	1.26	10.94	15.23	16.55	21.77	26.75
27	5.72	4.41	2.43	1.86	1.56	10.93	15.24	16.54	21.74	26.64
28	5.72	4.33	2.39	1.88	1.27	10.94	15.21	16.63	21.63	26.60
29	5.78	4.45	2.45	1.88	1.52	10.92	15.13	16.59	21.63	26.58
30	5.79	4.32	2.38	1.88	1.71	10.90	15.13	16.43	21.62	26.44
31	5.86	4.54	2.50	1.87	1.54	10.88	15.02	16.42	21.45	26.49
32	5.85	4.15	2.29	1.86	1.23	10.74	15.02	16.42	21.42	26.42
33	5.87	4.40	2.42	1.88	1.30	10.75	14.97	16.41	21.24	26.26
34	5.50	4.29	2.36	1.89	1.36	10.71	14.96	16.41	21.24	26.27
35	5.89	4.53	2.50	2.05	1.73	10.67	14.94	16.36	21.29	26.18
36	5.90	4.82	2.66	2.04	1.35	10.66	14.91	16.34	21.22	25.90
37	5.95	3.85	2.12	2.08	1.40	10.61	14.90	16.34	21.10	25.84
38	5.56	4.84	2.67	2.07	1.22	10.58	14.89	16.33	21.02	25.69
39	5.57	5.15	2.84	2.03	1.52	10.53	14.85	16.31	21.01	25.58
40	5.90	5.15	2.88	2.06	1.83	10.52	14.81	16.28	21.01	25.46

Table I-6:- Shear modulus and damping ratio of pit 2 at 200kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	7.30	4.42	2.79	1.66	1.00	9.48	15.77	22.27	24.51	25.75
2	7.31	4.84	2.60	1.52	1.21	7.90	15.66	23.09	23.47	25.65
3	7.30	5.67	3.26	1.60	1.21	7.89	15.66	20.30	23.36	25.60
4	7.90	5.31	3.05	1.68	1.19	7.87	15.41	20.19	23.30	25.60
5	7.59	4.89	2.81	1.76	1.20	9.30	15.54	20.03	23.30	24.00
6	7.80	5.03	2.89	1.85	1.22	7.68	15.54	20.03	24.04	25.05
7	7.90	5.05	2.90	1.91	1.19	7.55	15.48	19.96	23.21	25.27
8	7.94	4.87	2.80	1.93	1.16	7.48	15.48	19.92	23.20	24.97
9	7.99	4.93	2.83	1.95	1.14	7.40	15.37	20.10	22.92	24.80
10	7.69	5.05	2.90	1.81	1.28	7.97	15.32	19.76	22.83	24.84
11	7.70	4.90	2.82	1.97	1.10	7.21	15.30	19.67	22.77	24.56
12	7.85	4.76	2.73	2.00	1.08	7.10	15.11	19.63	22.72	24.44
13	8.25	5.14	2.95	1.98	1.07	7.03	15.19	19.68	22.72	24.37
14	8.27	5.19	2.98	1.94	1.05	7.01	14.96	19.60	22.62	24.31
15	8.28	5.00	2.87	1.91	1.30	8.05	14.85	19.54	22.56	24.27
16	7.25	5.10	2.93	1.93	1.03	6.92	14.72	19.58	22.51	24.27
17	8.35	5.14	2.95	1.94	1.01	6.91	14.40	19.23	22.32	22.29
18	8.35	5.23	3.00	1.92	1.00	6.90	14.31	19.36	22.28	22.14
19	8.38	5.15	2.96	1.91	1.00	6.88	14.28	19.33	22.23	21.94
20	7.83	5.00	2.87	1.91	1.31	8.15	14.24	19.29	22.22	21.89
21	7.75	5.30	3.04	1.92	0.98	6.61	14.15	19.24	22.11	21.78
22	7.80	5.31	3.05	1.92	0.98	6.62	13.93	19.12	22.11	21.37
23	8.00	5.15	2.96	1.89	0.97	6.54	13.82	19.08	21.97	21.29
24	8.11	5.25	3.01	1.89	0.96	6.50	13.64	19.05	21.77	21.23
25	8.15	5.36	3.08	1.90	1.34	8.16	13.45	19.05	21.75	21.13
26	8.18	5.27	3.02	1.90	0.95	6.34	13.38	19.03	21.73	21.05
27	8.20	5.06	2.91	1.88	0.95	6.24	13.25	18.99	21.69	21.00
28	8.35	5.49	3.15	1.89	0.94	6.23	13.13	18.96	21.68	20.90
29	8.30	5.50	3.16	1.89	0.93	6.15	13.00	18.99	21.61	20.67
30	8.75	5.21	2.99	1.89	1.35	8.27	12.89	18.62	21.60	20.57
31	8.90	5.39	3.10	1.88	0.93	6.06	12.72	18.83	21.56	20.14
32	9.00	5.54	3.18	1.88	0.93	5.95	12.66	18.60	21.54	20.13
33	8.18	5.36	3.08	1.89	0.92	5.95	12.62	18.49	21.49	19.95
34	8.30	5.14	2.95	1.90	0.91	5.91	12.46	18.62	21.49	19.94
35	8.35	5.62	3.23	2.02	1.37	8.28	12.33	18.61	21.43	19.90
36	8.38	5.58	3.21	2.01	0.91	5.78	12.23	18.49	21.40	19.36
37	8.45	5.37	3.08	2.04	0.90	5.75	12.22	18.54	21.27	19.32
38	8.48	5.45	3.13	2.03	0.90	5.69	12.14	18.32	20.98	19.16
39	8.50	5.62	3.23	2.01	0.90	5.64	12.07	19.28	20.88	19.11
40	8.55	5.49	3.15	2.03	1.39	8.39	11.91	18.14	18.42	19.04

Table I-7:- Shear modulus and damping ratio of pit 2 at 300kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	10.15	5.62	6.37	3.65	2.99	8.94	13.96	19.68	22.75	23.13
2	11.31	6.83	6.46	4.37	3.31	8.87	13.57	19.49	22.81	24.58
3	11.83	7.55	6.44	4.20	3.25	8.83	13.41	19.32	22.77	24.48
4	12.31	7.80	6.35	4.05	3.22	8.80	13.41	19.07	22.75	24.29
5	11.53	8.28	6.32	3.73	3.23	8.79	13.40	18.42	22.75	23.04
6	11.91	9.14	6.36	3.94	3.17	8.76	13.40	19.17	22.65	24.20
7	12.65	8.78	6.40	3.92	3.12	8.74	13.26	18.97	22.57	24.14
8	12.07	9.61	6.47	3.81	3.10	8.70	13.26	17.51	22.55	24.09
9	12.47	8.50	6.53	3.81	3.09	8.70	13.25	18.53	22.46	24.01
10	11.81	9.68	6.58	3.76	3.45	8.66	13.23	18.41	22.35	24.00
11	11.96	8.95	6.56	3.55	3.06	8.59	13.15	18.37	22.31	23.99
12	12.43	9.35	6.61	4.52	3.12	8.58	13.25	18.20	22.22	23.93
13	12.41	9.36	6.64	3.79	3.26	8.55	13.11	17.65	22.16	23.92
14	12.41	9.07	6.65	3.89	3.33	8.50	13.06	18.17	22.09	23.86
15	11.66	9.57	6.65	3.85	3.48	8.41	13.02	17.88	22.11	23.79
16	12.35	9.31	6.70	3.88	3.36	8.40	13.00	18.37	21.93	23.80
17	11.50	9.23	6.69	4.06	3.51	8.39	12.95	17.21	21.91	23.43
18	12.36	9.49	6.69	4.15	3.60	8.28	13.01	17.35	22.19	23.40
19	12.79	9.09	6.69	4.14	3.60	7.98	12.99	17.22	21.27	23.39
20	11.45	9.35	6.70	3.86	3.61	7.55	12.77	17.30	21.35	23.31
21	11.78	9.40	6.70	3.98	3.67	7.47	12.74	18.96	21.91	23.29
22	11.70	9.45	6.70	3.95	3.67	7.41	12.62	17.79	21.95	23.28
23	11.23	8.79	6.70	4.00	3.69	7.34	12.48	17.46	22.21	23.28
24	12.29	8.68	6.71	4.05	3.73	7.27	12.39	17.08	21.42	23.16
25	12.10	9.29	6.70	4.01	3.49	7.24	12.57	17.02	21.20	23.20
26	11.71	9.35	6.69	4.35	3.12	6.99	12.63	16.95	21.32	23.29
27	12.13	9.38	6.71	4.47	3.20	6.86	12.38	16.95	22.43	23.84
28	11.82	9.82	6.74	4.48	3.55	6.72	12.33	16.87	21.56	22.44
29	11.82	9.65	6.71	4.75	3.74	6.59	12.24	16.60	21.37	23.50
30	12.54	9.60	6.72	4.08	3.74	6.49	12.14	16.91	21.08	23.13
31	13.06	9.65	6.72	4.75	3.75	6.26	12.27	16.32	20.99	23.08
32	11.83	9.39	6.72	4.74	3.74	6.23	12.22	16.18	20.85	23.02
33	11.65	9.54	6.74	4.78	3.77	6.15	12.14	16.16	20.79	23.02
34	12.63	9.52	6.71	4.78	3.77	6.16	12.83	15.91	20.79	22.98
35	12.84	9.98	6.71	4.20	3.77	5.97	12.29	15.73	20.48	22.98
36	12.77	9.59	6.72	4.77	3.77	5.89	12.19	16.35	20.40	22.92
37	11.66	9.65	6.71	4.79	3.80	5.76	11.92	15.57	20.28	22.87
38	11.95	9.87	6.71	4.78	3.80	5.62	11.63	15.44	20.23	23.76
39	12.22	9.54	6.71	4.78	3.80	5.54	11.70	15.32	19.98	22.72
40	12.59	9.94	6.74	4.41	3.80	5.27	11.49	15.07	19.98	22.61

Table I-8:- Shear modulus and damping ratio of pit 2 at 400kPa

Strain level	0.01%	0.10%	1%	2.50%	5.00%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G(MPa)					Damping ratio, (%)				
1	15.06	10.54	7.97	4.04	4.01	7.04	9.73	15.75	18.11	19.53
2	15.48	10.84	8.07	4.90	3.97	6.93	9.62	15.67	18.04	20.21
3	15.23	10.80	8.05	4.85	3.94	6.87	9.58	15.59	18.00	19.99
4	13.96	10.30	7.94	4.85	3.93	6.87	9.53	15.63	17.95	19.91
5	15.09	12.14	7.90	4.80	3.95	6.67	9.45	15.45	17.95	19.86
6	16.46	12.22	7.95	4.77	3.87	6.65	9.45	15.46	17.92	19.68
7	16.58	12.96	8.00	4.72	3.84	6.43	9.55	15.23	17.84	19.81
8	15.35	12.57	8.08	4.68	3.81	6.35	9.55	15.23	17.83	19.74
9	16.57	12.79	8.16	4.63	3.77	6.85	9.48	15.14	17.82	19.71
10	16.23	12.55	8.22	4.27	4.04	6.63	9.25	15.10	17.79	19.65
11	15.80	11.82	8.21	4.61	4.57	6.31	9.43	15.02	17.74	15.91
12	16.49	13.25	8.27	4.60	4.53	6.52	8.97	14.98	17.66	19.57
13	16.10	12.40	8.30	4.55	4.51	6.20	8.77	14.86	17.60	19.53
14	16.12	13.25	8.31	4.53	4.49	6.33	8.56	14.98	17.52	19.47
15	16.16	13.59	8.32	4.28	4.13	6.16	8.51	14.92	17.33	19.24
16	16.60	12.98	8.37	4.49	4.45	6.16	8.47	14.65	17.28	19.22
17	16.12	13.20	8.36	4.47	4.43	5.95	8.37	14.41	17.26	19.18
18	16.46	13.05	8.37	4.46	4.42	5.97	8.22	14.45	17.21	19.10
19	16.73	13.58	8.37	4.45	4.41	5.92	8.18	14.21	17.05	19.05
20	16.34	12.78	8.38	4.43	4.16	5.94	8.08	14.42	17.06	19.04
21	16.78	12.22	8.38	4.41	4.37	5.82	8.03	14.75	17.10	18.90
22	16.63	13.42	8.37	4.41	4.37	5.82	8.08	14.08	16.95	18.77
23	16.00	12.99	8.38	4.40	4.36	5.76	8.01	14.05	16.84	18.77
24	16.33	13.05	8.38	4.38	4.34	5.78	8.40	14.05	16.76	18.74
25	16.46	13.55	8.38	4.37	4.33	5.75	7.99	14.04	16.69	18.70
26	16.68	13.06	8.37	4.36	4.32	5.78	8.03	13.93	16.58	18.61
27	16.30	13.57	8.39	4.35	4.31	5.73	7.95	13.98	16.47	18.60
28	16.64	13.31	8.42	4.34	4.30	5.68	7.90	13.81	16.38	18.53
29	16.64	13.43	8.38	4.33	4.29	5.74	7.97	13.82	16.32	18.53
30	16.40	13.46	8.40	4.32	4.29	5.30	7.63	13.78	16.21	18.49
31	16.49	13.30	8.41	4.31	4.28	5.27	7.53	13.72	16.19	18.43
32	16.30	13.65	8.40	4.31	4.27	5.28	7.43	13.82	16.01	18.38
33	16.21	12.86	8.42	4.30	4.26	5.28	7.47	13.69	15.94	18.40
34	16.22	13.61	8.39	4.29	4.25	5.95	7.26	13.52	15.94	18.30
35	16.46	13.56	8.39	4.36	4.41	5.58	7.57	13.49	15.81	18.31
36	16.56	13.69	8.40	4.28	4.24	5.72	7.26	13.49	15.81	18.29
37	16.36	13.70	8.39	4.27	4.23	5.26	7.25	13.48	15.75	18.23
38	16.38	13.22	8.38	4.27	4.23	5.24	7.08	13.65	15.59	18.22
39	16.28	13.12	8.39	4.26	4.22	5.07	6.90	13.49	15.37	18.25
40	16.59	13.77	8.43	4.38	4.47	5.17	6.95	13.25	15.37	18.19

Table I-9:- Shear modulus and damping ratio of pit 3 at 200kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	4.20	3.49	2.67	1.44	1.35	15.11	15.99	19.30	18.74	23.65
2	4.28	3.50	2.87	1.48	1.33	14.92	15.79	19.26	18.63	22.45
3	4.50	3.71	2.82	1.50	1.35	14.67	15.37	19.13	18.52	21.35
4	4.61	3.84	2.84	1.49	1.39	14.54	15.26	18.35	17.89	22.05
5	4.86	3.66	3.10	1.77	1.61	14.11	15.26	18.79	17.80	21.53
6	4.91	4.08	3.16	1.74	1.62	15.46	15.26	17.18	17.80	22.19
7	4.80	4.09	3.28	1.81	1.65	14.75	14.94	15.75	17.65	20.97
8	4.85	4.21	3.13	1.90	1.69	14.24	14.94	17.15	17.52	21.02
9	4.93	4.10	3.14	1.77	1.74	14.54	14.69	17.10	17.25	21.71
10	5.20	4.07	3.25	1.78	1.76	14.36	13.84	16.97	17.31	21.07
11	5.06	4.11	3.20	1.78	1.87	14.28	12.78	16.30	17.31	21.50
12	5.17	4.15	3.07	1.81	1.88	13.33	12.39	16.27	16.95	21.31
13	5.13	4.16	3.11	1.74	1.90	13.08	12.35	15.35	17.11	21.80
14	5.17	4.20	3.19	1.68	1.91	12.83	12.13	15.87	16.39	21.08
15	5.16	4.19	3.05	1.70	1.95	11.84	12.41	15.79	16.34	22.19
16	5.14	4.20	3.08	1.66	2.02	11.48	12.21	15.85	16.35	21.52
17	5.17	4.28	3.04	1.66	2.05	10.51	11.96	15.76	16.70	21.88
18	5.15	4.11	3.23	1.65	2.15	10.65	11.85	15.92	16.38	20.70
19	5.22	4.43	3.30	1.67	2.12	10.48	11.74	15.74	16.67	20.69
20	5.22	4.50	3.34	2.01	2.15	9.32	10.95	15.66	16.93	20.36
21	5.22	4.38	3.47	2.01	2.02	9.61	11.73	15.48	16.93	20.46
22	5.14	4.45	3.61	2.04	2.02	8.36	10.95	15.47	15.51	20.68
23	5.12	4.54	3.44	2.03	2.11	8.97	10.59	15.21	15.84	20.51
24	5.10	4.55	3.45	2.04	2.02	9.34	10.54	15.15	15.65	19.61
25	5.17	4.60	3.57	1.99	2.06	9.07	11.11	15.07	15.75	20.17
26	5.37	4.62	3.52	2.02	2.10	8.38	10.86	15.06	15.69	20.21
27	5.48	4.62	3.37	2.00	2.14	8.41	10.62	15.18	15.96	21.01
28	5.47	4.61	3.42	2.02	2.13	8.22	10.40	15.04	15.06	20.32
29	5.47	4.77	3.51	1.97	2.14	8.29	10.34	14.91	15.63	20.54
30	5.28	4.70	3.56	2.19	2.18	8.20	10.21	15.10	15.27	20.08
31	5.75	4.66	3.63	2.18	2.16	8.42	10.26	14.82	16.26	21.96
32	5.21	4.53	3.67	2.19	2.18	8.13	9.99	14.91	15.68	20.14
33	5.80	4.61	3.82	2.14	2.05	7.91	9.84	14.84	15.92	20.67
34	5.50	4.68	3.97	2.17	1.85	7.97	9.78	14.59	15.92	20.14
35	5.92	4.76	3.78	2.16	2.01	7.98	9.71	14.71	15.31	19.01
36	5.64	4.62	3.80	2.18	1.99	8.00	9.71	14.66	15.36	20.07
37	5.36	4.50	3.93	2.13	1.98	7.76	9.93	14.33	15.66	19.36
38	5.65	4.60	3.87	2.16	2.12	7.59	10.00	14.43	15.23	19.20
39	5.97	4.68	3.78	2.15	2.18	7.94	8.18	14.26	15.92	20.14
40	5.39	4.81	3.79	2.23	2.21	7.85	9.83	14.21	15.26	19.96

Table I-10:- Shear modulus and damping ratio of pit 3 at 300kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G (MPa)					Damping ratio, (%)				
1	6.19	4.94	4.22	2.12	1.51	12.50	15.63	16.87	18.96	21.99
2	6.25	5.05	4.28	2.18	1.62	12.10	15.10	16.17	18.17	20.00
3	6.24	5.48	4.27	2.17	1.75	12.01	14.85	13.41	15.07	19.50
4	6.52	4.98	4.20	2.25	1.81	11.50	12.50	12.58	14.13	18.84
5	6.81	4.96	4.11	2.11	1.84	10.14	11.29	13.45	15.12	18.49
6	6.29	5.41	4.20	2.84	1.94	11.34	11.29	13.45	15.12	15.50
7	6.72	5.20	4.24	2.81	2.06	10.14	11.49	12.03	13.51	15.80
8	6.38	5.32	4.29	2.71	2.04	10.64	12.06	12.62	14.18	15.60
9	6.62	6.03	4.34	2.71	2.04	9.91	11.23	11.76	13.21	15.55
10	6.23	6.73	4.37	2.80	2.39	10.20	11.56	12.10	13.60	15.45
11	6.32	6.30	4.37	2.46	2.00	10.26	11.62	12.17	13.68	15.54
12	6.59	6.54	4.40	3.40	2.06	10.24	11.61	12.16	13.66	15.52
13	6.58	6.54	4.42	2.69	2.20	10.07	11.41	11.94	13.42	15.25
14	6.58	6.37	4.43	2.78	2.27	10.10	11.44	11.98	13.46	15.30
15	6.14	6.66	4.44	2.96	2.41	9.97	11.29	11.83	13.29	15.10
16	6.55	6.51	4.47	2.78	2.30	9.89	11.21	11.73	13.18	14.98
17	6.05	6.46	4.46	2.95	2.44	9.77	11.07	11.59	13.02	14.80
18	6.55	6.62	4.47	3.04	2.53	9.64	10.92	11.43	12.85	14.60
19	6.81	6.38	4.47	3.03	2.54	9.66	10.95	11.47	12.88	14.64
20	6.92	6.53	4.97	3.06	2.54	9.81	10.86	11.37	12.78	14.52
21	6.21	6.57	4.98	2.87	2.60	9.25	10.73	11.24	12.63	14.35
22	6.16	7.17	4.97	2.85	2.60	9.52	10.64	11.14	12.51	14.22
23	5.89	6.20	4.97	2.89	2.62	9.57	10.66	11.16	12.54	14.25
24	6.51	6.14	4.98	2.94	2.66	9.56	10.40	10.89	12.24	13.91
25	6.40	6.50	4.97	3.16	2.43	9.39	10.32	10.80	12.14	13.79
26	6.17	7.04	4.97	3.23	2.07	9.42	10.20	10.68	12.00	13.63
27	6.42	6.55	4.98	3.35	2.14	9.30	10.10	10.58	11.89	13.51
28	6.23	6.81	5.00	3.35	2.48	9.23	10.13	10.60	11.91	13.54
29	6.23	6.71	4.98	3.61	2.66	9.12	9.88	10.35	11.62	13.21
30	6.66	6.68	4.99	3.62	2.67	8.99	9.84	10.30	11.57	13.15
31	6.96	6.71	5.24	3.61	2.68	9.02	9.81	10.27	11.54	13.11
32	6.24	6.56	5.24	3.61	2.67	8.94	9.91	10.38	11.66	13.25
33	6.13	6.65	5.25	3.64	2.70	8.84	9.73	10.19	11.45	13.01
34	6.71	6.64	5.23	3.64	2.70	8.76	9.71	10.17	11.42	12.98
35	6.84	6.90	5.23	3.63	2.70	8.78	9.39	9.84	11.05	12.56
36	6.79	6.68	5.24	3.63	2.70	8.57	9.63	10.09	11.33	12.88
37	6.14	7.04	5.23	3.66	2.72	8.50	9.55	10.00	11.24	12.77
38	6.31	6.84	5.23	3.65	2.73	8.40	9.61	10.06	11.31	12.85
39	6.69	6.45	5.23	3.65	2.73	8.32	9.44	9.88	11.11	12.62
40	6.94	6.85	5.66	3.65	2.72	9.13	10.28	10.10	11.35	12.90

Table I-11:- Shear modulus and damping ratio of pit3 at 400kPa

Strain level	0.01%	0.10%	1%	2.50%	5%	0.01%	0.10%	1%	2.50%	5%
Cyclic No	Shear modulus, G(MPa)					Damping ratio, (%)				
1	7.47	5.30	4.37	3.00	1.80	13.55	14.15	16.80	17.69	19.65
2	8.27	5.76	4.92	3.84	1.99	13.93	13.93	16.54	17.42	19.35
3	8.12	5.80	4.91	3.80	2.01	13.69	13.69	16.25	17.11	19.01
4	8.37	6.50	4.85	3.80	2.20	13.33	13.33	15.83	16.66	18.51
5	8.23	6.80	4.13	2.96	2.19	12.43	13.35	14.32	15.59	18.66
6	8.85	9.18	4.85	3.72	2.60	12.07	12.50	13.46	14.64	17.22
7	8.93	9.63	4.88	3.67	2.79	11.58	11.58	12.91	14.04	16.51
8	8.20	9.40	4.93	3.63	2.76	11.24	11.24	12.53	13.62	16.03
9	8.92	9.53	4.98	3.58	2.72	11.55	11.55	12.88	14.01	16.48
10	8.72	9.39	5.01	3.58	2.29	10.99	10.99	12.25	13.32	15.67
11	8.46	8.94	5.00	3.56	3.52	8.72	8.72	9.72	10.57	12.43
12	8.87	9.80	5.04	3.55	3.48	10.96	10.96	12.22	13.29	15.63
13	8.64	9.30	5.06	3.50	3.46	11.09	11.09	12.37	13.44	15.26
14	8.65	9.80	5.07	3.49	3.44	10.76	10.83	12.07	13.12	15.75
15	8.68	10.01	5.07	3.47	3.42	10.89	11.18	12.46	13.55	15.32
16	8.94	9.64	5.11	3.44	3.40	10.63	10.87	12.12	13.17	15.81
17	8.66	9.78	5.10	3.42	3.38	10.97	11.22	12.51	13.60	15.37
18	8.86	9.69	5.10	3.42	3.37	10.67	10.90	12.16	13.22	15.50
19	9.02	10.01	5.10	3.40	3.36	11.01	11.00	12.26	13.33	15.51
20	8.79	9.52	5.11	3.38	3.34	10.71	11.01	12.27	13.34	13.81
21	9.05	9.19	5.11	3.37	3.32	10.80	10.83	12.07	13.12	13.32
22	8.96	9.91	5.11	3.36	3.32	10.81	10.44	11.64	12.66	13.76
23	8.58	9.65	5.11	3.35	3.31	10.63	10.79	12.03	13.07	13.26
24	8.78	9.69	5.11	3.34	3.29	10.25	10.39	11.59	12.60	13.72
25	8.86	9.99	5.11	3.32	3.28	10.59	10.75	11.99	13.03	12.89
26	8.99	9.69	5.10	3.32	3.27	10.20	10.10	11.26	12.24	12.80
27	8.76	10.00	5.12	3.30	3.26	10.56	10.03	11.18	12.16	12.70
28	8.96	9.84	5.13	3.29	3.25	9.92	9.95	11.10	12.07	12.50
29	8.96	9.91	5.11	3.29	3.24	9.85	9.80	10.93	11.88	12.40
30	8.82	9.93	5.13	3.28	3.24	9.77	9.72	10.84	11.78	12.30
31	8.87	9.84	5.13	3.27	3.23	9.62	9.64	10.75	11.69	12.18
32	8.76	10.05	5.12	3.26	3.22	9.54	9.55	10.65	11.57	12.14
33	8.71	9.57	5.14	3.26	3.21	9.46	9.51	10.61	11.53	12.05
34	8.71	10.02	5.12	3.25	3.20	9.37	9.44	10.53	11.45	11.95
35	8.85	10.00	5.12	3.24	3.20	9.34	9.37	10.44	11.35	11.45
36	8.91	10.08	5.13	3.23	3.19	9.27	8.97	10.01	10.88	11.54
37	8.79	10.08	5.12	3.23	3.18	9.20	9.04	10.09	10.96	11.25
38	8.81	9.79	5.11	3.22	3.18	8.81	8.82	9.83	10.69	11.15
39	8.80	10.08	5.12	3.21	3.17	8.88	8.74	9.75	10.59	11.10
40	8.89	9.79	6.17	3.84	3.48	8.66	8.70	9.70	10.55	11.09

