Shear Strength Behaviour of Silty Soil in Kolkata Region

Thesis Submitted for the Partial Fulfilment of the Requirement for the Degree

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Master of Engineering (M.E.) in Civil Engineering

Specialization in

Soil Mechanics and Foundation Engineering

By

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I hereby recommend that the thesis prepared under my supervision by **DINABANDHU TRIPATHI** (Class Roll No. 002210402030, Examination Roll No. M4CIV24027, University Registration No. 163473 of 2022-2023) entitled **"Shear Strength Behaviour of Silty Soil in Kolkata Region**" be accepted in partial fulfilment of the requirements for the Degree of Master of Civil Engineering with specialization in Soil Mechanics and Foundation Engineering from Jadavpur University during the year 2023-24.

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The foregoing thesis titled **"Shear Strength Behaviour of Silty Soil in Kolkata Region"** prepared by **DINABANDHU TRIPATHI** (Class Roll No. 002210402030, Examination Roll No. M4CIV24027, University Registration No. 163473 of 2022-2023) is hereby approved as a creditable study for an Engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve this thesis only for the purpose for which it is submitted.

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Contents

Abstract

Silty soil / clayey silt / silty clay is a commonly available soil found in the upper reaches, down to a depth of 3-4m to even 15-16m in some locations, of soil deposit in and around Kolkata, India. This silty soil as available in the Kolkata region is generally light brown in color, with low plasticity, and it has low to moderate strength on saturation. Such deposits are also found in the alluvial deposits of north India, particularly in Ganga basin areas. Hence it is very much important to study the behavior of such soil in order to gain some knowledge of their properties, particularly their shear strength under various conditions to meet the requirements from engineering practices.

Though a number of studies have been conducted in this direction, in general, the properties of reported silty soil may not be applicable for to all types of soil. Therefore, to better analyze the characteristics of locally available silty soil, this thesis highlights the shear strength behaviour of the silty soil as collected from a depth of 2-3m of the Rajarhat zone of Kolkata and analyzes their shear strength parameters at different dry densities and moisture contents based on the results of the conventional direct shear test.

The dry sample exhibited maximum friction angle and after adding water to the sample, there is a sharp decline in the value of friction angle which goes on decreasing with further addition of water, due to the fact that water acting like a lubricant and is decreasing the friction. It is further noticed that there is a general trend of rising in the value of friction angle with the rise in the dry density. These findings ascertains that the shear strength of the silty soil of the Kolkata region also increase with the increase in dry densities and decrease with the increase of moisture content for same dry density. Also it can be ascertained from the test results that like granular soils, silt also shows greater shear stress with the increase of normal stress.

Finally, this study reveals that, for different moisture content (w) and dry density (γ_d) internal friction angle (φ) varies from 24.22 degree to 33.14 degree and cohesion (c) varies from 0.024 to 0.232 kg/cm^2 respectively. Maximum friction angle has been found for dry soil while maximum cohesion for soil at 4% water content.

Chapter 1

1.0 Introduction

1.1 General

Alluvial deposits of the great rivers of the Indo-Gangetic plain are encountered extensively in northern and central parts of India. These deposits consist primarily of silty soil having varying amounts of sand and clay. Silty clay/ clayey silt is a commonly available soil found in the upper region in and around Kolkata, India. Silt in and around the regions of Kolkata has consists primarily of silt (60–80%), varying amounts of sand (5-10%) with insignificant clay content (10–40%). This type of soil is generally light brown in color, with low plasticity, and it has low strength on saturation and high dry strength. Therefore it is very much important to study the behavior of such soil in the Kolkata Region of West Bengal where such silt deposit is very much predominant in the river surrounding areas. The direct way to investigate the mechanical properties of soils is to evaluate variation of their shear strength which is a function of various factors such as degree of compaction, dry density, moisture content etc.

1.2 Need for present study

Most geotechnical engineers consider the behavior of silts as being somewhere between the behavior of clays, at one extreme, and the behavior of sands, at the other extreme. However, such an approximation does not provide a realistic framework for capturing the behavior of silts. Broadly speaking, silts represent a class of geo-materials intermediate between clays and sands; with some properties, like plasticity, comparable to that of clays, while other mechanical properties, such as their possible dilation under shearing and liquefaction under cyclic loading, similar to those of typical clean sands. With respect to grain size distribution, silty soils can generally be regarded as a transitional soil featuring properties that are pertinent to both sands and clays. The principal behaviour of sands and clays have been extensively studied and described over the years. However, the behaviour of silt and silty soils has been paid less attention until recent years. Since silty soils may range in composition from silty sands to clayey silts, the behaviour of silty soils may be difficult to judge a priori. A clean silt will have its own characteristic properties which only can be revealed by extensive testing. For example, a silt may appear as very stiff in a dried state, whereas it loses strength quickly when submerged into water. An important reason for the deficient studies of silt behaviour in the laboratory is the difficulties in retrieving undisturbed samples. Even with reconstituted samples it will be difficult to prepare samples with a structure similar to the in-situ conditions. Despite of these difficulties, we still need to obtain systematic knowledge of the properties, particularly the shear strength, of silty soils under various conditions to meet the requirements from engineering practice.

In other words, there is very little research on the dry density and moisture content of silty soil. Coupled with different soil properties, previous research conclusions may not apply to all types of soil. Therefore, to better analyze the strength characteristics of silty soil, this research work analyzes the shear strength parameters of silty soil, collected from upper reaches of Rajarhat areas of Kolkata, based on the results of the direct shear tests with various combinations of dry densities and moisture contents.

1.3 Objective and scope of work

The objective of this study is to investigate the shear strength behavior of silty soil commonly found in the Kolkata Region of West Bengal.

The scope of work includes several steps which are to be followed in this experimental study. The steps are:

(a) Literature review related to the shear strength characteristics of soils particularly silty soils.
(b) Collection of silty soil sample from the Rajarhat area of the Kolkata Region.

(c) Evaluation of physical properties (Atterberg limits, Grain size distribution, and compaction characteristic) by various testing as recommended by several IS Codes and manuals.

(d) Preparation of the specimens on various combinations of both the moisture content and dry densities.

(d) Conducting Direct shear tests on the prepared soil specimens applying three different normal stresses.

(e) Analysis of experimental results with the help of figures and tables.

1.4 Organization of thesis

The thesis has been divided into five chapters. The table and figures have been presented in a sequence as they appear in the text.

In **Chapter 1** an attempt has been made to introduce the problem along with need for present Research, scope and objectives of the work and organization of thesis.

Chapter 2 furnishes a detailed literature review on the relevant topic.

Chapter 3 Presents experimental programs that are carried out in the laboratory.

Chapter 4 Furnishes the detailed discussions in regard to the test results obtained.

Chapter 5 Depicts concluding remarks along with major findings, limitations and future scope of study.

References are furnished at the end.

Chapter 2

2.0 Literature Review

2.1 General

Silt is solid, dust-like sediment that water, ice, and wind transport and deposit. It is made up of rock and mineral particles that are larger than clay but smaller than sand. Individual silt particles are so small that they are difficult to see. To be classified as silt, a particle must be less than 0.075 millimeters across. Civil engineers in the United States define silt as material made of particles that pass a number 200 sieve (0.074 mm or less) but show little plasticity when wet and little cohesion when air-dried. The International Society of Soil Science (ISSS) defines silt as soil containing 80% or more of particles between 0.002 mm to 0.02 mm in size while the U.S. Department of Agriculture puts the cutoff at 0.05mm.

Silt is found in soil, along with other types of sediment such as clay, sand, and gravel. Silty soil is slippery when wet, not grainy or rocky. The soil itself can be called silt if its silt content is greater than 80 percent. When deposits of silt are compressed and the grains are pressed together, rocks such as siltstone form.

Silt is created when rock is eroded, or worn away, by water and ice. As flowing water transports tiny rock fragments, they scrape against the sides and bottoms of stream beds, chipping away more rock. The particles grind against each other, becoming smaller and smaller until they are silt-size. Glaciers can also erode rock particles to create silt. Finally, wind can transport rock particles through a canyon or across a landscape, forcing the particles to grind against the canyon wall or one another. All three processes create silt.

A simple explanation for silt formation is that it is a straightforward continuation to a smaller scale of the disintegration of rock into gravel and sand.

Quartz silt grains are usually found to have a platy or bladed shape. This may be characteristic of how larger grains abrade, or reflect the shape of small quartz grains in foliated metamorphic rock, or arise from authigenic growth of quartz grains parallel to bedding in sedimentary rock.[24] Theoretically, particles formed by random fracturing of an isotropic material, such as quartz, naturally tend to be blade-shaped.

Mechanisms for silt production include:

- Erosion of initially silt-sized grains from low-grade metamorphic rock.
- Production of silt-sized grains from fracture of larger grains during initial rock weathering and soil formation, through processes such as frost shattering[12] and haloclasty.[13]
- Production of silt-sized grains from grain-to-grain impact during transport of coarser sediments.
- Formation of authigenic quartz during weathering to clay.
- Crystallization of the tests of siliceous organisms deposited in mudrock.

Laboratory experiments have produced contradictory results regarding the effectiveness of various silt production mechanisms. This may be due to the use of vein or pegmatite quartz in some of the experiments. Production of silt from vein quartz is very difficult by any mechanism, whereas production of silt from granite quartz proceeds readily by any of a number of mechanisms. However, the main process is likely abrasion throughtransport,including fluvial comminution, aeolian attrition and glacial gr inding.

Because silt deposits (such as *loess*, a soil composed mostly of silt) seem to be associated with glaciated or mountainous regions in Asia and North America, much emphasis has been placed on glacial grinding as a source of silt. High Asia has been identified as a major generator of silt, which accumulated to form the fertile soils of north India and Bangladesh, and the loess of central Asia and north China. Loess has long been thought to be absent or rare in deserts lacking nearby mountains (Sahara, Australia). However, laboratory experiments show aeolian and fluvial processes can be quite efficient at producing silt, as can weathering in tropical climates. Silt seems to be produced in great quantities in dust storms, and silt deposits found Israel, Tunisia, Nigeria, and Saudi Arabia cannot be attributed to glaciation. Furthermore, desert source areas in Asia may be more important for loess formation than previously thought. Part of the problem may be the conflation of high rates of production with environments conducive to deposition and preservation, which favors glacial climates more than deserts.

Loess associated with glaciation and cold weathering may be distinguishable from loess associated with hot regions by the size distribution. Glacial loess has a typical particle size of about 25 microns. Desert loess contains either larger or smaller particles, with the fine silt produced in dust storms and the coarse silt fraction possibly representing the fine particle tail of sand production.

Silt can be distinguished from clay in the field by its lack of plasticity or cohesiveness and by its grain size. Silt grains are large enough to give silt a gritty feel, particularly if a sample is placed between the teeth. Clay-size particles feel smooth between the teeth. The proportions of coarse and fine silt in a sediment sample are determined more precisely in the laboratory using the pipette method, which is based on settling rate via Stokes' law and gives the particle size distribution accordingly. The mineral composition of silt particles can be determined with a petrographic microscope for grain sizes as low as 10 microns.

Silt is granular material of a size between sand and clay and composed mostly of broken grains of quartz. Silt may occur as a soil (often mixed with sand or clay) or as sediment mixed in suspension with water. Silt usually has a floury feel when dry, and lacks plasticity when wet. Silt can also be felt by the tongue as granular when placed on the front teeth (even when mixed with clay particles).

Silt is a common material, making up 45% of average modern mud. It is found in many river deltas and as wind-deposited accumulations, particularly in central Asia, north China, and North America. It is produced in both very hot climates (through such processes as collisions of quartz grains in dust storms) and very cold climates (through such processes as glacial grinding of quartz grains.)

Silt is a very common material, and it has been estimated that there are a billion trillion trillion (10^{33}) silt grains worldwide. Silt is abundant in aeolian and alluvial deposits, including river deltas, such as the Nile and Niger River deltas. Bangladesh is largely underlain by silt deposits of the Ganges delta. Silt is also abundant in northern China, central Asia, and North America. However, silt is relatively uncommon in the tropical regions of the world.

Loess tends to lose strength when wetted, and this can lead to failure of building foundations. The silty material has an open structure that collapses when wet. Quick Clay (a combination of very fine silt and clay-sized particles from glacial grinding) is a particular challenge for civil engineering.[14]

The failure of the Teton Dam has been attributed to the use of loess from the Snake River floodplain in the core of the dam.[15] Loess lacks the necessary plasticity for use in a dam core, but its properties were poorly understood, even by the U.S. Bureau of Reclamation, with its wealth of experience building earthen dams.

Silt is susceptible to liquefaction during strong earthquakes due to its lack of plasticity. This has raised concerns about the earthquake damage potential in the silty soil of the central United States in the event of a major earthquake in the New Madrid Seismic Zone.

Loess is soil rich in silt which makes up some of the most fertile agricultural land on Earth. However, silt is very vulnerable to erosion, and it has poor mechanical properties, making construction on silty soil problematic. The failure of the Teton Dam in 1976 has been attributed to the use of unsuitable loess in the dam core, and liquefaction of silty soil is a significant earthquake hazard. Windblown and waterborne silt are significant forms of environmental pollution, often exacerbated by poor farming practices.

Silt is easily transported in water and is fine enough to be carried long distances by air in the form of dust. While the coarsest silt particles (60 micron) settle out of a meter of still water in just five minutes, the finest silt grains (2 microns) can take several days to settle out of still water. When silt appears as a pollutant in water the phenomenon is known as siltation.

Silt can change landscapes. For example, silt settles in still water. So, deposits of silt slowly fill in places like wetlands, lakes, and harbors. Floods deposit silt along riverbanks and on floodplains. Deltas develop where rivers deposit silt as they empty into another body of water. About 60 percent of the Mississippi River Delta is made up of silt.

In southeast Bangladesh, in the Noakhali district, cross dams were built in the 1960s whereby silt gradually started forming new land called "chars". The district of Noakhali has gained more than 73 square kilometers (28 sq mi) of land in the past 50 years. With Dutch funding, the Bangladeshi government began to help develop older chars in the late 1970s, and the effort has since become a multi-agency operation building roads, culverts, embankments, cyclone shelters, toilets and ponds, as well as distributing land to settlers. By fall 2010, the program will have allotted some 100 square kilometers (20,000 acres) to 21,000 families.

A main source of silt in urban rivers is disturbance of soil by construction activity. A main source in rural rivers is erosion from plowing of farm fields, of forests.

2.2 Physical Properties of Silt

Silty soil has the following key properties:

- Particle Size: Silty soil is composed of granular particles whose mineral origin is quartz and feldspar, and are larger than clay but smaller than sand, typically ranging from 0.002 to 0.075 millimeters in diameter.

- Silt is created by a variety of physical processes capable of splitting the generally sand-sized quartz crystals of primary rocks. These involve chemical weathering of rock and a number of physical weathering processes such as frost shattering. The main process is abrasion through water, air or glaciers. The main transport means are fluvial comminution, aeolian attrition and glacial grinding.

- Silt and clay contribute to turbidity in water. Silt is easily transported in water or air and is fine enough to be carried long distances by air in the form of dust.

- Silt is chemically distinct from clay, and unlike clay, grains of silt are approximately the same size in all dimensions.

- Silt may occur as a soil, often mixed with sand and clay or as sediment mixed in suspension with water in rivers and streams and as deposits in the bottom.

- Silt has a moderate specific area with a typically non-sticky, plastic feel. Silt usually has a floury feel when dry, and a slippery feel when wet.

- Texture: Silty soil has a smooth, slick, and somewhat powdery texture when dry. When wet, it can feel slightly sticky or slippery.

- Water Retention: Silty soils have a moderate to high water-holding capacity compared to sandy soils, making them better able to retain moisture.

- Drainage: Silty soils have moderate drainage capabilities, neither extremely well-draining nor poorly draining. They can become compacted and prone to waterlogging if overworked when wet.

- Nutrient Content: Silty soils are relatively fertile and nutrient-rich, as the small particle size allows for greater surface area to hold nutrients.

- Workability: Silty soils are relatively easy to work and till when at the proper moisture level, but can become quite sticky and difficult to manage if worked when too wet.

- Erosion Prone: The fine particle size of silty soils makes them vulnerable to wind and water erosion if left unprotected.

- If the soil contains more than 80% silt, it can be called silt

2.3 Engineering Properties of Silt

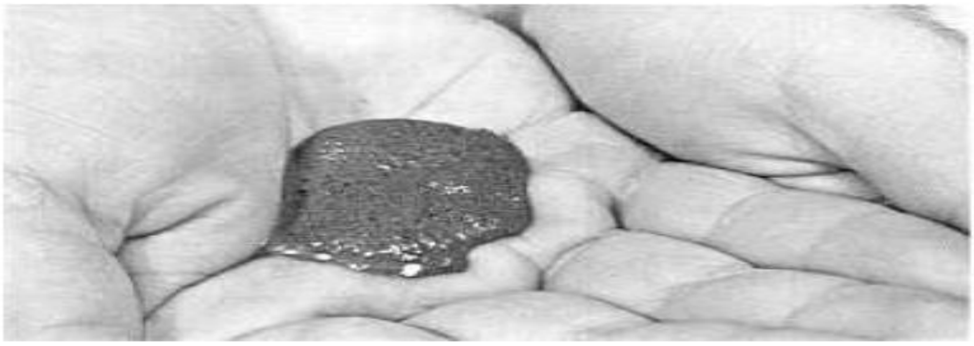
It is very important to be aware of the engineering properties of a soil for the geotechnical engineers. Some of the important engineering properties of these soils are as follows.

1. Grain Size Distribution.
2. Consistency limits(Liquid Limit LL, Plastic Limit PL)
3. Plasticity/Compressibility(Plasticity Index, P.I)
4. Maximum Dry Density(MDD) and corresponding Optimum Moisture Content(OMC)
5. Cohesion(c)
6. Angle of Internal Friction(φ)

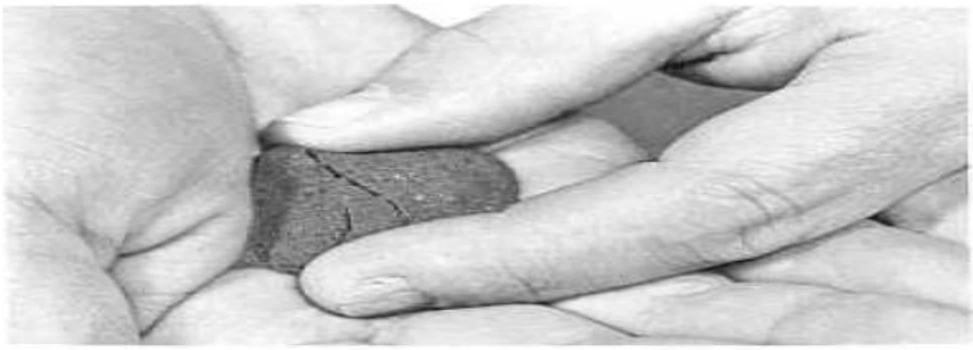
Silt and Clay are considered to be smaller family members of soil group; even small amounts of fines can have significant effects on the engineering properties of soils. If as little as 10 percent of the particles in sand and gravel are smaller than the No.200 sieve size, the soil can be virtually impervious, especially when the coarse grains are well graded.

Silica is decided to be acidic and magnesia bricks are strongly basic. However, fire clay bricks are generally placed in the neutral group. Chemical reaction may take place when the refractory comes in contact with fuel ashes, slag, gases inside the furnace, and the products such as glass or steel. Moreover, serious frost heaving in well graded sands and gravels can be caused by fines making up less than 10 percent of the total soil weight. The utility of coarse-grained materials for roads can be improved by the addition of a small amount of clay to act as a binder for the sand and gravel particles. Soils containing large quantities of silt and clay are the most troublesome to the engineer. These materials exhibit marked changes in engineering properties with changes in water content.

Hard, dry clay, for example, may be suitable as a foundation for heavy loads so long as it remains dry, but it may become unstable when wet. Many of the fine soils shrink on drying and expand on wetting, which may adversely affect structures founded upon them or constructed of them. Even when the water content does not change, the properties of fine soils may vary considerably between their natural condition in the ground and their state after being disturbed.



(A) REACTION TO SHAKING.



(B) REACTION TO SQUEEZING.

Fig. 2.3.1 Reaction to shaking and squeezing of fine grained soil sample

Deposits of fine particles that have been subjected to loading in geologic time frequently have a structure that gives the material unique properties in the undisturbed state. When the soil is excavated for use as a construction material or when the natural deposit is disturbed, for example by driving piles, the soil structure is destroyed and the properties of the soil are changed radically. Silts are different from clays in many important respects, but because of their similar appearance, they are often mistaken for each other, sometimes with unfortunate results. Dry, powdered silt and clay are indistinguishable, but they are easily identified by their behavior in the presence of water. Recognition of fines as either silt or clay is an essential part of the Geotechnical Engineering.

Silts are the non-plastic fines, they are inherently unstable in the presence of water and have a tendency to become "quick" when saturated that is, they assume the character of a viscous fluid and can flow. Silts are fairly impervious, difficult to compact, and highly susceptible to frost heaving. Silt masses undergo change of volume with change of shape (the property of dilatancy), in contrast with clays, which retain their volume with change of shape (the property of plasticity). The dilatancy of silt together with its quick reaction to vibration affords a means of identifying typical silt in the loose, wet state. When dry, silt can be pulverized easily under finger pressure (indicative of very slight dry strength), and has a smooth feel between the fingers unlike the grittiness of fine sand.

Silts differ among themselves in size and shape of grains. This is reflected mainly in the property of compressibility. Generally, the higher the liquid limit of a silt, the more compressible it is. The liquid limit of a typical bulky-grained, inorganic silt is about 30 percent; whereas, highly micaceous or diatomaceous silts (elastic silts), consisting mainly of flaky grains, may have very high liquid limits

2.4 Previous researches on Shear strength behavior of soil

Moayed et al.(2019) [1] investigated the effect of silt presence on shear strength parameters of unsaturated sandy soils. In the investigation, in different silt percent, the shear strength parameters of the soil such as internal friction angle and dilation angle are calculated and compared. Investigation showed that when the sample contains up to 10% silt, peak shear strength and internal friction angle have an upward trend. However, if the sample contains 10% to 50% of silt, a downward trend is seen in peak shear strength and internal friction angle.

Banupriya et al. (2015) [5] experimented stress-strain and strength characteristics of sand-silt mixtures. They found that the angle of internal friction decreases with increases in the silt content from 10 to 100% to the sand. The difference in the angle of internal friction of 10-40% of non-plastic silt content the reduction is more when compared to the other proportion of 50-100% of non-plastic silt content.

Kang et al.(2022) [4] studied the effect of moisture content and dry density on shear strength of silty clay based on direct shear test. In the test to explore the influence of dry density, firstly the moisture content of the sample was held constant for different dry densities. In the second part, to investigate the effect of water content, the dry density was controlled to be same. The result of the study show that with the same guaranteed moisture content, it can be seen that the shear strength increases with the increase in dry density.

Listyawan et al. (2021) [2] did shear strength evaluation of silt-clay soil under uni-axial compression where the effect of different moisture content and applied pressure to soil shear strength parameters are evaluated.The result showed that moisture content having a great impact on soil shear strength parameter. By increasing the soil moisture content, the cohesion of soil become decrease and the value of friction angle increase then decrease in certain moisture content.

Usmani et al. (2011) [3] did Experimental Evaluation of Shear-Strength Behavior of Delhi Silt under Static Loading Conditions. The capital city of India, Delhi, lies in the Indo-Gangetic alluvial trough. The soils of the Delhi region are known as “Delhi silt” because of the dominance of silt and, by and large, are non-plastic. The study corroborated that the nature of Delhi silt is transitional, that is, it can be described by neither a sand nor a clay type of framework. All aspects of the mechanical behavior captured in this study (e.g., stress-strain volumetric response, pore pressure, and shear strength) were found to be affected by the amount of fines present in the sand and the loading conditions.

In terms of exploring the influence of dry density on the shear strength of soil, it has been analyzed by domestic and foreign scholars through different research methods. For example, Gao et al.[7] and Shen et al.[8] used indoor triaxial tests to study the deformation and strength variation laws of remolded soils and conducted triaxial shear tests on soils with different initial dry densities, different suction forces, and different moisture contents, respectively, and integrated the shear strength of remodeled soils.

In order to study the unsaturated nature of silty clay, Huang et al.[6] used an undrained triaxial test method to analyze the strength variation law of loess-like silty clay in the Three Gorges area by conducting triaxial shear tests under different dry density conditions, respectively.
Regarding the research on the influence of moisture content on the shear strength of soil, due to the difference of soil properties, the law of change is also not the same. In this regard, domestic and foreign scholars have carried out a lot of research on the influence mechanism of various soil moisture content (w). For example, Huang et al.[9] used indoor direct shear tests to analyze the strength changes of undisturbed soil and remolded soil under different moisture contents.
In order to analyze the influencing factors of soil shear strength parameters, Chen et al. and Wang et al. [10] [11] used direct shear test and triaxial shear test to comprehensively analyze the

factors affecting the variation characteristics of soil shear strength under the conditions of different moisture content, dry density of red clay soil and sandy loam soil respectively.

Sorting out the existing research results, it is not difficult to find that most of the existing research results focus on the analysis of a single influencing factor, while the analysis of the coupling effect of multiple factors is relatively small, and the existing research is mainly for general soils.

2.5 Critical Appraisal of Literature

There are several researches conducted previously by different researchers for investigation of shear strength properties of various types of soil combinations like silty clay, clay, sand-silt mixtures. However, there are some lacunas in these researches which can be broadly studied in future. The lacunas are stated as:

(a) The study on the shear strength behavior of silty soil of low compressibility is very limited.

(b) Particularly for Kolkata region such an experimental study is the need of the hour.

Chapter 3

3.0 Experimental program

3.1 Materials

Material of testing is silty soil sample collected from a depth of 1.0 – 2.0m at a site from Rajarhat area of Kolkata. Its properties were evaluated by various testing as recommended by several IS Codes and manuals.

Atterbarg Limits Determination: Liquid Limit (LL) = 23.00% as was determined according to IS Code 2720 (part-V) -1985.

Plastic Limit (PL) = 19.50% as was determined according to IS: 2720 (Part 5) – 1985

Plasticity Index = (LL-PL) = 3.50%

Hence as per IS code 1498-1970, the soil classification falls in the category of ML or Silt of low compressibility.

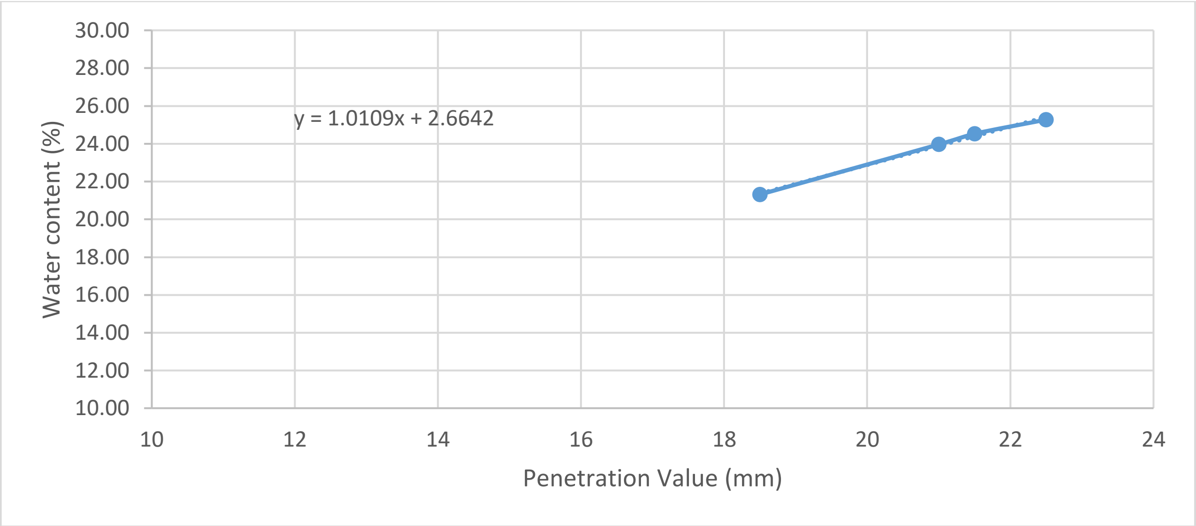


Fig. 3.1.1: Liquid limit determination

Grain size distribution: It was done by a combined sieve analysis as well as hydrometer method following IS 460-1985 and IS: 2720 (Part 4): 1985 respectively. The result of the analysis is Sand: 6% Silt: 76%, Clay: 18%.

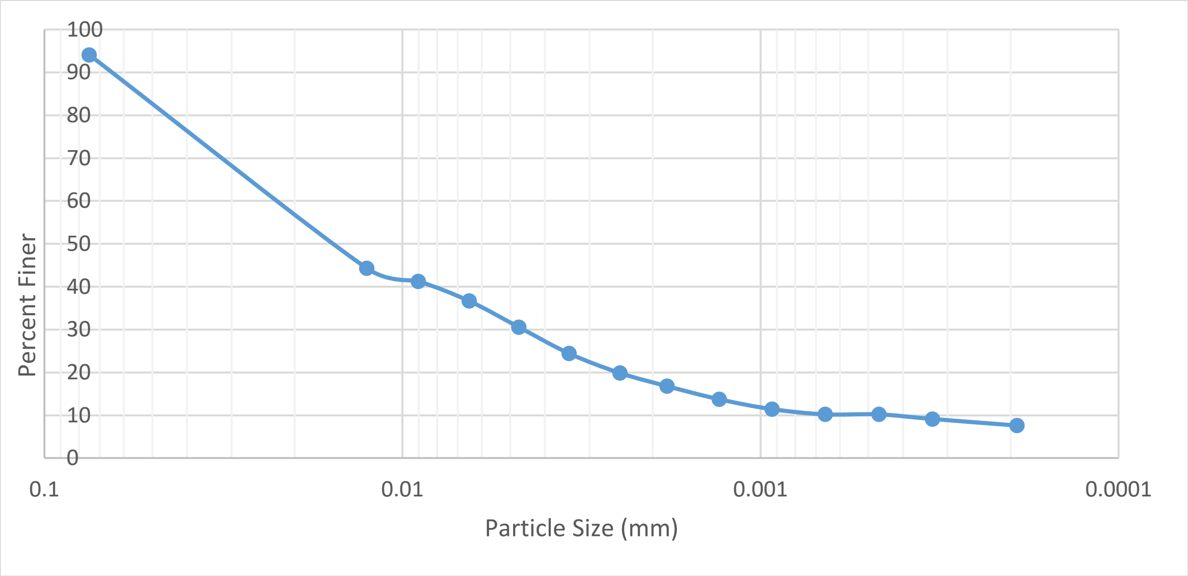


Fig. 3.1.2: Grain size distribution

Compaction Characteristics: Standard proctor test was conducted on the soil sample following IS: 2720, Part VII-1980.The result of this test yield that the Maximum dry density (γd) max=1.70 gm/cc and corresponding optimum moisture content (OMC) is 12%.

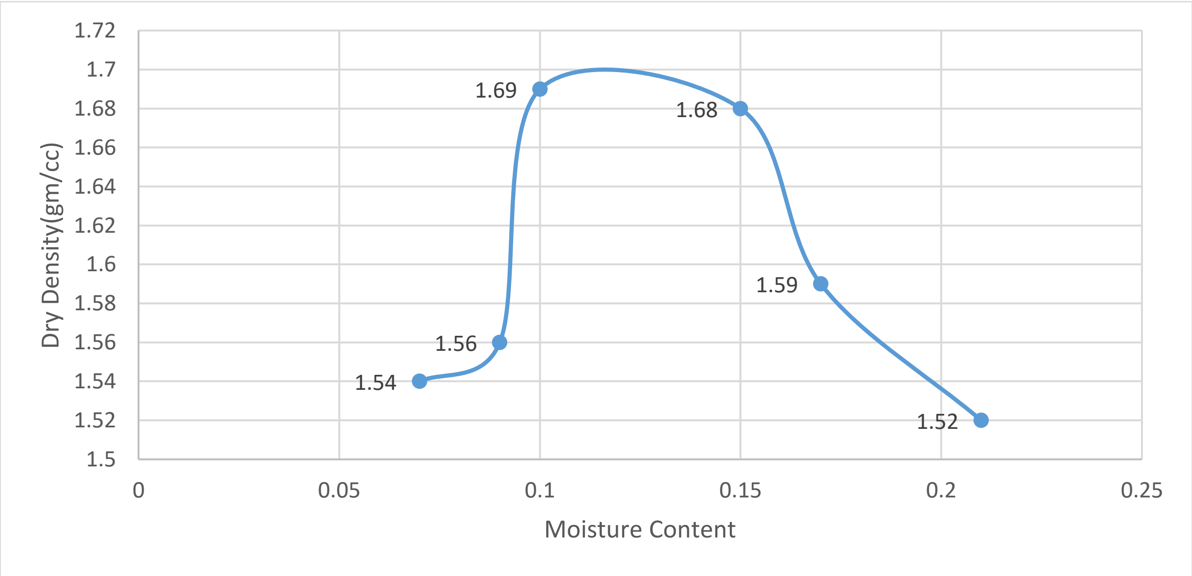


Fig. 3.1.3: MDD vs. OMC Graph from std. proctor test

3.2 Preparation of Specimen

In order to prepare the test specimens, the three different target dry densities (**γd**) were selected to be 1.50, 1.65 and 1.75 gm/cc. and several water contents selected to be as 0%, 4%, 8%, 12% and 15%. From the dry density as selected, we can easily determine the bulk density (γ_b) from the formulae, Bulk density (γ_b) = Dry density (γ_d) x (1+ w).The volume of the mould of direct shear test is 126 cc. Multiplying it with the evaluated bulk density we can get the weight of the sample we have to prepare for the direct shear test. Accordingly following this procedure total 15 number of soil samples were prepared as tabulated below.

Table-3.2.1: Moisture content and dry density of soil specimens

Number of sample	Moisture content(w) in percent	Dry density (γd), gm/cc	Bulk density(γb), gm/cc	Weight of prepared sample(gm)
1	0	1.50	1.50	189
2	0	1.65	1.65	208
3	0	1.75	1.75	221
4	4	1.50	1.56	197
5	4	1.65	1.72	216
6	4	1.75	1.82	229
7	8	1.50	1.62	204
8	8	1.65	1.78	224
9	8	1.75	1.89	238
10	12	1.50	1.68	212
11	12	1.65	1.85	233
12	12	1.75	1.96	247

13	15	1.50	1.73	218
14	15	1.65	1.90	239
15	15	1.75	2.01	253

Fig. 3.2.1: Soil sample preparation

Fig. 3.2.2: Soil sample preparation

3.3 Test Procedure

Direct shear test, also called the shear box test, is the oldest shear test that is in use and is also quite simple to perform. The soil specimen that is to be tested is confined in a metal box of square cross-section that is split into two halves horizontally, a small clearance being maintained between the two halves of the box. Solid metal plates were placed above and below the specimen. A pressure pad is placed on top and the entire box is placed in the trolley. The set-up is shown in the photograph (Fig. 3.3.2) taken during conducting of the test. One half of the box is fixed and the other half is pushed or pulled relative to the fixed one. A vertical load is applied to the specimen through a static weight hanger and the soil is sheared gradually by applying a horizontal force which causes the two halves of the box to move relative to each other. The shear is applied at a constant rate of strain 0.625mm/min. The magnitude of the shear load is measured by means of a proving ring. The shear deformation is measured during the test with the help of a dial gauge.

The procedure is repeated at least on three specimens, each subjected to a different vertical load. Normal stress and shear stress on the failure plane are obtained by dividing the normal force and the shear force by the normal area of the specimen. Values of shear stress at failure are plotted against the normal stress for each test conducted. The shear strength parameters cohesion and Friction angle are obtained from the best fit straight line through the points.

Fig. 3.3.1: Sheared plane view as captured during the test.

. Fig. 3.3.2: The test set-up photograph taken during the test

Chapter 4

4.0 Results and Discussions

4.1 General

Direct shear test was conducted based on the various combinations of moisture content (w) and dry density (γ_d) as mentioned in table 3.1. Amongst these combinations, the test could be conducted on 13 specimens out of the 15 prepared soil specimens because of the difficulty in placing the specimen no. 3 (w=0%,γ_d=1.75 gm/cc) and specimen no.15(w=15%,γ_d=1.75 gm/cc)inside the box.

The results of the experiments has been depicted in the form various graphs. The graphs between the Horizontal displacements (mm) of the specimen vs. shear stress (kg/cm2) has been plotted and further discussed in the following paragraph 4.2. Similarly the graphs between normal stresses (kg/cm2) vs. shear stress (kg/cm2) has been plotted and discussed in paragraph 4.3.Also for better understanding of the peak shear stress, the graphs between Horizontal Displacement to reach peak shear stress vs. Normal stress diagrams has been shown in paragraph 4.4.In paragraph 4.5 and 4.6, Variations of Friction Angle (φ) and Cohesion (c) with Dry Density (γ_d) and Variations of Friction Angle (φ) and Cohesion (c) with moisture content (W) has been plotted and discussed.

4.2 Shear stress vs. Horizontal displacement diagrams

The figures (4.2.1 to 4.2.13), as depicted below, show the variation of shear stress with the Horizontal displacement in the specimen for several combinations of w and γ_d. From these graphs it is revealed that the increase in normal stress is also causing increase in the shear stress values for a fixed value of horizontal displacement. Also one thing can be noticed is that the rate of increase in the value of shear stress is more when the value of normal stress is more than that of smaller values of normal stresses. Further it can also be noticed that there is no sharp decrease in the shear stress values after attaining of the peak value, rather the peak value remains constant for a long time or it decreases in avery much gradual manner.

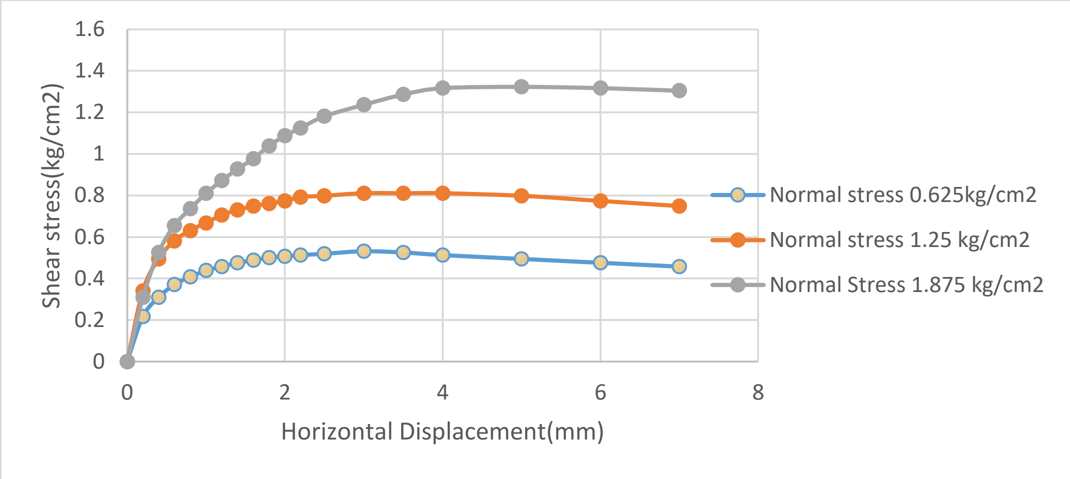


Fig. 4.2.1: Shear stress vs horizontal displacement
Water content= 0%, Dry density =1.50 gm/cc

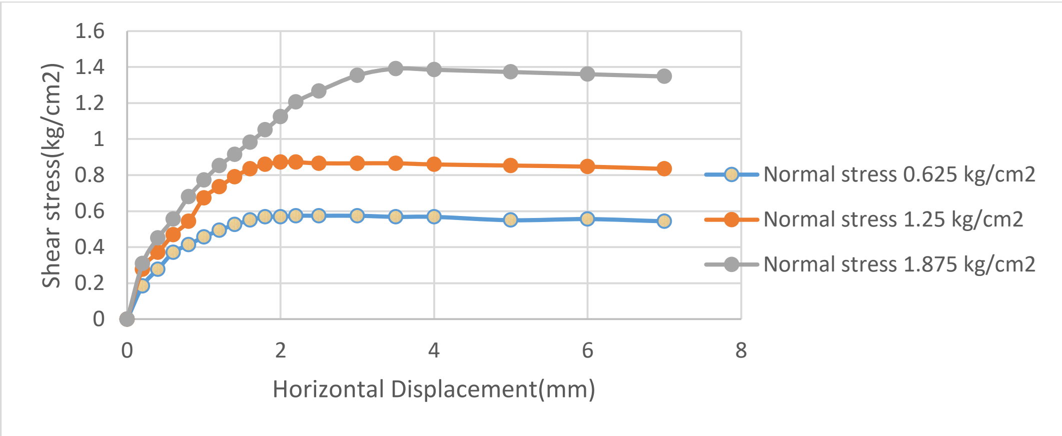


Fig. 4.2.2: Shear stress vs horizontal displacement
Water content= 0%, Dry density =1.65 gm/cc

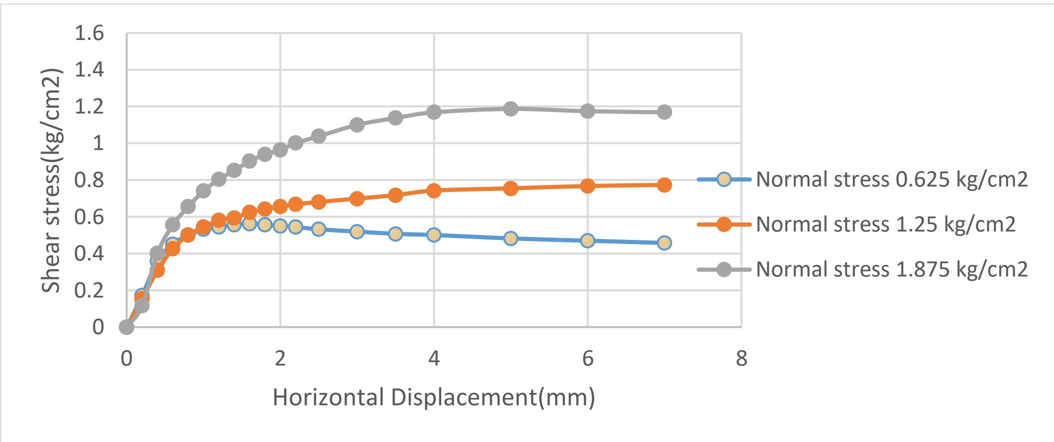


Fig. 4.2.3: Shear stress vs horizontal displacement
Water content= 4%, Dry density =1.50 gm/cc

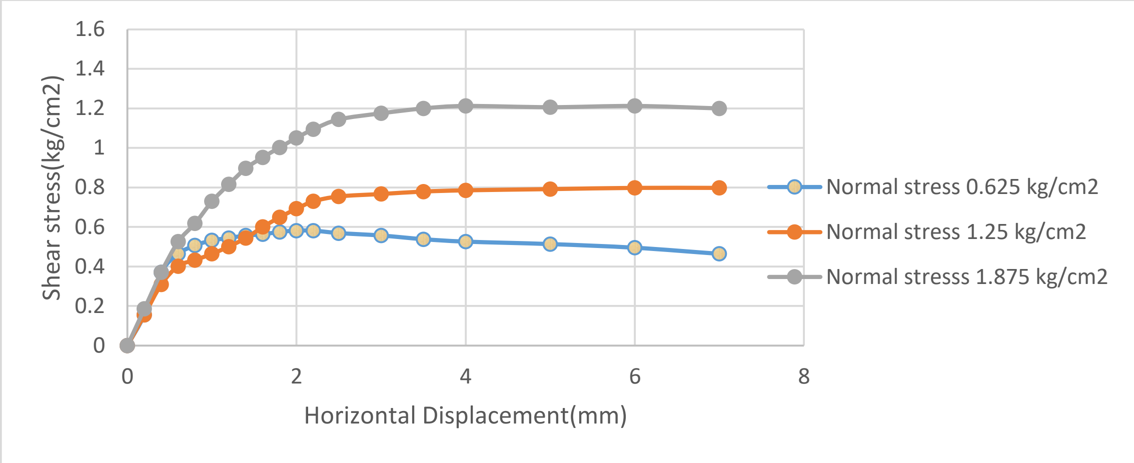


Fig. 4.2.4: Shear stress vs horizontal displacement
Water content= 4%, Dry density =1.65 gm/cc

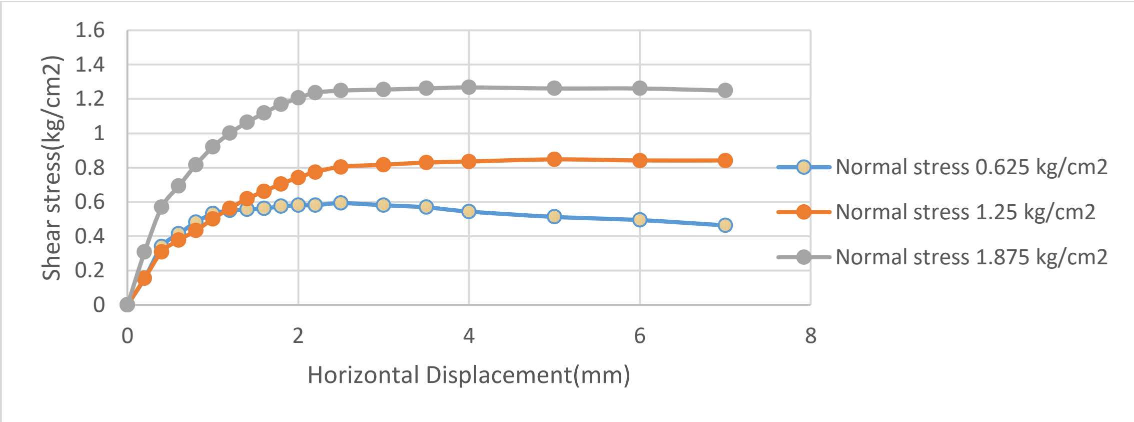


Fig. 4.2.5: Shear stress vs horizontal displacement
Water content= 4%, Dry density=1.75 gm/cc

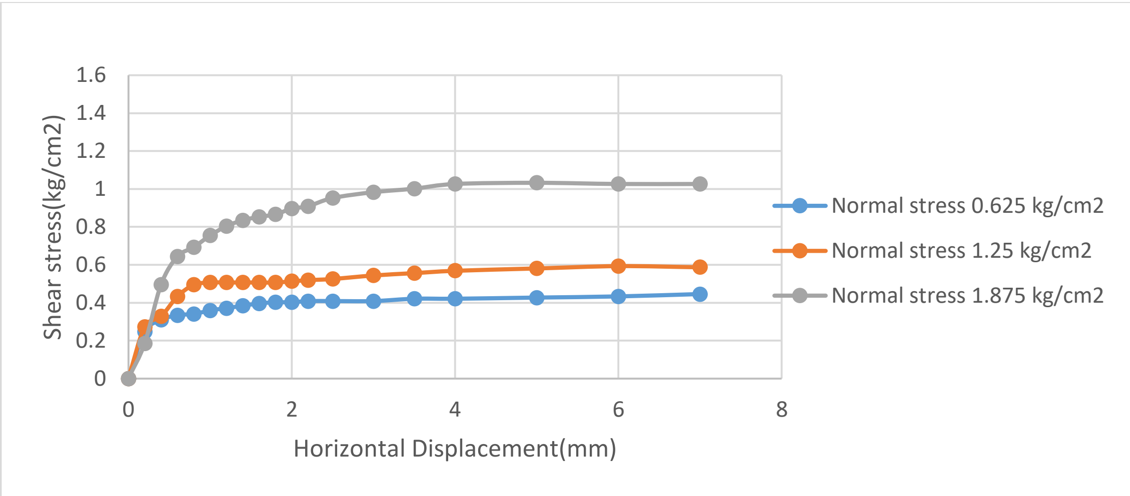


Fig. 4.2.6: Shear stress vs horizontal displacement
Water content= 8%, Dry density =1.50 gm/cc

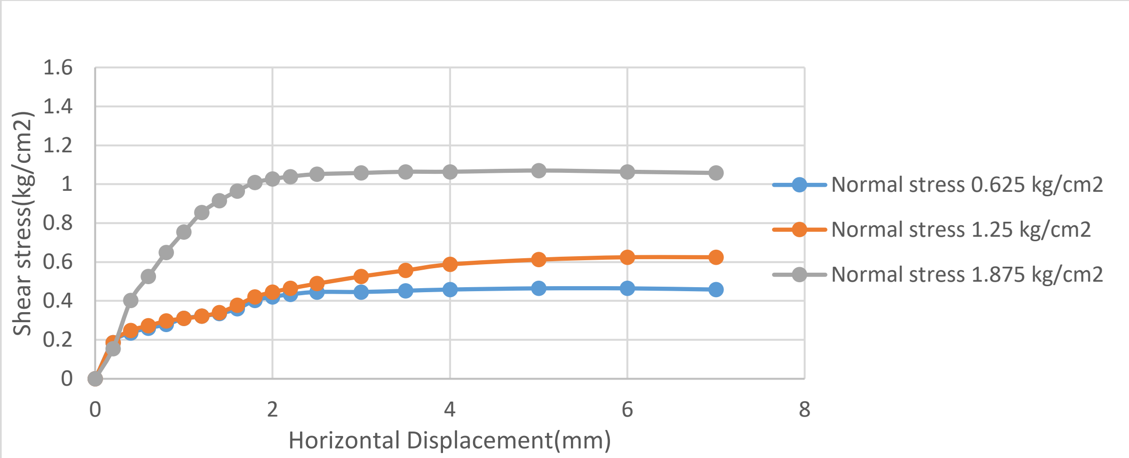


Fig. 4.2.7: Shear stress vs horizontal displacement
Water content= 8%, Dry density=1.65 gm/cc

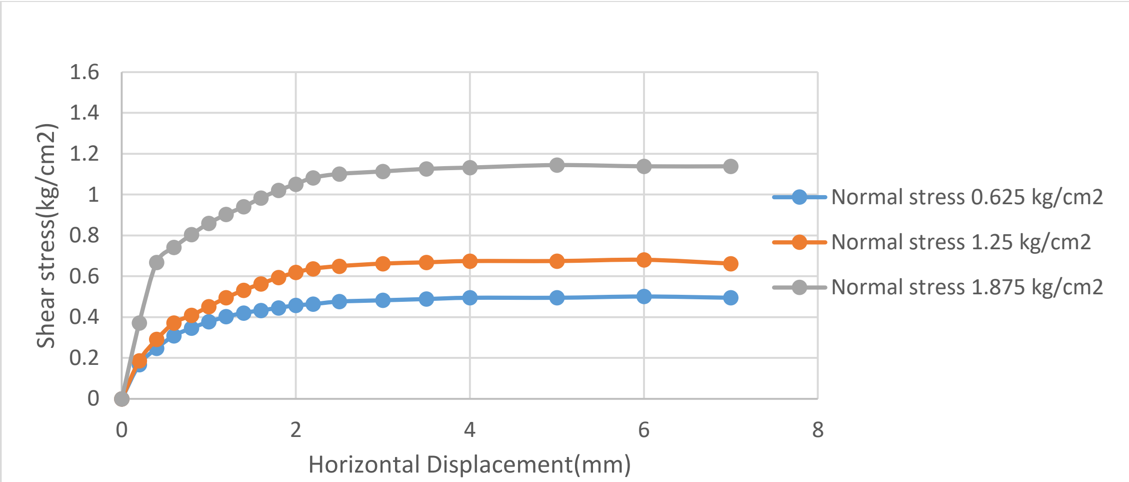


Fig. 4.2.8: Shear stress vs horizontal displacement
Water content= 8%, Dry density =1.75 gm/cc

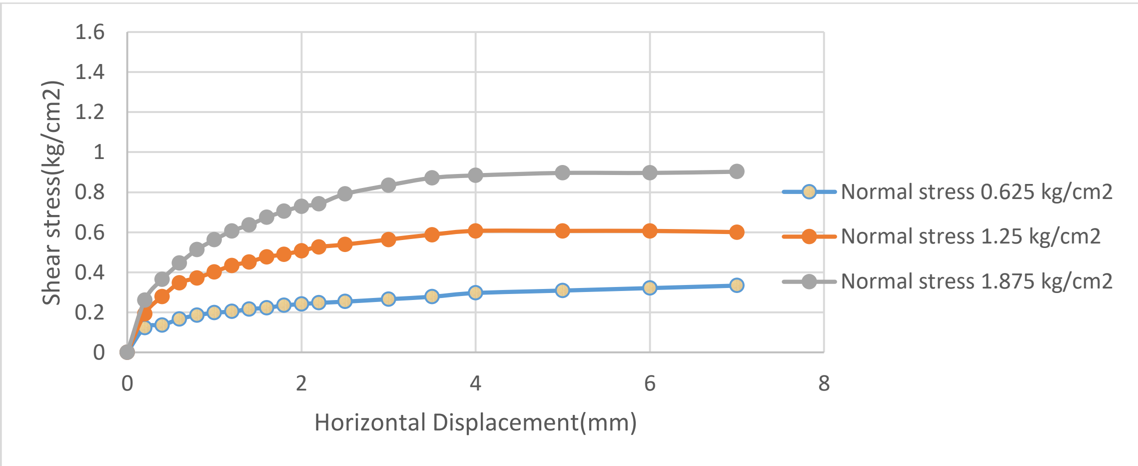


Fig. 4.2.9: Shear stress vs horizontal displacement
Water content= 12%, Dry density =1.50 gm/cc

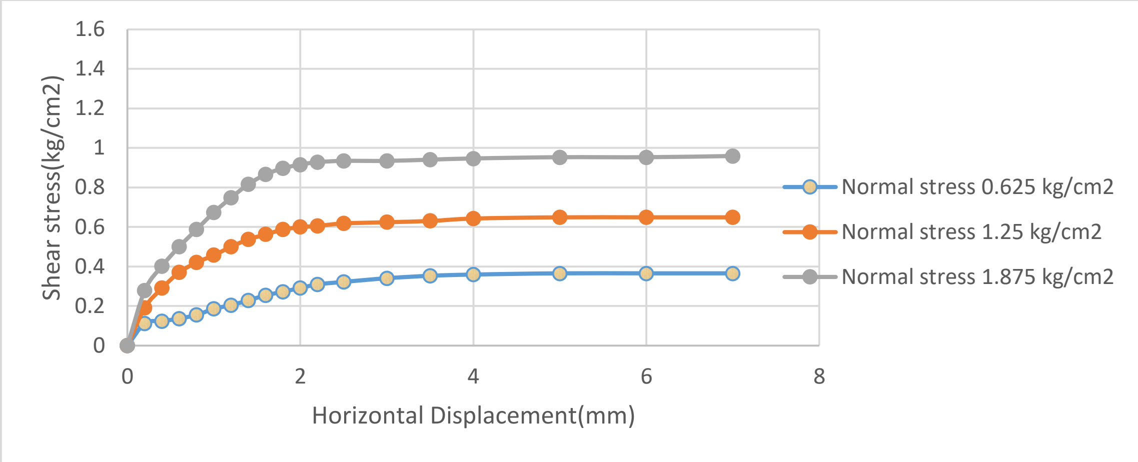


Fig. 4.2.10: Shear stress vs horizontal displacement
Water content= 12%, Dry density =1.65 gm/cc

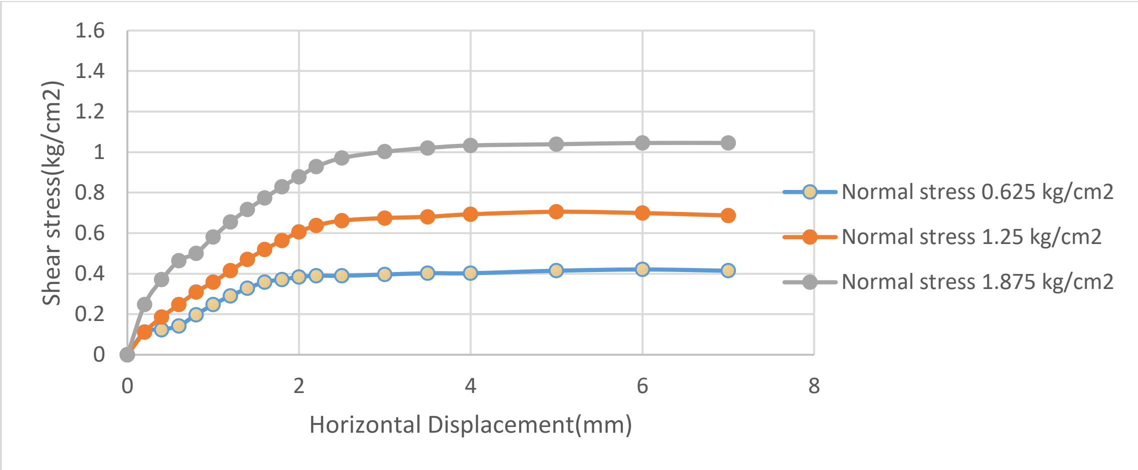


Fig. 4.2.11: Shear stress vs horizontal displacement
Water content= 12%, Dry density=1.75 gm/cc

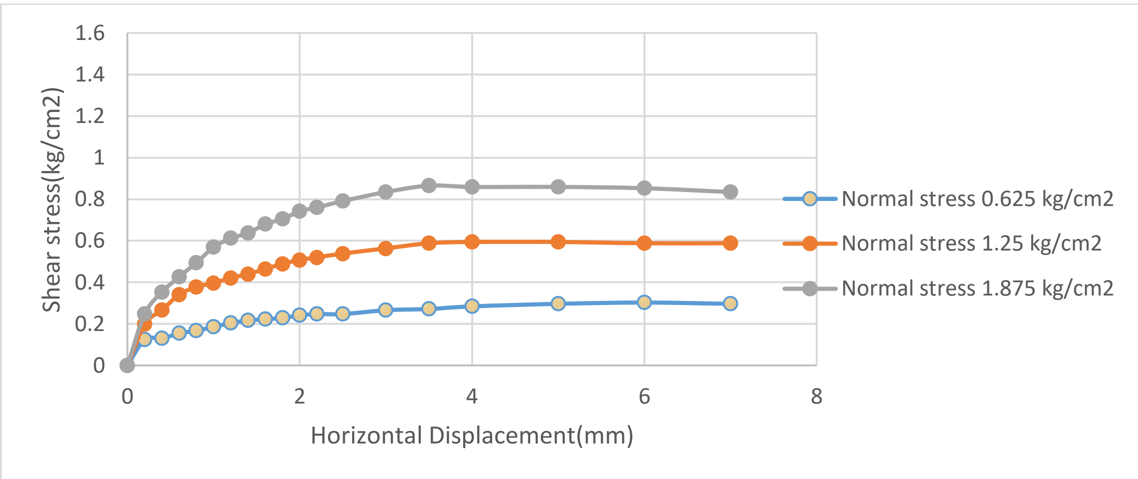


Fig. 4.2.12: Shear stress vs horizontal displacement
Water content= 15%, Dry density =1.50 gm/cc

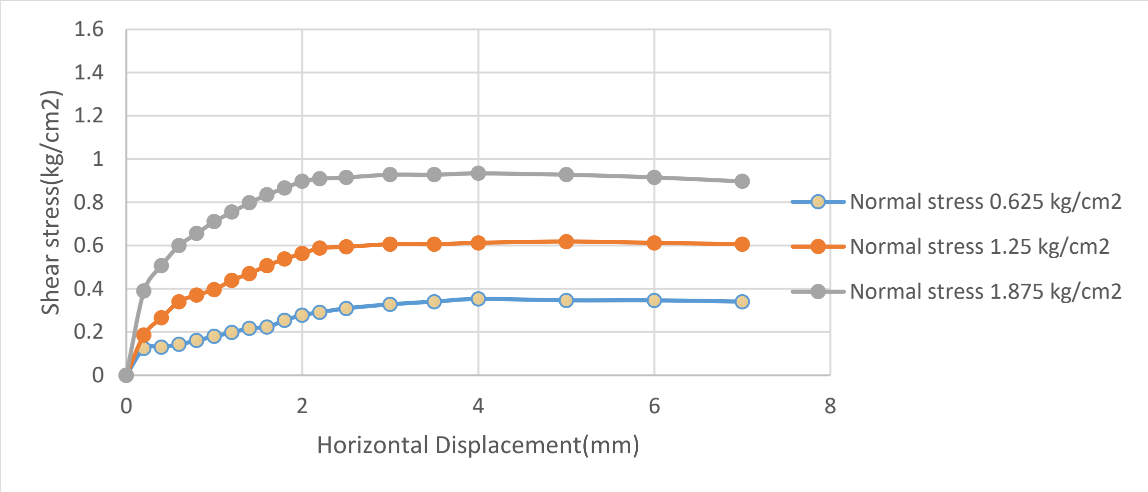


Fig. 4.2.13: Shear stress vs horizontal displacement
Water content= 15%, Dry density =1.65 gm/cc

4.3 Shear stress vs. Normal stress diagrams

The same test procedure has been repeated for each specimen three times with normal stress values of 0.625,1.25,1.875 kg/cm2 respectively so as to develop the straight line in the graph between shear stress vs. normal stress. The gradient of that straight line will give the value of tangent of the internal friction angle (φ) and the y-intercept will give the value of cohesion(c).

From the plotted figures(4.3.1 to 4.3.13) it can be said that the internal friction angle (φ) value is varying from 24.22 degree to 33.14 degree for different moisture content (w) and dry density(γ_d) combinations also the c value is varying from 0.024 kg/cm2 to 0.232 kg/cm2.

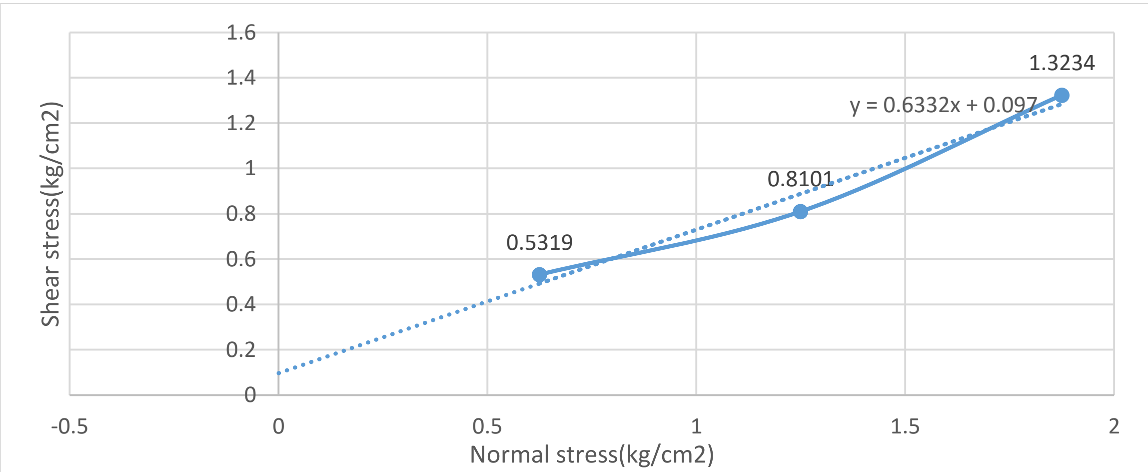


Fig. 4.3.1: Shear stress vs. Normal stress
Water content= 0%, Dry density=1.50 gm/cc

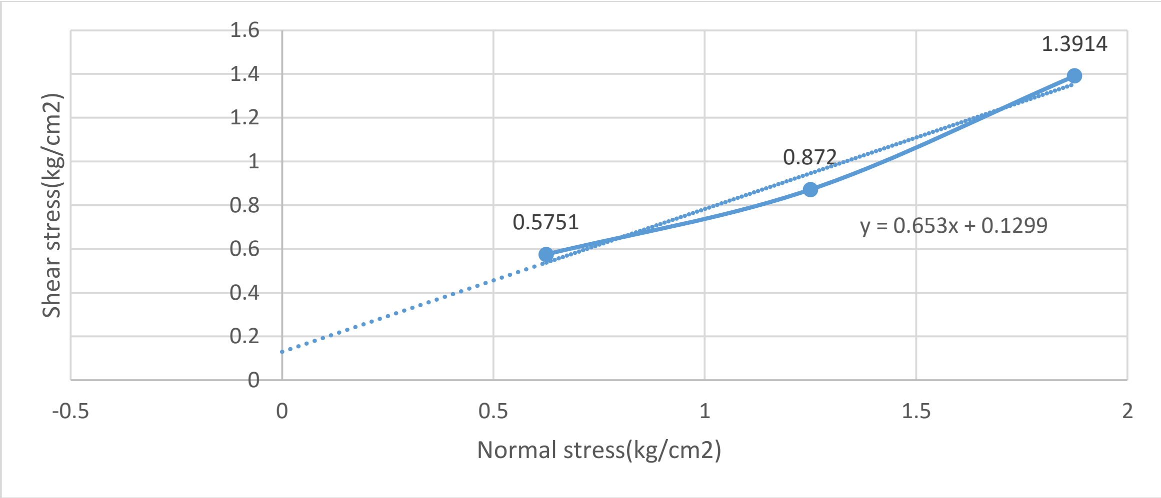


Fig. 4.3.2: Shear stress vs. Normal stress
Water content= 0%, Dry density=1.65 gm/cc

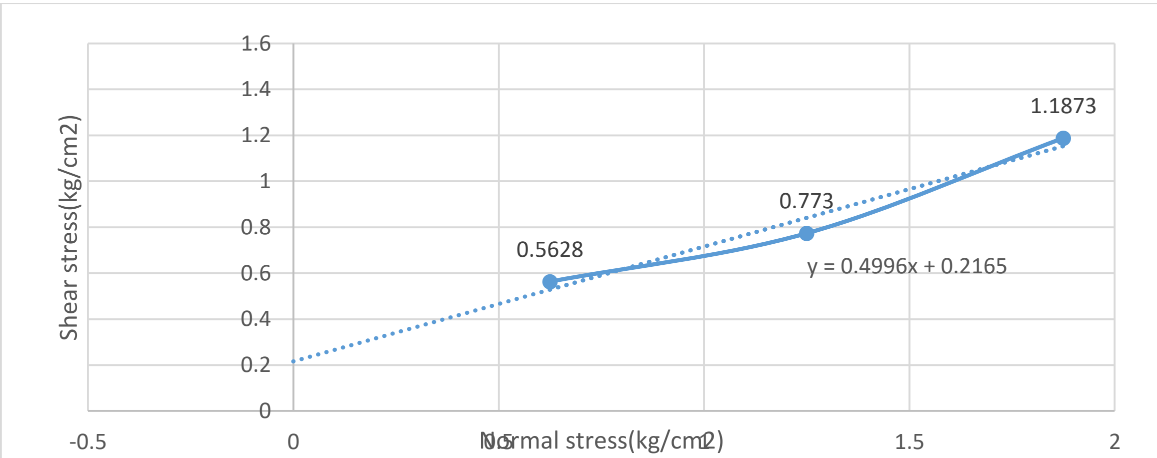


Fig. 4.3.3: Shear stress vs. Normal stress
Water content= 4%, Dry density=1.50 gm/cc

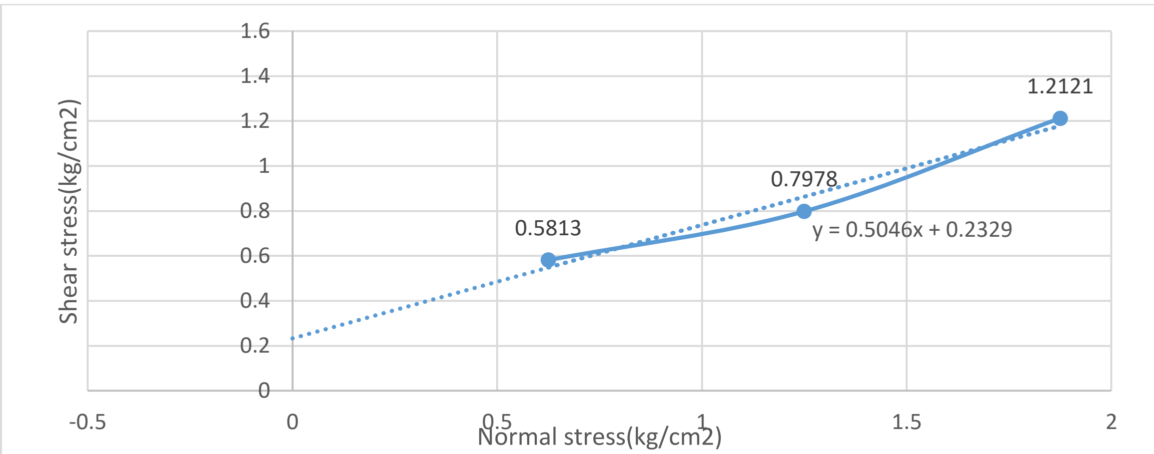


Fig. 4.3.4: Shear stress vs. Normal stress
Water content= 4%, Dry density=1.65 gm/cc

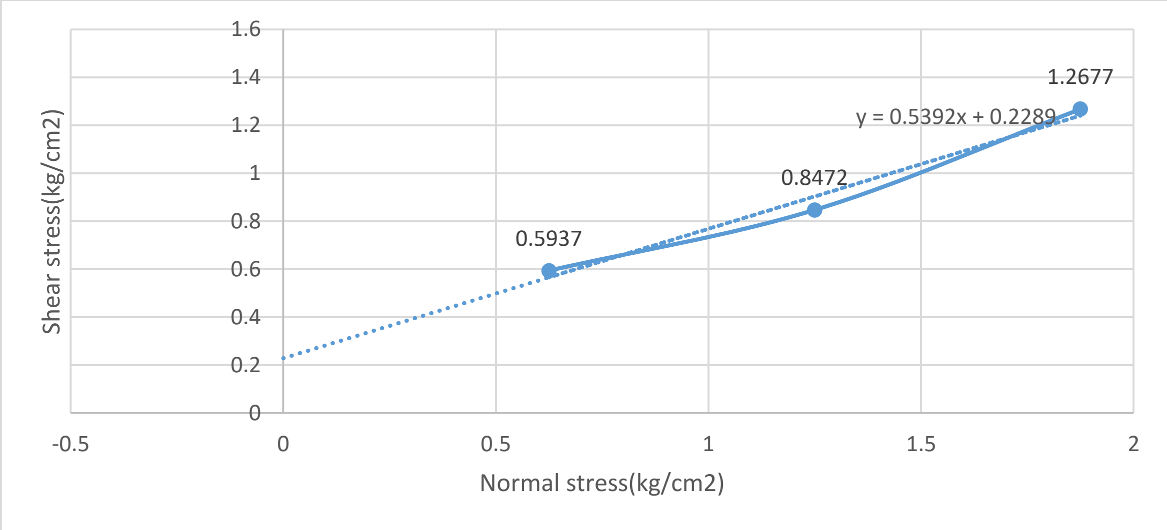


Fig. 4.3.5: Shear stress vs. Normal stress
Water content= 4%, Dry density=1.75 gm/cc

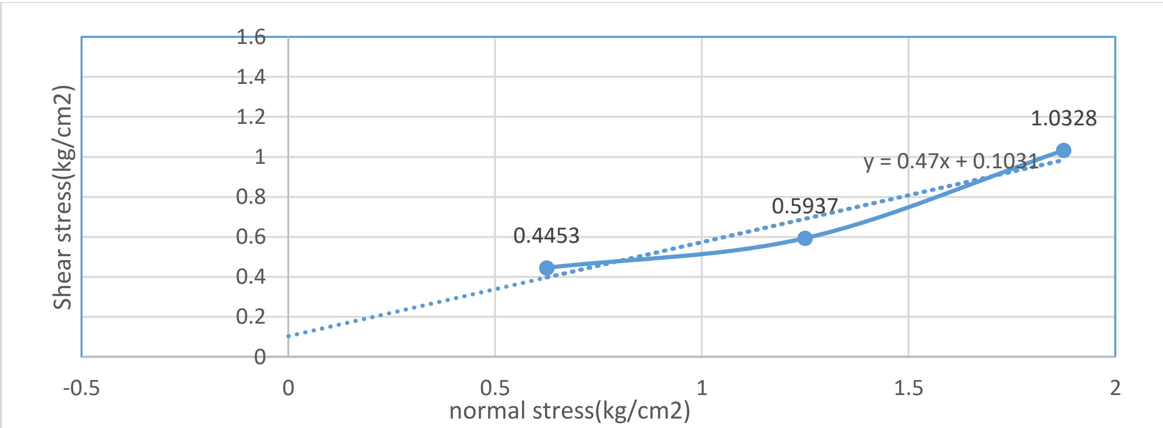


Fig. 4.3.6: Shear stress vs. Normal stress
Water content= 8%, Dry density=1.50 gm/cc

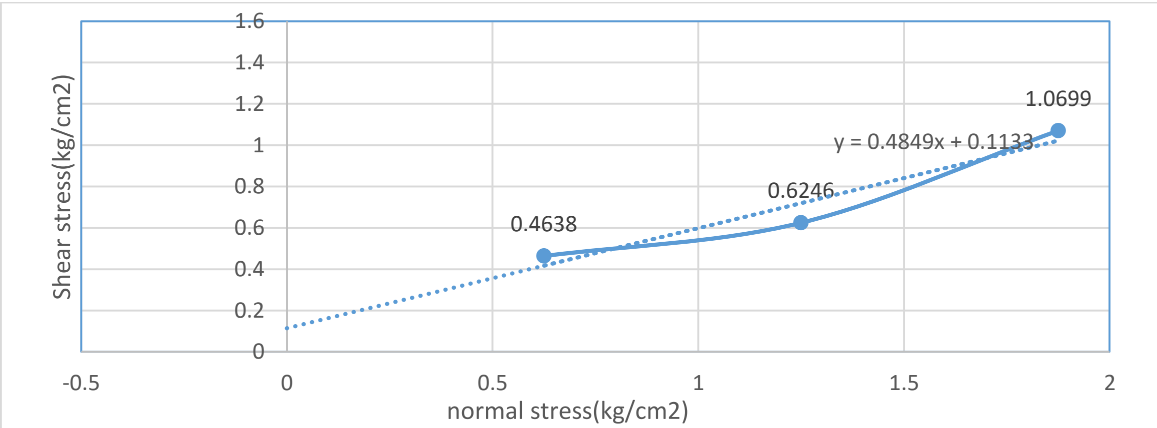


Fig. 4.3.7: Shear stress vs. Normal stress
Water content= 8%, Dry density=1.65 gm/cc

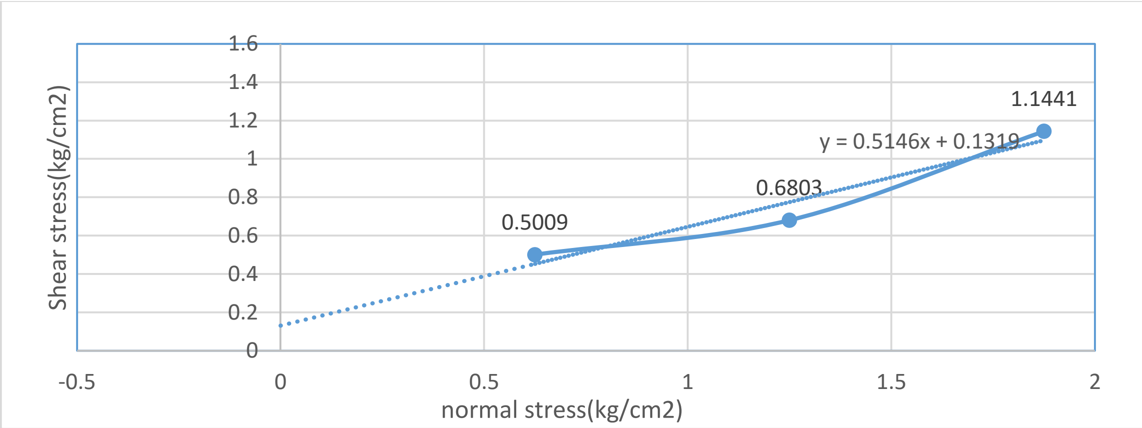


Fig. 4.3.8: Shear stress vs. Normal stress
Water content= 8%, Dry density=1.75 gm/cc

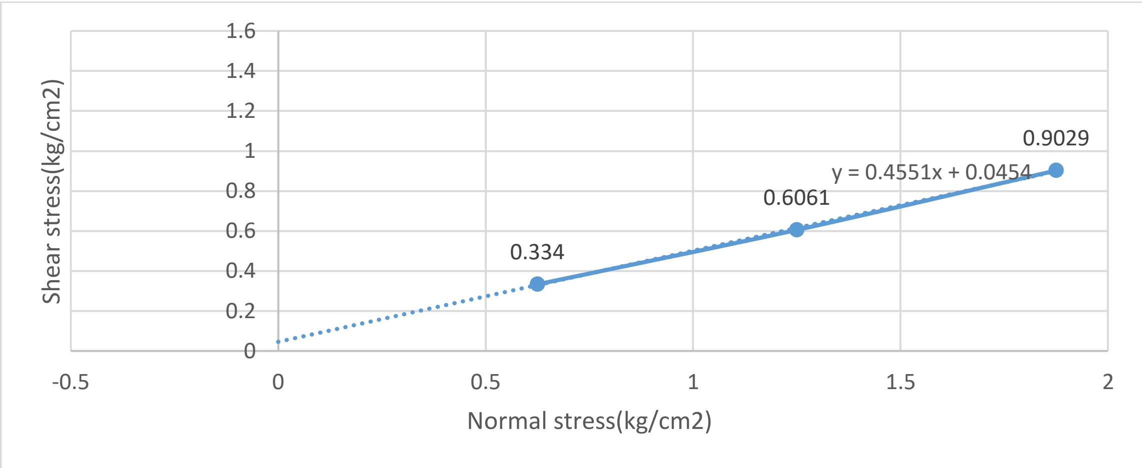


Fig. 4.3.9: Shear stress vs. Normal stress
Water content= 12%,, Dry density=1.50 gm/cc

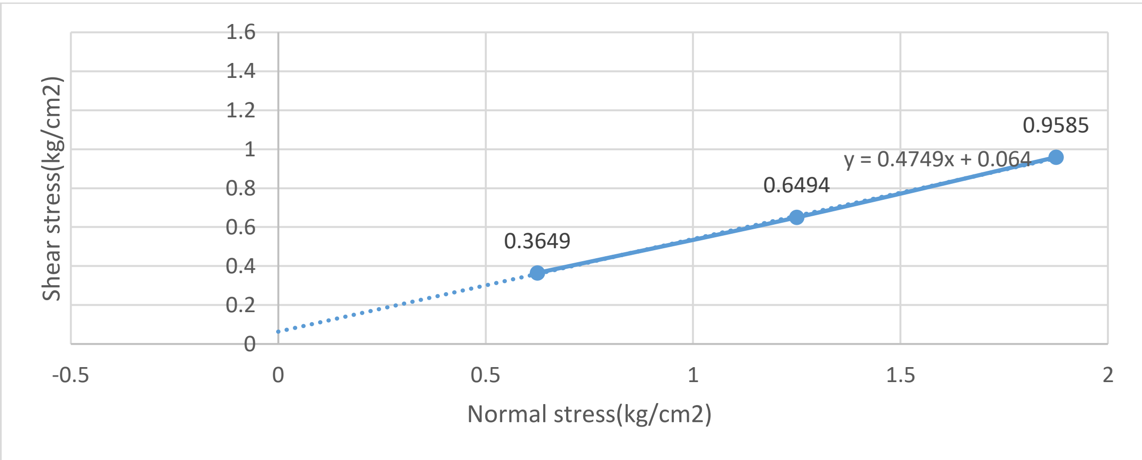


Fig. 4.3.10: Shear stress vs. Normal stress
Water content= 12%, Dry density=1.65 gm/cc

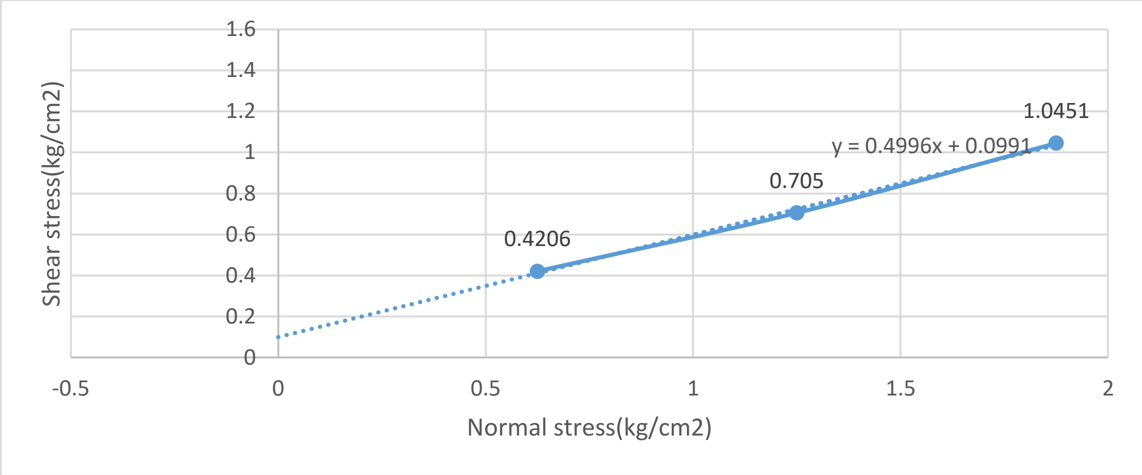


Fig. 4.3.11: Shear stress vs. Normal stress
Water content= 12%, Dry density=1.75 gm/cc

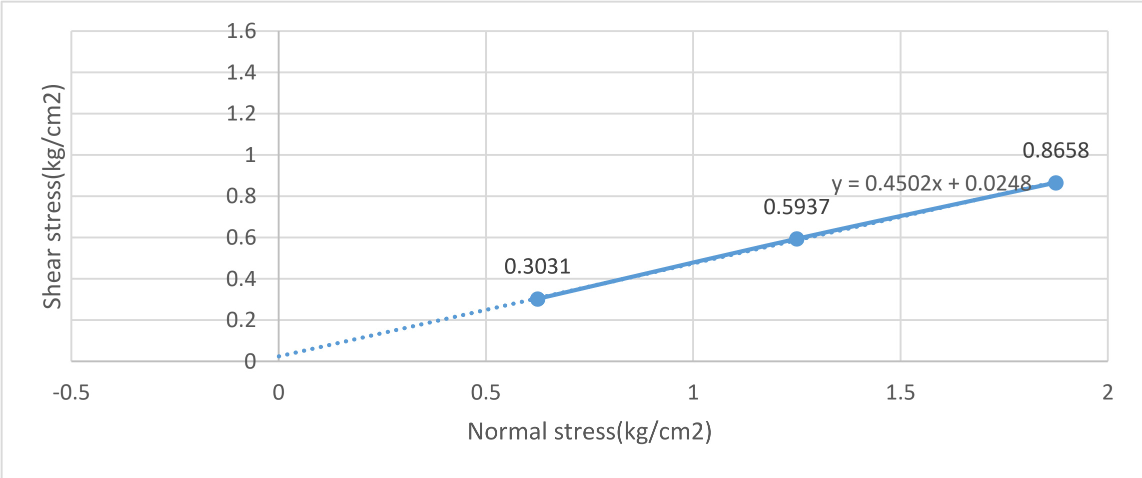


Fig. 4.3.12: Shear stress vs. Normal stress
Water content= 15%, Dry density=1.50 gm/cc

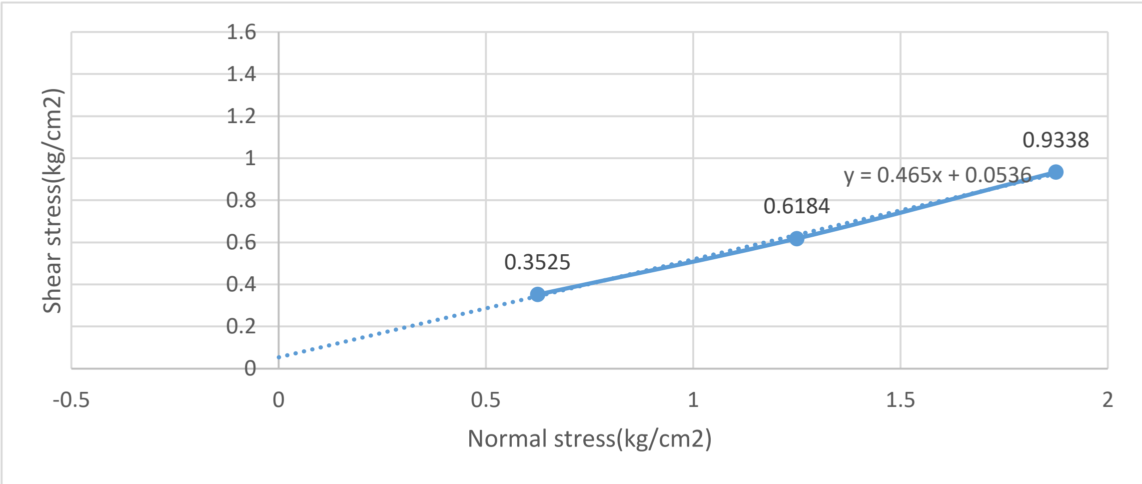


Fig. 4.3.13: Shear stress vs. Normal stress
Water content= 15%, Dry density=1.65 gm/cc

4.4 Horizontal displacement to reach peak shear stress vs. Normal stress diagrams

Horizontal displacement corresponding to peak shear stress for different normal stresses for various combinations of dry density and moisture content have been plotted in figure 4.4.1 – 4.4.13. From these figures it may be seen that except for dry soil and that with 4% water content at normal stress of 0.6 kg/cm2, for all other combinations the horizontal displacement corresponding to peak shear stress is, in general, is in the range of 4 – 7mm with an average of 5.5mm which is likely to be corresponding to shear strain of about 10%.

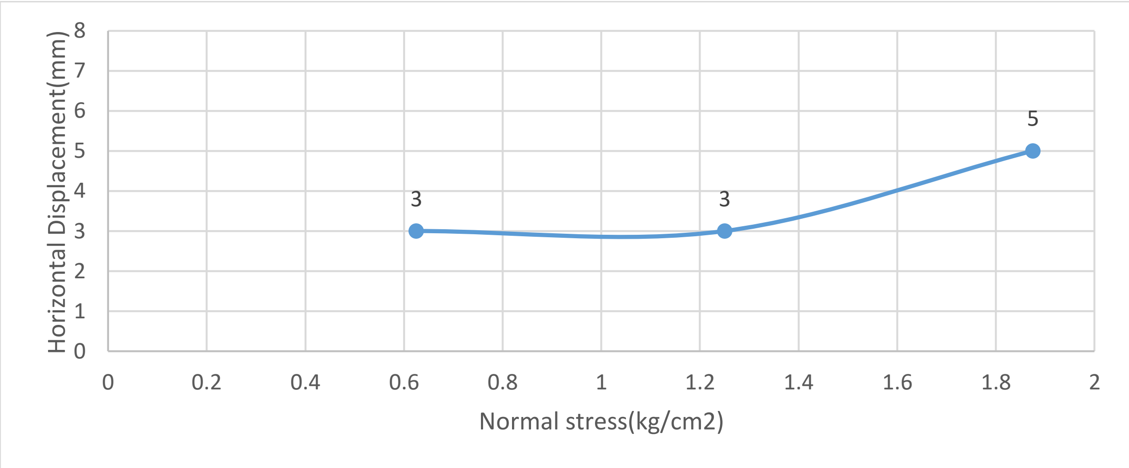


Fig. 4.4.1: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 0%, Dry density=1.50 gm/cc

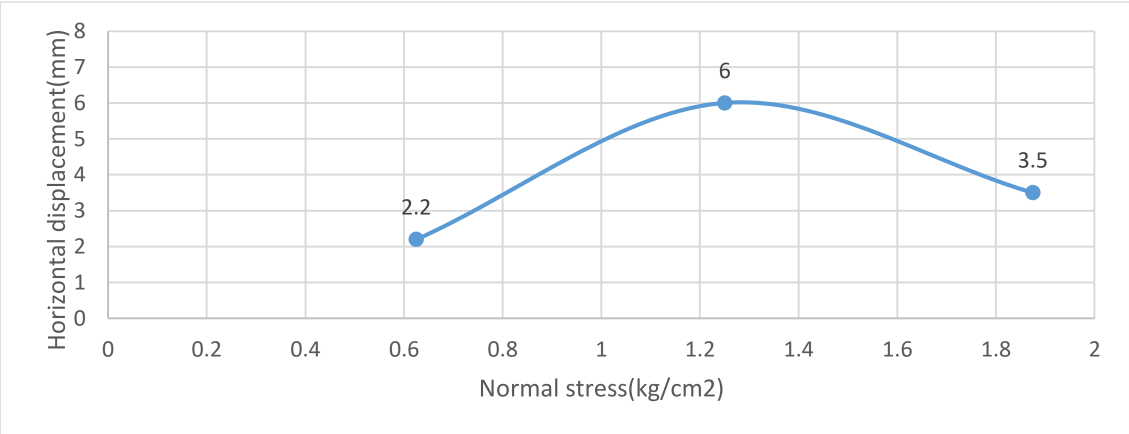


Fig. 4.4.2: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 0%, Dry density=1.65 gm/cc

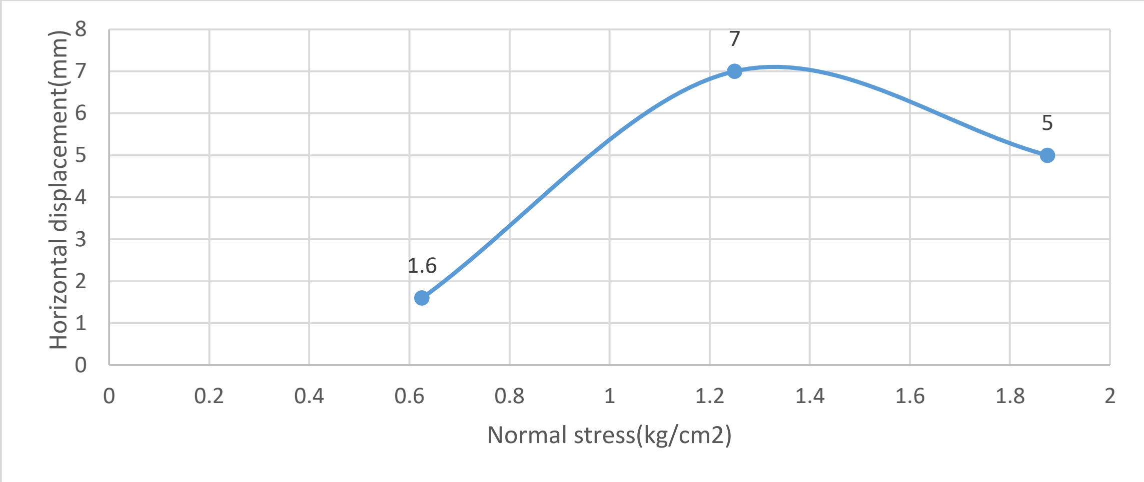


Fig. 4.4.3: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 4%, Dry density=1.50 gm/cc

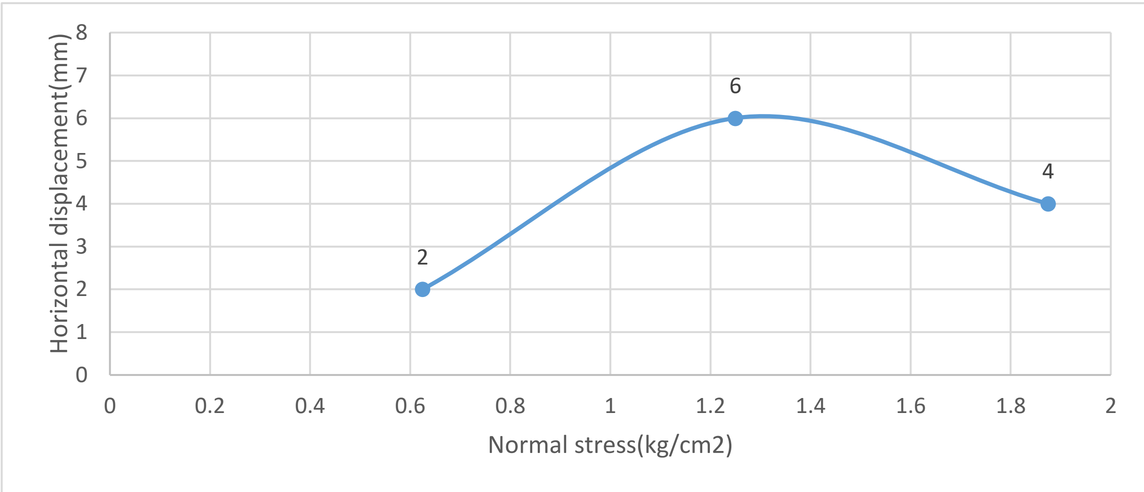


Fig. 4.4.4: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 4%, Dry density=1.65 gm/cc

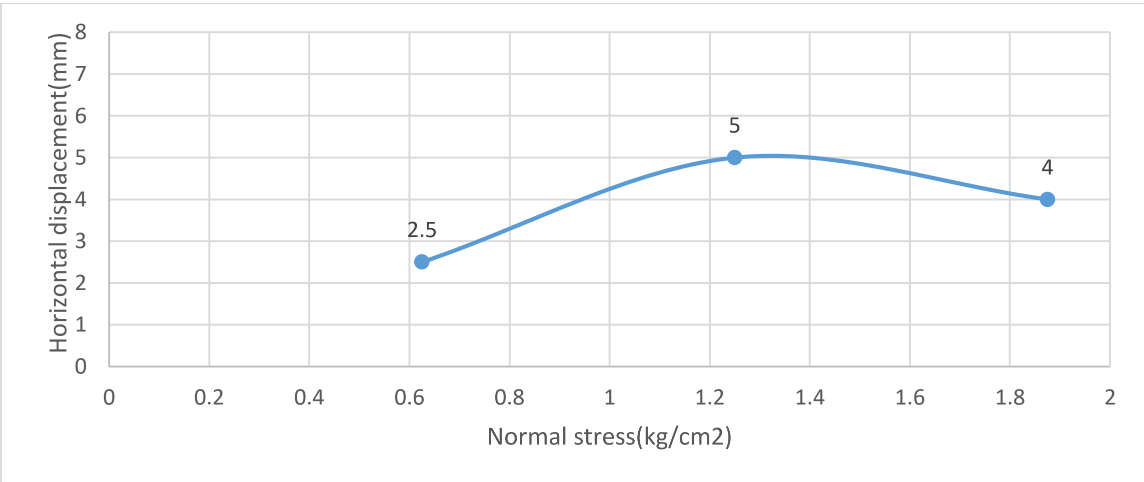


Fig. 4.4.5: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 4%, Dry density=1.75 gm/cc

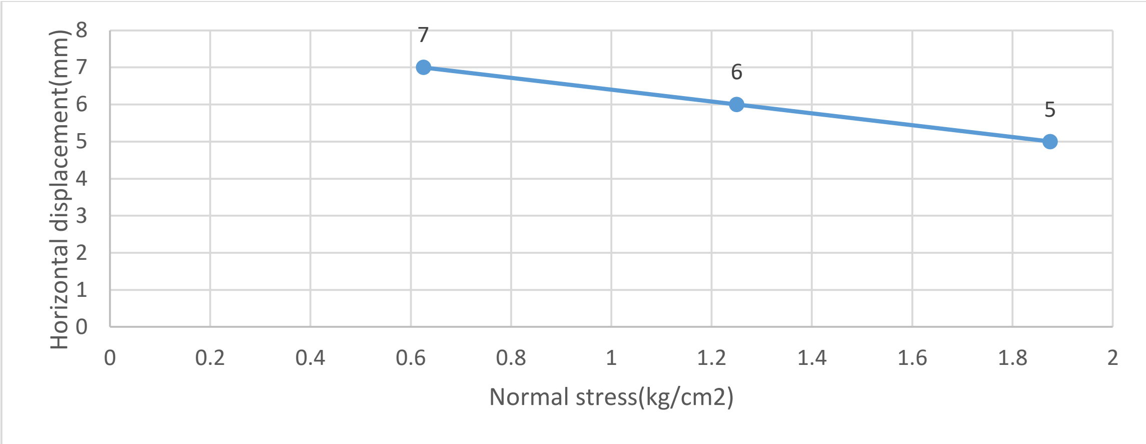


Fig. 4.4.6: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 8%, Dry density=1.50 gm/cc

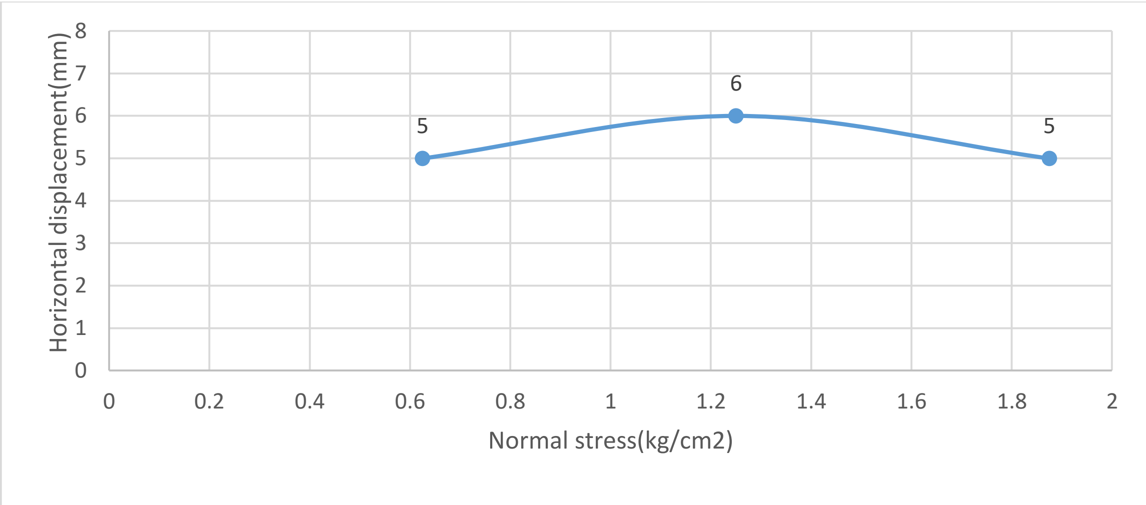


Fig. 4.4.7: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 8%, Dry density=1.65 gm/cc

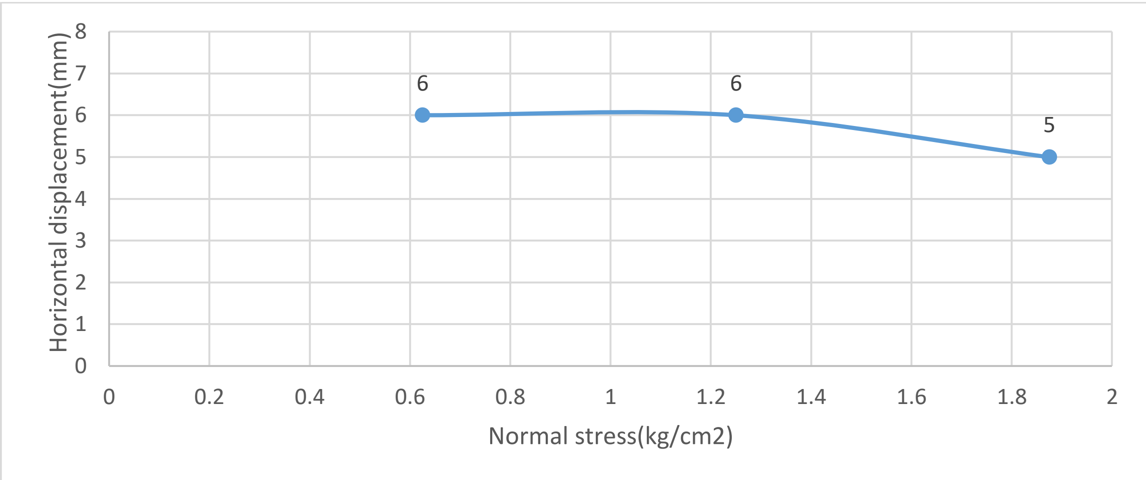


Fig. 4.4.8: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 8%, Dry density=1.75 gm/cc

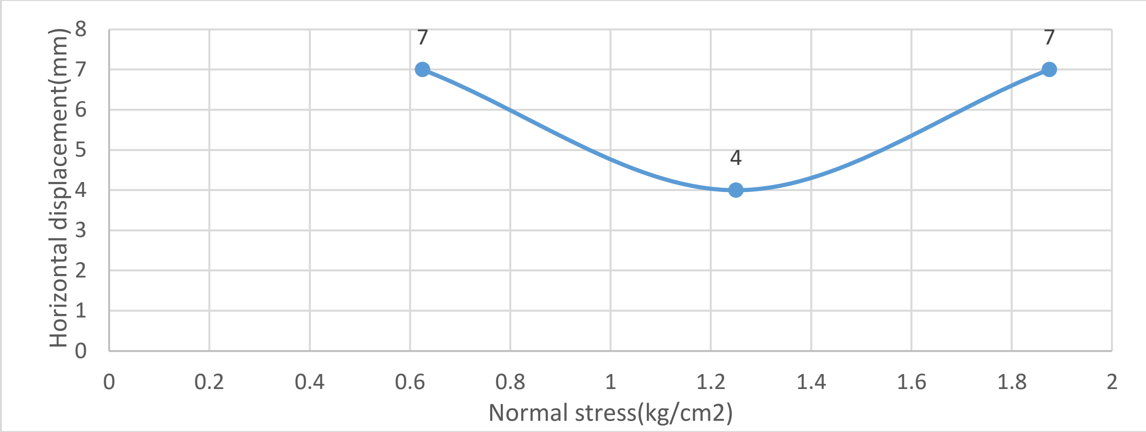


Fig. 4.4.9: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 12%, Dry density=1.50 gm/cc

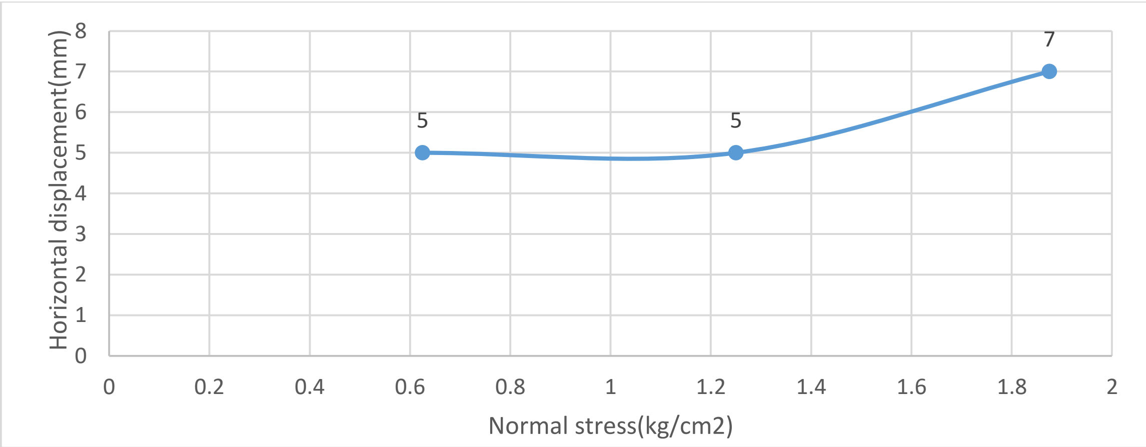


Fig. 4.4.10: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 12%, Dry density=1.65 gm/cc

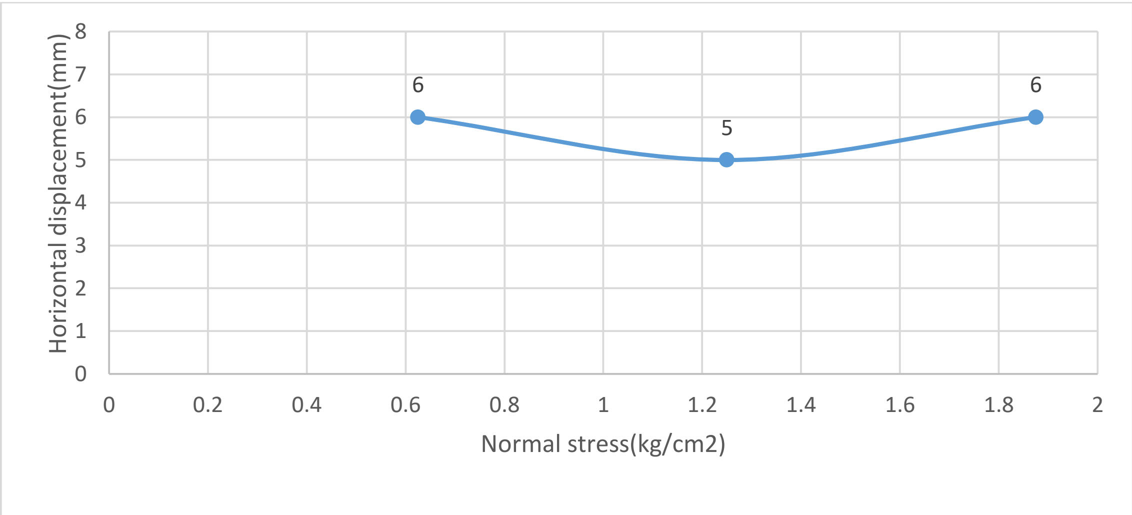


Fig. 4.4.11: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 12%, Dry density=1.75 gm/cc

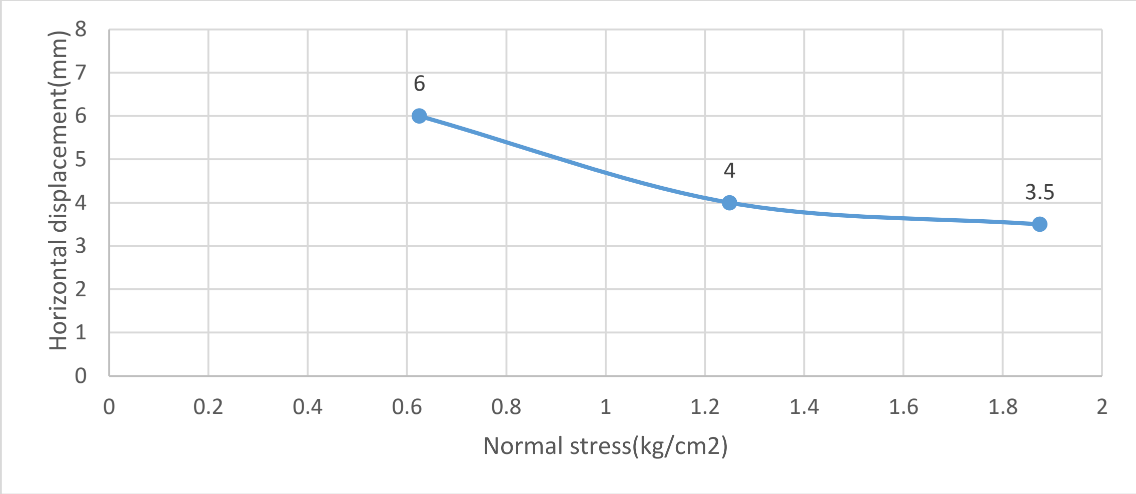


Fig. 4.4.12: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 15%, Dry density=1.50 gm/cc

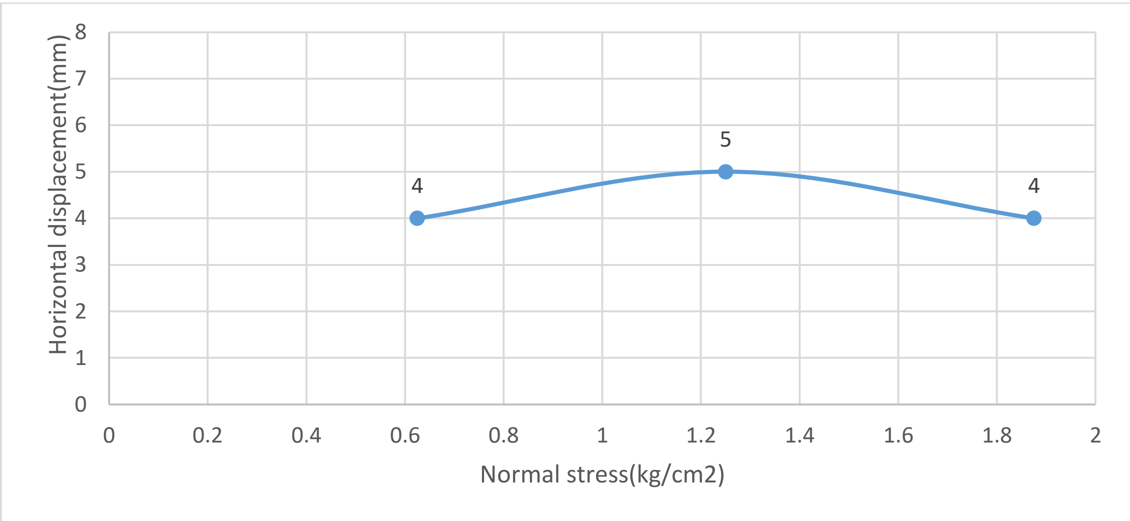


Fig. 4.4.13: Horizontal displacement to reach peak shear stress vs. Normal stress
Water content= 15%, Dry density=1.65 gm/cc

4.5 Variations of Friction Angle (φ) and Cohesion (c) with Dry Density (γ_d)

The figure (4.5.1) of Dry density vs. friction angle graph has been plotted for different moisture contents starting from 0% to 15%. It can be seen that there is a general trend of rising in the value of friction angle with the rise in the dry density. Also one thing special to be noted is that when the moisture content was nil, the sample exhibited maximum friction angle and after adding water to the sample there is a sharp decline in the value of friction angle due to the fact that water is acting like a lubricant and is decreasing the friction angle.

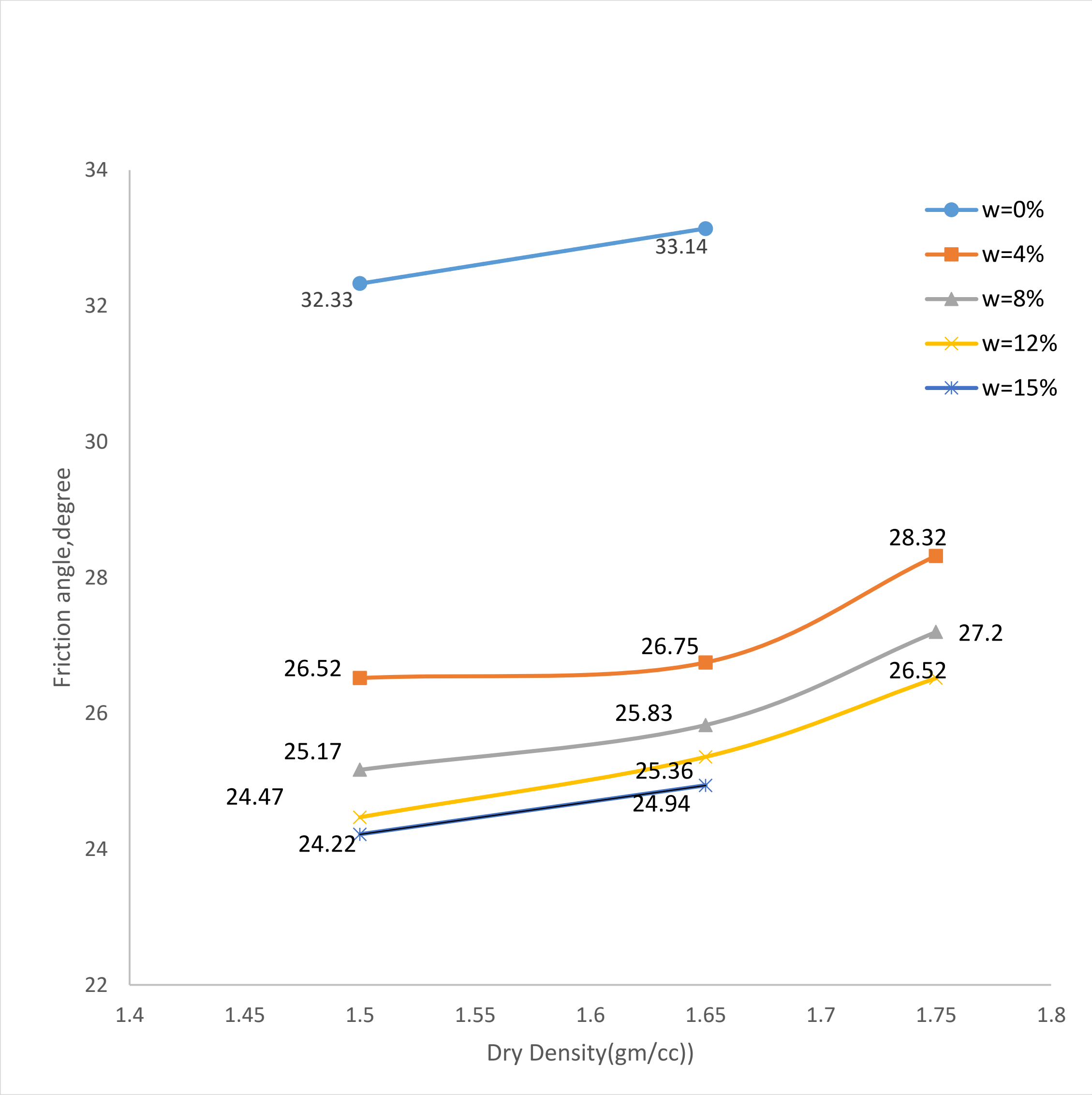


Fig. 4.5.1: Variations of Friction Angle (φ) with Dry Density (γ_d)

From the figure (4.5.2) of Dry density vs. cohesion graph plotted for different moisture contents starting from 0% to 15%, it can be decided that there is a general trend of rising in the value of cohesion though the gradient of the trend lines in this case is more flatter than the friction angle with the rise in the dry density. Cohesion is found to be maximum for water content of 4% which may be due to surface tension effect and is negligible above 12%.

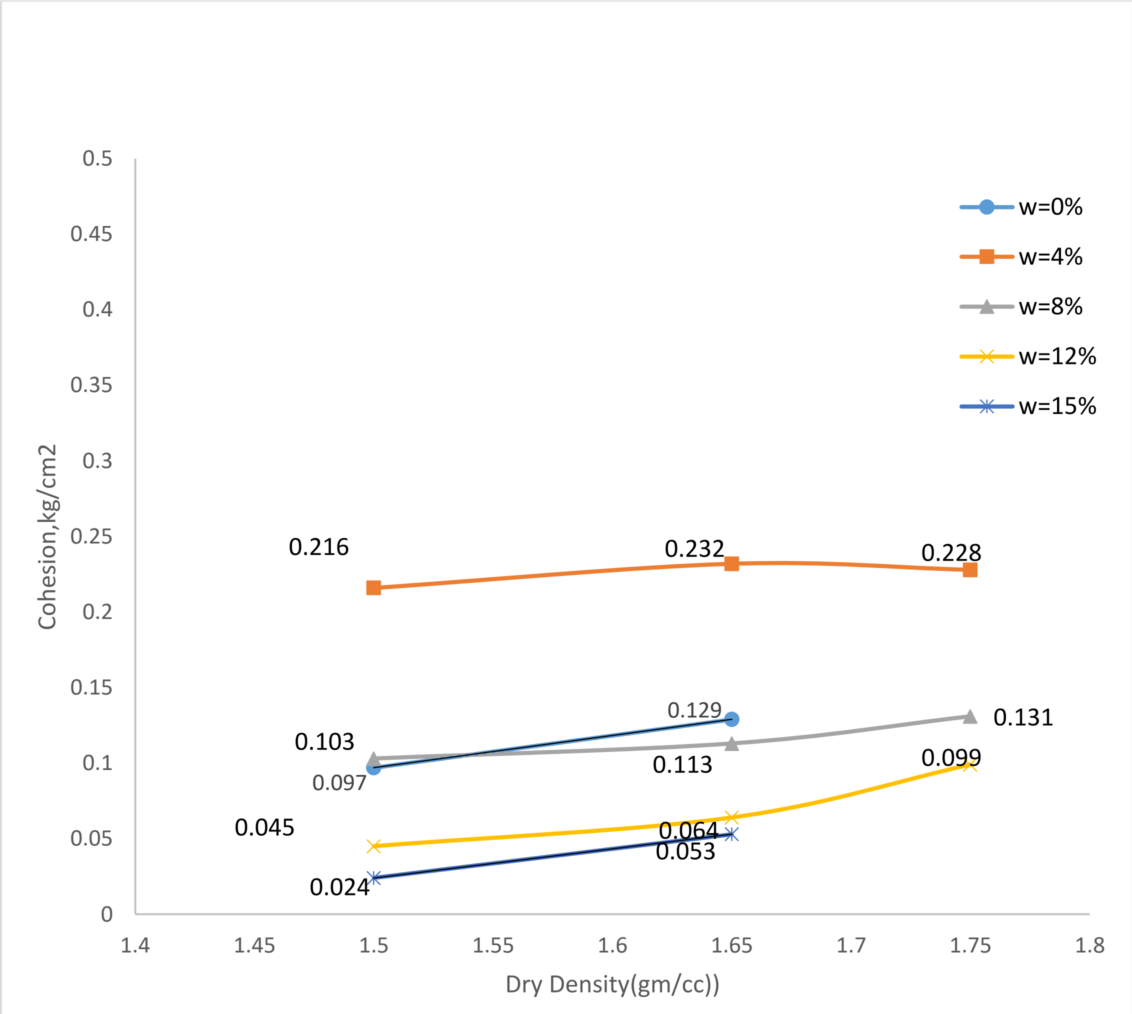


Fig. 4.5.2: Variation of cohesion(c) with Dry Density (γ_d)

From the above two plots it can be concluded that the shear strength of the silty soil sample as was collected from the Kolkata region increases with the increase in the dry density as both the c and Φ values are increasing with dry density.

4.6 Variations of Friction Angle (φ) and Cohesion (c) with moisture content (w)

The variation of friction angle with moisture content has been plotted for different dry densities of 1.50, 1.65 and 1.75 have been plotted in fig. 4.6.1. From this figureit can be seen that there is a general trend of falling in the value of friction angle with the rise in the moisture content. Also one thing special to be noted is that when the moisture content was nil, the sample exhibited maximum dry density and after adding water to the sample there is a sharp decline in the value of friction angle due to the fact that water acting like a lubricant and is decreasing the friction.

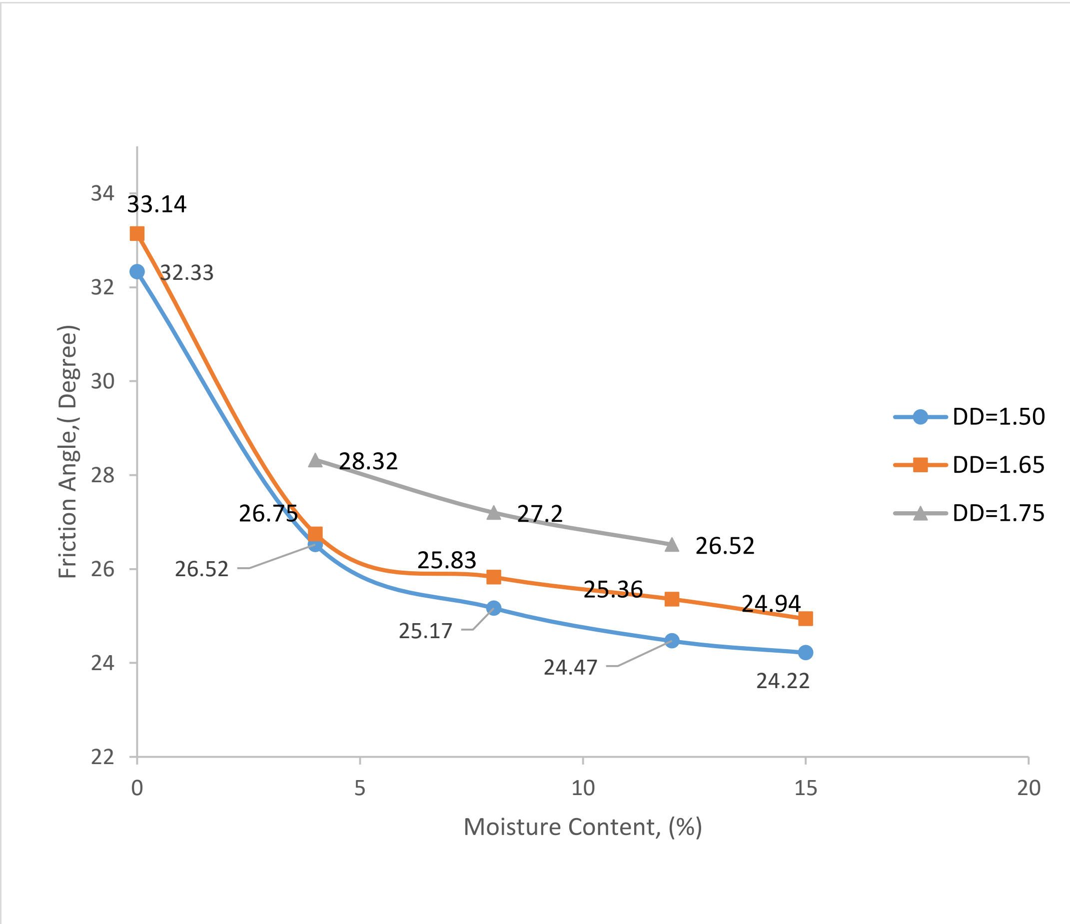


Fig. 4.6.1: Variations of Friction Angle (φ) with moisture content (w)

From the figure (4.6.2) of Moisture content vs. cohesion graph plotted for different dry densities of 1.50, 1.65 and 1.75; it can be concluded that there is a no general trend of falling or rising in the value of friction angle with the rise in the moisture content. Firstly until moisture content value of 4 to 5%, there is an increase in the value of cohesion. Any further increase in the water content will reduce the cohesive force between the molecules. This may be due to the fact that the silt molecules are not totally non-plastic, rather from the atterberg limit data we found that the sample is low in plasticity and a mild amount of water will cause the molecular bond stronger thereby increasing the cohesion. But if the water content is high the bonding gets weaker.

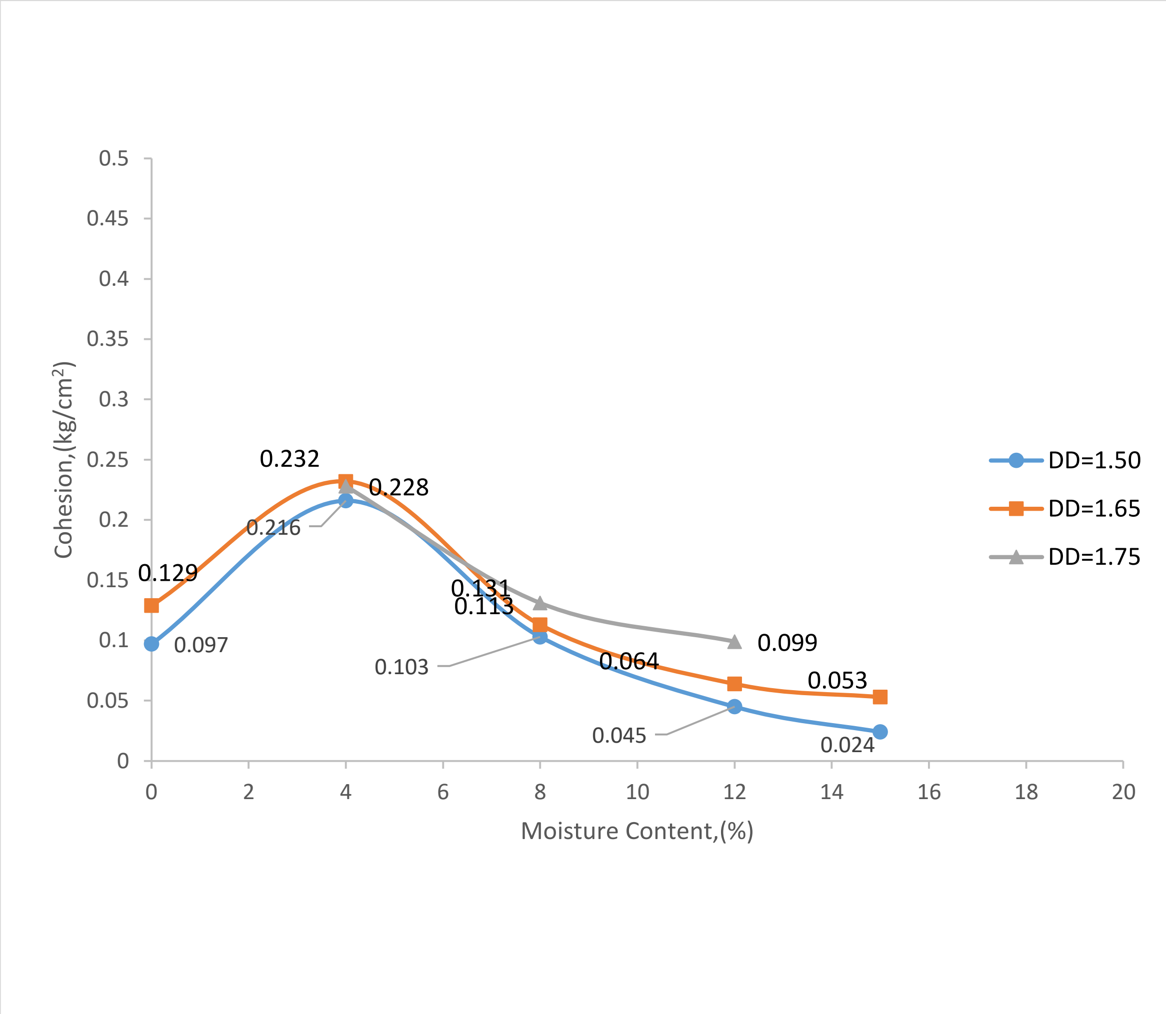


Fig. 4.6.2: Variations of cohesion(c) with moisture content (w)

Chapter 5

5.0 Conclusions

The following conclusions have been drawn after the evaluation of the shear strength properties of the silty soil in Kolkata Region.

1. The silty soil in this region is of low plasticity with low liquid limit and plastic limit values and can be classified under ML category of soil classification
2. The shear strength of the silt of Kolkata region increases with the increase in dry density this is due to the fact that both the cohesion and internal friction angle is increasing with the rising value of the dry density.
3. There is a general trend that the shear strength of the silt of this region decreases with the rise in moisture content though for very small amount of moisture content in the range of (0 to 4%) this may not be always true because though the friction angle is decreasing sharply, but the cohesion is increasing in this range.
4. Like any other category of soil, the shear strength of silt in Kolkata region is also increases with the increase in normal stresses.

Scope of Further studies

However it is acknowledged that, above results are based on limited no of direct shear tests only. And the silt of Kolkata region deserves more attention and other tests like triaxial tests with various combinations of water content (w) with Dry Density (γ_d) needs to be conducted for studying the shear strength properties of this soil further and evaluating all the shear strength aspects of this soil.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

This is to declare that I, DINABANDHU TRIPATHI (Class Roll No. 002210402030, Examination Roll No. M4CIV24027, University Registration No. 163473 of 2022-2023), have prepared this thesis entitled **"Shear Strength Behaviour of Silty Soil in Kolkata Region"** under the supervision of Dr. Ramendu Bikas Sahu . This manuscript is original and not directly plagiarized in any sense. However, the literature studied for the preparation of this report has been cited wherever required and also presented in the list of references.

Jadavpur, Kolkata
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CERTIFICATE OF RECOMMENDATION

I hereby recommend that the thesis prepared under my supervision by **DINABANDHU TRIPATHI** (Class Roll No. 002210402030, Examination Roll No. M4CIV24027, University Registration No. 163473 of 2022-2023) entitled **"Shear Strength Behaviour of Silty Soil in Kolkata Region"** be accepted in partial fulfilment of the requirements for the Degree of Master of Civil Engineering with specialization in Soil Mechanics and Foundation Engineering from Jadavpur University during the year 2023-24.

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