ABSTRACT

With the rapid economic growth, domestic living standard improvement and urban population increase in India, a tremendous amount of municipal solid waste is being generated every day and is becoming one of the foremost issues of urban management. The planning and management of domestic waste is important to both the municipalities and the local community for a variety of reasons including environmental impact, financial cost, health and hygiene, city beautification, natural resource consumption. In order to achieve the goal which is to protect the environment, a proper waste disposal system is necessary for which a competent base liner is very important and need to be designed appropriately. Shear strength is an important property to determine the stability of liner. A liner material must be able to withstand any physical force such as stresses. To construct a soil liner with acceptable shear strength and permeability values, compaction is usually carried out at site to improve the soil properties of liner. A proper planning was also required for a competent landfill. The planning is such as pre-treatment of waste, for example eliminate or reduce the concentration of certain unwanted material such as heavy metals and organic substances. Liquid generated at landfill, also known as leachate, also need to be collect, reprocess and periodically analysed. To construct a soil liner with good shear strength and sufficient impermeable value, compaction is usually carried out at site to improve the soil liner. Compaction is a process where is carried out to increase the shear strength, to decrease the permeability A study was conducted in the laboratory to investigate the relationship between the degree of compaction of soil and its effect on the shear strength. Types of compaction used in the test are standard. Soil properties such as specific gravity, Atterberg limit and particle size distribution are also determined in the laboratory test. The soil used in this test was a silty clay. Test result shows that the silty clay is classified as soil with high plasticity, CH under the Indian Standard with specific gravity of 2.71, liquid limit of 53% and plasticity of 26%. The results indicated that the higher degree of compaction under low moisture content and mixing with some various percentage of Fly Ash it will give higher shear strength for soil. The maximum dry densities and were found 1.691 g/cc. It is also observed that addition of Fly Ash of such proportions there is a significant change shown in decreasing permeability of soil.

CHAPTER-1

INTRODUCTION

1.1 General Overview

Landfill site a site for the disposal of waste materials by burial and is the oldest form of treatment. Historically, landfills have been the most common methods of organized waste disposal and remain so in many places around the world. Today, growing population and increasing in living standards all over the world has urge engineers to improve and design competent waste disposal strategies especially in urban area where there is a high growth in waste quantity and toxicity. A competent landfill would require a high-quality design especially in choosing the site where geologically subsoil is stable with low water permeability as a natural barrier to avoid any waste water leakage. The leachate monitoring points must be designed so they spread loads and don't overstress or punch through the liner. A competent landfill also required a strong and impermeable soil liner and a technical barrier, which is a combination of successive clay liners covered with geomembrane and geosynthetic protective sheet. It's having very low hydraulic conductivity and low gas permittivity also moderate to high shear strength sufficient to ensure minimum deformation under the design loading with a factor of safety.

A proper planning was also required for a competent landfill sites to execute. The planning is such as pre-treatment of waste, for example eliminate or reduce the concentration of certain unwanted material such as heavy metals and organic substances. Liquid generated at landfill, also known as leachate, also need to be collect, reprocess and periodically analyzed. Leachate characterization should include an assessment and demonstration of the quantity and composition of leachate anticipated at the proposed facility.Then a well-designed capping system at the end of the landfill is important and usually is fit with geomembrane. In order to achieve the goal which is to protect the environment, a good base liner is very important and need to be design carefully. If one of the components in the landfill fails after decades, for example geotextile, then the soil liner would have to be able to take over its task. Soil ability to support an imposed load is determined by its shear strength. Hence, shear strength is an important property to determine the stability of liner. According The Municipal Solid Waste (Management and Handling) Rules, 2000, in India, a liner material must have sufficient strength to prevent failure owing to pressure, the stress of installation, and the stress of daily operation.

For example, the stresses might be due to the heavy equipment used to move and compact waste (Environment Protection Act, 86). The soil liner would also need to have high shear strength to cope of mechanical movement under or above the liner. To construct a soil liner with good shear strength and sufficient impermeable value, compaction is usually carried out at site to improve the soil liner. Compaction is a process where is carried out to increase the shear strength, to decrease the permeability and also reduce the tendency to settle in years to come. Several different methods are used to compact soil in the field; some examples include tamping, kneading, vibration, and static load compaction.

1.2 Problem Statement

Determination of shear strength is very much important for the soil used in landfill liner. That is because the strength is required to deal with mechanical movement and also to take load from the waste over it. The strength is also much equally important to maintain the properties of soil. The quantity of waste generated daily is continuously increased whereas the land used for landfill is getting lesser in area wise. Hence, the limited space required the waste to be stack higher at the landfill and a stronger liner and methodology is required to withstand this greater load.

1.3 Objectives of Study

Generally, the objective of the study is to determine the relationship between the type of compaction and the shear strength of soil. In other words, the more specific objectives of the study are:-

1) To determine the basic engineering properties of the soil.
2) To determine the maximum dry densities and the optimum moisture contents of the soil

compacted at different compactive effort.

3) To determine the shear strength of soils compacted at various moisture contents and compactive efforts with certain mixing of fly ash.

4) To determine the hydraulic conductivity of soil and effects of mixing of fly ash with it.

1.4 Scope of Study

This study is focused on identifying the relationship between the compaction type and shear strength of soil. The sample used in this study is Bawana putt Silty clay. Laboratory test that will be performed include Atterberg limit, particle size distribution, Specific gravity (pycnometer test), also permeability test. Only soil particles passing 2 mm will be used for compaction and strength test. The compaction methods will be used for this experiment is standard Procter test. Unconfined compressive strength test (UCT) will be used to determine the shear strength of the soil after compaction.

1.5 Significance of Study

It is important to determine the shear strength of the soil is to be used for landfill liner. Hence, by carrying out this experiment, we can predict what the moisture content and the best compaction type for this soil to achieve the minimum unconfined compressive strength of 200 kPa (Daniel and Wu 1993).

1.6 Expected Findings

By the end of this research, the below is the results that are expected to obtained.

1) The shear strength of soil value obtain is different for different type of compaction carried out to the soil sample. The sample which undergoes compaction test is predicted to have highest shear strength as it experience the highest compaction effort.

2) To be able to establish a relationship between the compaction type, effort with the shear strength.

3) To be able to determine the most suitable compaction method for this soil to achieve the highest shear strength.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For a civil and environmental engineering practice, properties of soil that are to be use is important as no designer or civil engineer today would attempt to build a structure without the knowledge on the soil. The primary factors in controlling the performance of compacted soil liners are the hydraulic conductivity, potential shrinkage with moisture content as index and strength of the soil (Oweis and Raj P Khera, 1998). All these components are tied directly to compaction. Therefore, tests will be conducted on this Silty clay to test its suitability to be used as clay liner at landfill.

2.2 Landfill

A landfill site is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common methods of organized waste disposal and remain so in many places around the world. Landfills may include internal waste disposal sites where a producer of waste carries out their own waste disposal at the place of production as well as sites used by many producers. Many landfills are also used for waste management purposes, such as the temporary storage, consolidation and transfer, or processing of waste material sorting, treatment, or recycling. A landfill also may refer to ground that has been filled in with rocks instead of waste materials, so that it can be used for a specific purpose, such as for building houses. Unless they are stabilized, these areas may experience severe shaking or liquefaction of the ground in a large earthquake.

One of the factors which are required to have serious attention for designing landfill is the liner, which play a role as preventing leachate generated under the landfill from sipping through the soil and pollute the underground water. Liners are broadly classified into 4 main categories, which is soil (earthen) liner or compacted clay liner (CCL), geomembrane, geosynthetic clay liner, and vertical cut-off wall. The purpose of all this liner is to restrict the flow of fluid or leachate from entering the environment.

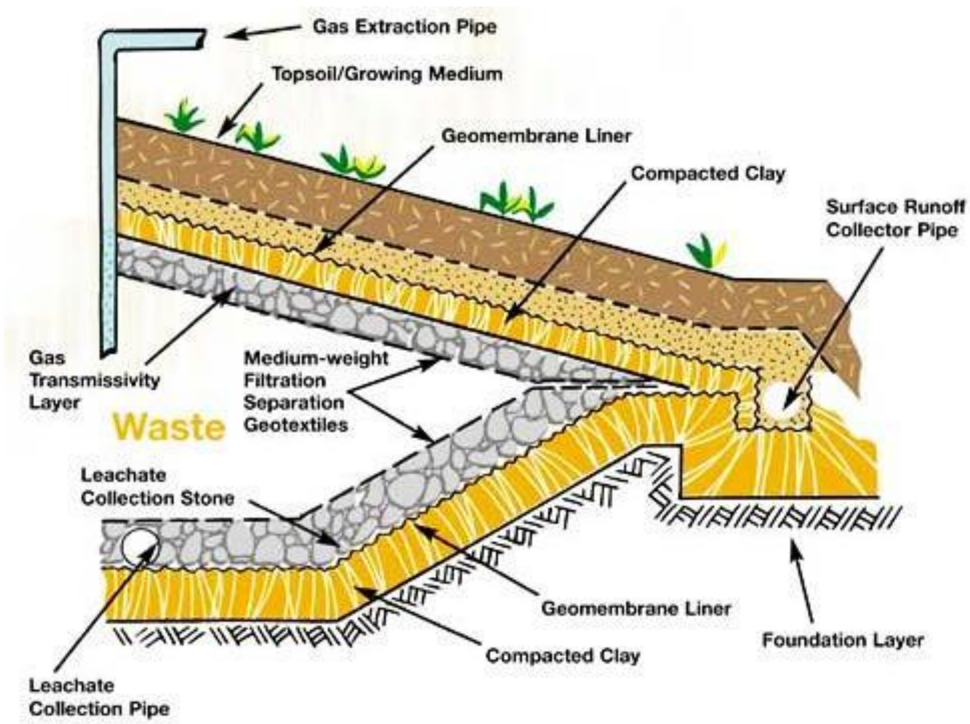

Figure 2.1: A Cross-section of a best practice land fill cell

2.3 Narela-Bawana landfill site

Narela-Bawana landfill site is the first scientific landfill site in the city where close to 1,300 metric tonnes of solid waste will be segregated and processed to obtain refuse derived fuel (RDF) for industrial use, manure, recyclable material etc. The site will be used to process garbage collected from Rohini and Civil Line zones. It is an important project and will be completed in two phases. In the first phase, we are going to scientifically dispose of the solid waste and in the next phase, we will convert the garbage dumped at the site into energy. Only 25% of the total garbage collected will be dumped at the site. Built at a cost of Rs 70 crore, the site will have facilities for material recovery, treating leachate (toxic water discharged from garbage during decomposing), trapping harmful gases and make RDF. The leachate will be collected and treated before being released in the storm water drains. the landfill sites now has a mechanism to prevent toxics from seeping into the soil, thereby polluting the ground water. At the Narela-Bawana site, put up a thick liner to prevent leachate from leaching down. The landfill will be lined with two layers of clay and a high-density polythene layer in between. For this purpose taken clay found nearby Narela-Bawana landfill site.

Figure 2.2: Landfill site at Narela-Bawana in northwest Delhi.

2.4 Clay Liner

The Ministry of Environment and Forest has specified that compacted clay maybe used as an effective barrier for the containment of landfill leachate. Compacted clay liners have proven to be a very effective barrier system. Usually a landfill will always be located in low permeability strata as a result of manmade excavation to a layer of natural clayey soil. However, these natural clay deposits are not acceptable as the only liner because of their potential to contain fissures and fractured zones. It is necessary to construct a clay liner by reworking on the existing soil to produce a low-permeability, high strength and uniform material (Sharsby, 2000). Liner systems are used to provide short, medium and long-term of protection to the environment. And therefore, it must be strong, durable, and resistant to chemical attack and puncture especially although high load is applied on top.

Generally the most important factors that influenced the stability of landfill liner are:

- Interface shear strength of various geosynthetic material
- Interface shear strength between geosynthetics and soil materials
- Internal shear strength of GCLs,
- Internal shear strength of solid waste and
- Slope and height of waste fill during each lift
- Consideration of post-peak soil shear strengths and
- Concern over low shear strength of CCL placed below (Qian et al, 2001)

Soil or earthen liners are usually made of natural inorganic clay or clayey soil to achieve a low permeability at site. Soil which is classified as CH, CL, and SC are all suitable to be used as the material for soil liner.
Below are the basic requirements for the clay liner:-

- The coefficient of permeability of the liner must be 10-9 m/s or less (Daniel, 1993).
- Liner soil should have at least 30% fines (Daniel, 1993) and 15% clay (Benson et al, 1994).
- Volumetric shrinkage upon drying of less than about 4% (Daniel and Wu, 1993).
- Minimum unconfined compressive strength of 200 kPa or 100 kPa of unconfined shear strength (Daniel and Wu, 1993).

2.5 Compaction

Compaction is the process of densification of soil mass by reducing air voids. The purpose of laboratory compaction test is so determine the proper amount of water at which the weight of the soil grains in a unit volume of the compacted is maximum, the amount of water is thus called the Optimum Moisture Content (OMC). Compactions in a process of densification of an unsaturated soil by reducing the volume of voids filled with air by applying mechanical means (Sharma, 2004).An important characteristic of cohesive soils is that compaction improves their shear strength and compressibility properties. Such characteristics follow the principles stated by R.R. Proctor in 1933. The most recognizable development of his theory was a test now known as the “Standard Proctor,” which is used to estimate the maximum density of soils. This technique will result in increasing the shear strength of the soil and lower its compressibility (Craig, 1987). The compaction may also increase the bearing capacity of the soil, increase the factor of safety against possible failure and reduce the shrinking and swelling characteristics of the soils (Das, 1990). The purpose of applying mechanical energy to the soil is to force the soil particles to become close together and thereby increase the density of the soil. Increasing in compactive efforts will result in higher dry unit weights and lower hydraulic conductivity (Bozbey and Guler, 2006). The compressibility of saturated soils depends on the soils composition, the quantity and chemical composition of the pore water, the temperature, the content of the organic matter, and the fabric of soils (Mitchell, 1993).

When a clay soil is relatively dry, it achieves very high shear strength upon compaction due to the interlocking between soils. If water is then added to the soil, it will eventually become weaker and during compaction, the soil particles will slipover each other and become closer together. Lambe and Whitman (1979) state that for a given compactive effort and dry density, the soil tends to be more flocculated for compaction on the dry side as compared to compaction on the wetter side (i.e. on the wetter side the soil is more dispersive).

2.5.1 Theory of Compaction

Soil compaction is a densification and reduction in porosity, associated with changes to the soil structure and (usually) an increase in strength and a reduction in hydraulic conductivity (Soane and van Ouwerkerk, 1994). Compaction is one kind of densification that is realized by rearrangement of soil particles without outflow of water. It is realized by application of mechanic energy. It does not involve fluid flow, but with moisture changing altering. Compaction is the process of densification of soil mass by reducing air voids. The purpose of laboratory compaction test is so determine the proper amount of water at which the weight of the soil grains in a unit volume of the compacted is maximum the amount of water is thus called the Optimum Moisture Content (OMC).

The points thus obtained are joined together as a curve. The maximum dry density and the corresponding OMC are read from the curve. There are several theories and concepts proposed to explain the compaction process of soil and moisture content relationship. Proctor assumes that the soil mass is composed of gravel, sands, silts and clays, and compaction is the act of forcing fine grains into the voids between the larger grains. It is contended that the water coats the surface of the soil grains and serves as a lubricant which reduces the friction resistance between the soil particles and permits the compacting force to become more efficient in arranging the fine grain soils into the voids between larger particles. If the moisture content is not sufficient to produce adequate lubrication, the nit weight of the compacted soil will be relatively low because the compacting force is not enough to overcome the frictional resistance between the soil grains.

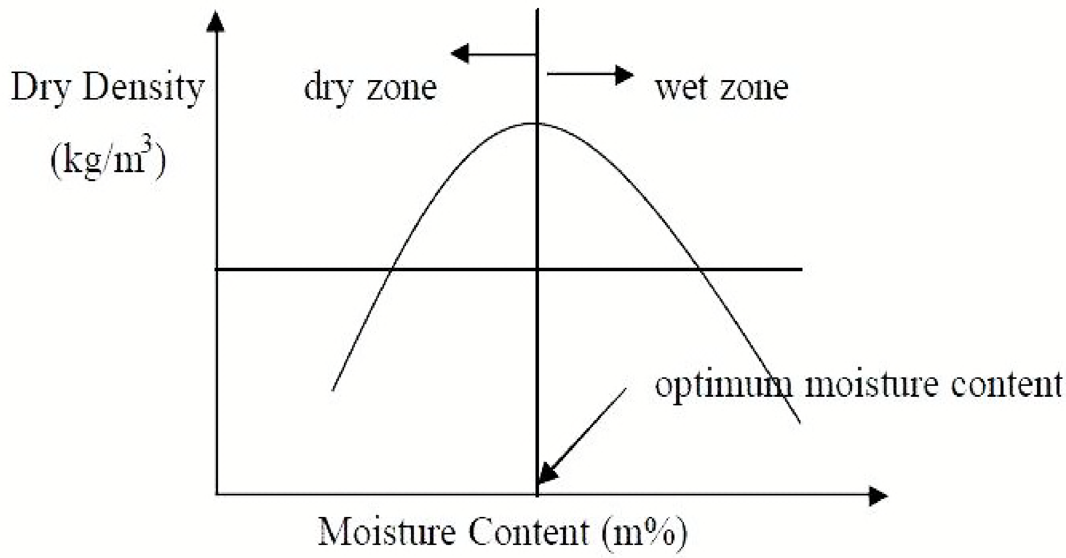

Figure 2.3: Typical Compaction Curve (Lambe, 1960)

Lambe (1960) used a physicochemical concept to explain the unit weight or density and moisture relationship of soil. Low density, as shown in Figure 2.1, is due to insufficient water for the diffuse double layer which gives a higher concentration of electrolytes and reduces the inter particle repulsion causing a tendency toward flocculation of electrolytes and reduces the antiparticle repulsion causing a tendency toward flocculation of the colloids. Further increase of moisture content, at the dry side induces further expansion of the double layer, further reducing of the electrolyte concentration, and continued reduction in the net attractive forces between particles.

For the higher compactive effort which gives greater input of work, the more nearly parallel are the clay particles. Olson (1963) found out concepts of effective stress theory. For compaction at relatively low moisture content, increases in moisture increase the degree of saturation, which results in higher pore water pressure and pore air pressure. When water content is further increase until enough water to make all air voids become discontinuous, the air permeability will drop to zero as shown in Figure 2.2, and no further densification is possible, the soil has reached the so-called optimum moisture content.

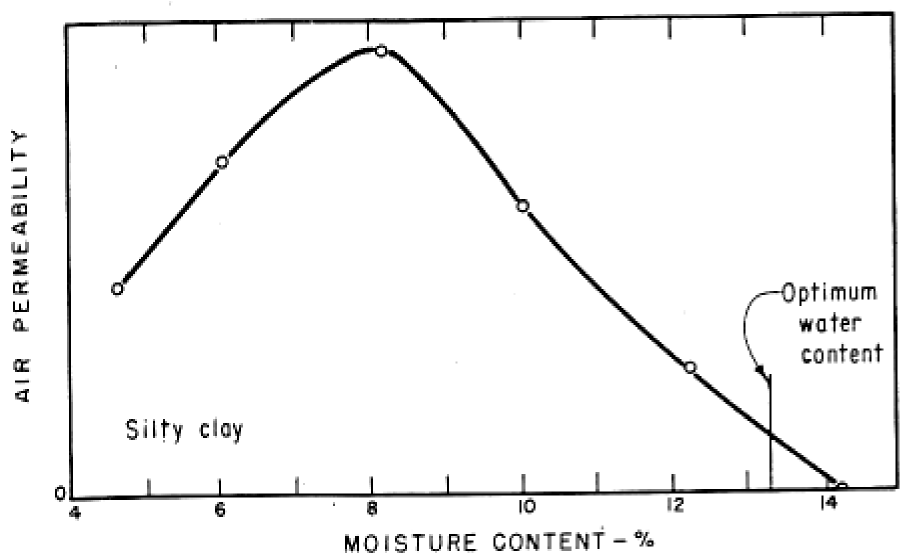

Figure 2.4: Air permeability curve of compacted soil (Olson, 1963)

2.5.2 Factors Influencing Compaction

From Figure 2.1, we can clearly see that water plays an important part in soil compaction especially for the fine-grained soils. Water acts as lubricant agent for the soil particles when it is added during the soil compaction process.

For each compactive effort, at the dry side of optimum water content the dry density increases with the increasing water content. This is due to the development of large water film around the particles, which tend to lubricate the particles and make them easier to be moved about and reoriented into a denser configuration (Holtz and Kovacs, 1981). Water also acts as lubricant to soil and when water presence, it reduces the attractive force between particles and it increases inter particle repulsion which permits the particles to slide easily between one another into a more oriented arrangement and making it denser (Shroff and Shah, 2003). The densest soil is obtained at the optimum moisture content. However, when the soil reaches a limit called optimum moisture content, an increase in moisture content tends to reduce the dry density of soil. This is because the excess water begins to push the particles apart. Therefore it is impossible to force the soil particles close together because a clay soil cannot drain out the fluid instant and the water in voids is essentially incompressible.

Compactive effort also plays an important role in compaction. According to Drew and White (2005) compaction energy is a key factor in determining soil strength and stiffness parameters and should be considered during the planning phase of any earthwork construction operation for all types of soil and all types of compaction method. The compaction methods vary depending on the rammer weight, rammer drop, size and height of mould, and also the number of layer and blows per layer. The work done, E by the rammer is shown in Equation 2.1. Figure 2.3 shows how the compactive effort shifts the positions of water-density curve upward and to the left. At any given water content, greater compactive effort will produce greater dry density.

$$E = W_r \, (H/V) \, N_B.N_L \tag{2.1}$$

Where,

E = work done

W_r = Rammer Weight

H = Rammer Height

V = volume of compacted soil

N_B = Number of blows per layer

N_L = Number of layers

Another factor that affects compaction is the type of soil. Well graded coarse grain soils are able to reach much higher density than fine-grained soil. For the higher percentage of fine aggregate, fluctuations in gradation would have less effect on maximum dry density (Johnson and Sallberg, 1962).

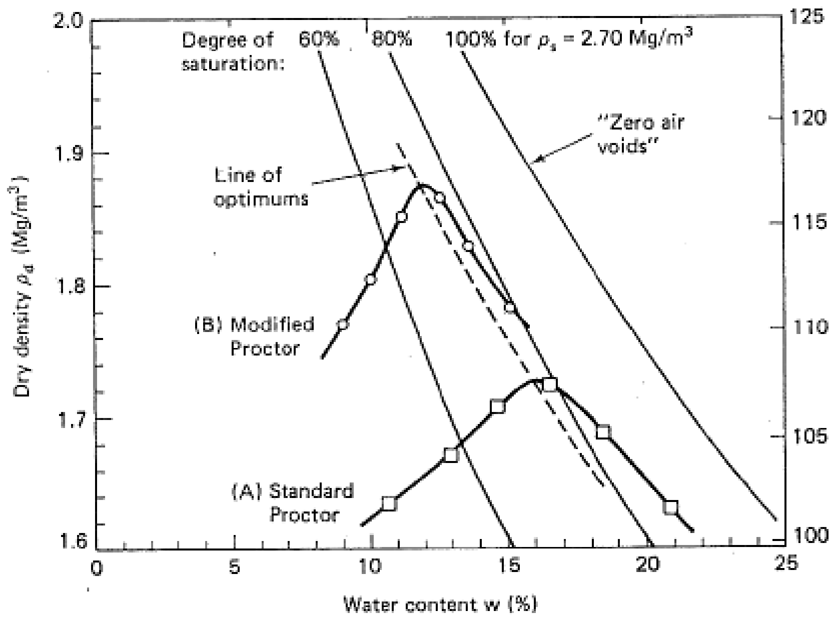

Figure 2.5: Standard Proctor test and the Modified Proctor test

2.5.3 Dry Density of Soil

Dry density is the ratio of the mass of the solid phase of the soil (i.e., dried soil) to its total volume (solid and pore volumes together).The dry density of soil is the totally removed water from the soil and also considered that the volume of the soil will not change. The unit for dry density is given as weight per volume, in kg per m^3. The weight of soil particles in 1 unit of soil volume is also known as dry density. Soil density is the dry weight of soil plus together with the moisture and void in soil. For heterogeneous and multiphasic materials, however, such as porous media, application of this definition can lead to different results, depending on the exact way the mass and volume of the system are defined. The dry density of most soils varies within the range of 1.1-1.6 g/cm^3. In sandy soils, dry density can be as high as 1.6 g/cm^3; in clayey soils and aggregated loams, it can be as low as 1.1 g/cm^3 (Hillel 1980b). Because of its high degree of aggregation (i.e., small total porosity), concrete has, in general, a higher dry density than soil.
The relationship between dry density, soil density and moisture content is shown in
Equation 2.2

$$\rho_d = (\rho / (1+w)] \tag{2.2}$$

Where, ρ_d = Dry density of soil

ρ = Bulk density of soil

w = Moisture content

2.5.4 Optimum Moisture Content

The water content at which a specified compactive force can compact a soil mass to its maximum dry unit weight. Optimum moisture content of soil is a situation where all the air pores in soil are totally closed and the permeability of air in soil is equals to zero. This is important parameters in determining the maximum dry density during tests. Water is playing an important role in giving strength, permeability and also compressibility to soil. Figure 2.4 shows that dry density of soil is increasing when water content increases at the dry side of moisture content. It will continue until the soil reaches the optimum moisture content that gives maximum dry density. After optimum moisture content, any further increase in moisture will reduced the density of soil.

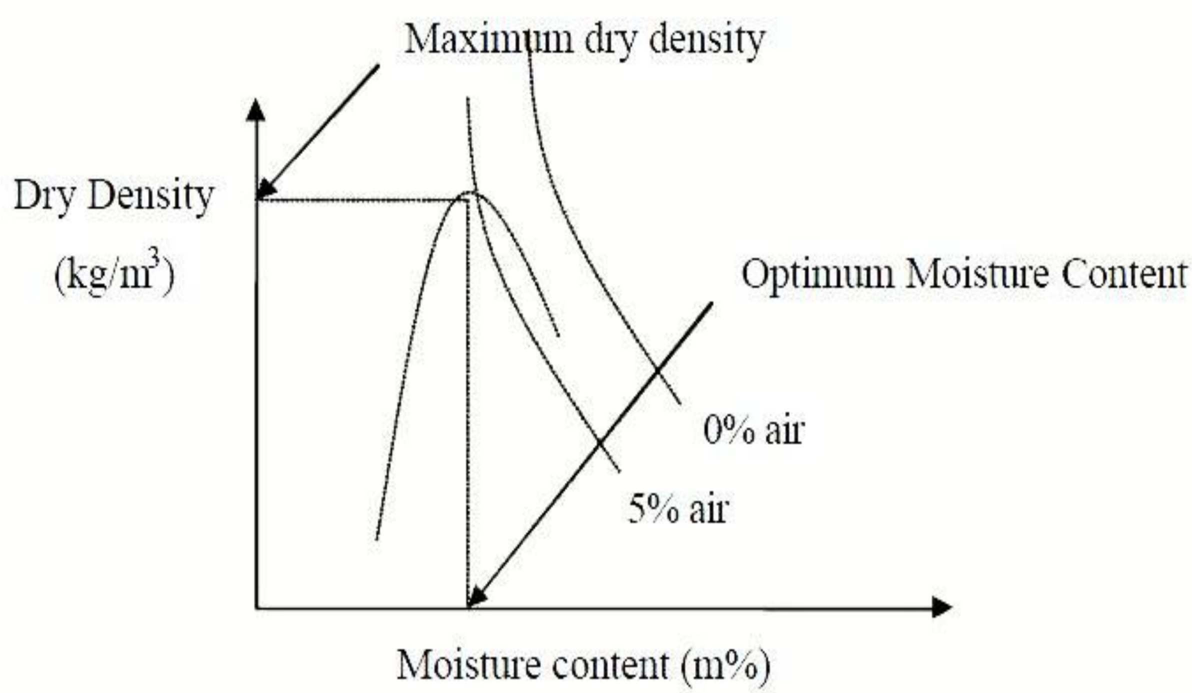

Figure 2.6: Relationship between water content and dry density (Lambe, 1960)

2.5.5 Laboratory Compaction Test

Compaction is the process of densification of soil mass by reducing air voids. The purpose of laboratory compaction test is so determine the proper amount of water at which the weight of the soil grains in a unit volume of the compacted is maximum the amount of water is thus called the Optimum Moisture Content (OMC). In the laboratory different values of moisture contents and the resulting dry densities, obtained after compaction are plotted both to arithmetic scale, the former as abscissa and the latter as ordinate. The points thus obtained are joined together as a curve. The maximum dry density and the corresponding OMC are read from the curve. In this two tests, soil is divide and compact in parts in a mould using certain amount of blows of a standard size hammer and weight falling from a specific distance. Standard Proctor (IS 2720-Part VII) and Modified Proctor (IS 2720- Part VIII) are used to determine the maximum dry density of soil after compaction. The results of this tests is a graph of dry density versus moisture content, and value for maximum dry density and optimum moisture content can be determine from the graph. These tests are used to provide field control of earthwork, where typical specification will required that the soil at site to be compacted to certain degree.

2.5.5.1 Standard Proctor Test (IS 2720:1974 Part VII)

The standard was originally developed to simulate field compaction in the lab. This test is introduced by Proctor (1933) in US, and is used to determine the satisfactory state of compaction for soils being used in the construction of large dams. The proctor compaction test is a test that compact the soil material at various moisture contents.

The standard practice of this test recommends a compaction mould with 1000 cc of volume capacity. The mould is fixed to a detachable plate. The soil is compacted in this mould for 3 layers, and each layer will take 25 blows of 2.6 kg of hammer at height of 310 mm. By knowing the weight of compacted soil and its water content, the bulk density of each test can be determined using Equation 2.3 and dry density using Equation 2.2. Figure 2.5 shows the size and dimension of the standard mould used in compaction according to IS 2720.

$$\rho = (W - W_m / V_m) \quad (2.3)$$

Where, ρ = Bulk density of soil

W = Weight of soil

W_m= Weight of empty mould

Vm = Volume of mould

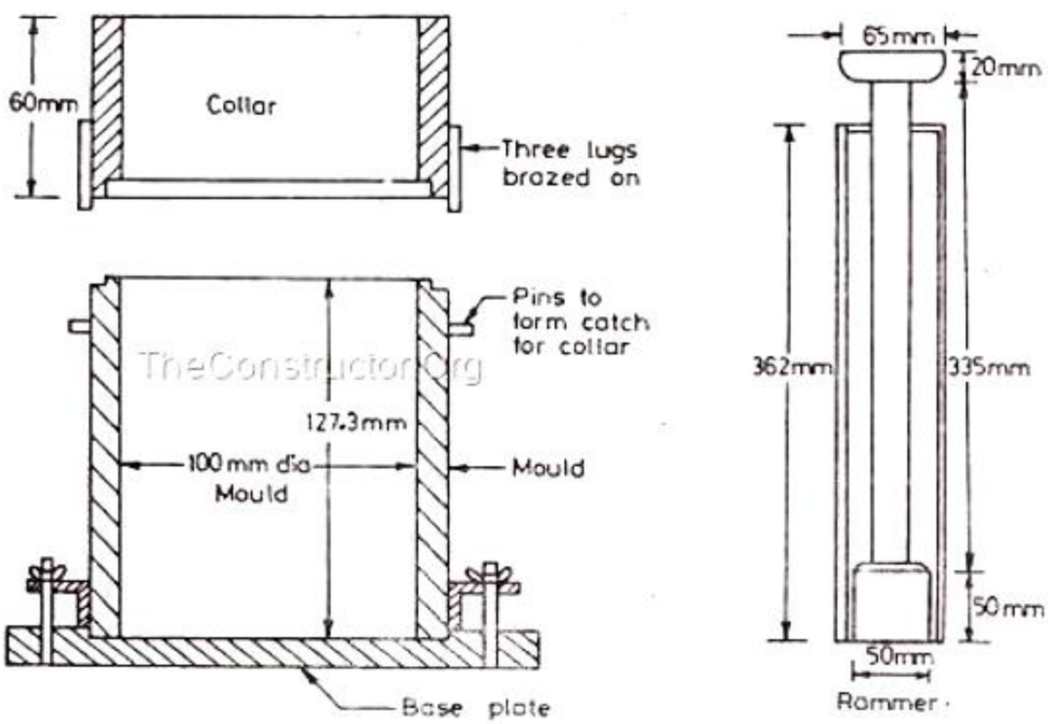

Figure 2.7: Mould and rammer for Standard and Modified Compaction

2.5.5.2 Modified Proctor Test (IS 2720:1983 Part VIII)

The Modified Procter test is developed during world war II to better simulate the better compaction required for air fields to support heavier aircraft. The modified was developed to simulate larger compaction effort for more serious loads and bigger equipment . This test has been developed to give a higher standard of compaction. With the introduction to heavier and advance earth compaction machinery, higher densities become more obtainable at site. Therefore, modified proctor test is introduced, with same mould but heavier rammer, to increase the compaction energy to produce higher compacted densities. This test uses a rammer with 4.9 kg and with a drop height of 450 mm. The mould used for this test is the same as the standard compaction test. The soil is compacted into 5 equal layers, with 25 blows each. The compaction energy is about is about 4.5 times higher than standard Proctor test. Figure 2.5 shows the size and dimension of the standard mould used in compaction according to IS 2720.

2.6 Shear Strength of Soil

The shear strength of a soil is its resistance to shearing stresses .It is a measure of the soil resistance to deformation by continuous displacement of its individual soil particles. Shear strength in soils depends primarily on interactions between particles Shear failure occurs when the stresses between the particles are such that they slide or roll past each other or by fracture of the particle (i.e through crushing). In practical situation, shear stress is more significant than crushing because the soil is not confined and the soil particles moves. The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any planes (Das, 2005). Shear strength can also means shear resistance to failure (Sharma and Reddy, 2004). To the Mohr-Coulomb failure criterion of material,the shear strength of a soil that with total normal stress can be expressed by Equation 2.4.

$$\tau = c + \sigma \tan\Phi \tag{2.4}$$

Where, τ = shear strength

c = cohesion of soil

σ = normal stress on the plane of shearing; and

Φ = friction angle.

If the normal stress (σ) is known, then both the cohesion (c) and internal friction angle. Φ which are the strength parameters of the soil are required to determine the shear strength of the soil. Cohesion is define as the ionic bond between soil grain particles and is predominant in clayey soil and insignificant in sand (Liuand Evett, 2005). The internal friction angle Φ is define as the strength or frictional resistance from the direct contact between solid materials (the grain, granular soil) to overcome sliding. This value is depend on the nature and condition of the surfaces in contact and is independent on the applied force.

Laboratory testing that are used to determine the shear strength are direct shear test, the Triaxial compression test, and the unconfined compression test. For cohesive soil, vane shear test can be used to determine the cohesive strength or cohesion of soils, which is the important parameter in determines the shear strength of soil.

2.7 Compaction Effect on Shear Strength

Various soil property tests are used to identify the soil condition prior to compaction to ensure correctly compacted soil layers. The shear strength of compacted clay depends on the density as well as the moisture content. The angle of friction (Þ) decreases rapidly with increasing moisture contents and rapidly increases when the moisture content is reduced. The cohesion component of shear strength attains its peak value at around optimum moisture content and then decreases (Cokca et al, 2004).According to Attom (1996), at fix compaction energy, the unconfined shear strength increases with increasing the water content up to the optimum. Once the water content exceeds the optimum the unconfined shear strength decreases. Craig (1987: revised 2004) states that in general for a higher degree of compaction the higher will be the shear strength and the lower the compressibility of the soil which is measured in terms of the dry density of the soil. . Degree of Compaction, Cd is given by the ratio between measured in situ dry density and the maximum dry density as determined by the 2.6 kg Proctor test in percent. The percentage of air voids at any given moisture content indicates that the compactive effort has achieved a limiting density.

The unconfined shear strength of the clay is significantly increased by increasing the compaction energy effort when the water content of the soil is below the optimum water content. Increasing the compaction effort has a small or no effect on the unconfined shear strength of the soil when the water content of the soil is above the optimum. This behaviour can be explained by Lambe (1960) based on Figure 2.6, which is when the water content at the dry side of the optimum increases, the higher compactive energy causes the flocculated particles to come closer to each other in a denser position resulting in increasing the shear strength.

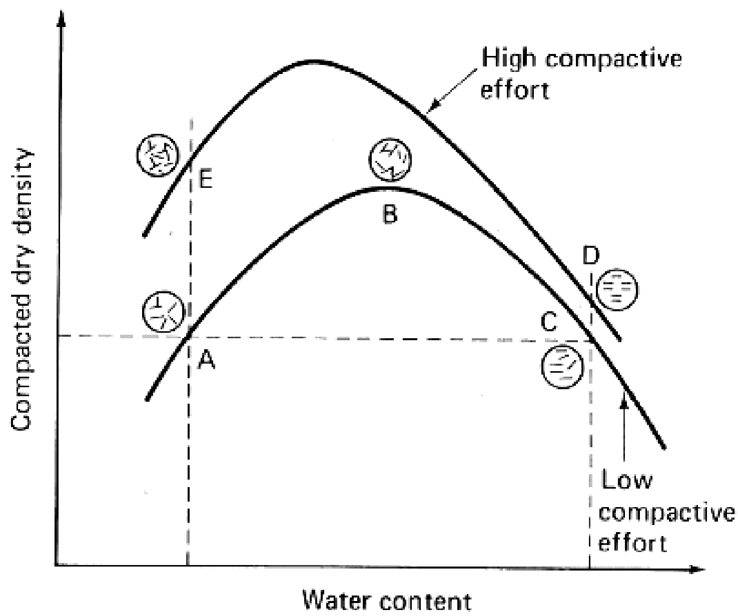

Figure 2.8: Effects of compaction on soil structure (Lambe, 1960)

In well-built soil liners, the moisture content during the compaction should be higher by a few percentage point compare to the optimum moisture content. The strength of soil is the highest at the maximum dry density and optimum moisture content. It will decrease with increasing moisture content along point B as shown in Figure 2.6. For this graph, a relationship between peak shear strength (at optimum moisture content) and the shear strength at along point B with higher moisture content may be approximated (Leroueil et al, 1992) by Equation 2.5.

$$(C_w / C_{wopt}) = \exp[-5.8(w - w_{opt}) / PI] \quad (2.5)$$

Where, C_w = Undrained shear strength of compacted soil in the SPT

C_{opt} = Undrained shear strength at w_{opt}

w = Moisture content (%)

The value depends on the maximum dry density and the type of soil.The shear strength of soil with higher moisture content can be easily estimated if this value is determined carefully at lab. The equation can also be used to anticipate the mobility difficulty at higher moisture content during compaction (Leroueil et al, 1992).

2.8 Effect of Changing Water Content on Shear Strength

The principal mechanical parameters of soils are moisture content, loadbearing capacity, shear strength and soil settlement, which in turn influences soil density. Water is one of the components of soil. Water may present from the range of none to saturation in soil. When the voids are only partially filled with water, a soil is said to be partially saturated. Any soil's characteristics and engineering behaviour are greatly influenced by its water content. This is especially true for fine grained soils (Liu and Evett, 2005).

According to Zhang et al (2005), a soil with moisture content near its liquid limit will behave more like a liquid than a soil, and therefore such soil will have low shear strength. Hence, water in soil has effect on the shear strength of soil. When water is surrounding the soil particles, it reduces the grain to grain contact and therefore the friction is also reduced and lead to a further reduction in the shear strength of soil. Figure 2.8 shows that when moisture content in soil increases, shear strength of soil will decrease for all compaction type.

As the amount of water increases the electrolyte concentration is reduced, leading to an increase in diffused double layer. Expansion takes place and the distance between the clay particles increases, resulting in a reduction of both the internal friction and cohesion. (Seed and Chan, 1959; Daniel and Wu, 1993)

2.9 Unconfined Compression Test (IS 2720:1983 Part VIII)

The unconfined compression test is used to measure the unconfined compressive strength of a cohesive soil. Unconfined Compression Test (UCT) is a simple laboratory testing method to assess the mechanical properties of rocks and fine-grained soils. It provides a measure of the undrained strength and the stress-strain characteristics of the rock or soil. The unconfined compression test is applicable only to coherent materials such as saturated clays or cemented soils thatretain intrinsic strength after removal of confining pressure. It is suitable for slow-draining soil. The axial force represents only by the source of external pressure imposed onto the soil. This is because the soil sample must be capable of standing in the testing apparatus under its own internal strength. The top and bottom of the soil are assumed to be frictionless (i.e. free from shear stress). This test is limited for soil with cohesion only. The test results are generally similar to conventional triaxial test results.

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. According to the IS: 2720-1997, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. Whichever occurs first during the performance of a test. The undrained shear strength (su) of clays is commonly determined from an unconfined compression test. The undrained shear strength of a cohesive soil is equal to one-half the unconfined compressive strength (qu) when the soil is under the Φ = 0 condition (Φ = internal friction angle). The most critical condition for the soil usually occurs immediately after construction, which represents undrained conditions, when the undrained shear strength is basically equal to the cohesion (c). This is expressed as:

$$s_u = c = q_u / 2 \tag{2.6}$$

Where, s_u = Undrained shear strength

q_u = Unconfined compressive strength

Then, as time passes, the pore water in the soil slowly dissipates, and the intergranular stress increases, so that the drained shear strength, su, given by Equation 2.7 must be used.

$$s_u = c + \sigma`\tan\Phi \tag{2.7}$$

Where, τ = shear strength

σ = normal stress on the plane of shearing; and

Φ = friction angle.

$$\sigma` = (\sigma - u) \tag{2.8}$$

$\sigma`$ = total water pressure

σ = normal stress on the plane of shearing;

u = pore water pressure

2.10 Hydraulic Conductivity

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient. Hydraulic conductivity, symbolically represented as K, is a property of vascular plants, soil or rock that describes the ease with which water can move through pore spaces or fractures. Compacted clay liners are an integral component of lining systems used for municipal and hazardous waste landfills. Because the primary purpose of a compacted clay liner is to impede the flow of fluids, the most significant factor affecting its performance is hydraulic conductivity (Daniel , 1990).

Soils rich in clay minerals are used for constructing compacted soil liners because they have low hydraulic conductivity and can attenuate inorganic contaminants. Although the hydraulic conductivity of clayey soils is normally considered to be low, the hydraulic conductivity of compacted clays can vary tremendously depending on the soil composition and the conditions under which they are compacted (Lambe 1954; Mitchell et al 1965; Garcia-Bengochea et al 1979; Acar and Oliveri 1990; Benson et al 1994).

For example, Benson and Daniel (1990); smaller, yet significant changes in hydraulic conductivity also occur as a consequence of variations in soil composition (Benson et al 1994). A review of factors influencing the hydraulic conductivity of compacted clays is contained in base of soil with moister contents.

Benson et al (1994); In their study, the hydraulic conductivity of specimens collected from 67 compacted clay liners throughout the United States was examined. They reported that the hydraulic conductivity of these specimens depends greatly on the molding water content and dry unit weight achieved during compaction. In particular, specimens compacted at combinations of water content and dry unit weight yielding higher initial saturation (degree of saturation at compaction) have lower hydraulic conductivity.

Richerds-vivayan et al (1994) also reported that hydraulic conductivity is sensitive to the Atterberg limits and particle size distribution. Soils that are more plastic (higher liquid limit or higher plasticity index) or contain a greater quantity of fines (clay-size particles) have lower hydraulic conductivity.

The similarity between the contours of initial saturation and the zones of similar hydraulic conductivity was expected, because contours of constant initial saturation generally fall parallel to the line of optimums (Mitchell et al 1965; Mundell and Bailey 1985; Boutwell and Hedges 1989; Benson and Boutwell 1992;Benson et al 1994; Othman and Luettich 1994).

Combinations of water content and dry unit weight corresponding to low initial saturation (<70%) tend to fall dry of the line of optimums. For compaction dry of the line of optimums, the clods are stiff and difficult to remold (Benson and Daniel 1990) and the clay particles are flocculated (Lambe 1958).

Consequently, large interclod pores exist as well as a more permeable micro-structure. These conditions result in higher hydraulic conductivity. Conversely, combinations of water content and dry unit weight corresponding to high initial saturation (>90%) tend to fall wet of the line of optimums. Compaction wet of the line of optimums permits greater remolding of clods, elimination of large interclod voids, and preferential re-orientation of clay particles, all of which result in lower hydraulic conductivity (Garcia-Bengochea et al 1979; Acar and Oliveri 1990; Benson and Daniel 1990).

Composition of the soil can also significantly affect hydraulic conductivity, particularly for compection wet of the line of optimum where flow is controlled by the size, shape, and connectivity of micro scale pores (Acar and Oliveri 1990; Benson et al 1994).

In particular, soils having a greater quantity of fines and clay, and more active clay minerals, generally have lower hydraulic conductivity because they contain clay particles that are smaller and have thicker double layers (Lamb e 1954; Daniel 1987; Kenney et al 1992; Benson et al 1994).

To confirm that similar behaviour was true for the soils in this study, relationships existing between hydraulic conductivity wet of the line of optimums (molding water contents approximately 2% wet of optimum water content for each compactive effort and index properties of the soils were examined.(Mesri and Olson 1971; D ' Appolonia 1980;)

Hydraulic conductivity, symbolically represented as K, is a property of vascular plants, soil or rock that describes the ease with which water can move through pore spaces or fractures. The K-value is subject to variation in space and time, which means that we must adequately assess a representative value. It depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity, K_{sat}, describes water movement through saturated media. Hydraulic conductivity is defined by Darcy's law, which, for one-dimensional vertical flow, can be written as follows:

$$U= K\ (dh/dz) \tag{2.9}$$

Where, U= Darcy's velocity

K= Hydraulic conductivity

h = Hydraulic head,

z = Vertical distance

The term coefficient of permeability is also sometimes used as a synonym for hydraulic conductivity. On the basis of Equation 2.9, the hydraulic conductivity is defined as the ratio of Darcy's velocity to the applied hydraulic gradient. The dimension of *K* is the same as that for velocity, that is, length per unit of time (IT^{-1}).

Hydraulic conductivity is one of the hydraulic properties of the soil; the other involves the soil's fluid retention characteristics. These properties determine the behavior of the soil fluid within the soil system under specified conditions. More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition. The hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid, and the relative amount of soil fluid (saturation) present in the soil matrix.

The permeability of a soil is a measure of its capacity to allow the flow of a fluid through it. The principle is that soil consists of solid particles with voids between them. In general the voids are interconnected, which enables water to pass through them. The degree of permeability is determined by applying a hydraulic difference across a sample of soil, which is fully saturated and measuring the consequent rate of flow of water.The "coefficient of permeability" in expressed in terms of a velocity. The flow of water through soils of all types, from gravel's and sands to clays are governed by the same physical laws. The difference between the permeability characteristics of extreme types of soil is merely one of degree, even though clay can be ten million times less permeable than sand. Clays are not completely impermeable, although they may appear to be so if the rate of low through them is not greater than the rate of evaporation loss. The method used for measuring permeability depends upon the characteristics of the material. Permeability tests on natural disturbed soil are probably carried out more frequently in-situ than in the laboratory, but field inspection and testing is beyond the scope of this laboratory guide. There are two types of laboratory tests for the direct measurement of the permeability of soils: Constant head test-for soils of high permeability, such as sands. The constant head test is a permeability test in which water is made to flow through a soil sample under a constant difference in head or hydraulic gradient. Falling head test for soils of intermediate and low permeability, such as silts and clays. The falling head test is a permeability test in which the piezometer tube used for measuring the head also provides the water, which passes through the sample, and therefore the level falls during the test. For the indirect assessment of permeability careful inspection of the soil, together with a properly conducted particle size analysis, are required. These procedures are useful either when it is not practicable to make a direct measurement, or as a check on direct measured values.

2.10.1 Estimation by empirical approach

2.10.1.1 Estimation from grain size

Allen Hazen derived an empirical formula for approximating hydraulic conductivity from grain size analyses:

$$K=C\ (D_{10})^2 \qquad (2.10)$$

Where, C= Hazen's empirical coefficient, which takes a value between 0.4 and 10.0, with an average value of 1.0

D_{10} = Diamreter of the 10 percentile grain size of material.

2.10.1.2 Pedotransfer function

A Pedotransfer function (PTF) is a specialized empirical estimation method, used primarily in the soil sciences, however has increasing use in hydrogeology.There are many different PTF methods, however, they all attempt to determine soil properties, such as hydraulic conductivity, given several measured soil properties, such as soil particle size, and bulk density.

2.11 Determination by experimental approach

There are relatively simple and inexpensive laboratory tests that may be run to determine the hydraulic conductivity of a soil: constant-head method and falling-head method.

2.12 Laboratory methods

2.12.1 Constant Head Permeability Test

Constant head permeability tests are used to calculate seepage potential through earthen dams and embankments such as dikes, according to the University of Texas at Arlington. The testing uses a specialized device referred to as a constant head permeameter. In the test, the permeameter is filled with test soil and water run through the sample until the soil is saturated. The amount of water that is discharged from the soil and water mixture in a measured length of time is used as an input to a formula used to determine the soil permeability. The length of time used in the test can vary, but should be consistent during all tests performed for a location.

$$K = (QL/Aht) \tag{2.10}$$

Where, K= Hydraulic conductivity

Q = Volume of Water

A = Area of Specimen

h = Hydraulic Head of Water

2.12.2 Falling Head Permeability

The falling head method of testing soil permeability is also used in estimating water seepage in dams and other water-containing structures. The soil is saturated with water in a permeameter. The permeameter is placed underwater with a stand pipe extending above the water. The period of time water flows from the stand pipe is measured and used as part of a falling head soil sample of cross-sectional area *A* and length *L* is placed between two highly conductive plates. The soil sample column is connected to a standpipe of cross-sectional area *a*, in which the percolating fluid is introduced into the system. Thus, by measuring the change in head in the standpipe from H_1 to H_2 during a specified interval of time *t*, the saturated hydraulic conductivity can be determined as follows (Klute and Dirksen 1986):

$$K = (aL/At) \log (h_1 / h_2) \tag{2.11}$$

Where, K= Hydraulic conductivity

A = Area of Specimen

h_1, h_2 = Hydraulic Head of Water

t = time

L = Length of the Sample.

2.12.2.1 Falling head test with consolidometer

2.12.2.2 Purpose

The falling head permeability test with consolidometer is a common laboratory testing method used to determine the permeability of relatively less pervious soil. By this test determine the permeability of fine grained soils with intermediate and low permeability such as silts and clays. This testing method can be applied to an undisturbed sample.

2.12.2.3 Equipment

Consolidation device (including ring, porous stones, water reservoir, and load plate), Dial gauge (0.0001 inch = 1.0 on dial), Sample trimming device, glass plate, Metal straight edge, Clock, Moisture can, Filter paper, Graduated glass stand pipe, Supporting frame to stand pipe and the clamps.

Figure 2.9: Consolidometer

2.12.2.4 Saturation of Sample

Fill the consolidometer cell with soil sample which is prepared at optimum moister content and saturate the sample as follows.

1. Connect the water reservoir through the rubber tube at the base of the consolidometer.
2. Set the water reservoir at a level a little above the top of the consolidometer cell and start to the de-aerated water supply.
3. Allow de-aerated water to enter the cells which slowly percolate upwards through the sample. Continue this until water not seen to top of perforated cover.

4. Left the sample at this situation for next 24 hours to complete saturation.
5. The cell is now ready for test under the normal conditions.

2.12.2.5 Test Procedure

1. Clean and dry the metal ring. Measure its diameter and height. Take the mass of empty ring,
2. Apply a little grease on the inside to the mould.
3. Put the soil sample in the ring which prepared with optimum moister content. The ring is to be pressed with hands.
4. Remove the soil around the ring. Trim the specimen flush with the top and bottem of the ring.
5. Saturate the porous stones by the distilled water put them inside a container with the distilled water at least 1 hour.
6. Assemble the consolidometre. Place the bottom porous stone, bottom filter paper, specimen, top filter paper and the top porous stone, one by one. Press very lightly to make sure that the stones adhere to the sample.
7. Being careful to prevent movement of the ring and porous stones .Place the dial gauge centrally on the top of assembly. Dial gauge is set in such a way its shown initial reading zero.
8. After some time dial gauge showing clockwise or anticlockwise movement i.e. showing swelling or compression of soil sample, then put some minor weight at weight stand to maintain dial gauge reading to zero.
9. Connect the mould assembly to the stand pipe having the water level at about above the soil specimen
10. Connect the stand pipe of suitable diameter to the inlet at the bottom of consolidometer. Fill the stand pipe with the water.
11. Allow the water to flow via saturated soil specimen through stand pipe.
12. Select the heights h_1 and h_2 measured above the centre of outlet such that their difference is about 300 to 400 mm.
13. Open the valve and start the stop clock .Record the time interval for the head to fall from h_1 to h_2.

14. Stop the flow of water also the stop clock.
15. Repeat the test using the same initial and final readings on the stand pipe with using soil sample at wet side of optimum moister content for know the variation of the permeability k of soil sample at OMC and wet side of OMC.

2.13 Table of saturated hydraulic conductivity (*K*) values found in nature

Values are for typical fresh groundwater conditions using standard values of viscosity and specific gravity for water at 20°C and 1 atm. See the similar table derived from the same source for intrinsic permeability values.

<table>
<tr><td>K (cm/s)</td><td>10^{2}</td><td>10^{1}</td><td>10^{0}</td><td>10^{-1}</td><td>10^{-2}</td><td>10^{-3}</td><td>10^{-4}</td><td>10^{-5}</td><td>10^{-6}</td><td>10^{-7}</td><td>10^{-8}</td><td>10^{-9}</td><td>10^{-10}</td></tr>
<tr><td>K (ft/day)</td><td>10^{5}</td><td>10,000</td><td>1,000</td><td>100</td><td>10</td><td>1</td><td>0.1</td><td>0.01</td><td>0.001</td><td>0.0001</td><td>10^{-5}</td><td>10^{-6}</td><td>10^{-7}</td></tr>
<tr><td>Relative Permeability</td><td colspan="4">Pervious</td><td colspan="4">Semi-Pervious</td><td colspan="5">Impervious</td></tr>
<tr><td>Aquifer</td><td colspan="4">Good</td><td colspan="5">Poor</td><td colspan="4">None</td></tr>
<tr><td>Unconsolidated Sand & Gravel</td><td colspan="2">Well Sorted Gravel</td><td colspan="3">Well Sorted Sand or Sand & Gravel</td><td colspan="4">Very Fine Sand, Silt, Loess, Loam</td><td colspan="4"></td></tr>
<tr><td>Unconsolidated Clay & Organic</td><td colspan="4"></td><td colspan="2">Peat</td><td colspan="3">Layered Clay</td><td colspan="4">Fat / Unweathered Clay</td></tr>
<tr><td>Consolidated Rocks</td><td colspan="4">Highly Fractured Rocks</td><td colspan="3">Oil Reservoir Rocks</td><td colspan="2">Fresh Sandstone</td><td colspan="2">Fresh Limestone Dolomite</td><td colspan="2">Fresh Granite</td></tr>
</table>

Source: Modified test from Bear, 1972

Table 2.1: Saturated hydraulic conductivity (*K*) values found in nature

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 Introduction

This research focus on the determining the optimum shear strength of soil by using different type of compaction, which is standard proctor compaction, modified proctor compaction. The shear strength of compacted soil will be obtained from Triaxial Unconfined Compression (UCT) tests. Laboratory tests also are conduct to determine the relationship between compactive effort and moisture content on shear strength of soil. Among the procedures and steps taken to complete this research are identifying the topics, literature review, data selection, data collection, and also analysis.

3.2 Literature Review

After the process of topic selection, the next important step in research is to carry out the literature review. This is a process where we need to read from books, reference, journals and articles which are related to the topic. All resources are obtained from the library of DTU and internet. It is important to read and to analysis the data from the source because we need to apply in data analysis and correlation. Last but not least, meeting and getting advises from supervisor is also equally important in guiding and improving the content of the research.

3.3 Soil Collection and Preparation

The disturbed soil sample that is used in this research is Silty clay, which is originally from Bawana Putt, Delhi. All the soil sample is air dried before any further test is carried out. The air dried sample is then kept in air tight container to avoid any moisture content changes to the soil. Soil that are to be used in compaction or other properties tests with certain moisture content is prepared by weighing out samples follow by adding water to reach the desired moisture contents. After thorough mixing, sample is undergo the process of mellowing, where samples were sealed in plastic bags and then stored for a period of at least 24 hours in the laboratory to ensure complete hydration of the soil. Following hydration, specimens were compacted in the compaction molds, extruded, weighed and prepared for Uniaxial Compression Test.

3.4 Preliminary Soil Testing

It is relevant for the sample to required classification, soil index and properties and compaction testing before is sent for shear strength tests. Index tests are the basic and advanced types of laboratory tests performed on soil to determine the physical properties of soil. This tests that are performed in the laboratory includes water content, specific gravity test (pycnometer test), particle size distribution test, hydrometer test, Atterberg limit test, and compaction. Only soil particles passing 2 mm will be used for compaction and strength test.

3.4.1 Laboratory Compaction test

Laboratory compaction tests are used to determine the relationship between water content and dry unit weight and also to find the maximum dry unit weight and optimum moisture content of soil. Compaction test are based on any one of the following methods which is dynamic or impact, kneading, static and vibratory. For many civil engineering projects, soil are compacted by mechanical means with Laboratory compaction tests are used to determine the relationship between water content and dry unit weight and also to find the maximum dry unit weight and optimum moisture content of soil. Compaction test are based on any one of the following methods which is dynamic or impact, kneading, static and vibratory. For many civil engineering projects, soil are compacted by mechanical means with Table 3.1 show the requirement and specification for all compaction type.

3.4.2 Particle Size Distribution

Sieve analysis determines the grain size distribution curve of soil sample by passing them through a stack of sieve of decreasing mesh opening size and by measuring the weight of soil retained in each sieve. The sieve analysis is generally applied to the soil fraction larger than

0.075 mm. Grain smaller than 0.075 mm are sorted by using hydrometer analysis. Sieving can be performing in dry or wet condition. Dry sieving is used only for soils with a negligible amount of plastic fines, whereas wet sieving is applied to soils with plastic fines. In this study, dry sieving is used to determine the particle size distribution of soil.

Objective of sieve analysis is to group soil particles into different range of sizes, and subsequently, the relative proportions by dry weight, of each size range. The data collected are plotter into particle size distribution curve. Grading curve is then used to classify the soil according to IS: 2720 – PART – IV.

3.4.3 Hydrometer Test

Hydrometer test is used to determine the grain size distribution of fine grain soil having particle size smaller than 0.075 mm. If soil sample have particle sizes ranging from silt to clay, sieving and hydrometer test are combined to produce a grain size distribution curve over a wide range of grain size.

3.4.4 Atterberg Limit

Atterberg Limit test are done to determine the liquid limit of soil as per IS: 2720 (Part 5) – 1985. The liquid limit of fine-grained soil is the water content at which soil behaves practically like a liquid, but has small shear strength. Its flow closes the groove in just 25 blows in Casagrande's liquid limit device. This test is to determine the soil moisture content, which deform from plastic to liquid. The objective of the Atterberg limits test is to obtain basic index information about the soil used to estimate strength and settlement characteristics. It is the primary form of classification for cohesive soils. Fine-grained soil is tested to determine the liquid and plastic limits, which are moisture contents that define boundaries between material consistency states. These standardized tests produce comparable numbers used for soil identification, classification and correlations to strength. The liquid (LL) and plastic (PL) limits define the water content boundaries between non-plastic, plastic and viscous fluid states.

Fig.3.1 A. Casagrande Liquid limit apparatus

3.4.4.1 Liquid Limit: IS: 2720 -Part V

The Liquid Limit is the moisture content at which the soil passes from the plastic to the liquid state as determined by the Liquid Limit test. The liquid limit test determines the liquid limit of a soil. Only soil passing 425 µm test sieve is used in this test. Liquid limit of the soil is taken as the moisture content when the soil penetration is 20 mm.

3.4.4.2 Plastic Limit Test: IS: 2720 -Part V

The plastic limit test is used to determine the lowest moisture content at which the soil behaves plastically. It is carried out only on the soil fraction passing 425 µm sieve and it is performed in conjunction with the liquid limit test. By convention, the plastic limit of soil is defined as the water content at which the soil begins to crumble when rolled into a thread 3 mm in diameter. With the value of Liquid Limit and Plastic Limit, Plasticity Index can be determined by using Equation 3.1.

$$PI = LL - PL \quad (3.1)$$

Where, PI = Plasticity index

LL = Liquid limit

PL = Plastic limit

3.4.5 **Pycnometer Test: IS: 2386**

Pycnometer test is used to find the specific gravity of soil sample. Specific gravity is an important parameter in soil classification. Specific gravity, Gs of a soil is the ratio between the unit masses of soil particles and water. To ensure the value of specific gravity achieved is accurate, all the air in the small pycnometer container must be vacuum out. Any presence of air inside the soil will reduce the results of specific gravity. Therefore, the pycnometers are placed in a vacuum pump and check regularly to ensure all the air is removed.

3.5 Unconfined Compression Test (UCT): IS: 2720 -Part X

This test was conducted to determine the shear strength parameter of soil sample that obtained from Bawana Putt, Delhi. The primary purpose of the Unconfined Compression Test is to quickly determine a measure of the unconfined compressive strength of rocks or fine-grained soils that possess sufficient cohesion to permit testing in the unconfined state. This measure is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. This test also helps to determine the relationship between type of compaction and the effect of the shear strength parameter. This unconfined compression test is a special type of unconsolidated-undrained test that is commonly used for clay specimens. In this test, the confining pressure is equals to zero. An axial load is rapidly applied to the specimen to cause failure.

For this test, a remolded sample is prepared as the soil is classified as disturbed. The remolded soil has a diameter of 35 mm and height of 78 mm. This remolded sample is prepared from compaction mould, which is larger than the test specimen. A sampling tube is pushed into the compaction mould contain soil after compaction. The tube is then took out and cut into the desired length and this sample is then used as the specimen for Unconfined Compression test.

3.6 Analysis of Results

After obtaining the results from this test, the dial readings is converted to the appropriate load and length and transfer these values to the column of deformation and total load. Cross section of sample (A_0) is then determined by using Equation 3.2. By using Equation 3.3 and 3.4, strain (ϵ), and corrected area (A') can be calculated.

$$A_0 = (\pi / 4) \times d^2 \tag{3.2}$$

Where, A_0 = Area of cross section
d = Diameter of sample

$$\epsilon = (L / L_0) \tag{3.3}$$

Where, ϵ = Strain of soil
L = Length of soil
L_0 = Initial length of soil

$$A` = [A_0 / (1 - \epsilon)] \tag{3.4}$$

Where, A_0 = area of cross section
A` = corrected area

Calculation is continued by determining the water content, w (%). To determine the stress-strain and strength characteristic of soils, a stress-strain curve was plotted with the obtained test data. The stress (σ) can be computed as below.

$$\sigma = (P / A`) \tag{3.5}$$

Where, σ = Deviator stress
P = Axial force
A` = Corrected Area

The unconfined compression test gives result in term of undrained shear strength with shear parameters cu (Undrained cohesion) and Φu (internal friction angle). The maximum undrained shear strength is taken at the maximum value of axial stress. Perfect undrained condition gives a predominant **cu** value and zero for Φu. Therefore, the shear strength of soil is taken as half of the value of undrained shear strength. Mohr circle is then drawed with the data obtained from test. Mohr circle of unconfined compression test, its tangent will be a straight line parallel to x-axis and intercept y-axis at cu value.

3.7 Constant Head Permeability Test

Constant head permeability tests are used to calculate seepage potential through earthen dams and embankments such as dikes, according to the University of Texas at Arlington. The testing uses a specialized device referred to as a constant head permeameter. In the test, the permeameter is filled with test soil and water run through the sample until the soil is saturated. The amount of water that is discharged from the soil and water mixture in a measured length of time is used as an input to a formula used to determine the soil permeability. The length of time used in the test can vary, but should be consistent during all tests performed for a location.

3.8 Falling Head Permeability

The falling head method of testing soil permeability is also used in estimating water seepage in dams and other water-containing structures. The soil is saturated with water in a permeameter. The permeameter is placed underwater with a stand pipe extending above the water. The period of time water flows from the stand pipe is measured and used as part of a mathematical formula to calculate soil permeability.

CHAPTER 4

ANALYSIS OF RESULTS

4.1 Introduction

This limit and particle size distribution chapter presents the results of the properties of soil, which are specific gravity, liquid limit, and plastic limit. Maximum dry density and optimum moisture content at various compaction type and shear strength of the soil after undergoes standard compaction is shown and discuss in this chapter. The results of the tests are presented by tables and plots of compaction curves showing the optimum moisture content and the maximum dry density. Graph of shear Strength versus moisture content is also plot to show the result of shear strength of soil which undergoes different compaction.

4.2 Basic Engineering and Properties of soil

To obtain the parameters of the engineering properties of Bawana Putt clay, several laboratory testing were carried out. The basic parameters include soil type from classification test, specific gravity (Gs), liquid limit, plastic limit, plasticity index (PI), maximum dry density (ρd) and optimum moisture content through compaction tests. Basic properties of Bawana Putt clay are summarized in Table 4.1.

The knowledge of specific gravity is required in calculation of soil properties such as zero air void curve in dry density versus moisture content curve obtained from different compaction type and also is used in hydrometer test analysis. The average specific gravity value for Bawana Putt clay is 2.71. This result is in the range of silty clay as according to The Central Soil and Material research station Delhi, which classifies specific gravity of silty clay at the range of 2.67 to 2.85. The dry density of soil is 1.691 g/cc for standard compaction at the optimum moisture of 15.07 %. From Figure 4.1 Bawana Putt clay contains of 0% gravel, 10% of sand, 61% of silt and 29%. The Liquid limit of the soil is 52.71% and Plastic limit and plasticity index for Bawana Putt clay are 26.82%, and 25.89% respectively. According to IS 2720, Bawana Putt clay is classified as silty clay with high plasticity, CH.

Table 4.2: Basic properties and classification of Bawana Putt clay

Index Properties	Specific Gravity (Gs)	2.71
	Maximum Dry Density (ρ_d) Standard Compaction Strength UCS	1.691 g/cc
		213.70 kPa
Atterberg Limits	Liquid Limit	52.71
	Plastic Limit	26.82
	Plasticity Index (PI)	25.89
Particle Size Distribution	Gravel	0%
	Sand	10%
	Silt	61%
	Clay	29%
Classification	Silty clay with high plasticity, CH.	

4.3 Atterbergs Limits:

4.3.1 Bawana Putt Clay

Liquid Limit = 52.71 %

Plastic limit = 26.82 %

Plasticity Index = 25.89 %

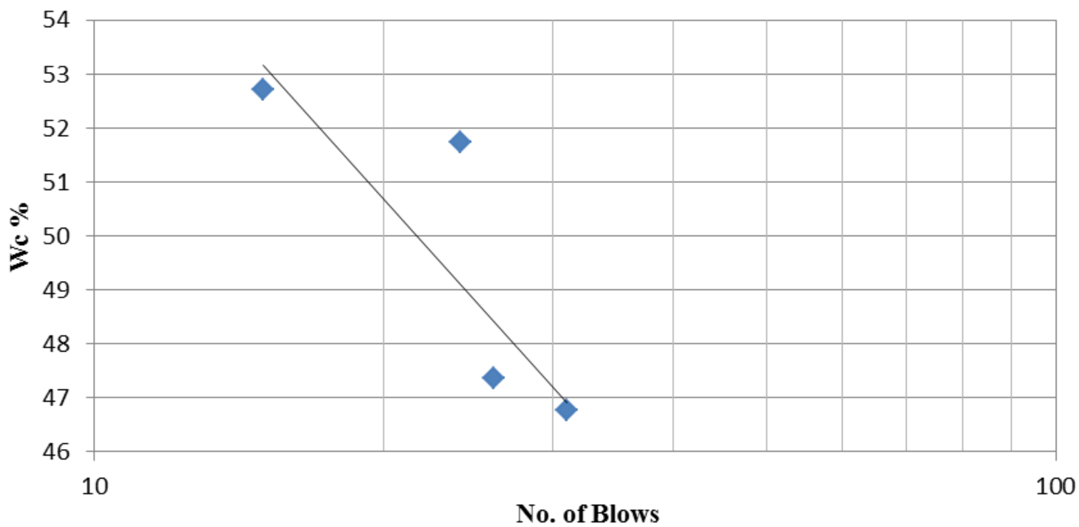

Fig 4.1 Liquid limit test

4.3.2 Bawana Putt Clay + 04% Fly Ash

Liquid Limit = 48.29 %
Plastic limit = 27.28 %
Plasticity Index = 21.01 %

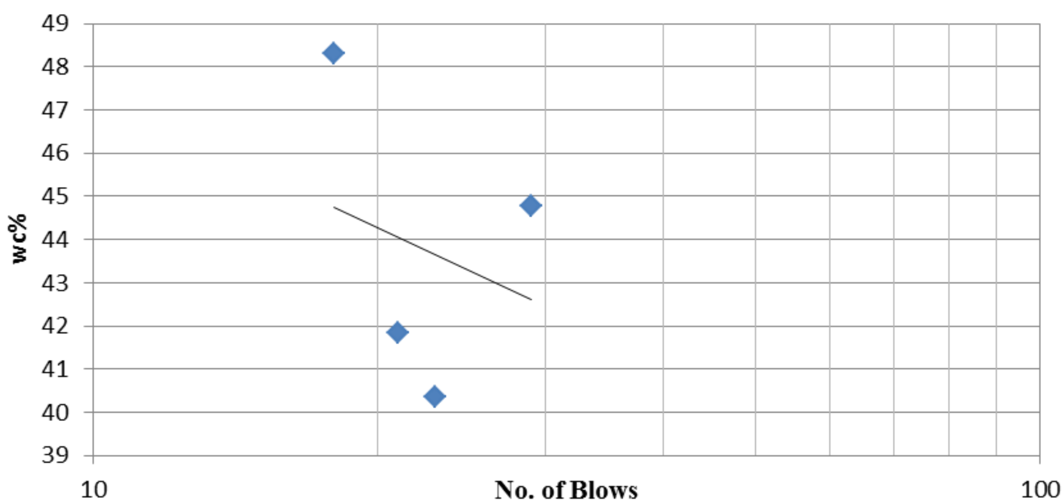

Fig 4.2 Liquid limit test

4.3.3 Bawana Putt Clay + 08% Fly Ash

Liquid Limit = 45.63 %

Plastic limit = 28.86 %

Plasticity Index = 17.77 %

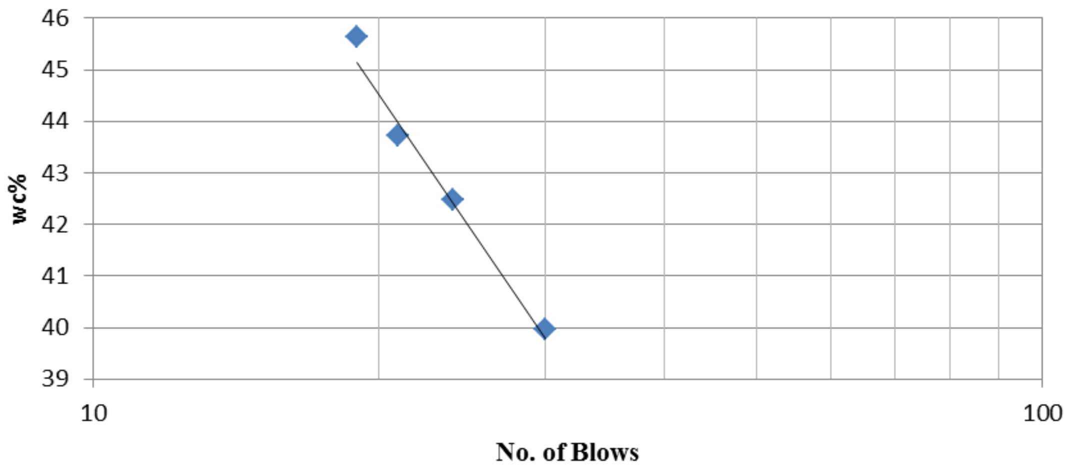

Fig 4.3 Liquid limit test

4.3.4 Bawana Putt Clay + 12% Fly Ash

Liquid Limit = 43.86 %

Plastic limit = 29.31 %

Plasticity Index = 14.55 %

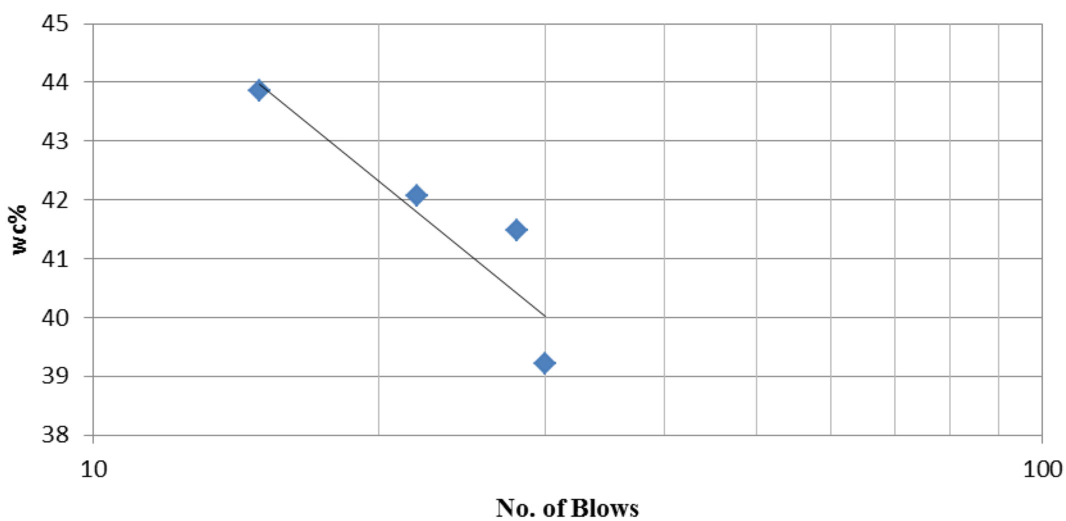

Fig 4.4 Liquid limit test

4.3.5 Bawana Putt Clay + 16% Fly Ash

Liquid Limit = 39.46 %

Plastic limit = 29.74 %

Plasticity Index = 9.73 %

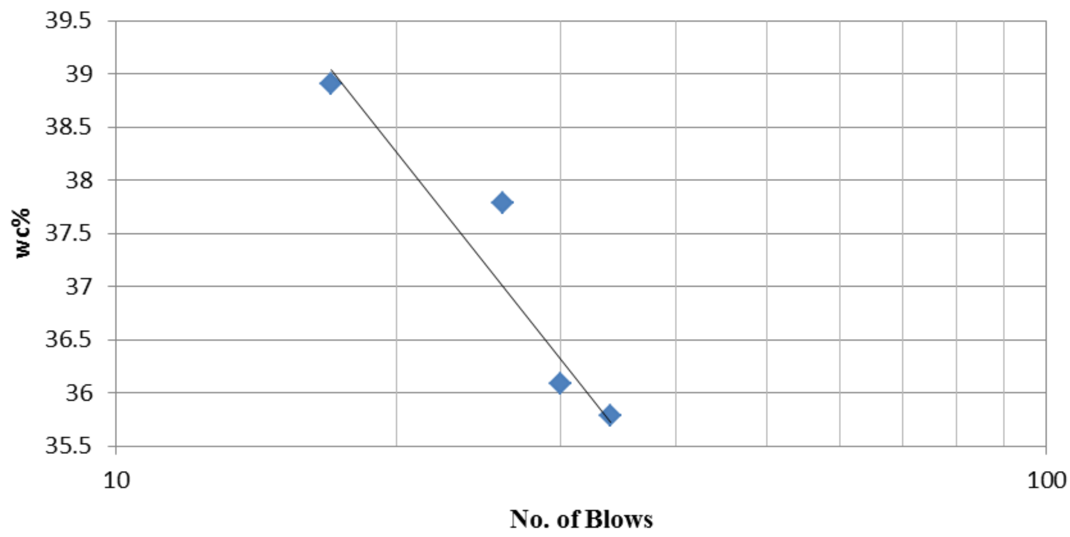

Fig 4.5 Liquid limit test

4.3.6 Bawana Putt Clay + 20% Fly Ash

Liquid Limit = 40.23 %

Plastic limit = 27.29 %

Plasticity Index = 12.94 %

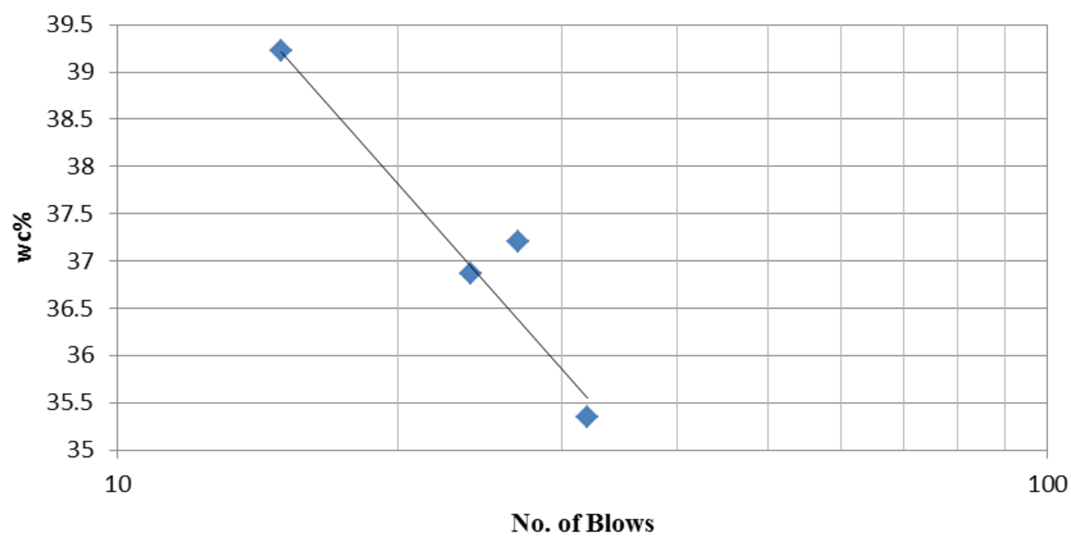

Fig 4.6 Liquid limit test

4.4 Compaction Test (Standard Proctor Test):

4.4.1 Bawana Putt Clay

Optimum Moister Content w_0 = 17.78 %

Dry Density $(\rho_d)_{max}$ = 1.64 g/cc

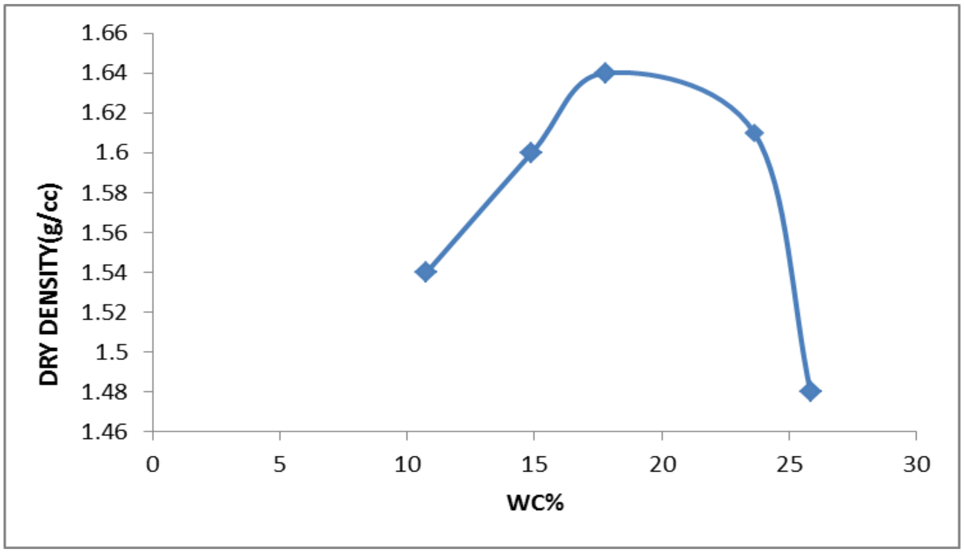

Fig 4.7 Graph of Maximum Dry Density vs Moister Content

4.4.2 Bawana Putt Clay + 04% Fly Ash

Optimum Moister Content w_0 = 14.79 %

Dry Density $(\rho_d)_{max}$ = 1.67 g/cc

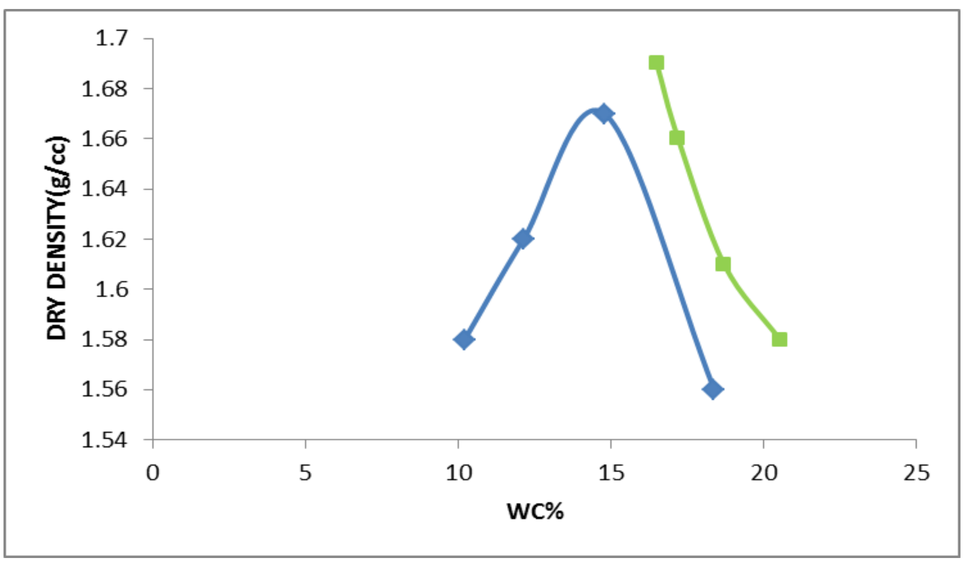

Fig 4.8 Graph of Maximum Dry Density vs Moister Content

4.4.3 Bawana Putt Clay + 08 % Fly Ash

Optimum Moister Content w_0 = 13.68 %

Dry Density $(\rho_d)_{max}$ = 1.66 g/cc

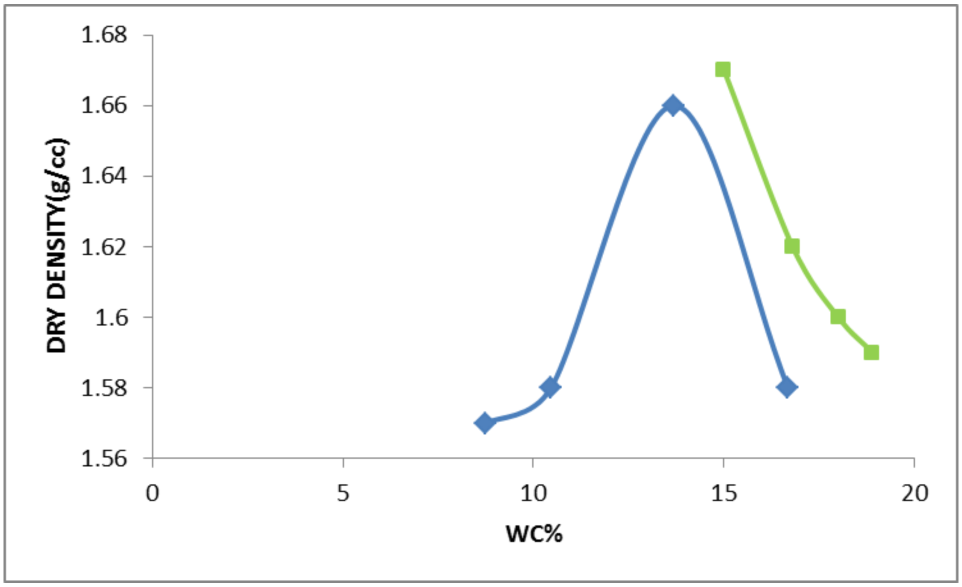

Fig 4.9 Graph of Maximum Dry Density vs Moister Content

4.4.4 Bawana Putt Clay + 12% Fly Ash

Optimum Moister Content w_0 = 15.29 %

Dry Density $(\rho_d)_{max}$ = 1.68 g/cc

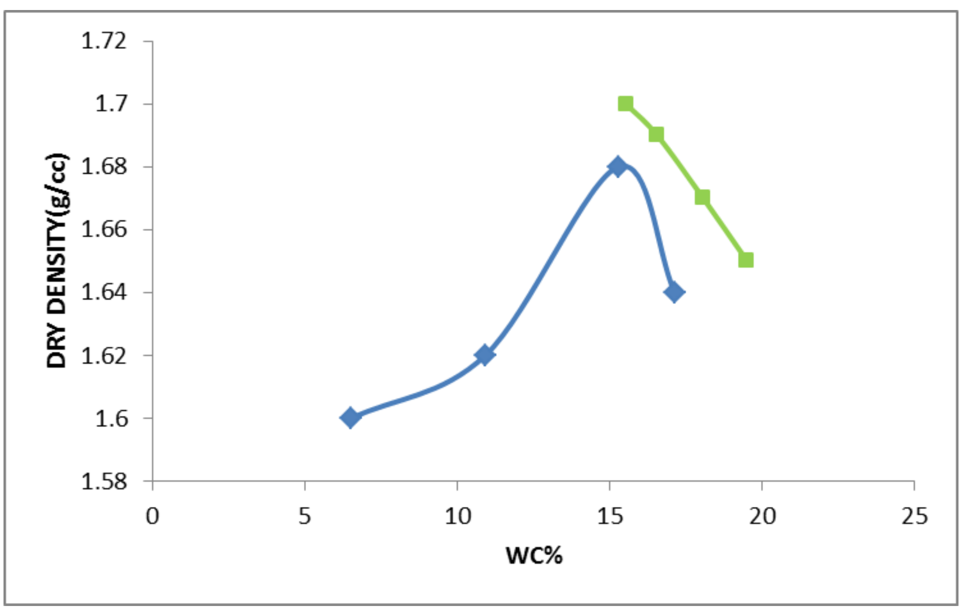

Fig 4.10 Graph of Maximum Dry Density vs Moister Content

4.4.5 Bawana Putt Clay + 16% Fly Ash

Optimum Moister Content w_0 = 15.07 %

Dry Density $(\rho_d)_{max}$ = 1.69 g/cc

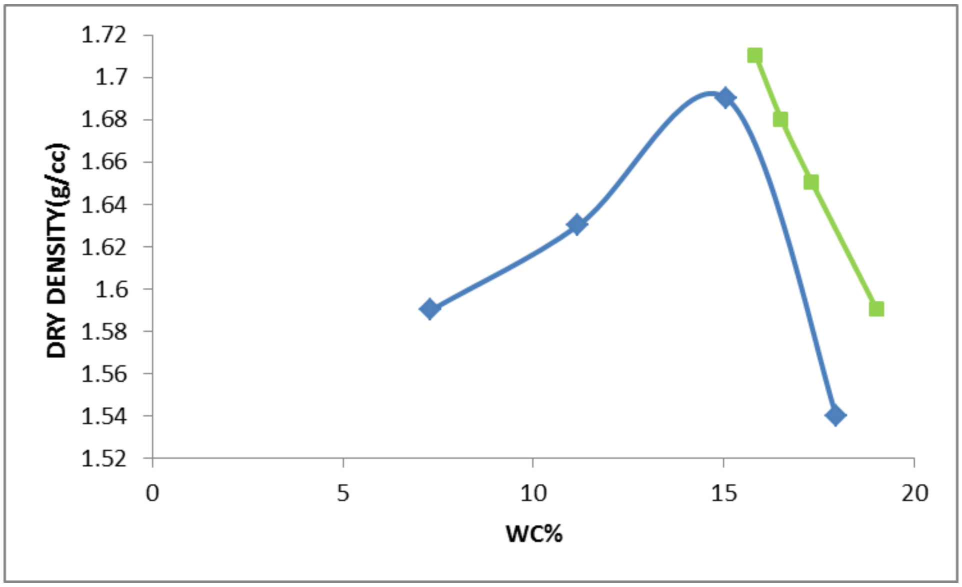

Fig 4.11 Graph of Maximum Dry Density vs Moister Content

4.4.6 Bawana Putt Clay + 20% Fly Ash

Optimum Moister Content w_0 = 13.36 %

Dry Density $(\rho_d)_{max}$ = 1.66 g/cc

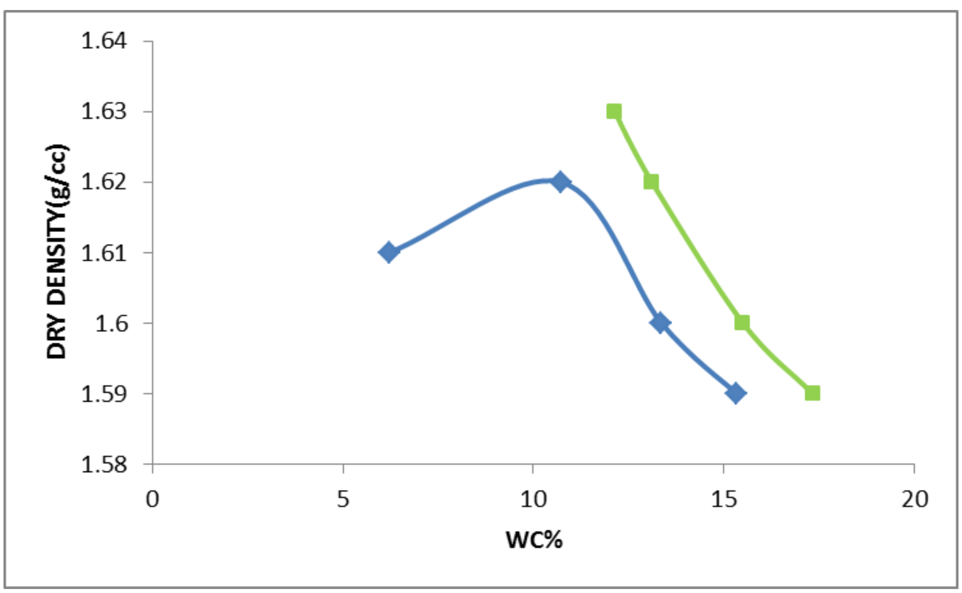

Fig 4.12 Graph of Maximum Dry Density vs Moister Content

4.5 Unconfined Compression Strength Test:

4.5.1 Bawana Putt Clay

From graph: UCS = 0.1425 N/mm^2

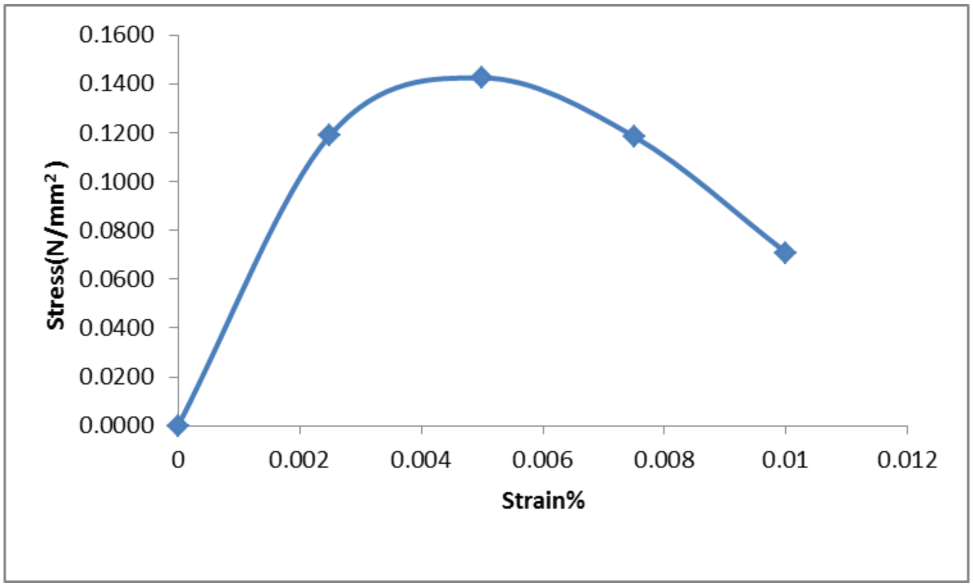

Fig 4.13 Stress-strain curve for soil by UCS test

4.5.2 Bawana Putt Clay + 04% Fly Ash

From graph: UCS = 0.1662 N/mm^2

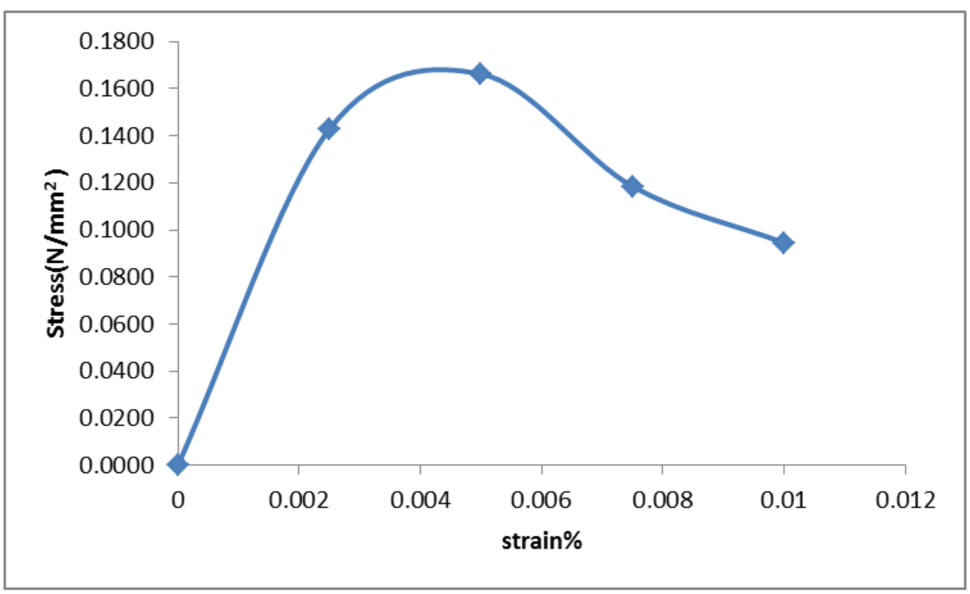

Fig 4.14 Stress-strain curve for soil by UCS test

4.5.3 Bawana Putt Clay + 08% Fly Ash

From graph: UCS = 0.1895 N/mm^2

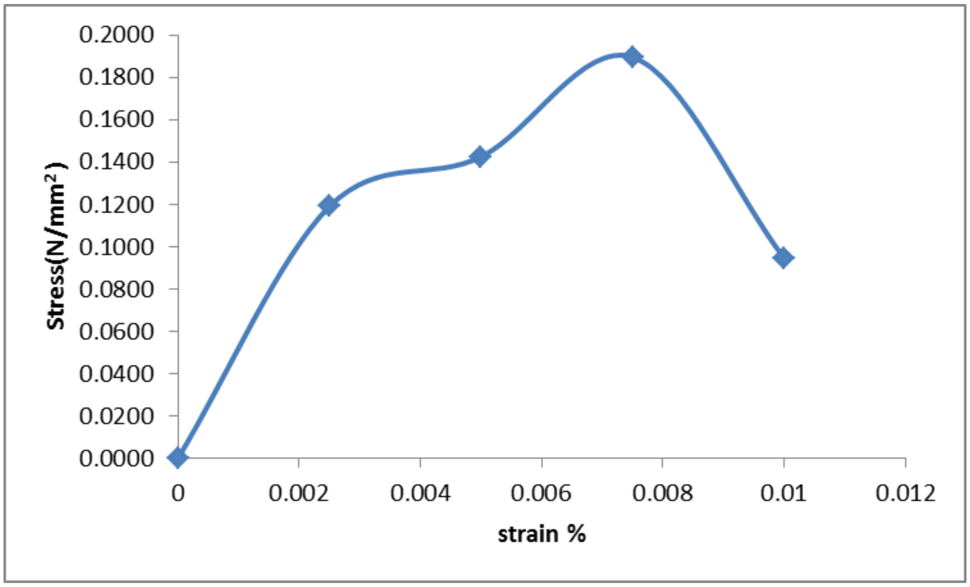

Fig 4.15 Stress-strain curve for soil by UCS test

4.5.4 Bawana Putt Clay + 12% Fly Ash

From graph: UCS = 0.2132 N/mm^2

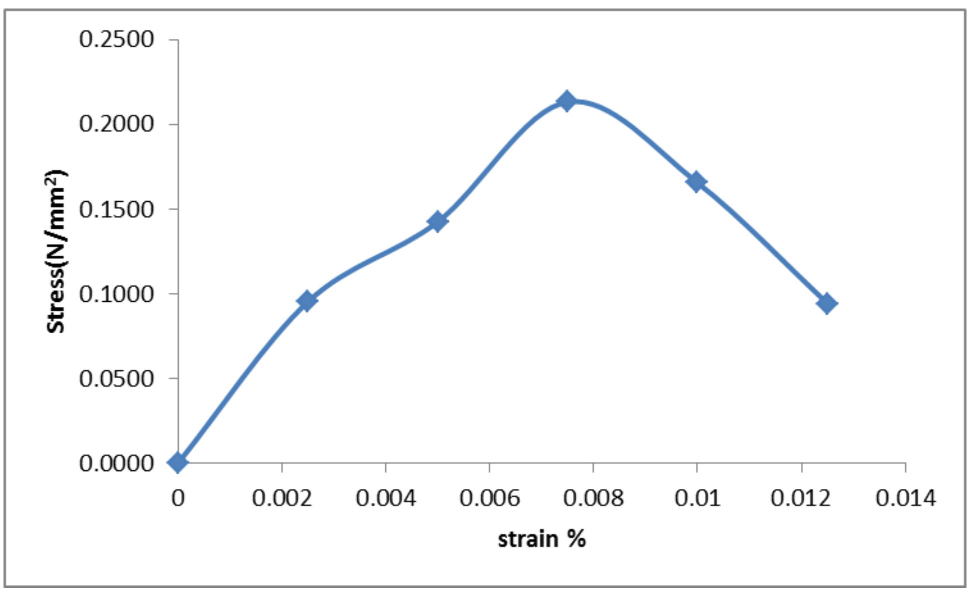

Fig 4.16 Stress-strain curve for soil by UCS test

4.5.5 Bawana Putt Clay + 16% Fly Ash

From graph: UCS = 0.2369 N/mm^2

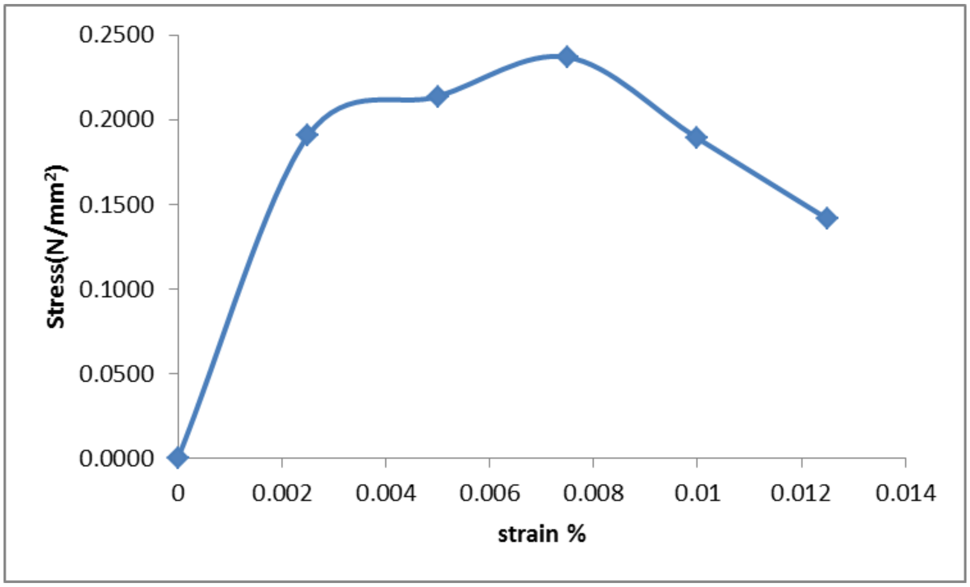

Fig 4.17 Stress-strain curve for soil by UCS test

4.5.6 Bawana Putt Clay + 20% Fly Ash

From graph: UCS = 0.2137 N/mm^2

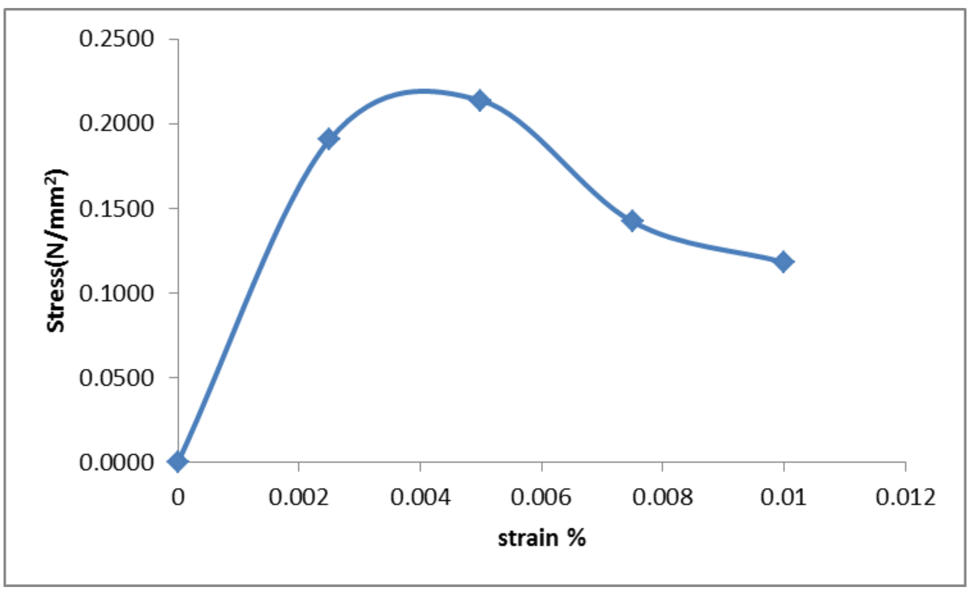

Fig 4.18 Stress-strain curve for soil by UCS test

4.6 Permeability Test

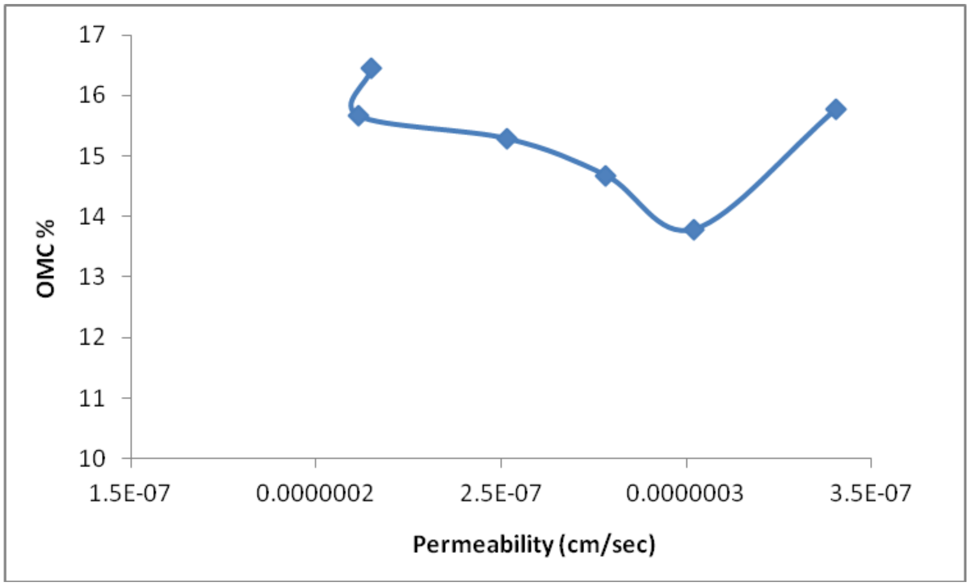

Fig 4.19 OMC Vs Permeability

4.6.1 Permeability test at wet side of OMC

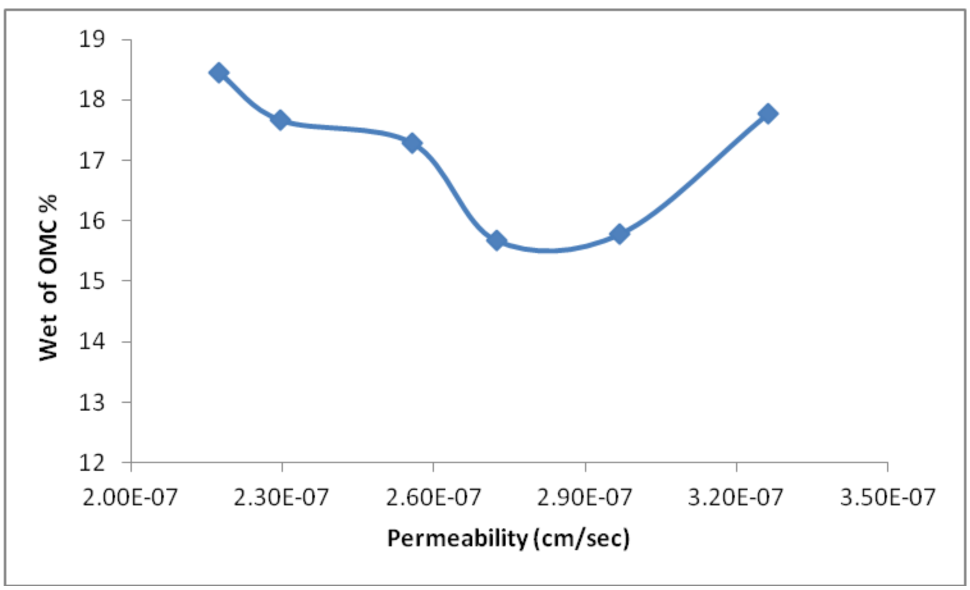

Fig 4.20 Wet of OMC Vs Permeability

CHAPTER 5

COMPARISON OF RESULT

5.1 Comparison of Results of Liquid Limit.

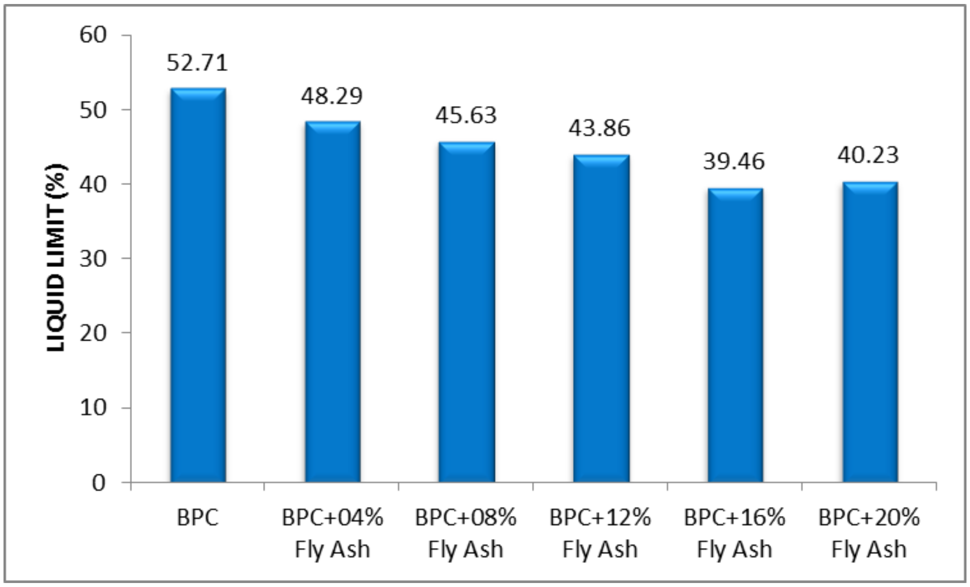

Fig 5.1 Comparison of Results of Liquid Limit

5.2 Comparison of Results of Plastic Limit.

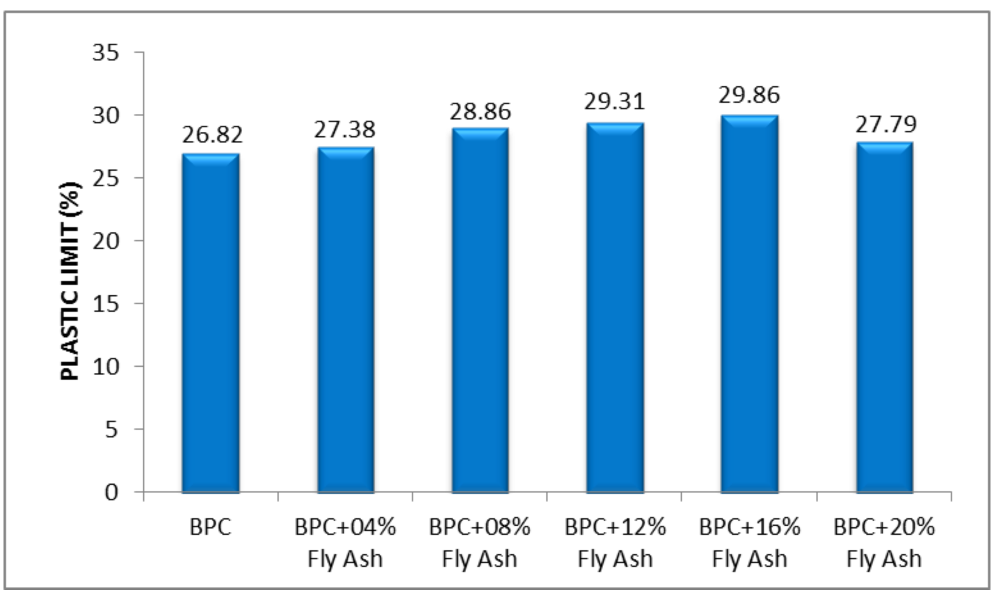

Fig 5.2 Comparison of Results of Plastic Limit

5.3 Comparison of Results of Maximum Dry Density.

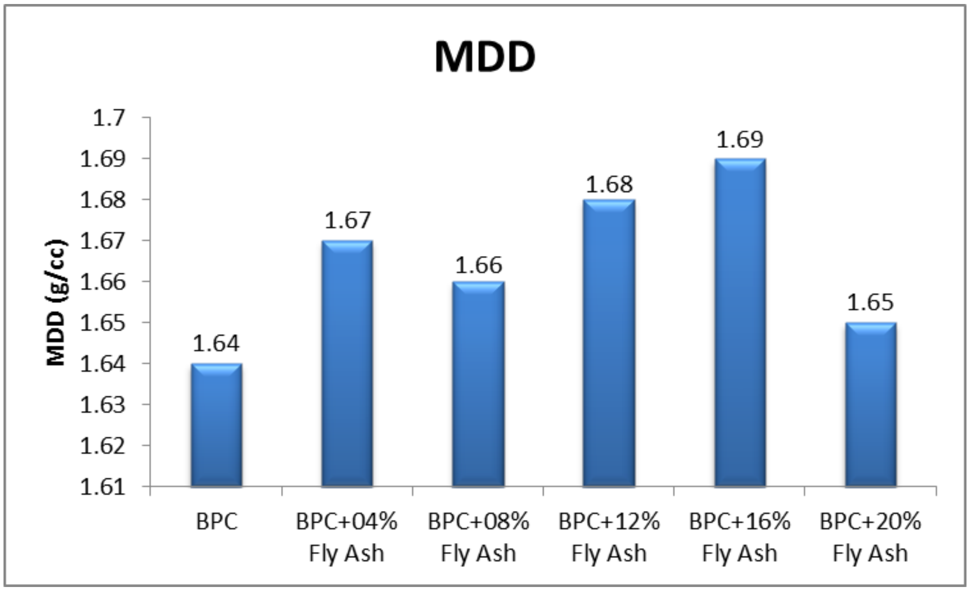

Fig 5.3 Comparison of Results of Maximum Dry Density

5.4 Comparison of Results of Optimum Moister Content.

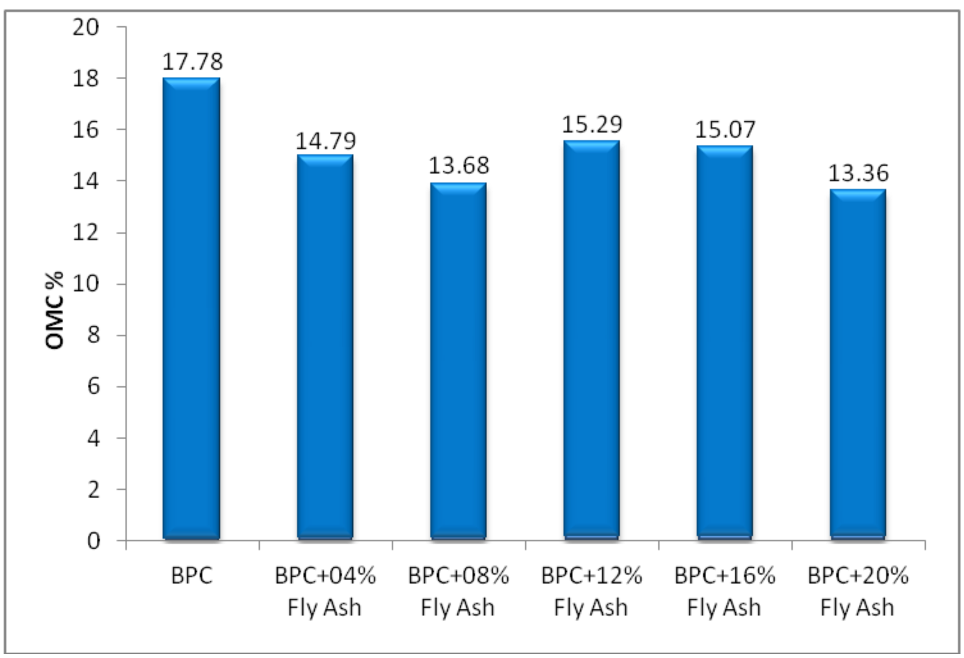

Fig 5.4 Comparison of Results of Optimum Moister Content

5.5 Comparison of Results of Unconfined Compression Strength.

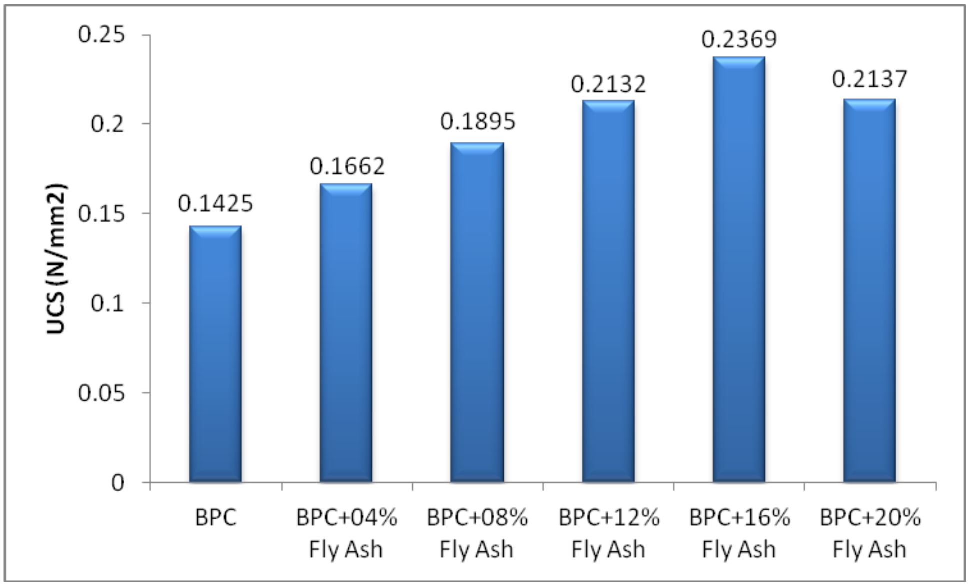

Fig 5.5 Comparison of Results of Unconfined Compression Strength

5.6 Comparison of Results of Hydraulic Conductivity Test.

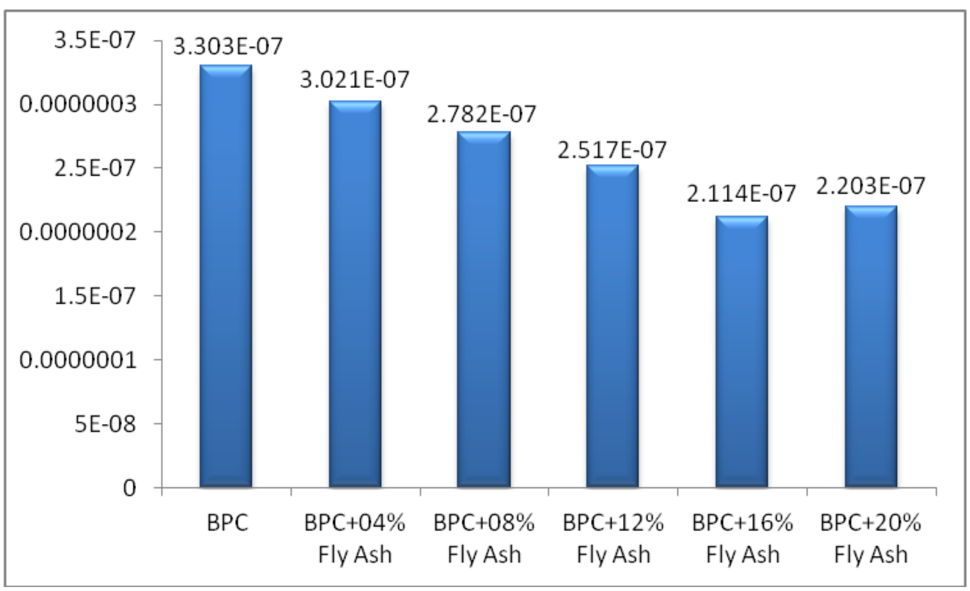

Fig 5.6 Comparison of Results of Hydraulic Conductivity Test

CHAPTER 6

CONCLUSION

6.1 Introduction

The objective of this test is to determine the relationship between the type of compaction and the improving shear strength of soil as well as reduce permeability, using standard compaction test. Basic soil property test is also carried out in order to classify the soil. Those tests are such as dry sieving, specific gravity, hydrometer test, Atterberg limit, Standard Procter test, unconfined compression strength test and permeability test. Sample used in this project Bawana Putt clay. The conclusion and recommendation are given in this session.

6.1 Conclusion

1. Bawana Putt clay is a soil with specific gravity 2.71, Liquid limit of 52.71%, plasticity index of 26.82 %, and therefore, it is categories as silty clay,CH with high plasticity based on the Indian Standard.
2. The maximum dry densities and were found 1.691 g/cc at optimum moisture contents of soil are 15.07% for standard compaction at mix of Bawana Putt clay +16% Fly Ash.
3. For the soil used in this study, the maximum shear strengths were in the range of 143 kPa to 237 kPa. High compactive effort, at optimum water content, maximizes the undrained strength.
4. Optimum moisture content as well as plasticity index was found gradually decreasing by adding 16 % Fly Ash with Bawana Putt clay.
5. It is observed that addition of Fly Ash of such proportions there is a significant change shown in decreasing permeability of soil. In initial stage without mixing fly Ash At

optimum moister content it having permeability k 3.404×10^{-7} cm/sec. After mixing Fly Ash at different proportion with Bawana Putt Clay, it is found that at mixing of 15 to 16% of Fly ash it decrease to 2.114×10-7 cm/sec. This has shown a significant change to desire permeability value k for a clay liner.

As a result of present work we obtained the Relationship between Compective Effort, Hydraulic Conductivity and Shear Strength of Compacted soil. Low MDD of Bawana Putt Clay is because of inherent low strength due to the dominance of clay fraction. It is observed that addition of Fly Ash with Bawana Putt Clay there is a significant change in Maximum Dry density as well as unconfined compressive strength of Bawana Putt Clay.

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Appendix A

Particle Size Distribution (Dry Sieving)

Mass of soil = 50 g

Sieve Size	Mass Retained (g)	% mass retained	Cummulative of % mass retained	% mass passing
4.75mm	0	0	0	100
2 mm	0	0	0	100
1 mm	0.758	1.516	1.516	98.48
600 µm	1.279	2.558	4.078	97.44
425 µm	2.910	5.821	9.895	94.19
300 µm	2.981	5.964	15.859	94.04
212 µm	4.903	9.805	25.664	90.19
150 µm	5.497	10.994	36.658	89.01
75 µm	28.201	56.401	93.059	43.59
passing 75µm	3.471	6.941	100.000	93.06

Appendix B

Sieving Data (From Hydrometer Test)

Initial total dry mass after pre-treatment = 50 g

Dry mass retained on 75 µm sieve = 4.385 g

Sieve Size µm	Mass Retained (g)	Cummulative Mass (g)	Percentage Passing (%)
0.00475	0	50	100
0.002	0	50	100
0.001	0.107	49.893	77.79
600	0.336	49.557	99.11
425	0.219	49.338	98.68
300	0.287	49.051	98.10
212	0.363	48.688	97.34
150	0.421	48.267	96.54
75	2.224	46.043	92.21
Pass	0.428	45.615	91.23

Appendix C

Atterbergs Limits

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
BPC	52.71	26.82	25.89
BPC+4% Fly Ash	48.29	27.28	21.01
BPC+8% Fly Ash	45.63	28.86	17.77
BPC+12% Fly Ash	43.86	29.31	14.55
BPC+16% Fly Ash	39.47	29.74	9.73
BPC+20% Fly Ash	40.23	27.79	12.44

Appendix D

Compaction Test (Standard Proctor Test)

Sample	Optimum Moister Content (%)	Dry Density (g/cc)
BPC	17.78	1.64
BPC+4% Fly Ash	14.79	1.67
BPC+8% Fly Ash	13.68	1.66
BPC+12% Fly Ash	15.29	1.68
BPC+16% Fly Ash	15.07	1.69
BPC+20% Fly Ash	13.36	1.66

Appendix E

Unconfined Compression Strength Test

Sample	Unconfined Compression Strength (N/mm^2)
BPC	0.1425
BPC+4% Fly Ash	0.1662
BPC+8% Fly Ash	0.1895
BPC+12% Fly Ash	0.2132
BPC+16% Fly Ash	0.2369
BPC+20% Fly Ash	0.2137

Appendix F

Permeability Test: At optimum Moister Content

a = Area of stand pipe

= 0.754 cm^2

A = Area of specimen

= $\pi/4$ ($6^{2)}$

= 28.274 cm^2

L = Length of sample

t = Time Interval in second

$K = (aL/At) \log_{10} (h_1 / h_2)$

Sample	OMC %	Time Interval (ses)	h_1 (cm)	h_2 (cm)	Permeability,K (cm/sec)
BPC	17.78	57600	100	70	3.303×10^{-7}
BPC+4% Fly Ash	14.79	63080	100	70	3.020×10^{-7}
BPC+8% Fly Ash	13.68	68400	100	70	2.782×10^{-7}
BPC+12% Fly Ash	15.29	75600	100	70	2.517×10^{-7}
BPC+16% Fly Ash	15.07	90020	100	70	2.114×10^{-7}
BPC+20% Fly Ash	13.36	86760	100	70	2.203×10^{-7}

Permeability Test: At Wet Side of Optimum Moister Content

Sample	OMC %	Time Interval (ses)	h_1 (cm)	h_2 (cm)	Permeability,K (cm/sec)
BPC	19.78	59400	100	70	3.262×10^{-7}
BPC+4% Fly Ash	16.79	64080	100	70	2.969×10^{-7}
BPC+8% Fly Ash	15.68	69300	100	70	2.724×10^{-7}
BPC+12% Fly Ash	17.29	77410	100	70	2.458×10^{-7}
BPC+16% Fly Ash	17.07	90720	100	70	2.097×10^{-7}
BPC+20% Fly Ash	15.36	87480	100	70	2.174×10^{-7}