Bentonite Amended Fly Ash for Environmental Hydraulic Barrier

by

Nozie Elliana Bt Abdullah

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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Approved by,

(Noorfidza Bt Yub Harun)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JANUARY 2005

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources of person.

NOZIE ELLIANA BT ABDULLAH

ABSTRACT

The objectives of this study is to conduct compaction tests, hydraulic conductivity tests, and shear strength tests on fly ash with and without kaolinite clay mixed at various fraction. The project requires student to study the utilizing of fly ash, with kaolinite, a type of Bentonite clay for purpose of making the environmental hydraulic barrier. The study is aimed to find the alternate markets for re-use of the waste material (fly ash). To achieve the project objective, the compaction and hydraulic conductivity tests have been conducted. However due to time constraint, shear strength test could not conducted. The fly ash used for this project is provided by TNB Jana Manjung Power Plant. Before the experiment started, the fraction of fly ash added with kaolinite is set so that the results can be varied. Compaction and permeability test is conducted with the same fraction so that the results from two experiments can be differentiated. The scopes of the study are to study the characteristics of the fly ash and clay, conducted the tests and analyze the outcome. From compaction tests results, the dry density-moisture content curve is constructed where the maximum dry density and optimum moisture content is obtained. From the curve constructed the results shows that sample of 100% fly ash gives the highest maximum dry density. In order to conclude the best fraction obtained the sample with highest dry density and lowest optimum moisture content is analyzed. As for the permeability tests, the value of hydraulic conductivity is calculated and it is vary as the fraction of sample vary. The hydraulic conductivity is decreasing as the fraction of fly ash decreasing. But from the results, it is shown that fly ash is suitable to reduce the conductivity of clay. As the conclusions, the fly ash can possibly be the environmental hydraulic barrier but further tests has to be conducted to get an accurate results and additional elements could be added to improve the characteristics of the sample.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

The main concern of this project is to study the waste product which is fly ash that is believed to have a potential in construction. Fly used in this project is taken from Tenaga Nasional Berhad Jana Manjung Electrical Power Plant where fly ash is the waste production from the burning of coal. To study the effect of using fly ash, one of the materials widely used in construction which is clay is used together with fly ash. The type of this clay used in this project is kaolinite clay. Kaolin is actually China clay that is very pure forms of white clay used in ceramic industry. The sample of fly ash and kaolinite that is being tested is mixed in various fractions; 100% fly ash, 40% fly ash and 60% kaolinite, 30% fly ash and 70% kaolinite, and 20% fly ash and 80% kaolinite. The experimental results will be discussed later in Chapter 4.

1.1.1 Ash Disposal

Coal is widely used to generate electricity. About 12 to 15% of coal in power plants ends up as ash consisting of boiler slag, bottom ash, cinders, and fly ash. Boiler slag is produced as residue from wet-bottom or cyclone boilers, flows out from the furnace into cold water, and solidifies to form crystals and angular, black, glasslike particles.

There are two kinds of ash generated by an incinerator: the bottom ash which falls through the grate system in the furnace, and the fly ash, which is the very fine material which is collected in the boilers, the heat exchangers, and the air pollution control devices. As far as toxic metals are concerned, it is chemical truism to state that the better the air pollution control the more toxic the fly ash becomes. Table below listed the constituent of bottom ash and fly ash.

Table 1.1: Typical Compositions of Bottom Ash and Fly Ash

Constituent	Bottom ash %	Fly ash %
Silica (SiO_2)	21-60	34-58
Alumina (Al_2O_3)	10-37	20-40
Iron oxide (Fe_2O_3)	5-37	4-24
Calcium (CaO)	0-22	2-30
Magnesium (MgO)	0-4	1-6
Sulfates (SO_3)	-	0.5-4
Water soluble alkalis	0-7	2-6

Fly ash produced by burning subbituminous coal, or lignite, is called *Class C* fly ash. This type of fly ash contains lime and other compounds that impart self-cementing properties. According to ASTM standard C 618, the chemical composition of Class C fly ash must be such that $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$ and sulfur trioxide may not exceed 5%. This class of fly ash is more common in the western and Midwestern United States.

Fly ash formed by burning bituminous coal, or anthracite, is known as *Class F* fly ash. Its chemical composition must be such that $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$ and sulfur trioxide may not exceed 5% (ASTM C 618). This category of fly ash is primarily generated in the eastern United States. Although it is pozzolanic, it shows few self-cementing properties. The engineering properties of fly ash are influenced most by free lime and unburned carbons. Low-volume coal combustion waste, such as boiler cleaning waste, exhibits toxicity levels that would characterized them as hazardous based on EPA test.

At least a half of the amount of fly ash produced annually is disposed of by landfill, thus contributing to environmental pollution due to leaching of its toxic constituents. One of the critical constituents is fluoride which maybe toxic at elevated levels in water. Fly ash contains heavy metals and the content varies with the type of fuel used for combustion.

The absolute quantity of heavy metals is relatively small. Fly ash can be used in all possible structural courses in road construction, as binding material for stabilization, and for community and environmental construction. It is also an excellent additive to other soil construction materials or by-products to be recycled in soil construction.

1.1.2 Bentonite Clay

Clays have been used since Stone Aged and today there are among the most important minerals used by manufacturing and environmental industries. The characteristics common to all clay minerals derive from their chemical compositions, layered structured, and size. Clays have all great affinity for water. Some swell easily and may double in thickness when wet.

Clays occur under a fairly limited range of geologic conditions. Most clay minerals form when rocks are in contact with water, air, or steam. The environments of formation include soil horizons, continental and marine sediments, geothermal fields, volcanic deposits, and weathering rock formations. Most clay minerals form where rocks are in contact with water, air, or steam. Examples of these situations include weathering boulders on a hillside, sediments on sea or lake bottoms, deeply buried sediments containing pore water, and rocks in contact with water heated by magma (molten rock). All of these environments may cause the formation of clay minerals from preexisting minerals. Extensive alteration of rocks to clay minerals can produce relatively pure clay deposits that are of economic interest, for example, bentonites that are used for drilling muds.

Bentonite is a clay mineral which is largely composed of Montmorillonite which is mainly a hydrous aluminum silicate. It is highly colloidal and plastic clay with the unique characteristic of swelling to several times its original volume when placed in water. Sodium Bentonite is noted for its affinity for water which gives it tremendous selling properties. Sodium Bentonite contains exchangeable sodium captions. When dispersed in water it breaks down into small plate-like particles negatively charged on the surface, positively charged on the edges. This unique ion exchange is responsible for the binding action which takes place. Bentonite's small plate-like particles provide a tremendous potential for surface area. These characteristics give Bentonite an enormous range of potential uses. For instance, this special clay can be used as an animal feed binder, a natural soil sealant or drilling mud, a foundry sand binder, or as a stucco and mortar plasticizer.

1.2 Problem Statement

Disposal of huge amount of fly ash in landfills and surface impoundments or its re-use in construction materials is of environmental concern. While much effort has been devoted to the problem of leaching of heavy metals from disposed fly ash, the release of non-metals has attracted considerably less attention. Of these, arsenic, selenium, and boron stand out as potentially harmful to both vegetarians and animals.

The project requires student to study utilizing of Bentonite together with fly ash for purpose of making the environmental hydraulic barrier. The study is aimed to find the alternate markets for re-use of the waste material (fly ash). The mixture of both Bentonite and fly ash is believed to be a potentially suitable for the hydraulic barrier applications such as landfill liner, landfill caps, and vertical cutoff walls. In this project, the Bentonite used is the kaolinite which is a type of clay minerals.

To prove the compatibility of both kaolinite and fly ash, several tests have to be made and the combination is to be made in various fractions. This is for comparing the effectiveness of every fraction to obtain the most stable sample. If the conducted tests show impressive results, than new construction material can be developed and utilize in the future. Hence by using fly ash as one of the material used for construction, the amount of waste disposal could be reduced from time to time.

1.3 Objective and Scope of Study

Objectives of the study is to conduct compaction tests, hydraulic conductivity tests, and shear strength tests on fly ash with and without kaolinite clay mixed at various fractions.

Scope of study which will be undergoing here are:

a) Understand the characteristics of Bentonite clay and fly ash that will be the main fraction for the mixture of the barrier.
b) Understand all the procedure of compaction, permeability, and shear strength tests and conduct the experiments within the period of the project.
c) Analyze the result and come up with problem solving techniques if any problem faced. Discuss and conclude the result.
d) Recommend any methods or techniques and apply if possible.

CHAPTER 2
LITERATURE REVIEW

2.1 Bentonite and Fly Ash as a Barrier Material

Review of literature reveals a number of earlier studies on the reliability of fly ash and Bentonite in the soil industries. Research was made by Muhammad and K. Ashamed (2003) with the main goal to evaluate feasibility of utilizing the soil-ash mix or an equivalent ash-soil system as an alternative material in landfill cap and liner construction. The experimental results of homogeneously-mixed soil and ash samples indicated that a relatively large percentage of soil is needed in order to achieve a hydraulic conductivity compatible with the current regulatory requirements.

Compaction characteristics are an integral component of the ash-soil mix for alternative landfill material. It is important to determine the compaction characteristic of only those materials that satisfy the hydraulic compatibility requirements. Therefore a series of pilot tests is conducted to evaluate the composition, by weight, of suitable ash-soil combination in terms of their hydraulic compatibility. The pilot test series indicated that the only soil that can achieve the acceptable levels of hydraulic conductivity is Bentonite clay, mixed at a very large percentage with the ash.

The compatibility of the ash-soil mix hinges on the ability of the mixture to simulate a typical clay liner or cover. Examination of the grain size distribution and compaction characteristics of the ash material indicate that addition of sandy soils will not achieve the required hydraulic conductivity of comparable systems. Therefore it was decided to use Bentonite as an additive to the ash. Bentonite is natural clay formed as a result of mechanical and chemical weathering of volcanic ash that has been deposited in salt or fresh water. Sodium and Calcium Montmorillonite, which constitute the main mineral in Bentonite clays are present in salt and fresh water deposits, respectively.

Bentonite exhibits low hydraulic conductivity (up to 10^{-10} cm/s), high fluid absorption capacity, and can swell to several times its original volume. Its also has the capability of storing limited amounts of metal ions by absorption. Its swelling capacity depends on factors such mineral composition, grain size, aggregate size, cation exchange capacity, chemical concentration of the permeating liquid and the chemical composition of the first wetting liquid. By the material to the ash, the hydraulic conductivity could be decreased, and the retention capacity of calcium and chloride could be increased.

2.2 Fly Ash Characterization

The characteristics of fly ash have been studied by any researchers. The studies of Aimin Xu (1997) stated that, fly ash, or pulverized fuel ash, is a residue derived from the combustion of pulverized coal in furnaces of thermal power plant. The characteristics of fly ash vary accordingly to the combustion operation system as well as the coal composition.

Various suspension-firing system such as vertical firing and horizontal firing, have been widely used, which afford a high stem-generation capacity and quick response to load changes. The combustion temperature is high (approximately 1200°C) and the ash, is finely divided into form (usually less than 1000 μm in size) is carried along in the air stream, collected by electrical or mechanical precipitators (dry process) while it is quickly cooled. In some power stations, the old wet collection process is still in use (see Figure 2.1).

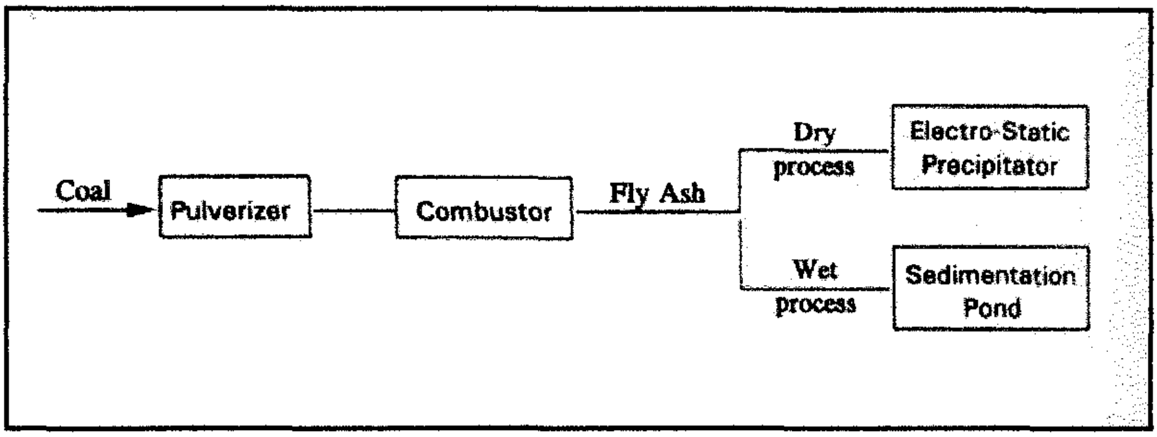


Figure 2.1: Schematic diagram of coal burning and ash collection processes.

Fly ash collected by a dry process is usually rather homogeneous in particles size whereas that collected by a wet process is more segregated due to the fact that the sedimentation speed is lower for smaller or lighter particles, and its contain large quantities of water. The coarser portion of the coal ash which is 15-20% by mass (Joshi and Lohtia, 1993) is heavy and falls to the bottom of the furnace and thus is called bottom ash. Residue of combustion consists about 85% fly ash and 15% bottom ash (Joshi and Lohtia, 1993).

With the ignition of burnable matter, under high temperature, the inorganic compounds in coal melt and liquid assumes in spherical shape forming fly ash glass embedded with various minerals. The collision between particles results in some larger particles or particles made up of several smaller ones bonded together. It is often seen under microscopic examination that some particles have enclosed pockets of air, or appear to be hollow spheres. Various shapes of fly ashes are shown in Figure 2.2.

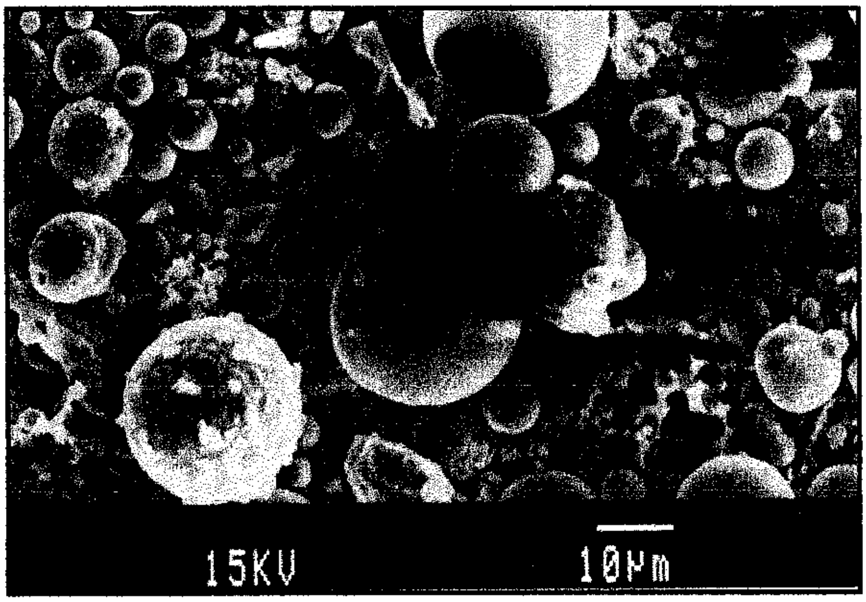


Figure 2.2: Fly Ash Particles

The combustion system directly influences ash composition. A form of coal burning referred to as *fluidized-bed combustion* has been in used since 1970s. This process has a high heat-transfer so that it uses lower temperature (approximately 1000°C). Consequently, the formation of nitrogen oxides is lower than the volatilization of potassium, sodium and sulfur found in the coal are also lowered. While the low temperature process produces less air pollution, it is also results in a different fly ash composition when compared to ashes produced under higher processing temperatures. In recent years, in order to reduce air pollution, lime stone powder is introduced into the combustion system to absorb the sulfur released from burning high sulfur coals, which form calcium sulfide-sulfate and lime ((Joshi and Lohtia, 1993).

The chemical composition of an ash depends on the coal composition, while its mineralogical composition may vary considerably from the original matter and is also a function of the fineness of the fuel and the combustion operation. In response to the demands for power, the ignition efficiency changes and peak temperatures varies. This results in a varying amount of unburned carbon in the ash. Further more, it has been reported that the residence time of fly ash in furnace causes variations in the alkali content and the vitrification degree of the fly ash.

Coals used in thermal power stations are mainly anthracite (hard coal, with carbon content higher than 80%, burning with little smoke), bituminous coal (composed of carbon and volatile matter in similar proportions, burning with a great deal of smoke), subbituminous coal (similar in composition to the bituminous coal, with more moisture), and lignite coal (brown coal, similar to subbituminous coal in a solid matter composition, usually with a high moisture content). The composition of coal and ash vary considerably. The first two types of coals usually produce low calcium ashes, where the latter two lead to high calcium ashes.

Being a finely divided powder consisting of silica-alumina glass of various forms, fly ash in concrete functions as a filter between cement grains and aggregate, and as an effective binder providing a cementitious property. In fact, when fly ash is a major constituent of concrete, it physically alters the properties of the system. There is also some evidence that fly ash influences the formation of hydration product at very early stages (Diamond, 1991)

The ability of fly ash to react with various chemicals has been utilized to solve some engineering problems such as improving materials for prefabricated building components. Limestone for making cement often contains impurities. As a result, the cement may not comply with established standards for cement composition. Using fly ash and other pozzolanic materials in concretes made with such cements initially reduces the amount of harmful compounds in the system (Aimin Xu, 1997)

2.3 Clay Mineral Structure

In the study of clay mineral, there are two types of bonds that are important which are *primary bonds* which hold together the atoms, and *secondary bonds* which hold together water molecules of adjacent sheets of crystalline lattice and affect its mineral characteristics.

Primary bonds can be either ionic bonds or covalent bonds. In *ionic bonds*, element release or gain electrons in the outer shell of their atoms. In *covalent bonds*, two atoms share the valence electrons in their outer shells. If the centers of the bonded ions in a molecule do not coincide, the bonds are known as *polar covalent bonds*. Such molecules have both a positive and a negative charge and are known as polar molecules, or *dipoles*. Water is an example of a dipole. If the arrangement within the molecule is symmetric, the polar covalent bonds yield nonpolar molecules. Carbon tetrachloride is one such example.

The force of attraction between dipoles is called the *dipole force*. If the positively charged end of the participating dipole is hydrogen, then the attracting force is called a *hydrogen bond* and is stronger than an ordinary dipole bond. Properties of clay minerals and their interaction with water are significantly influenced by the hydrogen bond. *Van der Waals* bonds are due to fluctuating dipolar bonds and are relatively weak and non-directional. However, they may contribute to cohesion. Secondary bonds and electrostatic forces are greatly affected by applied stresses.

In its idealized form, the crystalline structure of a clay mineral is composed of two basic building blocks; a silica tetrahedron and an aluminum octahedron. The silica tetrahedron (SiO_4) consists of a silicon atom (Si^{4+}) surrounded by four oxygen atoms (O^{2-}). Silica tetrahedral shares their oxygen atoms to form either chains or sheets. A silica sheet is formed when the shared oxygen atoms in the tetrahedral lie in a plane a have hexagonal holes, as shown in Figure 2.3.

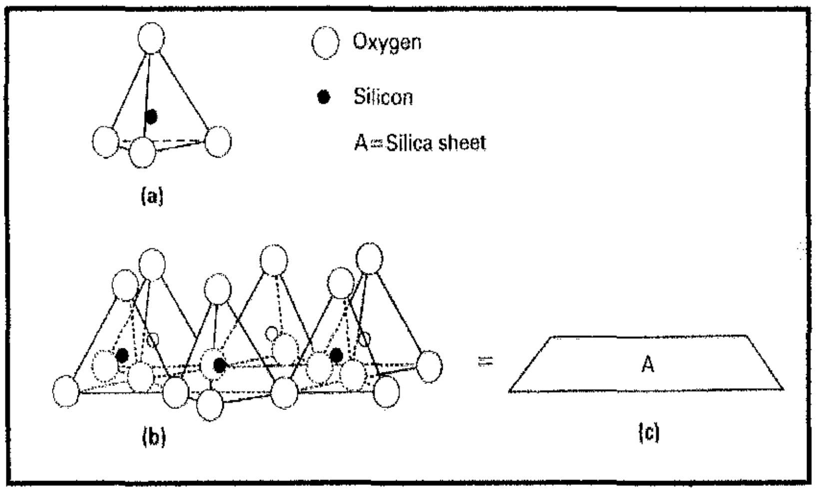


Figure 2.3: A silica tetrahedron and a silica sheet

The aluminum octahedron consists of aluminum (Al^{3+}) or magnesium (Mg^{2+}) surrounded by hydroxyls, as shown in Figure 2.4. Sheet structure of octahedral units is formed by the sharing of hydroxyls and is represented by rectangles in the figure. In only aluminum is present, it is called gibbsite [Al_2 (OH) $_6$)]; if only magnesium is present, it is called brucite [Mg_3 (OH) $_6$)]. Various clay minerals are formed as these sheets stack on top of each other with different ions bonding them together. The ions on the surface of a clay particle may be O^{2-} or $(OH)^-$, thus giving it a net negative charge.

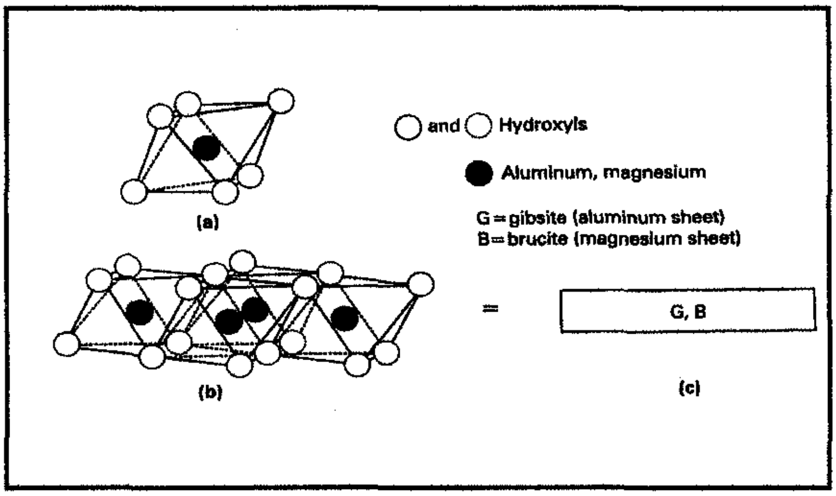


Figure 2.4: An octahedron and an octahedron sheet

If clay particles fracture, other electrical forces may develop at the edges such that the internal ions, which are usually positive in charge, are exposed. The edges may then attract dipoles, anions, or the negatively charged faces of other clay particles. Different clay minerals are formed if during this interaction the normal locations of aluminum, magnesium, or silicon ions are occupied partially or wholly by other ions. This substitution of one kind of ion with another without a change in the crystal structure is known as *isomorphous substitution.* The isomorphous substitution causes a change in the net negative charge and may result in some distortion of crystal lattice. This charge deficiency is balanced by the external adsorption of cations at the surface of clay particles and between the layers.

The properties of clay mineral can be altered by exchanging the externally adsorbed ions or by water adsorbed in particles surface. Externally adsorbed cations can be replaced by other cation, which is known as the *ion exchange.* The replacing power for some of the commonly occurring cations in soil minerals increases from sodium to iron:

$$Na^+ < K^+ < NH_4^+ < Mg^{2+} < Ca^{2+} < Al^{3+} < Fe^{3+}$$

The ability of a mineral to adsorb external cations is known as *cation exchange capacity* (CEC). The CEC of a soil is the number of cations in milliequivalents that neutralize one hundred grams of dry clay (meq/100g). One milliequivalent is one milligram of hydrogen or any ion that will combine with one milligram of hydrogen or displace it.

2.3.1 Kaolinite

Kaolinite is formed in the weathering or orthoclase feldspar under good drainage conditions with low pH. It has a low swelling potential, low liquid limit, low activity, and yields hydraulic conductivity of 10^{-6} cm/s or higher. Kaolinite crystal layers consist of tetrahedron and octahedron sheets that are held together by the strong hydrogen bond between oxygen and hydroxyl. A schematic of kaolinite is shown in Figure 2.5. When kaolinite sheets are stacked on each other, the hydroxyl of octahedron sheets are attracted to the oxygen of silica tetrahedron sheet by means of oxygen bonds. The bonds which are ionic and covalent are strong, but not as strong as the primary bonds. Therefore, cleavage occurs. These sheets can extend greatly in two directions and typically such crystals are 70 to 100 layers thick.

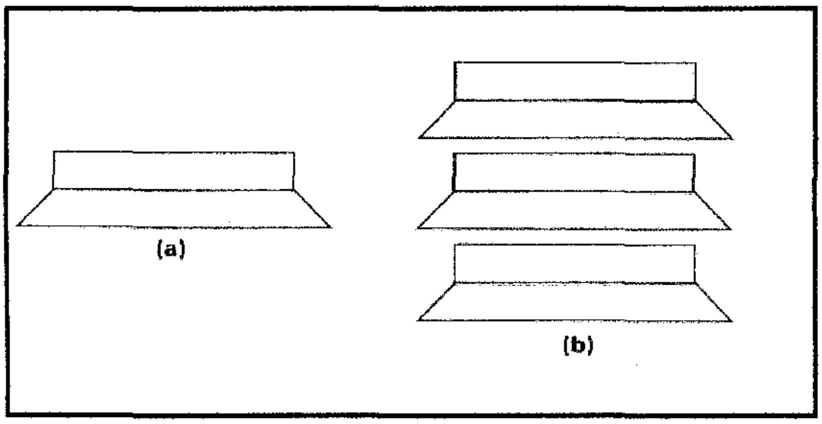


Figure 2.5: Kaolinite structure. (a) Basic building block, (b) stacked blocks forming particles

Since kaolinite contains a tetrahedron octahedron sheet, it is called a two-layer sheet or a one-to-one mineral. The kaolinite platelets are about 0.05 micron thick, have a diameter-to-thickness ratio of about 20 and are usually hexagonal in shape. The structural formula is $(OH)_8Si_4Al_4O_{10}$, where one Si in 400 is substitute by Al.

2.4 Clayey Barrier System

Soil barrier, containing enough clay minerals to provide low permeability, are used to extensively to prevent the rapid advective migration of various leachates from waste disposal sites. Clayey barriers vary from thin Bentonite liners (1-3 cm thick), to compacted clayey liners (0.9-3 m thick), and to natural undisturbed clayey barriers up to 30 or 40 m thick. (Rowe, Quigley, and Booker, 1995).

2.5 Soil Improvement by Compaction

Soil for construction may not always be totally suitable for supporting structures such as buildings, bridges, highways and dams. Some soils need to be densified to increased its unit weight and also shear strength. Sometimes the top layers of soil are undesirable and must be removed and replaced with better soil on which the structural foundation can be built. The soil used as fill should be well compacted to sustain the desired structural load. Compacted fills may also be required in low-lying areas to raise the ground elevation for construction of the foundation.

Fly ash has been successfully used as both a general and a structural fill for over 40 years and has been demonstrated to be a valuable resource in construction with the advantages of low density, high shear strength, and no consolidation. There are many methods by which the soil can be improved and the soil improvement is frequently termed soil stabilization. The improvement is important to increase shear strength, reduce permeability and reduce compressibility. Some of the methods of improvement are the compaction, vibroflotation, preloading, and sand and stone columns.

Compaction is the least expensive, simplest and most effective way of improvement methods and is applicable in both cohesionless and cohesive soils. It is the process of mechanically densifying a soil or aggregate. Densification is accomplished by pressing the particles into closer contact while expelling air from the soil mass. By this method, the density and strength will be increased while at the same time reduce the permeability. Compaction can be performed in the laboratory with static, kneading, gyratory, vibratory, or impact compactors. However, impact compaction test that use a falling hammer to provide the compaction energy are the standard in practice today.

Because the laboratory compaction test is intended to simulate field conditions, and since heavier construction equipment has been produced over time, different laboratory test have been needed to replicate various field compactive efforts. Appendix D compares several common laboratory compaction test methods. There are minor differences in mold size and method of handling large aggregate particles, but there are two basic tests. One is commonly referred to as *standard Proctor* and imparts approximately 12,375 ft.lb/ft^3 of energy in compaction of the sample. The other, commonly referred to as modified Proctor, uses approximately 56,250 ft.lb/ft^3 of energy to compact the sample (Murthy, 2003). The major difference between these tests is the amount of energy applied to the sample by using different weight hammers and different numbers of blows per layer.

The standard Proctor test is developed in connection with the construction of earth fill dams in California. A soil at selected water content is placed in layers into a mold of given dimensions (Appendix C) with each layer compacted by 25 or 56 blows of a 5.5 lb (2.5 kg) hammer dropped from a height of 12 in (305 mm), subjecting the soil to a total compactive effort. The resulting dry unit weight is determined. The procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content of the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve moisture-density curve. The values of water content and standard maximum dry unit weight are determined from compaction curve as shown in Figure 2.6.

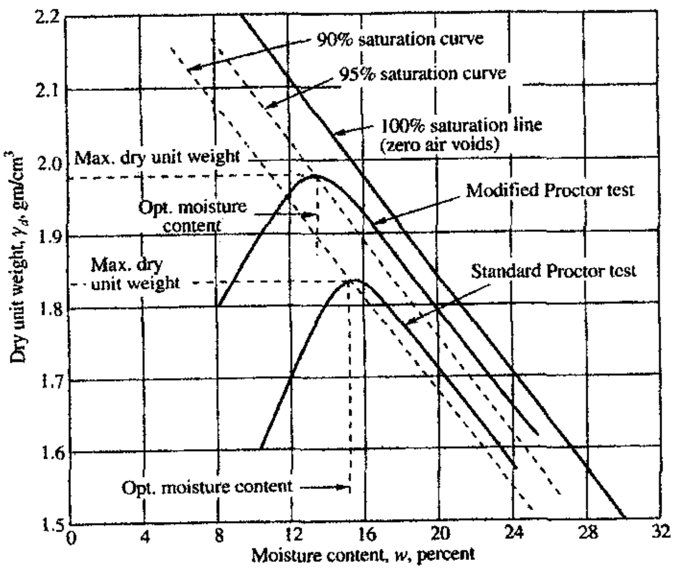


Figure 2.6: Moisture content-dry unit weight relationship

For each test, the moist unit weight of compaction γ can be calculated as

$$\gamma = \frac{W}{V_{(m)}} \qquad (2.1)$$

where W is the weight of the compacted soil in the mould and $V_{(m)}$ is the volume of the mould. The moisture content of the compacted soil is determined in the laboratory. With known moisture content, the dry unit weight γ_d can be calculated as

$$\gamma_d = 1 + \frac{\gamma}{1 + \frac{w(\%)}{100}} \qquad (2.2)$$

where w (%) is the percentage of the moisture content. For a given moisture content, the theoretical maximum dry unit weight is obtained when there is no air in the void spaces. That is when the degree of saturation equals 100%. Thus, the maximum dry unit weight at given moisture content with zero air voids can be given by

$$\gamma_{zav} = \frac{G_s \gamma_w}{1 + e} \qquad (2.3)$$

where γ_{zav} = zero-air-void unit weight

γ_w = unit weight of water

e = void ratio

G_s = specific gravity of soil solids

For 100% saturation, $e = wG_s$, so

$$\gamma_{zav} = \frac{G_s \gamma_w}{1 + e} = \frac{\gamma_w}{w + \frac{1}{G_s}} \qquad (2.4)$$

where w is the moisture content. To obtain the variation of γ_{zav} with moisture content, the following procedure is used:

- Determine the specific gravity of soil solids
- Know the unit weight of water (γ_w)
- Assume several values of w, such as 5%, 10%, 15%, and so on
- Use equation 2.4 to calculate γ_{zav} for various values of w.

For fly ash, the maximum dry unit weight ranges from 74.4 lb/ft^3 (11.7 kN/ m^3) to 127.5 lb/ft^3 (20 kN/ m^3) and the optimum moisture content from 9% to 50%. The average dry unit weight and optimum moisture content for Class F are about 82.8 lb/ft^3 (13 kN/ m^3) and 25% respectively. The corresponding values for Class C fly ash are 94.2 lb/ft^3 (14.8 kN/ m^3) and 20% respectively (Oweis and Khera, 1998). In compaction tests on fresh fly ash, new samples must be used for each test as the recompacted fly ash behaves quite differently. The dry unit weight increases as the specific gravity of the fly ash solids increase. Presence of unburned carbon reduces its specific gravity, unit weight, and strength. Usually the higher unit weights are associated with lower optimum moisture content.

2.6 Soil Permeability

Permeability is actually the measure of the rate at which water flows through a soil mass. A material is permeable if it contains continuous voids. All materials such as rocks, concrete, and soils are permeable. The permeability coefficient or hydraulic conductivity, κ of soil is measured in the laboratory to observe the permeability behavior of soils.

In general, there are two types of permeability test that are usually conducted in the laboratory for measuring the hydraulic conductivity of soils. The tests are constant head test and falling head permeability test. The apparatus used for the constant head permeability test is called a *constant head permeameter* and the one used for falling head test is *falling head permeameter*.

2.6.1 Constant Head Permeability Test.

Constant head test is commonly used for coarse-grained materials (clean sands and gravels). In this test, the head of water is maintained on the specimen remains constant throughout the test. The required quantities in this test is quantity of water flowing through the soil Q, the length of specimen, L, head of water, h, and the elapsed time t. because relatively little water will flow through a fine-grained soil and Q would be very small and difficult to measure accurately, this test is not used for materials with low coefficients of permeability (less than about 10 x 10^{-4} cm/s) (Rollings and Rolling Jr., 1996).

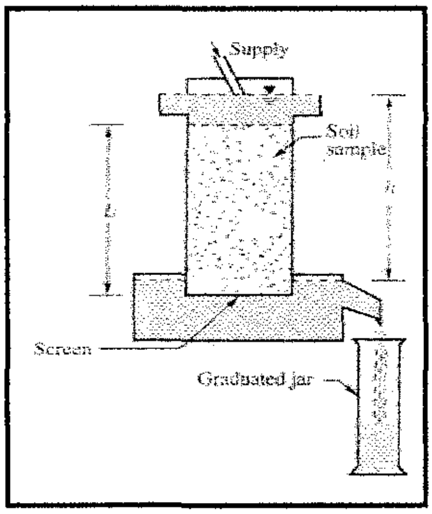


Figure 2.7: Constant head permeability apparatus

The value of κ can be obtained directly from Darcy's Law expressed as follows

$$Q = k\frac{h}{L}At \qquad (2.5)$$

or

$$k = \frac{QL}{hAt} \qquad (2.6)$$

2.6.2 Falling Head Permeability Test

The falling head test is normally conducted on finer-grained soils (fine sands to fat clays). In this test, the head of water is not constant but falls as water flows through the soil mass. The upper surface of the water must remain above the top of the soil. Readings of the remaining head are taken throughout the test and are used to calculate the quantity of water flowing throughout the specimen. The head of water is usually maintained in a small diameter burette or standpipe so that changes in head can be determined easily.

A falling head permeameter is shown in Figure 2.8. The soil sample is kept in a vertical cylinder of cross-sectional area A. a transparent stand pipe of cross sectional area, A is attached to the test cylinder. The test cylinder is kept in a container filled with water, the level of which is kept constant by overflows. Before the beginning of the test the soil sample is saturated by allowing the water to flow continuously through the sample from the stand pipe. After saturation is complete, the stand pipe is filled with water up to a height of h_0 and a stop watch is started.

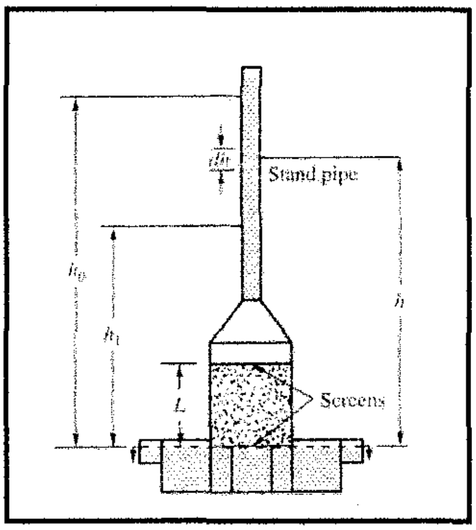


Figure 2.8: Falling head permeability apparatus

In order to obtain the value of hydraulic conductivity, the initial time is assumed to be t0. the time t1 when the water level drops from ho to h1 is noted. The hydraulic conductivity can be determined on the basis of the drop in head (h_0-h_1) and the elapsed time (t_1-t_0) required for the drop. H is the head of water at any time t. the drop by an amount *dh* in time *dt*. The quantity of water flowing through the sample in time dt from Darcy's Law is

$$dQ = \kappa i A dt = k\frac{h}{L}Adt \qquad (2.7)$$

where, i = h/L the hydraulic gradient.

The quantity of discharged can be expressed as

$$dQ = -adh \qquad (2.8)$$

Since the head decreases as time increases, dh is negative quantity in Eq. (2.8). Eq. (2.7) can be equated to Eq. (2.8)

$$-adh = k\frac{h}{L}Adt \qquad (2.9)$$

The discharged Q in time (t1-t0) can be obtained by integrating Eq. (2.7) or (2.8). Therefore, Eq. (2.9) can be rearranged and integrated as follows

$$-a\int_{h_0}^{h_1}\frac{dh}{h}=\frac{kA}{L}\int dt \qquad \text{or} \qquad a\log_e\frac{h_0}{h_1}=\frac{kA}{L}(t_1-t_0)$$

The general expression for κ is

$$k=\frac{aL}{A(t_1-t_0)}\log_e\frac{h_0}{h_1} \qquad \text{or} \qquad k=\frac{2.3aL}{A(t_1-t_0)}\log_{10}\frac{h_0}{h_1} \qquad (2.10)$$

CHAPTER 3
METHODOLOGY/ PROJECT WORK

3.1 Procedure Identification

There are several steps to be followed in order to complete all the tasks throughout the project. The research project started with the preliminary report where it is the initial proposal before students proceed to the next steps. At the end of the project, students will submit the final report which is the project dissertation. The methodology is summarized in the Gantt chart included in Appendix A.

Before the experiment started, some researches have been made in order to understand the behavior of the fly ash and clay as well. As many studies have been made on utilizing fly ash as compaction material, it is important to understand all the procedures that have to be taking into account and later, the results can be compared with the theoretical value. The preparation of sample is done before the experiment and various fraction of fly ash and kaolinite is set.

Two tests that have been conducted are compaction and permeability. The compaction test covers the determination of the dry density of soil passing 2 mm test sieve when it is compacted in a specific manner over a range of moisture contents. The range includes the optimum moisture content at which the maximum dry density for this degree of compaction is obtained. In this test a 2.5 kg rammer falling through a height of 300 mm is used to compact the soil in three layers into a 1L compaction mould. The objective is to determine the relationship between the dry density of soil and its moisture content using the compaction method.

The test procedure for permeability covers the determination of the coefficient of permeability using a falling-head permeameter in which the flow of water through the sample is laminar. The volume of water passing through the soil in a known time is measured, and the hydraulic gradient is measured using the manometer tubes.

At the end of the experiments, the results are analyzed from the dry density-moisture content curve and the value of hydraulic conductivity calculated. Then conclusion is made from the results whether the objective of the project is achieved or not. For the overall experimental procedure, please refer Appendix B.

3.2 Tools Required

The equipment required for compaction test is the BS Standard compaction mould and the standard proctor test equipment. As for permeability, the equipment required is the permeameter cell and a set of manometer tube or glass.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Compaction on Fly Ash and Kaolinite

Compaction is actually a process that will results in an increasing of soil density or unit weight and at the same time, reducing the air volume. The degree of compaction is measured by dry unit weight where it is depend on the moisture content and the compactive effort of the compaction process. Compactive effort is the energy that is imparted to the soil during compaction process and the example of the compactive effort is weight of hammer, number of impacts. For a given compactive effort, the maximum dry unit weight occurs at optimum moisture content. Below is the figure for the theoretical curve of the dry density, ρ_d and moisture content, w relationship.

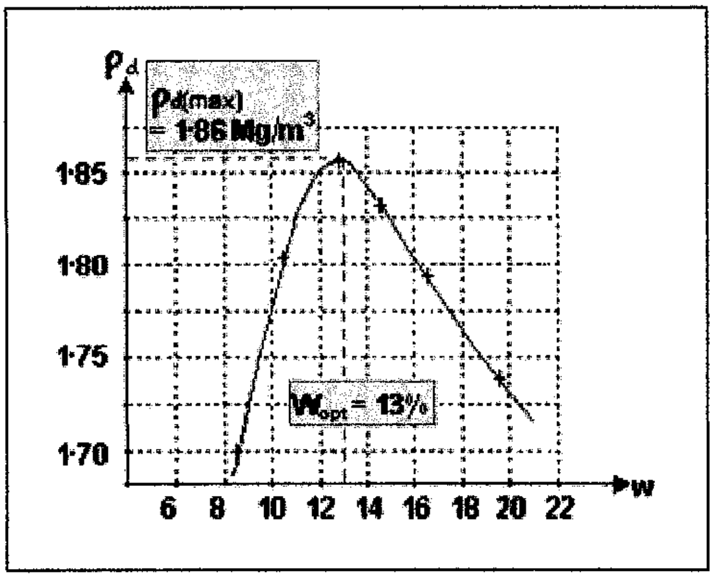


Figure 4.1: Typical dry density-moisture content curve

Is small amount of water is added to a soil that is then compacted, the soil will have a certain unit weight. If the moisture content of the same soil is gradually increased and the energy of compaction is the same, the dry unit weight of the soil will gradually increases. The reason is that water acts as a lubricant between the soil particles and under compaction it helps rearrange the soil particles into a denser state. The increase in dry unit weight will increase the moisture content for a soil. If there is further addition of water to the soil, it will result in reduction of dry unit weight. The reason is because the particles of water take up the spaces that supposedly occupied by solid particles. The moisture content at which the maximum dry unit weight is obtained is referred to as the optimum moisture content.

Compaction test is conducted for four different samples of various fractions;

Table 4.1: Representative sample for compaction test

Sample	Fly ash (%)	Kaolinite (%)
1	100	0
2	40	60
3	30	70
4	20	80

For sample 1 (Figure 4.2), the trend of the dry density and moisture content curve seems to follow the theoretical curve. The maximum dry unit weight obtained is 1.853 Mg/m^3 while the optimum moisture content is 6.2%. The curve is increasing at the beginning for first and second reading with increasing of the w. However for the third reading, w is slightly decreasing but somehow ρ_d is still increasing. Further increasing in ρ_d and w is observed for reading 4, and 5. At this point, the maximum ρ_d is obtained at reading 5. Further addition of water results in decreasing of ρ_d but the moisture content is somehow falling instead of increasing. The decreasing of the w at this point is probably because of the content of water added to the sample is not accurately measured.

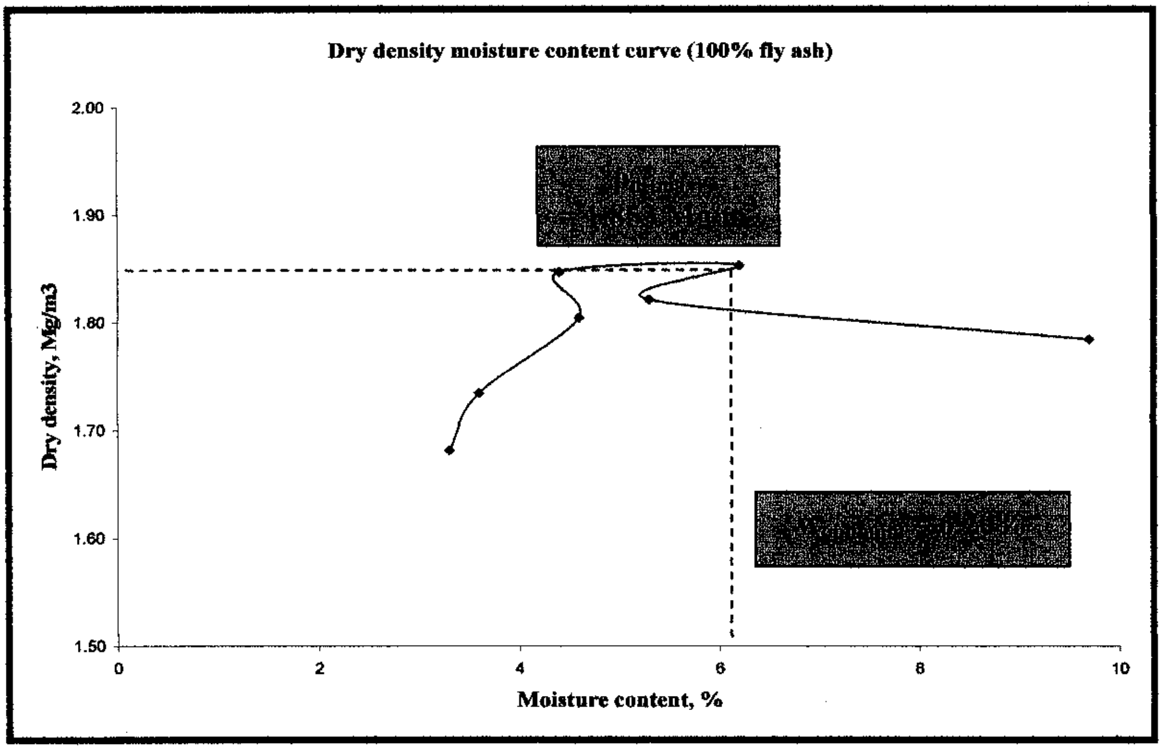


Figure 4.2: Dry density moisture content curve for sample 1

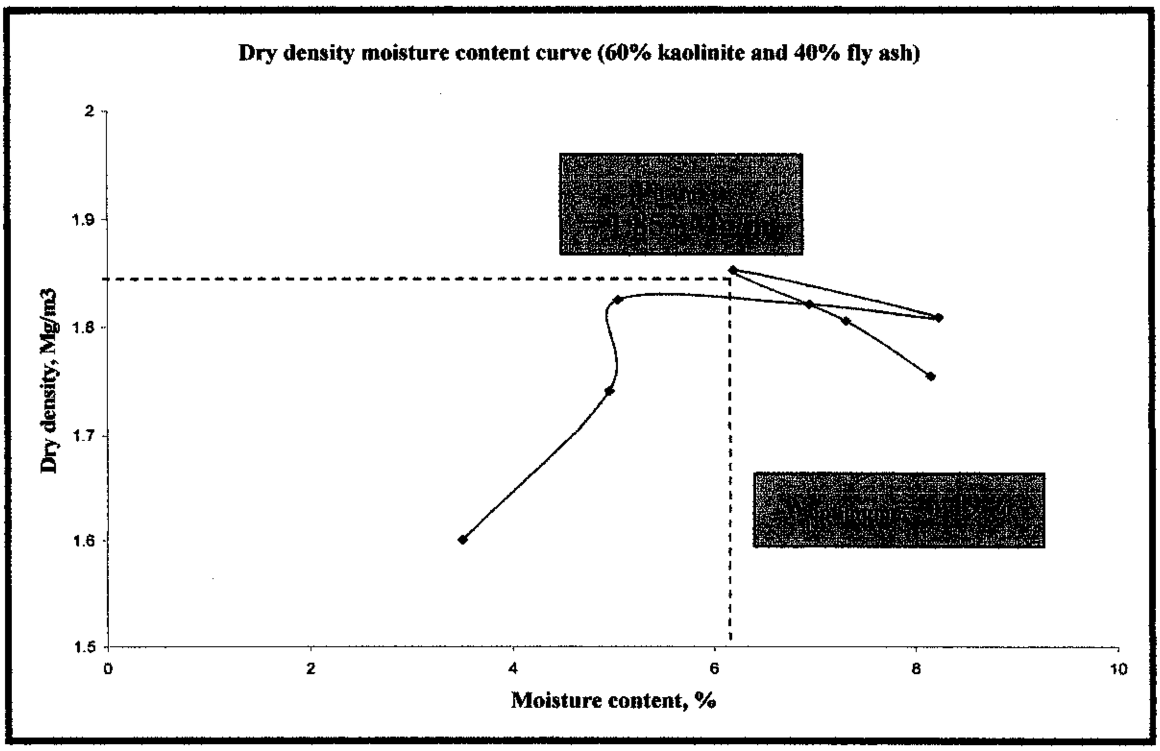


Figure 4.3: Dry density moisture content curve for sample 2

The ρ_d and *w* curve for sample 2 (Figure 4.3) does not seem to be the same as the theoretical one. If refer to reading 4, the ρ_d started to decrease with increasing of *w*. But then, the ρ_d increase to the maximum at reading 5 and starting for this point, the ρ_d continue to fall with the increasing of moisture content. The next curve observed for sample 3 (Figure 4.4) is quite good except for the decreasing of *w* at reading 6 and 7. Overall, the curve is slightly response to the actual relationship of ρ_d and *w*.

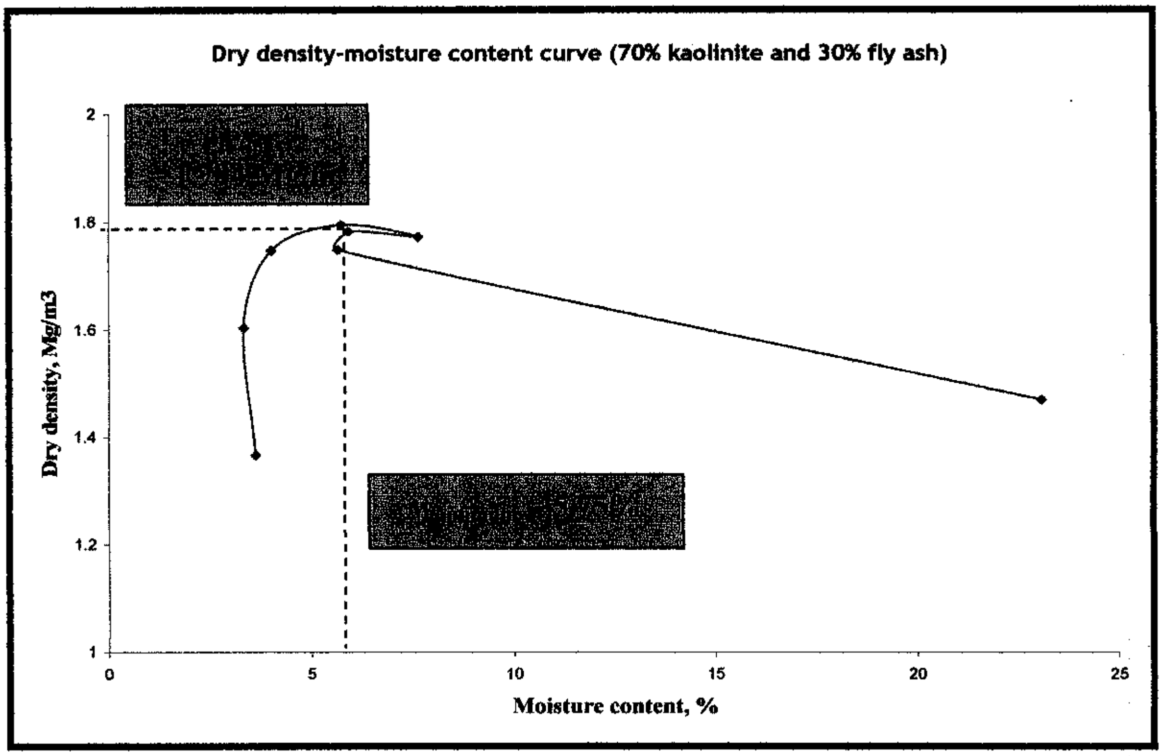


Figure 4.4: Dry density moisture content curve for sample 3

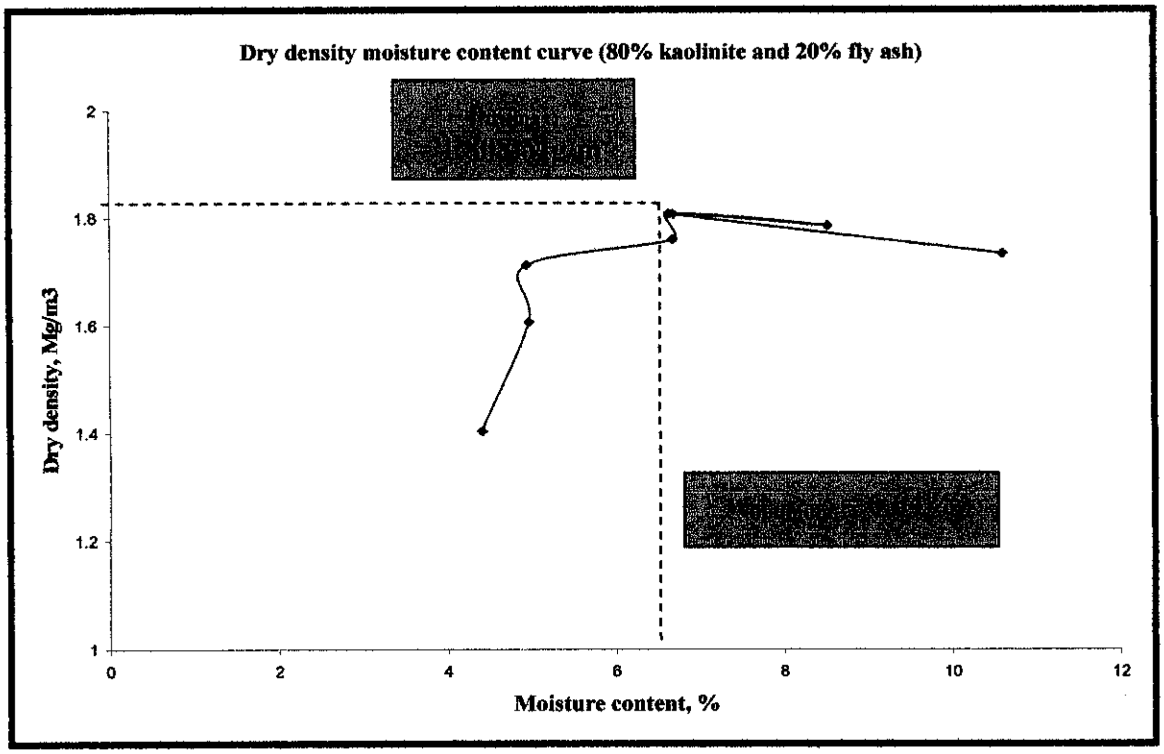


Figure 4.5: Dry density moisture content curve for sample 4

The curve for the sample 4 (Figure 4.5) behave the same as the curve for sample 2. After the point where the ρ_d started to decrease and w is at maximum, the value of ρ_d is increasing at maximum with decreasing of w before the ρ_d continue to decrease. The condition is actually resulted from the decrease in value of moisture content that is suppose to increase from time to time.

Comparing the four different curves, the highest maximum dry density is obtained for the curve of sample 1 and sample 2. However, if refer to the moisture content, the different is slightly lower which is 6.20% for sample 1 and 6.19% for sample 2. It is actually complicated to conclude the best fraction if it is to be utilized for the environmental hydraulic barrier. This is due to the relationship of maximum dry density and moisture content. The highest maximum dry density for experimental value gives the high optimum moisture content value, but the lower maximum dry density gives the lower optimum moisture content value. But if compared to the theoretical trend, sample 3 gives the best trend. Even though the value of maximum dry density is the lowest among four samples, the difference is actually low because value is between 1.79 to 1.85 and the optimum moisture content is the lowest.

Suitable condition for soil to be a hydraulic barrier is when it has lower optimum moisture content and high maximum dry density. "The moisture content of a soil is important because it gives a first indication of the condition or consistency of the material" (Rollings and Rollings Jr., 1996). When the soil has lower optimum moisture content, the dry density or unit weight will actually be high and for hydraulic barrier properties, this is importance to ensure that the barrier is strong and tough. As stated earlier in Chapter 2, the maximum dry unit weight for fly ash ranges from 74.4 lb/ ft3 to 127.5 lb/ft3 and the optimum moisture content ranges from 9-50%. The experimental results for fly ash yields the maximum dry density in this range but lower optimum moisture content than the actual range.

From the experimental results, the decreasing of moisture content is slightly because of loss of soil between first and second weighing and loss of moisture from sample before the first weighing. Besides non accurate or poorly calibrated balance might contribute to loss of moisture content from sample. During the experiment as well, if the water is not thoroughly mixed into the soil, the particle of water may not penetrate well into the soil particle. Hence, some of the soil has high moisture content and on the other parts, the moisture content is slightly lower.

Compaction also affects by few factors in engineering behavior. When moisture content is low, the soil is stiff and difficult to compress. Hence low unit weight and high air contents are obtained. As explained earlier in this chapter, water that acts as a lubricant will cause the soil to soften and more workable resulting in a denser mass, higher unit weights and lower air contents under compaction. The water and air combination tend to keep the particles apart with further compaction and prevent any appreciable decrease in the air content of the total voids. However, dry unit weight of soil will fall ass the moisture content increase.

If the amount of energy applied per unit weight of soil is increased (for all types of soil with all method of compaction), the maximum dry density will also increase correspond to the decreasing of optimum moisture content. The closer packing of soil particles will occur as the amount of compaction increase. With the amount of compaction applied, the shear strength of a soil increases. Value of cohesion and angle of the shearing resistance will become greater as more compaction is applied to the soil. Greater shear strength is attained at moisture content lower than the optimum moisture content.

At low water content, the repulsive forces between particles are smaller than the attractive forces. The particles tend to flocculate in a disorderly array. As water content increases, the repulsion beyond particles increases, permitting the particles to disperse and hence making the particles to arrange themselves in an orderly way. Increasing the compactive effort at any given water content increases the orientation of particles and therefore gives a higher density.

The compaction will decrease the permeability of a soil. If refer to the figure, the decreasing of permeability is corresponds to an increase in molding water content on the dry side of the optimum water content. From Figure 4.6, the hydraulic conductivity normally decreases from high values when compacted at water content less than optimum water content for the soil.

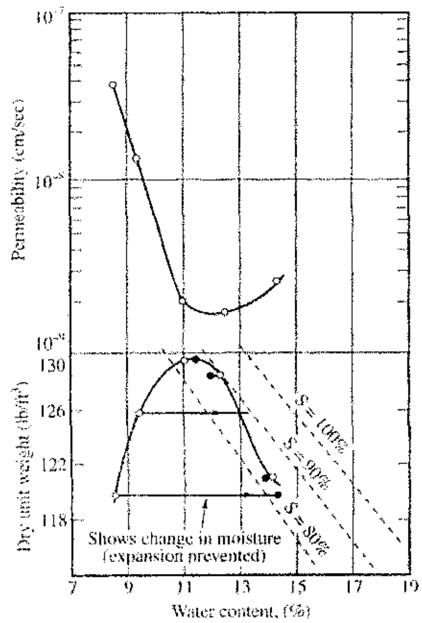


Figure 4.6: Compaction-permeability relationship curve

4.2 Permeability of Fly Ash and Kaolinite

The coefficient of permeability or hydraulic conductivity, κ is actually a measure of the ease with which water flows through permeable material. The hydraulic conductivity is basically related to the compaction of soil where the compaction will result in reducing the hydraulic conductivity value. Low hydraulic conductivity soil is important in geotechnical construction or hydraulic barrier, because the soil would be able to retain the flow of fluid through the barrier.

For this experiment, the aim is to calculate the hydraulic conductivity (or coefficient of permeability). The result obtained from the experiment is tabulated in the table below:

Readings:
Sample Diameter = **9.984cm**
Sample Length = **13.012 cm**

Tube Diameter = **0.601 mm and 0.705 cm**

Tube length = **100 cm**

Table 4.5: Results of hydraulic conductivity test

Sample	Tube Area (cm^2)	Sample Area (cm^2)	h_1 (cm)	h_2 (cm)	Time (s)	κ (cm/s)
1	188.80	286.49	80	40	243	2.45×10^{-2}
3	188.80	286.49	98	83	1270	1.12×10^{-3}
4	221.48	286.49	99	84	1110	1.49×10^{-3}

The experiment for determination of hydraulic conductivity was conducted to sample 1, 3, and 4. However due to time constraint, test for sample 2 could not be conducted. Based on the results, the hydraulic conductivity for sample 1 2.45×10^{-2} cm/s. Based on literature review, the hydraulic conductivity for fly ash range from 1×10^{-7} cm/s to 8×10^{-5} cm/s (Sear, 2001). Sear concludes that the range of the hydraulic conductivity value is relatively low and hence resulted in poor drainage characteristics. From other sources, the hydraulic conductivity of fly ash ranges from 10^{-7} to 10^{-4} cm/s (Oweis and Khera, 1998). Hence the experimental value does not meet the range of hydraulic conductivity value referred from other researchers.

By the addition of kaolinite clay, the hydraulic conductivity value decrease to 1.12×10^{-3} cm/s for sample 3. The typical value of hydraulic conductivity for clay soils ranges from 10-7 to 10-9 cm/s. The experimental value obtained is lower than the typical hydraulic conductivity for clay, might be due to addition of fly ash that is believed to reduce the hydraulic conductivity of soil. The ability of fly ash as fill material in geotechnical construction and hydraulic barrier might have been proven here. Other than that, laboratory hydraulic conductivity values are often lower than those in the field (Oweis and Khera, 1998) as there might be a difference in structure of the prepared sample and undisturbed sample in the field.

The hydraulic conductivity value yields for sample 4 is slightly higher than before which is 1.49 x 10^{-3}. Thus from the results, it could be concluded that sample 3 with the fraction of 30% fly ash is the optimum fraction that suitable for hydraulic barrier with the lowest hydraulic conductivity value. The fraction of fly ash used is tested and conclusion that the ash cannot be used too many or too low can be made.

The inaccurate determination of the hydraulic conductivity of the sample might be affect of some factors. The sample might not be incomplete saturated at the beginning of the test. The sample saturation is one of the factors that have significant effect on determination of hydraulic conductivity. If a soil sample is not completely saturated, its measured hydraulic conductivity will be lower. Normally soil sample will not always yield complete saturation. Various methods for specimen saturation have been used. Compacted samples are sometimes allowed to soak from the bottom and in some instances; vacuum is applied at the top while permitting inflow at the bottom (Oweis and Khera, 1998). Other than that, if leakage of water between side of specimen and container occurs, the flow of water into the specimen will be affected. Hence, saturation of specimen might not be completed.

Non-uniform compaction can results in poor results of hydraulic conductivity value. In compacted soil, the hydraulic conductivity depends on the water content during compaction and method of compaction. If the impact of compaction is greater, then it would results in lower hydraulic conductivity as the particles is pack closer to each other and water cannot easily penetrate into it. With the increasing size of compacted specimen, the hydraulic conductivity will be increasing as well.

Effect of hydraulic gradient would also contribute to the accuracy of hydraulic conductivity value. From Darcy's Law

$$q = kiA$$

where i=h/L which is the hydraulic gradient. Referring from the Darcy's Law, the hydraulic gradient is inversely proportional to the hydraulic conductivity. Meaning, hydraulic conductivity decreases with increasing of hydraulic gradient. High gradient cause migration of soil particles that may cause either clogging in the larger pores or an increase in pore size and pore volume due to erosion. These changes result in hydraulic conductivity values that are not always reliable.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Bentonite is one kind of soil that is widely used in industry especially construction due to its various clay characteristics that make it suitable for the construction purpose. Fly ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases.

The study focuses on how the mixture of both kaolinite and fly ash can be utilized for the purpose of environmental hydraulic barrier. Environmental concern is taken into account as the fly ash contains different kind of heavy metals that could possibly harm human being and the environment as well. Besides the study aim to research on how the waste product is going to benefit the human being.

To achieve the objectives several test has to be made to prove the effectiveness of the mixture on becoming the barrier which are compaction test, shear strength test, and hydraulic conductivity test. However, due to the time constraint and problem regarding with the equipment, the shear strength test could not be conducted.

The results for the compaction test, shows the trend for the curve of dry density and moisture content relationship. However all the fraction that have being tested did not exactly behave similar to the theoretical one. But somehow, the relationship of the dry density and moisture content could be observed where the maximum dry density for the sample is obtained at the optimum moisture content. For compaction test, the best fraction to have the best dry density and optimum moisture is 30% fly ash with 70% kaolinite.

For permeability, the hydraulic conductivity values for three different fractions have been determined. From the results, it can be concluded that as the kaolinite is added to the fly ash, the hydraulic conductivity of the sample become lower. The effect of the fly ash as a fill material is also observed as the value of hydraulic conductivity of the kaolinite clay is slightly lower than the value obtain from the literature review. Thus it is been proven that fly ash can improved the performance of soil by decreasing the hydraulic conductivity value. The lowest hydraulic conductivity obtained fro fraction of 30% fly ash and 70% kaolinite. Hence fraction of 30% fly ash is the optimum fraction suitable for hydraulic barrier.

The study has observed the compatibility of Bentonite and fly ash as an environmental hydraulic barrier. From compaction test method, the trend of the curve cannot possibly distinguish that it is suitable to become a hydraulic barrier. Perhaps several testing should be conducted more to obtained the desired results. For future planning, the ratio of the kaolinite with the fly ash could possibly be added with other element such as cement, instead of using only two elements. The addition of the third element perhaps could help in improving the characteristics of the soil behavior.

The other test which is shear strength is also important to observe the strength of the soil. Besides the shear strength has a relationship with the compaction as well. In the future, perhaps this test will be able to be conducted. For the entire tests, it is also recommended that the test is conducted for several times so that the accuracy of the results could be obtained. Overall, in this project, the compaction and permeability test have been successfully conducted and the soil characteristics have been observed.

REFERENCES:

1. Braja M. Das, 2004, Principles of Foundation Engineering, California State University, Sacramento.
2. Braja M. Das,2000, Fundamentals of Geotechnical Engineering, California State University, Sacramento
3. Marian P. Rollings and Raymond S. Rollings, Jr., 1996, Geotechnical Materials in Construction, Vicksburg, Mississippi
4. Robert B Johnson, and Jerome V. De Graff, 1998, Principles of Engineering Geology, Colorado State University and U.S Forest Service.
5. John N. Cercica, 1995, Geotechnical Engineering Foundation and Design, Youngstown State University.
6. V.N.S Murthy, 2002, Principles and Practices of Soil Mechanics and Foundation Engineering, Bangalore, India
7. Issa S. Oweis and Raj P. Khera, 1998, Geotechnology of Waste Management, Converse Consultant and New Jersey Institute of Technology.
8. N. Dixon, E.J Murray and D.R.V Jones, 1998, Geotechnical Engineering of Landfills, the Nottingham Trent University.
9. T.S. Nagaraj and Norihiko Miura, 2001, Soft Clay Behavior Analysis and Assessment, Indian Institute of Science, Bangalore, and Institute of Lowland Technology, Saga, Japan.
10. R. Kerry Rowe, Robert M. Quigley, and John R. Booker, 1995, Clayey Barrier System for Waste Disposal Facilities, University of Western Ontario, London, and University of Sydney.
11. Lindon K.A. Sear, 2001, the Properties and Use of Coal Fly Ash, United Kingdom Quality Ash Association.
12. V.M Malhotra, 1993, Fly Ash, Silica, Fume, Slag, and Natural Pozzolans in Concrete, America Concrete Institute.
13. K. Wesche, 1991, Fly Ash in Concrete, properties and Performance, The International Union of Testing and Research Laboratories for Materials and Structure.

14. Satish Chandra and Aimin Xu, 1997, Waste Materials Used in Concrete Manufacturing, Chalmers University of Technology Goteborg, Sweden.
15. A John Chandler, 1997, Municipal Solid Waste Incinerator Residues, A.J Chandler and Associates Ltd, Willowdale, Ontario, Canada.
16. Ravindra K. Dhir, Tom D. Dyer, and Kevin A. Paine, 2000, Use of Incinerator Ash, University of Dundee.
17. U. Dayal, R. Sinha and V. Kumar, 1999, Fly Ash Disposal and Deposition, Indian Institute of Technology and Department of Science and Technology, India.
18. Davidson, Leslie. May 2000 <http://fbe.uwe.ac.uk/public/geocal/cwk/compaction/>
19. Sahu, B.K.2001 <http://www.flyash.info/2001/conprod2/90sahu.pdf/>

APPENDICES

Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1. Project Topic being assigned to students	■													
2. Preliminary Research (*preparations of the preliminary reports*) -Introductions, theories, objectives, planning.		■	■											
3. Project Works - Practical and experiments - Researches				■	■	■	■	■						
4. Preparations of the Progress Report								■						
5. Project Works - Practical and experiments - Data analysis and Discussions								■	■	■	■			
6. Preparations of the Dissertation Final Draft												■		
7. Preparations of the Oral Presentation													■	
8. Preparations of the Project Dissertation														■

APPENDIX A: Final year research project Gantt chart

APPENDIX B: Experimental procedure

A) Compaction Test

The apparatus required for this experiment are:

a) BS Standard Compaction Mould.
b) Standard Compaction Rammer, 2.5 kg.
c) 200 mm dia Receiver.
d) 200 mm dia sieve 20.0 mm and 37.5 mm.
e) Spatula, 100 mm blade.
f) Straight edge, 300 mm.
g) Sample tray 910 x 910 x 76 mm.
h) 10 kg x 1g laboratory scale.
i) Proctor/ core cutter extruder.

Below is the procedure for conducting this experiment;

1) The mould is weighed with the base plat attached to 1 g (m_1). The internal dimension is measured to 0.1 mm.
2) The extension is attached to the mould and the mould is placed assembly on solid base.
3) 3 kg of soil (mixture of fly ash and kaolinite) with water content 300 mL is placed in the mould so that when compacted it occupies a little over one-third of the height of the mould body.
4) 27 blows are applied from the rammer dropped from a height of 300 mm above the soil as controlled by the guide tube.
5) Step 3 and 4 is repeated twice more, so that the amount of soil used is sufficient to fill the mould body, with the surface not more that 6 mm proud of the upper edge of the mould body.
6) The extension is removed, the excess soil is striked off, and the surface of the compacted soil is carefully level off to the top of the mould using the straight

edge. Any coarse particles that removed in the leveling process are replaced by finer material from the sample, and the soil is again well pressed in.

7) The soil and mould with base plate is weighed to 1 g (m_2).
8) The soil and mould is removed and placed on the metal tray. Representative sample of the soil is taken for determination of its moisture content.
9) The remainder of the soil is break up, rubbed through the 20 mm test sieve, and mixed with the remainder of the prepared test sample.
10) Suitable increment of water is added (2%) and mixed thoroughly into the soil.
11) Step 3-10 is repeated to give a total of at least five determinations. The moisture content shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

B) Permeability Test

The apparatus required for the experiment are:

a) A permeameter cell.
b) A vertical adjustable reservoir tank.
c) A set of manometer tubes of glass or transparent plastics.
d) A pinch cock on the flexible tubing adjacent to each gland.
e) Filter material of a suitable grading for placing adjacent to the perforated plates at each end of the permeameter.
f) Measuring cylinders of 100 mL, 500 mL, and 1000mL capacity.
g) A stop watch readable to 1s.
h) A balance readable to 1g.

The procedures are:

Initial Procedure:

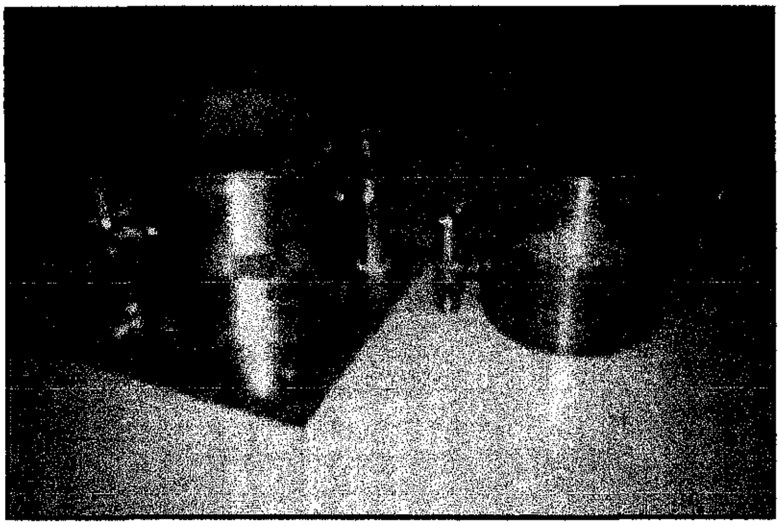
1) The internal diameter of the permeameter cell is measured at several places and the average diameter is recorded to the nearest 1mm (D).

2) The distance between each manometer gland and the next along the same vertical line is measured to the nearest 1mm.
3) The apparatus is assembled such as in figure 2.6.
4) The length of the sample is measured and the average measurement L, (mm) is recorded.
5) The control valve is closed.
6) The inlet reservoir is set at a little level above the top of the permeameter cell and the supply valve is opened. The manometer tube pinch cocks is opened one by one. As water flows into the manometer tubes, the flexible tubing is checked to ensure that no air is strapped in it. The water in all tubes shall reach the level of the reservoir surface. The permeameter cell is ready for test under the normal condition of downward flow.

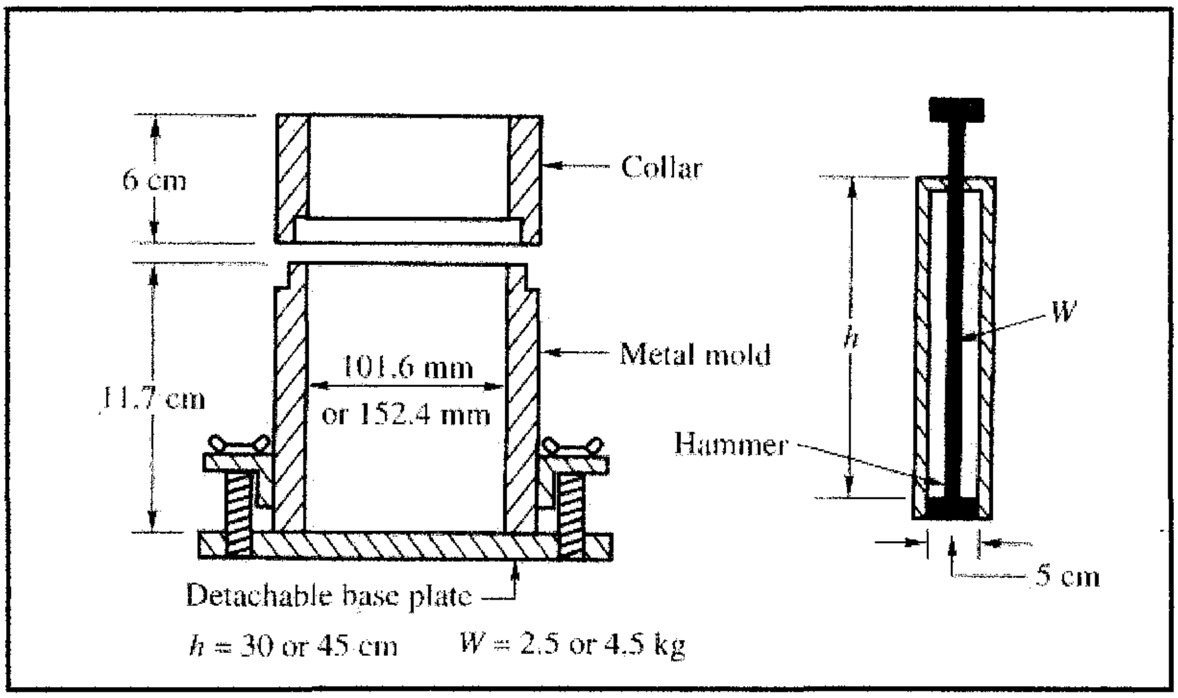
Test Procedure for Downward Flow of Water through the Sample:

1) The height of the inlet reservoir is adjusted to a suitable level with regard to the hydraulic gradient to be imposed on the sample.
2) The control valve at the base is opened to produce flow through the sample under a hydraulic gradient appreciably less than unity. The water level in the manometer tube is allowed to become stable before starting the test measurements.
3) The height of the initial water sample in the manometer tube is recorded, and timer is started until the level reach at certain point. Time taken for the water level reach the point from the initial reading is recorded. Step 1 to 3 is repeated until consistent readings are obtained.

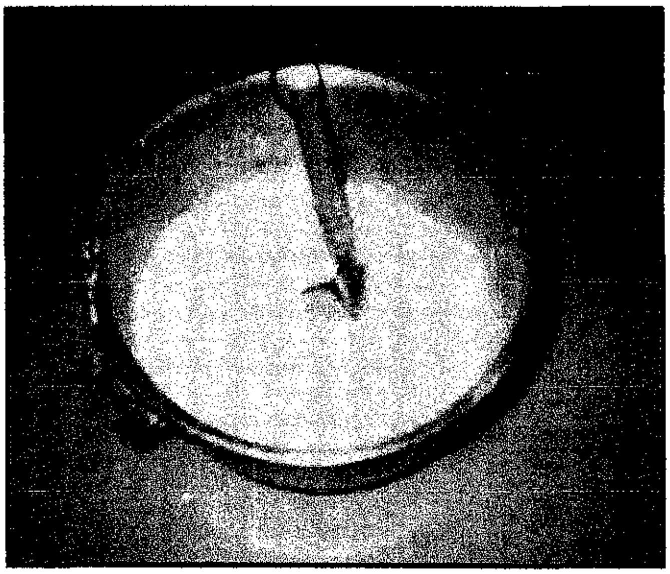
APPENDIX C: Compaction test apparatus and equipment



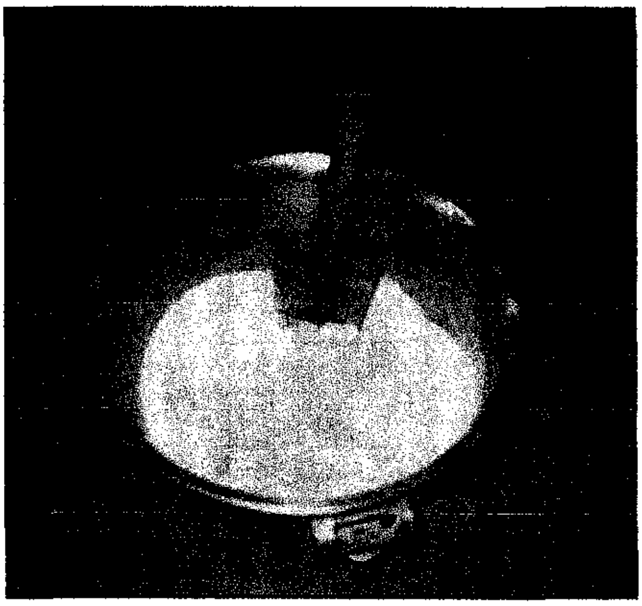
BS Standard Compaction Mould with base



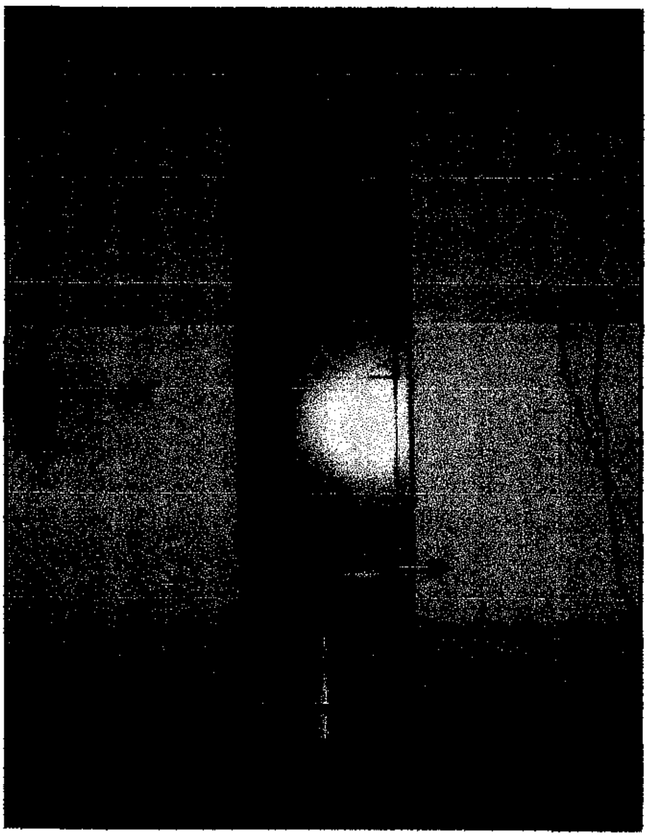
BS Standard Compaction Mould with base and hammer (dimension)



Kaolinite



Mixture of kaolinite and fly ash



Proctor test equipment

APPENDIX D: Specification for standard proctor compaction test

	Procedure		
Item	**A**	**B**	**C**
Diameter of mould	4 in. (101.6 mm)	4 in. (101.6 mm)	6 in. (152.4 mm)
Height of mould	4.584 in. (116.43 mm)	4.584 in. (116.43 mm)	4.584 in. (116.43 mm)
Volume of mould	0.0333 ft^3 (944 cm^3)	0.0333 ft^3 (944 cm^3)	0.075 ft^3 (2124 cm^3)
Weight of hammer	5.5 lb (2.5 kg)	5.5 lb (2.5 kg)	5.5 lb (2.5 kg)
Height of drop	12 in. (304.8 mm)	12 in. (304.8 mm)	12 in. (304.8 mm)
No. of layers	3	3	3
Blows per layer	25	25	56
Energy of compaction	12,375 ft-lb/ ft^3 (600 kN-m/m^3	12,375 ft-lb/ ft^3 (600 kN-m/m^3	12,375 ft-lb/ ft^3 (600 kN-m/m^3

APPENDIX E: Sample calculation

A) Compaction Test

1) Calculate the internal volume, V (in m^3), of the mould

$$V = \pi\left(\frac{D^2}{4}\right)\times L$$

Where,

V = volume in m^3

D = internal diameter of mould in m

L = height of mould in m

$$V = \pi\left(\frac{0.115^2}{4}\right)\times 0.105$$

$$V = 9.96\times10^{-4} m^3 / 996mL$$

2) Calculate the bulk density, ρ (in Mg/m3), of each compacted specimen from the equation:

$$\rho = \frac{m_2 - m_1}{V}$$

Where,

m_1 = the mass of mould and base plate in g

m_2 = the mass of mould, base plate and compacted soil in g

$$\rho = \frac{6820 - 5050_1}{996} = 1.78g/mL\left(1.78Mg/m^3\right)$$

3) Calculate the moisture content, w of each compacted specimen

$$w = \frac{mass\_of\_wet\_specimen - mass\_of\_dry\_specimen}{mass\_of\_dry\_specimen}\times 100$$

$$w = \frac{(53.99 - 50.12)g}{50.12} \times 100 = 7.72\%$$

4) Calculate the dry density, ρ_d (in Mg/m3), of each compacted specimen from the equation:

$$\rho_d = \frac{100\rho}{100 + w}$$

Where,

w = moisture content of the soil in %

$$\rho_d = \frac{100 \times 1.78}{100 + 7.72} = 1.65 Mg/m^3$$

B) Permeability Test

Determinations of hydraulic conductivity for 100% fly ash:

Using equation

$$k = \frac{2.303aL}{At} \log \frac{h_1}{h_2}$$

Where

a = tube area

d = tube diameter (0.601 cm)

h = tube length (100 cm)

L = sample length (13.012 cm)

D = sample diameter (9.984 cm)

A = sample area

t = time (243s)

h_1 = initial head (80 cm)

h_2 = final head (40 cm)

Tube area

$$a = 2\pi r\left(\frac{d}{2}\right)h$$

$$a = 2\pi\left(\frac{0.601cm}{2}\right)100cm$$

$=188.80\ cm^2$

Sample area

$$A = 2\pi\frac{D^2}{4} + 2\pi\frac{D}{2}L$$

$$a = 2\pi\left(\frac{9.984^2\,cm}{4}\right) + 2\left(\frac{9.984}{2}\right)\times 13.012cm$$

$=286.49mm^2$

$$k = \frac{2.303\times 188.80\times 13.012}{286.49\times 243}\log\frac{80}{40}$$

$= 2.45 \times 10^{-2}$ cm/s

APPENDIX F: Summary of calculation results

Table 1: Compaction results sample 1

Test Number	1	2	3	4	5	6	7
m_1 (g)	6270	6270	6270	6270	6270	6270	6270
m_2 (g)	8000	8060	8150	8190	8230	8180	8220
Mass of compacted soil (m_1-m_2) (g)	1730	1790	1880	1920	1960	1910	1950
Bulk density, ρ (Mg/m3)	1.74	1.80	1.89	1.93	1.97	1.92	1.96
Moisture content %	3.3	3.6	4.6	4.4	6.2	5.3	9.7
Dry density, ρ_d (Mg/m3)	1.68	1.73	1.80	1.85	1.85	1.82	1.78

Table 2: Compaction results for sample 2

Test Number	1	2	3	4	5	6	7	8
m_1 (g)	5050	5050	5050	5050	5050	5050	5050	5050
m_2 (g)	6700	6870	6960	6990	7000	7010	6980	6940
Mass of compacted soil (m_1-m_2) (g)	1650	1820	1910	1940	1950	1960	1930	1890
Bulk density, ρ (Mg/m3)	1.657	1.827	1.918	1.948	1.958	1.968	1.938	1.898
Moisture content %	3.51	4.96	5.05	6.94	8.22	6.19	7.31	8.15
Dry density, ρ_d (Mg/m3)	1.601	1.741	1.826	1.821	1.809	1.853	1.806	1.755

Table 3: Compaction results for sample 3

Test Number	1	2	3	4	5	6	7	8
m_1 (g)	5050	5050	5050	5050	5050	5050	5050	5050
m_2 (g)	6460	6700	6860	6940	6950	6930	6890	6850
Mass of compacted soil (m_1-m_2) (g)	1410	1650	1810	1890	1900	1880	1840	1800
Bulk density, ρ (Mg/m3)	1.426	1.657	1.817	1.898	1.908	1.886	1.847	1.807
Moisture content %	3.62	3.32	4.02	5.75	7.65	5.92	5.66	23.07
Dry density, ρ_d (Mg/m3)	1.366	1.603	1.747	1.794	1.772	1.782	1.748	1.468

Table 4: Compaction results for sample 4

Test Number	1	2	3	4	5	6	7	8
m_1 (g)	5050	5050	5050	5050	5050	5050	5050	5050
m_2 (g)	6510	6730	6840	6920	6970	6980	6970	6960
Mass of compacted soil (m_1-m_2) (g)	1460	1680	1790	1870	1920	1930	1920	1910
Bulk density, ρ (Mg/m3)	1.466	1.687	1.797	1.878	1.928	1.938	1.928	1.918
Moisture content %	4.41	4.97	4.94	6.68	6.64	8.52	6.69	10.60
Dry density, ρ_d (Mg/m3)	1.404	1.607	1.713	1.760	1.808	1.786	1.807	1.734

APPPENDIX G: Kaolin data

	General Kaolinite Information
Chemical Formula:	Al2Si2O5(OH)4
Composition:	Molecular Weight = 258.16 gm
	Aluminum 20.90 % Al 39.50 % Al_2O_3
	Silicon 21.76 % Si 46.55 % SiO_2
	Hydrogen 1.56 % H 13.96 % H_2O
	Oxygen 55.78 %
Empirical Formula:	$Al_2Si_2O_5(OH)_4$
Locality:	Kao-Ling, China.
Name Origin:	Named after the locality.

Sources: www.mineral.com