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Effect of Compaction conditions on the Hydraulic and Compressibility Behaviour of Fly Ash - Bentonite mixtures

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Abstract:*Landfill liners are used for the efficient containment of waste materials generated from different sources. In the absence of impermeable natural soils, compacted mixtures of expansive soil and sand have found wide applications as landfill liners. It is to be noted that, in case, these materials are not locally available, the cost of the project increases manifold due to its import from elsewhere. Also, sand has become an expensive construction material due to its limited availability. With this in view, the present study attempts to explore a waste material such as fly ash as a substitute for sand. The major objective of this study is to maximize the use of fly ash for the said application. Different criteria for evaluating the suitability of material for landfill liner have been proposed in this study. However, further investigations are required with different source of fly ash and alternative material to generalize the findings.*

Keywords: *LandfillLiner, Design Criteria, Fly ash, Hydraulic Conductivity, Compressibility.*

I. Introduction

One of the major environmental problems is safe disposal of solid waste material such as municipal waste, industrial waste, hazardous waste and low level radioactive waste (Hanson et al., 1989). The waste materials are generally placed in a confinement termed as landfills. Landfills are usually lined with an impermeable material to prevent contamination of the surrounding soil and underlying groundwater by waste leachate. Thus, the most significant factor affecting its performance is hydraulic conductivity (Daniel et al., 1984). Compacted clay liners are widely used in solid waste landfills due to their cost effectiveness and large capacity of contaminant attenuation. In the absence of impermeable natural soils, compacted mixtures of expansive soil and sand have found wide applications as contaminant barriers (Daniel and Wu, 1993). It is to be noted that, in case, these materials are not locally available, the cost of the project increases manifold due to its import from elsewhere. Also, sand has become an expensive construction material due to its limited availability. Therefore, it is of paramount importance to research new materials for landfill liner construction without compromising on the primary objective of efficient waste containment. The improved efficiency refers to better performance in terms of containment or sustainability of containment (Shackelford et al., 2005).

In this study, effort has been made to evaluate the usefulness of fly ash as a liner material. Fly ash is a waste produced from coal-fired power generating stations and is readily available and need to be safely disposed. A large amount of the fly ash produced is disposed in monofills (Nhan et al., 1996). The disposal of fly ash is becoming expensive each year due to the large area of land needed for its disposal. One of the amicable solutions to the problem is reuse of fly ash for some meaningful applications. Thepozzolanic and self-hardening properties of fly ash have naturally made it a very attractive material for use in a variety of constructionapplications such as fills, concrete, pavements, grouts etc. (Nhan et al., 1996). However, the utility of fly ash for geoenvironmental projects such as landfill liner material has not been explored systematically.

With this in view, the present study purports to examine the suitability of fly ashas a landfill liner material. The major objective of this study is to maximize the use of fly ash for the liner application. Therefore, different fly ash-cement and fly ash-bentonite mixes weresubjected to hydraulic conductivity, Shear strength and compressibility evaluation. Different criteria for evaluating the suitability of material for landfill liner have been proposed in this study. Based on the results, 90% fly ash+10% cement and 95% fly ash+5% cement mixes compacted with 5% wet of OMC and MDD condition satisfies the hydraulic conductivity criteria for landfill liner. However, further investigations are required with differentsource of fly ash and expansive soil to generalize the findings.

II. Literature Review

The following section deals with a comprehensive literature review on different criteria used in designing landfill liners, different studies related to fly ash, fly ash-cement and fly ash-bentonite mixtures (compressibility, permeability, strength, etc.) and permeability determination for non plastic soils. Several researchers have proposed different criteria used indesigning liners, investigated the factors influencing them. Some of these studies are presented below, followed by the summary and critical appraisal of the reviewed literature.

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Review on different type of Landfill liners

Landfill liner:A landfill liner, or composite landfill liner, is intended to be a low permeable barrier, which is laid down under engineered landfill sites. Until it deteriorates, the liner retards migration of leachate, and its toxic constituents, into underlying aquifers or nearby rivers, causing spoliation of the local water.

In modern landfills, the waste is contained by landfill liner system. Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities.

Modern landfills generally require a layer of compacted clay with a minimum required thickness and a maximum allowable hydraulic conductivity, overlaid by a high-density polyethylenegeomembrane.

Purpose of liner: The primary purpose of the liner system is to isolate the landfill contents from the environment and therefore, to protect the soil and ground water from pollution originating in the landfill. The greatest threat to ground water posted by modern landfill is leachate. Landfills liners done to prevent the uncontrolled release of leachate into the environment.

Solid waste in landfills has become a very difficult problem, so provide the Landfills. The liner system is the main component of landfill site to protect leachate. Leachate consisting of heavy metals, due this pollution of ground water, surface water and soil contaminant takes place.

The liner is the most important element of a waste disposal landfill. It protects the environment from harm. It acts as a barrier to prevent or minimize the migration of pollutants into the environment from the landfill. Thus, the most significant factor affecting its performance is hydraulic conductivity (Daniel et al., 1987, 1990). Liners are commonly composed of compacted natural inorganic clays or clayey soils. Clayey soils are used for constructing landfill liners because they have low hydraulic conductivity and can attenuate inorganic contaminants. If natural clay or clayey soils are not available, kaolinite or commercially available high-swelling clay (bentonite) can be mixed with local soils or sand.

Many developed countries contribute more waste. These wastes are protected by providing landfills. Modern landfills are highly containment systems, so engineers to do design for minimize the impact of solid waste (municipal solid waste, industrial waste, hazardous waste, radioactive waste, and construction and demolition debris) on the environment and human health. These waste forms leachate and this consisting of heavy metals due this pollution of ground water, surface water and soil contaminant so provide landfill liner system.

Special lining materials (Bentonite) should be used for the construction of surface caps and bottom liners because of water permeability and physical/chemical resistance. Synthetic liners are sufficiently impermeable for water but durability may be a problem. For that reason natural lining materials may be preferred, provided they can satisfy the permeability requirements. Laboratory studies have indicated that this low conductivity limit can be satisfied quite well with swelling clay materials like bentonite (Hoeks& Agelink 1982) and saturated conductivity should be as low as 5×10^{-10} m/sec to reduce the leakage of water to less than 50mm/year.

Composition of leachate: Leachate is the liquid that results from rain, snow, dew, and natural moisture that percolates through the waste in landfill, while migrating through waste, the liquid dissolves salts, picks up organic constituents (Ivona Skultetyova,2009), and this contain heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), Zinc (Zu), Nickel (Ni) etc**.** and composition varies due to a number of different factors such as the age and type of waste and operational practices at the site. The leachate consists of many different organic and inorganic compounds that may either dissolve or suspended. The conditions within a landfill vary over time from aerobic to anaerobic thus allowing different chemical reactions to take place. Most of landfill leachate has high BOD, COD, ammonia, chloride, sodium, potassium, hardness and boron levels.

Landfill components and functions:

- A ‘liner system’ at the base and sides of the landfill which prevents migration of leachate or gas to the surrounding soil.
- A ‘leachate collection and control facility’which collects and extracts leachate from with in and from the base of landfill and the treats the leachate.
- A ‘gas collection and control facility’(optional for smalllandfills) which collects and extracts gas from with in and from the top of the landfill and then treats it or uses it for energy recovery.
- A ‘final cover system’ at the top of the landfill which enhances surface drainage, prevent infiltrating water and supports surface vegetation.
- A ‘surface water drainage system’ which collects and removes all surface runoff fromm the landfill site.
- An ‘environmental monitoring system’ which periodically collects and analysis air, surface water, soil gas and ground water samples around the landfill site.

- A ‘closer and post closersystem’which lists the top 6 components that must be taken to close and secure a landfill site once the filling operation completed and the activities for long term monitoring, operation and maintenance of the complete landfill. (urbanindia.nic.in)

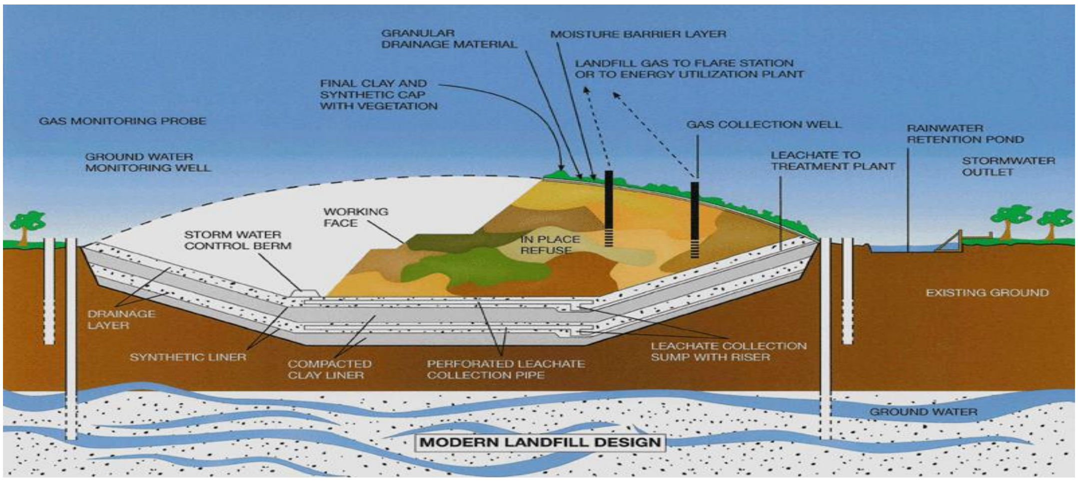

Figure 2.1: Cross section of landfill components (Reference)

Society produces many different solid waste that pose different threats to environment and community health. Different disposal sites are available for those different types of waste. The potential threat posed by waste determines the type of liner system required for each landfill.

Type of liners

The different types of architecture used for landfill liners are as follows: single liner (clay or geomembranes), single composite (with or without leak control), double liner, and double composite liner.

Single liner:

A single liner system includes only one liner, which can be either a natural material (usually clay), Figure 2a, or a single geomembranes, Figure 2b. This configuration is the simplest, but there is no safety guarantee against the leakage, so a single liner may be used only under completely safe hydro geological situations.

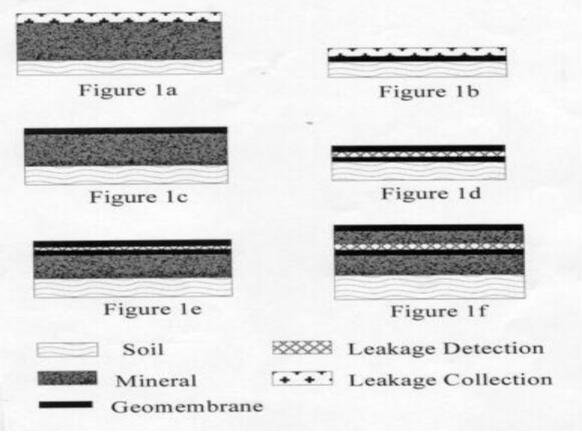

Figure 2.2 Cross section of different liner system (Reddy, 1999)

A leachate collection system, termed as LCS (soil or geosynthetic drainage material), may beplaced above the liner to collect the leachate and thus decrease the risk of leakage.

Single composite:

A single composite liner system, Figure 2c, includes two or more different low-permeability materials in direct contact with each other. Clayey soil with a geomembranes is the most widely recommended liner.

Geotextile - Bentonite composites are often used as substitutes for mineral liners (liners usingstones or rocks as material) for application along slopes, even though many engineers prefer clay. One of the main advantages of composite liners over single liners is the low amount of leakage through the liner, even in the presence of damage, such as holes in the geomembranes.

Double liner:

A double liner system, Figure2d, is composed of two liners, separated by a drainage layer called the leakage detection system. A collection system may also be placed above the top liner. Double liner systems may include either single or composite liners. Nowadays, regulations in several states require double liner systems for MSW landfills. A clay layer may be placed under a double liner made of membranes as shown in Figure 2e.

Double composite liner:

Double composite liners are systems made of two composite liners, placed one above the other, Figure 2f. They can include a LCS above the top liner and an LDS between the liners. Obviously, the more components in the liner system, the more efficient are the system against leakage.

Leachate collection system (LCS):

The Main advantage is to decrease the possibility of leakage through the clay. So it is always possible to place a leachate collecting system above the membrane.

Leachate detection system (LDS):

The main role this system is to detect, collect, and remove liquids between the two liners. So it is separate the two low permeable materials which form of two single liners separated by layer of permeable material (sand and gravel or geonet). It is placed between clay and geomembrane (Ivona, 2009; Reddy and Boris (1999))Kerry, Hughes et al.).

National regulations for landfill liners in various European countries:

Figure 2.3 shows a comparative view of typical sections for the base sealing of a landfill liner for domestic waste in France, Netherlands, Austria, Germany, Switzerland, and European Union (EU)-Proposal.

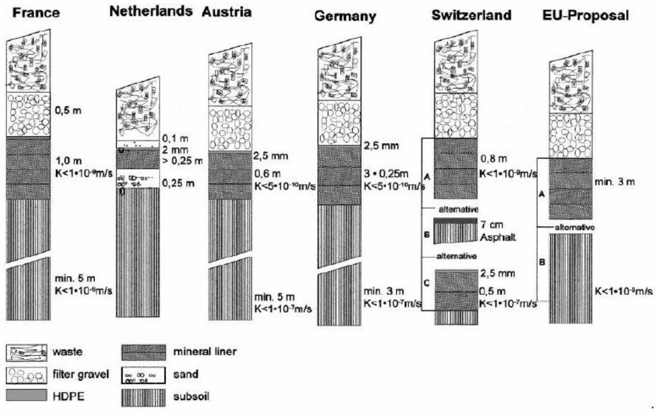

Figure 2.3 National regulations of landfill liners (Dietrich, 2002)

Liner components and functions:

IvonaSkultetyova (2009) has explained about the liner components and its functions.

Clay:

- It is a cohesive soil, have very finer material and contain low hydraulic conductivity. For liners hydraulic conductivity is most important parameter.
- The thickness of clay layer is depends on characteristics of the underlying geology and installation of liner type.
- The effectiveness of clay liners can be reduced by fractures induced by freeze-thaw cycles, drying out, and the presence of some chemicals (salts from leachate).

Geomembranes:

- These liners are constructed from various plastic materials, including polyvinyl chloride (PVC) and high-density polyethylene (HDPE), Mostly HDPE used.
- This material is strong, resistant to most chemicals, and is considered to be impermeable to water. Therefore, HDPE minimizes the transfer of leachate from the landfill to the environment.
- The thickness of geomembranes used in landfill liner construction is regulated by state laws.

Geotextile:

- It is used to prevent the movement of soil and refuse particles into the leachate collection system and to protect geomembranes from punctures. These materials allow the movement of water but trap particles to reduce clogging in the leachate collection system.

Geosynthetic Clay Liner (GCL):

- These liners consist of a thin clay layer (4 to 6 mm) between two layers of a geotextile. These liners can be installed more quickly than traditional compacted clay liners, and the efficiency of these liners is impacted less by freeze-thaw cycles.

Geonet:

- It is used in landfill liners in place of sand or gravel for the leachate collection layer.
- Sand and gravel are usually used due to cost considerations, and because geonets are more susceptible to clogging by small particles. This clogging would impair the performance of the leachate collection system.
- These are conveying liquid more rapidly than sand and gravel.

Review on different criteria used in designing liners

Matthew (1999) has explained placing of liners on site, the important variables in the construction of soil liners are the compaction variables: soil water content, type of compaction, compactive effort, size of soil clods, and bonding between lifts.

The acceptable zone is bounded between the line of optimums and the zero air voids curve. During compaction most important factors are moisture content and dry density values and can be greatly affect a soil's ability to restrict the transmission of flow. Fig 2.4 shows the influence of moulding water content on hydraulic conductivity of the soil. The lower half of the diagram is a compaction curve and shows the relationship between dry density and water content of the soil. The smallest hydraulic conductivity of the compacted clay soil usually occurs when the soil is moulded at moisture content slightly higher than the optimum moisture content.

Ideally, the liner should be constructed when the water content of the soil is wet of optimum. Uncompacted clay soils that are dry of their optimum water content contain dry hard clods that are not easily broken down during compaction. After compaction, large, highly permeable pores are left between the clods. In contrast, the clods in wet uncompacted soil are soft and weak. Upon compaction, the clods are remolded into a homogeneous relativelyimpermeable mass of soil. Low hydraulic conductivity is the single most important factor in constructing soil liners. In order to achieve that low value in compacted soil, the large voids or pores between the clods must be destroyed. Soils are compacted while wet because the clods can best be broken down in that condition.

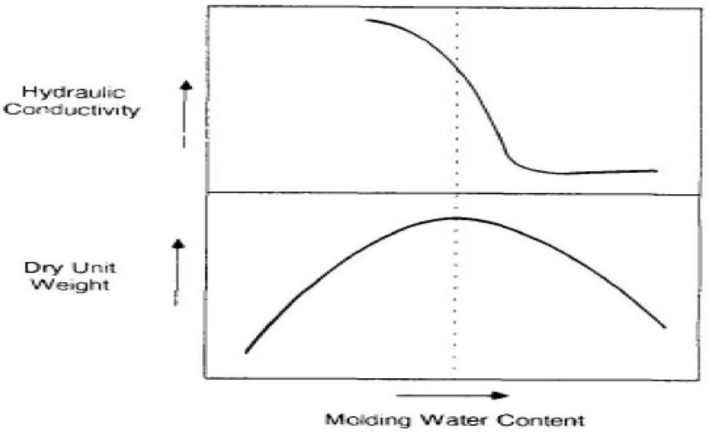

Figure 2.4 Variation of hydraulic conductivity,dry density and molding water content US-EPA (United states of environmental protection agency, 1989).

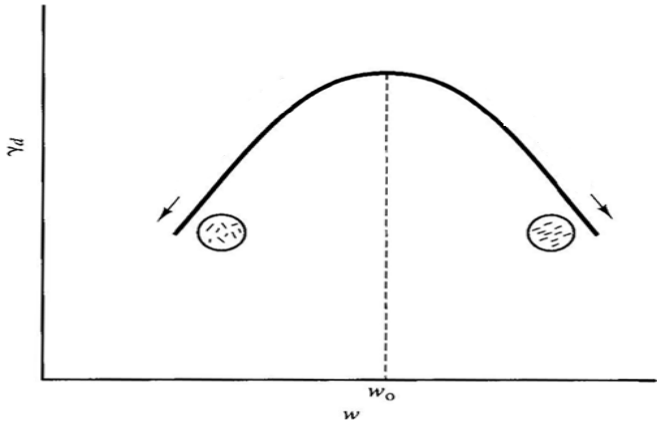

Figure: 2.5 Variation of dry density (γ_d) and moulding water content (w) with structure

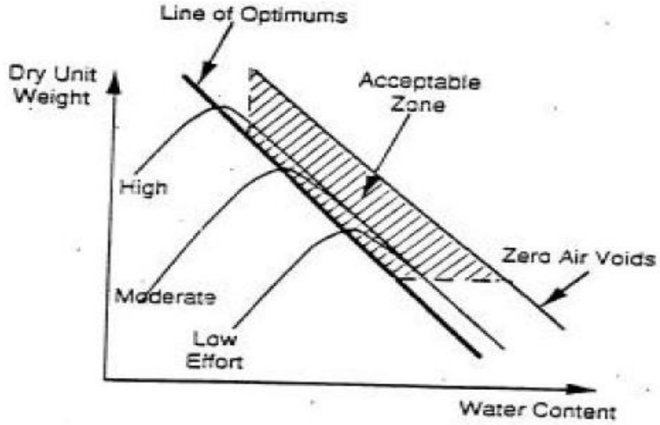

Figure 2.6 Acceptable zone of dry density and moisture content with compactiveefforts (Cawley 1999)

There are four types of liner design

Standard design:

- In case of standard design we need minimum 4 ft. thick layer of re-compacted clay or other material with permeability of less than 10^{-7} cm/sec.
- Finished liner must be sloped at ≥ 2%.
- This method is not suitable where large quantity of liner material is not easilyavailable on site or nearby site.

Alternative design:

This is the most desirable liner system because of the reduced permeability and thickness requirement. It is feasible for areas with no available silt or clay material. The added cost of synthetic liner is often out-weighted by cost reduction in clay material.

- Alternative design provides a liner which consists of two liners. The thickness ofupper liner should be ≥ 50 mm and for lower liner ≥ 2 ft.
- Upper liner should be made of synthetic material and lower liner of compacted clay. Thehydraulic conductivity (k) of lower liner should be $\leq 10^{-6}$ cm/sec.
- The finish layer should be sloped at ≥ 2%.

Equivalent design:

Equivalent design is consist of some specific criteria like double liner and very deep naturaldeposits of material with higher permeability than the standard case. It should be approved and justify for the situation of the particular site.

Arid design:

In that case liners are not required in arid areas like Rajasthan. In those places annual rainfall is <2 inch.

Whether it is arid area or not for all four design method we have to check for liner system need or not before design.

Daniel and Yung (1993) have conducted a series of laboratory on a clayey soil from a site in Texas to define ranges of water content and dry unit weight at which compacted test specimens would have (i) low hydraulic conductivity (10^{-9} m/s) (ii) minimal potential for shrinkage upon drying (4%) and (iii) adequate shear strength (200 k Pa). The importantobservations are stated below:

- This study illustrates that it is possible to compact clayey sand to a low hydraulic conductivity and simultaneously produces a compacted material with minimal potential toshrink and crack when desiccated.
- It is observed from this study that the engineer has at least four ways to deal with theproblem of desiccation of low hydraulic conductivity ,compacted soil barriers

1) Use clayey sands, which combine the attributes of low hydraulic conductivity and low shrinkage upon drying.
2) Specify a range of compaction water content and dry unit weight that ensures bothlow hydraulic conductivity and low shrinkage potential.
3) Rely on large compressive stress which would help to close preexisting desiccationcracks and prevent the development of new ones.
4) Protect the soil from drying by placing a thicker layer of topsoil or placement ofgeomembranes above, below or above and below the soil barrier to minimize drying.

Elsbury et al., (1990) have developed a list of factors that can influence thepermeability of compacted soil liners and the findings are:

- It is observed from this study that the seepage through the liner was predominantly through the macro voids between the soil clods and along the inter lift boundary, notthrough the fine pores between soil particles within the clods.
- The thickness of liner affects the overburden stress and length of seepage paths.
- Two most important factors that led to the failure to destroy the soil clods and to bond thelifts were 1) using a relatively light roller and 2) compacting the soil at a moisture contentdry of the lowest moisture content at which the roller can remold the clods.
- It is observed from this study that the in-situ density and permeability showed very poorcorrelation with laboratory permeability tests. A similar poor correlation was found with the initial degree of saturation of the soil.

Scope of the study

Based on the critical appraisal presented above, the following scope of the study hasbeen defined:

1) Determination of compaction, strength, compressibility and permeability characteristicsof fly ash-expansive soil mix.
2) To develop a new setup for low permeability soil such as bentonite.
3) Evaluating the suitable fly ash-expansive soil mix that can be used as landfill liner.
4) Propose different combination of parameters as design criteria for fly ash-expansive soilmix

III. Materials And Methods

Fly ash (FA)

The fly ash used in this present study is an industrial by-product of obtained from the Farakka thermal power plant located in West Bengal. The ash was obtained from electrostatic precipitator (ESP). The fly ash obtained from this plant has CaO content in the range of 1.72% to 2.6% (Pandian et al. 1998) and, it thus can be classified F type as per ASTM C 618-99.

Bentonite (B)

A locally available bentonite with a liquid limit value of 423% was used for this study.

Characterization tests

Moisture content (IS: 2720 Part 2)

The standard method (oven-drying method) was used to determine the moisture contents of samples. Small, representative specimens obtained from large bulk samples were weighted and then oven-dried at 110^0C for 24 hours. The sample was then reweighted to obtain the weight of moisture. The difference in weight was divided by the weight of the dry soil, giving the water content on dry weight basis.

Specific gravity (IS: 2720 Part 3)

The specific gravity value of soil solids was determined by placing a known weight of oven-dried soil in a density bottle, and then filled up with water. The weight of displaced water was then calculated by comparing the weight of soil and water in the bottle with the weight of bottle containing only water. The specific gravity was then calculated by dividing the weight of the dry soil by the weight of the displaced water.

Atterberg limits (IS: 2720 Part 5)

Representative samples of the soil were taken to determine Atterberg limits (plastic and liquid limits) by using the size fraction passing through 0.425 mm sieve. Casagrande apparatus was used to determine the liquid limit. The plastic limit was determined with the thread-rolling method. The plastic index was then computed based on the liquid and plastic limits obtained. The liquid limit and plastic index were then used to classify the soil.

Compaction test (IS: 2720 Part 7)

Compaction tests were performed to determine the maximum dry density (MDD) and optimum moisture content (OMC) for the soil, fly ashThe MDD and OMC values are used to prepare specimens for other tests like California bearing ratio test and unconfined compression test to determine the engineering properties of particular soils.

In the final phase of in this project was pure fly ash, cement. In order to study the effect of cement content and compaction conditions on the hydraulic conductivity and compressibility behavior of the mixtures, tests were carried for the four different mixtures, i.e. 100% fly ash, 98% fly ash + 2% cement, 95% fly ash + 5% cement, and 90% fly ash + 10% cement.

Table 3.1Physical property of three different materials

Sl. No.	Material	Specific gravity	Liquid limit	Plastic limit
1	Fly ash (class F)	2.04	-	-
3	Bentonite	2.64	423	33

Table 3.2 Compaction behavior of fly ash, fly ash – cement

Sr. No.	Different type of mixture	5% dry of OMC (%)	OMC (%)	5% wet of OMC (%)	95% MDD (gm/cc)	MDD (gm/cc)
1	100% FA	12	17	22	1.253	1.319
2	95% FA+5% B	13	18	23	1.328	1.398
3	90% FA+10% B	14.8	19.8	24.8	1.341	1.412

Methods

Consolidation test (IS: 2720 Part 15)

Consolidation test was carried out in order to assess the hydraulic conductivity andcompressibility of the mixture. Indirect determination of the hydraulic conductivity fromconsolidation tests has several advantages and disadvantages over permeability tests, which are in the following.

(1) can apply vertical pressures simulating those in field;
(2) can measure vertical deformations;
(3) can test sample under a range of vertical stresses;
(4) thin samples permits short testing time;
(5) cost effective method for obtaining hydraulic conductivity data over a range sample states;

However it has also some disadvantages over other methods. Those are,

(1) Some soil types may be difficult to trim into consolidation ring;
(2) Thin samples may not be representative;
(3) Potential for side wall leakage;

Despite of some disadvantages, the consolidometer permeability test is potentially the most useful among the other methods viz.rigid wall permeameter and flexible wall (triaxial) permeameter because of the flexibility which it offers for testing specimens under a range of confining stresses and for accurate determination of the change in sample thickness as a result of both seepage forces and chemical influence on the soil structure. Furthermore, the thinner samples relative to the other test type means that the pore fluid replacement can be achieved in a short time for a given hydraulic gradient.

The hydraulic conductivity can be calculated from the consolidation test results by fitting Terzaghi's theory of consolidation (Terzaghi, 1923) to the observed laboratory time-settlement observation and extracting the hydraulic conductivity from calculated coefficient of consolidation. The fitting operation was carried out using Taylor's square root method. Aquestion mayarise, how the hydraulicconductivity calculated byTerzaghi's theory iscomparable to that determined directly by permeability tests. Terzaghi (1923) made suchcomparison when he first developed the theory; he found satisfactory agreement. Casagrande and Fadum (1944) reported that they always found satisfactory agreement provided that there was adistinct change in curvature when the primary settlement curve merged with the secondarysettlement curve.Taylor(1942) presented comparison for remolded specimens of Boston blue clay, based on the square root fitting method, and showed that the measured hydraulic conductivity generally exceeded the calculated values. He attributed this difference in hydraulic conductivity to Terzaghi's assumption that the sole cause of delay in compression in the timerequired for the water to be squeezed out, i.e. to the hydraulic conductivity of the clay. Taylor (1942) concluded that the structure of clay itself possessed a time dependent resistance to compression so that the total resistance to volume change came partly from the structuralresistance of the clay itself. By attributing all of the resistance to low hydraulic conductivity, Terzaghi's theory must inevitably lead to an underestimate of the hydraulic conductivity. On the based of several experiments Mesri and Olson (1971) concluded that the calculated hydraulic conductivity was low only by 5 to 20 % for both remolded and undisturbed clay provided the clay is normally consolidated at the time of determination.

In regards to the determination of the hydraulic conductivity of clayey soil, the consolidation test has been widely used (Newland and Alley, 1960; Mesri and Olson, 1971; Budhu, 1991; Sivapullaiah et al., 2000).This test generally provides the hydraulic conductivity comparable with the permeability test (Terzaghi, 1923; Casagrande and Fadum, 1944) although slightlyunderestimates the hydraulic conductivity compared with the permeability test (Taylor, 1942; Mitchell and Madson, 1987). Consolidation tests were carried out to determine the hydraulicconductivity of the mixtures.

The test was carried out on the sample of 60 mm diameter and 20 mm thickness according to ASTM D 2435 using standard consolidometers. The samples were prepared by adding water to the different fly ash - cement mixtures (with cement content of 0 %, 2 %, 5 %, 7 %, and 10 %), and fly ash-bentonite mixtures (with bentonite content of 5 % and 10 %). Then the mixtures were mixed with water to obtain the optimum moisture content (OMC). Then the sample was kept in a humidity controlled desiccator for 24 hours in order to attain the moisture equilibrium. The inside of the ring was smeared with a very thin layer of silicon grease in order to avoid friction between the ring and soil sample. Filter paper was placed at the bottom and top of the sample. A top cap with a porous stone was placed above the soil sample. Then the mixtures were compacted in the consolidation ring to its maximum dry density (MDD). The entire assemblywas placed in the consolidation cell and positioned in the loading frame. The consolidation ringwas immersed in the water. Then the consolidation cells were allowed to equilibrate for 24 hours prior to commencing the test. All the samples were initially loaded with a stress of 0.05 kg/cm^2, increasing by an increment ratio of 1 (i.e. 0.1, 0.2, 0.5, 1, 2 kg/cm^2 etc) to a maximum pressure of 8 kg/cm^2.

Determination of Hydraulic Conductivity and Compressibility

For each pressure increment the change in the thickness of soil sample was measured from the readings of the dial gauge. Then the change in the void ratio corresponding to an increase in the overburden pressure was calculated by the Eq. 1,

$\Delta e = \Delta H (1+e)/H$ (Eq. 1)

Where, ΔH = Change in the thickness of sample due to increase in pressure

H = Initial thickness of the sample, e = Initial void ratio

From the calculated void ratios, a plot of void ratio, e vs log of pressure, p, was plotted. The compression index (Cc) was calculated from the slope of this curve, or

$$\text{Compression index (Cc)} = -\frac{e_i - e_j}{\log\left(\frac{p_i}{p_j}\right)} \quad \text{(Eq. 2)}$$

Where,

e_i = Void ratio corresponds to a consolidation pressure of p_i

e_j = Void ratio corresponds to a consolidation pressure of p_j

From the consolidation test result, a time-settlement curve was obtained at each pressure increment. The coefficient of consolidation $c_v$was obtained using Taylor's square root time ($\sqrt{T}$)method.

The co-efficient of volume change can be calculated by the formula,

$$m_v = a_v/(1+e) \quad \text{(Eq.3)}$$

Where, a_v = coefficient of compressibility

= $\Delta e/\Delta\sigma$ where,

$\Delta\sigma$ = Change in pressure

Δe = Change in void ratio

The hydraulic conductivity, k, was calculated using the Eq. 4 for various pressure increments using the c_v, and coefficient of volume change, m_v

$$k=c_v m_v \gamma_w \quad \text{(Eq. 4)}$$

Where, $\gamma_w$is the unit weight of the pore fluid

Linear Shrinkage test (IS: 2720 Part 20)

Linear shrinkage, as used in this test method, refers to the change in linear dimensions that has occurred in test specimens after they have been subjected to soaking heat for a period of 24 hours and then cooled to room temperature.

Most insulating materials will begin to shrink at some definite temperature. Usually the amount of shrinkage increases as the temperature of exposure becomes higher. Eventually a temperature will be reached at which the shrinkage becomes excessive. With excessive shrinkage, theinsulating material has definitely exceeded its useful temperature limit. When an insulatingmaterial is applied to a hot surface, the shrinkage will be greatest on the hot face. The differentialshrinkage which results between the hotter and the cooler surfaces often introduces strains and may cause the insulation to warp. High shrinkage may cause excessive wrap age and thereby may induce cracking, both of which are undesirable.

The test was carried out on the sample of 25 mm diameter and125 mm thickness according to using standard mould confirming to IS 12979: 1990. Soil sample weighing about 150 g from the thoroughly mixed portion of the material passing 425 micron IS Sieve [IS 460 (Part 1): 1985] obtained in accordance with IS 2720 (Part 1): 1983 was taken for the test specimen.

About 150 g of the soil sample passing 425 micron IS Sieve was placed on the flat glass plate and thoroughly mixed with distilled water, using the palette knives, until the mass becomes a smooth homogeneous paste, with moisture content approximately 2 % above the liquid limit of the soil. In the case of clayey soils, the soil paste shall be left to stand for a sufficient time (24 hours) to allow the moisture to permeate throughout the soil mass. The thoroughly mixed soil water paste was placed in the mould such that was slightly proud of the sides of the mould. The mould was then gently jarred to remove any air pockets in the paste. Then the soil was leveled off along the top of the mould with the palette knife. The mould was placed in such way that the soil-water mixture (paste) can air dry slowly, until the soil was shrunk away from the walls of the mould. Drying was completed first at a temperature of 60 to 65° C until shrinkage has largely ceased and then at 105 to 110° C to complete the drying. Then the mould and soil was cooled and the mean length of soil bar measured because the specimen was become curved during drying.

Determination of Linear Shrinkage test

The linear shrinkage of the soil shall be calculated as a percentage of the original length of the specimen from the following formula:

Linear Shrinkage (LS), (%) = (1 - Ls / L) 100%

Where,

L = Length of the mould (mm)

Ls = Length of the of the oven dry specimen (mm)

Triaxial test (IS: 2720 Part 11)

Unconsolidated undrained test (UU) test was performed on all specimens using a strain rate of 1.2 mm/min. Corrections to the cross sectional areas were applied prior to calculating the compressive stress on the specimens. Each specimen was loaded until peak stress was obtained, or until an axial strain of approximately 20% was obtained. The testing procedure and instructions are followed as per the operating manual of HEICO electronic system for the triaxial.

The triaxial test is used to determine the shear parameters and to assess the stress-strain behavior of fly ash, and fly ash - bentonite mixes. Many factors affect the unconfined compressive strength of a blended soil, but the more important factors are the type of soil, cement content, bentonite content, water content and curing time. Therefore, an investigation was carried on how these factors would influence the strength of the improved soils.

Preparation of specimens

The required amounts of soil, fly ash, cement, and water were measured to start the procedure. A few additional grams of fly ash and milliliters of water were taken to offset the losses during the preparation of specimens. The fly ash, fly ash – cement, and fly ash – bentonite mixes were first mixed together in the dry state and the dry mixes was mixed with optimum water amount. All mixing was done by mixing tool and proper care was taken to prepare homogeneous mixes. To prepare the specimens, a 38 mm inner diameter and 76 mm long mould with detachable collars at both ends was used. To ensure uniform compaction, the entire quantity of the mixture was placed inside the mould-collars assembly and compressed alternately from the two ends until the specimen reached the dimensions of the mould.

The specimen was extruded from the mould immediately. For curing, the specimens were wrapped in polyethylene sheets and sealed to prevent any change in moisture content. Four specimens for each curing time were prepared in order to provide an indication of the reproducibility as well as to provide sufficient data accurate interpolation of the results. All specimens cured at room temperature, but were exposed to ambient constant humidity within desiccators during the curing period of 0, 3, 7, 14 and 28 days. A small quantity of water was kept at the bottom of the desiccators. The desiccators was closed with a lid and kept at room temperature. Cement was added in four proportions, specifically 0 %, 2 %, 5 % and 10 % weight of air-dried soil.

IV. Consolidation tests on fly ash – bentonite mixtures

Effect of compaction conditions on e - log k for fly ash-bentonite mixes

Hydraulic conductivity is one of the most important criteria for soil to be used as a liner material at the waste disposal site. Most of the regulatory authority in the world has recommended that the material to be used as a liner material must have a minimum value of hydraulic conductivity of less than 10^{-7} cm/sec compacted at optimum moisture content (OMC) and maximum dry density (MDD). Figures 4.19 to 4.21 show the relationship between void ratio and hydraulic conductivity for the five different compaction conditions with three different mixes. Result shows that the hydraulic conductivity value for the five different compaction conditions for three mixes have decreased with the decrease in the void ratio. Result of the hydraulic conductivity for five different compaction conditions with three different mixes in which 5% wet of OMC and MDD condition with 95% fly ash + 5% bentonite mix obtained a lower value and it satisfy the hydraulic conductivity criteria for a landfill liner.

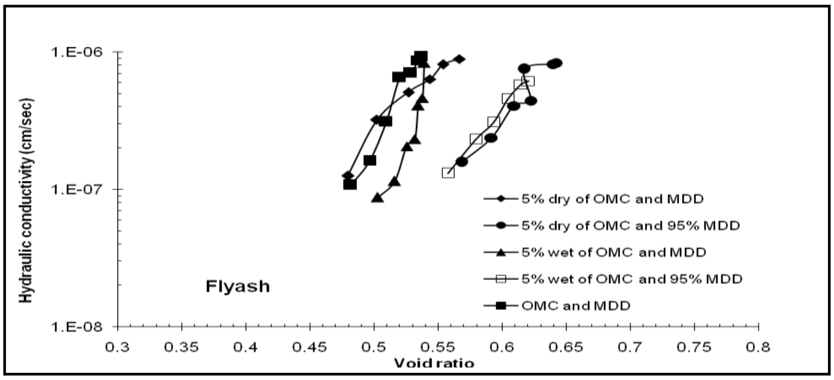

Figure 4.19e – log k plots of fly ash with different compaction conditions

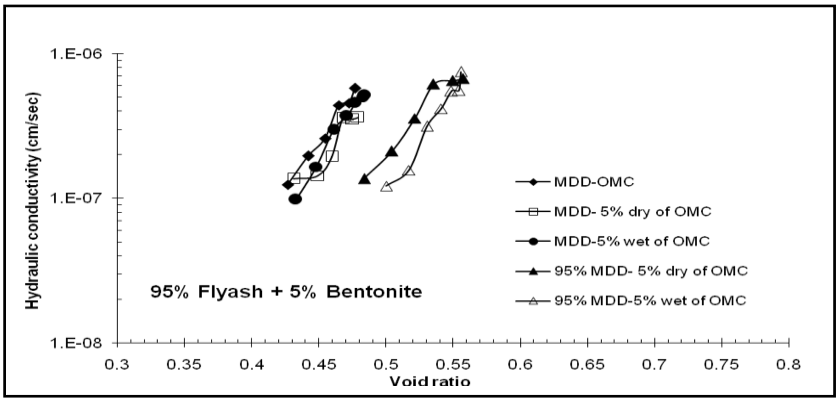

Figure 4.20e – log k plots of 95% fly ash+5% bentonite with different compaction conditions

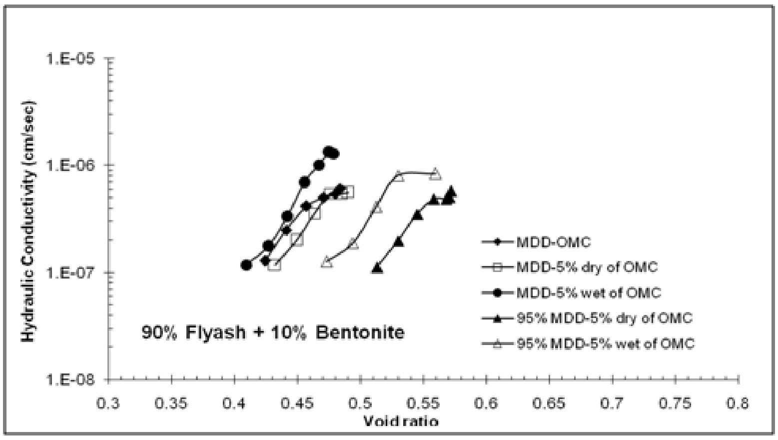

Figure 4.21e – log k plots of 90% fly ash+10% bentonite with different compaction conditions

Effect of compaction conditions on e–log p for fly ash-bentonite mixes

Figures 4.22 to 4.24 show the relation between the pressure and void ratio for five different compaction conditions with three different mixes. The result shows that with increase in overburden pressure the void ratio of the fivedifferent compaction conditionswith threedifferent mixes are decreases. The increase in the overburden pressure on the five different compaction conditions with three different mixes can be correlated with the increase in the pressure on the liner due to the increase in the weight of the overburden weight due to dumping of more and more waste material. The result shows that the decrease in the void ratio with an increase in the pressure is quite marginal in the beginning. However, with an increase in the load the five different compaction conditions of three different mixes get compressed significantly. Result shows that the three different mixes with a 5% wet of OMC and MDD condition possessed a lower void ratio at any given overburden pressure. This can be attributed to the presence of the higher amount of fine particles in the fly ash. With the increase in the fine content of the mixture the void ratio decreases.

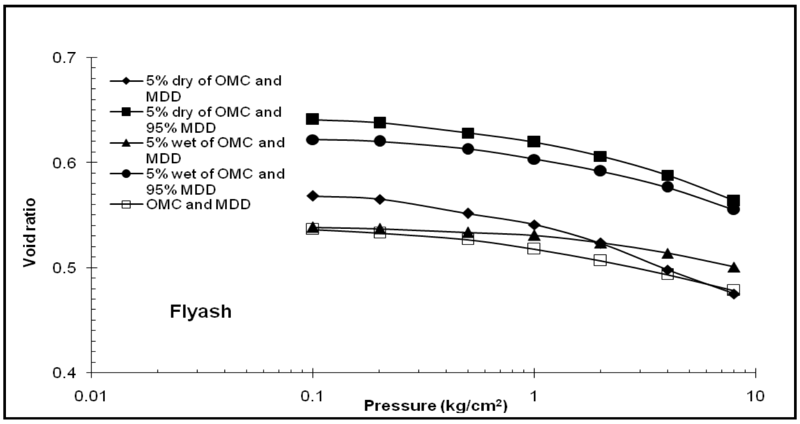

Figure 4.22e – log p plots of fly ash with different compaction conditions

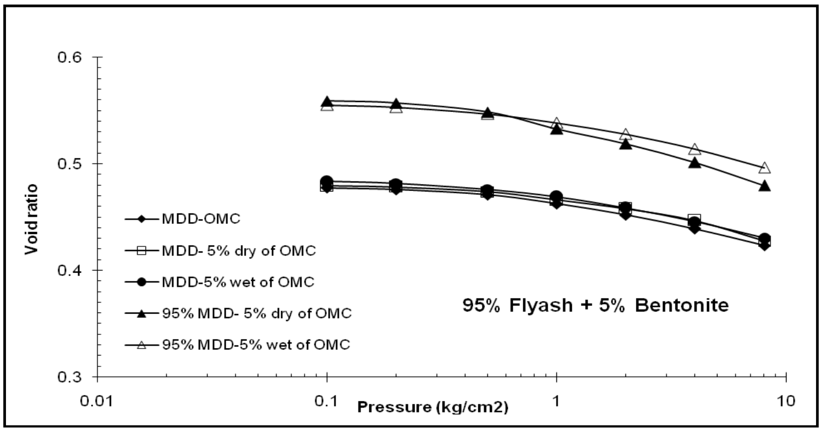

Figure 4.23e – log p plots of 95% fly ash+ 5% bentonite with different compaction conditions

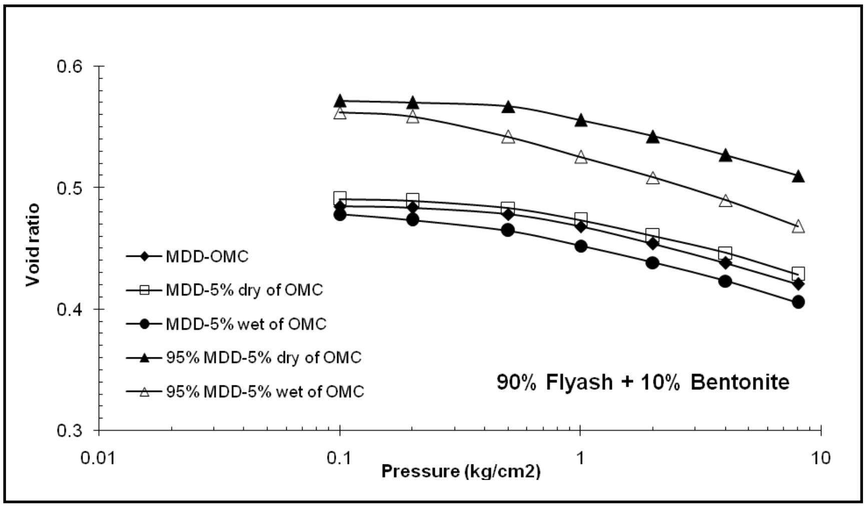

Figure 4.24e – log p plots of 90% fly ash+ 10% bentonite with different compaction conditions

4.2.3 Effect of bentonite content on e-log k for five compaction conditions

In case of fly ash and bentonite mix, result of hydraulic conductivity shows that all three mixtures satisfy the hydraulic conductivity criteria require for a liner material. For all the mixtures the value of hydraulic conductivity was found to be less than 10^{-7} cm/sec, the limiting criteria for the use of a landfill liner material. Figure 4.25 to 4.29 shows a relationship between void ratio and hydraulicconductivity for the three mixtures. It shows that the hydraulic conductivity value for the threemixtures decreased with a decrease in the void ratio. The decrease in the hydraulic conductivity with the decrease in the void ratio was quite steep at the beginning for the pure fly ash and 95% fly ash + 5% bentonite mixtures. However, the hydraulic conductivity of the 90% fly ash + 10% bentonite normally decreases but here increases due to the presence of salts in the fly ash.

In a comparison among the three mixtures, it can be seen that with the increase in the bentonite content the hydraulic conductivity increases. In other words, at the same void ratio mixture with higher bentonite content exhibits a higher hydraulic conductivity. Generally, the hydraulic conductivity tends to decreases with the increase in the bentonite content (Chapuis, 1990). This opposite trend can be explained in terms of the presence of various salts in the fly ash (Ohtsubo et al., 2004). When fly ash-bentonite mixtures comes in contact with water, the various cations such as Na^{+}, Ca^{2+} leached out from fly ash and react with the bentonite present in the mixture. Because of these cations the repulsive force of the diffuse double layer in the mineral of bentonite decreases and the bentonite becomes flocculated (van Olphen, 1977). As the bentonite gets flocculated, the flow path becomes open and the hydraulic conductivity increases (Benson and Daniel, 1990).

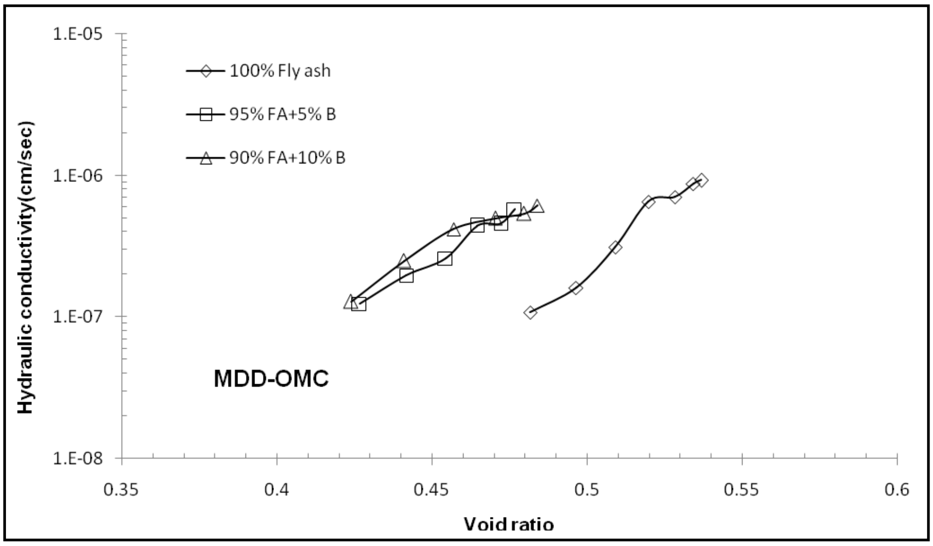

Figure 4.25e – log k plots of different mix compacted with OMC and MDD

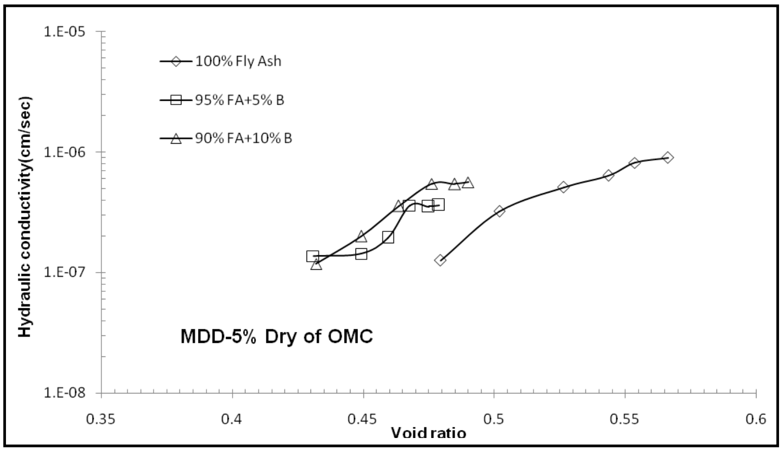

Figure 4.26e – log k plots of different mix compacted with 5% Dry of OMC and MDD

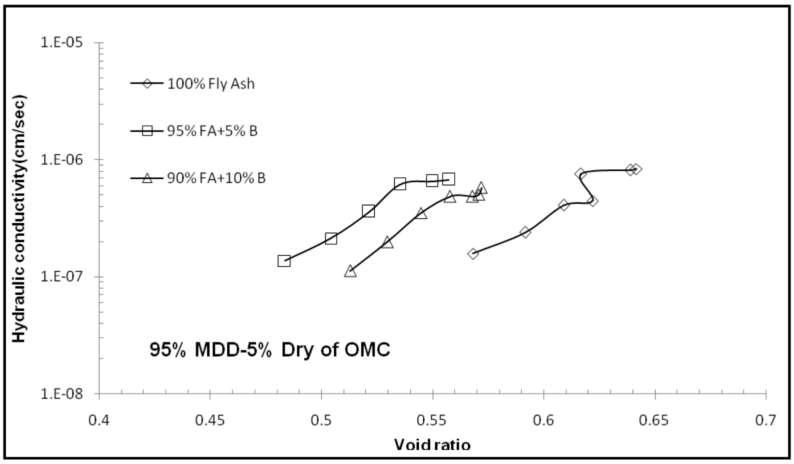

Figure 4.27e – log k plots of different mix compacted with 5% Dry of OMC and 95%MDD

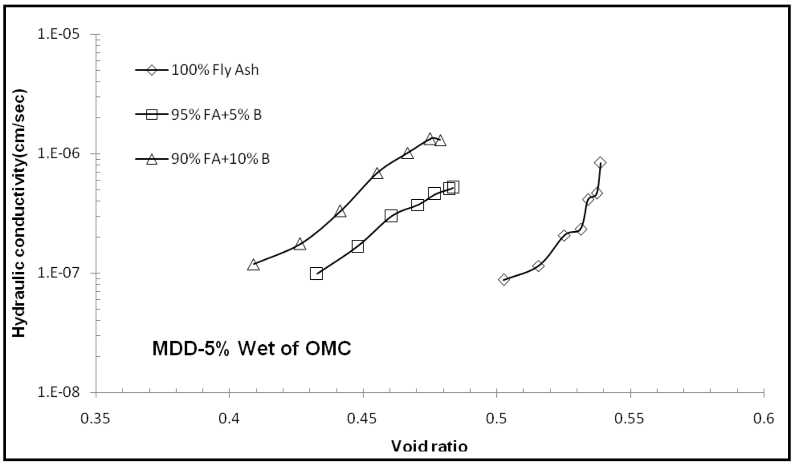

Figure 4.28e – log k plots of different mix compacted with 5% Wet of OMC and MDD

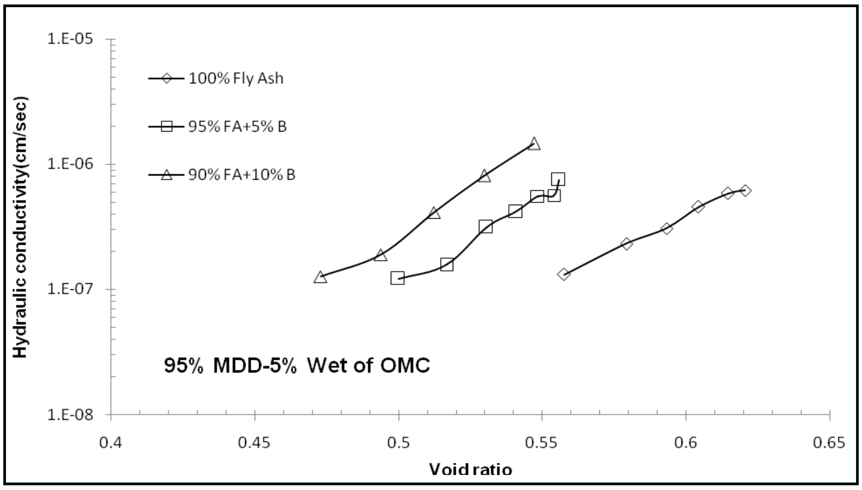

Figure 4.29e – log k plots of different mix compacted with 5% Wet of OMC and 95%MDD

Effect of bentonite content on e-log p for five compaction conditions

Figure 4.30 to 4.34shows the relation between the pressure and void ratio for the three mixtures. The resultshows that with an increase in the overburden pressure the void ratio of the mixture decreases.From the figure we can say that lower bentonite content gives higher void ratio with the increase overburden pressure. The result shows that the decrease in the void ratio with an increase in the pressure is quite marginal in the beginning. However, with an increase in the load the mixtures get compressed significantly.

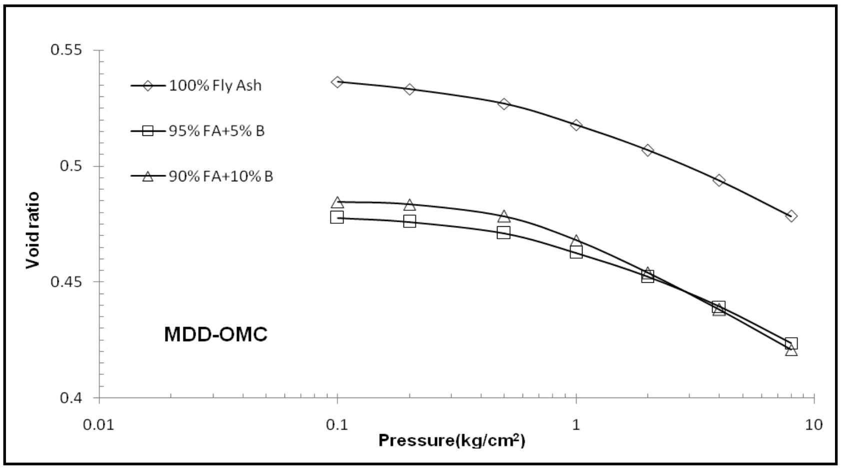

Figure 4.30e – log p plots of different mix compacted with OMC and MDD

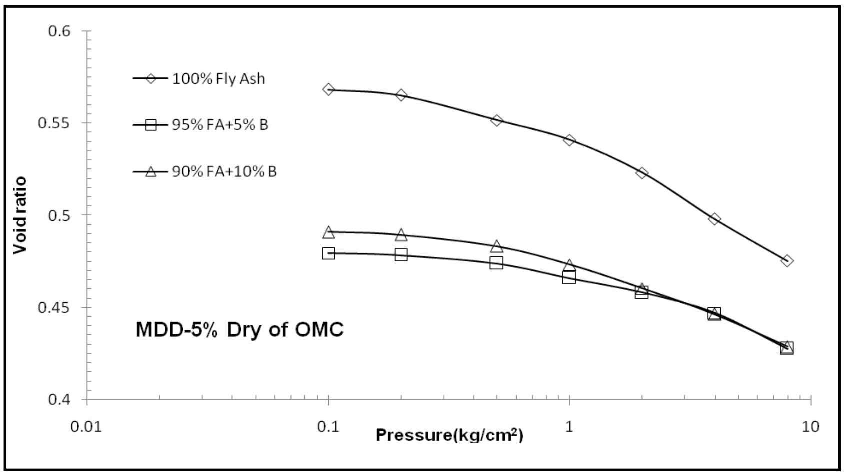

Figure 4.31e – log p plots of different mix compacted with 5%Dry of OMC and MDD

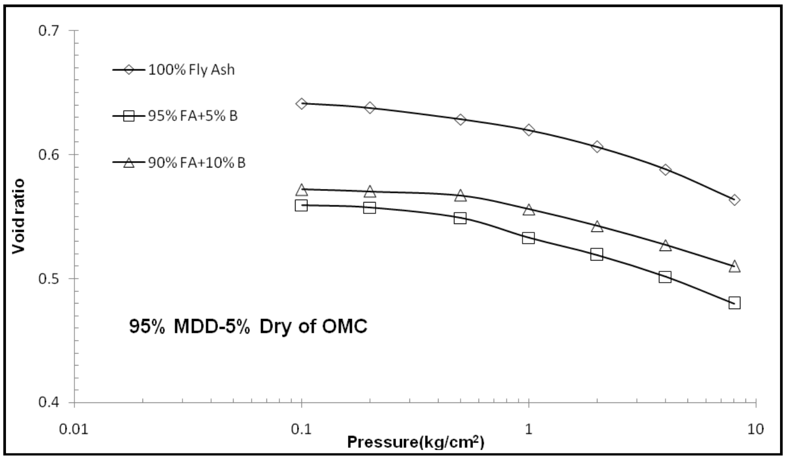

Figure 4.32e – log p plots of different mix compacted with 5%Dry of OMC and 95%MDD

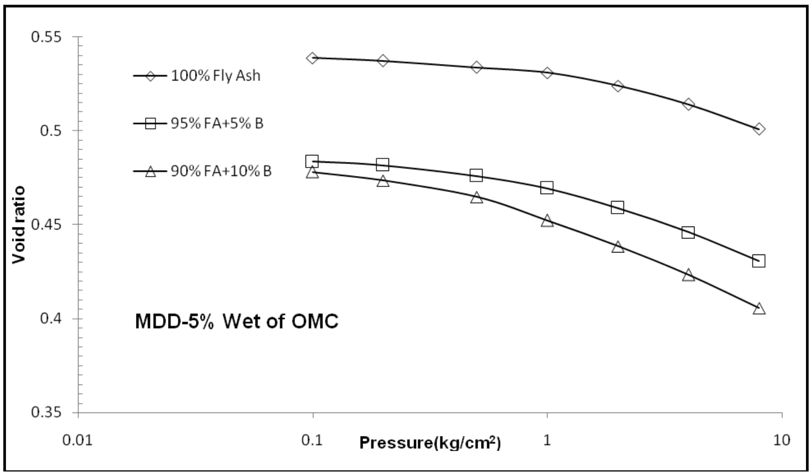

Figure 4.33e – log p plots of different mix compacted with 5%Wet of OMC and MDD

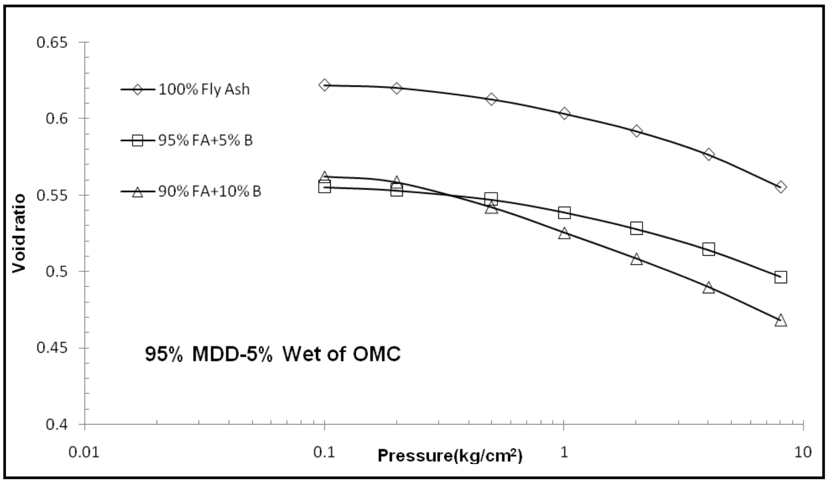

Figure 4.34e – log p plots of different mix compacted with 5%Wet of OMC and 95%MDD

Compression index (Cc) for fly ash-bentonite mixes with five compaction conditions

Compression index (Cc) for all the three mixes with five compaction conditions was determined from the Figure 4.30 to 4.34 and tabulated in Table 4.2. The data in Table shows thecompression index of the three mixes with five compaction conditions gets affected marginally by the presence of the bentonite.

Table 4.2 Compression index (Cc) for fly ash-bentonite mixes with five compaction conditions

Sr.No	Different mix proportions	Different compaction conditions	Compression index (Cc)
1	100% FA	OMC and MDD	0.044
2	95% FA+ 5% B	OMC and MDD	0.053
3	90% FA+10% B	OMC and MDD	0.049
4	100% FA	5% Dry of OMC and MDD	0.083
5	95% FA+ 5% B	5% Dry of OMC and MDD	0.049
6	90% FA+10% B	5% Dry of OMC and MDD	0.046
7	100% FA	5% Dry of OMC and 95% MDD	0.081
8	95% FA+ 5% B	5% Dry of OMC and 95% MDD	0.073
9	90% FA+10% B	5% Dry of OMC and 95% MDD	0.056
10	100% FA	5% Wet of OMC and MDD	0.044
11	95% FA+ 5% B	5% Wet of OMC and MDD	0.056
12	90% FA+10% B	5% Wet of OMC and MDD	0.059
13	100% FA	5% Wet of OMC and 95% MDD	0.071
14	95% FA+ 5% B	5% Wet of OMC and 95% MDD	0.059
15	90% FA+10% B	5% Wet of OMC and 95% MDD	0.063

Linear shrinkage (Ls) for fly ash-bentonite mixes with five compaction conditions

Linear shrinkage (Ls) for all the fly ash-bentonite mixtures with five compaction conditions found the value was zero. The length and the diameter of all the fly ash-bentonite mixtures did not reduce after keeping in oven for 24 hours.

Comparisons between cement and bentonite mix with fly ash (5% and 10%)

Effect of cement and bentonite content on e-log k for five compaction conditions

It is recommended that the material to be used as a liner material must have a minimum value of hydraulic conductivity of less than 10^{-7} cm/sec compacted at five different compaction conditions. In Figure 4.35 to 4.39 agraphical relation between void ratio and hydraulic conductivity for 5 % and 10 % cement and bentonite content has been established. Result shows that hydraulic conductivity value for the four mixtures decreased with a decrease in the void ratio. The figure shows that 90 % fly ash and 10 % cement mixture gives lower value of hydraulic conductivity.

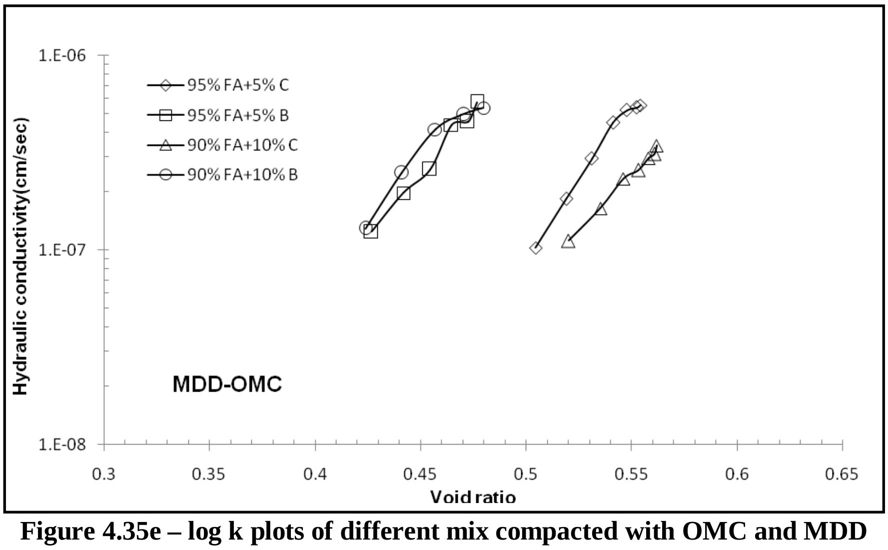

Figure 4.35e – log k plots of different mix compacted with OMC and MDD

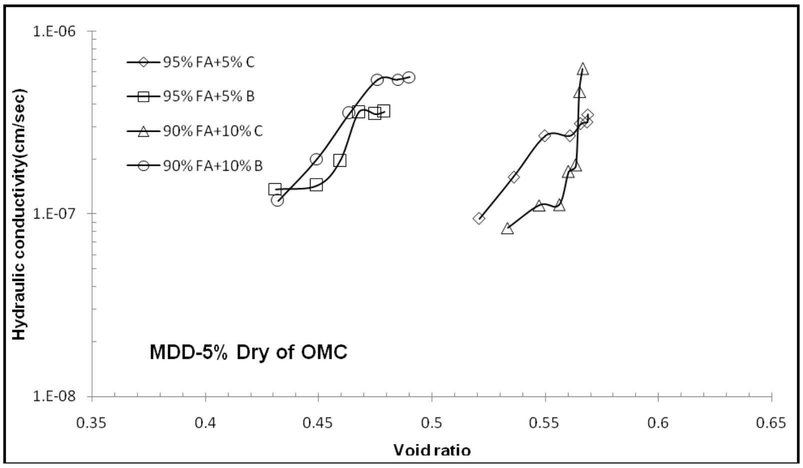

Figure 4.36e – log k plots of different mix compacted with 5% Dry of OMC and MDD

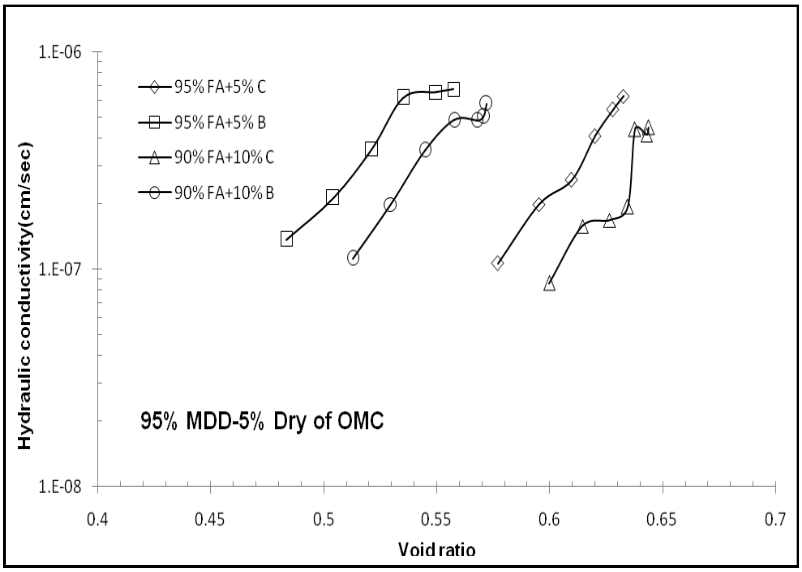

Figure 4.37e – log k plots of different mix compacted with 5% Dry of OMC and 95%MDD

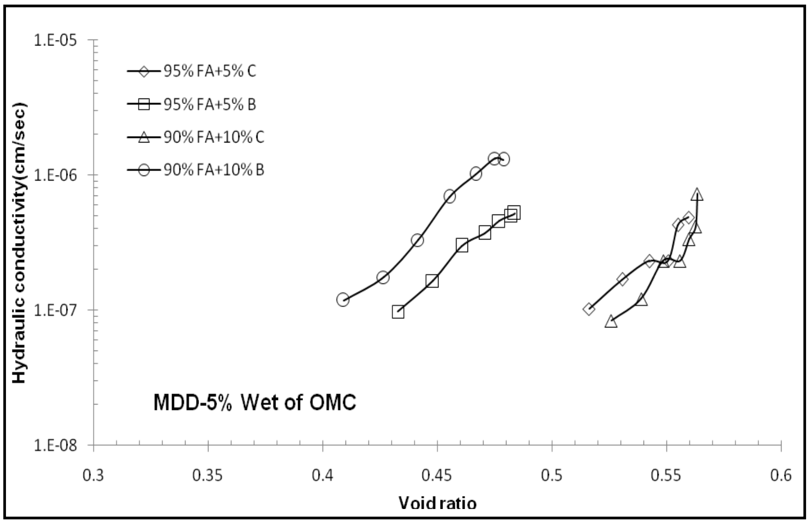

Figure 4.38e – log k plots of different mix compacted with 5% Wet of OMC and MDD

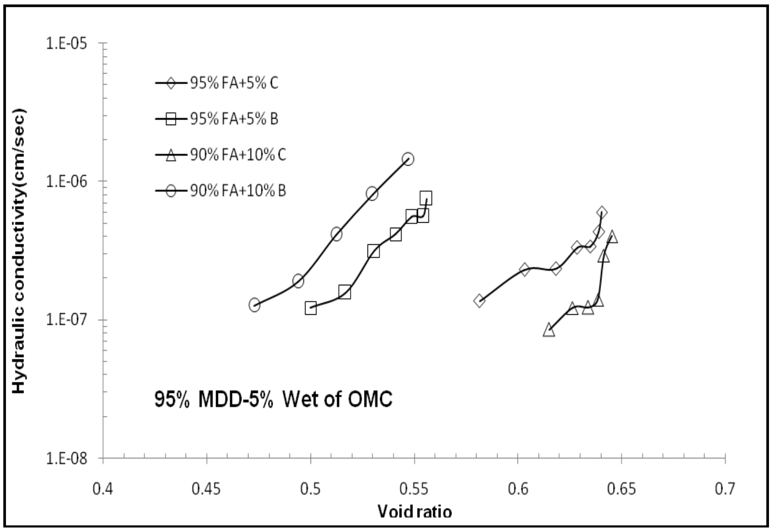

Figure 4.39e – log k plots of different mix compacted with 5% Wet of OMC and 95%MDD

Effect of cement and bentonite content on e-log p for five compaction conditions

Figure 4.40 to 4.44 shows the relation between pressure and void ratio for the four mixtures. The result shows that the both 5 % and 10 % cement content gives higher value than 5 % and 10 % bentonite content. Whereas 90 % fly ash and 10 % bentonite gives lowest value of void ratio. The increase in the overburden pressure on the four mixtures can be correlated with the increasein the pressure on the liner due to the increase in the weight of the overburden pressure becauseof more waste material.

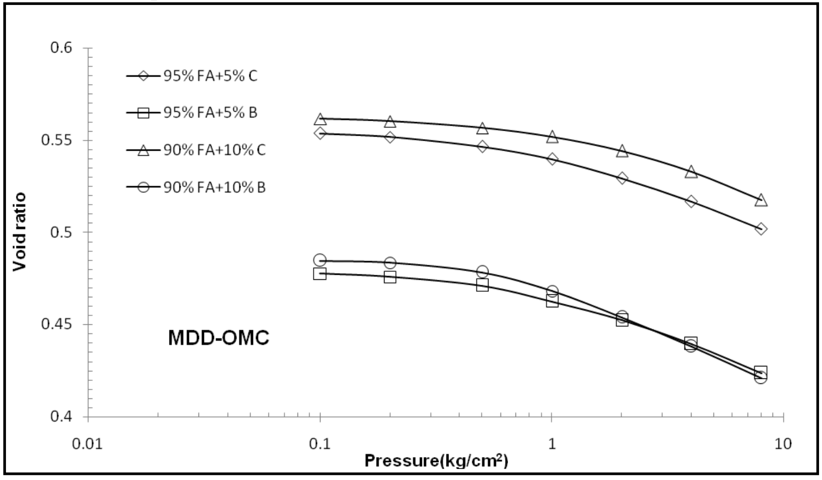

Figure 4.40e – log p plots of different mix compacted with OMC and MDD

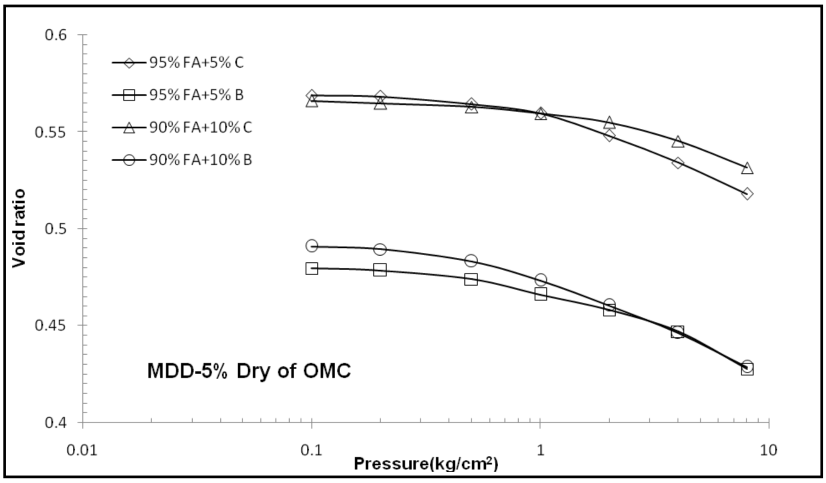

Figure 4.41e – log p plots of different mix compacted with 5% Dry of OMC and MDD

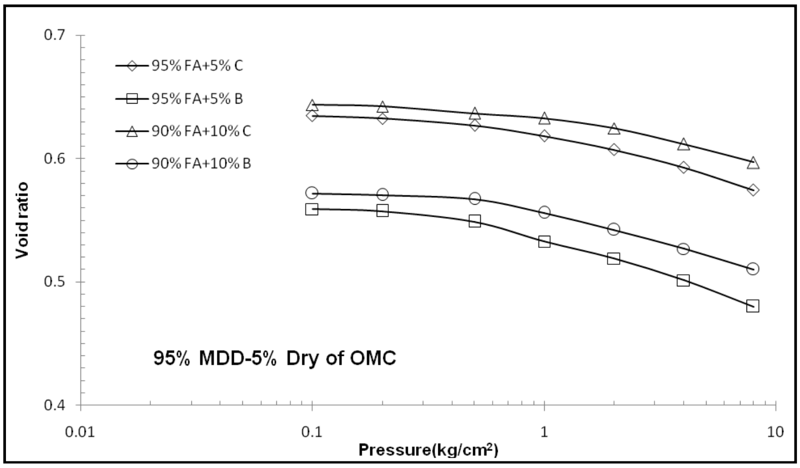

Figure 4.42e – log p plots of different mix compacted with 5% Dry of OMC and 95%MDD

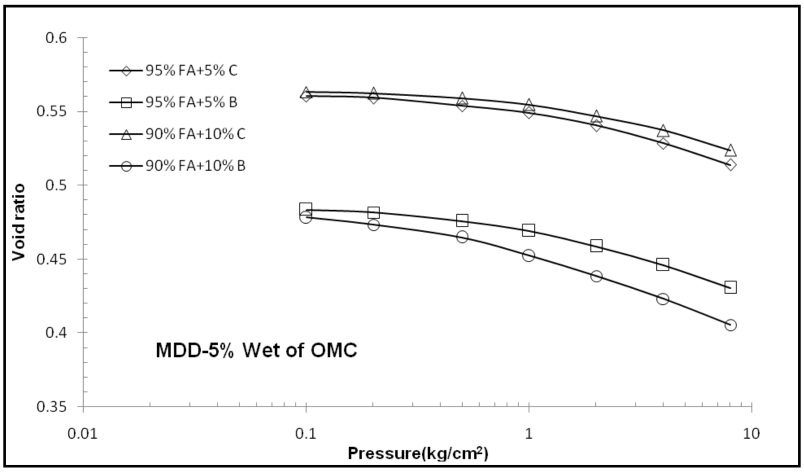

Figure 4.43e – log p plots of different mix compacted with 5% Wet of OMC and MDD

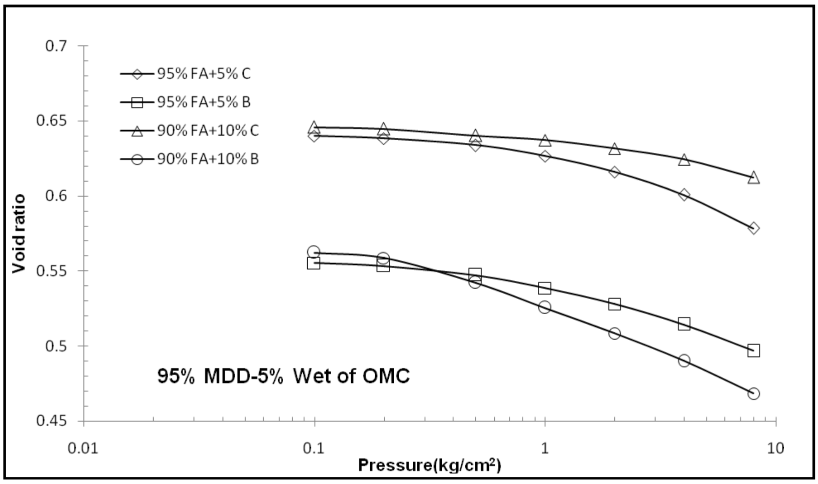

Figure 4.44e – log p plots of different mix compacted with 5% Wet of OMC and 95%MDD

Unconsolidated undrained tests on fly ash

Shear stress-strain behaviour of fly ash-cement mixtures

The stress-strain curves obtained in triaxial compression tests are given in Figures 4.45 to 4.48 for the 100% FA, 98% FA +2% C, 95% FA +5% C and 90% FA +10% C mixtures with the confining pressure 4 kg/cm^2, 3 kg/cm^2, 2 kg/cm^2 and 1 kg/cm^2 respectively. The effect of confining pressure on the stress-strain behavior is shown in graphs that the stress is increased up to 3% strain after that it becomes constant up to 20% strain.

Stress path behaviour of fly ash-cement mixtures

Figures 4.49 to 4.52 are shows the total stress paths using the MIT stress space p versus q from the triaxial compression test series on fly ash. The result shows that the stress paths, which are all in similar shape and linearly varying with the confining pressure. The same stress-strain and stress paths behaviour is shown in case of 100% FA, 98% FA+2% C, 95% FA+5% C and 90% FA+10% C mixtures.

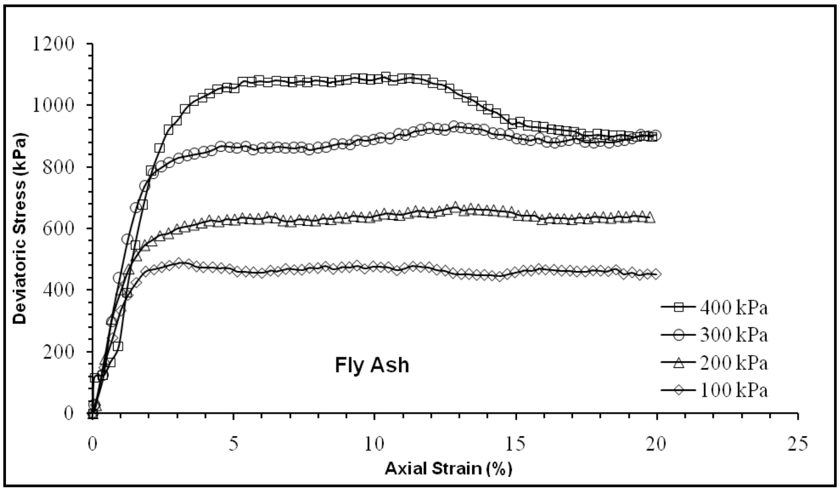

Figure 4.45 Stress-strain plots of Fly Ash

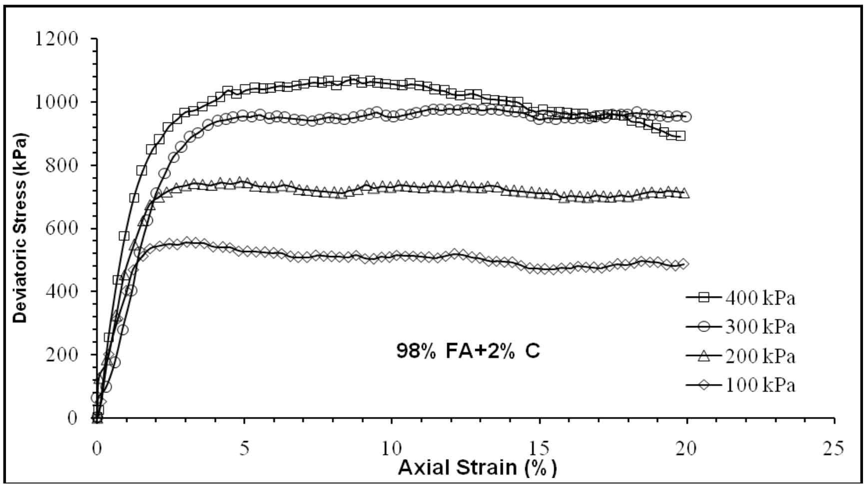

Figure 4.46 Stress-strain plots of 98% FA+2% C

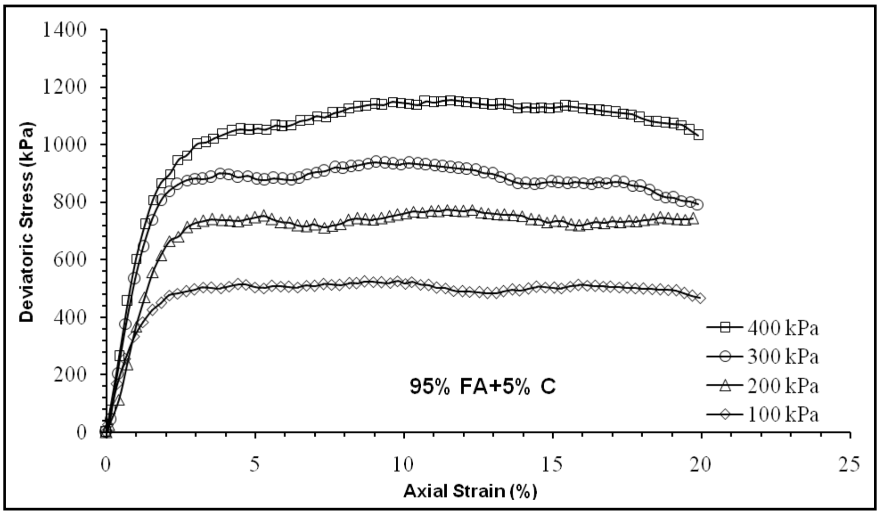

Figure 4.47 Stress-strain plots of 95% FA+5% C

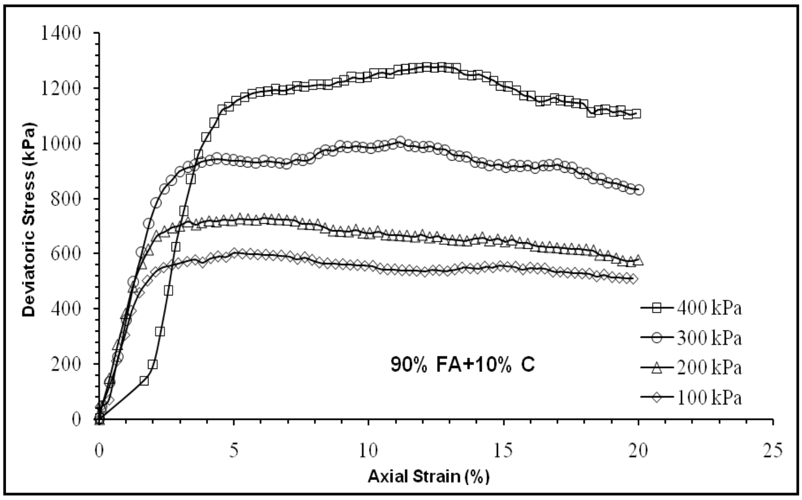

Figure 4.48 Stress-strain plots of 90% FA+10% C

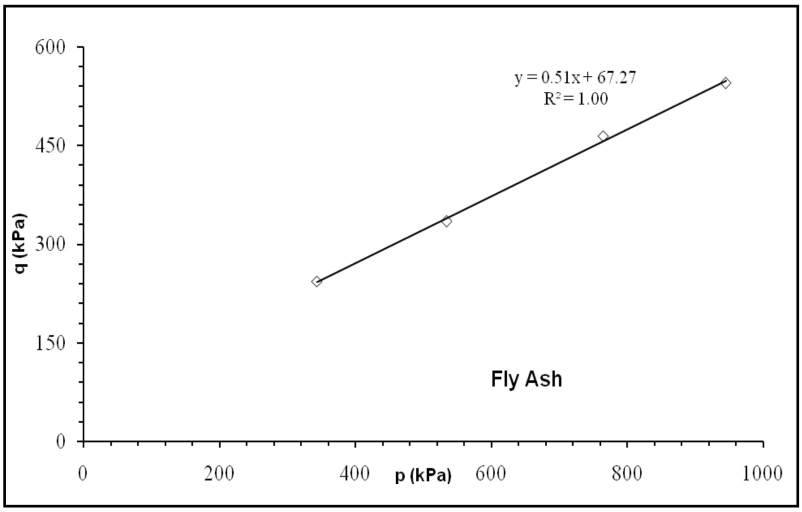

Figure 4.49 p-q plot of Fly Ash

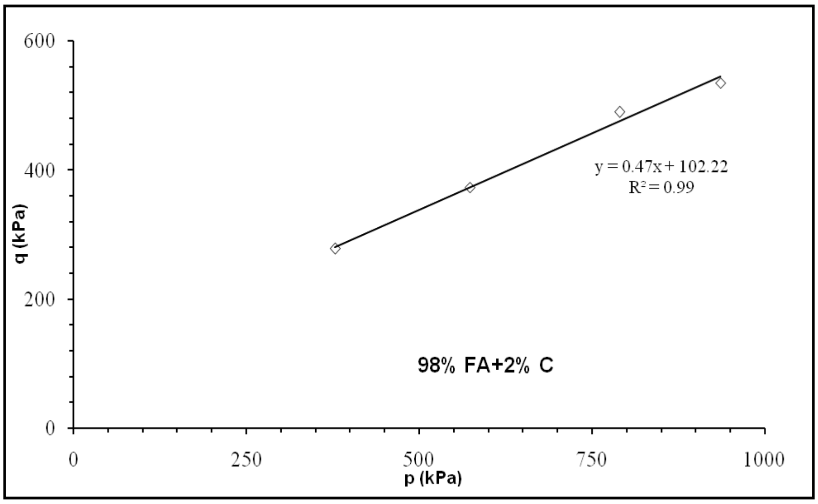

Figure 4.50 p-q plot of 98% FA+2% C

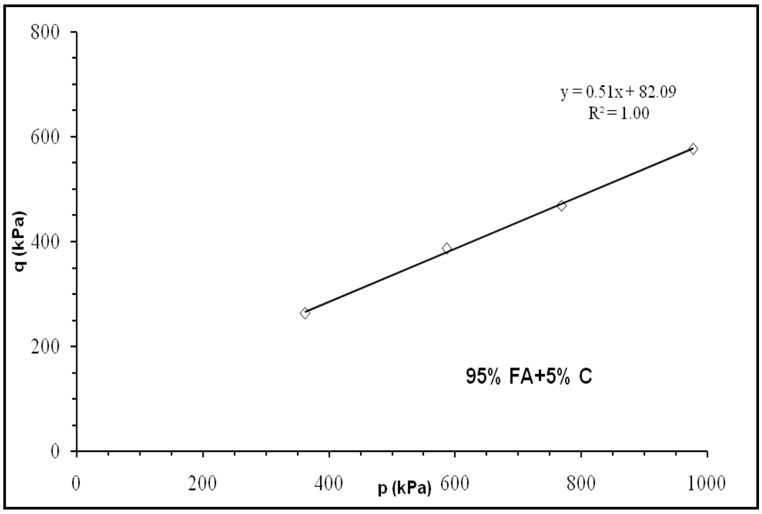

Figure 4.51 p-q plot of 95% FA+5% C

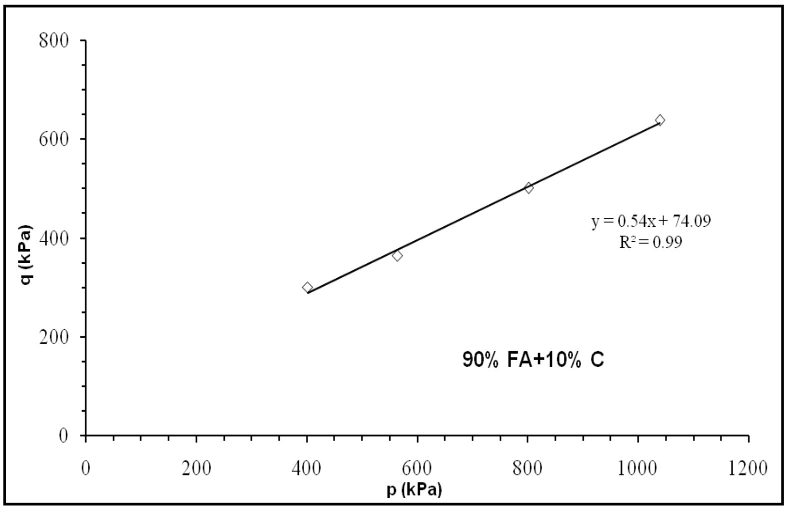

Figure 4.52 p-q plot of 90% FA+10% C

Shear stress-strain behaviour of fly ash-bentonite mixtures

The stress-strain curves obtained in triaxial compression tests are given in Figures 4.53 to 4.55 for the 100% FA, 95% FA +5% B and 90% FA +10% B mixtures with the confining pressure 4 kg/cm^2, 3 kg/cm^2, 2 kg/cm^2 and 1 kg/cm^2 respectively. The effect of confining pressure on the stress-strain behavior is shown in graphs that the stress is increased up to 3% strain after that it becomes constant up to 20% strain.

Stress path behaviour of fly ash-bentonite mixtures

Figures 4.56 to 4.58 are shows the total stress paths using the MIT stress space p versus q from the triaxial compression test series on fly ash. The result shows that the stress paths, which are all in similar shape and linearly varying with the confining pressure. The same stress-strain and stress paths behaviour is shown in case of 100% FA, 95% FA+5% B and 90% FA+10% B mixtures.

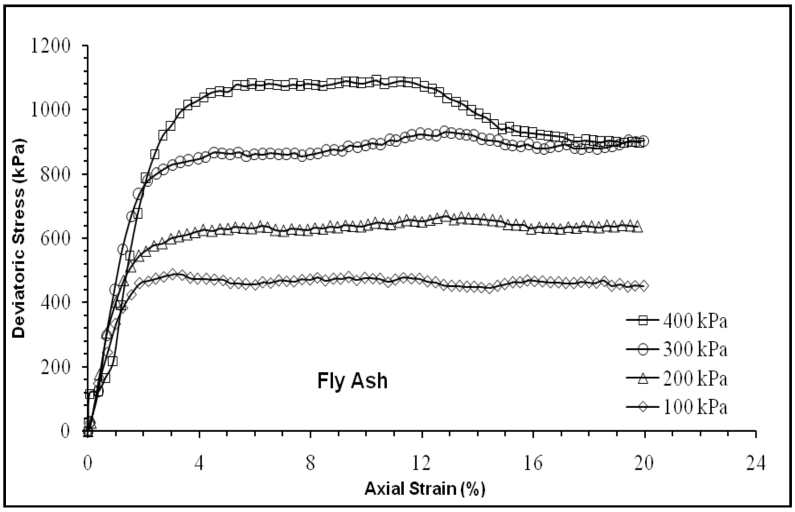

Figure 4.53 Stress-strain plots of Fly Ash

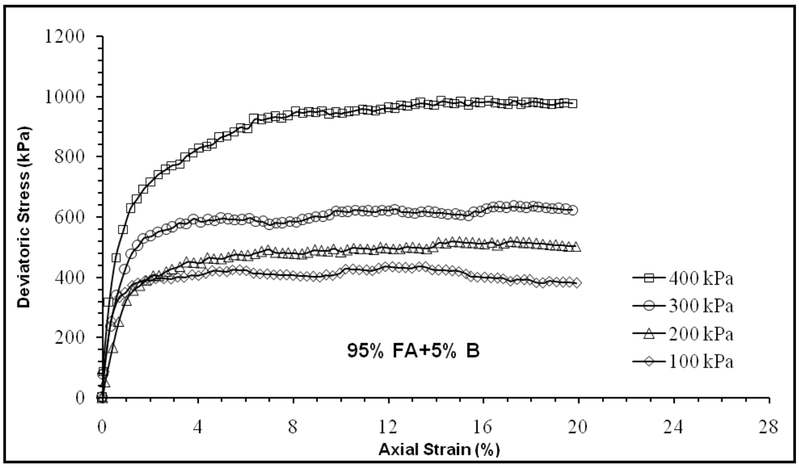

Figure 4.54 Stress-strain plots of 95% FA+5% B

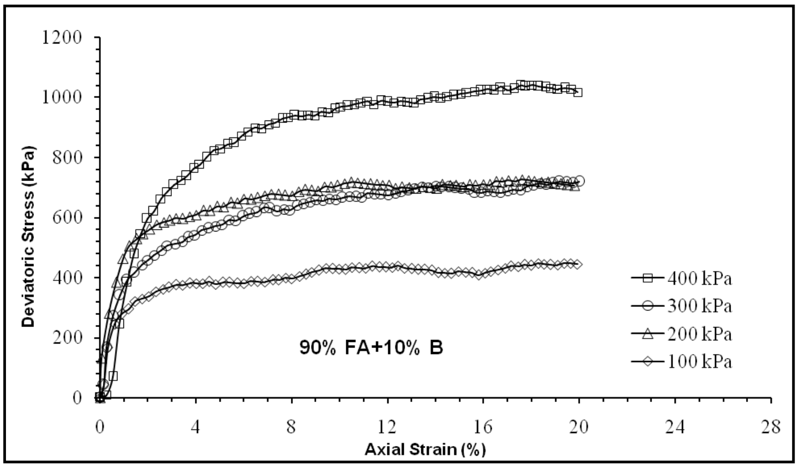

Figure 4.55 Stress-strain plots of 90% FA+10% B

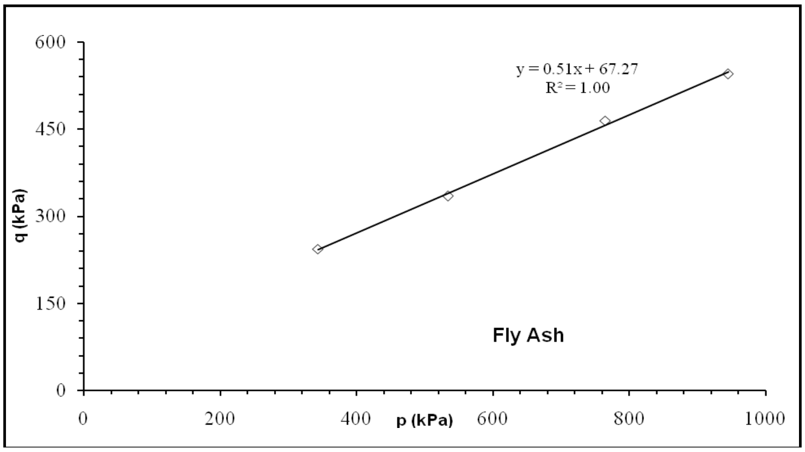

Figure 4.56 p-q plot of Fly Ash

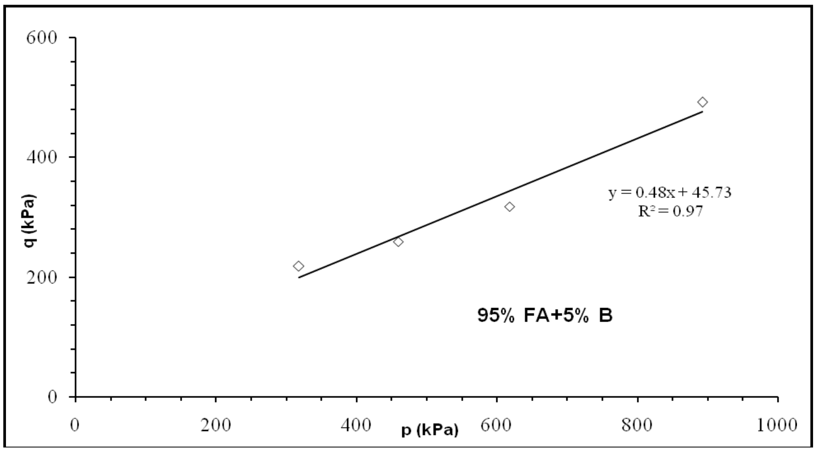

Figure 4.57 p-q plot of 95% FA+5% B

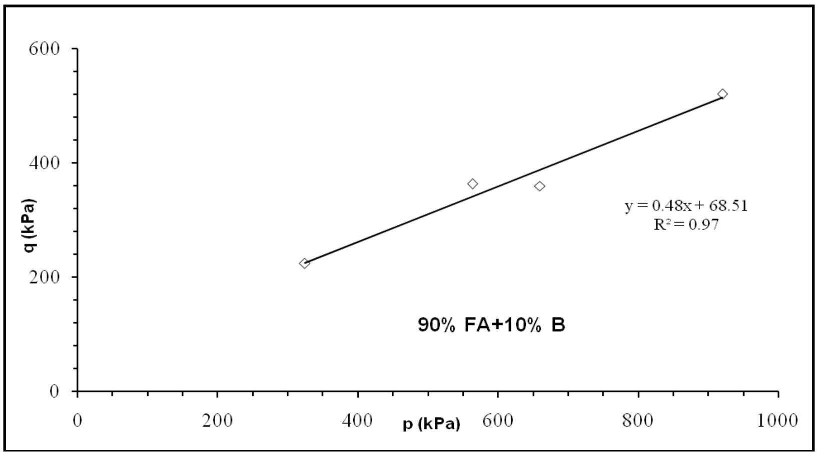

Figure 4.58 p-q plot of 90% FA+10% B

Shear strength (c and Ø) values of various mixes

The c and **Ø** values of various mixes are shown in Table 4.3

Table 4.3 Shear strength values of various mixes

S. No	Mix proportion	c – value in kpa	Ø – value in degrees
Shear strength comparison between fly ash and fly ash - bentonite			
1	100% FA	78.21	30.66
2	95% FA+5% B	52.13	28.69
3	90% FA+10% B	78.09	28.69

Concluding remarks

The experimental programwas carried out to study the effects of initial compaction condition and cement and bentonite content on the hydraulic and compressibility behaviour of fly ash - bentonite mixtures. The result of one dimensional consolidation, linear shrinkage and unconsolidated undrained triaxial tests was analyzed. The observations and conclusions can be summarized as follows:

- For any given compaction condition, the increase in cement content decreases the hydraulic conductivity and compression index.
- For any given compaction condition, the increase in bentonite content increases the hydraulic conductivity and compression index due to the presence of salts in the fly ash.
- At a given compaction density, the hydraulic conductivity and compression index decreases with an increase in the initial compaction water content.
- At a given water content, the hydraulic conductivity and compression index decreases with increase in the compaction density.
- Mixture with 95% fly ash + 5% bentonite mix with 5% wet of OMC and MDD compaction condition gives the lowest hydraulic conductivity and compression index compare to all the tested samples and full fills the hydraulic conductivity criteria for a landfill liner.
- The linear shrinkage test for all the fly ash – bentonite mixes with different mixes proportions with different compaction conditions found the value was zero. The length and diameter of all the mixes did not reduce after keeping in oven for 24 hours. It will be full fills the linear shrinkage criteria for a landfill liner.
- For shear strength criteria if the cement content increases cohesion decreases and angle of internal friction increases and in case of bentonite increases cohesion increases and angle of internal friction remains constant or little amount of variation.

Scope of Future work

Based on the result presented above, further studies can be carried out:

1) Determination of compaction, strength, compressibility and permeability characteristics of fly ash material.
2) To develop a new setup for locally available soil.
3) To evaluate the suitable fly ash-expansive soil mix that can be used as landfill liner.
4) To propose different combination of parameters as design criteria for fly ash-expansive soil mix.

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