# CHARACTERIZATION AND UTILIZATION OF FLY ASH

A THESIS SUBMITTED IN FULFILLMENT OF THE REQUIRMENTS FOR THE DEGREE OF

**BACHELOR OF TECHNOLOGY**

**IN**

**MINING ENGINEERING**

**By**

**ANKUR UPADHYAY**

**MANISH KAMAL**

**DEPARTMENT OF MINING ENGINEERING**
**NATIONAL INSTITUTE OF TECHNOLOGY**
**ROURKELA, ORISSA - 769008**
**2007**

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**Under the Guidance of**

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**Date:** **Ankur Upadhyay**

**Manish Kamal**

# NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

# CERTIFICATE

This is to certify that the thesis entitled, "Characterization and utilization of fly ash" submitted by Sri Ankur Upadhyay & Sri Manish Kamal is fulfillment of the requirements for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any Degree or Diploma.

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# ABSTRACT

Nearly 73% of the country's total installed power generation capacity is thermal of which coal-based generation is 90%. Some 85 thermal power stations, besides several captive power plants use bituminous and sub-bituminous coal and produce large quantities of fly ash. High ash content (30% - 50%) coal contributes to these large volumes of fly ash. The country's dependence on coal for power generation has unchanged. Thus fly ash management is a cause of concern for the future.

The purpose of this project is to find a suitable utilization for a particular fly ash sample depending upon its geotechnical properties and thus reduce the need for vast areas for disposal of fly ash which in turn causes considerable damage to the environment.

In this project various geotechnical experiments are performed on fly ash samples. Some of them are Standard Procter Compaction test, Liquid limit test, Permeability study, Unconfined compressive strength study etc. Based on the results obtained from these experiments, a suitable end use for the fly ash based on the characteristics of the sample is ascertained. The results from the geotechnical experiments help in determining the potential of the fly ash for use, in highway embankments, in construction of bricks, as an aggregate material in Portland cement, filling of low lying areas etc.

From the results obtained it was found that the fly ash can be compacted over a large moisture content range thus it has a potential to be used in fills and embankments. Also since fly ash is having low permeability thus it further benefits the use in fills and embankments by reducing the chances of damage to the ground water resources. The low specific gravity of fly and the pozzolanic activity of fly ash aids for its use along-with cements for construction purposes and also in manufacturing of bricks.

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# CHAPTER 1

# INTRODUCTION

## 1.1 ASH FROM COAL COMBUSTION

The quality of coal depends upon its rank and grade. The coal rank arranged in an ascending order of carbon contents is:

Peat << Lignite << sub-bituminous coal << bituminous coal << anthracite

Indian coal is of mostly sub bituminous rank followed by bituminous and lignite (brown coal). The ash content in Indian coal ranges from 35 % to 50 %.

The coal properties including calorific values differ depending upon the colliery. The calorific value of the Indian coal (~ 15 MJ/Kg) is less than the normal range of 21 MJ/kg to 33 MJ/kg (gross).

There are generally three categories of coal ashes available from thermal power stations:

- Dry fly ash – collected from different rows of electrostatic precipitator in dry form. The fly ash produced from the burning of pulverized coal in a coal-fired boiler is a fine-grained, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, bag-houses, or mechanical collection devices such as cyclones.
- Bottom ash – collected at the bottom of the boiler furnace and is characterized by better geotechnical properties.
- Pond ash – Fly ash and bottom ashes are mixed together with water to form slurry which is pumped to the ash pond area. In the ash pond the, ash gets settled and excess water is decanted. This deposited ash is pond ash.

## 1.2 FLY ASH

Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. When mixed with lime and water the fly ash forms a cementitious compound with properties very similar to that of Portland cement. Because of this similarity, fly ash can be used to replace a portion of cement in the concrete, providing some distinct quality advantages. The concrete is denser resulting in a tighter, smoother surface with less bleeding.

A comparison of fly ash particles sizes to those of several types of soils is presented in the Figure 1.1. Fly ash is a fine residue composed of unburned particles that solidify while suspended in exhaust gases. Fly ash is carried off in stack gases from a boiler unit, and is collected by mechanical methods or electrostatic precipitators. Because it is collected from exhaust gases, fly ash is composed of fine spherical silt size particles in the range of 0.074 to 0.005 mm (Ferguson 1993). Fly ash collected using mechanical precipitators usually has coarser particles than fly ash collected using electrostatic precipitators.

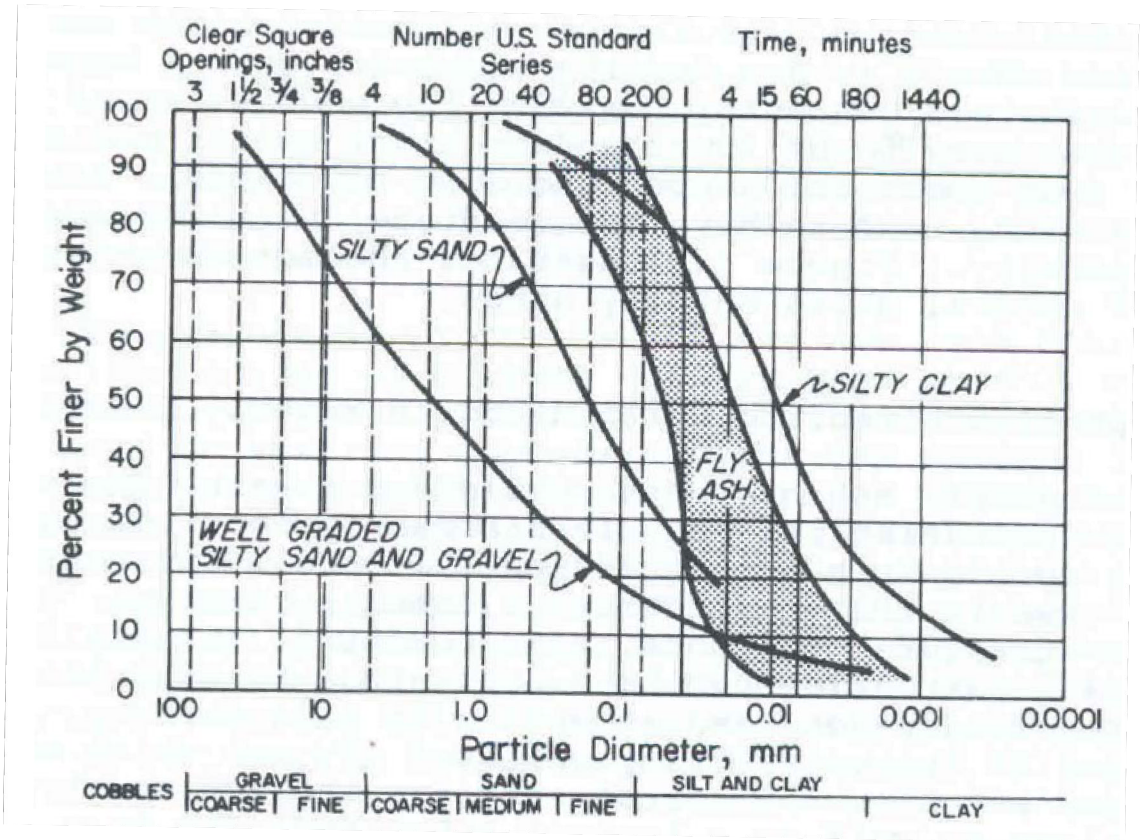


Figure 1.1 Comparison of fly ash particles to those of several soils (from Meyers et al. 1976)

## 1.3 ENVIRONMENTAL IMPACTS OF FLY ASH

The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 sq. km. of land. Since coal currently accounts for 70% of power production in the country, there is a need of new and innovative methods for reducing impacts on the environment.

The problem with fly ash lies in the fact that not only does its disposal require large quantities of land, water and energy, its fine particles, if not managed well, can become airborne. Currently more 100 million tones of fly ash are being generated annually in India, with 65000 acres of land being occupied by ash ponds. Such a huge quantity dose poses challenging problems, in the form of land use, health hazards and environmental damages.

### 1.3.1 Hazards

By virtue of its physical characteristics and sheer volumes generated, fly ash poses problems like:

- It is a very difficult material to handle in dry state because it is very fine and readily airborne even in mild wind.
- It disturbs the ecology of the region, being a source of soil, air and water pollution.
- Long inhalation of fly ash causes silicosis, fibrosis of lungs, bronchitis, pneumonitis etc.
- Flying fine particles of ash poses problems for people living near power stations, corrode structural surfaces and affect horticulture.
- Eventual settlement of fly ash particles over many hectares of land in the vicinity of power station brings about perceptible degeneration in soil characteristics.

## 1.4 NEED FOR UTILIZATION OF FLY ASH

Considering that the Ninth plan (1997-2002) had proposed a pivotal place to thermal power generation it was estimated that it shall increase at an annual rate of around 8-10%. Consequently, fly ash generation shall touch the 100 million tonne / year mark by year 2000 & 125 million tonne by 2003-2004.

The major sources of fly ash production in India are the thermal power units. It is estimated that by the end of the tenth plan period (March 2007) an additional 124000 MW of power sector expansion will be required in India to meet the rising energy demand. Though the state of Orissa is not thickly industrialized, the fly ash generation in the state is to the tune of 93 lakh tones per annum. As far as thermal power sectors in Orissa are concerned about 22.6% of fly ash is being utilized. This trend in future may require large amount of land area for disposal of fly ash.

According to Central Electricity authority of India, there are around 85 major coal fired thermal power plants and 305 hydro plants existing in India. As per the ministry of power statistics, the total installed generating capacity (Thermal + wind) during 2003-2004 was about 79838 MW and hydropower generation was 29500 MW. In addition to this, there are more than 1800 selected industrial units which had captive thermal power plants of greater than 1 MW capacity.

Some of the prominent Power Plants which are also producing and providing good quality Fly Ash include the following:

| | | | |
|---|---|---|---|
| Ropar | Rihand | Dahanu | Ramagundam |
| Kota | Singrauli | Trombay | Korba |
| Annapara | Unchahar | Vindyanchal | |
| Dadri | Chandrapur | Raichur | |

Present Scenario on Fly Ash in India

- Over 73 % of the total installed power generation is thermal
- 230 - 250 million MT coal is being used every year
- High ash contents varying from 30 to 50%
- More than 110 million MT of ash generated every year
- Ash generation likely to reach 170 million MT by 2010
- Presently 65,000 acres of land occupied by ash ponds
- Presently as per the Ministry of Environment & Forest Figures, 30% of Ash is being used in Fillings, embankments, construction, block & tiles, etc.

The fly ash produced as a result of burning of Indian coal has tremendous potential to be utilized for different applications. Rough estimates of existing utilization are around 30% of the total generated fly ash as against 10 % in 1999 and 3-5% in 1994. The fly ash being generated from the various industries will continue to increase in the subsequent years. The current percentage of utilization of fly ash in India is very less as compared to the other countries like Germany, Netherlands etc where the utilization is above 90 %.

As nearly 73% of the country's total installed power generation capacity is thermal of which coal-based generation is 90%. Some 85 thermal power stations, besides several captive power plants use bituminous and sub-bituminous coal and produce large quantities of fly ash. High ash content (30% - 50%) coal contributes to these large volumes of fly ash. Also the country's dependence on coal for power generation has unchanged. *Thus fly ash management is a major cause of concern for the future.*

## 1.5 OBJECTIVE OF THIS REPORT:

The main objective of utilization of this report is:

- Review of literature on:
  - The production of fly ash in India
  - The necessity for the utilization of fly ash
  - Disposal methods of fly ash
- Characterization of different types of fly ash.
  - Based on their physical and chemical properties.
- Utilization of fly ash
  - Find out a particular end use for a particular waste generated during any of the processes involved.
  - To reduce the toxicity of hazardous wastes or to minimize its impacts on the environment
  - Find out an alternative method of disposal of potentially harmful wastes.

# CHAPTER 2

# LITERATURE REVIEW

GENERATION
CARACTERIZATION
UTILIZATION
DISPOSAL

# LITERATURE REVIEW

## 2.1 FLY ASH GENERATION

The fly ash produced from the burning of pulverized coal in a coal-fired boiler is a fine-grained, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, baghouses, or mechanical collection devices such as cyclones.

In general, there are three types of coal-fired boiler furnaces used in the electric utility industry. They are referred to as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces. The most common type of coal burning furnace is the dry-bottom furnace.

When pulverized coal is combusted in a dry-ash, dry-bottom boiler, about 80 percent of all the ash leaves the furnace as fly ash, entrained in the flue gas. When pulverized coal is combusted in a wet-bottom (or slag-tap) furnace, as much as 50 percent of the ash is retained in the furnace, with the other 50 percent being entrained in the flue gas. In a cyclone furnace, where crushed coal is used as a fuel, 70 to 80 percent of the ash is retained as boiler slag and only 20 to 30 percent leaves the furnace as dry ash in the flue gas. A general flow diagram of fly ash production in a dry-bottom coal-fired utility boiler operation is presented in Figure

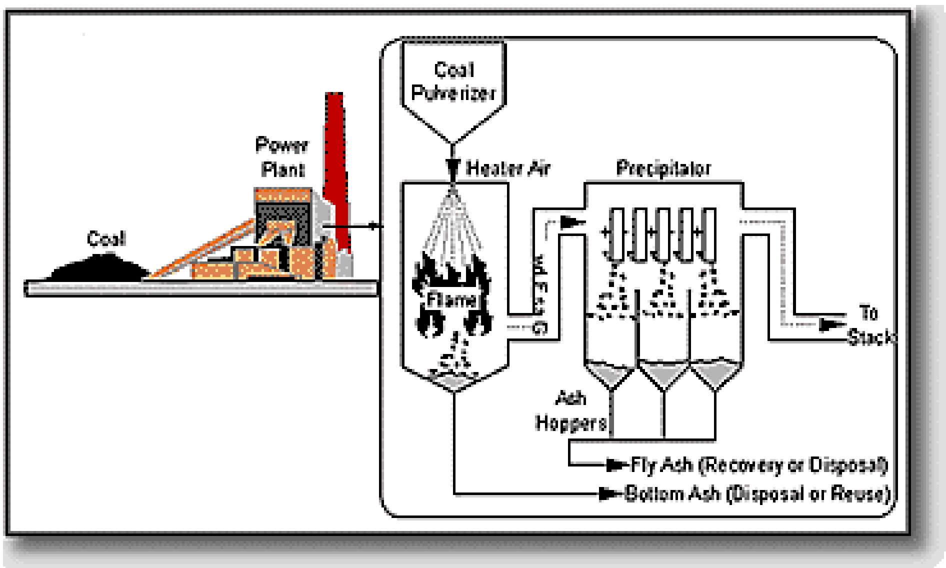


Figure 2.1 Generation of ash at the power plants

## 2.2 TRANSPORTATION

Fly ash can be supplied in four forms

- *Dry*: This is currently the most commonly used method of supplying fly ash. Dry fly ash is handled in a similar manner to portland cement. Storage is in sealed silos with the associated filtration and desiccation equipment or in bags.
- *Conditioned*: In this method, water is added to the fly ash to facilitate compaction and handling. The amount of water added being determined by the end use of the fly ash. Conditioned fly ash is widely used in aerated concrete blocks grout and specialist fill applications.
- *Stockpiled:* conditioned fly ash not sold immediately is stockpiled and used at a later date. The moisture content of stockpiled ash is typically 10 to 15 %. This is used mainly in large fill and bulk grouting applications.
- *Lagoon:* Some power stations pump fly ash as slurry to large lagoons. These are drained and when the moisture content of deposited fly ash has reached a safe level may be recovered. Because of the nature of the disposal technique the moisture content can vary from around 5 % to over 30 %. Lagoon fly ash can be used in similar applications as stockpiled & conditioned fly ash)

## 2.3 CHARACTERIZATION OF FLY ASH

Coal-based thermal power plants all over the world face serious problems of handling and disposal of the ash produced. The high ash content (30–50%) of the coal in India makes this problem complex. At present, about 85 thermal power stations produce nearly 110 million tonnes of coal ash per annum. Safe disposal of the ash without adversely affecting the environment and the large storage area required are major concerns. Hence attempts are being made to utilize the ash rather than dump it. The coal ash can be utilized in bulk only in geotechnical engineering applications such as construction of embankments, as a backfill material, as a sub-base material, etc. For this, an in-depth understanding of the physical and chemical properties, and engineering and leaching behavior are required. This necessitates characterization of the fly ash with reference to geotechnical applications.

### 2.3.1 Physical properties

Physical properties help in classifying the coal ashes for engineering purposes and some are related to engineering properties. The properties discussed are specific gravity, grain size distribution, index properties, free swell index and specific surface as well as classification.

#### *2.3.1.1 Specific gravity*

Specific gravity is one of the important physical properties needed for the use of coal ashes for geotechnical and other applications. In general, the specific gravity of coal ashes varies around 2.0 but can vary to a large extent (1.6 to 3.1). Because of the generally low value for the specific gravity of coal ash compared to soils, ash fills tend to result in low dry densities. The reduction in unit weight is of advantage in the case of its use as a backfill material for retaining walls since the pressure exerted on the retaining structure as well as the foundation structure will be less. The other application areas include embankments especially on weak foundation soils, reclamation of low-lying areas, etc. The variation of specific gravity of the coal ash is the result of a combination of many factors such as gradation, particle shape and chemical composition. It is known that coal ash comprises mostly glassy cenospheres and some solid spheres. The reason for a low specific gravity could either be due to the presence of large number of hollow cenospheres from which the entrapped air cannot be removed, or the variation in the chemical composition, in particular iron content, or both.

The investigations show that the specific gravity generally lies between 1.46 and 2.66. In most of the cases, fly ash will have higher specific gravity compared to pond and bottom ashes of the same locality. When the particles are crushed, they show a higher specific gravity compared to the uncrushed portion of the same material.

#### *2.3.1.2 Grain size distribution*

Grain size distribution indicates if a material is well graded, poorly graded, fine or coarse, etc. and also helps in classifying the coal ashes. Coal ashes are predominantly silt sized with some sand-size fraction. Leonards and Bailey have reported the range of gradation for fly and bottom ashes which can be classified as silty sands or sandy silts.

The extensive investigation carried out on Indian coal ashes demonstrates that the fly ashes consist predominantly of silt-size fraction with some clay-size fraction. The pond ashes consist of silt-size fraction with some sand-size fraction. The bottom ashes are coarser particles consisting predominantly of sand-size fraction with some silt-size fraction.

Based on the grain-size distribution, the coal ashes can be classified as sandy silt to silty sand. They are poorly graded with coefficient of curvature ranging between 0.61 and 3.70. The coefficient of uniformity is in the range of 1.59–14.0.

*2.3.1.3 Index properties*

Index properties are extensively used in geotechnical engineering practice. Among them, liquid limit is an important physical property for use in classification and for correlations with engineering properties. While a number studies have been made on the liquid limit of fine-grained soils not much work has been done on coal ashes. Currently, two methods (Percussion cup and fall cone methods) are popular for the determination of liquid limit of fine-grained soils. In the Percussion cup method it is very difficult to cut a groove in soils of low plasticity and the soils have tendency to slip rather than flow. Hence, this method is not suitable for fly ashes which are nonplastic in nature. Even in the Cone penetration method, there is a tendency for the fly ash in the cup to liquify at the surface. There is also a variation of water content in the cup with depth and it is very difficult to get a smooth level surface of the ash in the cup.

A new method of determining liquid limit called "Equilibrium water content under $K_o$ stress method" has been found to be effective for the determination of liquid limit of coal ashes. The proposed method is simple, reasonably error free, less time consuming and has good reproducibility. However, it is not suitable for class C fly ashes which gain strength with time.

The results obtained using the proposed method show that fly ashes have liquid limit water content ranging from 26 to 51%, 22 to 64% for pond ashes, and 45 to 104% for bottom ashes. The liquid limit values exhibited by coal ashes are not due to their plasticity characteristics but are due to their fabric and carbon content. All the coal ashes tested are non-plastic and hence plastic limit could not be determined. It was also not possible to carry out shrinkage limit tests since the ash pats crumbled upon drying. Since the amount of shrinkage is very less, the shrinkage limit will be quite high. Hence shrinkage will not be a constraint.

*2.3.1.4 Free swell index*

Free swell index in soil engineering serves as a tool to identify swelling soils. The free swell test method proposed by Holtz and Gibbs to estimate the swell potential suffers from certain limitations. Sridharan et al. modified the definition of free swell index itself to take care of the limitations. There is hardly any information on the free swell index of coal ashes in published literature. Hence, experiments were carried out at IISc to study the free swell index of coal ashes. The results indicate that 70% of the coal ashes show negative free swell index which is due to flocculation. Since the clay-size fraction in coal ashes is very less, the free swell index is negligible.

*2.3.1.5 Specific surface*

The study of specific surface of soils is widely recognized as a means to understand their physical and engineering behavior. Even though coal ashes are primarily silt/sand-sized particles and their specific surface is expected to be very low, results need be obtained for completeness and for use in certain cases. With this in mind, the surface area measurements were made using Desiccator method and Blaines Air Permeability method.

*2.3.1.6 Classification*

For an effective and efficient use of coal ashes in geotechnical engineering practice, their classification from geotechnical engineering point of view is important. While a number of studies have been made on the physical and engineering properties of coal ashes and their utilization in geotechnical engineering practice, no information is available with respect to their classification.

### 2.3.2 Chemical properties

The chemical properties of the coal ashes greatly influence the environmental impacts that may arise out of their use/disposal as well as their engineering properties. The adverse impacts include contamination of surface and subsurface water with toxic heavy metals present in the coal ashes, loss of soil fertility around the plant sites, etc. Hence this calls for a detailed study of their chemical composition, morphological studies, pH, total soluble solids, etc.

*2.3.2.1 Chemical composition*

Chemical composition suggests the possible applications for coal ash. The investigations carried out on Indian fly ashes show that all the fly ashes contain silica, alumina, iron oxide and calcium oxide. The silica content in fly ashes is between 38 and 63%, 37 and 75% in pond ashes, and 27 and 73% in bottom ashes. The alumina content ranges between 27 and 44% for fly ashes, 11 and 53% for pond ashes and 13 and 27% for bottom ashes. The calcium oxide is in the range of 0 to 8% for fly ashes, 0.2 to 0.6% for pond ashes and 0 to 0.8% for bottom ashes. It is found that all the Indian coal ashes satisfy the chemical requirements for use as a pozzolona. According to ASTM classification, only Neyveli fly ash can be classified as Class C fly ash and all other coal ashes fall under Class F.

*2.3.2.2 X-ray diffraction*

X-ray diffraction studies are carried out primarily to identify the mineral phases. The studies carried out indicate that coal ashes predominantly consist of quartz and feldspar minerals.

The studies carried out at IISc reveal that the major mineral found in coal ashes is quartz with lesser proportions of feldspars, carbonates and chlorites. The coal ashes exhibit both crystalline and amorphous phases. The range of chemical composition of Indian coal ashes together with that for soil (for comparison purposes) is reported in Table .2.1

| **Compounds** | **Fly ash** | **Pond ash** | **Bottom ash** | **Soils** |
|---|---|---|---|---|
| $SiO_2$ | 38–63 | 37.7–75.1 | 23–73 | 43–61 |
| $Al_2O_3$ | 27–44 | 11.7–53.3 | 13–26.7 | 12–39 |
| $TiO_2$ | 0.4–1.8 | 0.2–1.4 | 0.2–1.8 | 0.2–2 |
| $Fe_2O_3$ | 3.3–6.4 | 3.5–34.6 | 4–10.9 | 1–14 |
| MnO | 0–0.5 | bd–0.6 | bd–0.3 | 0–0.1 |
| MgO | 0.01–0.5 | 0.1–0.8 | 0.1–0.7 | 0.2–3.0 |
| CaO | 0.2–8 | 0.2–0.6 | 0.1–0.8 | 0–7 |
| $Na_2O$ | 0.07–0.43 | 0.05–0.31 | bd–0.3 | 0.2–3 |
| LOI | 0.2–3.4 | 0.01–20.9 | 0.61–51.6 | 5–16 |

Table 2.1 Range of chemical composition of Indian Coal Ashes

*2.3.2.3 pH*

In general, fly ash can be classified as an amorphous ferro-alumino silicate mineral. The amorphous iron aluminium oxides as well as manganese oxides present on the surface of fly ash particles act as a sink, adsorbing the trace elements. It is this quantity of trace element which is available for leaching. The degree of solubility of these oxide sinks determines the release of the elements associated with them into the aqueous medium. The pH of the aqueous medium affects the solubility of these oxides and hence their physico-chemical characteristics. Further, the mobilization of trace elements in aqueous medium is often regulated by the solubility of hydroxide and carbonate salts which also depends on the pH of the aqueous media.

The investigations carried on Indian coal ashes at IISc show that fly ash has higher pH values compared to pond and bottom ashes. The fly ash with higher free lime and alkaline oxides exhibits higher pH values. Since all the coal ashes tested are nearly alkaline, they can be used in reinforced cement concrete which will be safe against corrosion.

*2.3.2.4 Total soluble solids*

The presence of soluble solids is an important aspect requiring examination since the water soluble solids greatly influence the engineering properties. Further, the solubility of nutrient elements such as calcium, magnesium, iron, sulphur, phosphorus, potassium and manganese affect the crop yield to a great extent.

The present investigations showed that the soluble solids range between 400 and 17600 ppm for fly ashes, 800 and 3600 ppm for pond ashes, and 1400 and 4100 ppm for bottom ashes.

*2.3.2.5 Lime reactivity*

The strength of fly ash generally improves with time due to pozzolanic reactions. Reactive silica and free lime contents are necessary for pozzolanic reactions to take place. Lime reactivity is a property which depends on the proportion of reactive silica in coal ash.

Based on the work at IISc, the lime reactivity is found to be high for coal ashes with high silica content. It was also found to be high for fly ash compared to bottom and pond ashes. The results indicate that a high percentage of free lime in coal ash plays an important role in increasing its lime reactivity.

### 2.3.3 Compaction behavior

The density of coal ashes is an important parameter since it controls the strength, compressibility and permeability. Densification of ash improves the engineering properties. The compacted unit weight of the material depends on the amount and method of energy application, grain size distribution, plasticity characteristics and moisture content at compaction.

The variation of dry density with moisture content for fly ashes is less compared to that for a well-graded soil, both having the same median grain size. The tendency for fly ash to be less sensitive to variation in moisture content than for soils could be explained by the higher air void content of fly ash. Soils normally have air void content ranging between 1 and 5% at maximum dry density, whereas fly ash contains 5 to 15%. The higher void content could tend to limit the build up of pore pressures during compaction, thus allowing the fly ash to be compacted over a larger range of water content.

### 2.3.4 Strength behavior

An important engineering property that is necessary for using fly ash in many geotechnical applications is its strength. The compressive strength characteristics of fine ash are higher than those of coarser ash specimen. Also most of the shear strength of the fly ash specimen is due to internal friction.

Effects of additives – various research works carried out on the fly ashes in different part of the country have shown that the strength increases with the addition of gypsum and lime. In few cases addition of gypsum alone has no effects on the strength characteristics of fly ash.

### 2.3.5 Permeability behavior

Permeability is an important parameter in the design of liners to contain leachate migration, dykes to predict the loss of water as well as the stability of slopes and as a sub-base material. The coefficient of permeability of ash depends upon the grain size, degree of compaction and pozzolanic activity. The permeability of fly ashes is in the range of 8 x $10^{-6}$ cm/s to 1.87 x $10^{-4}$ cm/s, 5 x $10^{-5}$ cm/s to 9.62 x $10^{-4}$ cm/s for pond ashes, and 9.9 x $10^{-5}$ cm/s to 7 x $10^{-4}$ cm/s for bottom ashes.

### 2.3.6 Leaching behavior

If water contacts or passes through a porous media, each constituent present in the matrix dissolves into pore water at some finite rate because there is no such thing as a completely insoluble material (Conner 1990). Permeation of the contaminated pore water out of the porous matrix due to any driving force is called "leaching." The contaminated water that is generated as water passes through a porous matrix is called "leachate." The capacity of the waste material to leach is called its "leachability."

Depending on the sources of coals used in thermal power plants, fly ash may contain various toxic elements. Due to serious environmental problems involved, the leaching of these toxic elements from ash ponds is gaining considerable importance. The review of literature reveals that the release of contaminants from fly ash and their subsequent influence on ground-water quality is governed by several factors including quality of coal, sources of water, pH, time, temperature, etc. The leachate characteristics are highly variable and even within a given landfill site, leachate quality varies over time and space.

## 2.4 FLY ASH CLASSIFICATION

Depending upon the type of coal from which the fly ash is generated the composition of the fly ash is given in Table

| Component | Bituminous | Sub-bituminous | Lignite |
|---|---|---|---|
| $SiO_2$ | 20 – 60 | 40 – 60 | 15 – 45 |
| $Al_2O_3$ | 5 – 35 | 20 – 30 | 10 – 25 |
| $Fe_2O_3$ | 10 – 40 | 4 – 10 | 4 – 15 |
| CaO | 1 – 12 | 5 – 30 | 15 – 40 |
| MgO | 0 – 5 | 1 – 6 | 3 – 10 |
| $SO_3$ | 0 – 4 | 0 – 2 | 0 – 10 |
| $Na_2O$ | 0 – 4 | 0 – 2 | 0 – 6 |
| $K_2O$ | 0 – 3 | 0 – 4 | 0 – 4 |
| LOI | 0 – 15 | 0 – 3 | 0 – 5 |

Table 2.2 Normal range of chemical composition for fly ash produced from different coal types (expressed as percent by weight)

Variability of the chemical and physical properties of fly ash depends on several factors such as coal type and source, type of boiler, conditions during combustion, type of emission control devices, and storage and handling methods. Changes in any of these factors affect the characteristics of the fly ash, and its engineering properties.

Coal type is one of the factors having the greatest effect on the fly ash characteristics. In general as the amounts $SiO_2$, $Al_2O_3$ and free lime (CaO) increases the pozzolanic activity of the fly ash increases (Meyers et al. 1976).

**Classification as per ASTM Standards C 618 - 99**

Fly ash is classified into two classes, F and C, based on the chemical composition of the fly ash. The chemical requirements stipulated in ASTM C 618 for classifying fly ashes are shown in Table 2.3. When the chemical composition does not comply with the requirements either for Class C or F that stipulated in ASTM C 610, the fly ash is classified as off-specification fly ash.

Class F fly ash is produced from burning anthracite and bituminous coals. This fly ash has siliceous or siliceous and aluminous material, which itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form cementitious compounds (Chu et al. 1993). Class C fly ash is normally produced from lignite and sub-bituminous coals, and usually contains a significant amount of calcium hydroxide (CaO), also known as lime (Cockrell et al. 1970). In addition to having pozzolanic properties, Class C fly ash also is cementitious (ASTM C 618-99).

The chemical composition of fly ash influences its color. The color of fly ash ranges from light brown or cream to dark brown or gray. Color is useful for estimating the calcium oxide content and organic content of fly ash. Lighter color fly ash generally has a greater percentage calcium oxide. Darker colors suggest higher organic content (Cockrell et al. 1970).

| Chemical Requirements | Class of Fly Ash | |
|---|---|---|
| | F* | C* |
| Silicon Dioxide (SiO2) plus Aluminum Oxide (Al2O3) plus Iron Oxide (Fe2O3), min (%) | 70 | 50 |
| Sulfur Trioxide (SO3), max (%) | 5 | 5 |
| Moisture Content, max (%) | 3 | 3 |
| Loss on Ignition, max (%) | 6 | 6 |

Table 2.3 Classification of fly ash based on ASTM Standards

## 2.5 UTILIZATION OF FLY ASH

Fly ashes produced from bituminous and sub-bituminous coals can be used in several civil engineering applications. One common application is an admixture to Portland cement to increase workability, strength, and reduce heat of hydration of concrete. Fly ash can be used in combination with lime, or by itself for soil stabilization of road base and subbases to increase the bearing capacity of soil. Fly ash is also combined with water, Portland cement, and sand to produce flowable fills that flow like liquid and set up like a solid. Other fly ash applications that have been reported include use in grouts, fast-track concrete pavements, and as structural fills and backfills

### 2.5.1. Fly Ash in Portland cement Concrete

Fly ash is used in concrete admixtures to enhance the performance of concrete. Portland cement contains about 65 percent lime. Some of this lime becomes free and available during the hydration process. When fly ash is present with free lime, it reacts chemically to form additional cementations materials, improving many of the properties of the concrete.

*Benefits to Fresh Concrete***:** Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior. The resulting benefits are as follows:

- *Improved workability:* The spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix, thus providing a lubricant effect. This same effect also improves concrete pumpability by reducing frictional losses during the pumping process and flat work finishability.
- *Decreased water demand:* The replacement of cement by fly ash reduces the water demand for a given slump. When fly ash is used at about 20 percent of the total cementitious, water demand is reduced by approximately 10 percent. Higher fly ash contents will yield higher water reductions. The decreased water demand has little or no effect on drying shrinkage/cracking. Some fly ash is known to reduce drying shrinkage in certain situations.
- *Reduced heat of hydration:* Replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete. This reduction in the heat of

hydration does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements.

*Benefits to Hardened Concrete*: One of the primary benefits of fly ash is its reaction with available lime and alkali in concrete, producing additional cementitious compounds.

- *Increased ultimate strength:* The additional binder produced by the fly ash reaction with available lime allows fly ash concrete to continue to gain strength over time. Mixtures designed to produce equivalent strength at early ages (less than 90 days) will ultimately exceed the strength of straight cement concrete mixes.
- *Reduced permeability:* The decrease in water content combined with the production of additional cementitious compounds reduces the pore interconnectivity of concrete, thus decreasing permeability. The reduced permeability results in improved long-term durability and resistance to various forms of deterioration.
- *Improved durability:* The decrease in free lime and the resulting increase in cementitious compounds, combined with the reduction in permeability enhance concrete durability.

Fly Ash Properties affecting use in PPC

- *Fineness:* The fineness of fly ash is important because it affects the rate of pozzolanic activity and the workability of the concrete.
- *Specific gravity:* Although specific gravity does not directly affect concrete quality, it has value in identifying changes in other fly ash characteristics.
- *Chemical composition:* The reactive aluminosilicate and calcium aluminosilicate components of fly ash are routinely represented in their oxide nomenclatures such as silicon dioxide, aluminum oxide and calcium oxide.

### 2.5.2. Fly Ash in Stabilized Base Course

Fly ash and lime can be combined with aggregate to produce a quality stabilized base course. These road bases are referred to as pozzolanic-stabilized mixtures (PSMs). Typical fly ash contents may vary from 12 to 14 percent with corresponding lime contents of three to five percent. Portland cement may also be used in lieu of lime to increase early age strengths. The resulting material is produced, placed, and looks like cement stabilized aggregate base.

*Benefits*,. PSM bases have advantages over other base materials:

- Use of locally available materials
- Provides a strong, durable mixture
- Lower costs
- Autogenous healing
- Increased energy efficiency
- Suitable for using recycled base materials
- Can be placed with conventional equipment

Specification Requirements

- *Strength***.** Closely controlled curing conditions are important as both time and temperature significantly affect strength.
- *Durability***.** It is important to ensure that adequate resistance to freeze-thaw cycling is achieved before the onset of colder months.

### 2.5.3. Fly Ash in Flowable Fill

Flowable fill is a mixture of coal fly ash, water, and Portland cement that flows like a liquid, sets up like a solid, is self leveling, and requires no compaction or vibration to achieve maximum density. In addition to these benefits, a properly designed flowable fill may be excavated later. For some mixes, an optional filler material such as sand, bottom ash, or quarry fines, is added. Flowable fill is also referred to as controlled low-strength material, flowable mortar, or controlled density fill. It is designed to function in the place of conventional backfill materials such as soil, sand, or gravel and to alleviate problems and restrictions generally associated with the placement of these materials.

*The benefits* of using flowable fill include:

- Allows placement in any weather, even under freezing conditions
- Achieves 100 percent density with no compactive effort

- Fills around/under structures inaccessible to conventional fill placement techniques
- Increases soil-bearing capacities
- Prevents post-fill settlement problems
- Increases the speed and ease of backfilling operations
- Decreases the variability in the density of the backfilled materials
- Improves safety at the job site and reduces labor costs
- Decreases excavation costs
- Allows easy excavation later when properly designed

Specification Requirements

- *Strength development:* Strength development in flowable fill mixtures is directly related to the amount of cementitious material and water content. With low CaO (Class F) fly ashes, the cement content and water content relate directly to strength development. With high CaO (Class C) fly ashes, no cement may be required and strength is related directly to the fly ash and water content.
- *Flowability*: Flowability is basically a function of the water and entrained air content. The higher the water and air content, the more flowable the mix.

### 2.5.4. Fly Ash in Structural Fills/Embankments

Fly ash can be used as a borrow material to construct fills and embankments. When fly ash is compacted in lifts, a structural fill is constructed that is capable of supporting highway buildings or other structures. Fly ash has been used in the construction of structural fills/embankments that range from small fills for road shoulders to large fills for interstate highway embankments.

*Benefits*, When used in structural fills and embankments, fly ash offers several advantages over soil and rock:

- Cost-effective where available in bulk quantities
- Eliminates the need to purchase, permit, and operate a borrow pit
- Can be placed over low bearing strength soils

- Ease of handling and compaction reduce construction time and equipment costs

*Physical, engineering, and chemical properties of the ash:*

The physical and engineering properties of fly ash that will determine the behavior of the embankment are grain-size distribution, moisture-density relationships, shear strength, compressibility, permeability, capillarity, and frost susceptibility. Laboratory tests designed for testing soil properties may be applied to testing fly ash. The chemical characteristics of the fly ash affect the physical behavior as well as the quality of the leachate produced by the ash. The utility company or its marketing agent can provide information on the physical, engineering, and chemical composition of the ash and leachate characteristics.

*Environmental impacts:*

The trace element concentrations in many fly ashes are similar to those found in naturally occurring soils. Although the leachates of some fly ashes may contain trace element concentrations that exceed drinking water quality standards, this is also true of certain soils. State environmental regulatory agencies can guide you through applicable test procedures and water quality standards. The amount of leachate produced can be controlled by assuring adequate compaction, grading to promote surface runoff, and daily proof-rolling of the finished subgrade to impede infiltration. When construction is finished, a properly seeded soil cover will reduce infiltration. For highway embankments, the pavement may be an effective barrier to infiltration.

### 2.5.5. Fly Ash in Soil Improvement

Fly ash is an effective agent for chemical and/or mechanical stabilization of soils, soil density, water content, plasticity, and strength performance of soils. Typical applications include: soil stabilization, soil drying, and control of shrink-swell.

*Benefits*: Fly ash provides the following benefits when used to improve soil conditions:

- Eliminates need for expensive borrow materials
- Expedites construction by improving excessively wet or unstable subgrade
- By improving subgrade conditions, promotes cost savings through reduction in the required pavement thickness

- Can reduce or eliminate the need for more expensive natural aggregates in the pavement cross-section

*Soil Stabilization to Improve Soil Strength*

Fly ash has been used successfully in many projects to improve the strength characteristics of soils. Fly ash can be used to stabilize bases or subgrades, to stabilize backfill to reduce lateral earth pressures and to stabilize embankments to improve slope stability. Typical stabilized soil depths are 15 to 46 centimeters (6 to 18 inches). The primary reason fly ash is used in soil stabilization applications is to improve the compressive and shearing strength of soils. The compressive strength of fly ash treated soils is dependent on:

- In-place soil properties
- Delay time
- Moisture content at time of compaction
- Fly ash addition ratio

### 2.5.6. Use of fly ash for treatment of Acid Mine Drainage:

Both acid mine drainage and fly ash from coal burning power generation pose substantial environmental and economic problems. Leachates from stockpiled fly ash (FA) are highly siliceous, calcium rich, and extremely alkaline (pH >12). Acid mine drainage (AMD) is highly acidic (pH 2-4), sulphate-rich and frequently carry a high transition metal and heavy metal burden. It is produced when groundwater comes into contact with sulphide minerals that are undergoing oxidation. The extreme pH levels, mineralization, ionic content and toxicity of these wastes are sufficiently environmentally damaging and they require expensive storage, remediation and disposal techniques to reduce their impacts.

Several research studies have also been carried out on the application of fly ash for the control of acid generation from sulphidic wastes and for amendment of acidic soils. Recent studies have shown that treatment of acid mine drainage (AMD) with fly ash is possible. Fly ash and fluidised bed ash can be used to treat AMD but their overdose could lead to trace metal accumulation with negative consequences to the environment.

### 2.5.7. Developments in Fly Ash Utilization

Several new and important technologies are being commercialized in the areas of fly ash beneficiation and utilization to bring fly ash into conformance with current AASHTO and ASTM specifications for use in concrete. As the fly ash utilization industry has matured, quality control, quality assurance, and improved product performance have increasingly become important. Technologies have been commercialized to improve and assure fly ash quality for conventional concrete applications. Also, fly ash utilization technologies have been developed to produce high performance concrete products.

*Other Developments:*

Ultra fine fly ash: As compared to typical fly ash, with a mean particle diameter ranging from 20-30 micrometers, ultra fine fly ash can be produced with a mean particle diameter of 1-5 microns. The reduced particle size means that the pozzolanic reaction, which is normally a slow process, is accelerated. Further, the finer particles may more completely react than the coarser particles of fly ash. So, the durability and strength benefits that one observes with a typical fly ash at a late age (more than one year) can be attained at a much earlier age (less than 90 days) and with a smaller dosage of an ultra fine fly ash.

High volume fly ash concrete (HVFAC**).** HVFAC refers to concrete where the fly ash comprises more than 30 percent of the total cementitious materials. HVFAC has a lower cost and is more durable than conventional concrete, and affords improved resistance to ASR and sulfate attack. Several successful field applications have been completed. Adequate early strengths and set times are obtained by using high range water reducers to achieve a very low water/cement ratio. Allowable cement substitution rates are currently limited by state transportation department specifications.

## 2.6. DISPOSAL OF FLY ASH

Although the scope for use of ash in concrete, brick making, soil-stabilization treatment and other applications has been well recognized, only a small quantity of the total ash produced in India is currently utilized in such applications. Most of the ash generated from the power plants is disposed off in the vicinity of the plant as a waste material covering several hectares of valuable land. The bulk utilization of ash is possible in two areas, namely, ash dyke construction and filling of low-lying areas. Coal ash has been successfully used as structural fills in many developed countries. However, this particular bulk utilization of ash is yet to be implemented in India. Since most of the thermal power plants in India are located in areas where natural materials are either scarce or expensive, the availability of fly ash is bound to provide an economic alternative to natural soils.

### 2.6.1. Fly ash Characterization and Testing

The properties of ash are a function of several variables such as coal source, degree of pulverization, design of boiler unit, loading and firing conditions, handling and storage methods. Thus, it is not surprising that a higher degree of variation can occur in ash, not only between power plants but within a single power plant also. A change in any of the above factors can result in detectable changes in the properties of the ash produced. The degree to which any change affects the utilization potential of ash is a function of the nature and degree of the change and the particular application for which the ash might be used. The physical, geotechnical and chemical parameters to characterize flyash are the same as those for natural soils, e.g., specific gravity, grain size, Atterberg limits, compaction characteristics, permeability coefficient, shear strength parameters and consolidation parameters. The procedures for determination of these parameters are also similar to those for soils.

### 2.6.2. Fly ash Disposal in Ash Ponds

Primarily, the fly ash is disposed off using either dry or wet disposal scheme. In dry disposal, the fly ash is transported by truck, chute or conveyor at the site and disposed off by constructing a dry embankment (dyke). In wet disposal, the fly ash is transported as slurry through pipe and disposed off in impoundment called "ash pond". Most of the power plants in India use wet disposal system, and when the lagoons are full, four basic options are available: (a) constructing new lagoons using conventional constructional material, (b) hauling of fly ash from the existing lagoons to another disposal site, (c) raising the existing dyke using conventional constructional material, and (d) raising the dyke using fly ash excavated from the lagoon ("ash dyke"). The option of raising the existing dyke is very cost effective because any fly ash used for constructing dyke would, in addition to saving the earth filling cost, enhance disposal capacity of the lagoon. The constructional methods for an ash dyke can be grouped into three broad categories: (a) Upstream method, (b) Downstream method and (c) Centerline method. Fig.2.2 – 2.4 shows typical configurations of embankments constructed using the different methods. The construction procedure of an ash dyke includes surface treatment of lagoon ash, spreading and compaction, benching and soil cover.

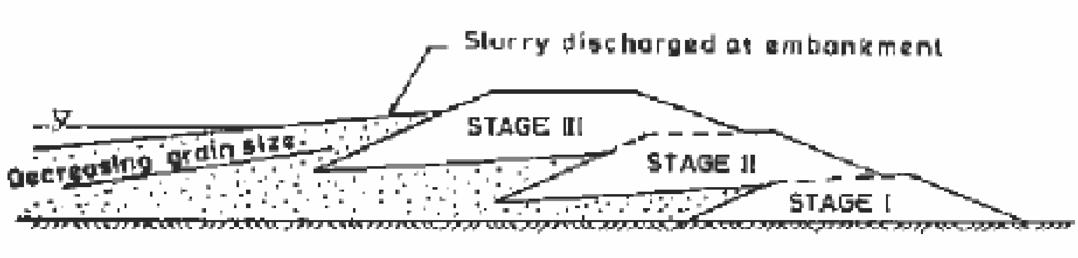


Figure 2.2 Upstream Method

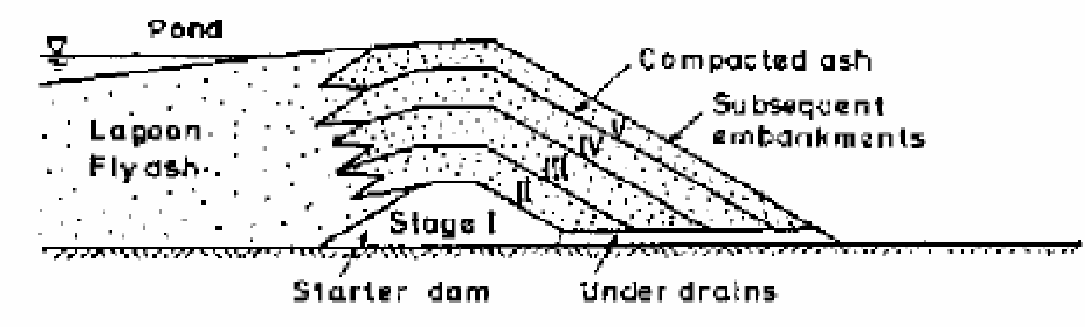


Figure 2.3 Downstream Method

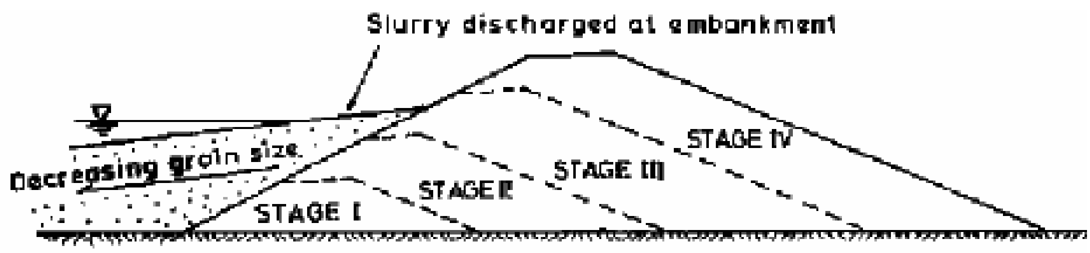


Figure 2.4 Centerline Method

An important aspect of design of ash dykes is the internal drainage system. The seepage discharge from internal surfaces must be controlled with filters that permit water to escape freely and also to hold particles in place and the piezometric surface on the downstream of the dyke. The internal drainage system consists of construction of rock toe, 0.5m thick sand blanket and sand chimney. After completion of the final section including earth cover the turfing is developed from sod on the downstream slope.

### 2.6.3. Fly ash as Fill Material

Large scale use of ash as a fill material can be applied where (a) fly ash replaces another material and is therefore in direct competition with that material, (b) fly ash itself is used by the power generating company producing the fly ash to improve the economics of the overall disposal of surplus fly ash; and (c) at some additional cost, fly ash disposal is combined with the rehabilitation and reclamation of land areas desecrated by other operations.

Fills can be constructed as structural fills where the fly ash is placed in thin lifts and compacted. Structural fly ash fills are relatively incompressible and are suitable for the support of buildings and other structures. Non-structural fly ash fill can be used for the development of parks, parking lots, playgrounds and other similar lightly loaded facilities. One of the most significant characteristics of fly ash in its use as a fill material is its strength. Well-compacted fly ash has strength comparable to or greater than soils normally used in earth fill operations. In addition, lignite fly ash possesses self-hardening properties which can result in the development of shear strengths. The addition of cement can induce hardening in bituminous fly ash which may not self-harden alone. Significant increases in shear strength can be realized in relatively short periods of time and it can be very useful in the design of embankments.

### 2.6.4. Environmental Considerations

The environmental aspects of ash disposal aim at minimizing air and water pollution. Directly related to these concerns is the additional environmental goal of aesthetically enhancing ash disposal facilities. The ash produced in thermal power plants can cause all three environmental risks - air, surface water and groundwater pollution. The pathways of pollutant movement through all these modes are schematically represented in Figure 2.5.

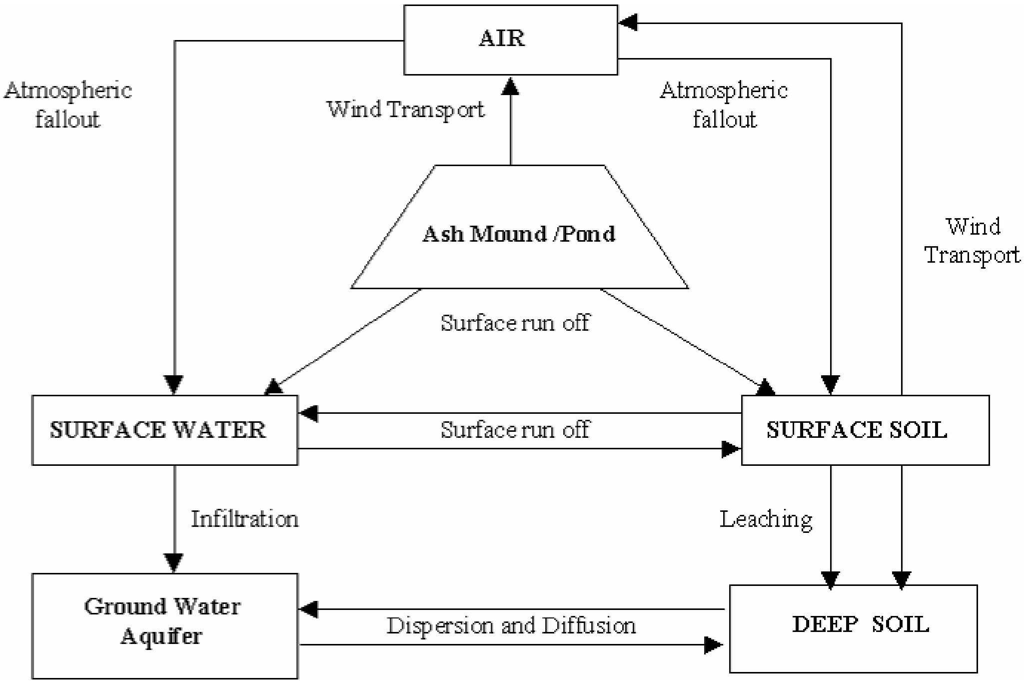


Figure 2.5 Pathways of Pollutant Movement around Ash Disposal Facility

Air pollution is caused by direct emissions of toxic gases from the power plants as well as wind-blown ash dust from ash mound/pond. The air-borne dust can fall in surface water system or soil and may contaminate the water/soil system. The wet system of disposal in most power plants causes discharge of particulate ash directly into the nearby surface water system. The long storage of ash in ponds under wet condition and humid climate can cause leaching of toxic metals from ash and contaminate the underlying soil and ultimately the groundwater system. However, most of these environmental problems can be minimized by incorporating engineering measures in the design of ash ponds and continuous monitoring of surface and groundwater water systems.

### 2.6.5. Disposal in Underground mines

One alternative to the typical disposal methods is the return and disposal of the byproducts in underground coal mines. This alternative could be economically beneficial to both the coal mining industry and the electric generating industry as well as provide environmental benefit.

The coal industry routinely slurries fine-coal waste from coal preparation and sludge from acid-mine drainage treatment facilities to underground mine workings in lieu of surface impoundment disposal. Therefore, it is not hard to conclude that injection of coal combustion byproducts into underground mines is technologically feasible.

*Environmental Concerns/ Benefits*

Modification to mine drainage patterns may occur and could affect adjacent property owners. In addition, there is potential for modifying or degrading local groundwater conditions and if dewatering a mine void area prior to filling with coal combustion byproducts is required, subsidence may be induced. However, there are some benefits to underground disposal that should be highlighted.

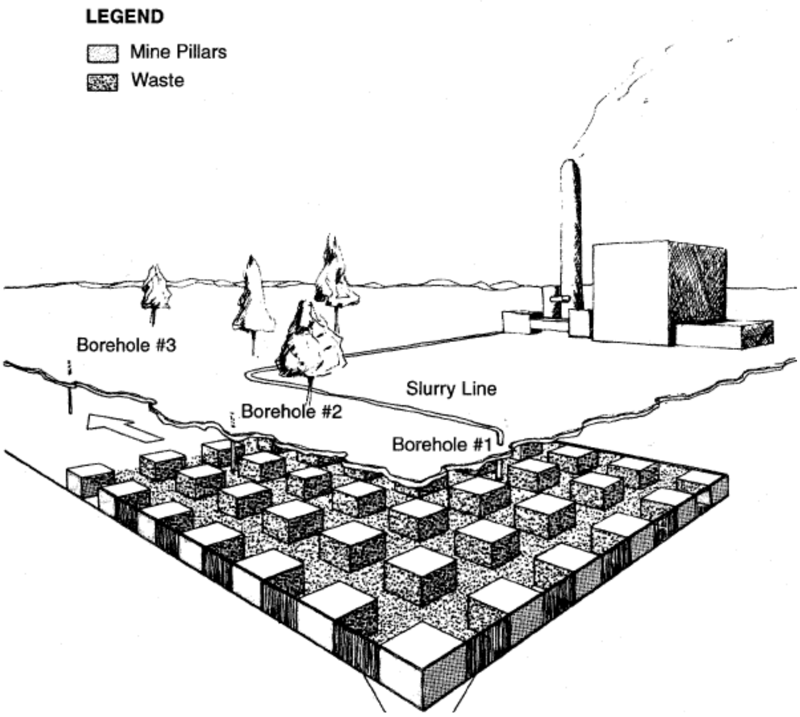


Figure 2.6 Underground mine backfilling

- Disposal underground reduces the number of surface disposal sites and the environmental, health, safety and social problems associated with them.
- Disposal underground improves mine support and reduces potential for subsidence.
- Alkaline coal combustion byproducts may help to neutralize existing acid mine drainage, provide mitigation of acid mine seeps, and may work to improve groundwater quality.
- Filling the voids in acid producing seams can reduce groundwater contact and acid production.
- Groundwater flow may be impeded, thereby reducing the volume of acid mine seepage.
- Underground disposal may help prevent/control mine fires.

# CHAPTER 3

# SAMPLE COLLECTION

## 3.1 SAMPLE COLLECTION

The sample collection of different types of ashes such as fly ash, bottom ash and pond ash has different procedures. The fly ash and the bottom ashes are generated at the power plant and can be collected directly from the discharge points. In most of the power plants sampling pipes are provided at places near the discharge point or near the storage point for collection of ash samples. The sample can be directly collected into a bucket or any other container and can be suitable packed for transportation.

*Precautions to be taken:*

- Care should be taken while packing of fly ash samples, the packing material should be in good condition.
- Suitable precautions must be taken to ensure the sample is not coming directly in contact with moisture or water.

For our project we collected samples from two different locations:

- Indian Charge Chrome Limited, Chowdhar (ICCL) and,
- Rourkela Steel Plant, Captive Power plant I (RSP, CPP I)

### 3.1.1 Sample from ICCL Chowdhar

- About 15 kg sample was collected from the ICCL Chowdhar.
- The sample was directly collected from near the storage point through a sampling pipe.
- The fly ash collected from the plant was light grey in color.
- The sample was packed into a plastic bag first and then it was put into a thick sack to make it easy to carry.

### 3.1.2 Sample from RSP, CPP I

- About 20 kg of fly ash was collected from Captive Power Plant - I of Rourkela steel Plant.
- The sample was collected from near the hopper of the power plant.
- The fly ash sample collected was dark grey in color.
- The sample was collected in a bucket and was directly transferred into a sack.

# CHAPTER
# 4

# GEOTECHNICAL PROPERTIES

## EXPERIMENTS CONDUCTED

## 4.1 DETERMINATION OF SPECIFIC GRAVITY

**Objective:** To determine the specific gravity of soil fraction passing 4.75 mm I.S sieve by density bottle.

**Need and Scope of the Experiment:** The knowledge of specific gravity is needed in calculation of soil properties like void ratio, degree of saturation etc.

**Apparatus Required**

1. Density bottle of 50 ml with stopper having capillary hole.
2. Balance to weigh the materials (accuracy 10gm).
3. Wash bottle with distilled water.
4. Alcohol and ether.

**Procedure**

1. Clean and dry the density bottle.
   (a) Wash the bottle with water and allow it to drain.
   (b) Wash it with alcohol and drain it to remove water.
   (c) Wash it with ether, to remove alcohol and drain ether.
2. Weigh the empty bottle with stopper ($W_1$)
3. Take about 10 to 20 gm of oven soil sample which is cooled in a desiccators. Transfer it to the bottle. Find the weight of the bottle and soil ($W_2$).
4. Put 10ml of distilled water in the bottle to allow the soil to soak completely. Leave it for about 2 hours.
5. Again fill the bottle completely with distilled water put the stopper and keep the bottle under constant temperature water baths ($T_x^0$ ).
6. Take the bottle outside and wipe it clean and dry note. Now determine the weight of the bottle and the contents ($W_3$).

7. Now empty the bottle and thoroughly clean it. Fill the bottle with only distilled water and weigh it. Let it be $W_4$ at temperature ($T_x^0$ C).
8. Repeat the same process for 2 to 3 times, to take the average reading of it.

**Observations & Calculations**

$$\textit{Specific gravity of soil} = \frac{\text{Density of water at 27 C}}{\text{Weight of water of equal volume}}$$

$$= \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$$

$$= \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)}$$

**Interpretation and Reporting**

Unless or otherwise specified specific gravity values reported shall be based on water at $27^0$C. So the specific gravity at $27^0$C = K×Sp. gravity at $T_x^0$C.

$$\textit{where} \quad K = \frac{\text{Density of water at temperature } T_x^0 \text{C}}{\text{Density of water at temperature } T_x^0 \text{C}}$$

The specific gravity of the soil particles lie with in the range of 2.65 to 2.85. Soils containing organic matter and porous particles may have specific gravity values below 2.0. Soils having heavy substances may have values above 3.0.

**Results :**

The specific gravity of the samples was found out to be:

Sample from ICCL, Chowdhar = 2.12 g/$cm^3$

Sample from RSP, CPP I = 2.46 g/$cm^3$

## 4.2 PROCTOR TEST

**Objective**

To determine the optimum moisture content (OMC) and the maximum dry density (MDD) of the given soil sample.

**Need and Scope of the Experiment**

This method covers the determination of the relationship between the moisture content and density of soils compacted in a mould of a given size with a 2.5 kg rammer dropped from a height of 30 cm.

**Apparatus Required**

1. Proctor mould having a capacity of 974 cc with an internal diameter of 10 cm and a height of 12.7 cm. The mould shall have a detachable collar assembly and a detachable base plate.
2. Rammer: A mechanical operated metal rammer having a 5.08 cm diameter face and a weight of 2.5 kg. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free fall of 30 cm.
3. Sample extruder.
4. A balance of 15 kg capacity.
5. Sensitive balance.
6. Straight edge.
7. Graduated cylinder.
8. Mixing tools such as mixing pan, spoon, towel, spatula etc.
9. Moisture tins.

**Procedure**

1. Take a representative oven-dried sample, approximately 5 kg in the given pan. Thoroughly mix the sample with sufficient water to dampen it to approximately four to six percentage points below optimum moisture content.
2. Weigh the proctor mould without base plate and collar. Fix the collar and base plate. Place the soil in the Proctor mould and compact it in 3 layers giving 25 blows per layer with the 2.5 kg rammer falling through.

3. Remove the collar, trim the compacted soil even with the top of the mould by means of the straight edge and weigh.
4. Divide the weight of the compacted specimen by 974 cc and record the result as the wet weight $g_{wet}$ in grams per cubic centimeter of the compacted soil.
5. Remove the sample from the mould and slice vertically through and obtain a small sample for moisture determination.
6. Add water in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points and repeat the above procedure for each increment of water added. Continue this series of determination until there is either a decrease or no change in the wet unit weight of the compacted soil.

**Observation & Calculation**

- Weight of empty mould – 2080 g
- Internal diameter of the mould – 10 cm
- Height of the mould – 12.7 cm
- Volume of the mould – (π × $10^2$ × 12.7 / 4)

- $\text{Wet density (gm/cc)} = \dfrac{\text{weight of compacted soil}}{\text{Vol. of mould (cm}^3\text{)}}$
- $\text{Moisture content (\%)} = \dfrac{\text{weight of water}}{\text{Weight of dry soil}} \times 100$
- $\text{Dry density (gm/cm}^3\text{)} = \dfrac{\text{Wet density (gm/cm}^3\text{)}}{(1 + \frac{\text{M.C.}}{100})}$

Plot the dry density against moisture content and find out the maximum dry density and optimum moisture for the soil.

**Results**

*ICC, Chowdhar Fly ash sample*

*<u>The results of the tests on fly ash samples collected from ICCL, Chowdhar:</u>*

Optimum Moisture content = 37.53 %

Maximum dry density = 0.983 g/cm$^3$, 983 kg/m$^3$

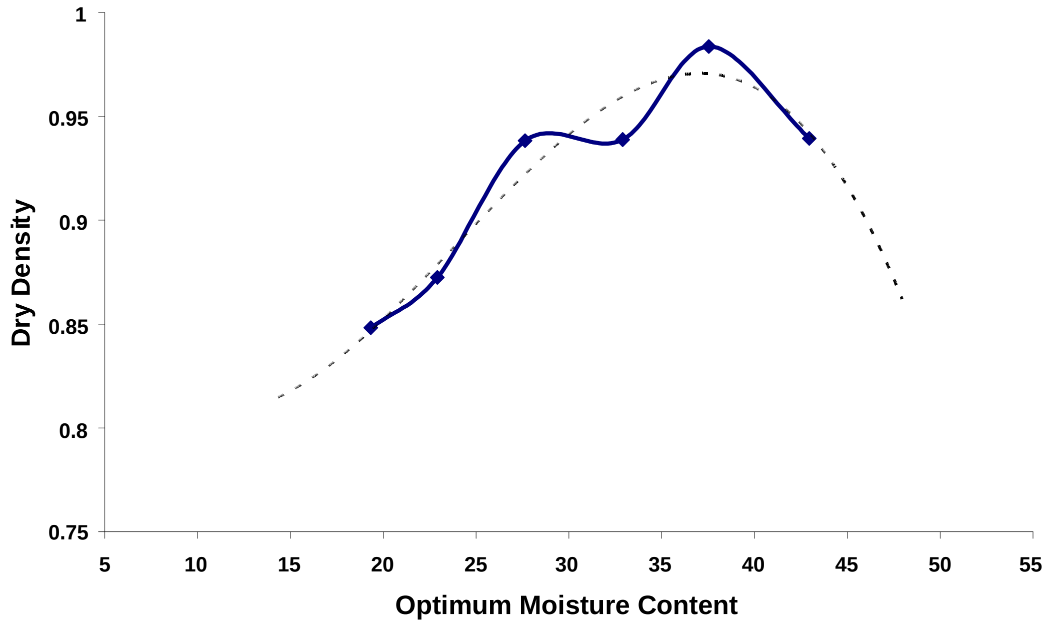


Figure 4.1 Procter test results (ICCL)

*RSP, CPP I, Fly ash sample*

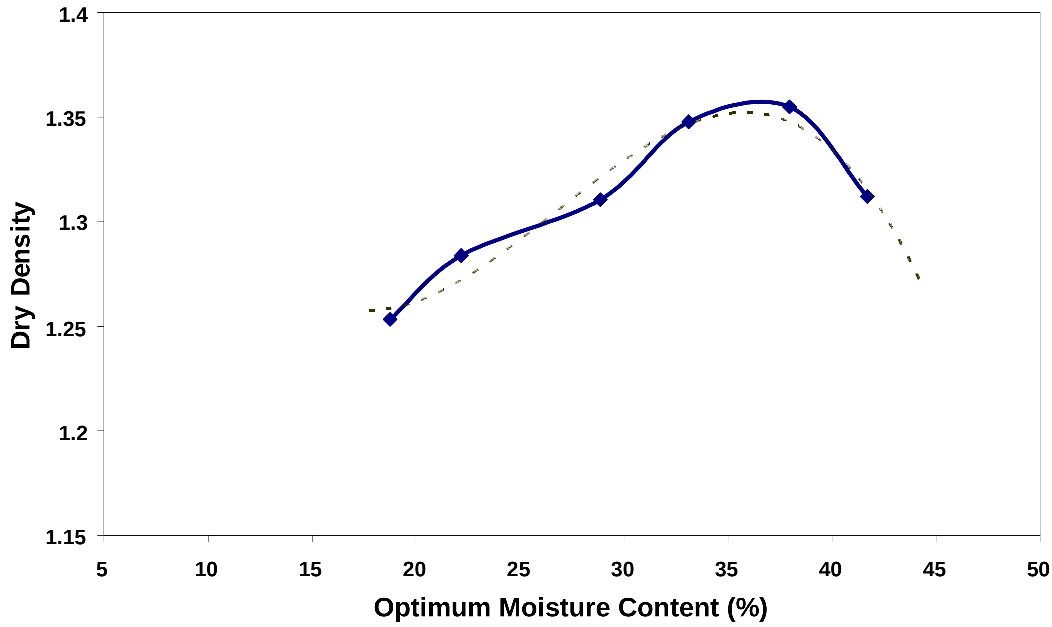


Figure 4.2 Procter test results (RSP)

<u>*Results from samples of RSP, CPP I:*</u>

Optimum Moisture content = 37.95 %

Maximum dry density = 1.354 g/cm$^3$, 1354 kg/m$^3$

## 4.3 DIRECT SHEAR TEST

### Objective

To determine the shearing strength of the sample, using direct shear apparatus.

### Need and Scope of the Experiment

In many engineering problems such as design of foundation, retaining walls, slab bridges, pipes, sheet piling, the value of the angle of internal friction and cohesion of the soil involved are required for the design. Direct shear test is used to predict these parameters quickly.

### Apparatus Required

1. Direct shear box apparatus
2. Loading frame (motor attached).
3. Dial gauge.
4. Proving ring.
5. Tamper.
6. Straight edge.
7. Balance to weigh upto 200 mg.
8. Aluminum container.
9. Spatula.

### Knowledge of Equipment:

Strain controlled direct shear machine consists of shear box, soil container, loading unit, proving ring, dial gauge to measure shear deformation and volume changes. A two piece square shear box is one type of soil container used. A proving ring is used to indicate the shear load taken by the soil initiated in the shearing plane.

### Procedure

1. Check the inner dimension of the soil container.
2. Put the parts of the soil container together.
3. Calculate the volume of the container. Weigh the container.
4. Place the soil in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the soil.

5. Weigh the soil container, the difference of these two is the weight of the soil. Calculate the density of the soil.
6. Make the surface of the soil plane.
7. Put the upper grating on stone and loading block on top of soil.
8. Measure the thickness of soil specimen.
9. Apply the desired normal load.
10. Remove the shear pin.
11. Attach the dial gauge which measures the change of volume.
12. Record the initial reading of the dial gauge and calibration values.
13. Before proceeding to test check all adjustments to see that there is no connection between two parts except sand/soil.
14. Start the motor. Take the reading of the shear force and record the reading.
15. Take volume change readings till failure.
16. Add 5 kg normal stress 0.5 $kg/cm^2$ and continue the experiment till failure.
17. Record carefully all the readings. Set the dial gauges zero, before starting the experiment

**General Remarks**

- In the shear box test, the specimen is not failing along its weakest plane but along a predetermined or induced failure plane i.e. horizontal plane separating the two halves of the shear box. This is the main draw back of this test. Moreover, during loading, the state of stress cannot be evaluated. It can be evaluated only at failure condition i.e Mohr's circle can be drawn at the failure condition only. Also failure is progressive.
- Direct shear test is simple and faster to operate. As thinner specimens are used in shear box, they facilitate drainage of pore water from a saturated sample in less time. This test is also useful to study friction between two materials – one material in lower half of box and another material in the upper half of box.
- The angle of shearing resistance of sands depends on state of compaction, coarseness of grains, particle shape and roughness of grain surface and grading. It

varies between $28^o$ (uniformly graded sands with round grains in very loose state) to $46^o$ (well graded sand with angular grains in dense state).

- The volume change in sandy soil is a complex phenomenon depending on gradation, particle shape, state and type of packing, orientation of principal planes, principal stress ratio, stress history, magnitude of minor principal stress, type of apparatus, test procedure, method of preparing specimen etc. In general loose sands expand and dense sands contract in volume on shearing. There is a void ratio at which either expansion contraction in volume takes place. This void ratio is called critical void ratio. Expansion or contraction can be inferred from the movement of vertical dial gauge during shearing.
- The friction between sand particles is due to sliding and rolling friction and interlocking action.

The ultimate values of shear parameter for both loose sand and dense sand approximately attain the same value so, if angle of friction value is calculated at ultimate stage, slight disturbance in density during sampling and preparation of test specimens will not have much effect.

**Observation and Calculation**

The values of shear stresses are noted down for a particular normal stress provided to the specimen compacted into the shear box. A graph is then plotted between the normal and the shear stresses involved in the procedure and from the graph the cohesive force and the friction angle of the fly ash is calculated. The representation of the relation between the shear stress, cohesive force, the normal stress and the angle of internal friction is given in the next page.

$$S = C + \sigma \tan \phi$$

Where S = shear strength of the sample

C = cohesion of the sample

Φ = Angle of internal friction.

**Results**

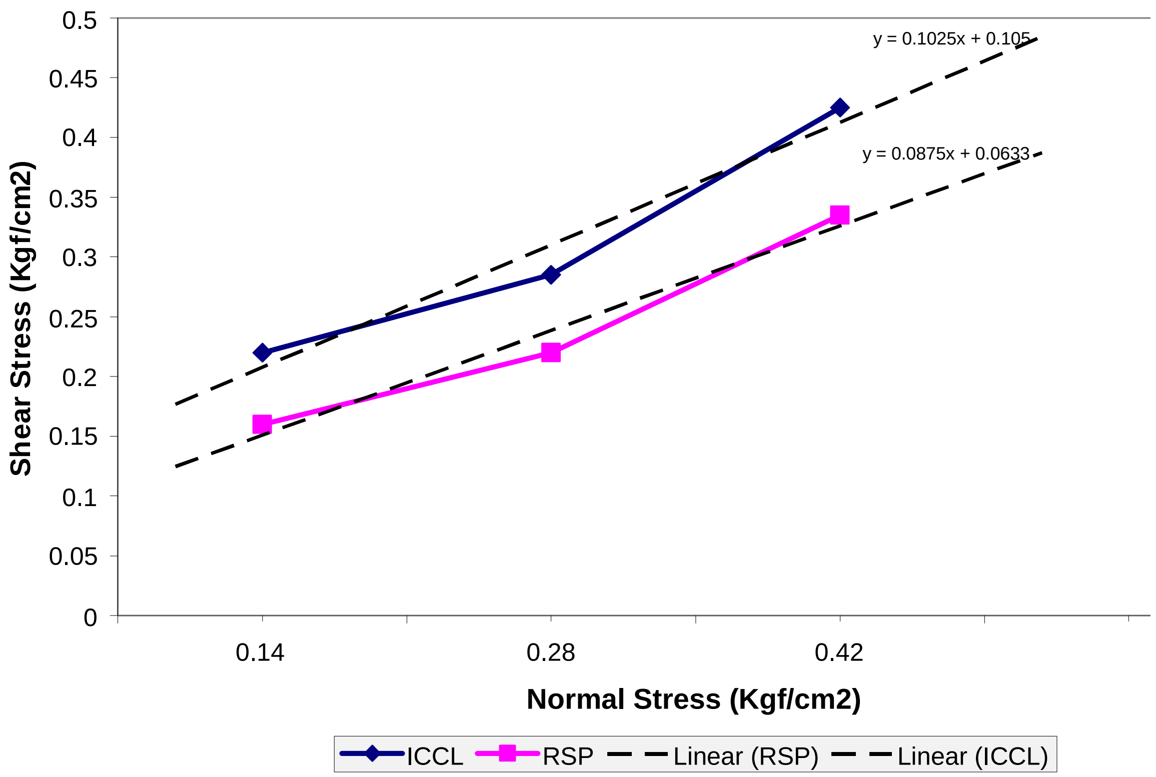


Figure 4.3 Direct shear strength results

*For the fly ash sample of ICCL, Chowdhar*

Peak shear strength before failure = 0.425 $kgf/cm^2$

Cohesive force = 0.105 $Kgf/cm^2$

Angle of internal friction = 36.697°

*For the fly ash sample of ICCL, Chowdhar*

Peak shear strength before failure = 0335 $kgf/cm^2$

Cohesive force = 0.0633 $Kgf/cm^2$

Angle of internal friction = 32.514°

## 4.4 PERMEABILITY TEST

### 4.4.1 Constant Head

*Objective*: To determine the coefficient of permeability of a soil using constant head method.

*Need And Scope*: The knowledge of this property is much useful in solving problems involving yield of water bearing strata, seepage through earthen dams, stability of earthen dams, and embankments of canal bank affected by seepage, settlement etc.

*Planning and Organization*

- Preparation of the soil sample for the test
- Finding the discharge through the specimen under a particular head of water.

*Definition of Coefficient of Permeability*

The rate of flow under laminar flow conditions through a unit cross sectional are of porous medium under unit hydraulic gradient is defined as coefficient of permeability.

*Equipment*

1. Permeameter mould of non-corrodible material having a capacity of 1000 ml, with an internal diameter of 100 ± 0.1 mm and internal effective height of 127.3 ± 0.1 mm.
2. The mould shall be fitted with a detachable base plate and removable extension counter.
3. Compacting equipment: 50 mm diameter circular face, weight 2.76 kg and height of fall 310 mm as specified in I.S 2720 part VII 1965.
4. Drainage bade: A bade with a porous disc, 12 mm thick which has the permeability 10 times the expected permeability of soil.
5. Drainage cap: A porous disc of 12 mm thick, having a fitting for connection to water inlet or outlet.
6. Constant head tank: A suitable water reservoir capable of supplying water to the permeameter under constant head.
7. Graduated glass cylinder to receive the discharge.
8. Stop watch to note the time.
9. A meter scale to measure the head differences and length of specimen.

*Preparation of Specimen for Testing*

Undisturbed Soil Sample

1. Note down the sample number, bore hole number and its depth at which the sample was taken.
2. Remove the protective cover (paraffin wax) from the sampling tube.
3. Place the sampling tube in the sample extraction frame, and push the plunger to get a cylindrical form sample not longer than 35 mm in diameter and having height equal to that of mould.
4. The specimen shall be placed centrally over the porous disc to the drainage base.
5. The angular space shall be filled with an impervious material such as cement slurry or wax, to provide sealing between the soil specimen and the mould against leakage from the sides.
6. The drainage cap shall then be fixed over the top of the mould.
7. Now the specimen is ready for the test.

Disturbed Soil Sample

1. A 2.5 kg sample shall be taken from a thoroughly mixed air dried or oven dried material.
2. The initial moisture content of the 2.5 kg sample shall be determined. Then the soil shall be placed in the air tight container.
3. Add required quantity of water to get the desired moisture content.
4. Mix the soil thoroughly.
5. Weigh the empty permeameter mould.
6. After greasing the inside slightly, clamp it between the compaction base plate and extension collar.
7. Place the assembly on a solid base and fill it with sample and compact it.
8. After completion of a compaction the collar and excess soil are removed.
9. Find the weight of mould with sample.
10. Place the mould with sample in the permeameter, with drainage base and cap having discs that are properly saturated.

*Test Procedure*

1. For the constant head arrangement, the specimen shall be connected through the top inlet to the constant head reservoir.
2. Open the bottom outlet.
3. Establish steady flow of water.
4. The quantity of flow for a convenient time interval may be collected.
5. Repeat three times for the same interval.

*Observation and Recording*

The flow is very low at the beginning, gradually increases and then stands constant. Constant head permeability test is suitable for cohesionless soils. For cohesive soils falling head method is suitable.

*Computation*

Coefficient of permeability for a constant head test is given by

$$k = \frac{qL}{Ah}$$

where k = coefficien t of permeabili ty in cm/sec

q = Discharge $cm^3$/sec

L = Length of specimen in cm.

A = Cross -sectional area of specimen in $cm^2$

H = Constant head causing flow in cm.

*Presentation of data*

The coefficient of permeability is reported in cm/sec at $27^{o}$ C. The dry density, the void ratio and the degree of saturation shall be reported.

### 4.4.2 Falling Head Method

*Objective*

To determine the coefficient of permeability of the given soil sample, using falling head method.

*Need And Scope*

The test results of the permeability experiments are used:

1. To estimate ground water flow.

2. To calculate seepage through dams.
3. To find out the rate of consolidation and settlement of structures.
4. To plan the method of lowering the ground water table.
5. To calculate the uplift pressure and piping.
6. To design the grouting.
7. And also for soil freezing tests.
8. To design pits for recharging.

Thus the study of seepage of water through soil is very important, with wide field applications.

The falling head method of determining permeability is used for soil with low discharge, where as the constant head permeability test is used for coarse-grained soils with a reasonable discharge in a given time. For very fine-grained soil, capillarity permeability test is recommended.

*Principle of the Experiment*

The passage of water through porous material is called seepage. A material with continuous voids is called a permeable material. Hence permeability is a property of a porous material which permits passage of fluids through inter connecting conditions.

Hence permeability is defined as the rate of flow of water under laminar conditions through a unit cross-sectional area perpendicular to the direction of flow through a porous medium under unit hydraulic gradient and under standard temperature conditions.

The principle behind the test is Darcy's law for laminar flow. The rate of discharge is proportional to (i x A)

$$q = k \times i \times A$$

where q= Discharge per unit time.

A=Total area of c/s of soil perpendicular to the direction of flow.

i=hydraulic gradient.

k=Darcy's coefficient of permeability = The mean velocity of flow that will occur through the cross-sectional area under unit hydraulic gradient.

*Planning and Organization*

The tools and accessories needed for the test are:

1. Permeameter with its accessories.
2. Standard soil specimen.
3. Deaires water.
4. Balance to weigh up to 1 gm.
5. I.S sieves 4.75 mm and 2 mm.
6. Mixing pan.
7. Stop watch.
8. Measuring jar.
9. Meter scale.
10. Thermometer.
11. Container for water.
12. Trimming knife etc.

*Knowledge of Equipment*

(a) The permeameter is made of non-corrodible material with a capacity of 1000 ml, with an internal diameter of 100   0.1 mm and effective height of 127.3  0.1 mm.

(b) The mould has a detachable base plate and a removable exterior collar.

(c) The compacting equipment has a circular face with 50 mm diameter and a length of 310 mm with a weight of 2.6 kg.

(d) The drainage base is a porous disc, 12 mm thick with a permeability 10 times that of soil.

(e) The drainage cap is also a porous disc of 12 mm thickness with an inlet/outlet fitting.

(f) The container tank has an overflow valve. There is also a graduated jar to collect discharge.

(g) The stand pipe arrangements are done on a board with 2 or 3 glass pipes of different diameters.

*Preparation of the Specimen*

The preparation of the specimen for this test is important. There are two types of specimen, the undisturbed soil sample and the disturbed or made up soil sample.

Undisturbed soil specimen

It is prepared as follows:

1. Note down-sample no., borehole no., depth at which sample is taken.
2. Remove the protective cover (wax) from the sampling tube.
3. Place the sampling tube in the sample extract or and push the plunger to get a cylindrical shaped specimen not larger than 85 mm diameter and height equal to that of the mould.
4. This specimen is placed centrally over the drainage disc of base plate.
5. The annular space in between the mould and specimen is filled with an impervious material like cement slurry to block the side leakage of the specimen.
6. Protect the porous disc when cement slurry is poured.
7. Compact the slurry with a small tamper.
8. The drainage cap is also fixed over the top of the mould.
9. The specimen is now ready for test.

Disturbed Specimen

The disturbed specimen can be prepared by static compaction or by dynamic compaction.

(a) Preparation of statically compacted (disturbed) specimen:

1. Take 800 to 1000 gms of representative soil and mix with water to O.M.C determined by I.S Light Compaction test. Then leave the mix for 24 hours in an airtight container.
2. Find weight 'W' of soil mix for the given volume of the mould and hence find the dry density $\gamma_d$ for $W = \gamma_d$ (1+W)V by weighing correct to 1 gm.
3. Now, assemble the permeameter for static compaction. Attach the 3 cm collar to the bottom end of 0.3 liters mould and the 2 cm collar to the top end. Support the mould assembly over 2.5 cm end plug, with 2.5 cm collar resting on the split collar kept around the 2.5 cm- end plug. The inside of the 0.3 lit. Mould is lightly greased.

4. Put the weighed soil into the mould. Insert the top 3 cm –end plug into the top collar, tamping the soil with hand.
5. Keep, now the entire assembly on a compressive machine and remove the split collar. Apply the compressive force till the flange of both end plugs touches the corresponding collars. Maintain this load for 1 mt and then release it.
6. Then remove the top 3 cm plug and collar place a filter paper on fine wire mesh on the top of the specimen and fix the perforated base plate.
7. Turn the mould assembly upside down and remove the 2.5 cm end plug and collar. Place the top perforated plate on the top of the soil specimen and fix the top cap on it, after inserting the seating gasket.
8. Now the specimen is ready for test.

(b) Preparation of Dynamically Compacted Disturbed sample:

1. Take 800 to 1000 gms of representative soil and mix it with water to get O.M.C, if necessary. Have the mix in airtight container for 24 hours.
2. Assemble the permeameter for dynamic compaction. Grease the inside of the mould and place it upside down on the dynamic compaction base. Weigh the assembly correct to a gram (w). Put the 3 cm collar to the other end.
3. Now, compact the wet soil in 2 layers with 15 blows to each layer with a 2.5 kg dynamic tool. Remove the collar and then trim off the excess. Weigh the mould assembly with the soil (W2).
4. Place the filter paper or fine wore mesh on the top of the soil specimen and fix the perforated base plate on it.
5. Turn the assembly upside down and remove the compaction plate. Insert the sealing gasket and place the top perforated plate on the top of soil specimen. And fix the top cap.
6. Now, the specimen is ready for test.

*Experimental Procedure*

1. Prepare the soil specimen as specified.
2. Saturate it. De-aired water is preferred.
3. Assemble the permeameter in the bottom tank and fill the tank with water.

4. Inlet nozzle of the mould is connected to the stand pipe. Allow some water to flow until steady flow is obtained.
5. Note down the time interval 't' for a fall of head in the stand pipe 'h'.
6. Repeat step 5 three times to determine 't' for the same head.
7. Find 'a' by collecting 'q' for the stand pipe. Weigh it correct to 1 gm and find 'a' from q/h=a.

Therefore the coefficient of permeability

$$k = \frac{2.3 \times a \times L \times (\log_{10} h_{21} / h_2)}{A \times t} \quad cm / \sec$$

$$K \ at \ standard \ temperature \ of \ 27^{o} C = Kx \gamma_t / \gamma_{27}$$

$$\gamma_t = Viscosity \ of \ water \ at \ temperature, t \ {}^0C$$

$$\gamma_{27} = Viscosity \ of \ water \ at \ room \ temperature \ 27^0 C$$

*Interpretation of the result*

*There are high values, medium values and low values for permeability*

$K > 10^{-1}\ cm / \sec$, *the permeability is high*

$= 10^{-1}\ cm / \sec$, *it is medium*

$< 10^{-1}\ cm / \sec$, *it is low.*

*Results*

For the calculation of the permeability of the fly ash samples the falling head method of permeability measurement was used.

The results of the tests were found out as:

Permeability of fly ash sample from ICCL, Chowdhar = $1.009 \times 10^{-4}$ cm/s

Permeability of fly ash sample from RSP, CPP I = $2.880 \times 10^{-4}$ cm/s

## 4.5 UNCONFINED COMPRESSION TEST

**Objective**

To determine the shear parameters of cohesive soil

**Need and Scope of the Experiment**

It is not always possible to conduct the bearing capacity test in the field. Some times it is cheaper to take the undisturbed soil sample and test its strength in the laboratory. Also to choose the best material for the embankment, one has to conduct strength tests on the samples selected. Under these conditions it is easy to perform the unconfined compression test on undisturbed and remoulded soil sample. Now we will investigate experimentally the strength of a given soil sample.

**Planning and Organization**

We have to find out the diameter and length of the specimen.

**Equipment**

1. Loading frame of capacity of 2 t, with constant rate of movement. What is the least count of the dial gauge attached to the proving ring!
2. Proving ring of 0.01 kg sensitivity for soft soils; 0.05 kg for stiff soils.
3. Soil trimmer.
4. Frictionless end plates of 75 mm diameter (Perspex plate with silicon grease coating).
5. Evaporating dish (Aluminum container).
6. Soil sample of 75 mm length.
7. Dial gauge (0.01 mm accuracy).
8. Balance of capacity 200 g and sensitivity to weigh 0.01 g.
9. Oven, thermostatically controlled with interior of non-corroding material to maintain the temperature at the desired level. What is the range of the temperature used for drying the soil!
10. Sample extractor and split sampler.
11. Dial gauge (sensitivity 0.01mm).
12. Vernier calipers

**Experimental Procedure (Specimen)**

1. In this test, a cylinder of soil without lateral support is tested to failure in simple compression, at a constant rate of strain. The compressive load per unit area required to fail the specimen as called unconfined compressive strength of the soil.

**Preparation of specimen for testing**

Undisturbed specimen

1. Note down the sample number, bore hole number and the depth at which the sample was taken.
2. Remove the protective cover (paraffin wax) from the sampling tube.
3. Place the sampling tube extractor and push the plunger till a small length of sample moves out.
4. Trim the projected sample using a wire saw.
5. Again push the plunger of the extractor till a 75 mm long sample comes out.
6. Cutout this sample carefully and hold it on the split sampler so that it does not fall.
7. Take about 10 to 15 g of soil from the tube for water content determination.
8. Note the container number and take the net weight of the sample and the container.
9. Measure the diameter at the top, middle, and the bottom of the sample and find the average and record the same.
10. Measure the length of the sample and record.
11. Find the weight of the sample and record.

Moulded sample

1. For the desired water content and the dry density, calculate the weight of the dry soil Ws required for preparing a specimen of 3.8 cm diameter and 7.5 cm long.
2. Add required quantity of water Ww to this soil.

   Ww = WS ´ W/100 gm

3. Mix the soil thoroughly with water.

4. Place the wet soil in a tight thick polythene bag in a humidity chamber and place the soil in a constant volume mould, having an internal height of 7.5 cm and internal diameter of 3.8 cm.
5. After 24 hours take the soil from the humidity chamber and place the soil in a constant volume mould, having an internal height of 7.5 cm and internal diameter of 3.8 cm.
6. Place the lubricated moulded with plungers in position in the load frame.
7. Apply the compressive load till the specimen is compacted to a height of 7.5 cm.
8. Eject the specimen from the constant volume mould.
9. Record the correct height, weight and diameter of the specimen.

**Test procedure**

1. Take two frictionless bearing plates of 75 mm diameter.
2. Place the specimen on the base plate of the load frame (sandwiched between the end plates).
3. Place a hardened steel ball on the bearing plate.
4. Adjust the center line of the specimen such that the proving ring and the steel ball are in the same line.
5. Fix a dial gauge to measure the vertical compression of the specimen.
6. Adjust the gear position on the load frame to give suitable vertical displacement.
7. Start applying the load and record the readings of the proving ring dial and compression dial for every 5 mm compression.
8. Continue loading till failure is complete.
9. Draw the sketch of the failure pattern in the specimen.

**General Remarks**

Minimum three samples should be tested. Upto 6% strain the readings may be taken at every ½ min (30 sec).

**Results**

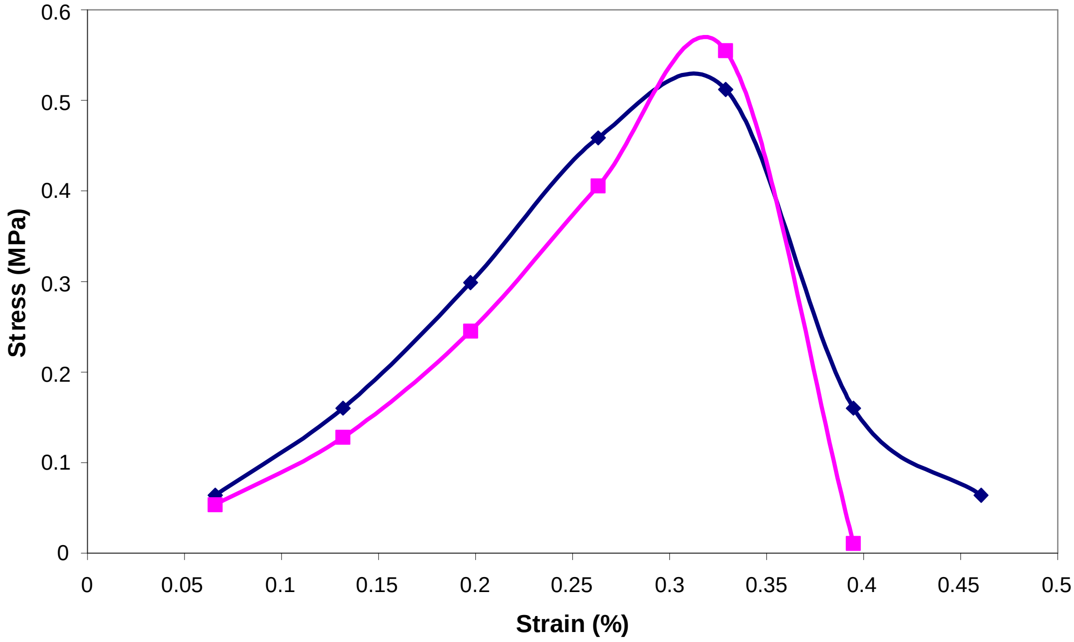


Figure 4.4 UCS test results, (*ICCL, Chowdhar sample)*

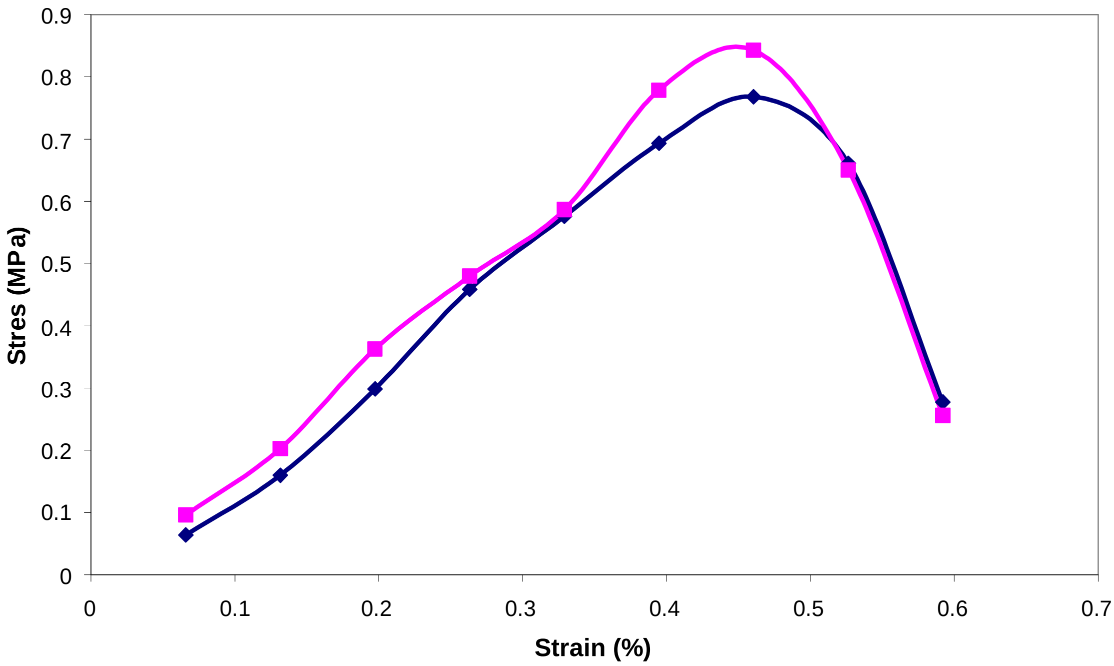


Figure 4.5 UCS test results, *(RSP, CPP I sample)*

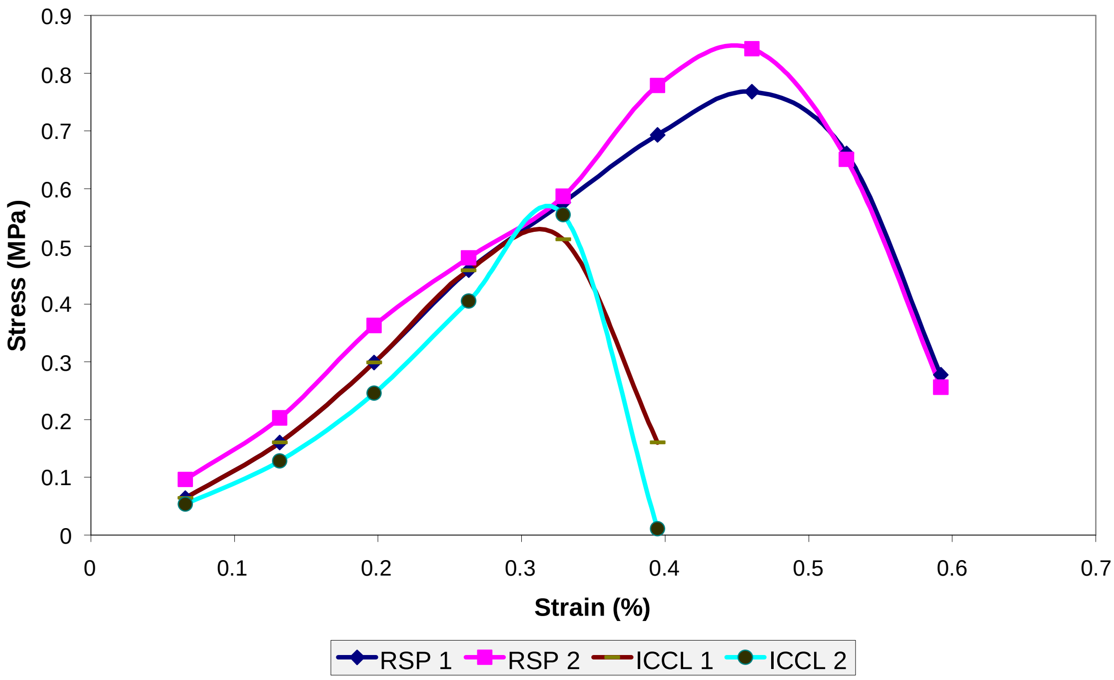


Figure 4.6 Combined representations of the results

**Results**

The ultimate compressive strength of the sample was found out to be:

Sample of ICCL, Chowdhar = 0.53 MPa

Sample of RSP, CPP I = 0.81 MPa

## 6 LIQUID LIMIT

**Objective:** To determine the liquid limit of given sample by cone penetration test.

**Theory and Terminology**: Liquid limit is the water content corresponding to the boundary between liquid and plastic states of soil mass.

**Apparatus**:

(a) Cone penetrometer: It consists of a metallic cone with half angle 15° - 30° and 30.5 mm coned length.

(b) Cup: 50 mm diameter and 50 mm height.

(c) Balance of weight box

(d) Moisture tin

(e) Oven

**Procedure**:

1. Take about 150 gms of air dried sample.
2. Soak the sample with distilled water for 30 – 40 minutes.
3. The wet sample is transferred to the cup of the cone penetrometer apparatus.
4. Adjust the cone point just to touch the surface of the sample paste and clamp the zero indicator.
5. Release the cone and record the penetration after a lapse of 30 seconds.
6. Repeat the test till a penetration of 15 – 30 mm is obtained.

**Calculation:**

$$We = Wy + 0.01 \times (25 - y) \times (Wy + 15)$$

Where We = Liquid limit

Wy = Moisture content of sample

y = depth of penetration

**Results**

| | | |
|---|---|---|
| Liquid limit of ICCL, Chowdhar sample | = 46.20 % | ~ 46 % |
| Liquid limit of RSP, CPP I sample | = 44.28 | ~ 44 % |

# CHAPTER

# 5

# DISCUSSION

## 5.1 ICCL, CHOWDHAR FLY ASH SAMPLE

Various tests carried out on the fly ash sample from the ICCL, Chowdhar shows that the fly ash is having a high optimum moisture content, high permeability, low shear strength and low compressive strength. Because of the permeability of the sample, for the fly ash ash to be utilized for backfilling of voids or abandoned area, a toxicity or leaching characteristics study must be carried out to ensure no damage is being done to the groundwater resources.

This fly ash can be utilized along with the cement as it increases the flow characteristics of cement and reduces the water content required in the cement. Also when used in cement fly ash will help in improving the ultimate strength of concrete due to its pozzolanic property. The addition of fly ash also reduces the permeability of cement and increases its durability.

As fly ash can be compacted over a large range of moisture content thus it has a potential to be utilized in fills and embankments. This fly ash can also be utilized for stabilizing of various aggregates; it helps in forming light weight aggregates because of its low specific gravity.

## 5.2 RSP, CPP I FLY ASH SAMPLE

The results on the fly ash samples collected from the RSP CPP I indicated that the fly ash is having low permeability and high specific gravity. Thus this sample can be used in land fills and embankments and it poses less threat to the underground water resources owing to its low permeability and also it can be compacted over a large range of moisture content.

This fly ash can be utilized in cement applications as it improves the strength and durability characteristics of cement. It can also be used in proper mixtures with water cement for filling of various areas by forming flowable mixture which is self leveling and on drying hardens to provide stability. As the fly ash shows flow characteristics with suitable moisture content thus it can be used for flowable filling.

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