# EFFECT OF FLY ASH ON STRENGTH AND SWELLING ASPECT OF AN EXPANSIVE SOIL

A PROJECT SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**
**In**
**Civil Engineering**

SUBMITTED BY:

**Rajdip Biswas: 10401004**
**Nemani V.S.R Krishna: 10401028**

Department of Civil Engineering
National Institute of Technology
Rourkela
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Under the Guidance of

**Prof. N.R. Mohanty**

Department of Civil Engineering
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**National Institute of Technology**
**Rourkela**

# CERTIFICATE

This is to certify that the thesis entitled, "**Effect of fly-ash on strength and swelling aspect of an expansive soil**" submitted by **Sri Rajdip Biswas** and **Sri Nemani V.S.R Krishna** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them 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.

Date:

Prof. N.R.Mohanty
Dept. of Civil Engineering
National Institute of Technology

**National Institute of Technology**
**Rourkela**

# ACKNOLEDGEMENT

We convey our deep reverence for our guide Prof N.R.Mohanty, Department of Civil Engineering for his valuable guidance and constant encouragement at every step.

We are indebted to the Department of Civil Engineering NIT Rourkela for providing us all facilities required for the experimental work.

Rajdip Biswas
Roll no: 10401004
Dept. of Civil Engineering
N.I.T Rourkela

Nemani V.S.R Krishna
Roll no: 10401028
Dept. of Civil Engineering
N.I.T Rourkela

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# ABSTRACT

Swelling soil always create problems more for lightly loaded structures than moderately loaded structures. By consolidating under load and changing volumetrically along with seasonal moisture variation, these problems are manifested through swelling, shrinkage and unequal settlement. As a result damage to foundation systems, structural elements and architectural features defeat the purpose for which the structures are erected. An attempt to study such unpredictable behavior and through research on how to bring these problems under control form the backdrop for this project work. Pre-stabilization is very effective method in tackling expansive soil. Therefore a number of laboratory experiments are conducted to ascertain host of soil engineering properties of a naturally available expansive soil before and after stabilization. Pre and post stabilized results are compared to arrive at conclusion that can thwart expansive soil problems.

Index properties of expansive soil like liquid limit, plastic limit and shrinkage limit with and without fly-ash have been compared. Along with these Atterberg limits, grain size distribution has also determined. The swelling potential of expansive soil is determined with different percentage of fly-ash. For different percentages of fly-ash 1) maximum dry density and 2) optimum moisture contents are found by the proctor compaction test and the comparison graphs are drawn. The strength aspects of expansive soil are determined for soil specimens with different fly-ash concentrations through Unconfined Compression Test and California Bearing Ratio Test and the results are compared through the graphs.

The above experimental results are compared among them to obtain a percentage concentration of fly-ash with swelling soil which gives best results for lower value of swelling potential and higher strength.

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**Chapter-1**

# INTRODUCTION

# INTRODUCTION

For centuries mankind was wondering at the instability of earth materials, especially expansive soil. One day they are dry and hard, and the next day wet and soft. Swelling soil always create problem for lightly loaded structure, by consolidating under load and by changing volumetrically along with seasonal moisture variation. As a result the superstructures usually counter excessive settlement and differential movements, resulting in damage to foundation systems, structural elements and architectural features. In a significant number of cases the structure becomes unstable or uninhabitable. Even when efforts are made to improve swelling soil, the lack of appropriate technology sometimes results volumetric change that are responsible for billion dollars damage each year. It is due to this that the present work is taken up. The purpose was to check the scope of improving bearing capacity value and reduce expansiveness by adding additives. There are number of additives for soil modification like ordinary Portland cement, fly ash, lime fly ash etc.

In many centuries, coal is the primary fuel in thermal power plant and other industry. The fine residue from these plants which is collected in a field is known as fly ash and considered as a waste material. The fly ash is disposed of either in the dry form or mixed with water and discharged in slurry into locations called ash ponds. The quantity of fly ash produced world wide is huge and keeps increasing every day. Four countries, namely, China, India, United State and Poland alone produce more then 270 million tons of fly ash every year.

India has a totally installed capacity of 100,000 MW of electricity generation. Seventy-three percentage of this is based on thermal power generation. The coal reserves of India is estimated around 200 billion metric tons. Because of this, 90% of Indian thermal power stations are coal based. There are 85 coal based thermal power station and other power station in the country.

Presently, India produced nearly 100 million metric tons of coal ash that is expected to double in next 10 years. The most common method adopted in India for disposal of coal ashes is the wet method. This method requires, apart from a large capital investment about 1 acre of land for every 1 MW of installed capacity. Thus ash ponds occupy nearly 26,300ha of land in India. The utilization of fly ash was just 3% in 1994, but there is a growing realization about the need for conservation of the environment in India.

With the above in view, experiment on swelling soil has been done with fly-ash as additive. In this project report work has been done to see the effect on swelling aspect and on strength of some swelling soil by adding fly ash in different proportion into it as additive.

**Chapter-2**

# REVIEW OF LITRATURE

# REVIEW OF LITRATURE

## 2.1 Origin and occurrence of swelling soils

The key element which imparts swelling characteristics to any ordinary non-swelling soil is a clay mineral. There are several types of clay minerals of which Montomorillonite has the maximum swelling potential. The origin of such soil is sub aqueous decomposition of blast rocks, or weathering in situ formation of important clay mineral takes place under alkaline environments. Due to weathering conditions if there is adequate supply of magnesium of ferric or ferrous oxides and alkaline environments. Along with sufficient silica and aluminum, it will favor the formation of montomorillonite. The depth of expansive soil is shallow at the place of formation with the parent rock underneath. The alluvium deposits can be much deeper in low lying and flat areas, where these soils transported and deposited.

## 2.2 Nature of expansive soil

There are two distinct types of swelling in clays such as

- Elastic re-bounces in compressed soil mass consequent upon decrease in compressive force
- Expansion in water sensitive clays due to ingress of free water.

Clays exhibiting later type of swelling are referred as swelling clays in which clay minerals with predominantly expanding lattice are present. Clayey soil becomes hard when dry and they exhibit little cohesion and merge strength when they are wet, but all of them do not swell on wetting. Due to this, large differential settlement and decrease in ultimate bearing capacity at saturation occurs.  Hence these swelling clay soils exhibit foundation problems.

## 2.3 Clay mineralogy

Generally clay-minerals can be divided into three general groups on the basis of their crystalline arrangements such as:

- Kaolinite group
- Montmorillonite group
- Illite group

### 2.3.1. Kaolinite mineral

Kaolinite is a clay mineral with the chemical composition $Al_2Si_2O_5(OH)_4$. It is a layered silicate mineral, with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedral. Rocks that are rich in kaolinite are known as china clay or kaolin. The stacked layers of kaolinite are having a thickness of $7A^0$. Thus kaolin group of minerals are most stable and water can not enter between the sheets to expand the unit cells.

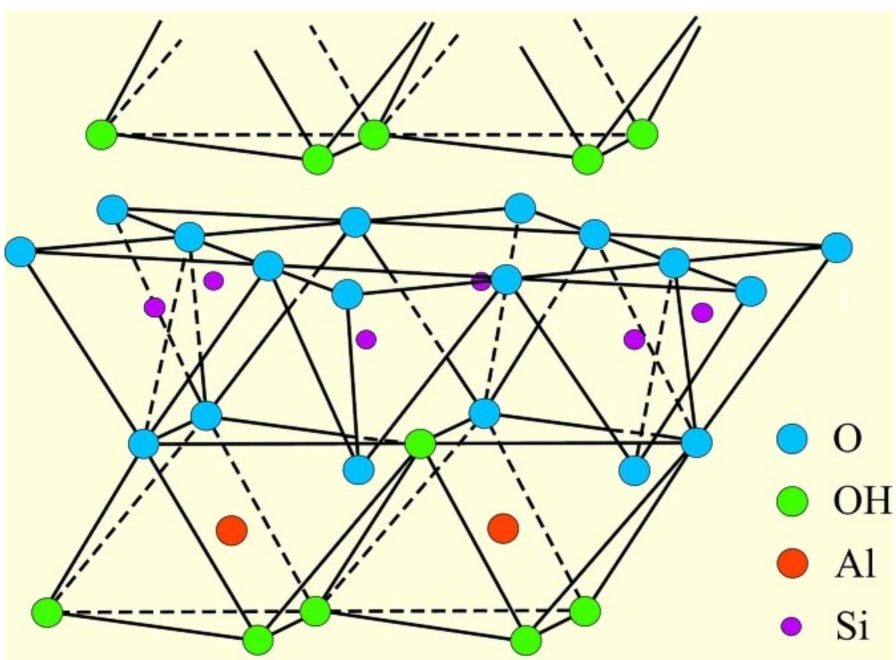
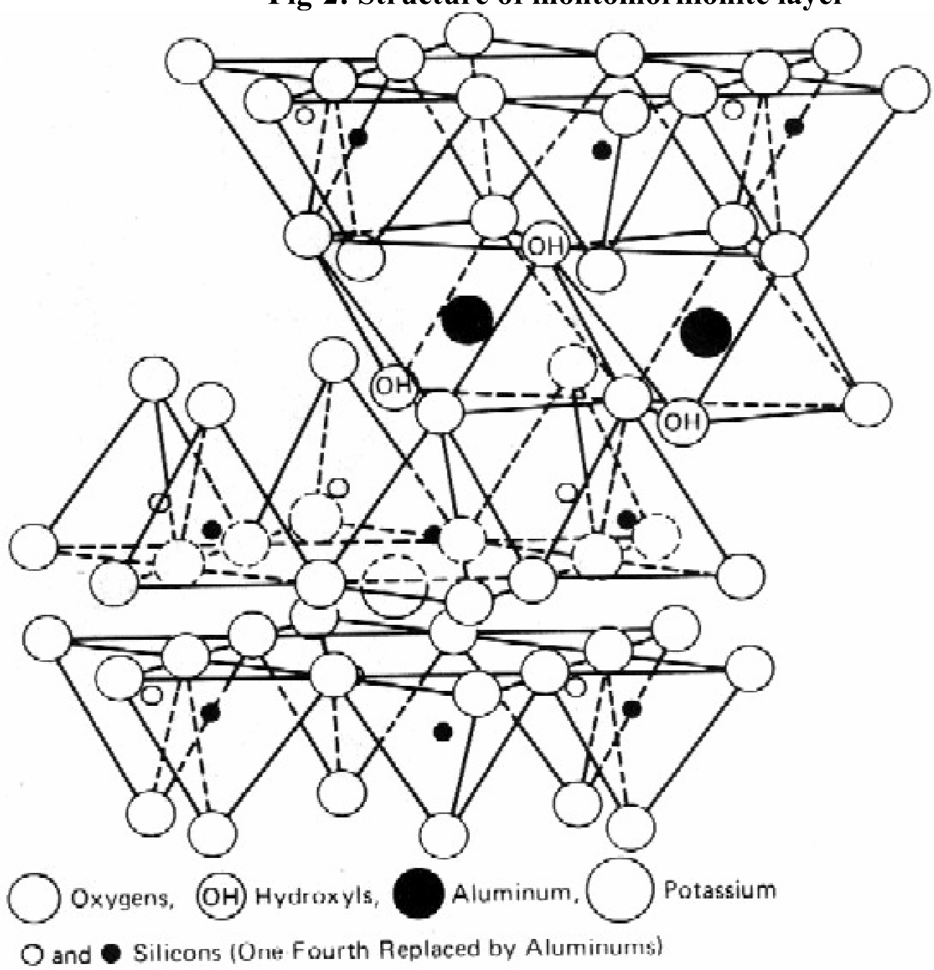



**Fig1: Structure of kaolinite layer**

### 2.3.2. Montomorillonite minerals

This Crystals form weaker bondage between them. These soils containing higher percentage of montomorillonite minerals exhibit high swelling and shrinkage characteristics; Structural arrangement of montomorillonite mineral is composed of units made of two silica tetrahedral sheets with a central aluminum octahedral sheet. The silica and gibbsite sheets are combined in such way that the tips of the tetrahedrons of each silica sheet and one of hydroxyl layers of octahedral sheet form a common layer. The atoms common to both gibbsite and silica layers never participate in the swelling. Water can enter between the sheets causing them to expand significantly and these structures can break to 10A0 thick structural units. Thus soils with montomorillonite minerals exhibit higher shrinkage and swelling characteristics depending upon the nature of exchangble cation presence.

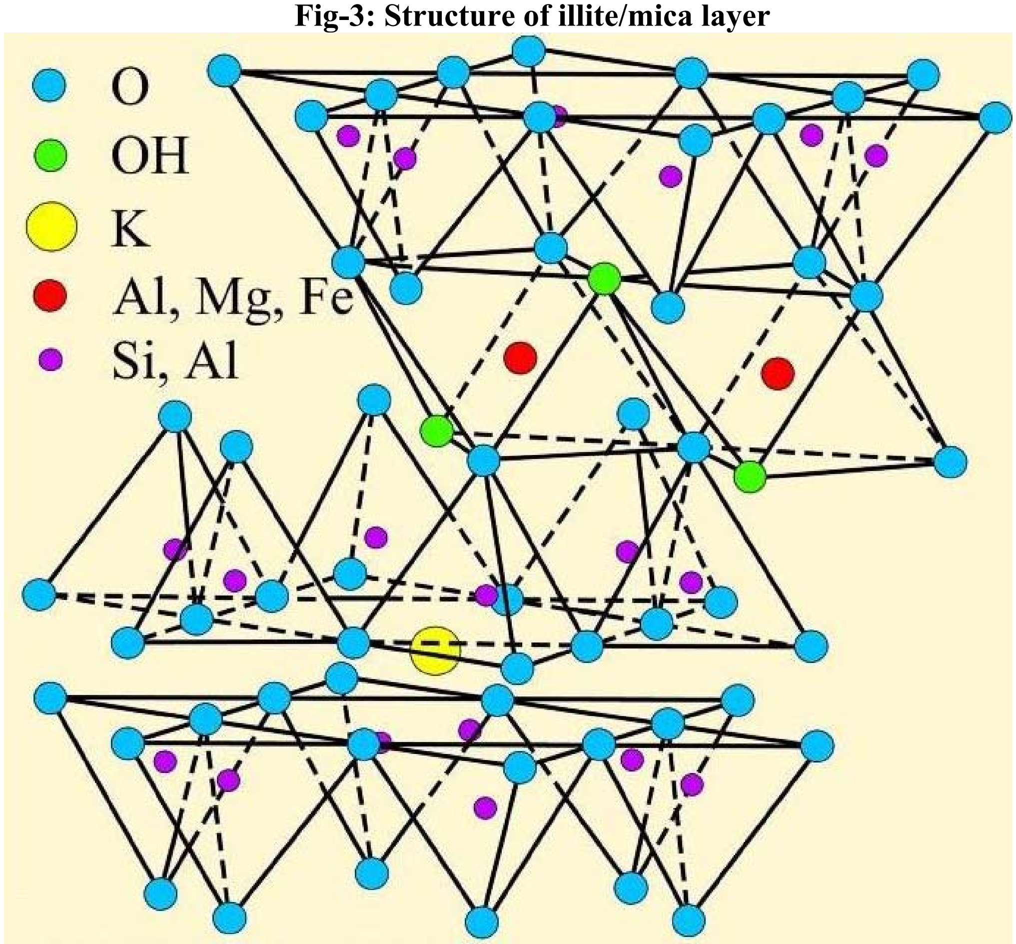
**Fig-2: Structure of montomorillonite layer**



### 2.3.3. Illite group

These minerals fall between the kaolinite and montomorillonite group so far as their structural arrangement is concerned. The spacing between the element silica gibbsite silica sheets depends upon the amount of available water to occupy the space. For this reason montomorillonite is said to have expanding lattice. Each thin platelet has a power to attract each flat surface, a layer of absorbed water approximately $200A^0$ thick thus separating palates a distance of $200A^0$ under zero pressure. In the presence of an abundance of water, the mineral can causes split up into about individual unit layers of $10A^0$ thick.

**Fig-3: Structure of illite/mica layer**



### 2.4 Identification and classification of swelling soils

#### 2.4.1 Tests conducted for identification

For identification of swelling soils, some laboratory tests are available. Clay minerals can be known by microscopic examination, X-ray diffraction and differential thermal analysis. From clay minerals by the presence of montomorillonite, the expansiveness of the soil can be judged. But the test is very technical. Another simple way of finding out expansiveness in laboratory is free-swell test. This test performed by slowly pouring 10CC of dry soil, passing through 425 μ sieve, into two 100CC graduated jar one filled with kerosene and other with water, swelling will takes place in the flask filled with water, hence noteing the swelled volume of the soil after it come to rest (after 24 hours) the free swell values are calculated in percentage. One should follow IS:2720-II for free swell index test.

$$\text{free swell value } [I_n] \text{ (in \%age)} = \frac{\text{(final volume-initial volume)}}{\text{initial volume}} \times 100$$

It is reported that good grade high swelling commercial Bentonite will have a free swell values 1200% to 2000%. Holtez Gibbs reported that soil having free swell values as low as 100% may exhibit considerable volume change, when wetted under light loading, and should be viewed with caution. Where soils is having free swell values below 50% seldom exhibit appreciable volume changes, even under very light loadings. But these limits are considerably influenced by the local climatic conditions.

The free swell test should be combined with the properties of the soil. A liquid limit and plasticity index, together pointers to swelling characteristic of the soil for large clay content. Also the shrinkage limit can be used to estimating the swell potential of a soil. A low shrinkage limit would show that a soil could have volume change at low moisture content. The swelling potential of a soil as related in general way to plasticity index, various degrees of swelling capacities and the corresponding range of plasticity index are indicated below through table.

**Table-1: Swelling potential Vs plasticity index**

| Swelling potential | Plasticity index |
|---|---|
| Low | 0-15 |
| Medium | 10-35 |
| High | 35-55 |
| Very high | 55 and above |

Weather a soil with high swelling potential will actually exhibit swelling characteristics depends on several factors. That of greatest importance is difference between field soil moisture content at the time the construction is under taken and the equilibrium moisture content that will finally be achieved under the conditions associated with the complicated structure. If the equilibrium moisture content is considerable and higher than field moisture content, then the soil is of high swelling capacity, vigorous swelling may occur by upward heaving of soil or structure by the development of large swelling pressure.

### 2.4.2 Methods of recognizing expansive soils

There are three groups of methods for recognizing expansive soils

- Mineralogical identification
- Indirect methods, such as the index properties, soil suction and activity
- Direct measurement.

Methods of mineralogical identification are important for exploring the basis properties of clays, but are impractical and uneconomical in practice. The other two groups of methods are generally used, out of which the direct measurement offers most useful data.

Potentially expansive soils are usually recognized in the field by their fissured or shattered condition, or obvious structural damage caused by such soils to existing buildings. The potential expansion or potential swell or the degree of expansion is a convenient term used to classify expansive soils. From which soil engineers ascertain how good or bad the potentially expansive soils are. The following tables give the various criteria proposed for classifying expansive soils.

**Table-2: Potential expansion Vs shrinkage limit and linear shrinkage**

| Shrinkage limit (in %age) | Linear Shrinkage (in %age) | Potential expansion or Degree of expansion |
|---|---|---|
| >12 | 0-5 | Non critical |
| 10-12 | 5-8 | marginal |
| <10 | >8 | Critical |

**Table-3: Classification system, as per (HOLTZ 1959)**

| Colloid content (in %age) | Plasticity index (in %age) | Shrinkage limit (in %age) | Probable expansion of total volume of clay (in %age) | Potential expansion or Degree of expansion |
|---|---|---|---|---|
| <5 | <18 | <15 | <10 | Low |
| 13-23 | 15-28 | 10-16 | 10-20 | Medium |
| 20-31 | 25-41 | 7-12 | 20-30 | High |
| >28 | >35 | >11 | >30 | Very high |

**Table-4: I.S. Classification system, as per (IS: 1498)**

| Liquid limit (in %age) | Plastic Limit (in %age) | Shrinkage limit (in %age) | Free swell Index (in %age) | Degree of expansion | Degree of severity |
|---|---|---|---|---|---|
| 20-35 | <12 | <15 | <50 | Low | Non critical |
| 35-50 | 12-23 | 12-30 | 50-100 | Medium | Marginal |
| 50-70 | 23-32 | 30-60 | 100-200 | High | Critical |
| 70-90 | >32 | >60 | >200 | Very High | Severe |

**Note**: Potential expansion is given for a confined sample with vertical pressure equal to overburden pressure expressed as a percentage of simple weight.

While estimating expansion in the design of foundation it is necessary to consider the following factors:

- Natural moisture content or rather than degree of saturation.
- Possibility of surface drainage being altered, after construction of building. If the moisture content of the soil is at shrinkage limit, maximum heave could occur on wetting, but if the soil is at its plastic limit the heave will be much less.
- Climate

**2.5 Causes of swelling**

The Mechanism of swelling is still not clear. There are different theories, and no semblance of finality can be said to have been reached. One of the reasons universally accepted for swelling of soils in the presence of high percentage of clay or colloid, had the swelling characteristics, of the clay mineral montomorillonite in it.

**2.6 Swell Pressures**

Expansive soils, swelled when come in contact with water and hence exert pressure. This pressure exerted by the expansive soil is called swell pressure. It is very much required to estimate the swell pressure and the likely heave for the design of a structure on such a soil, or taking a canal through such a soil, or construction of road embankment, or the core of a dam.

**2.7 Factors affecting swelling:**

The most important influencing factor is the initial moisture content or the molding water content incase of re-molded sample.

As per findings of Holts and Gibbs, "the remolded clays behaved much as undisturbed clays". The initial water content for a given dry density, will determine the water thirst of a given soil sample and its swell pressure. For the swelling to start, clay should have minimum initial moisture content ($w_n$) from which swelling will begin beneath a pre-paved sub-grade, given by:

$\underline{w_n (\%) = 0.2\, w_l + g}$ ………………………………………(1)

where, $w_l$ = liquid limit

As per SAVOCHAN (1970) during the swelling of the soil surface rises with time. Rate of this rise of soil surface is governed by fluctuation of temperature gradient in both upper and bottom layers. This expansion activity is also confined within an upper restricted zone of the soil (referred to as the active zone).irrespective of higher swelling potentially if the moisture content of the clay remains unchanged, there will be no farther volume change and structure founded. A slight change of moisture content is sufficient to cause detrimental swelling.

A clay sample with low water content has higher swelling capacity (hence higher swelling pressure) than the soil with higher water content. Karl Tarzghi (1925) stated that swelling is a form of decomposition

Factors those affect the swelling mostly depend on the environmental conditions of soil. A soil element close to the surface, swell more with the intake of water, but the same soil can not swell if it is below the surface over an overburden pressure which neutralizes the swelling pressure of the dry soil. Factor which are generally responsible for swelling are:

- Location of soil sample from the sample form the surface
- Shape size and thickness of sample
- initial water content
- Stress history
- Nature of pore fluids
- Temperature
- Volume change
- Unit weight of sample
- Time etc.

## 2.8 Problems associated with expansive clay

For all type of engineering construction over expansive soils are not suitable since they generate problems. But due to persistence of these types of soils in different parts of India, different irrigation project need to be developed on these deposits. Moreover examples of similar problems have also been recognized in many other parts of the world. Structures found on these soils are subjected to differential deflections which in turn cause distresses on expansive clays and produce hazardous damage to the structures .Reduction of moisture content cause shrinkage by the evaporation of vegetation whereas subsequent increase in moisture content causes heave in expansive soil. The rise of water table has got a considerable affect on the movement of foundation on expansive soils.

Whether a mass of clay has been compacted by nature or by artificial means, it is unlikely to expand as much horizontally as vertically. Experiments have shown that the compacted clay soils exhibit greater unit swelling in the horizontal direction than in vertical direction. Then magnitude of difference in swelling being very small, vertical swelling pressure is calculated to uplift forces on structure. In dry season due to evaporation the surface is getting reduced surrounding a building, which is erected on clay layer, but there is very little evaporation under the building. Thus there will be differential settlement at plinth level causing danger to structures.

If a structure is built during dry season with foundation lying within the unstable zone, the base of the foundation experiences swelling pressure as the partially saturated soil starts taking in water during wet season. This swelling pressure is developed due to its constraint offered by its foundation for the free swelling. If imposed pressure on the foundation by its structure is less than the swelling pressure the structure is likely to get lifted up locally which would load to cracks in the structure. On the other hand if the imposed bearing pressure is greater than the swelling pressure than there will not be any problem for the structure. If however a structure is built during wet season, it will experience settlement as the dry seasons will approach weather the bearing pressure is low or high. The imposed bearing pressure in the wet season should be within the allowable bearing pressure for the soil. Then as a better practice the structure should be constructed during dry season and should be completed before wet season.

### 2.9 Swelling time

When the compacted clay is exposed to water time is required for movement of water into the soil sample under the hydraulic gradient. The process is in many ways analogous to the process of consolidation where in the movement of water, in loaded clay is retarded by its low permeability. The long time required for the development of swell. The amount of water taken in, by the soil at various time periods is different, as corresponding void ratio. The rate of intake decreases gradually during next 100 minutes. Beyond 100 minutes, the rate of intake is very slow.

The initial high rate of intake may be due to the high order of capillary potential gradient between soil and water. After swelling the wetting height ($H_t$) is determined from the

Equation: $\underline{H_t = a.t}$ ……………………………………(2)

Where; a = a constant (found out experimentally)

t = time of swelling

### 2.10 Swelling behavior of compacted clay related to Index properties of soil

Numerous and widely different methods have been proposed by different research workers throughout the world for the characterization of soil in lab for the purpose of prediction their behavior under field conditions. These methods can broadly be classified in the two methods:

#### 2.10.1 Direct method

Direct method includes the direct measurement of swelling components, swell percent and swelling pressures and a great deal of such data is now available in published literature.

#### 2.10.2 The indirect method

Indirect method includes methods in which a measure soil properties is related to swell percent and swelling pressure of the soil by empirical or semi-empirical mathematical expressions or graphical illustrations.

## 2.11 Bearing capacity

Bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil.

## 2.12 Construction techniques in expansive soils:

In general three basic approaches may be adopted for foundations on expansive clays.

Altering the condition of expansive soil.

- By passing the expansive clay by the insulating the foundation from its effects.
- Providing a shallow foundation capable of withstanding differential movements and mitigating their effects in super structure.

### 2.12.1Alteration of soil condition:

Alteration of the condition of expansive soil includes stabilization of expansive soils, moisture control and compaction control and replacement of such soils to reduce or eliminate its volume change on wetting and drying.

- **Moisture barriers:**

Most moisture control methods are applied around the perimeter of structure in order to minimize edge wetting or drying of foundations and to maintain uniform water conditions beneath the structure. A recent study suggests that, vertical trenches, about 15 cm wide by 1.5 m deep and filed with gravel. Capillary barrier), lean concrete or mixture of granulated rubber, lime and fly ash serves as quite effective moisture barrier.

- **Pre-wetting**

The purpose of pre-wetting is to raise the moisture content of the near suitable clays prior to placement of the structure some cases it has been found effective, especially in minimizing sub grade heaving under highways. A well maintained garden is also recommended in some cases. This will assist in maintaining equilibrium of moisture movement from and toward the building.

- **Compaction control**

It has been seen that expansive class expand very little when compacted at low densities and high moisture conditions. GROMLEO Recommends compaction at 2% - 5% above the optimum moisture content compaction of expansive foundation soil, to contain low densities to allow slight swelling, however may be desirable because this procedure greatly reduces to swelling pressure.

- **Replacements**

A simple and easy solution for slabs and footings on expansive soils is to replace the foundation soil with non-swelling soils. Experience indicates that there is no danger of foundation movement f the subsoil consists of more than about 1.5 m of non swelling soil underlain by highly expensive soils (when 1975)

- **Cohesive non-swelling layer (C.N.S Layer):**

The CNS layer techniques have also been recently introduced in India for canal lining, foundation of cross drainage structures and buildings on expansive soils. Form a layer number of experiments conducted by KATT,R.K (1979), in has been seen that the shear strength if cohesive non-swelling soil layer is highly effective in counteracting the swelling and swelling pressure of its underlying expansive soil media. Generally, it causes the reduction of apparent cohesion, loss of shear strength and hence bearing capacity of the soil is also reduced drastically. Therefore it is essential to study the soil behavior at saturation.

Chapter-3

# PRESENT EXPERIMENTAL PROCEDURES

# PRESENT EXPERIMENTAL PROCEDURES

## 3.1 Grain size Analysis

Grain size analysis is done for

- Mechanical sieve and
- Hydrometer analysis

Expansive soil and for fly ash by using following procedures as per IS: 3104-1964

## 3.2 Specific Gravity

The specific gravity of soil was determined by using Pycnometer (volumetric flask) as per IS: 2720(part-III/sec-I) 1980.

## 3.3 Liquid limit

The liquid limit was determined in the laboratory by the help of standard liquid limit apparatus. About 120g of the specimen passes through 425μ sieve was taken. A groove was made by groove tool an IS: 9259-1979 designates. A brass cup was raised and allowed to fall on a rubber base. The water content correspond to 25 blows was taken as liquid limit. The value of liquid limit was found out for swelling soil and swelling soil with 20% fly-ash.

## 3.4 Plastic limit

The value of plastic limit was found out for swelling soil and swelling soil with 20% fly-ash as per IS: 2720(part-V)-1986.

### 3.5 Optimum moisture content and maximum dry density

The Optimum moisture content and dry density of swelling soil with various percentage of fly-ash (0%,10%,20%,30%,40%,50%) was determined by performing the "standard proctor test" as per IS: 2720(part VII)1965. The test consist in compacting soil at various water contents in the mould, in three equal layers, each being given 25 blows of 2.6kg rammer dropped from a height of 31cm. The collar removed and the excess soil is trimmed of to make it level. The dry density is determined and plotted against water content to find OMC and corresponding maximum dry density

### 3.6 Free swell Index

The free swell index for swelling soil as well as soil+fly-ash mix (0%,10%,20%,30%,40%,50%) was determined as per IS:2720 (part-II). The procedure involved in taking two oven dried soil samples (passing through 425µ IS sieve), 20g each were placed separately in two 100ml graduated soil sample. Distilled water was filled in one cylinder and kerosene (non-polar liquid) in the other cylinder up to 100ml mark. The final volume of soil was read after 24hours to calculate free swell index.

### 3.7 Unconfined compression test

This test was conducted on various sample with fly-ash concentration (0%,10%,20%,30%,40%,50%) prepared at OMC, subjected to unconfined compression test. The test so conducted with reference to IS: 2720 part-10(1991) & 4330-5(1970).

### 3.8 C.B.R test

C.B.R test were determined soil + fly-ash (0%,10%,20%,30%,40%,50%) as per IS:2720-16(1961).The sample so prepared at OMC. Two samples were made for each concentration of fly-ash, one sample tested at OMC (unsoaked) and other was tested at saturation after four days soaking.

**Chapter- 4**

# APPENDIX-A

# APPENDIX-A

## GRAIN SIZE DISTRIBUTION OF SWELLING SOIL

**Table-5: Mechanical Sieve Analysis of swelling soil**

| Sieve Size(mm) | Retaining (g) | %age of retain | Cum retain %age | %age of finer |
|---|---|---|---|---|
| 300 | 156 | 31.2 | 31.2 | 68.8 |
| 212 | 124 | 24.8 | 56.0 | 44.0 |
| 75 | 96 | 19.2 | 75.2 | 24.8 |

**Table-6: Hydrometer readings of Swelling Soil**

| SL No | Elapsed time (min) | Hydrometer reading | Meniscus reading | Corrected hydrometer reading | H | Effct. height He | Fact. M*10-5 | Particle size | % of finer corrs to N1 | % of finer corrs to N |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.5 | 23.00 | 0.5 | 23.50 | 11.8 | 20.15 | 1277 | 0.0810 | 79.81 | 19.79 |
| 2 | 1 | 22.50 | 0.5 | 23.00 | 11.9 | 20.25 | 1277 | 0.0570 | 78.07 | 19.36 |
| 3 | 2 | 20.50 | 0.5 | 21.00 | 12.3 | 20.65 | 1277 | 0.0410 | 71.13 | 17.64 |
| 4 | 4 | 20.00 | 0.5 | 20.50 | 12.4 | 20.75 | 1277 | 0.0290 | 69.40 | 17.21 |
| 5 | 8 | 20.00 | 0.5 | 20.50 | 12.4 | 20.75 | 1277 | 0.0200 | 69.40 | 17.21 |
| 6 | 16 | 18.00 | 0.5 | 18.50 | 12.8 | 21.15 | 1277 | 0.0150 | 62.46 | 15.49 |
| 7 | 30 | 18.00 | 0.5 | 18.50 | 12.8 | 21.15 | 1277 | 0.0110 | 62.46 | 15.49 |
| 8 | 45 | 17.50 | 0.5 | 18.00 | 12.9 | 21.25 | 1277 | 0.0087 | 60.72 | 15.05 |
| 9 | 60 | 17.00 | 0.5 | 17.50 | 13.0 | 21.35 | 1277 | 0.0076 | 58.99 | 14.62 |
| 10 | 240 | 15.50 | 0.5 | 16.00 | 13.3 | 21.65 | 1277 | 0.0040 | 53.78 | 13.33 |
| 11 | 300 | 15.00 | 0.5 | 15.50 | 13.4 | 21.75 | 1277 | 0.0030 | 52.05 | 12.90 |
| 12 | 1440 | 13.00 | 0.5 | 13.50 | 13.8 | 22.15 | 1277 | 0.0016 | 45.11 | 11.18 |

## GRAIN SIZE DISTRIBUTION OF FLY ASH

**Table-7: Mechanical Sieve Analysis of Fly-ash**

| Sieve Size (mm) | Retaining (g) | percentage retain | Cum retain percentage | percentage of finer |
|---|---|---|---|---|
| 2000 | 3.38 | 0.67 | 0.67 | 99.33 |
| 1000 | 3.51 | 0.70 | 1.37 | 98.63 |
| 600 | 6.52 | 1.30 | 2.69 | 97.33 |
| 425 | 7.60 | 1.52 | 4.19 | 95.81 |
| 212 | 86.50 | 17.30 | 21.49 | 78.51 |
| 150 | 171.53 | 34.31 | 55.80 | 44.20 |
| 75 | 52.66 | 10.52 | 66.32 | 33.68 |

**Table-8: Hydrometer readings of Fly-Ash**

| SL No | Elapsed time (min) | Hydrometer reading | Meniscus reading | Corrected hydrometer reading | H | Effct. height He | Fact. M*10-5 | Particle size | % of finer corrs to N1 | % of finer corrs to N |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 19.50 | 0.5 | 20.00 | 12.5 | 20.07 | 1321 | 0.059 | 72 | 24.25 |
| 2 | 2 | 17.00 | 0.5 | 17.50 | 13.0 | 20.57 | 1321 | 0.042 | 63 | 21.22 |
| 3 | 4 | 13.50 | 0.5 | 14.00 | 13.7 | 21.27 | 1321 | 0.030 | 50.4 | 16.97 |
| 4 | 8 | 10.50 | 0.5 | 11.00 | 14.3 | 21.87 | 1321 | 0.021 | 39.6 | 13.34 |
| 5 | 15 | 7.50 | 0.5 | 8.00 | 14.9 | 22.47 | 1321 | 0.016 | 28.8 | 9.70 |
| 6 | 30 | 4.50 | 0.5 | 5.00 | 15.5 | 23.07 | 1321 | 0.011 | 18.0 | 6.00 |
| 7 | 60 | 3.80 | 0.5 | 4.30 | 15.4 | 23.01 | 1321 | 0.008 | 15.48 | 5.21 |
| 8 | 120 | 2.50 | 0.5 | 3.00 | 15.9 | 23.47 | 1321 | 0.005 | 10.80 | 3.64 |
| 9 | 240 | 1.50 | 0.5 | 2.00 | 16.1 | 23.67 | 1321 | 0.004 | 7.2 | 2.43 |

## SPECIFIC GRAVITY

**Table-9: Specific gravity of swelling soil**

| Observation | Sample-1 | Sample-2 |
|---|---|---|
| Empty wt. of bottle(M1) | 125.93 | 368.81 |
| Bottle wt.+ Dry soil wt.(M2) | 175.93 | 397.70 |
| Bottle wt.+ Soil wt.+ Water wt.(M3) | 405.58 | 168.11 |
| Bottle wt.+ Water wt.(M4) | 376.37 | 368.81 |
| Specific gravity(G) | 2.405 | 2.303 |

**Table-10: Specific gravity of Fly Ash**

| Observation | Sample-1 | Sample-2 |
|---|---|---|
| Empty wt. of bottle(M1) | 103.51 | 110.49 |
| Bottle wt.+ Dry soil wt.(M2) | 107.33 | 50.00 |
| Bottle wt.+ Soil wt.+ Water wt.(M3) | 364.21 | 369.84 |
| Bottle wt.+ Water wt.(M4) | 366.32 | 397.57 |
| Specific gravity(G) | 2.25 | 2.24 |

## FREE SWELL INDEX TEST

**Table-11: Free swell index test of swelling soil with diff conc. of fly-ash**

| | Soil sample taken (g) | Height measured in water (cc) | Height measured in kerosene (cc) | Swelling Index (%age) |
|---|---|---|---|---|
| Swelling soil | 20 | 31 | 21 | 47.61 |
| Swelling soil+10% fly ash | 20 | 27 | 20 | 35.00 |
| Swelling soil+20% fly ash | 20 | 25 | 19 | 31.57 |
| Swelling soil+30% fly ash | 20 | 22 | 16 | 37.50 |
| Swelling soil+40% fly ash | 20 | 21 | 15 | 46.67 |
| Swelling soil+50% fly ash | 20 | 21 | 15 | 46.67 |

## LIQUID LIMIT TEST

**Table-12: Liquid Limit of swelling soil**

| SL No | Empty wt (g). | Wet soil+ Can wt (g). | Wet wt (g). | Dry wt (g). | Wt. of water (g) | Water content (%age) | No of blows |
|---|---|---|---|---|---|---|---|
| 1 | 2.36 | 10.0 | 7.64 | 4.64 | 3.00 | 62.65 | 42 |
| 2 | 2.54 | 13.6 | 11.06 | 6.76 | 4.30 | 63.60 | 39 |
| 3 | 2.40 | 12.6 | 10.10 | 6.10 | 4.00 | 65.57 | 28 |
| 4 | 2.51 | 11.2 | 8.69 | 5.19 | 3.50 | 67.43 | 26 |
| 5 | 2.46 | 14.0 | 11.54 | 6.74 | 4.80 | 71.21 | 18 |

## PLASTIC LIMIT TEST

**Table-13: Plastic limit of swelling soil**

| SL No | Can no | Empty wt (g). | Wet soil+ empty wt (g). | Wet wt (g) | Dry wt (g) | Water wt (g) | Plastic limit (%age) |
|---|---|---|---|---|---|---|---|
| 1 | 52 | 2.40 | 5.8 | 3.40 | 2.5 | 0.9 | 36 |
| 2 | 53 | 2.48 | 7.3 | 4.82 | 3.52 | 1.3 | 36.9 |
| 3 | 30 | 2.49 | 6.7 | 4.21 | 3.01 | 12 | 39.8 |
| **Average plastic limit** | | | | | | | **37.5** |

## SHRINKAGE LIMIT TEST

**Table-14**: **Shrinkage limit of swelling soil**

| SL No | Description | Sample(g) |
|---|---|---|
| 1 | Mass of empty mercury dish | 39.38 |
| 2 | Mass of mercury dish with mercury equal to volume of the shrinkage dish | 278.9 |
| 3 | Mass of mercury | 239.52 |
| 4 | Volume of shrinkage dish(V1) | 17.61 |
| 5 | Mass of empty shrinkage dish | 5.74 |
| 6 | Mass of shrinkage dish+ wet soil | 33.70 |
| 7 | Mass of wet soil(M1) | 27.96 |
| 8 | Mass of shrinkage dish+ dry soil | 21.80 |
| 9 | Mass of dry soil(Ms) | 16.06 |
| 10 | Mass of mercury dish + mercury equal in volume of dry pat | 161.6 |
| 11 | Mass of mercury displaced by dry pat | 112.1 |
| 12 | Volume of dry pat(V2) | 8.24 |
| 13 | Volumetric shrinkage(Vs) | 113.0 |
| 14 | Shrinkage ratio(SR) | 1.94 |
| 15 | Shrinkage limit | **15.75** |

# PROCTOR COMPACTION TEST

**Proctor compaction Test of swelling soil**

**Table-15.1**: **Water content (%)**

| SL No | Empty wt. (g) | Wet soil+ Can wt (g). | Wet wt (g). | Dry wt (g). | Water wt (g). | Water content (%age) |
|---|---|---|---|---|---|---|
| 1 | 9.63 | 35.3 | 25.67 | 21.77 | 3.90 | 17.9 |
| 2 | 9.96 | 45.1 | 35.19 | 29.59 | 5.60 | 18.9 |
| 3 | 9.97 | 41.3 | 31.33 | 25.93 | 5.40 | 20.8 |
| 4 | 9.64 | 48.2 | 38.56 | 29.76 | 8.80 | 29.5 |
| 5 | 9.77 | 50.1 | 40.33 | 32.03 | 8.30 | 25.9 |

**Table-15.2**: **Dry density (g/cc)**

| SL No | Mass of mould + comp soil (g). | Mass of mould (g) | Mass of comp soil (g) | Bulk density (g/cc) | Water content (%age) | Dry density (g/cc). |
|---|---|---|---|---|---|---|
| 1 | 3930 | 2385 | 1545 | 1.56 | 17.9 | 1.32 |
| 2 | 4090 | 2385 | 1705 | 1.73 | 18.9 | 1.45 |
| 3 | 4164 | 2385 | 1779 | 1.805 | 20.8 | 1.49 |
| 4 | 4175 | 2385 | 1790 | 1.816 | 29.5 | 1.40 |
| 5 | 4255 | 2385 | 1870 | 1.897 | 32.9 | 1.306 |

### Proctor compaction Test (with 10%flyash)

**Table-16.1**: Water content (%)

| SL No | Empty wt. of can (g). | Wet soil+ Can wt (g). | Dry soil wt +can wt (g). | Wet soil wt (g). | Dry soil wt (g). | Water wt (g). | Water content (%age) |
|---|---|---|---|---|---|---|---|
| 1 | 9.36 | 45.19 | 38.66 | 35.83 | 29.30 | 6.53 | 22.28 |
| 2 | 9.88 | 48.25 | 40.05 | 38.37 | 30.17 | 8.20 | 27.17 |
| 3 | 9.47 | 49.54 | 39.59 | 40.07 | 30.12 | 9.95 | 33.03 |
| 4 | 9.69 | 57.60 | 45.86 | 47.91 | 36.17 | 11.74 | 34.45 |
| 5 | 8.67 | 58.90 | 44.83 | 50.23 | 36.16 | 14.07 | 38.91 |

**Table-16.2**: Dry density (g/cc)

| SL No | Mass of mould + comp soil (g) | Mass of mould (g) | Mass of comp soil (g) | Bulk density (g/cc) | Water content (%age) | Dry density (g/cc) |
|---|---|---|---|---|---|---|
| 1 | 3745 | 2385 | 1660 | 1.660 | 22.28 | 1.357 |
| 2 | 3955 | 2385 | 1870 | 1.870 | 27.17 | 1.470 |
| 3 | 3910 | 2385 | 1825 | 1.825 | 33.03 | 1.372 |
| 4 | 3870 | 2385 | 1785 | 1.785 | 32.45 | 1.347 |
| 5 | 3840 | 2385 | 1755 | 1.755 | 38.91 | 1.263 |

### Proctor compaction (20%flyash)

**Table-17.1**: Water content (%)

| SL No | Empty wt. of can (g) | Wet soil+ Can wt (g). | Dry soil wt +can wt (g). | Wet soil wt. (g) | Dry soil wt. (g) | Water wt (g) | Water content (%age) |
|---|---|---|---|---|---|---|---|
| 1 | 10.05 | 33.65 | 29.78 | 23.60 | 19.73 | 3.87 | 19.61 |
| 2 | 9.97 | 39.95 | 34.77 | 29.98 | 24.80 | 5.18 | 20.88 |
| 3 | 9.54 | 62.06 | 49.91 | 52.52 | 42.98 | 9.54 | 22.19 |
| 4 | 12.89 | 52.40 | 41.49 | 39.51 | 28.60 | 10.91 | 38.14 |

**Table-17.2**: Dry density (g/cc)

| SL No | Mass of mould + comp soil (g) | Mass of mould (g) | Mass of compacted soil (g) | Bulk density (g/cc) | Water content (%age) | Dry density (g/cc) |
|---|---|---|---|---|---|---|
| 1 | 3740 | 2385 | 1655 | 1.655 | 19.61 | 1.384 |
| 2 | 3875 | 2385 | 1790 | 1.790 | 20.88 | 1.480 |
| 3 | 3950 | 2385 | 1865 | 1.865 | 22.19 | 1.526 |
| 4 | 3850 | 2385 | 1765 | 1.765 | 38.14 | 1.277 |

**Proctor compaction Test (30%flyash)**

**Table-18.1: Water content (%)**

| SL No | Empty wt. of can (g) | Wet soil+ Can wt (g). | Dry soil wt +can wt (g). | Wet soil wt (g). | Dry soil wt (g). | Water wt (g) | Water content (%age) |
|---|---|---|---|---|---|---|---|
| 1 | 9.97 | 43.98 | 38.76 | 34.01 | 28.79 | 5.22 | 18.22 |
| 2 | 9.27 | 45.72 | 38.81 | 36.45 | 29.54 | 6.91 | 23.39 |
| 3 | 9.11 | 44.90 | 37.18 | 35.79 | 28.07 | 7.72 | 27.50 |
| 4 | 9.42 | 48.64 | 38.51 | 39.22 | 29.09 | 10.13 | 34.82 |

**Table-18.2**: **Dry density (g/cc)**

| SL No | Mass of mould + comp soil (g) | Mass of mould (g) | Mass of compacted soil (g) | Bulk density (g/cc) | Water content (%age) | Dry density (g/cc) |
|---|---|---|---|---|---|---|
| 1 | 3720 | 2385 | 1635 | 1.635 | 18.13 | 1.384 |
| 2 | 3815 | 2385 | 1730 | 1.730 | 23.39 | 1.402 |
| 3 | 3910 | 2385 | 1825 | 1.825 | 27.50 | 1.431 |
| 4 | 3835 | 2385 | 1750 | 1.750 | 34.82 | 1.298 |

**Proctor compaction Test (40%flyash)**

**Table-19.1**: **Water content (%)**

| SL No | Empty wt. of can (g) | Wet soil+ Can wt (g). | Dry soil wt +can wt (g). | Wet soil wt (g). | Dry soil wt (g). | Water wt (g) | Water content (%age) |
|---|---|---|---|---|---|---|---|
| 1 | 9.54 | 37.86 | 33.60 | 28.32 | 24.06 | 4.26 | 17.70 |
| 2 | 9.97 | 48.98 | 41.56 | 39.01 | 31.59 | 7.42 | 23.48 |
| 3 | 10.35 | 49.47 | 40.92 | 39.12 | 30.57 | 8.55 | 27.97 |
| 4 | 9.27 | 50.35 | 39.79 | 41.08 | 30.52 | 10.56 | 34.60 |

**Table-19.2**: **Dry density (g/cc)**

| SL No | Mass of mould + comp soil (g) | Mass of mould (g) | Mass of compacted soil (g) | Bulk density (g/cc) | Water content (%age) | Dry density (g/cc) |
|---|---|---|---|---|---|---|
| 1 | 3670 | 2385 | 1585 | 1.585 | 17.70 | 1.346 |
| 2 | 3795 | 2385 | 1710 | 1.710 | 23.48 | 1.384 |
| 3 | 3875 | 2385 | 1790 | 1.790 | 27.97 | 1.398 |
| 4 | 3830 | 2385 | 1745 | 1.745 | 34.60 | 1.296 |

**Proctor compaction Test (50%flyash)**

**Table-20.1**: **Water content**

| SL No | Empty wt. of can (g) | Wet soil+ Can wt (g) | Dry soil wt +can wt (g). | Wet soil wt (g). | Dry soil wt (g) | Water wt (g) | Water content (%age) |
|---|---|---|---|---|---|---|---|
| 1 | 9.29 | 45.30 | 40.90 | 36.01 | 31.61 | 4.40 | 13.91 |
| 2 | 9.54 | 35.88 | 31.89 | 26.34 | 22.35 | 3.99 | 17.85 |
| 3 | 10.05 | 42.68 | 36.33 | 32.63 | 36.28 | 6.35 | 24.16 |
| 4 | 9.50 | 52.55 | 42.41 | 43.05 | 32.91 | 10.14 | 30.81 |
| 5 | 9.37 | 60.49 | 46.34 | 51.12 | 36.97 | 14.15 | 38.27 |

**Table-20.2**: **Dry density (g/cc)**

| SL No | Mass of mould + comp soil (g) | Mass of mould (g) | Mass of comp soil (g) | Bulk density (g/cc) | Water content (%age) | Dry density (g/cc) |
|---|---|---|---|---|---|---|
| 1 | 3595 | 2385 | 1510 | 1.510 | 13.91 | 1.325 |
| 2 | 3705 | 2385 | 1620 | 1.620 | 17.85 | 1.374 |
| 3 | 3780 | 2385 | 1695 | 1.695 | 24.16 | 1.395 |
| 4 | 3885 | 2385 | 1800 | 1.800 | 30.81 | 1.376 |
| 5 | 3805 | 2385 | 1720 | 1.720 | 38.27 | 1.244 |

## UNCONFINED COMPRESSIVE STRENGTH TEST

**Table-21: Unconfined compressive strength test for swelling soil only**

| SL No | OBSERVATION | | | | CALCULATION | | |
|---|---|---|---|---|---|---|---|
| | Dial Gauge | | Proving ring | | Strain(ε) | Corrected area ($mm^2$) | Compressive strength(σ1) ($N/mm^2$) |
| | Reading | Deformation (mm) | Reading | Load (KN) | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1963.49 | 0 |
| 2 | 50 | 0.5 | 10 | 0.034 | 0.0049 | 1973.26 | 0.017 |
| 3 | 100 | 1.0 | 14 | 0.048 | 0.0099 | 1982.92 | 0.024 |
| 4 | 150 | 1.5 | 30 | 0.102 | 0.0148 | 1992.78 | 0.051 |
| 5 | 200 | 2.0 | 47 | 0.160 | 0.0198 | 2002.74 | 0.080 |
| 6 | 250 | 2.5 | 58 | 0.197 | 0.0247 | 2012.80 | 0.098 |
| 7 | 300 | 3.0 | 69 | 0.235 | 0.0297 | 2022.96 | 0.116 |
| 8 | 350 | 3.5 | 75 | 0.255 | 0.0346 | 2033.22 | 0.125 |
| 9 | 400 | 4.0 | 82 | 0.279 | 0.0396 | 2043.59 | 0.137 |
| 10 | 450 | 4.5 | 84 | 0.286 | 0.0445 | 2047.64 | 0.140 |
| 11 | 500 | 5.0 | 86 | 0.292 | 0.0495 | 2064.65 | 0.141 |
| 12 | 550 | 5.5 | 89 | 0.303 | 0.0545 | 2073.37 | 0.146 |
| 13 | 600 | 6.0 | 87 | 0.296 | 0.0580 | 2084.38 | 0.142 |
| 14 | 650 | 6.5 | 86 | 0.292 | 0.0630 | 2095.50 | 0.139 |
| 15 | 700 | 7.0 | 85 | 0.289 | 0.0680 | 2106.74 | 0.137 |
| 16 | 750 | 7.5 | 85 | 0.289 | 0.0730 | 2118.11 | 0.136 |
| 17 | 800 | 8.0 | 82 | 0.279 | 0.0780 | 2129.59 | 0.131 |
| 18 | 850 | 8.5 | 82 | 0.279 | 0.0830 | 2141.20 | 0.130 |
| 19 | 900 | 9.0 | 81 | 0.275 | 0.0880 | 2152.90 | 0.128 |
| 20 | 950 | 9.5 | 80 | 0.272 | 0.0930 | 2164.80 | 0.126 |

**Table-22**: **Unconfined compressive strength test of swelling soil + 10% of fly ash**

| SL No | OBSERVATION | | | | CALCULATION | | |
|---|---|---|---|---|---|---|---|
| | **Dial Gauge** | | **Proving ring** | | **Strain(ε)** | **Corrected area ($mm^2$)** | **Compressive strength(σ1) ($N/mm^2$)** |
| | **Reading** | **Deformation (mm)** | **Reading** | **Load (KN)** | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1963.490 | 0 |
| 2 | 50 | 0.5 | 22 | 0.075 | 0.005 | 1973.457 | 0.038 |
| 3 | 100 | 1.0 | 40 | 0.136 | 0.010 | 1983.526 | 0.069 |
| 4 | 150 | 1.5 | 48 | 0.163 | 0.015 | 1993.698 | 0.082 |
| 5 | 200 | 2.0 | 52 | 0.177 | 0.020 | 2003.974 | 0.088 |
| 6 | 250 | 2.5 | 56 | 0.190 | 0.025 | 2014.358 | 0.094 |
| 7 | 300 | 3.0 | 60 | 0.204 | 0.030 | 2024.358 | 0.101 |
| 8 | 350 | 3.5 | 61 | 0.207 | 0.035 | 2035.450 | 0.102 |
| 9 | 400 | 4.0 | 63 | 0.214 | 0.040 | 2046.163 | 0.105 |
| 10 | 450 | 4.5 | 65 | 0.221 | 0.045 | 2056.163 | 0.107 |
| 11 | 500 | 5.0 | 66 | 0.224 | 0.050 | 2067.931 | 0.108 |
| 12 | 550 | 5.5 | 67 | 0.228 | 0.055 | 2078.989 | 0.110 |
| 13 | 600 | 6.0 | 68 | 0.231 | 0.060 | 2090.167 | 0.110 |
| 14 | 650 | 6.5 | 69 | 0.234 | 0.065 | 2101.465 | 0.111 |
| 15 | 700 | 7.0 | 69 | 0.234 | 0.070 | 2112.86 | 0.111 |
| 16 | 750 | 7.5 | 69 | 0.234 | 0.075 | 2124.432 | 0.110 |
| 17 | 800 | 8.0 | 69 | 0.234 | 0.080 | 2136.105 | 0.109 |
| 18 | 850 | 8.5 | 67 | 0.227 | 0.085 | 2147.906 | 0.106 |

**Table-23**: **Unconfined compressive strength test of swelling soil + 20% of fly ash**

| SL No | OBSERVATION | | | | CALCULATION | | |
|---|---|---|---|---|---|---|---|
| | **Dial Gauge** | | **Proving ring** | | **Strain(ε)** | **Corrected area ($mm^2$)** | **Compressive strength(σ1) ($N/mm^2$)** |
| | **Reading** | **Deformation (mm)** | **Reading** | **Load (KN)** | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1963.490 | 0.000 |
| 2 | 50 | 0.5 | 12 | 0.041 | 0.004 | 1973.259 | 0.021 |
| 3 | 100 | 1.0 | 29 | 0.099 | 0.009 | 1983.125 | 0.050 |
| 4 | 150 | 1.5 | 36 | 0.122 | 0.014 | 1993.090 | 0.061 |
| 5 | 200 | 2.0 | 52 | 0.177 | 0.019 | 2003.156 | 0.088 |
| 6 | 250 | 2.5 | 73 | 0.248 | 0.024 | 2013.156 | 0.123 |
| 7 | 300 | 3.0 | 80 | 0.272 | 0.029 | 2023.325 | 0.134 |
| 8 | 350 | 3.5 | 89 | 0.302 | 0.034 | 2039.197 | 0.148 |
| 9 | 400 | 4.0 | 91 | 0.298 | 0.039 | 2044.974 | 0.152 |
| 10 | 450 | 4.5 | 92 | 0.309 | 0.044 | 2055.459 | 0.152 |
| 11 | 500 | 5.0 | 93 | 0.312 | 0.049 | 2065.052 | 0.152 |
| 12 | 550 | 5.5 | 92 | 0.313 | 0.054 | 2075.755 | 0.151 |
| 13 | 600 | 6.0 | 91 | 0.309 | 0.059 | 2087.500 | 0.148 |

**Table-24**: **Unconfined compressive strength test of swelling soil + 30% of fly ash**

| SL No | OBSERVATION | | | | CALCULATION | | |
|---|---|---|---|---|---|---|---|
| | **Dial Gauge** | | **Proving ring** | | **Strain(ε)** | **Corrected area ($mm^2$)** | **Compressive strength(σ1) ($N/mm^2$)** |
| | **Reading** | **Deformation (mm)** | **Reading** | **Load (KN)** | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1963.500 | 0 |
| 2 | 50 | 0.5 | 7 | 0.024 | 0.004 | 1973.269 | 0.012 |
| 3 | 100 | 1.0 | 17 | 0.058 | 0.009 | 1983.135 | 0.029 |
| 4 | 150 | 1.5 | 25 | 0.085 | 0.014 | 1993.101 | 0.043 |
| 5 | 200 | 2.0 | 31 | 0.105 | 0.019 | 2003.167 | 0.052 |
| 6 | 250 | 2.5 | 41 | 0.139 | 0.024 | 2013.335 | 0.069 |
| 7 | 300 | 3.0 | 49 | 0.166 | 0.029 | 2023.607 | 0.082 |
| 8 | 350 | 3.5 | 55 | 0.187 | 0.034 | 2033.985 | 0.091 |
| 9 | 400 | 4.0 | 58 | 0.197 | 0.039 | 2044.469 | 0.096 |
| 10 | 450 | 4.5 | 61 | 0.207 | 0.044 | 2055.062 | 0.100 |
| 11 | 500 | 5.0 | 62 | 0.211 | 0.049 | 2065.766 | 0.102 |
| 12 | 550 | 5.5 | 64 | 0.218 | 0.054 | 2076.581 | 0.105 |
| 13 | 600 | 6.0 | 66 | 0.224 | 0.059 | 2087.511 | 0.107 |
| 14 | 650 | 6.5 | 68 | 0.231 | 0.064 | 2098.556 | 0.110 |
| 15 | 700 | 7.0 | 69 | 0.234 | 0.069 | 2109.718 | 0.111 |
| 16 | 750 | 7.5 | 69 | 0.234 | 0.074 | 2121.000 | 0.110 |
| 17 | 800 | 8.0 | 69 | 0.234 | 0.079 | 2132.403 | 0.110 |
| 18 | 850 | 8.5 | 69 | 0.234 | 0.084 | 2143.930 | 0.109 |
| 19 | 900 | 9.0 | 67 | 0.228 | 0.089 | 2155.582 | 0.106 |

**Table-25: Unconfined compressive strength test of swelling soil + 40% of fly ash**

| SL No | OBSERVATION | | | | CALCULATION | | |
|---|---|---|---|---|---|---|---|
| | **Dial Gauge** | | **Proving ring** | | **Strain(ε)** | **Corrected area ($mm^2$)** | **Compressive strength(σ1) ($N/mm^2$)** |
| | **Reading** | **Deformation (mm)** | **Reading** | **Load (KN)** | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1963.49 | 0 |
| 2 | 50 | 0.5 | 9 | 0.031 | 0.005 | 1973.559 | 0.016 |
| 3 | 100 | 1.0 | 21 | 0.071 | 0.010 | 1983.732 | 0.036 |
| 4 | 150 | 1.5 | 23 | 0.078 | 0.015 | 1994.011 | 0.039 |
| 5 | 200 | 2.0 | 36 | 0.122 | 0.020 | 2004.396 | 0.061 |
| 6 | 250 | 2.5 | 45 | 0.153 | 0.025 | 2014.890 | 0.076 |
| 7 | 300 | 3.0 | 57 | 0.194 | 0.030 | 2025.495 | 0.096 |
| 8 | 350 | 3.5 | 62 | 0.211 | 0.035 | 2036.212 | 0.104 |
| 9 | 400 | 4.0 | 64 | 0.217 | 0.040 | 2047.043 | 0.106 |
| 10 | 450 | 4.5 | 67 | 0.227 | 0.045 | 2057.990 | 0.110 |
| 11 | 500 | 5.0 | 69 | 0.234 | 0.051 | 2069.054 | 0.113 |
| 12 | 550 | 5.5 | 71 | 0.241 | 0.056 | 2080.238 | 0.116 |
| 13 | 600 | 6.0 | 71 | 0.241 | 0.061 | 2091.544 | 0.115 |

**Table-26: Unconfined compressive strength test of swelling soil + 50% of fly ash**

| SL No | OBSERVATION | | | | CALCULATION | | |
|---|---|---|---|---|---|---|---|
| | **Dial Gauge** | | **Proving ring** | | **Strain(ε)** | **Corrected area ($mm^2$)** | **Compressive strength(σ1) ($N/mm^2$)** |
| | **Reading** | **Deformation (mm)** | **Reading** | **Load (KN)** | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 1963.49 | 0 |
| 2 | 50 | 0.5 | 8 | 0.027 | 0.005 | 1973.45 | 0.013 |
| 3 | 100 | 1.0 | 15 | 0.051 | 0.010 | 1983.52 | 0.026 |
| 4 | 150 | 1.5 | 17 | 0.057 | 0.015 | 1993.69 | 0.029 |
| 5 | 200 | 2.0 | 30 | 0.102 | 0.020 | 2003.97 | 0.051 |
| 6 | 250 | 2.5 | 40 | 0.136 | 0.025 | 2014.84 | 0.067 |
| 7 | 300 | 3.0 | 52 | 0.177 | 0.030 | 2024.84 | 0.087 |
| 8 | 350 | 3.5 | 58 | 0.197 | 0.035 | 2035.45 | 0.096 |
| 9 | 400 | 4.0 | 62 | 0.210 | 0.040 | 2046.16 | 0.103 |
| 10 | 450 | 4.5 | 59 | 0.200 | 0.045 | 2056.99 | 0.097 |
| 11 | 500 | 5.0 | 54 | 0.184 | 0.050 | 2067.93 | 0.089 |

## UN SOAKED CALIFORNIA BEARING RATIO TEST

**Table-27: Unsoaked CBR test for swelling soil only**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 2.599 | 0.132 | | |
| 2 | 0.5 | 7 | 18.195 | 0.926 | | |
| 3 | 1.0 | 18 | 46.789 | 2.384 | | |
| 4 | 1.5 | 24 | 62.385 | 3.179 | | |
| 5 | 2.0 | 31 | 80.581 | 4.106 | | |
| 6 | 2.5 | 33 | 85.779 | 4.369 | 70 | 6.24 |
| 7 | 3.0 | 36 | 93.577 | 4.767 | | |
| 8 | 3.5 | 38 | 98.776 | 5.031 | | |
| 9 | 4.0 | 39 | 101.379 | 5.166 | | |
| 10 | 4.5 | 42 | 109.174 | 5.561 | | |
| 11 | 5.0 | 44 | 114.373 | 5.826 | 105 | 5.55 |
| 12 | 5.5 | 47 | 122.171 | 6.225 | | |
| 13 | 6.0 | 48 | 124.770 | 6.356 | | |
| 14 | 6.5 | 50 | 129.969 | 6.620 | | |
| 15 | 7.0 | 51 | 132.568 | 6.753 | | |
| 16 | 7.5 | 53 | 137.768 | 7.020 | | |
| 17 | 8.0 | 54 | 140.367 | 7.150 | | |

**Table-28: Unsoaked CBR test for swelling soil+10% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 12 | 31.193 | 1.589 | | |
| 2 | 0.5 | 30 | 77.982 | 3.974 | | |
| 3 | 1.0 | 42 | 109.174 | 5.563 | | |
| 4 | 1.5 | 50 | 129.969 | 6.623 | | |
| 5 | 2.0 | 57 | 148.165 | 7.550 | | |
| 6 | 2.5 | 62 | 161.162 | 8.212 | 70 | 11.73 |
| 7 | 3.0 | 69 | 179.358 | 9.139 | | |
| 8 | 3.5 | 73 | 189.756 | 9.669 | | |
| 9 | 4.0 | 77 | 200.155 | 10.199 | | |
| 10 | 4.5 | 80 | 207.952 | 10.596 | | |
| 11 | 5.0 | 84 | 218.349 | 11.126 | 105 | 10.60 |
| 12 | 5.5 | 86 | 223.542 | 11.391 | | |
| 13 | 6.0 | 90 | 233.945 | 11.921 | | |
| 14 | 6.5 | 93 | 241.743 | 12.318 | | |
| 15 | 7.0 | 94 | 244.343 | 12.451 | | |

**Table-29: Unsoaked CBR test for swelling soil+20% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 12 | 31.19 | 1.589 | | |
| 2 | 0.5 | 48 | 124.77 | 6.358 | | |
| 3 | 1.0 | 70 | 181.96 | 9.272 | | |
| 4 | 1.5 | 86 | 223.55 | 11.391 | | |
| 5 | 2.0 | 111 | 288.53 | 14.702 | | |
| 6 | 2.5 | 123 | 319.72 | 16.291 | 70 | 23.27 |
| 7 | 3.0 | 130 | 337.92 | 17.219 | | |
| 8 | 3.5 | 142 | 369.11 | 18.803 | | |
| 9 | 4.0 | 150 | 389.91 | 19.862 | | |
| 10 | 4.5 | 157 | 408.10 | 20.789 | | |
| 11 | 5.0 | 162 | 421.10 | 21.457 | 105 | 20.44 |
| 12 | 5.5 | 168 | 436.70 | 22.252 | | |
| 13 | 6.0 | 173 | 449.69 | 22.914 | | |
| 14 | 6.5 | 177 | 460.09 | 23.444 | | |
| 15 | 7.0 | 182 | 473.09 | 24.106 | | |
| 16 | 7.5 | 187 | 491.28 | 25.033 | | |

**Table-30: Unsoaked CBR test for swelling soil+30% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress($kg/cm^2$) | Stand load intensity($kg/cm^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | | |
| 2 | 0.5 | 3 | 7.798 | 0.397 | | |
| 3 | 1.0 | 14 | 36.391 | 1.852 | | |
| 4 | 1.5 | 27 | 70.183 | 3.572 | | |
| 5 | 2.0 | 35 | 90.979 | 4.630 | | |
| 6 | 2.5 | 42 | 109.174 | 5.556 | 70 | 7.93 |
| 7 | 3.0 | 54 | 140.367 | 7.144 | | |
| 8 | 3.5 | 57 | 148.165 | 7.541 | | |
| 9 | 4.0 | 63 | 163.761 | 8.334 | | |
| 10 | 4.5 | 68 | 176.758 | 8.996 | | |
| 11 | 5.0 | 73 | 189.755 | 9.657 | 105 | 9.19 |
| 12 | 5.5 | 78 | 202.753 | 10.319 | | |
| 13 | 6.0 | 81 | 210.550 | 10.716 | | |
| 14 | 6.5 | 84 | 218.349 | 11.112 | | |
| 15 | 7.0 | 87 | 226.147 | 11.509 | | |
| 16 | 7.5 | 89 | 231.346 | 11.774 | | |
| 17 | 8.0 | 91 | 236.544 | 12.038 | | |
| 18 | 8.5 | 93 | 241.743 | 12.303 | | |

**Table-31: Un soaked CBR test for swelling soil+40% fly-ash**

| S.No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress($kg/cm^2$) | Stand load intensity($kg/cm^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 2 | 5.199 | 0.265 | | |
| 2 | 0.5 | 6 | 15.596 | 0.794 | | |
| 3 | 1.0 | 11 | 28.593 | 1.455 | | |
| 4 | 1.5 | 24 | 62.385 | 3.175 | | |
| 5 | 2.0 | 31 | 80.581 | 4.101 | | |
| 6 | 2.5 | 42 | 109.174 | 5.546 | 70 | 7.79 |
| 7 | 3.0 | 52 | 135.168 | 6.879 | | |
| 8 | 3.5 | 62 | 161.162 | 8.202 | | |
| 9 | 4.0 | 69 | 179.358 | 9.637 | | |
| 10 | 4.5 | 73 | 189.755 | 9.657 | | |
| 11 | 5.0 | 83 | 215.749 | 10.980 | 105 | 10.457 |
| 12 | 5.5 | 87 | 226.147 | 11.509 | | |
| 13 | 6.0 | 93 | 241.743 | 12.303 | | |
| 14 | 6.5 | 100 | 259.939 | 13.229 | | |
| 15 | 7.0 | 102 | 265.138 | 13.494 | | |
| 16 | 7.5 | 105 | 272.936 | 13.891 | | |
| 17 | 8.0 | 102 | 265.138 | 13.494 | | |

**Table-32: Un soaked CBR test for swelling soil+50% fly-ash**

| S.No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 2 | 5.199 | 0.265 | | |
| 2 | 0.5 | 4 | 10.398 | 0.529 | | |
| 3 | 1.0 | 15 | 38.991 | 1.985 | | |
| 4 | 1.5 | 20 | 51.988 | 2.647 | | |
| 5 | 2.0 | 30 | 77.982 | 3.970 | | |
| 6 | 2.5 | 41 | 106.575 | 5.426 | 70 | 7.75 |
| 7 | 3.0 | 51 | 132.569 | 6.749 | | |
| 8 | 3.5 | 62 | 161.162 | 8.205 | | |
| 9 | 4.0 | 66 | 171.560 | 8.734 | | |
| 10 | 4.5 | 72 | 187.156 | 9.528 | | |
| 11 | 5.0 | 77 | 200.153 | 10.190 | 105 | 9.70 |
| 12 | 5.5 | 84 | 218.349 | 11.116 | | |
| 13 | 6.0 | 90 | 233.945 | 11.910 | | |
| 14 | 6.5 | 98 | 254.740 | 12.968 | | |
| 15 | 7.0 | 100 | 259.939 | 13.233 | | |
| 16 | 7.5 | 103 | 267.737 | 13.630 | | |

## SOAKED CALIFORNIA BEARING RATIO TEST

**Table-33: Soaked CBR test for swelling soil only**

| S.No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | | |
| 2 | 0.5 | 4 | 10.398 | 0.529 | | |
| 3 | 1.0 | 10 | 25.994 | 1.323 | | |
| 4 | 1.5 | 14 | 36.391 | 1.853 | | |
| 5 | 2.0 | 17 | 44.190 | 2.250 | | |
| 6 | 2.5 | 18 | 46.789 | 2.382 | 70 | 3.40 |
| 7 | 3.0 | 20 | 51.988 | 2.647 | | |
| 8 | 3.5 | 21 | 54.587 | 2.779 | | |
| 9 | 4.0 | 21 | 54.587 | 2.779 | | |
| 10 | 4.5 | 22 | 57.187 | 2.911 | | |
| 11 | 5.0 | 22 | 57.187 | 2.911 | 105 | 2.77 |
| 12 | 5.5 | 23 | 59.786 | 3.044 | | |
| 13 | 6.0 | 23 | 59.786 | 3.044 | | |
| 14 | 6.5 | 24 | 62.385 | 3.176 | | |
| 15 | 7.0 | 26 | 67.584 | 3.441 | | |
| 16 | 7.5 | 26 | 67.584 | 3.441 | | |
| 17 | 8.0 | 27 | 70.183 | 3.573 | | |
| 18 | 8.5 | 27 | 70.183 | 3.573 | | |

**Table-34: Soaked CBR test for swelling soil+10% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 2.599 | 0.132 | | |
| 2 | 0.5 | 3 | 7.798 | 0.397 | | |
| 3 | 1.0 | 7 | 18.196 | 0.926 | | |
| 4 | 1.5 | 11 | 28.593 | 1.456 | | |
| 5 | 2.0 | 13 | 33.792 | 1.720 | | |
| 6 | 2.5 | 14 | 36.391 | 1.853 | 70 | 2.65 |
| 7 | 3.0 | 15 | 38.991 | 1.985 | | |
| 8 | 3.5 | 15 | 38.991 | 1.985 | | |
| 9 | 4.0 | 16 | 41.590 | 2.117 | | |
| 10 | 4.5 | 16 | 41.590 | 2.117 | | |
| 11 | 5.0 | 17 | 44.190 | 2.250 | 105 | 2.14 |
| 12 | 5.5 | 17 | 44.190 | 2.250 | | |
| 13 | 6.0 | 18 | 46.789 | 2.382 | | |
| 14 | 6.5 | 18 | 46.789 | 2.382 | | |
| 15 | 7.0 | 19 | 49.388 | 2.514 | | |
| 16 | 7.5 | 19 | 49.388 | 2.514 | | |

**Table-35: Soaked CBR test for swelling soil+20% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 2.599 | 0.132 | | |
| 2 | 0.5 | 3 | 7.798 | 0.397 | | |
| 3 | 1.0 | 6 | 15.596 | 0.794 | | |
| 4 | 1.5 | 8 | 20.795 | 1.059 | | |
| 5 | 2.0 | 10 | 25.994 | 1.323 | | |
| 6 | 2.5 | 11 | 28.593 | 1.456 | 70 | 2.08 |
| 7 | 3.0 | 13 | 33.792 | 1.720 | | |
| 8 | 3.5 | 16 | 41.590 | 2.117 | | |
| 9 | 4.0 | 17 | 44.190 | 2.250 | | |
| 10 | 4.5 | 18 | 46.789 | 2.382 | | |
| 11 | 5.0 | 19 | 49.388 | 2.514 | 105 | 2.40 |
| 12 | 5.5 | 20 | 51.988 | 2.647 | | |
| 13 | 6.0 | 20 | 51.988 | 2.647 | | |
| 14 | 6.5 | 21 | 54.587 | 2.779 | | |
| 15 | 7.0 | 22 | 57.187 | 2.911 | | |
| 16 | 7.5 | 22 | 57.187 | 2.911 | | |

**Table-36: Soaked CBR test for swelling soil+30% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress($kg/cm^2$) | Stand load intensity($kg/cm^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | | |
| 2 | 0.5 | 1 | 2.599 | 0.132 | | |
| 3 | 1.0 | 4 | 10.398 | 0.529 | | |
| 4 | 1.5 | 5 | 12.997 | 0.662 | | |
| 5 | 2.0 | 7 | 18.196 | 0.926 | | |
| 6 | 2.5 | 10 | 25.994 | 1.323 | 70 | 1.93 |
| 7 | 3.0 | 13 | 33.792 | 1.720 | | |
| 8 | 3.5 | 16 | 41.590 | 2.117 | | |
| 9 | 4.0 | 18 | 46.789 | 2.382 | | |
| 10 | 4.5 | 21 | 54.587 | 2.779 | | |
| 11 | 5.0 | 22 | 57.186 | 2.911 | 105 | 2.77 |
| 12 | 5.5 | 25 | 64.985 | 3.308 | | |
| 13 | 6.0 | 27 | 70.183 | 3.573 | | |
| 14 | 6.5 | 28 | 72.783 | 3.705 | | |
| 15 | 7.0 | 29 | 75.382 | 3.838 | | |
| 16 | 7.5 | 29 | 75.382 | 3.838 | | |
| 17 | 8.0 | 30 | 77.982 | 3.970 | | |

**Table-37: Soaked CBR test for swelling soil+40% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress($kg/cm^2$) | Stand load intensity($kg/cm^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 2.599 | 0.132 | | |
| 2 | 0.5 | 3 | 7.798 | 0.396 | | |
| 3 | 1.0 | 5 | 12.997 | 0.661 | | |
| 4 | 1.5 | 9 | 23.394 | 1.197 | | |
| 5 | 2.0 | 11 | 28.593 | 1.455 | | |
| 6 | 2.5 | 14 | 36.391 | 1.852 | 70 | 2.65 |
| 7 | 3.0 | 19 | 49.388 | 2.514 | | |
| 8 | 3.5 | 21 | 54.587 | 2.778 | | |
| 9 | 4.0 | 23 | 59.786 | 3.043 | | |
| 10 | 4.5 | 25 | 64.985 | 3.317 | | |
| 11 | 5.0 | 27 | 70.183 | 3.572 | 105 | 2.45 |
| 12 | 5.5 | 28 | 72.783 | 3.704 | | |
| 13 | 6.0 | 29 | 75.382 | 3.836 | | |
| 14 | 6.5 | 30 | 77.982 | 3.969 | | |
| 15 | 7.0 | 30 | 77.982 | 3.969 | | |

**Table-38: Soaked CBR test for swelling soil+50% fly-ash**

| SL. No | Plunger penetration | Dial readings | App. Load(Kg) | C.B.R stress(kg/cm$^2$) | Stand load intensity(kg/cm$^2$) | CBR intensity(%age) |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | | |
| 2 | 0.5 | 1 | 2.599 | 0.132 | | |
| 3 | 1.0 | 2 | 5.199 | 0.265 | | |
| 4 | 1.5 | 3 | 7.798 | 0.397 | | |
| 5 | 2.0 | 6 | 15.596 | 0.794 | | |
| 6 | 2.5 | 8 | 20.795 | 1.058 | 70 | 1.51 |
| 7 | 3.0 | 10 | 25.994 | 1.323 | | |
| 8 | 3.5 | 13 | 33.792 | 1.720 | | |
| 9 | 4.0 | 16 | 41.590 | 2.117 | | |
| 10 | 4.5 | 18 | 46.789 | 2.381 | | |
| 11 | 5.0 | 20 | 50.988 | 2.595 | 105 | 2.47 |
| 12 | 5.5 | 22 | 57.187 | 2.910 | | |
| 13 | 6.0 | 22 | 57.187 | 2.910 | | |
| 14 | 6.5 | 24 | 62.385 | 3.175 | | |
| 15 | 7.0 | 26 | 67.584 | 3.440 | | |
| 16 | 7.5 | 27 | 70.183 | 3.572 | | |
| 17 | 8.0 | 28 | 72.783 | 3.704 | | |

## LIQUID LIMIT TEST

**Table-39: Liquid limit of swelling soil+20%flyash**

| SL No | Empty wt (g). | Wet soil+ Can wt (g). | Dry wt+ can wt (g). | Dry wt (g). | Wt. of water (g) | Water content (%age) | No of blows |
|---|---|---|---|---|---|---|---|
| 1 | 6.08 | 13.06 | 10.60 | 4.52 | 2.46 | 54.42 | 36 |
| 2 | 5.85 | 14.10 | 12.47 | 6.62 | 3.36 | 55.84 | 26 |
| 3 | 5.81 | 19.16 | 14.35 | 8.54 | 4.81 | 56.32 | 25 |
| 4 | 5.20 | 19.87 | 14.35 | 9.15 | 5.52 | 60.32 | 14 |

## PLASTIC LIMIT TESTS

**Table-40: Plastic limit of swelling soil+ 20% fly ash**

| SL No | Can no | Empty wt (g). | Wet soil+ empty wt (g). | Wet wt (g). | Dry wt (g). | Water wt (g). | Plastic limit (%age). |
|---|---|---|---|---|---|---|---|
| 1 | 31 | 3.48 | 13.00 | 10.57 | 7.09 | 2.43 | 34.27 |
| 2 | 16 | 3.28 | 15.68 | 12.45 | 9.17 | 3.23 | 35.22 |
| **Average plastic limit** | | | | | | | **34.74** |

## SHRINKAGE LIMIT TESTS

**Table-41**: **Shrinkage limit of swelling soil+20% fly ash**

| SL No | Description | Sample(g) |
|---|---|---|
| 1 | Mass of empty mercury dish | 39.38 |
| 2 | Mass of mercury dish with mercury equal to volume of the shrinkage dish | 290.77 |
| 3 | Mass of mercury | 241.21 |
| 4 | Volume of shrinkage dish(V1) | 17.73 |
| 5 | Mass of empty shrinkage dish | 5.74 |
| 6 | Mass of shrinkage dish+ wet soil | 34.43 |
| 7 | Mass of wet soil(M1) | 28.69 |
| 8 | Mass of shrinkage dish+ dry soil | 23.09 |
| 9 | Mass of dry soil(Ms) | 17.35 |
| 10 | Mass of mercury dish + mercury equal in volume of dry pat | 170.79 |
| 11 | Mass of mercury displaced by dry pat | 131.79 |
| 12 | Volume of dry pat(V2) | 9.66 |
| 13 | Volumetric shrinkage(Vs) | 83.54% |
| 14 | Shrinkage ratio(SR) | 1.62 |
| 15 | Shrinkage limit | **18.87** |

**Chapter-5**

# APPENDIX-B

# APPENDIX-B

**Fig-4: Free swell index at various percentage of fly-ash**

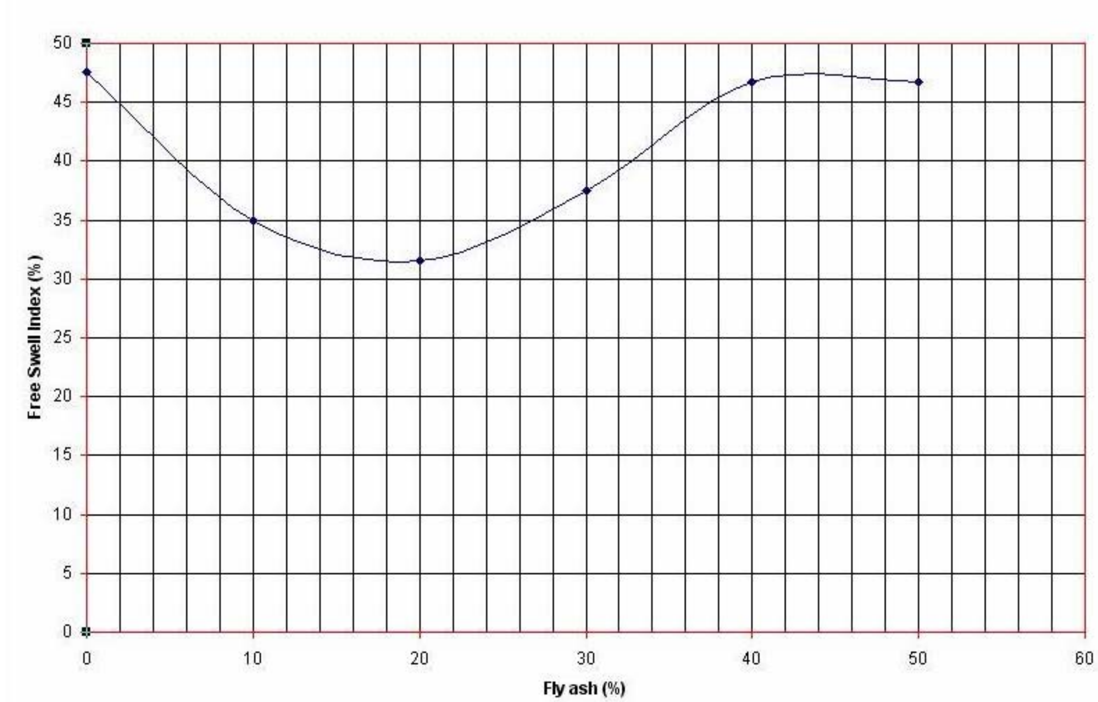



**Fig-5: Liquid limit of swelling soil**

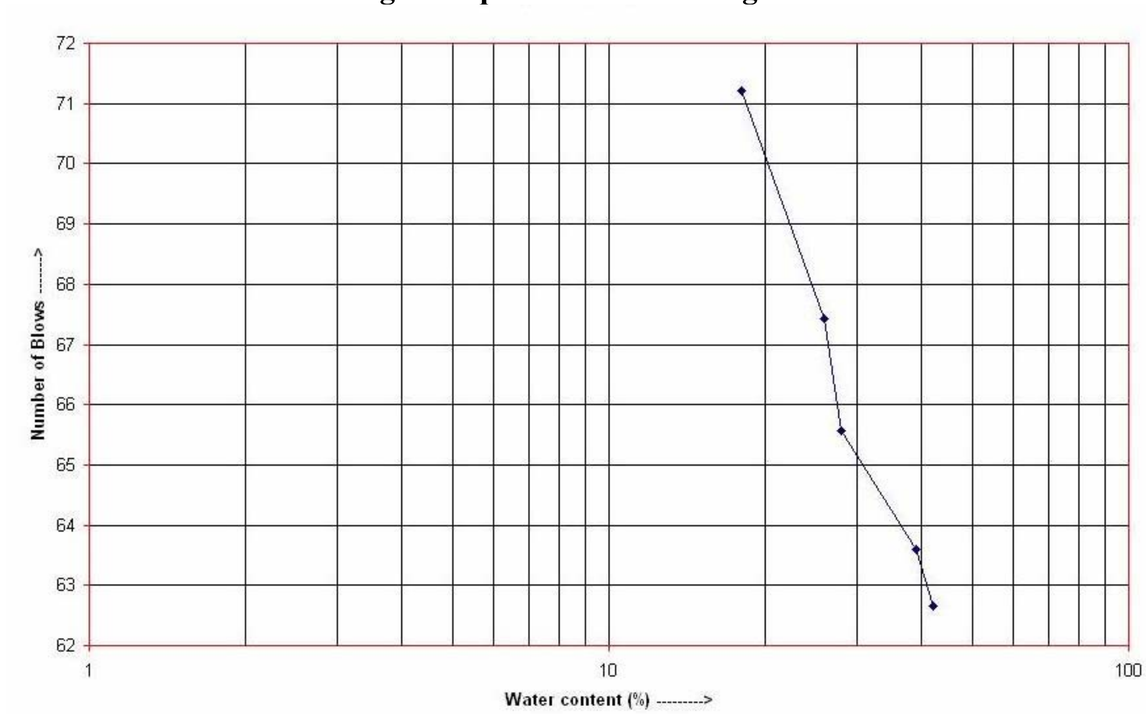


**Fig-6: Proctor compaction Test for swelling soil**


**Fig-7: Proctor compaction Test with swelling soil+10% fly-ash**

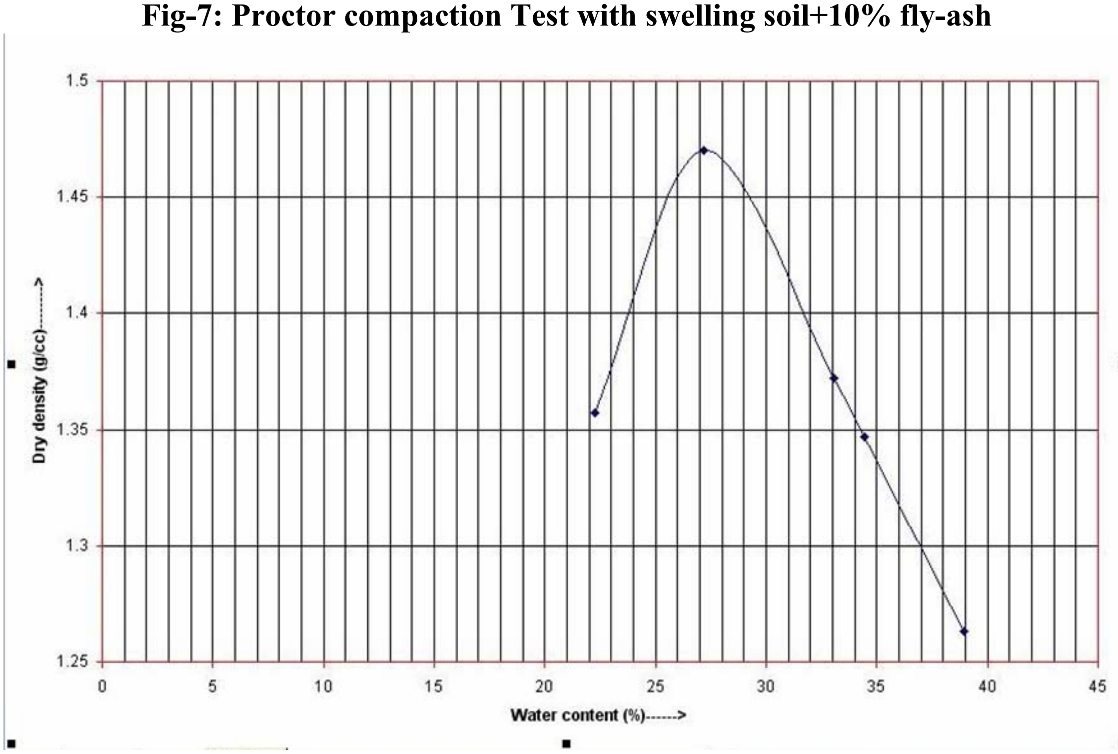


**Fig-8: Proctor compaction Test with swelling soil+20% fly-ash**


**Fig-9: Proctor compaction Test with swelling soil+30% fly-ash**

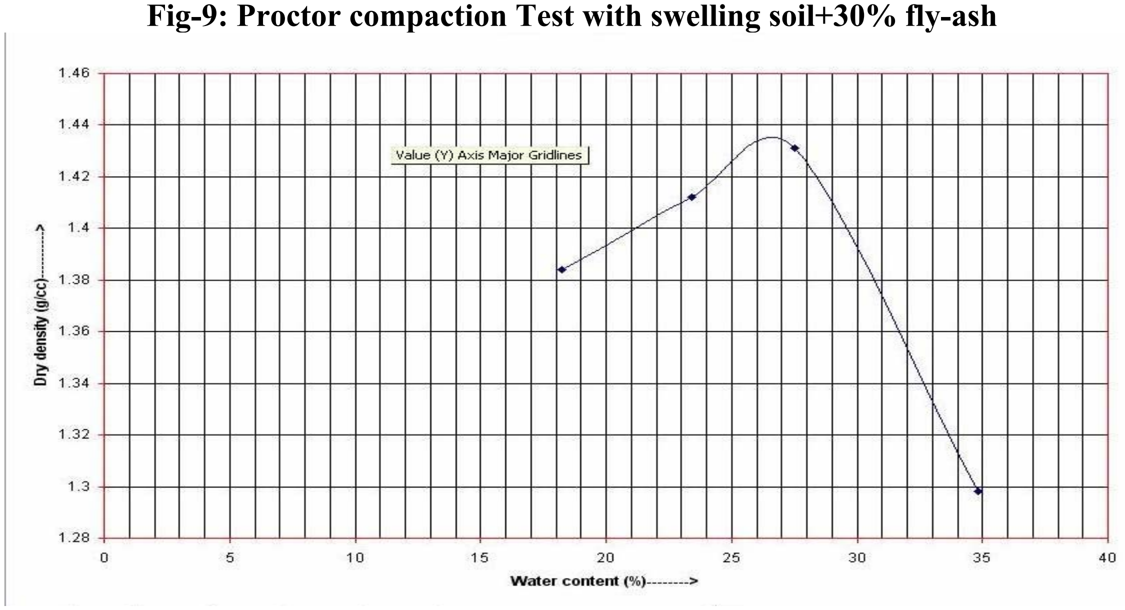


**Fig-10: Proctor compaction Test with swelling soil+40% fly-ash**

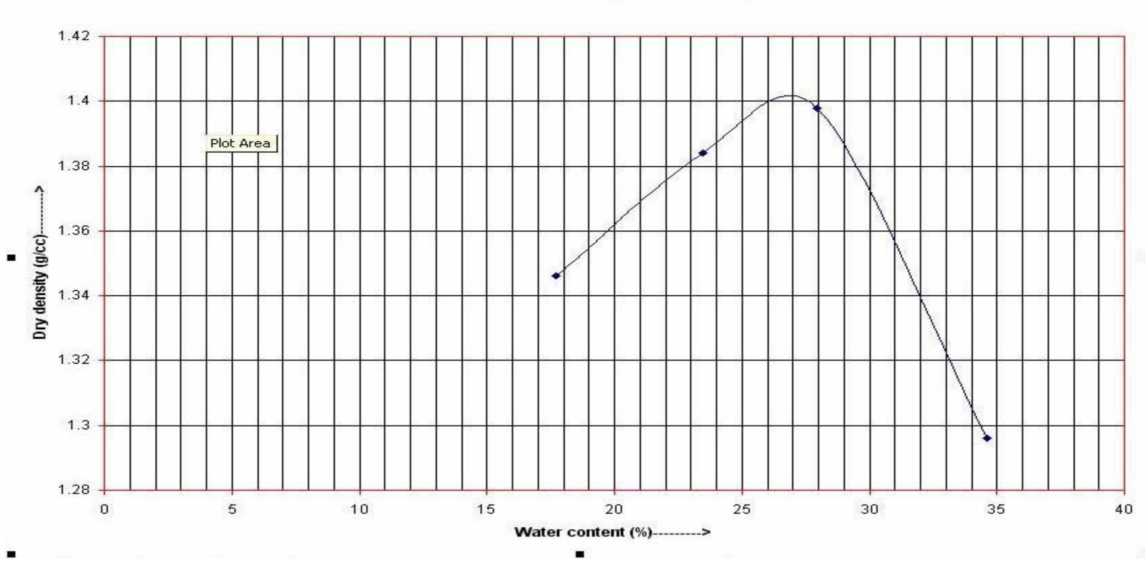



**Fig-11: Proctor compaction Test with swelling soil+50% fly-ash**

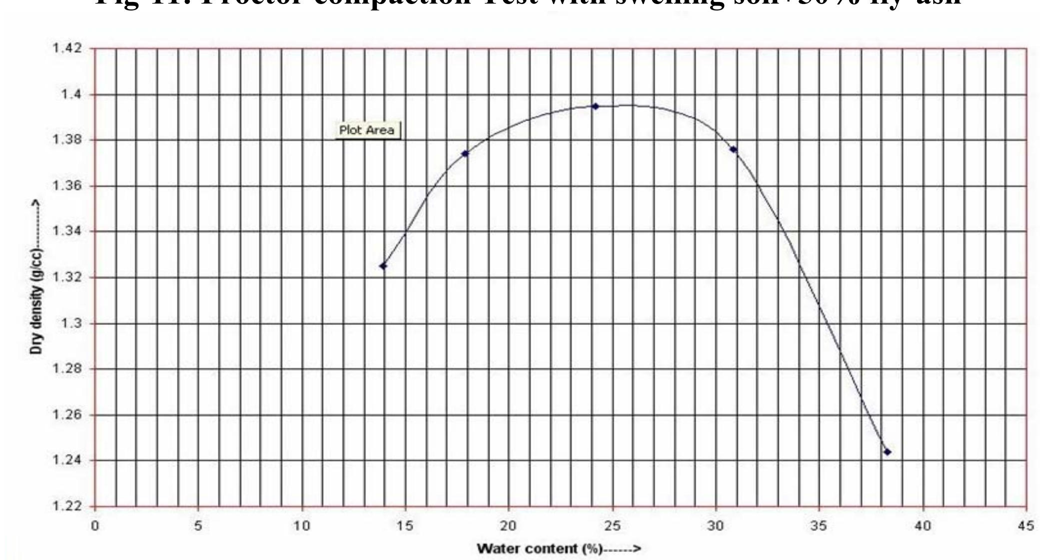


**Fig-12: Comparison of maximum dry density against fly-ash percentage**


**Fig-13: Comparison of Optimum Moisture Content against fly-ash percentage**

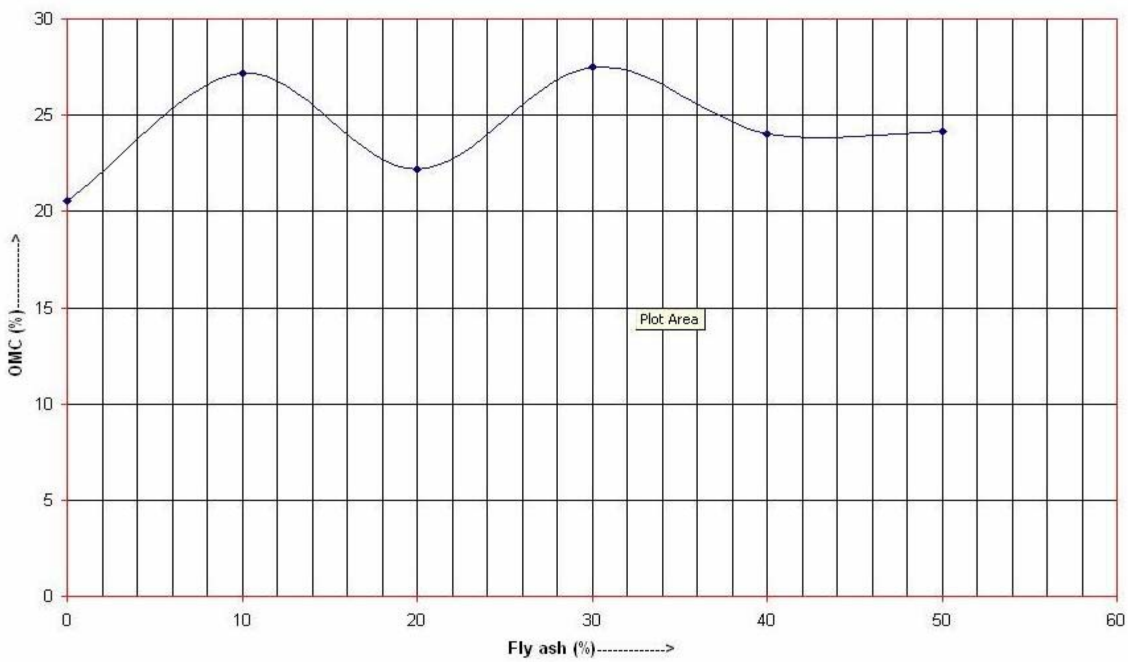


**Fig-14: Unconfined comp. strength of swelling soil only**

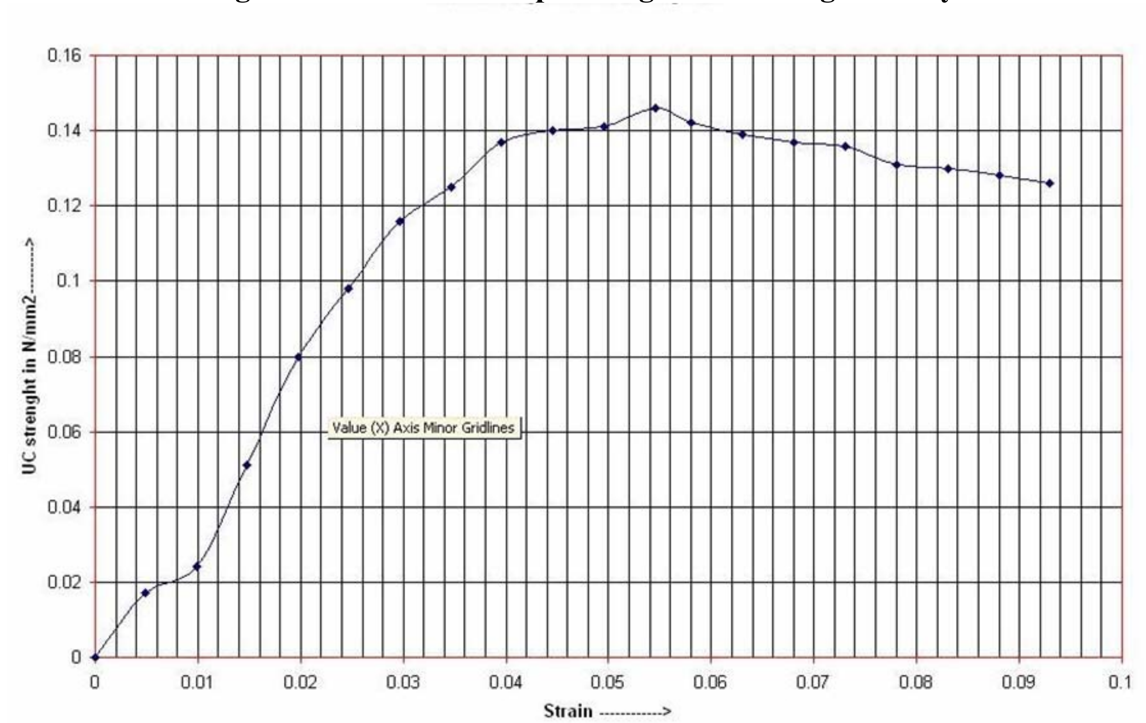



**Fig-15: Unconfined comp. strength of swelling soil+10% fly-ash**

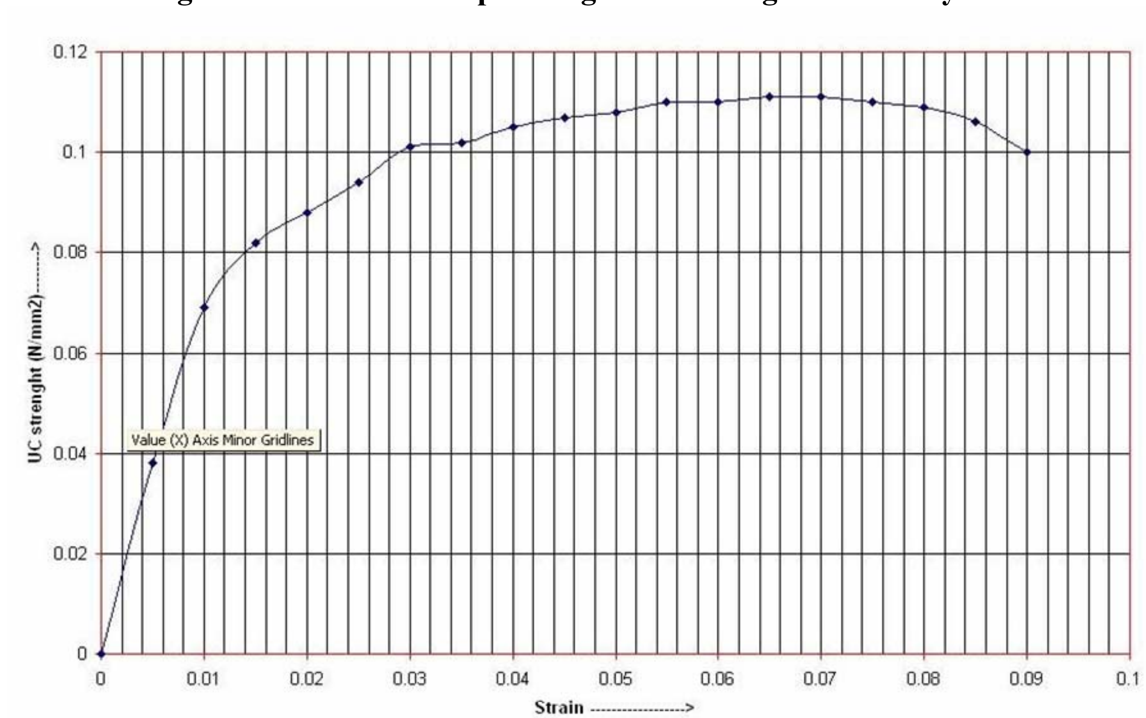


**Fig-16: Unconfined comp. 9olkstrength of swelling soil+20% fly-ash**

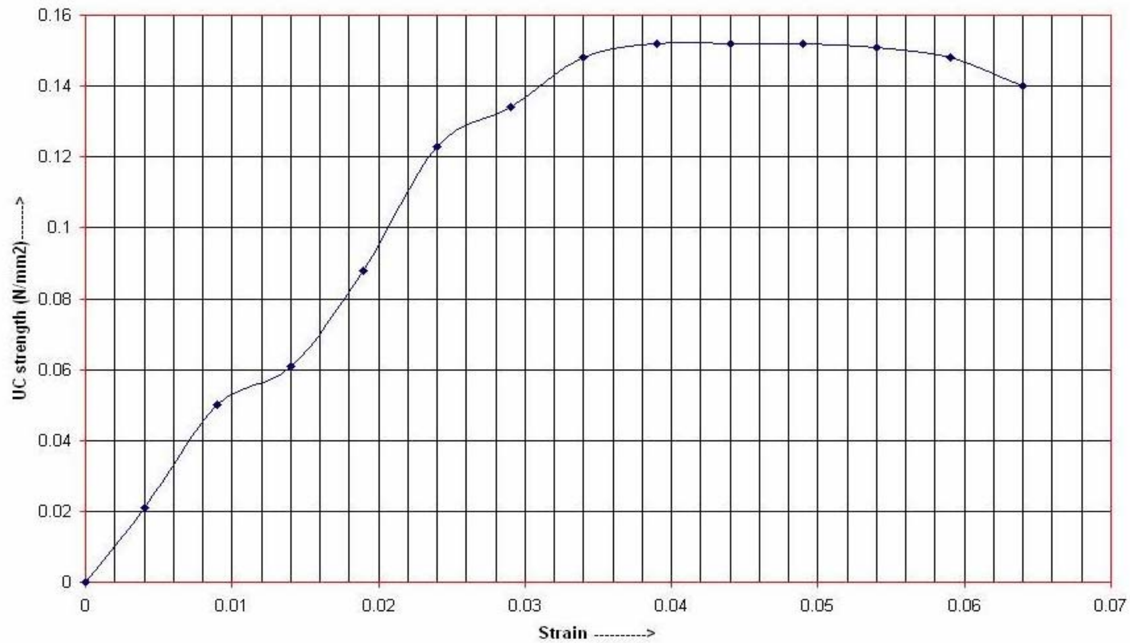



**Fig-17: Unconfined strength of swelling soil+30% fly-ash**

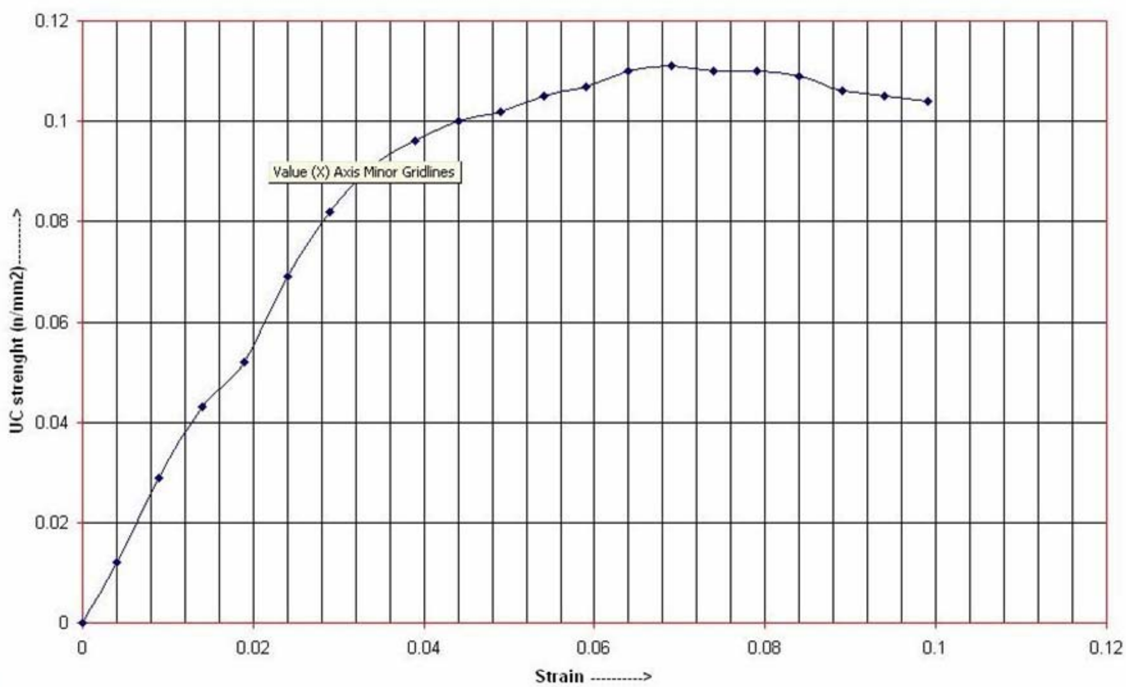


**Fig-18: Unconfined strength of swelling soil+40% fly-ash**

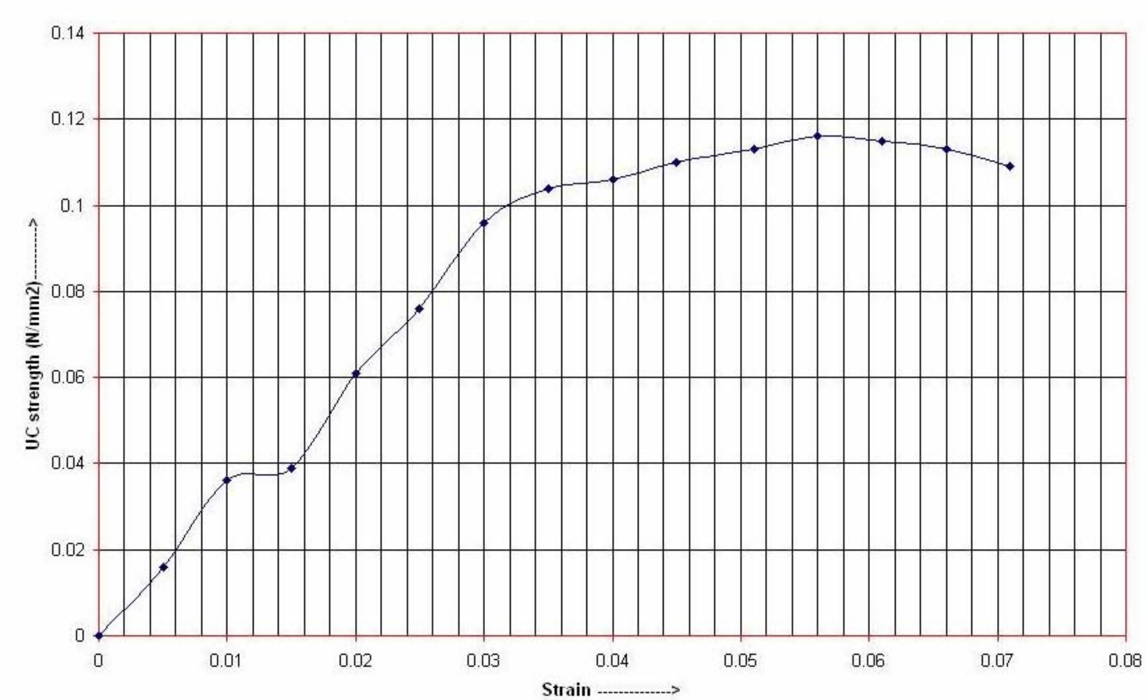



**Fig-19: Unconfined strength of swelling soil+50% fly-ash**

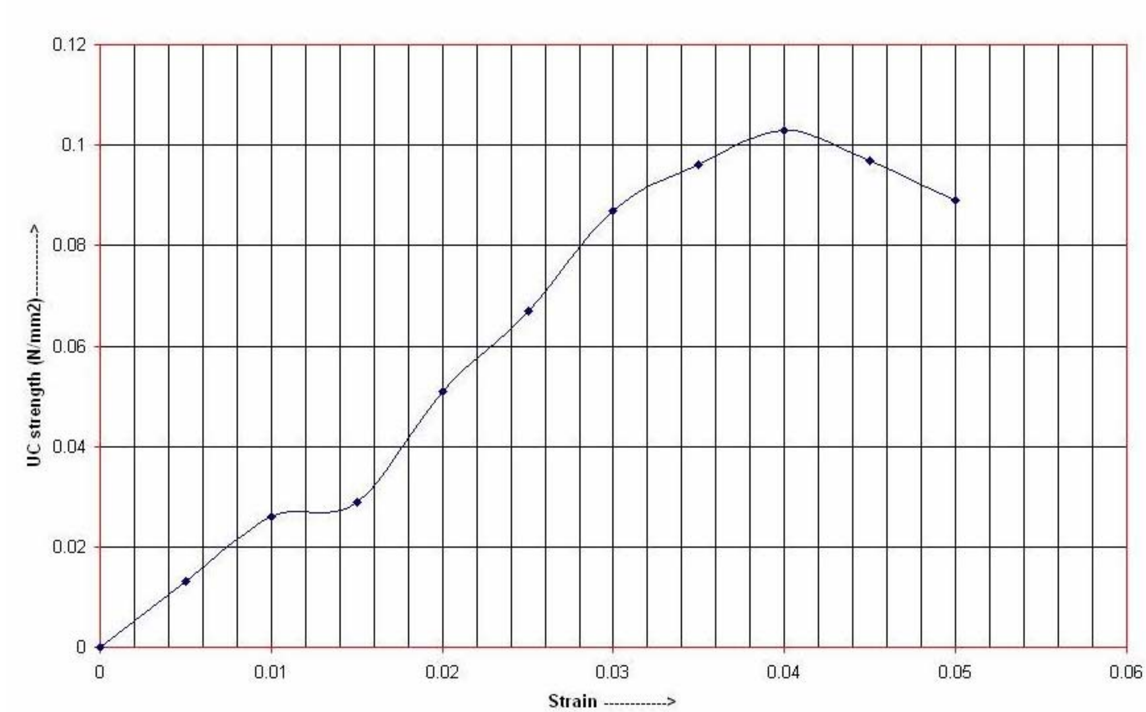


**Fig-20: Comparison between different percentage of fly-ash result obtained from "UCS" test**

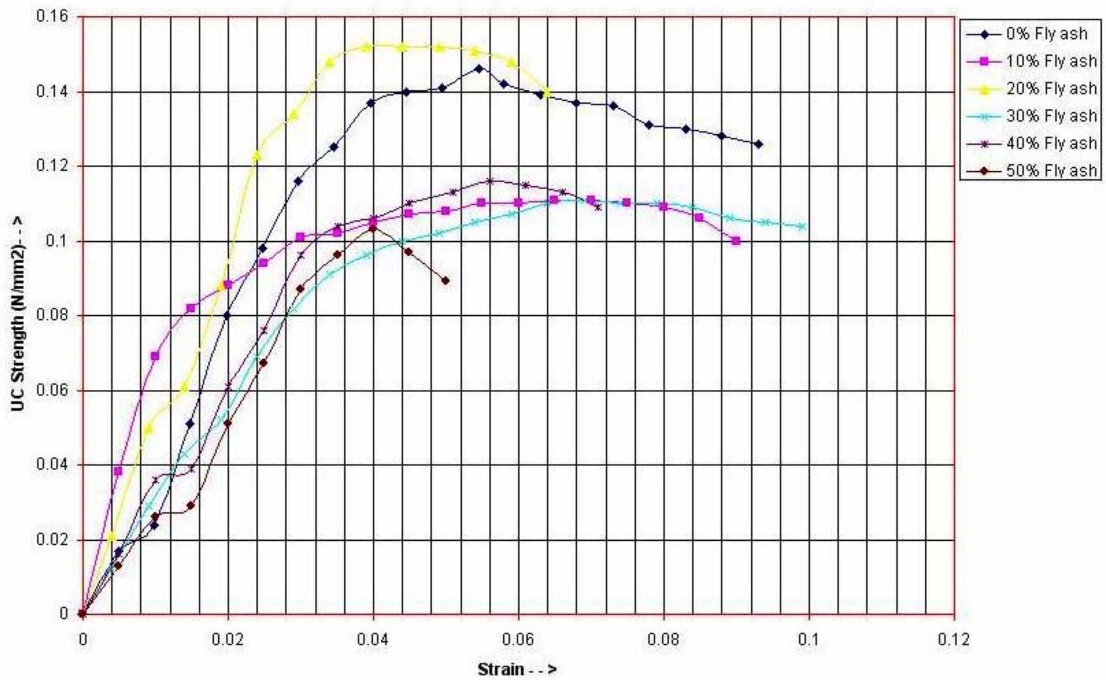



**Fig-21: Ultimate unconfined compressive strength of swelling soil with various percentage of fly-ash**

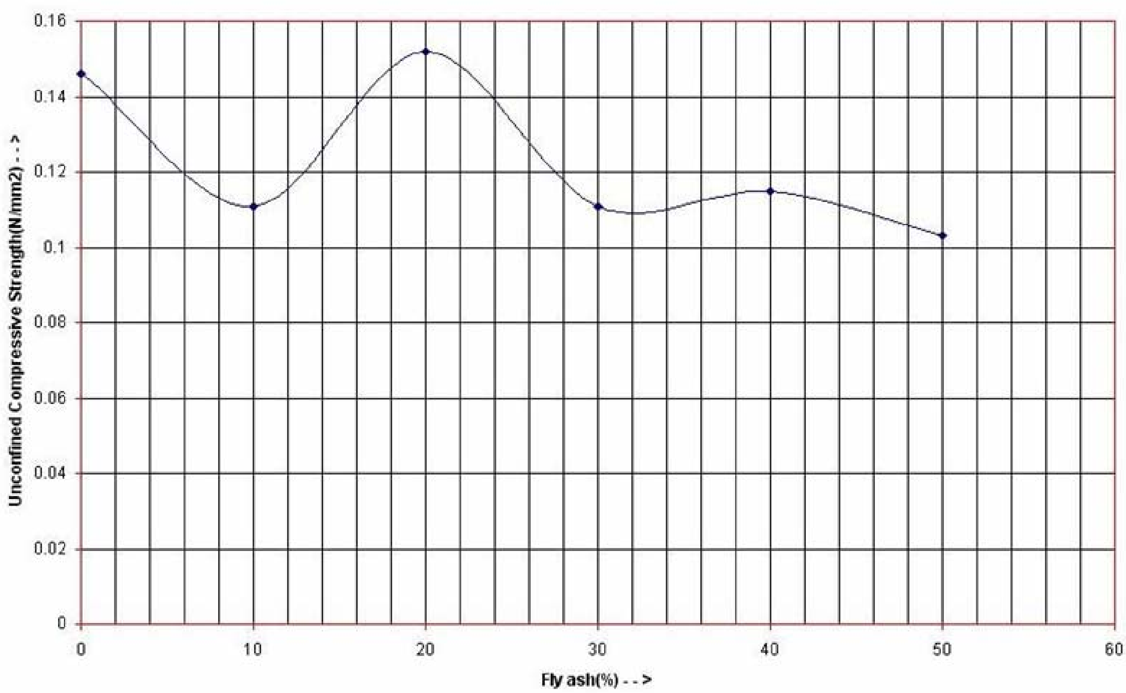


**Fig-22: Unconfined compressive strength of swelling soil With/without fly-ash**

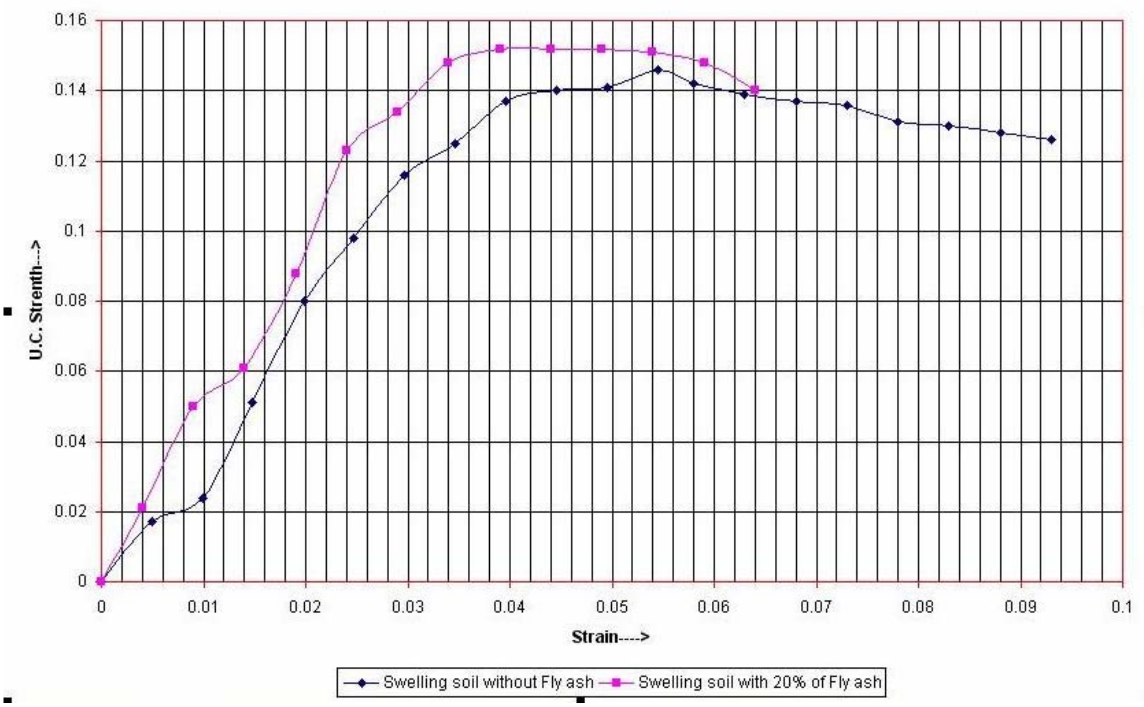


**Fig-23: California bearing ratio values of swelling soil with various Percentage of fly-ash**

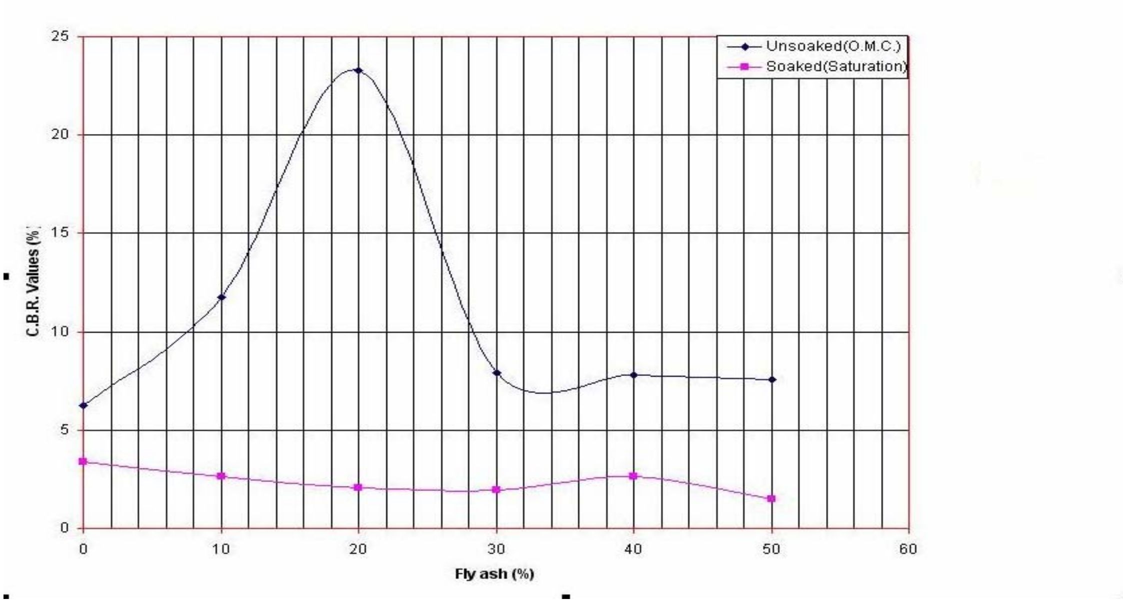
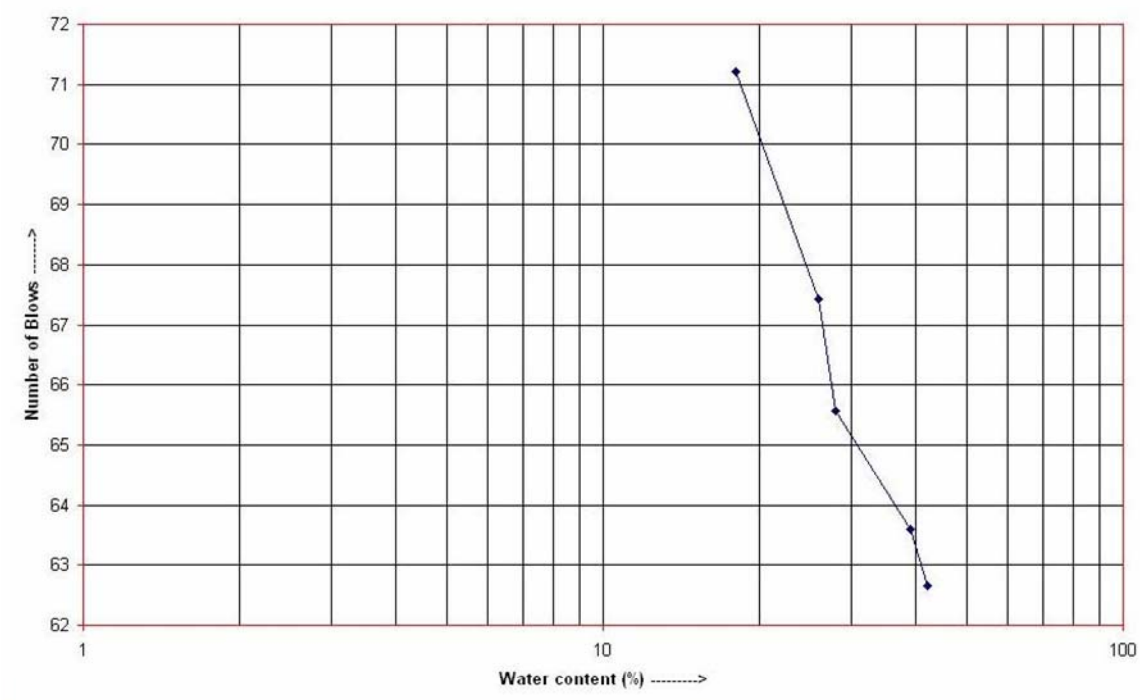



**Fig-24: Liquid limit of swelling soil+20% fly-ash**



**Chapter-6**

# IMPORTANT INDIAN STANDARD SPECIFICATIONS

# IMPORTANT INDIAN STANDARD SPECIFICATIONS

- **Methods of test for soil**: Prepare of dry soil sample for various test
  **IS**: 2720(part-I)-1973

- **Methods of test for soil:** Determination of water content
  IS: 2720(part-II)-1973

- **Methods of test for soil**: Determination of specific gravity
  IS: 2720(part-III/section-1)1980

- **Methods of test for soil:** Determination of liquid limit and plastic limit
  IS: 2720(part-V)-1986

- **Methods of test for soil:** Determination of California bearing ratio
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**Chapter-7**

# CONCLUSION

# CONCLUSION

- On increasing fly-ash content free swell index decreases steadily to a lowest value at 20% fly-ash and then it increases slightly to have a peak at 40% fly-ash content. Beyond 40% Fly-ash. it again declines.

- Unconfined compressive strength decreases on adding of fly-ash up to 10% and then increases up to 20% fly-ash content to have the greatest value of $q_u$ max =0. 152N/mm$^2$ .Then it declines to have another lower value at 30% fly-ash and takes another peak (at 0.116 N/mm$^{2)}$ at 40% fly-ash. Beyond this, it again declines.

- C.B.R value of unsoaked sample tested at OMC with 20% fly-ash content is found to be maximum (23.27 percent).Hence for the maximum C.B.R value the optimum value of fly-ash mix is 20 percent.

- The maximum dry density is highest (1.54g/cc) and optimum moisture content is least (22.29 percent) found by proctor compaction test, are obtained at 20 percent content of fly-ash.

- Atterberg limits are obtained are also optimum when the fly-ash content is 20 percent.

**Chapter-8**

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