

A PRELIMINARY INVESTIGATION INTO THE EFFECT OF USING COAL FLY ASH FOR REINFORCEMENT OF BLACK COTTON SOIL

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ABSTRACT: -Near about 53 million hectares of land area in India are made up with Black Cotton soil (Expansive soil). The property of these expansive soils, in general, is that they are very hard when in dry state, but they lose all of their strength when in wet state. In light of this property of expansive soils, these soils pose problems worldwide that serve as challenge to overcome for the Geotechnical engineers.

One of the most important aspects for construction purposes is soil stabilization, which is used widely in foundation and road pavement constructions; this is because such a stabilization regime improves engineering properties of the soil, such as volume stability, strength and durability. In this process, removal or replacing of the problematic soil is done; replacement is done by a better-quality material, or the soil is treated with an additive.

In the present study, using **fly ash** obtained from **Kolaghat Thermal Power Plant, West Bengal**, stabilization of black cotton soil obtained from **Paschim Medinipur, West Bengal** is attempted. With various proportions of this additive i.e., 10%, 20%, 30%, 40% & 50%, expansive soils is stabilized. Owing to the fact that fly ash possesses no plastic property, plasticity index (P.I.) of clay-fly ash mixes show a decrease in value with increasing fly ash content.

In conclusion, addition of fly ash results in decrease in plasticity of the expansive soil, and increase in workability by changing its grain size and colloidal reaction. Tested under both soaked and un-soaked conditions, the California Bearing Ratio (CBR) values of clay with fly ash mixes were observed. Analysis of the formerly found result exposes the potential of fly ash as an additive that could be used for improving the engineering properties of expansive soils.

Keywords: Black Cotton Soil, Fly Ash, Plasticity Index, California Bearing Ratio, Swelling.

INTRODUCTION: -

1.1 BLACK COTTON SOIL: - Black cotton soils, which are also called as expansive soil or swell-shrink soil, have the predisposition to shrink and swell with variation in moisture content.

As a result of this variation in the soil, significant distress occurs in the soil, which is subsequently followed by damage to the overlying structures. During periods of greater moisture, like monsoons, these soils imbibe the water, and swell; subsequently, they become soft and their water holding capacity diminishes. As opposed to this, in drier seasons, like summers, these soils lose the moisture held in them due to evaporation, resulting in their becoming harder. Expansive soils in the Indian subcontinent are mainly found over the Deccan trap (Deccan lava tract), which includes Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, and some scattered places in Odisha. These soils are also found in the river valley of Narmada, Tapi, Godavari and Krishna. The depth of black cotton soil is very large in the upper parts of Godavari and Krishna, and the north-western part of Deccan Plateau. Basically, after the chemical decomposition of rocks such as basalt by various decomposing agents, these are the residual soils left behind at the place of such an event. Cooling of volcanic eruption (lava) and weathering another kind of rock—igneous rocks—are also processes of formation of the type of soils. Rich in lime, alumina, magnesia, and iron, these soils lack in nitrogen, phosphorus and organic content. Consisting of high percentage of clay sized particles, the color of this soil varies from black to chestnut brown. 20% of the total land area, on an average, of this country is roofed by expansive soils. These soils are suitable for dry farming and for the growth of crops like cotton, rice, jowar, wheat, cereal, tobacco, sugarcane, oil seeds, citrus fruits and vegetables; there a son behind it is owed to the moisture retentive capacity of expansive soils, which is high. In the semi-arid regions, just in the last couple of decades, damages due to the swelling-shrinking action of expansive soils have been observed prominently in form of cracking and break-up of roadways, channel and reservoir linings, pavements, building foundations, water lines, irrigation systems, sewer lines, and slab-on-grade members.

1.2. COAL FLY ASH: - A waste material extracted from the gases emanating from coal fired furnaces, generally of a thermal power plant, is called coal fly ash or simply fly ash. One of the chief usages of volcanic ashes in the ancient ages were the use of it as hydraulic cements, and fly ash bears close resemblance to these volcanic ashes. These ashes were believed to be one of the best pozzolans (binding agent) used in and around the globe. The demand of power supply has exponentially heightened these days due to increasing urbanization and industrialization phenomena. Subsequently, this growth has resulted in the increase in number of powers supplying thermal power plants that use coal as a burning fuel to produce electricity. The mineral residue that is left behind after the burning of coal is the fly ash. The Electro Static Precipitator (ESP) of the power plants collect these fly ashes. Production of fly ash comes with two major concerns – safe disposal and management of fly ash. Because of the possession of complex characteristics of wasters which are generated

from the industries, and their hazardous nature, these wastes pose a necessity of being disposed in a safe and effective way, so as to not disturb the ecological system, and not causing any sort of catastrophe to human life and nature. Environmental pollution is imminent unless these industrial wastes are pre-treated before their disposal or storage. Essentially consisting of alumina, silica and iron, fly ashes are micro-sized particles. Fly ash particles are generally spherical in size, and this property makes it easy for them to blend and flow, to make a suitable concoction. Both amorphous and crystalline nature of minerals are the content of fly ash generated. Its content varies with the change in nature of the coal used for the burning process, but it basically is a non-plastic silt. For waste liners, fly ash is a potential material that can be employed; and in combination with certain minerals (lime and bentonite), fly ash can be used as a barrier material. In present scenario, the generation of this waste material in picture (fly ash) is far more than its current utilization. In other words, we are producing more of fly ash than we can spend.

1.1.1 Generation and Disposal

Usage of coal in thermal power plants for the generation of steam is a common practice. A method that was proved to be non-energy efficient was used in the past, where coal in form of lumps were expended in the furnaces of the boilers to generate the evaporated content: steam. Thus, in order to optimize the production of energy from coal mass, the thermal power plants began to use pulverized coal mass instead of the afore mentioned content.

In this process, firstly, the pulverized coal is infused into the combustion chamber, where the instant but efficient burning of fuel happens. The ash formed as a result of this is called the fly ash, and this fly ash contains molten minerals. The steam around this molten mass, when the coal ash travels with the flue gases, results in the spherical shape of the fly ash particle. Next, the employment of the economizer recovers the heat from the steam gases and fly ash. As a result of this process, the temperature of the fly ash shows a sudden reduction in value.

If this temperature fall is rapid, then the resulting structure of the fly ash material is amorphous. However, if the temperature drop during this cooling process is gradual, then the fly ash assumes a more crystalline in nature. This shows the implementation of the economizer, and how it improves the reactivity process. In the process where fly ash is not subjected to the economizer, it forms a 4.3% soluble matter, and its pozzolanic activity index clocks to 94%. Whereas, during the process where the fly ash exposed to the economizer, its pozzolanic activity clocks to 103% and it forms an 8.8% soluble matter. In conclusion, fly ashes are separated from the flue gases by a mechanical dust collector, which is commonly referred to as Electro Static Precipitator (ESP), or scrubbers.

Free of fly ashes, the rest of the flue gases are liberated into the atmosphere via the chimney. With about 90%-98%, the efficiency of ESPs for the separation of finer and lighter fly ash particles is high. In general, the fly ash consists of four to six hoppers, named as field. The fineness of the fly ash particles collected are thus proportional to the number of fields available in an ESP. Therefore, the fly ashes that are collected from the first hopper has a specific surface area of about $2800 \text{ cm}^2/\text{gm}$, whereas the fly ash collected from the last hopper exhibit a greater specific surface area, that is, $8200 \text{ cm}^2/\text{gm}$. With the scorching of pulverized coal, the resulting ash content forming during the process are either collected as fly ash or bottom ash. 80% of coal ashes that are removed from the flue gases are recovered as fly ash, whereas the remaining 20%, that are generally coarser in size, are collected at the bottom of the furnace as **bottom ash**. Either in dry form, or its collection from a water-filled hopper, bottom ash is taken from the bottom of the furnace. When there is a sufficient amount of bottom ash in the water- filled hopper, beyond which its disposal becomes imminent before moving on to the next process, the transference can occur by water jets or water sluice to a disposal pond which. This disposed waste is then called as **pond ash**.

1.1.2 Classification of Fly Ash

The extracted ash from the flue gases via an Electro Static Precipitator, after the process of pulverization, is called fly ash. It is the finest of particles among bottom ash, pond ash and fly ash. With some unburned carbon, the fly ash chiefly consists of non-combustible particulate matter. These generally consists of silt-sized particles.

On the basis of a lime reactivity test, fly ashes have been classified into four different types, as given:

- Cementitious fly ash
- Cementitious and pozzolanic fly ash
- Pozzolanic fly ash
- Non-pozzolanic fly ash

With free lime content and negligible reactive silica, this fly ash is called as cementitious. As opposed to this, with negligible free lime content, and chiefly reactive silica, this fly ash is called pozzolanic fly ash. Both reactive silica and free lime are predominant in cementitious and pozzolanic fly ash. Neither free lime, nor reactive silica are present in non-pozzolanic fly ash. The distinguishable difference between cementitious fly ash and pozzolanic fly ash is that the cementitious fly ash hardens when it comes in connection with water, whereas the pozzolanic fly ash hardens only after the activated lime reacts with water. Cementitious &

Pozzolanic Fly Ash and Pozzolanic Fly Ash are the types that are found widely.

Based on the chemical composition of fly ash, fly ash has been categorized into two categories, as given:

- Class C Fly Ash
- Class F Fly Ash

Burning of sub-bituminous type of coal and lignite, which contains more than 20% Calcium Oxide, gives the Class C fly ash. By ignition of anthracite and bituminous type of coal, Class F fly ash comes into the picture. This fly ash contains less than 20% Calcium Oxide.

1.1.3 Utilization of Fly Ash

The utilization of fly ash can be largely grouped into following three classes:

- The Low Value Utilizations, which includes back filling, structural fills, road construction, soil stabilization, embankment & dam construction, ash dykes, etc.
- The Medium Value Utilizations, which includes grouting, cellular cement, pozzolana cement, bricks/blocks, soil amendment agents, prefabricated building blocks, fly ash concrete, weight aggregative.
- The High Value Utilizations, which includes, fly ash paints, ceramic industry, extraction of magnetite, distempers, metal recovery, acid refractory bricks, floor and wall tiles, etc.

After these, there is still a large wastage of fly ash material observed; however, this has led to evolution of large number of for the management of fly ashes. Thanks to this, the utilization of fly ash has increased to 73 MT by the year 2012. Years 2010-2012 saw a wide acceptance of fly ash as a product that can be used in various purposes.

Presently, the production of fly ashes in India is about 130 MT/year, and this is expected to rise by 400 MT by the year 2016-2017, as stated by 2nd annual international summit for fly ash utilization 2012, scheduled on 17th-18th of January, 2013 at NDCC II convention Centre, NDMC Complex, New Delhi, India. As a palpable conclusion, the fly ash utilization in India is about 56%, as in 2010-2012, which leads to the fact that the rest 44% are waste material, dumped/disposed chiefly out in the open, and considering the adverse effect of this waste material on our environment, it is of necessity to utilize all of the fly ash produced by coal based thermal power plants. An increase of efforts has to be observed if we were to achieve a 100% utilization of this waste product.

If we were to execute the usage of fly ash properly in low value applications, more than 60% utilization of fly ash we currently produce can be seen. In present scenario, India is 65%-70% dependent on production of energy by coal based thermal power plants, which tallies the fly ash production of the country, as stated earlier, up to 130 MT/year.

1.3 Reaction mechanism of Fly ash and expansive soil

By itself, fly ash has little cementitious value, however, this changes in presence of moisture, with which it reacts chemically, and forms cementitious compounds. These compounds attributes to the improvement of compressibility and strength characteristics of a soil. Both classes of Fly ash (C & F) are pozzolans i.e., they contain siliceous and aluminous materials. Fly ash can thus produce an assortment of divalent and trivalent cations (Ca^{2+} , Al^{3+} etc.) under conditions that are ionized in nature, which in return can encourage flocculation of dispersed clay particles. Expansive soils can thus, be theoretically stabilized in an effective manner by cationic exchange with fly ash.

OBJECTIVE & JUSTIFICATION OF THE RESEARCH: -

Objectives of research

The objectives of the study are:

- To determine sub-soil characteristics of the black cotton soil.
- Identification of the sub-soil profile of black cotton soil.
- Determination of the soil design parameters of black cotton soil
- To study the effects of Coal Fly Ash on the Engineering properties of black cotton soil
- To check whether Coal Fly Ash can be used as a soil stabilizer or not.
- To check the ambit of reducing expansiveness and improving bearing capacity value by adding additives.
- To find out the best possible design mix proportion of soil and admixtures which gives maximum strength of stabilized soil compared to that of the original soil after adding admixtures.
- To determine the engineering properties for both un stabilized and stabilized soil for assessing the improvement of soil with stabilization, by the help of some common laboratory tests e.g., OMC, MDD, UCS, CBR test, both in unsoaked and soaked condition.
- To determine the free swell ratio values of expansive soil with varying fly ash content.
- Also, to establish the usage of Fly Ash as an additive, thereby helping utilize it which otherwise always lays as fine waste product from thermal power plants

Justification of Research

Almost 20% of land in India is roofed by expansive soils. With the rapid growth in industrialization and urbanization, land scarcity appears to be an imminent threat. Construction of civil engineering structures on expansive soils, however, pose a major risk to the structure in itself, because of the greater degree of instability in these kinds of soil. Tallied in billions of dollars per year is the loss in property every year globally owing to the instability in the expansive soils. On the other hand, disposal of fly ash has become a growing issue. India, as a developing country, is highly dependent on coal based thermal power plants for production energy, and this dependency isn't going to falter anytime soon. Pulverization of coal in these power plants produces many waste materials, including fly ash. As of 2012, the generation of fly ash rose to 130 MT/year. However, only 56% of this generated fly ash waste were only utilized. The residual fly ash is disposed of in places, and this poses threat to health, and also there duction in land area that can be otherwise utilized for purposes other than the disposal of fly ash. Keeping both the issues in mind, this research of reinforcing black cotton soil using fly ash is justified.

LITERATURE REVIEW

For the relative investigation of stabilization of black cotton soil, the accompanying study is executed.

2.1 Origin and occurrence of expansive soil

Clay mineral is the key element which divulges the swelling characteristics to any ordinary non-swelling/non-shrinking soil. Montmorillonite, out of several types of clay minerals has the maximum amount of swelling potential. In-situ formation of chief clay minerals occurs under alkaline conditions, or sub-aqueous decomposition of blast rocks can be seen the origin of such soil – expansive soil. This type of soil can also be formed due to weathering under alkaline environments, and under adequate supply of magnesium or ferric or ferrous oxides. Given there's a good availability of alumina and silica, the formation of Montmorillonite is favored.

2.2 Nature of expansive soil

Swelling in clays can be sub-categorized into two distinctive types, namely:

- • Elastic rebound in the compressed soil mass due to reduction in compressive force.
- Imbibing of water resulting in expansion of water-sensitive clays.

Swelling clays are the clays that exhibit latter type of swelling, where the clay minerals with largely inflating lattice are present. One of the fundamental characteristics of clayey soil is that they display little cohesion and strength when wet, but they become hard when devoid of water.

However, all of them do not swell due to wetting action. Decrease in ultimate bearing capacity at saturation, and large differential settlement due to this occurs. Thus, clayey soils exhibit foundation problems.

2.3 Identification and classification of expansive soils

Some laboratory tests are available for the identification purposes of swelling soils. By differential thermal analysis, microscopic examination, and X-ray diffraction. The presence of Montmorillonite in clay minerals allows the judgement of the expansiveness of the soil. This aspect is however very technical in nature. A simple aspect, as opposed to the aforementioned methods, is the free-swell test, that's done in the laboratory. This test is conducted by adding 10 gm of dry soil, passing through a 425 μ sieve into two separate 100 cc graduated jar – one filled with water, and the other with kerosene. Swelling occurs in the jar containing water. The swelled volume of the soil is then noted (After 24 hours period), and subsequently, the free swell index values, in percentage, are calculated. Good grade, high swelling, commercial Bentonite has been reported to have free swell values varying from 1200% to 2000%. In general, the swelling potential of as oil is related to plasticity index. With corresponding range of plasticity index, various degrees of swelling capacities are as indicated through the following table:

Swelling potential	Plasticity Index
Low	0-15
Medium	15-24
High	24-46
Very High	>46

Table 1: Swelling potential vs. Plasticity Index

Several factors participate in deciding whether or not a soil with high swelling potential exhibit swelling characteristics.

One of these factors, that occupy greatest importance, is the difference between soil moisture content at the time of construction, and final (equilibrium) moisture content finally achieved under various conditions allied with the complicated structure. The soil has a high swelling capacity if the equilibrium moisture content is higher than the soil moisture content. Large swelling pressure may develop as a result of the upheaving of the soil or structure, causing swelling.

2.4 Methods of recognizing expansive soils

Grouped into three categories, following are the methods of recognizing expansive soils:

- Mineralogical identification
- Indirect methods, such as soil suction, activity and index properties

- Direct measurement.

Impractical and uneconomical in practice, methods of mineralogical identification still hold importance in exploring basic properties of clay minerals. Direct measurement, out of the remaining two categories, offers the most useful data. By their shattered or fissured condition, or obvious structural damage to existing buildings caused by such soils, potentially expansive soils are usually identified in the field. To classify expansive soil, potential swell, or potential expansion, or the degree of expansion is a favored term used; from this, geotechnical engineers establish how good or bad the expansive soils are.

2.5 Causes of swelling

There are different theories, but the mechanism of swelling is still unclear. No conclusion to the mechanism has been reached. Soil consisting high percentage of clay or colloid, with Montmorillonite mineral present as the chief mineral is one of the most universally accepted reasons for the swelling of soils.

2.6 Swell Pressures

The pressure exerted by expansive soil when they swell, owing to their contact with water, is called swell pressure. The estimation of this swell pressure and likely becomes a very important task for designing a structure on such soils, or building the core of a dam, or constructing a road embankment, or taking a canal through such soils.

2.7 Factors affecting swelling

Initial moisture content, or the molding water in case of a re-molded sample is the most influencing factor.

“The behavior of re-molded clays is much as undisturbed clays”, as per Holts’ and Gibbs’ findings. For a given dry density, the value of initial water content will be a key factor in determining the water affinity of a given sample, as well as its swell pressure. A minimum moisture content (w_n) required by a clay for swelling to begin beneath a prepared sub-grade is

$$(\%) = 0.2w_1 + g$$

given by:

Where, w_1 = liquid limit

The factors that affect the swelling aspect of a soil largely depend on the soil’s environmental conditions. With the intake of water, swelling is more in a soil element which is close to the surface, but if below the surface, the same soil exhibits negligible swelling because the overburden pressure neutralizes the developing swelling pressure of the dry soil. Generally

responsible for swelling are the following factors:

- Location of the soil sample from the ground surface
- Thickness, as well as shape of the sample
- Change in volume
- Temperature
- Nature of pore fluid
- Time
- Stress history
- Unit weight of the sample taken, etc.

2.8 Problems associated with the expansive soil

Generation of problems for all kinds of construction over expansive soils is common, leading us to believe that such types of soil are not suitable for these purposes. However, given the placement of these kinds of soil over the country, it leaves engineers no other choice but to develop different structures on the soil, well aware of the risk. These structures chiefly are a part of irrigation projects. Buildings, and other kinds of structures constructed over these soils are subjected to differential deflections. These deflections cause distressing, and in turn leads to damage of the structure.

Moreover, the reduction in moisture content due to the evaporation of water in soil causes shrinkage, and heaving of soil occurs when there is a disproportionate increase in moisture content. The level of ground water table also has as significant impact on the moisture content of these soils, which in return affect the shrinkage-swelling cycles. In seasons which are dry in nature, the surface of clayey soil shrinks, however, little evaporation is there on the clayey soil on which the building stands. This causes differential settlement at plinth level, posing danger to the structure.

If the construction of a building on such type of soil is done in its dry season, the base of the structure's foundation would experience swelling pressures when the partially saturated soil underneath starts imbibing water in the wet season, developing swelling pressures. When the pressure imposed by the structure on the foundation is less than the swelling pressure developed, upliftment of such a structure occurs, which would lead to formation of cracks. The imposed bearing pressure if the building is constructed in the wet season should be within the permissible limits of bearing pressure for the soil. A better practice is to construct a building during dry season, and completing it before the onset of wet seasons. One of the methods of treatment of

expansive soil to make them fit for the construction purposes is called stabilization. According to Petry (2002), assortment of stabilizers can be grouped into:

- By-product stabilizers (Quarry dust, Fly ash, Slag, Phosphor-gypsum, etc.)
- Traditional stabilizers (Cement, Lime, etc.)
- Non-traditional stabilizers (Sulfonated oils, Potassium compounds, Polymer, Enzymes, etc.)
- Lots of geo-environmental problems are a result of industrial by-products whose disposal as fills in disposal sites adjacent to the industries demand large chunks of land, which can otherwise be utilized for construction, growing of vegetation, etc. purposes. Various attempts by different researchers and organizations have been made to utilize these by-products. Stabilization of expansive soil is one of the ways of fulfilling such a thing.

2.9 Stabilization using Fly Ash

- **Sharma et al. (1992)**, using mixtures of fly ash, blast furnace slag and gypsum, studied stabilization. He found that when fly ash, gypsum and blast furnace slag are used in proportions of 6:12:18, the swelling pressure decreases from 248 KN/m² to 17 KN/m², whereas an increase by 300% was observed in case of unconfined compressive strength.
- **Srivastava et al. (1997)**, studied the microscopic changes in the fabric and micro-structure of the expansive soil due to the addition of lime sludge and fly ash using SEM photography. He found that there were changes in the micro-structure and fabric of the expansive soil when 16% lime sludge and 16% fly ash were both added.
- **Srivastava et al. (1999)**, have also stated that the best stabilizing effect of the swelling and consolidation behaviors in an expansive soil mixed with fly ash and lime sludge was obtained when 16% lime sludge and 16% fly ash were added.
- **Cokca (2001)** found out that swelling pressure decreased by 75% after 7-day curing, and 79% after 28 day curing when soil specimens were treated with 25% Class C Fly ash (18.98% of Cao).
- **Pandian et al. (2001)**, made an effort towards stabilization of expansive soil by using Class F Fly ash. He found that fly ash can make for an effective additive when he saw that with 20% fly ash content, the CBR value of Black cotton soil improved (about 200%) significantly.

- **Turker et al. (2004)**, employed sand along with Class C & Class F fly ash for stabilization of expansive soil. Without any contradiction of belief, Class C fly ash was more effective in stabilization, and decrease in free swell with curing period was observed. The percentage content of soil, Class C fly ash and sand that gave the best result was 75%, 15% and 10% respectively.
- **Satyanarayana et al. (2004)**, aimed to study the mutual effect of addition of lime and fly ash on the engineering properties of the expansive soil. He found out that 70%, 26% and 4% were the optimum percent mixture of the ingredients for the construction of roads and embankments.
- **Phani Kumar et al. (2004)** saw that the hydraulic conductivity, swelling properties and plasticity of expansive ash mixture decreased, whereas the strength and dry unit weight increased with the increase of fly ash content in the mix. given water content, the resistance to penetration also increased with the increase in fly ash content.
- **Baytar (2005)** contemplated the stabilization of expansive soils using desulphogypsum and fly ash acquired from a thermal power plant by 0 to 30%. A variable percentage of lime (0 to 8%) was appended into the expansive soil desulphogypsum-fly ash mixture. The samples, thus formed, were cure for a period of 7 days and 28 days. It was observed that swelling percentage decrease, and there was an increase in rate of swell with increasing percentage of the stabilizer in the mixture. The curing process reduced the swelling percentage further; and with the addition of 30% desulphogypsum and 25% fly ash, reduction in swelling percentage were to such levels that stood comparable with the one where lime was only used as stabilizing compound for the expansive soil.
- **Amuetal (2005)** utilized fly ash and cement mixture for the stabilization purposes of expansive soil. Three distinct classes of samples:(i)12% cement, (ii)9% cement+3% flyash, and(iii)natural clay soil, were taken to be tested for Maximum Dry Densities (MDD), Unconfined Compressive Strength (UCS) Optimum Moisture Contents (OMC), California Bearing Ratios (CBR), and the Undrained Triaxial tests. The results of this test indicated that the sample with 9% cement and 3% fly ash showed better results with respect to CBR, OMC, MDD, and shearing resistance, in comparison to the other two samples. This indicated the value of fly ash as a stabilizing agent.
- **Sabatet al. (2005)** studied the stabilization of expansive soil using fly ash-marble powder mixture. He concluded that the optimum proportions of soil, fly ash, and

marble powder in the mixture in percentage by weight to give the best result were 65%, 20% and 15% respectively.

- **Rajesh et al. (2006)** talked about experimental investigation of clay beds stabilized with fly ash-lime segments and fly ash segments. An observation of swelling in clay beds of 100 m thickness strengthened with 30 mm diameter fly ash-lime and fly ash segments. There was a considerable decrease in heave in both fly ash-lime and fly ash columns. However, lime-fly ash mixture generated better results.
- **Wagh (2006)** utilized rock flour, lime and fly ash independently, further more in diverse extent to stabilize the black cotton soil from Nagpur Plateau, India. Rock flour or fly ash, or both together, when added to the black cotton soil showed an improved value of CBR to some degree, and there was an increase in angle of shearing resistance with their duction in cohesion value. CBR values increased significantly with the increase of both frictional resistance and cohesion where limes, in addition to both fly ash and rock flour, as added into the mixture.
- **Sharmaetal. (2007)** contemplated the impact on swelling of highly plastic expansive clay, and the compressibility of another non-expansive but highly plastic clay when fly ash was employed. At a given dry unit weight of the mixture, the swelling pressure and swell potential showed a decrease by nearly 50%. A decrease by 40% at 20% fly ash content in coefficient of secondary consolidation and compression index of both the samples was observed.

MATERIALS AND TEST METHODS

3.1 Materials

3.1.1 Expansive soil

As a part of this investigation, the expansive black cotton soil was acquired from **Paschim Medinipur, West Bengal**. The black cotton soil thus obtained was carried to the laboratory in sacks. A small amount of soil was taken, sieved through 4.75 mm sieve, weighed, and air-dried before weighing again to determine the natural moisture content of the same. The various geotechnical properties of the procured soil are as follows:

Sl. No.	Properties	Code Referred	Value
1	Specific Gravity	IS 2720 (Part 3/Sec 1) - 1980	2.44
2	Maximum Dry Density (MDD)	IS 2720 (Part 7) - 1980	1.52 gm/cc
3	Optimum Moisture Content (OMC)	IS 2720 (Part 7) - 1980	22.65%
4	Natural Moisture Content	IS 2720 (Part 2) - 1973	7.28%
5	Free Swell Index	IS 2720 (Part 40) - 1977	105%
6	Liquid Limit	IS 2720 (Part 5) - 1985	65%
7	Plastic Limit	IS 2720 (Part 5) - 1985	37.08%
8	Shrinkage Limit	IS 2720 (Part 6) - 1972	17.37%

Table 2: Geotechnical properties of Expansive Soil

3.1.2 Flyash

A waste material extracted from the gases emanating from coal fired furnaces, generally of a thermal power plant, is called fly ash. The mineral residue that is left behind after the burning of coal is the fly ash. The Electro Static Precipitator (ESP) of the power plants collect these fly ashes. Essentially consisting of alumina, silica and iron, fly ashes are micro-sized particles. Fly ash particles are generally spherical in size, and this property makes it easy for them to blend and flow, to make a suitable concoction. Both amorphous and crystalline nature of minerals are the content of fly ash generated. Its content varies with the change in nature of the coal used for the burning process, but it basically is a non-plastic silt. For the purpose of investigations in this study, fly ash was obtained from **Kolaghat Thermal Power Plant, West Bengal**. To separate out the vegetation and foreign material, this fly ash was screen through a 2 mm sieve. The samples were dried in the oven for about 24 hours before further usage.

3.2 Methodology Adopted

To evaluate the effect of fly ash as a stabilizing additive in expansive soils, series of tests, where the content of flyash in the expansive soil was varied in values of 10% to 50% (multiples of 10) by weight of the total quantity taken. The Indian Standard codes were followed during the conduction of the following experiments:

- Standard Proctor Test – IS: 2720 (Part 7) –1980
- Unconfined Compressive Strength (UCS) test – IS: 2720 (Part 10) –1991
- California bearing ratio (CBR) test – IS: 2720 (Part 16) -1987
- Free Swell Index Test – IS 2720 (Part 40) – 1977
- Liquid and plastic limit test- IS 2720 part (5)-1985

RESULTS AND DISCUSSION

4.1 Standard Proctor Test Result for soil – fly ash mixture

Mixture	Maximum Dry Density (MDD) (g/cm^3)	Optimum Moisture Content (OMC) (%)
Expansive Soil Only	1.52	22.65
Soil+10% Fly Ash	1.50	22.13
Soil+20% Fly Ash	1.52	22.56
Soil+30% Fly Ash	1.53	21.27
Soil+40% Fly Ash	1.47	23.57
Soil+50% Fly Ash	1.42	21.34

Table 3: Standard Proctor Test

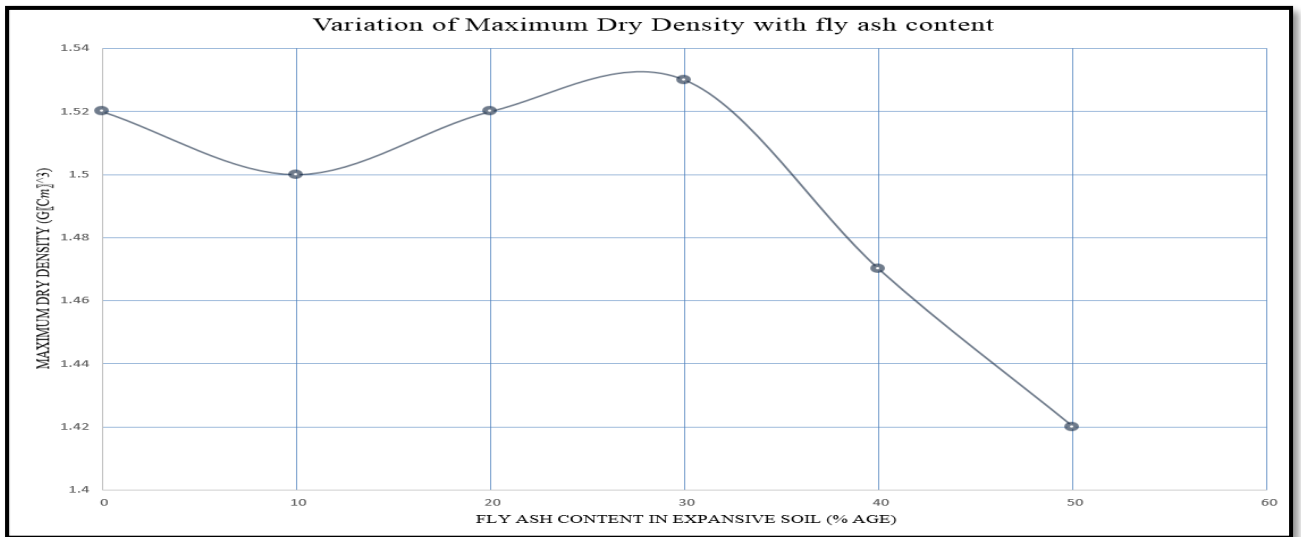


Figure 9: Variation of MDD values with different fly ash content in expansive soil

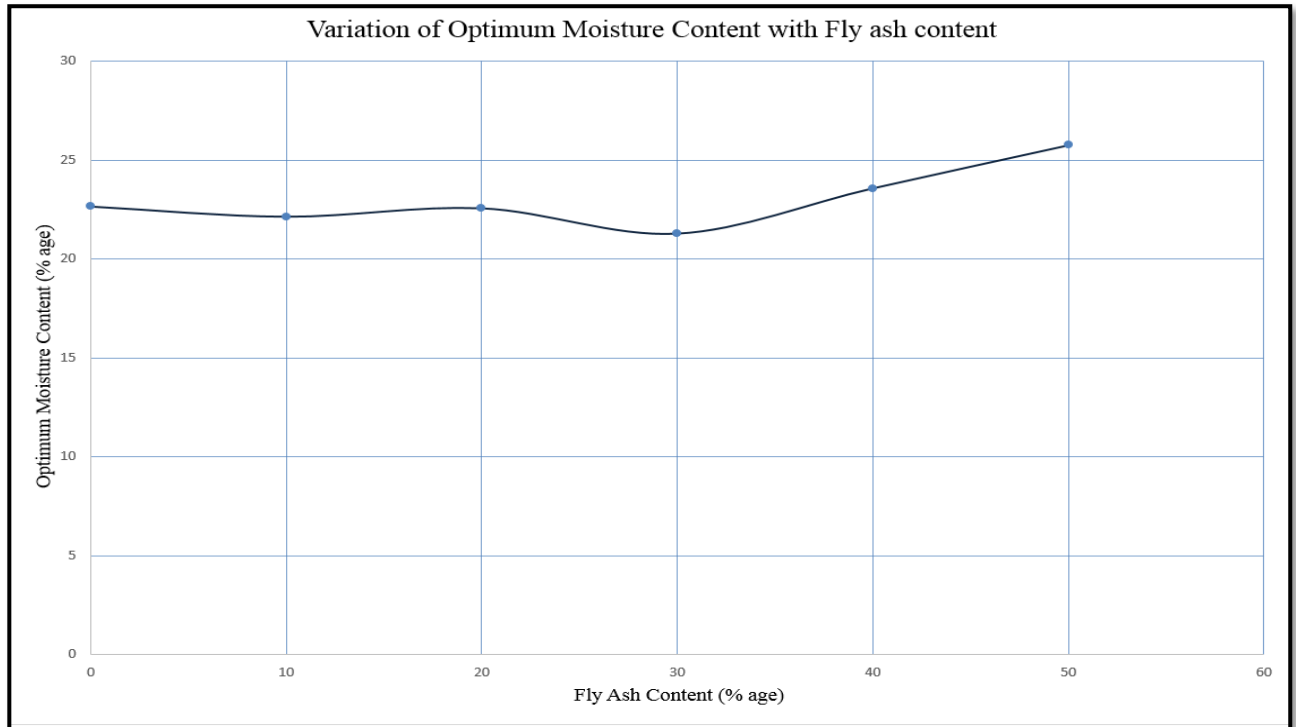


Figure10: Variation of OMC values with different fly ash content in expansive soil

4.2 Unconfined Compressive Strength (UCS) Test Result for soil – fly ash mixture

Mixture	Unconfined Compressive Strength (UCS) (N/mm ²)
Expansive Soil Only	0.197
Soil+10% Fly Ash	0.195
Soil+20% Fly Ash	0.206
Soil+30% Fly Ash	0.176
Soil+40% Fly Ash	0.170
Soil+50% Fly Ash	0.166

Table 4: Unconfined Compressive Strength Test

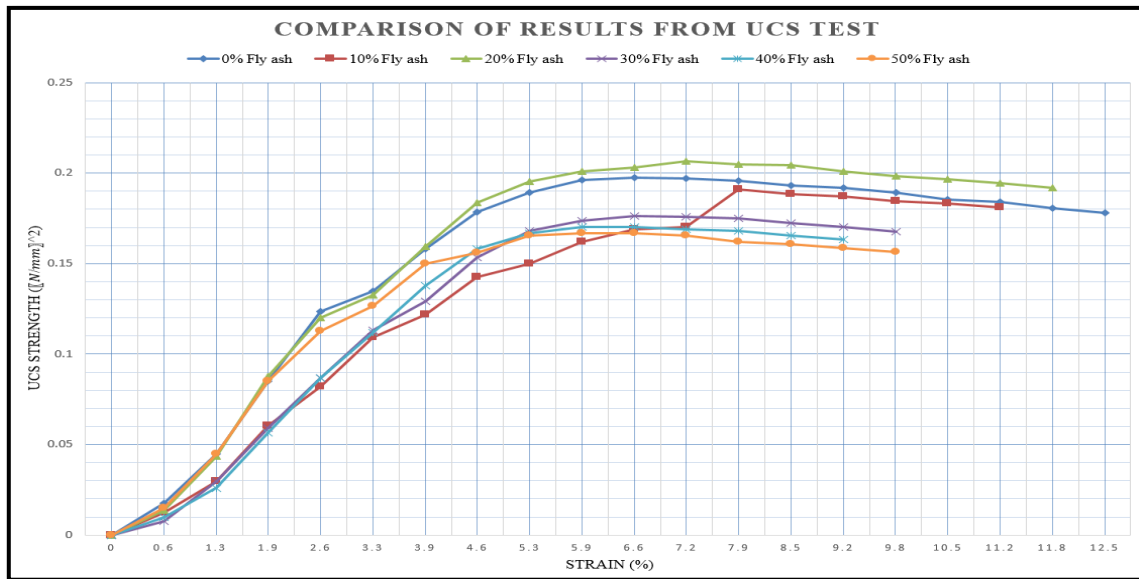


Figure 11: Comparison of UCS test readings in expansive soil, with varying fly ash content

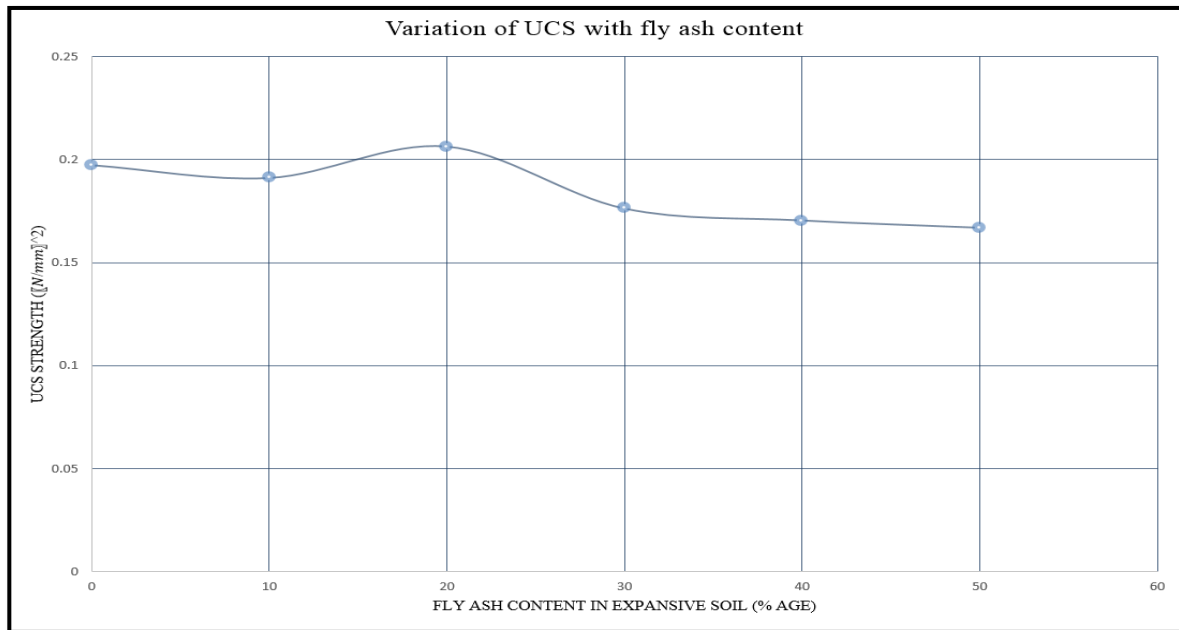


Figure12: Variation of UCS values of expansive soil with different fly ash content

4.3 California Bearing Ratio (CBR) Test Result for soil – fly ash mixture

Mixture	Un-Soaked CBR Intensity (%)	Soaked CBR Intensity (%)
Expansive Soil Only	5.99	4.44
Soil+10% Fly Ash	10.58	4.32
Soil+20% Fly Ash	16.67	5.28
Soil+30% Fly Ash	9.95	5.52
Soil+40% Fly Ash	8.61	4.08
Soil+50% Fly Ash	8.51	3.48

Table 5: CBR Test

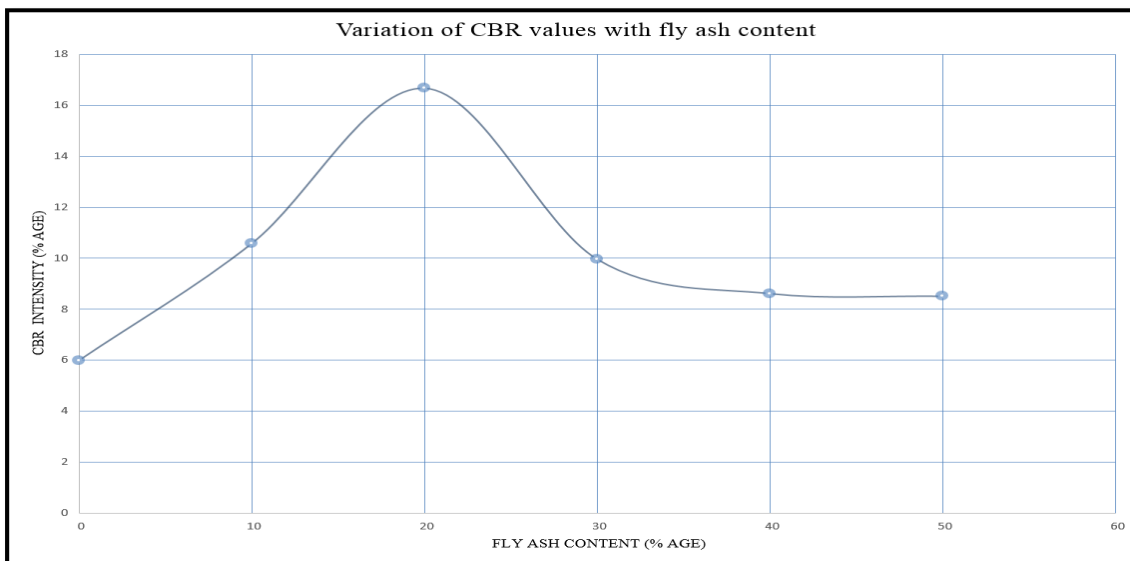


Figure13: Variation of Un-soaked CBR values of expansive soil with varying fly ash content

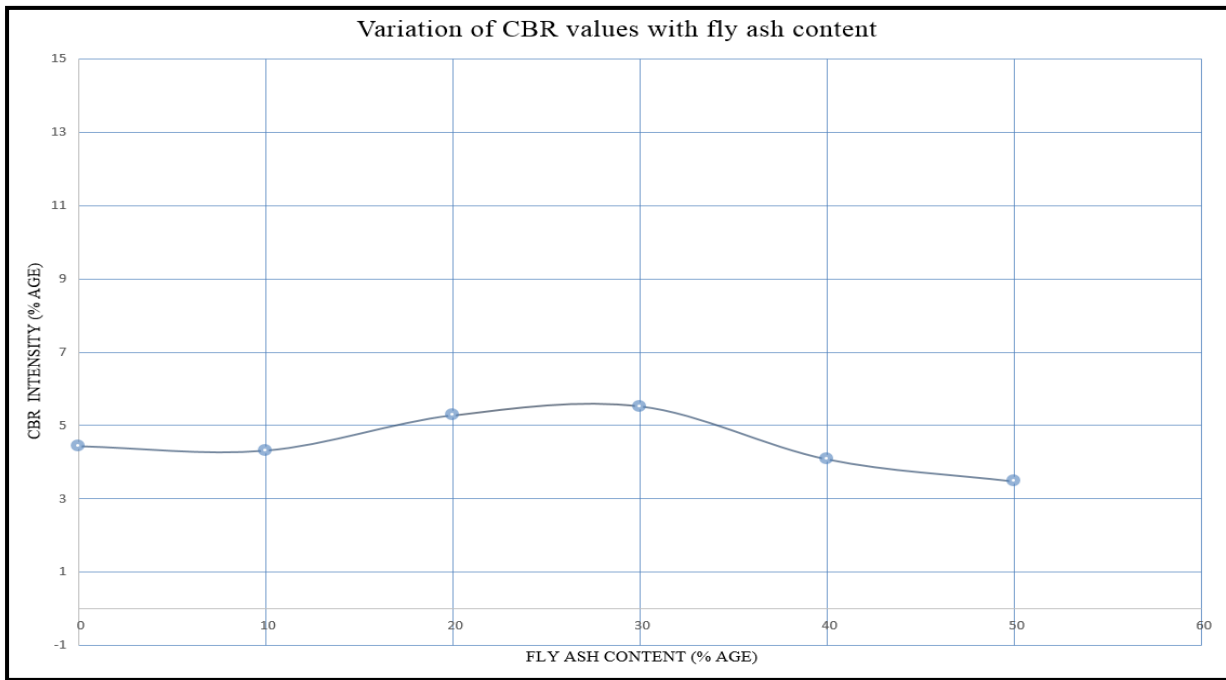


Figure 14: variations of soaked CBR values of expansive soil with varying fly ash content

4.1 Changes in Plasticity Index and Free Swell Ratio for soil – fly ash mixture

Mixture	Liquid limit	Plastic limit	Plasticity index	Free swell ratio
Only soil	65.6	35.8	29.8	2.05
Soil + 10% fly ash	61.2	34.6	26.6	1.92
Soil + 20% fly ash	58.8	33.2	25.6	1.84
Soil + 30% fly ash	56.4	31.5	24.9	1.77
Soil + 40% fly ash	51.8	28.67	23.13	1.63
Soil + 50% fly ash	49.2	26.3	22.9	1.53

Table6: Variation of plasticity index and free swell ratio with fly ash content in expansive soil

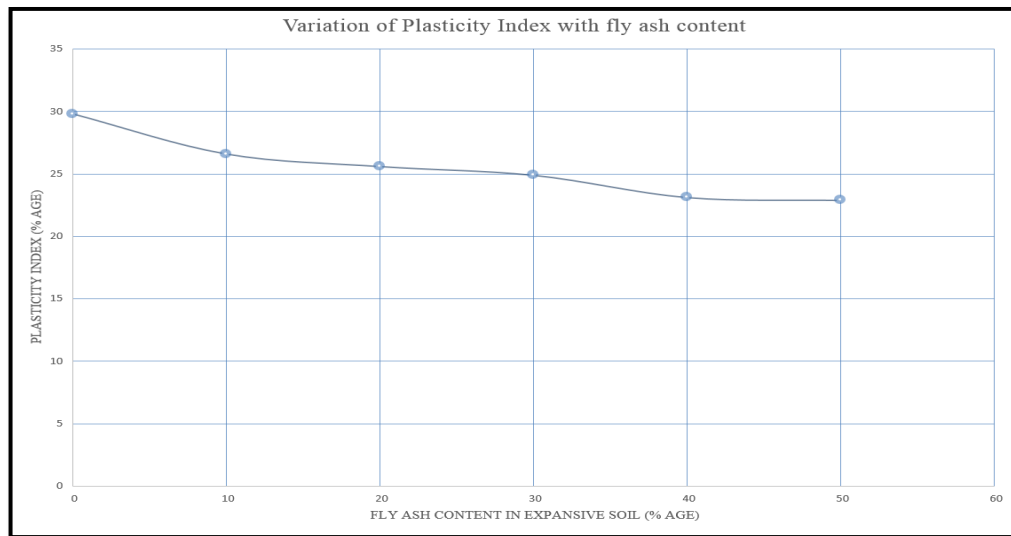


Figure15: Variation of plasticity index values of expansive soil with varying fly ash content

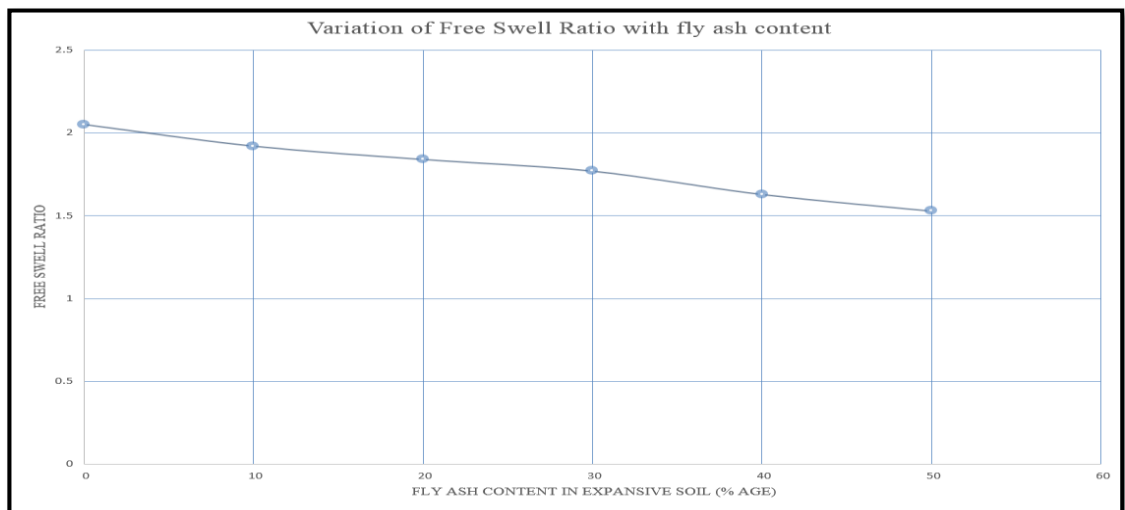


Figure16: Variation of free swell ratio values of expansive soil with varying fly ash content

4.5 Discussions

- Black cotton soil is combined with altering percentage of fly ash (from 0% to 50%, intervals in multiples of 10) by weight to observe its effect as an additive on the expansive soil.
- Maximum Dry Density (MDD) was found to change with varying content of fly. The highest value observed being at fly ash content of 30% by weight.

- The change in Unconfined Compressive Strength (UCS) of the soil with varying content of fly ash is observed. The graph shows the variation of UCS with changing fly ash content. The maximum value of UCS was obtained with the mixture of soil and 20% fly ash content by weight.
- Both un-soaked and soaked California Bearing Ratio (CBR) tests are conducted with varying content of fly ash in the black cotton soil. From the graphical comparison of these values against the varying fly ash content, it can be observed that 20% flyash and 30% flyash content gavethemaximumvalueofCBRintensityinun-soakedandsoaked soil-fly ash mixture respectively.
- The liquid limit and plastic limit of the soil-fly ash mixture varied with the changing fly ash content. Plasticity index values were computed from these experiments, which showed a consistent decreasing pattern with the increase of fly ash content.
- From the free swell ratio tests on the soil-fly ash mixture, the value of free swell ratio decreased with the increasing fly ash content.

CONCLUDING REMARKS

5.1 Conclusions

Based on the results obtained and comparisons made in the present study, the following conclusions can be drawn:

- The Maximum Dry Density (MDD) value of the black cotton soil initially decreased with the addition of fly ash. Then, it showed increment with increasing fly ash content in the soil-fly ash mixture. The maximum value of MDD was observed for a mixture of soil and 30% of fly ash content by weight. The MDD values consistently decreased thereafter.
- The Unconfined Compressive Strength (UCS) of the soil with variation of fly ash content showed similar trend as that of the MDD values, except the fact that the peak value was observed for a fly ash content of 20% by weight.
- In un-soaked California Bearing Ratio (CBR) tests of soil conducted with varying fly ash content, the CBR increased gradually with the increase in fly ash content till its valuation was 20% by weight of the total mixture; it decreased thereafter.
- The change in case of soaked California Bearing Ratio (CBR) tests of soil with varying fly ash content was, however, uneven. It decreased with the initial addition of fly ash (10% by weight of total mixture), and then increased till fly ash content reached 30% by weight of total mixture. The values decreased thereafter.
- With the increasing fly ash content in the soil-fly ash mixture, the decrease in value of free swell ratio was remarked. This decrease was also reciprocated by the plasticity index values. Plasticity index values are directly proportional to percent swell in an expansive

soil, thus affecting the swelling behavior of the soil-fly ash mixture.

- Thus, fly ash as an additive decreases the swelling, and increases the strength of the black cotton soil. Hence, Coal fly ash can be used for the stabilization of Black Cotton Soil as it has significantly improved the geotechnical properties of Black Cotton Soil.

5.2 Scope for future study

- Fly ash along with another additive like lime, murrum, marbles dust and other such materials can be used together and may be varied in quantity to obtain the best possible stabilizing mixture.
- Utilization of others waste materials to stabilize the geotechnical properties of Black Cotton Soil.

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