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STABILSATION OF EXPANSIVE SOIL USING FLY ASH

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ABSTRACT: In India, expansive soil spans about 51.8 million hectares of land (mainly Black Cotton soil). When these expansive soils are dry, they are exceedingly hard, but when they are wet, they lose all of their strength. Expansive soils provide challenges all over the world as a result of this property, offering a challenge for geotechnical engineers to tackle. One of the most important aspects of building is soil stabilisation, which is widely used in foundation and road pavement projects. This is because a stabilization regime like this improves the soil's engineering attributes like volume stability, strength, and durability. During this technique, the problematic soil is removed or replaced. To replace it, a higher-quality substance is utilized, or the soil is treated with an addition. This project uses fly ash acquired from Sesa Sterlite in Jharsuguda, Odisha, to stabilise black cotton soil from Nagpur.

INTRODUCTION

Expansive soils, also known as swell-shrink soils, have a tendency to shrink and swell when moisture content changes. Significant distress in the soil develops as a result of this variance in the soil, which is followed by damage to the underlying buildings. These soils absorb the water and swell during periods of higher precipitation, such as monsoons; as a result, they become mushy and their water holding capacity decreases. In contrast, during drier seasons, such as summer, these soils lose the moisture they have stored owing to evaporation, causing them to become harder. Generally found in semi-arid and arid regions of the globe, these type of soils are regarded as potential natural hazard – if not treated, these can cause extensive damage to the structures built upon them, as well causing loss in human life.

Expansive soils, also known as Black Cotton soils or Regur soils, are primarily found in the Deccan trap (Deccan lava tract), which encompasses Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, and a few isolated locations in Odisha. These soils can also be found in the Narmada, Tapi, Godavari, and Krishna river valleys. The higher reaches of the Godavari and Krishna rivers, as well as the northwestern part of the Deccan Plateau, have a lot of black cotton soil. On average, expansive soils cover around 20% of the country's overall geographical area.

Fly ash is a residue generated in combustion and comprises the fine particles that rise with the flue gases. Ash that does not rise is called bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is a heterogeneous material. Silicon dioxide, Aluminium oxide ,Ferric oxide and Calcium oxide (occasionally) are the main chemical components present in fly ash

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify rapidly while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 300 µm.

It significantly improves concrete performance and also provides many benefits in cement and non-cement applications. Also, when treated with sodium hydroxide, fly ash appears to function well as a catalyst for converting polyethylene into a substance similar to crude oil in a high-temperature process called pyrolysis.

ORIGIN AND OCCURRENCE OF THE EXPANSIVE SOIL

The clay mineral is the main component that reveals the swelling properties of any non-swelling/non-shrinking soil. Montmorillonite, out of several types of clay minerals has themaximum amount of swelling potential. In-situ formation of chief clay minerals occurs underalkaline conditions, or sub-aqueous decomposition of blast rocks can be seen the origin of suchsoil – expansive soil.**[1]** These 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 favoured.

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.

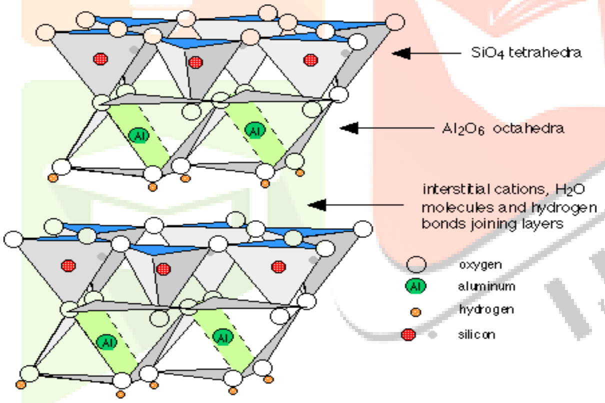
Clay Mineralogy

On the basis of their crystalline arrangement, clay minerals can be categorized into three general groups, namely:

a. Kaolinite group
b. Montmorillonite group
c. Illite group

a. Kaolinite group

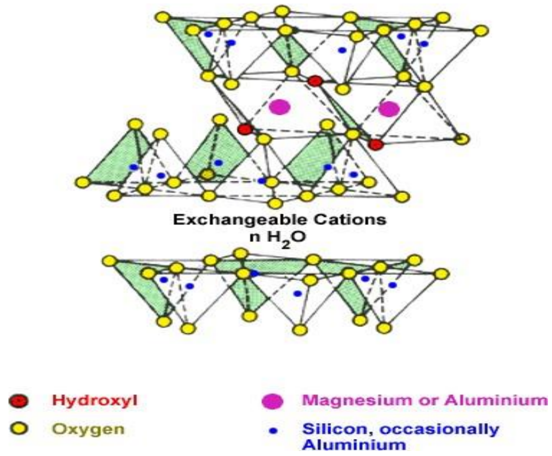
A clay mineral which has a chemical composition $Al_2Si_2O_5(OH)_4$ is called Kaolinite. This type of clay mineral has a layered silicate with oxygen atoms linking it to one octahedral sheet of alumina. China clay or Kaolin is the name given to rocks that are rich in this mineral. A thickness of 7Å is exhibited by the stacked layers of kaolinite; as a result of this, kaolin group of minerals are seen to be the most stable, which is also because of the fact that water cannot enter between the sheets to inflate that unit cell.**[2]**



Atomic structure of Kaolinite

b. Montmorillonite group

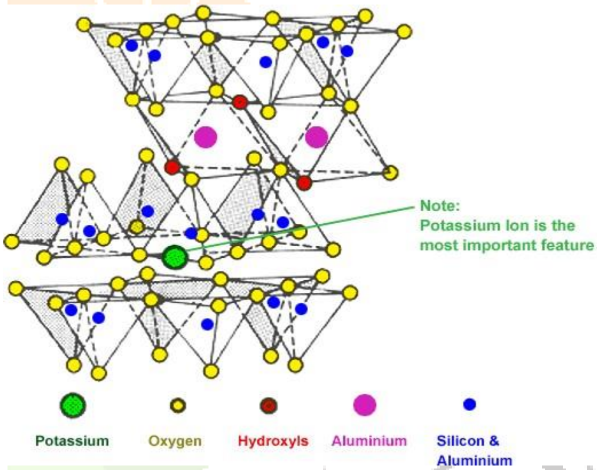
Two silica tetrahedral sheets combined with a central alumina octahedral sheet comprise the structural arrangement of Montmorillonite. The bond between crystal links is weak here. Thus, the soil containing higher percentage of Montmorillonite minerals demonstrate high shrinkage and swelling characteristics, depending on the nature of exchangeable cation present. The common layer of a Montmorillonite unit is formed by one of the hydroxyl layers of the octahedral sheet and the tips of the tetrahedrons from each silica sheet. Atoms which are common to both silica and gibbsite layers never participate in the process of swelling. During weak bond between the crystal forms, water can penetrate, breaking the structures to 10Å structural units.



Atomic structure of Montmorillonite

c. Illite group

As far as structural arrangement is concerned, Illite minerals fall between Montmorillonite and Kaolinite group. As in case of Montmorillonite unit structure, two silica tetrahedral sheets combined with a central alumina octahedral sheet comprise the structural arrangement of Illite.**[3]**The spacing between the elementary silica-gibbsite-silica sheets is mostly determined by the amount of water available to fill the vacancy. Owing to this reason, Montmorillonite is believed to have an expanding lattice. However, in presence of excess water, Illite can split up into individual layers of 10Å thick.



Atomic structure of Illite

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.**[4]** 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 aforementionedmethods, 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 water containing jar. Theswelled volume of the soil is then noted (after 24 hours period), and subsequently, the free swell index values, in percentage, are calculated. IS: 2720-II was followed for free swell index test.

Free Swell Value[ln](in%age)= [(final volume- initial volume)/(initial volume)]*100

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 a soil is related to plasticityindex. With corresponding range of plasticity index, various degrees of swelling capacities areas indicated through the following table:

Swelling potential vs. Plasticity Index

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

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.

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.Broken or fissured soils, as well as evident structural damage to existing buildings, are prominent indicators of potentially expanding soils in the field. Broken or fissured soils, as well as evident structural damage to existing buildings, are promineant indicators of potentially expanding soils in the field.s. To classify expansive soil, potential swell, or potential expansion, or the degree of expansion is a favoured term used; from this, geotechnical engineers establish how good or bad the expansive soils are.

Causes of swelling

There are different theories, but the mechanism of swelling is still unclear. No conclusion to the mechanism have 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.

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 soil.

Factors affecting swelling

Initial moisture content, or the moulding water in case of a re-moulded sample is the most influencing factor. "The behaviour of re-moulded 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 pre-paved sub-grade is given by:

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

(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 exhibit negligible swelling because theoverburden pressure neutralizes the developing swelling pressure of the dry soil.**[5-7]**

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
- Time
- Stress history
- Unit weight of the sample taken, etc.

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 soilsare 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 a significant impact on the moisture content of these soils, which in return affect the shrinkage-swelling cycles. In seasons which are dry innature, 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 dangerto the structure.

If a building is constructed on such soil during the dry season, the partially saturated soil beneath the structure's foundation will experience swelling pressures when the partially saturated soil underneath begins to imbibe water during the rainy season, causing 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.**[8]**

MATERIALS

The expansive black cotton soil was obtained as part of this experiment from Khairi, Nagpur, Maharashtra. Sacks were used to transport the black cotton dirt to the laboratory. To assess the natural moisture content of the same, a tiny amount of soil was extracted, sieved through a 4.75 mm sieve, weighed, and dried in air before weighing it again. The various geotechnicalproperties of the procured soil are as follows:

Geotechnical properties of expansive soil

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%

Fly ash

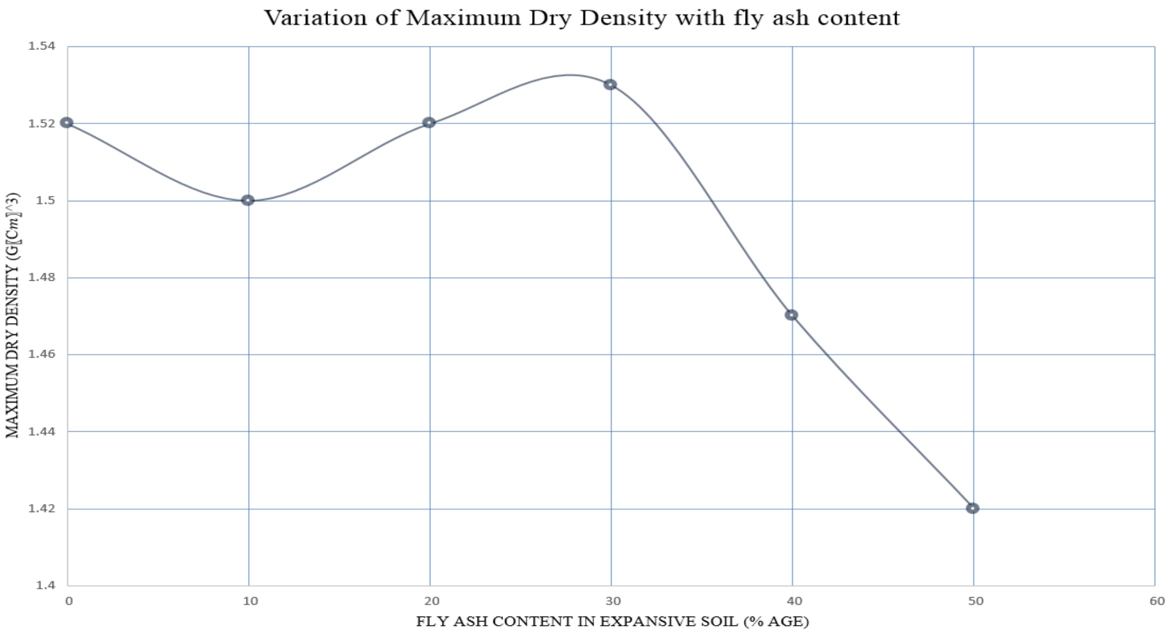
Fly ash is a waste product derived from the gases emitted by coal-fired furnaces, usually at a thermal power station. The mineral residue that is left behind after the burningof coal is the fly ash. The Electro Static Precipitator (ESP) of the power plants collect these fly ashes. Essentially consisting of alumina, silica and iron, fly ashes are micro-sized particles. Flyash 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 composition varies according on the type of coal used in the combustion process, but it is essentially a non-plastic silt **[9,10]**. Fly ash was collected from Sesa Sterlite in Jharsuguda, Odisha, for the purposes of this study. To separate out thevegetation 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.

Methodology adopted

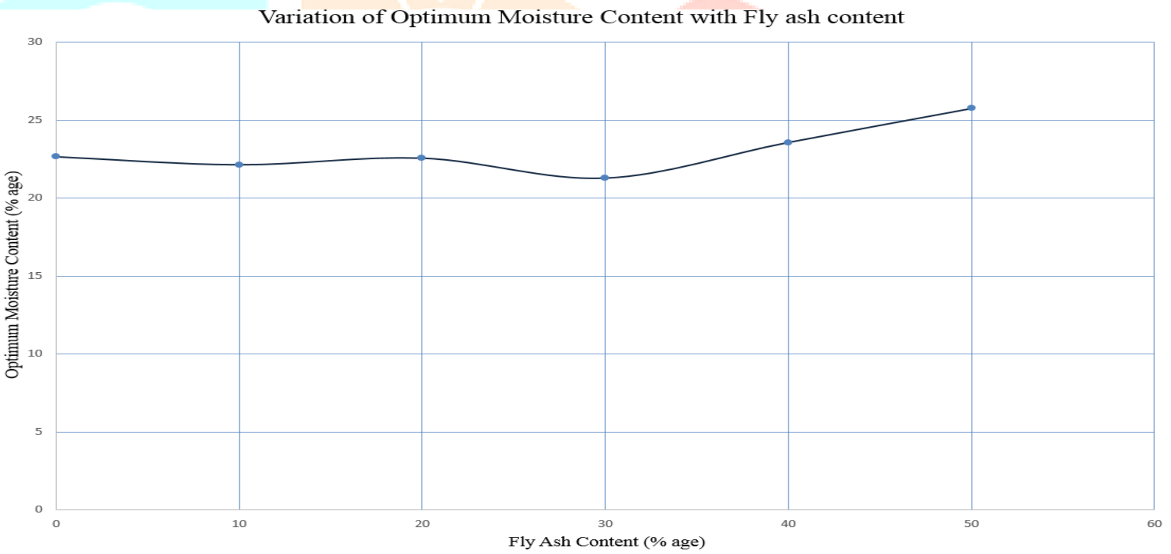
A series of tests were conducted to examine the effect of fly ash as a stabilising additive in expansive soils, with the content of fly ash in the expansive soil ranging from 10% to 50% (multiples of 10) by weight of the total quantity taken.. The Indian Standard codes were followed during the conduction 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 & Plastic limit test – IS 2720 (Part 5) – 198

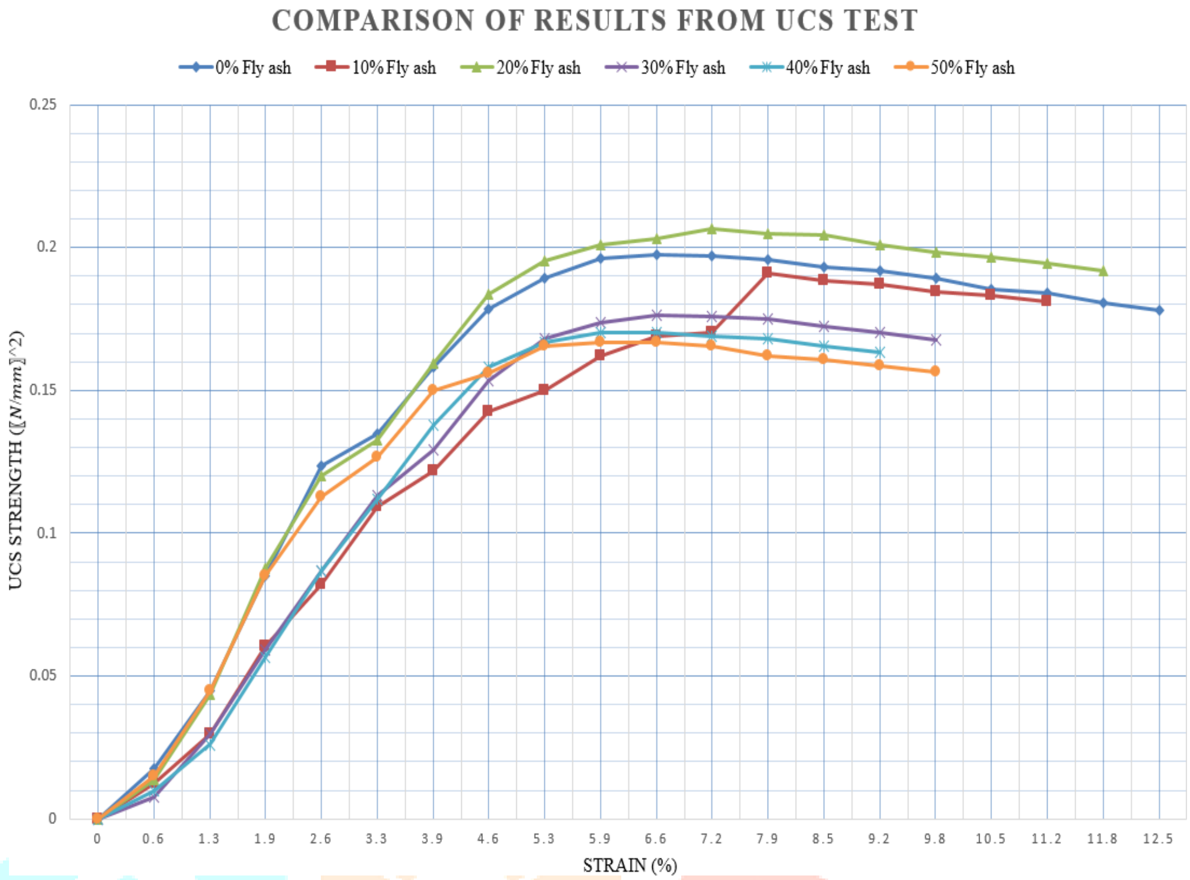
RESULTS



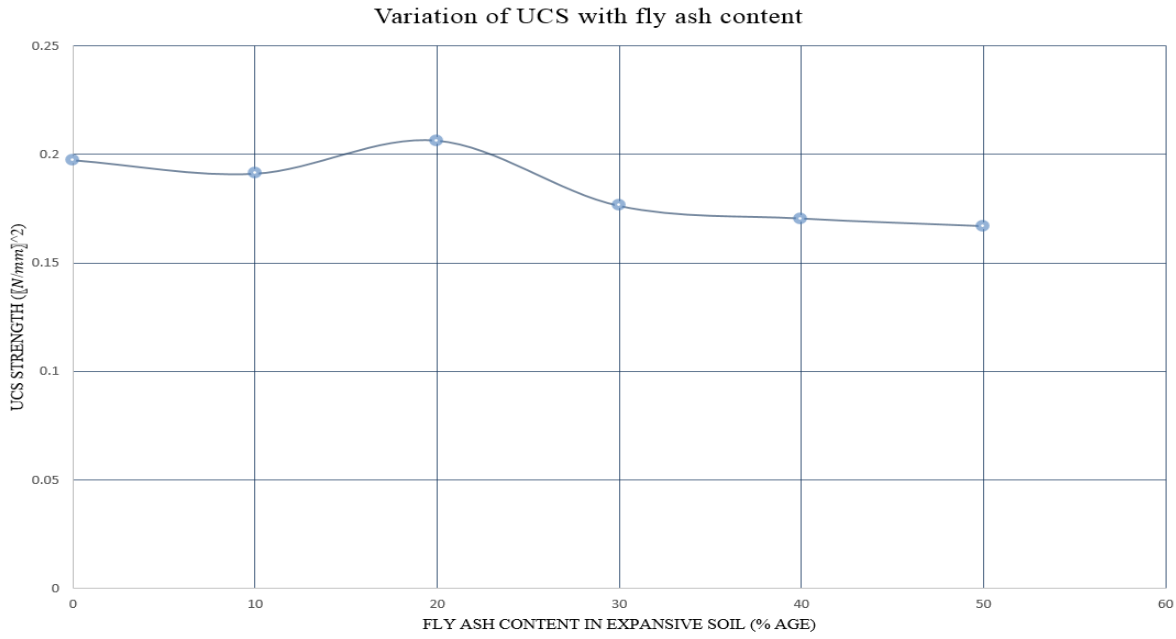
Variation of MDD values with different fly ash content in expansive soil



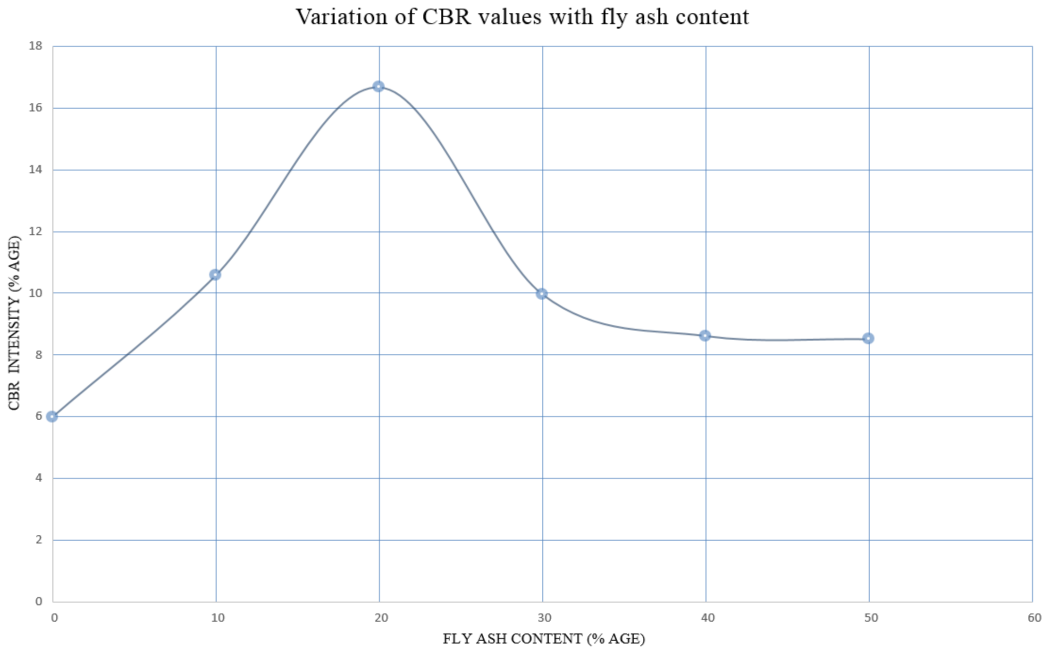
Variation of OMC values with different fly ash content in expansive soil



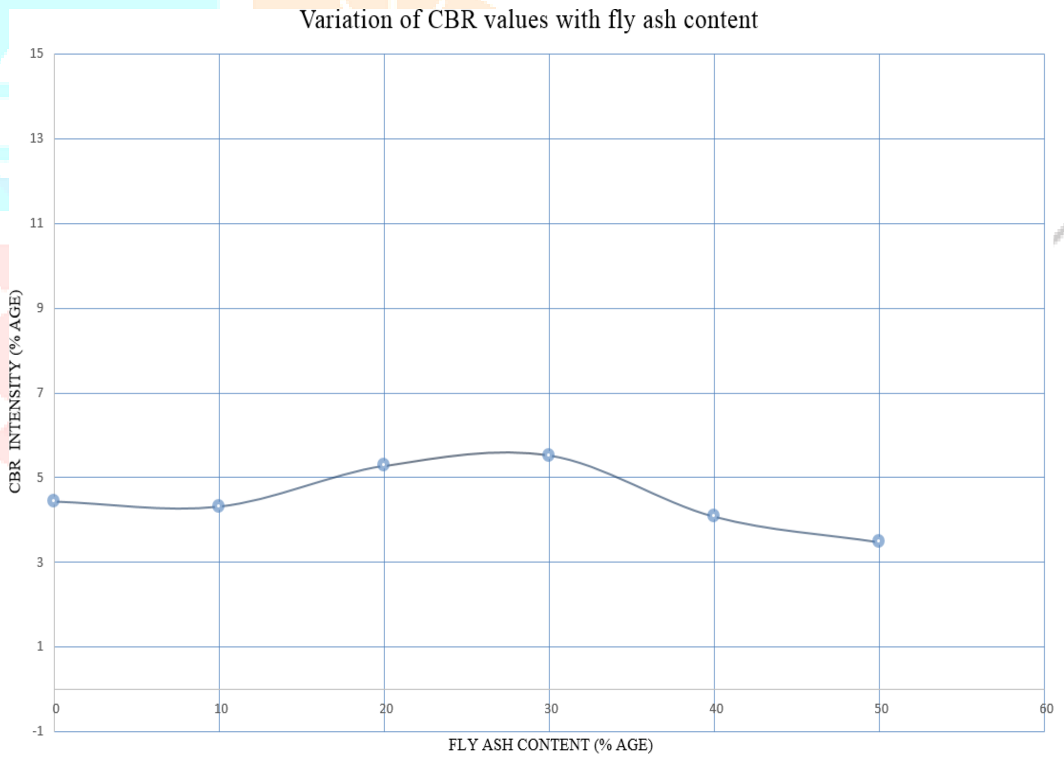
Comparison of UCS test readings in expansive soil, with varying fly ash content



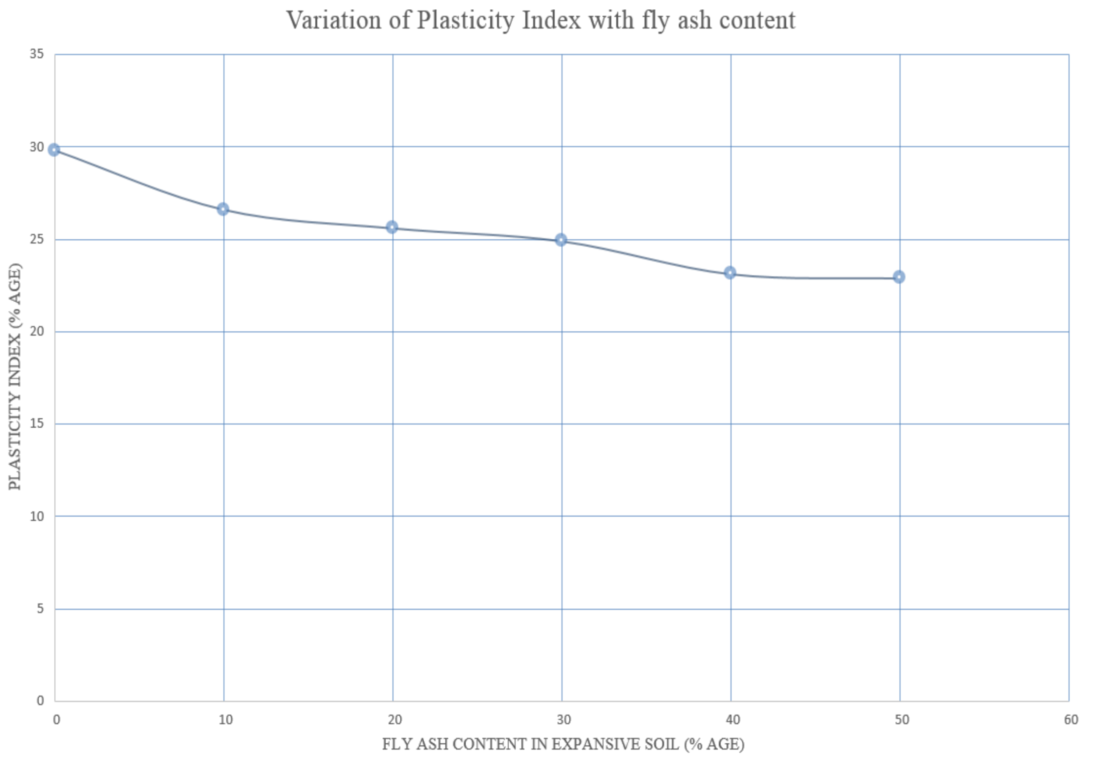
Variation of UCS values of expansive soil with different fly ash content



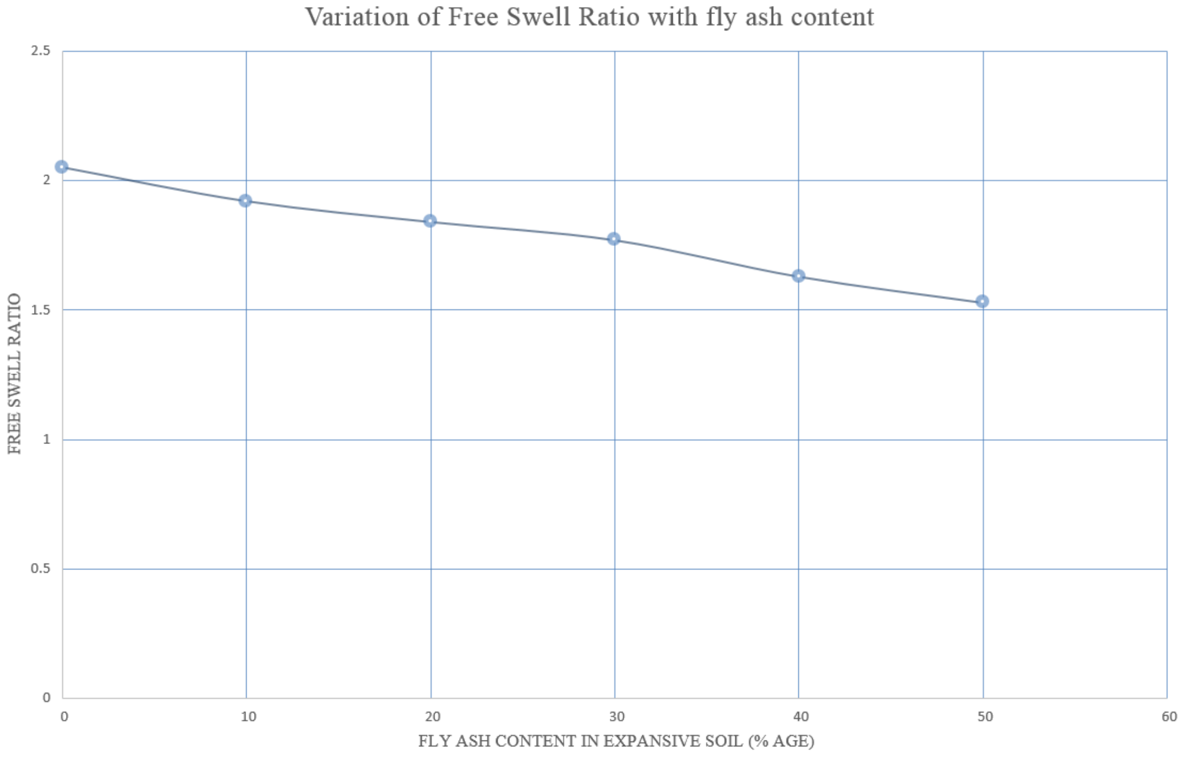
Variation of Un-soaked CBR values of expansive soil with varying fly ash content



Variation of soaked CBR values of expansive soil with varying fly ash content



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



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

Conclusions

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

- With the addition of fly ash, the black cotton soil's Maximum Dry Density (MDD) value initially fell. Then, as the amount of fly ash in the soil-fly ash mixture increased, it exhibited an increase. 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 for the fact that the peak value was found at a fly ash composition of 20% by weight.
- In un-soaked California Bearing Ratio (CBR) tests of soil conducted with varying fly ash con tent, 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 varyingfly 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 offree swell ratio was remarked. The plasticity index values also decreased as a result of this drop. The plasticity index values also decreased as a result of this drop. 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 cot--ton soil.

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