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# Implication of Fly Ash in Stabilizing Expansive Soil

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## Abstract

Expansive Black Cotton soils are extensively distributed worldwide and nearly 51.8 million hectares of land area in India are covered with Expansive soil (mainly Black Cotton soil). This black Cotton Soil is a source of great damage to infrastructure and buildings. It is, therefore, necessary to mitigate the problems posed by expansive soils and prevent cracking of structures. In the present study, using fly ash obtained from Katul Board, Durg, Chhattisgarh, stabilization of black cotton soil obtained from Durg, is attempted. With various proportions of this additive i.e. 0% to 50%, expansive soils are 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. 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.

## Introduction

Expansive soils are soil that has the ability to shrink or swell, and thus change in volume, in relation to changes in their 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. Generally found in semi-arid and arid regions of the globe, these types 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. Soils whose composition includes the presence of montmorillonite, in general, display these kinds of properties.

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 (Fig 01). Soil used for this study were Black cotton soil with properties described in table 1. These soils are also found in the river valleys 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. Black cotton soils are well developed from a variety of parent material such as basalt or igneous rocks. Further weathering of these materials results in soil rich in lime, aluminum, iron, and magnesium but are limited in major nutrients like nitrogen and phosphorus and have low organic inputs. Cooling of volcanic eruption (lava) and weathering another kind of rock – igneous rocks – are also processes of formation of these types of soils. Rich in lime, alumina, magnesia, and iron, these soils lack nitrogen, phosphorus and organic content.

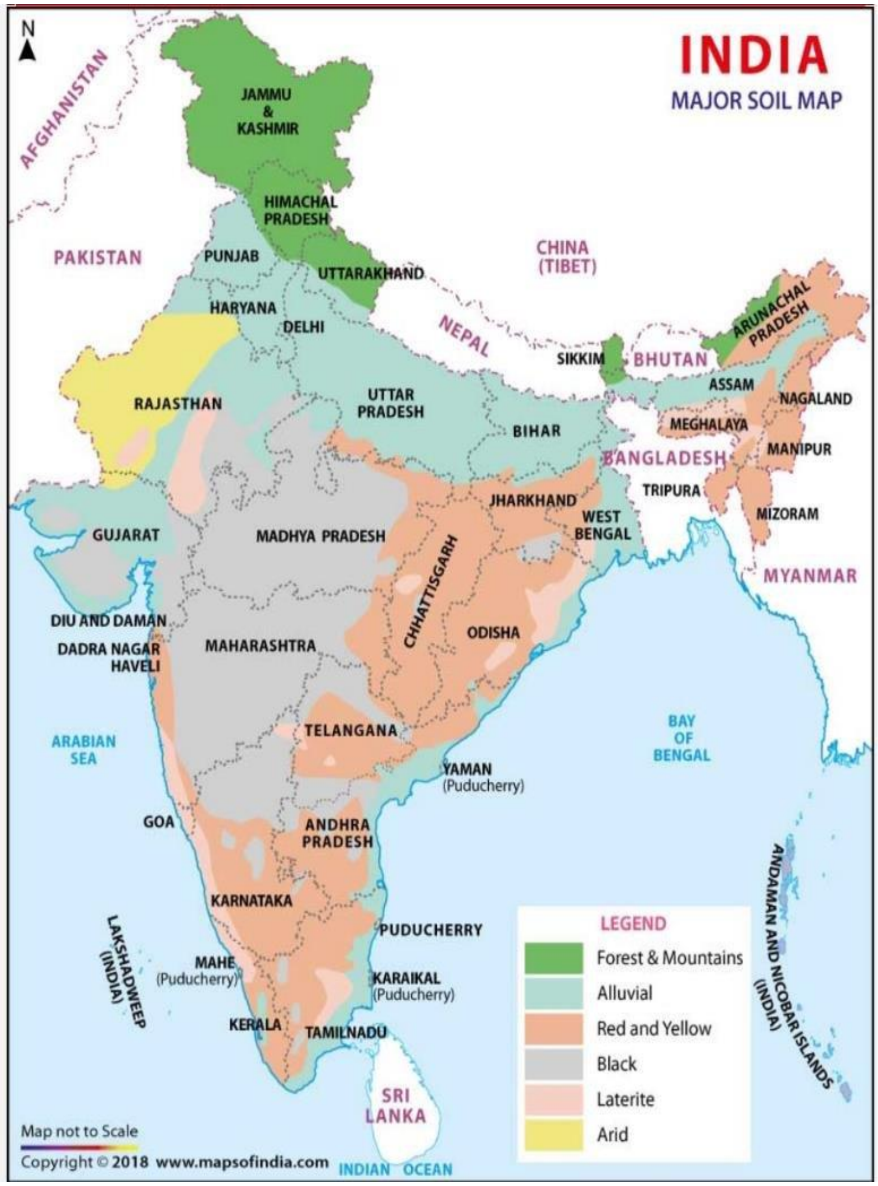

FIGURE 1. Major Soil Types in India

These soils are suitable for dry farming and for the growth of crops like cotton, rice, jowar, wheat, cereal, tobacco, sugarcane, oilseeds, citrus fruits and vegetables; the reason behind it is due to the moisture retention capacity of expansive soils, which is high. Damages due to the swelling shrinking action of expansive soils have been observed in the 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. The soil sample for this project has been taken from the Durg, Chhattisgarh.

| PROPERTY | RANGE |
|---|---|
| Field Moisture Content (%) | 10 – 35 |
| Field Dry Density (g/cc) | 1.15 - 1.65 |
| Liquid Limit (%) | 40 – 75 |
| Plastic Limit (%) | 18 – 35 |
| Shrinkage Limit (%) | 8 – 20 |
| Free Swell Index | 40 – 80 |
| Swelling Pressure (kg/cm$^2$) | 0.065 - 0.258 |

TABLE 0. Properties of the Black Cotton Soil

Soil Stabilization using Fly Ash: Fly ash is the combustion product of sub bituminous coal in electric power plants and requires being land filled. However, many countries have promoted the reuse of these types of wastes in the interest of sustainable construction. Therefore, the use of fly ash as a binding admixture not only improves the engineering properties of soil but also reduces the use of energy and greenhouse gases. Fly ash disperses the soil cement clusters into smaller clusters, thereby increasing the reactive surface for hydration and pozzolanic reactions. Due to these pozzolanic characteristics, the shear strength and bearing capacity of the organic soil can be increased by stabilizing it with fly ash. Fly ash reduces the plasticity index and shrinkage limit, which has a potential impact on the engineering properties of fine-grained soil. However, the effectiveness of the stabilization depends on the organic content present in the soil, which is not taken into account in the case of inorganic soil. Some waste materials such Fly Ash, rice husk ash, pond ash may be used to make the soil stable. Addition of such materials will increase the physical as well as chemical properties of the soil. Some expected properties to be improved are CBR value, shear strength, liquidity index, plasticity index, unconfined compressive strength and bearing capacity etc. The objective of this study was to evaluate the effect of Fly Ash derived from combustion of sub-bituminous coal at electric power plants in stabilization of soft fine-grained red soils. California bearing ratio (CBR) and other strength property tests were conducted on soil. The soil is in range of plasticity, with plasticity indices ranging between 25 and 30. Tests were conducted on soils and soil-Fly Ash mixtures prepared at optimum water content of 9%. Addition of Fly Ash resulted in appreciable increases in the CBR of the soil. For water contents 9% wet of optimum, CBRs of the soils are found in varying percentages such that 3, 5, 6 and 9. We will find the optimum CBR value of the soil is 6%. Increment of CBR value is used to reduce the thickness of the pavement and increase the bearing capacity of soil.

## Advantages of Soil Stabilization

Additive like fly ash can improves soil strength. It Helps to reduce soil volume change due to temperature or moisture. Improves soil workability and reduces dust in work environment. It also improves durability of the structure.

Expansive soil or clay is considered to be one of the more problematic soils and it causes damage to various engineering structures because of its swelling and shrinking potential when it comes into contact with water. Expansive soils behave differently from other normal soils due to their tendency to swell and shrink. And as a part of this study, the Expansive Soil or Black Cotton Soil is acquired from the nearby areas of Bhilai, India.

Fly ash is a byproduct of power generation with coal. The fly ash generated at National Thermal Power Corporation Limited (NTPC) stations and STEEL AUTHORITY OF INDIA LIMITED (SAIL) is ideal for use in the manufacture of cement, concrete, concrete products, cellular concrete products, bricks/blocks/ tiles etc. The Fly ash acquired for this project from Katul Board Durg C.G. Fly ash can be used to stabilize bases or subgrades, to stabilize backfill, to reduce lateral earth pressures, to stabilize embankments and to improve slope stability. The primary reason fly ash is used in soil stabilization applications is to improve the compressive and shearing strength of soils

Erdal Cokca (2001) studied the "*Effect of Flyash on Expansive Soil"*. He studied that Fly Ash consists of often hollow spheres of silicon, aluminium and iron oxides and unoxidized carbon. There are two major classes of fly ash, class C and class F. The former is produced from burning anthracite or bituminous coal and the latter is produced from burning lignite and sub bituminous coal. Both the classes of fly ash are pozzolans, which are defined as siliceous and aluminous materials. Thus, Fly ash can provide an array of divalent and trivalent cations ($Ca^{2+}$,$Al^{3+}$,$Fe^{3+}$etc) under ionized conditions that can promote flocculation of dispersed clay particles. Thus expansive soils can be potentially stabilized effectively by cation exchange using fly ash.

Raut, J.M., Bajad, S.P., and Khadeshwar, S.P. (2014), *"Stabilisation of Expansive Soils Using Fly ash and Murrum".* This paper describes a study carried out to check the improvement of expansive soil by using Fly Ash as well as Morrum for their experiment. Unconfined compressive test is carried on all the samples of soil mixtures with fly ash and morrum. And it is observed that, as the percentage of Morrum additive increases the cohesion values of the clay mixture decreases and angle of shearing resistance values increases. Also unconfined compressive strength increases. Increasing the percentage of fly ash additive, the cohesion values of the mix increases and angle of shearing resistance values decreases. As the percentage of murrum and fly ash combination increases the cohesion values of the mix increases and angle of shearing resistance values decreases up to 12.50% of murrum and fly ash combination and afterwards cohesion values decreases and angle of shearing resistance values increases.

Radhakrishnan, G., Kumar, M.A., and Raju, G.V.R.P. (2014), *"Swelling Properties of Expansive Soils Treated with Chemicals and Fly ash"*. This paper demonstrates the performance of a variety of additives such as non-cementitious: stone dust, cementitious: lime and fly ash, and chemical additives: CaCl2 and Na2SiO3, in reducing the swelling behavior of expansive soils. Results highlight that all the additives are effective in reducing swelling characteristics, and each additive showed its distinct response in stabilizing the expansive soils. Among the three categories of additives that have been employed for stabilization of three expansive soils, chemical additives exhibit better performance over its counterparts. Efforts were also made in the present study, to investigate the influence of valence of captions and mean particle diameter of additive on swelling characteristics. As such, results demonstrate that varieties of additives are effective in stabilization of expansive soils, but the selection of a particular additive type seems to be prudent if set on the basis of the prevailing site conditions.

Prof. Naik U.P - *"Stabilization of Expansive Soil"* International Journal of Engineering Science and Technology, vol 5, issue 12, 2016. From the investigation, it has been evaluated that Industrial waste material which is cheaply and easily available in abundant amounts i.e. pond ash and fly ash can improve the soil with the help of admixture like lime. This solution for soil improvement is environmentally friendly and eco-friendly pond ash can replaces the conventional earth material in some of the geotechnical constructions also.

Our main aim is to determine the scope of adding additives to reduce expansiveness and improve bearing capacity value. Also, to establish the use of Fly Ash as an additive, thereby assisting in the utilization of this fine waste product from thermal power plants, which is currently laying as a fine waste product. The Hypothesis on which we are working is that using fly ash along with black cotton soil with enhance the stabilization of soil upto certain limit. That we are going to find in this research.

## Methodology

To evaluate the effect of fly ash as a stabilizing additive in expansive soils, series of tests, where the content of fly ash in the expansive soil was varied in values of 10% to 50% (multiples of 10) by weight of the total quantity taken.

## Sample Collection

Collection of Fly Ash: Katul Board Durg, Chhattisgarh

Soil Sample: Black Cotton Soil From Durg Chhattisgrah

## Sampling technique

Undisturbed Soil Sample as well as Disturbed soil Sample both is obtained from Durg Field. For Disturbed sample we clear out the soil surface from where we have to collect the sample with the help of shovel, then after removal of top soil we took the black cotton soil sample by making hole on ground i.e. simple digging method.

For undisturbed sample we use hollow cylinder then cut the soil with it without disturbing it and put them in bag to bring it to lab along with container.

## Sample Preparation

For Soil Testing, Black Cotton Soil for Gradation is Oven Dried at 110$^{o}$ C. Then, Sieve Analysis IS performs using Different Sieve Size. For Atterberg Limit Test, Dried Black Cotton Soil Passing from 475 micron is used. And for optimum Moisture content test, Black Cotton soil passing from 4.75 mm sieve is used in CBR machine. This is done by undisturbed soil sample.

## Experimental Procedures

### Grain size Analysis

Grain size analysis is done for (1) Mechanical sieve – where different size of sieve for soil are used and arranged in Ascending order of fines to get retainment on it and for (2) Hydrometer analysis for fine grained soil <75 micron. Expansive soil and for fly ash by using following procedures as per IS: 3104-1964. This soil based experiment is carried out in order to get gradation of soil sample. What amounts of different grains are present in the soil sample? Accordingly we classify the soil types either sandy, clayey, silty, etc. fine grained or coarse grained.

### Specific Gravity

This test is performed in order to find the soil properties like void ratio, degree of saturation, porosity of soil. So that we can know the soil type.

The specific gravity of soil was determined by using Pycnometer (volumetric flask) as per IS: 2720(part-III/sec-I) 1980. Where we add soil in pycnometer of about 200 gm and weight it then add water in it and take weight again using only pycnometer and water only. Then calculating the specific gravity of sample.

## Liquid Limit

This method is adopted to find the plasticity of soil sample. The liquid limit was determined in the laboratory by the help of standard liquid limit apparatus i.e. Cassagrande apparatus. About 120g of the specimen passes through a 425µ sieve. A groove was made by a groove tool as IS: 9259-1979 designates. A brass cup was raised and allowed to fall on a rubber base. The water content corresponding 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.

## Plastic Limit

In order to find the boundaries between semisolid state of soil and plastic state we perform plasticity test. The value of plastic limit was found for swelling soil and swelling soil with 20% fly-ash as per IS: 2720(part-V)-1986. In this soil sample after passing 4.25 mm sieve is used where we add water in order to form soil ball which in turn is converted to thread until it crumbles of size 3mm and then kept in oven to find the moisture content.

## Optimum Moisture Content and Maximum Dry Density

This experiment is performed in order to find the dry density of soil. What compaction load is applied in soil at maximum limit without change in grains of soil? The Optimum moisture content and dry density of swelling soil with various percentages 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 consists 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 is removed and the excess soil is trimmed off to make it level. The dry density is determined and plotted against water content to find OMC and corresponding maximum dry density (Figure 02 - 09).

## California Bearing Ratio Tests

This soil testing method is performed to get the strength of soil sample. How much load it can bear so that we can design foundation or base of any structure specially pavement. CBR is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 and 5 mm (Table 2 - 5).

## Results

The effect and behavior of an additive on expansive soil, black cotton soil (or expansive soil) is observed when sampled soiled is mixed with fly ash, alternating its percentage (from 0% to 50%) for Standard Proctor Test and is Liquidity and Plasticity Index Test by weight. The result is tabulated in below tables (Table 01). The liquid limit and the 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 (Table 01).

The Different Atterberg limits which we have found using Cassagrande apparatus –liquid limit test Shows that in Black Cotton soil without fly ash it is around 65.6 while with different fly ash content as fly ash content increases liquid limit decreases to 49.2.

For Plastic limit Also as the fly ash content increases from 0 to 45 % the plastic limit decreases along with plasticity index.

| Mixture | Liquid limit | Plastic limit | Plasticity index |
|---|---|---|---|
| Only soil | 65.6 | 35.8 | 29.8 |
| Soil + 10% fly ash | 61.2 | 34.6 | 26.6 |
| Soil + 20% fly ash | 58.8 | 33.2 | 25.6 |
| Soil + 30% fly ash | 56.4 | 31.5 | 24.9 |
| Soil + 40% fly ash | 51.8 | 28.67 | 23.13 |
| Soil + 50% fly ash | 49.2 | 26.3 | 22.9 |

TABLE 1. Liquidity and Plasticity Index

## Standard Proctor Test For Expansive Soil Test

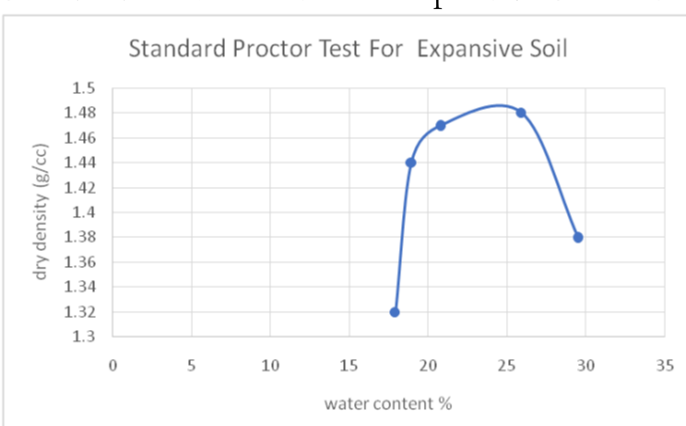


FIGURE 02: Proctor Test with Expansive Soil Only

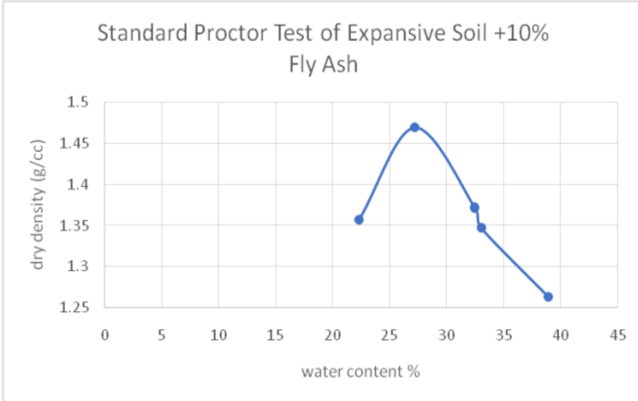


FIGURE 3: Proctor Test with Expansive Soil + 10% Fly Ash

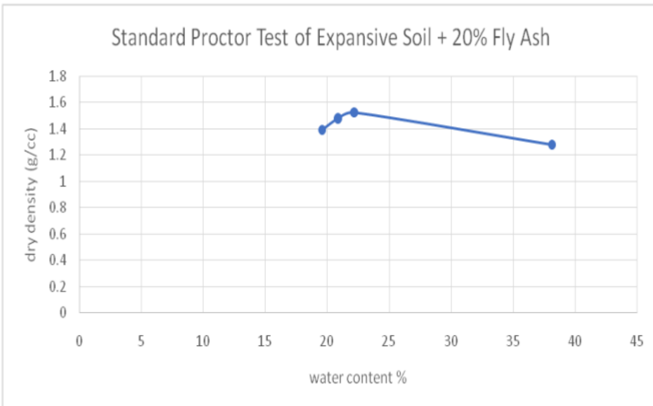


FIGURE 4: Proctor Compaction Test for Expansive Soil + 20% Fly Ash

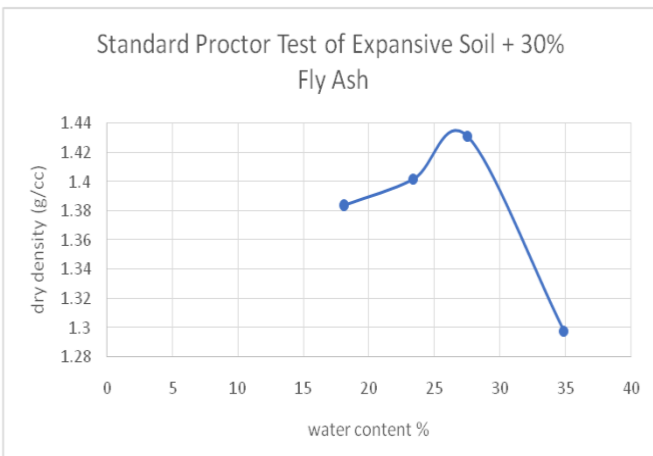


FIGURE 5: Proctor Test with Expansive Soil + 30% Fly Ash

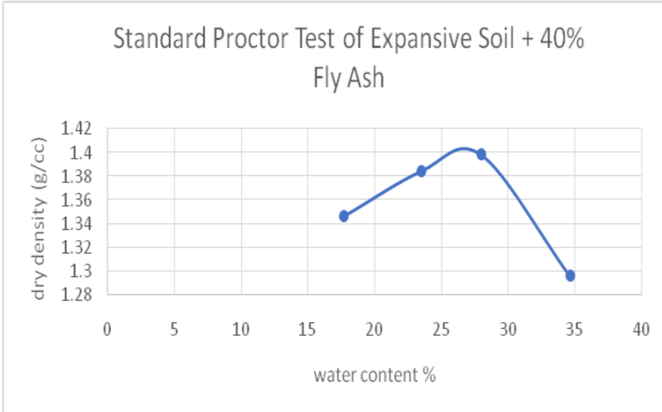


FIGURE 6: Proctor Test with Expansive Soil + 40% Fly Ash

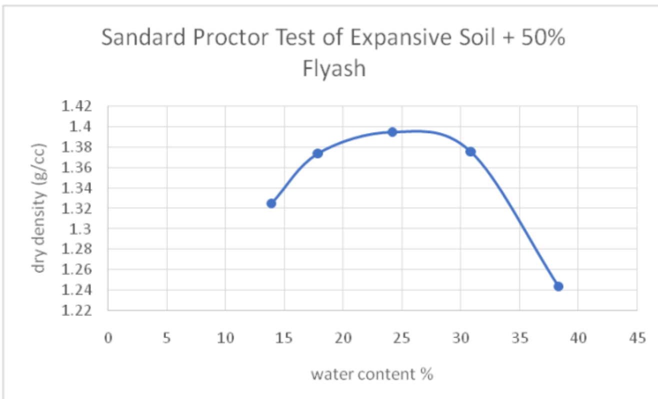


FIGURE 7: Proctor Test with Expansive Soil + 50% Fly Ash

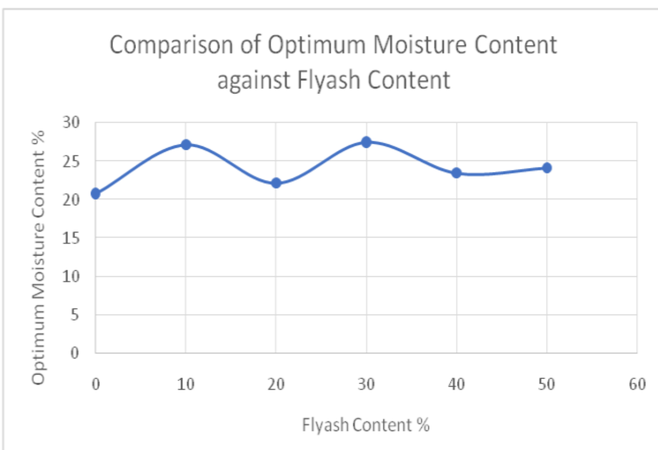


FIGURE 8: Comparison of Optimum Moisture Content against Fly Ash Content

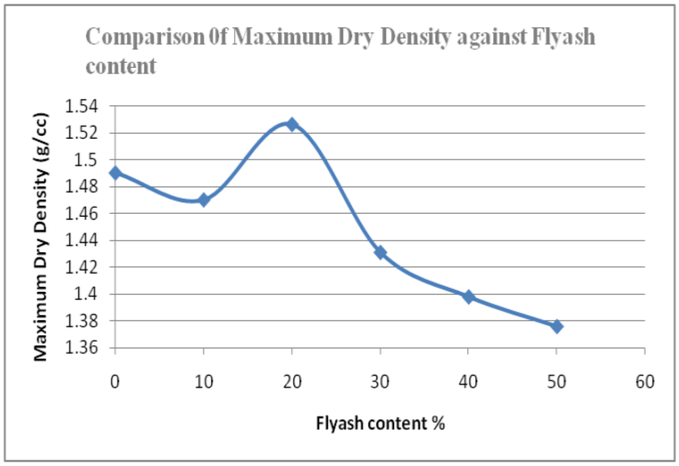


FIGURE 9: Comparison of Maximum Dry Density against Fly Ash Content

California Bearing Ratio (Cbr) Test For Soil - Fly Ash Content

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 4 |
| 3 | 1 | 5 |
| 4 | 1.5 | 7 |
| 5 | 2 | 8 |
| 6 | 2.5 | 9 |
| 7 | 3 | 11 |
| 8 | 4 | 13 |
| 9 | 5 | 14 |
| 10 | 7.5 | 16 |
| 11 | 10 | 18 |

TABLE 2: CBR Test + Expansive Soil Only

Result: The CBR of the Soil tested is = 4.32% at 2.5 mm penetration. The CBR of the Soil tested is = 4.48% at 5 mm penetration. CBR of Soil Specimen = 4.48% at 5 mm penetration (higher of the two).

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 3 |
| 3 | 1 | 4 |
| 4 | 1.5 | 6 |
| 5 | 2 | 7 |
| 6 | 2.5 | 8 |
| 7 | 3 | 9 |
| 8 | 4 | 10 |
| 9 | 5 | 11 |
| 10 | 7.5 | 13 |
| 11 | 10 | 14 |

TABLE 3: CBR Test + 10% Fly Ash

Result: The CBR of the Soil tested is = 3.48% at 2.5 mm penetration. The CBR of the Soil tested is = 3.52% at 5 mm penetration. The CBR Of Soil Specimen = 3.52% At 5 mm Penetration (higher of the two)

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 5 |
| 3 | 1 | 7 |
| 4 | 1.5 | 8 |
| 5 | 2 | 10 |
| 6 | 2.5 | 12 |
| 7 | 3 | 14 |
| 8 | 4 | 15 |
| 9 | 5 | 23 |
| 10 | 7.5 | 26 |
| 11 | 10 | 27 |

TABLE 4: CBR Test + 20% Fly Ash Content

Result: The CBR of the Soil tested is = 5.76% at 2.5 mm penetration. The CBR of the Soil tested is = 7.36% at 5 mm penetration. CBR of Soil Specimen = 7.36% at 5 mm penetration (higher of the two)

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 7 |
| 3 | 1 | 10 |
| 4 | 1.5 | 12 |
| 5 | 2 | 14 |
| 6 | 2.5 | 15 |
| 7 | 3 | 22 |
| 8 | 4 | 23 |
| 9 | 5 | 29 |
| 10 | 7.5 | 31 |
| 11 | 10 | 32 |

TABLE 5: CBR Test + 20% Fly Ash (tested again)

Result: The CBR of the Soil tested is = 7.20% at 2.5 mm penetration. The CBR of the Soil tested is = 8% at 5 mm penetration. CBR of Soil Specimen = 8% at 5 mm penetration (higher of the two)

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 5 |
| 3 | 1 | 7 |
| 4 | 1.5 | 8 |
| 5 | 2 | 9 |
| 6 | 2.5 | 11 |
| 7 | 3 | 13 |
| 8 | 4 | 15 |
| 9 | 5 | 17 |
| 10 | 7.5 | 20 |
| 11 | 10 | 23 |

TABLE 6: CBR Test + 30% Fly Ash

Result: The CBR of the Soil tested is = 5.28% at 2.5 mm penetration. The CBR of the Soil tested is = 5.44% at 5 mm penetration. CBR of Soil Specimen = 5.44% at 5 mm penetration (higher of the two)

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 2 |
| 3 | 1 | 3 |
| 4 | 1.5 | 5 |
| 5 | 2 | 6 |
| 6 | 2.5 | 7 |
| 7 | 3 | 9 |
| 8 | 4 | 12 |
| 9 | 5 | 13 |
| 10 | 7.5 | 15 |
| 11 | 10 | 16 |

TABLE 7: CBR Test + 40% Fly Ash

Result: The CBR of the Soil tested is = 3.36% at 2.5 mm penetration. The CBR of the Soil tested is = 4.16% at 5 mm penetration. CBR of Soil Specimen = 4.16% at 5 mm penetration (higher of the two)

| S. No. | Penetration | Proving Ring |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0.5 | 2 |
| 3 | 1 | 3 |
| 4 | 1.5 | 4 |
| 5 | 2 | 5 |
| 6 | 2.5 | 6 |
| 7 | 3 | 7 |
| 8 | 4 | 8 |
| 9 | 5 | 11 |
| 10 | 7.5 | 12 |
| 11 | 10 | 13 |

TABLE 8: CBR Test + 50% Fly Ash

Result: The CBR of the Soil tested is = 2.88% at 2.5 mm penetration. The CBR of the Soil tested is = 3.52% at 5 mm penetration. CBR of Soil Specimen = 3.52% at 5 mm penetration (higher of the two)

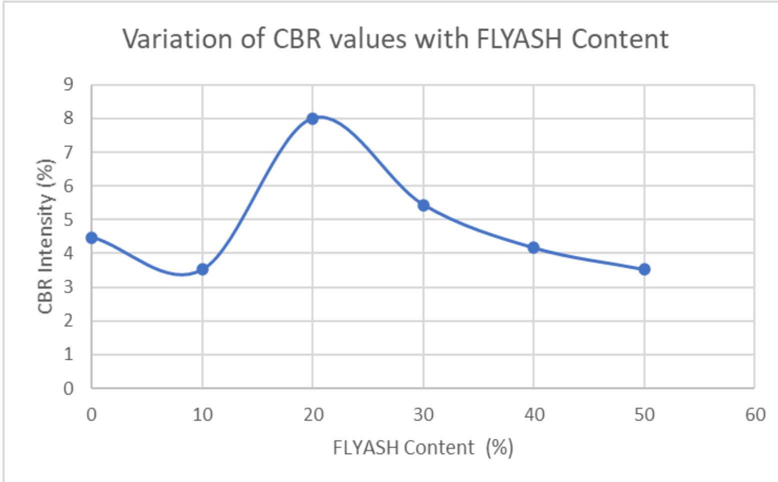


FIGURE 17: Variations of CBR Values with FLY ASH Cont

## Discussions

To observe its effect and behavior as an additive on expansive soil, black cotton soil (or expansive soil) is mixed with fly ash, alternating its percentage (from 0% to 50%) for Standard Proctor Test and is Liquidity and Plasticity Index Test by weight. The liquid limit and the 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. The change observed in Standard Proctor Test of the soil - fly ash mixture with varying percentage of fly ash is taken. From the observation table and graph, it can be observed that 20% fly ash content gave the maximum dry density value for Standard Proctor Test. 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% fly ash content gave the maximum value of CBR intensity in soil-fly ash mixture respectively. As Stated by Raut, Hajad and Khadeshwar that increasing fly ash additive increase cohesion value. In our research also enhancement of soil properties shows that cohesive force between particle gets on increasing as we add fly ash. Radhakrishanan and Raju Shows that additive in swelling soil increase its stabilization but depend on type of additive.. Prof. Naik UP also concludes the same thing that fly ash improves the soil properties and is also eco friendly.

## Conclusions

The following conclusions can be drawn based on the findings and comparisons made in this study:

- On increasing fly-ash content the plastic 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.
- The maximum dry density is highest (1.526g/cc) and optimum moisture content is least (22.29 percent) found by proctor compaction test, and is obtained at 20 percent content of fly-ash. Thus, fly ash as an additive decreases the swelling, and increases the strength of the black cotton soil.
- In 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.

Here the Hypothesis which we have put forward is true that fly ash content enhances the expansive soil quality and stabilizes it up to great extent.

## Scope For Future Study

Other additives, such as lime columns, jute/ coir fiber, nylon fibers, morrum, cement, and other materials, can be used in combination with fly ash in varying percentages to achieve the best possible soil stabilization mixture.

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