Utilization of fly-ash & geotextile on expansive soil subgrade

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ABSTRACT: Most of the highways in the central part of India have foundation problem due to availability of expansive soil i.e. black cotton soil. Mainly the black cotton soil is difficult to use in foundation because of shrinkage and swelling properties. This paper presents the results of an experimental study on the characteristic of expansive soil and to control swelling of expansive soil below the pavement layers. In this study, a series of California bearing ratio (CBR) tests have been carried out in soaked and unsoaked condition with specimen prepared with virgin black cotton soil as well as black cotton soil mixed with fly ash in different proportions (i.e. 0%, 10%, 20% & 30% of dry weight of soil) and reinforced with geotextile at different depth (i.e. top, middle & bottom). Fly ash can be attributed to pozzolanic activity forming stable compounds and control the swelling characteristics of the soil. The effects of the geotextile reinforcement on the strength and deformation characteristics have been presented. The study has revealed that the addition of geotextile reinforcement results in an appreciable improvement in its engineering performance.

Keyword: black cotton soil; geotextile; fly ash; California bearing ratio; swelling index.

1. Introduction

The quality and existence of pavement basically relates to the type of subgrade soil present. The subgrade composed of clay soil is very weak and overstressing caused by wheel load can be a possibility leading to overall pavement failure. It increases the maintenance cost. The black cotton soil shares the 20% of the Indian Territory, including Madhya Pradesh, Maharashtra, Gujarat, Tamilnadu, Andhra Pradesh and various areas of Uttar Pradesh. It is controversial soil for foundation and difficult to work with this type of soil because of its low California bearing ratio (CBR) value and its weight standard. But the development activities will not be stopped, so the improvement of the benefits must be achieved. Hence to achieve the desirable strength of black cotton soil in subgrade, utilization of geotextile as well as fly ash soil is a cost efficient and ecologically friendly method. With the role of geotextile comes into action which placed in subgrade provides various functions towards property improvement of poor subgrade soil i.e. reinforcement, separation, drainage and filtration. Fly ash can be attributed to pozzolanic activity forming stable compounds and control the swelling characteristics of soil (Tastan et. al. [1]).

Geotextile is applicable in various purpose of constructions such as reinforced retaining walls, coastal protection, river training, highways, airports, urban roads, ground improvements etc. (Philip and Charly [2]). Fly ash which is very easily available, can be used for the stabilisation of black cotton soil. The main objective of this study is that to present an experimental study on black cotton soil to deal with CBR improvement for the expansive soil subgrade system and effect of geotextile and fly ash on it. The study is aimed at better predict the response of expansive soil to CBR value by geotextile and fly ash. The swelling characteristics of expansive soil is evaluated by the pozzolanic behaviour of fly ash.

2. Background

In this respect, there are several researchers evaluated the experimental analysis on black cotton soil to improve its strength characteristics with different ground improvement method. Some of the investigation evaluated to strengthen the black cotton soil with reinforcing material like geotextile (Naeini and Mirzakhanlari[3]; Senthil Kumar and Pandiammal Devi[4]; Truptimalapattnaik et al.[5]) and waste plastic (Nsaif, M. H.[6]) and by adding admixture like fly ash and rice husk (Brooks, R. M.[7]; Chauhan and Jain[8]). Naeini and Mirzakhanlari[3] conducted CBR tests to investigate the behaviour of stress penetration in different soil species, including strengthened soil reinforcement and geographic textiles and add geo-textile to a wide range of interesting depths like single, double and three layers. Choudhary et al.[9] evaluated a series of CBR tests on expensive soil, which are reinforced by two different geotextiles- geotextiles and jute and compressed to the maximum dry density. Quarry dust, tire waste and squanders plastic also utilised to improve the CBR and SPT value for black cotton soil subgrade (Mercy Joseph Poweth et. al.[10]). Recently, Peddaiah et. al.[11] analysed that waste plastic was randomly distributed to improve the soil strength parameter and CBR values. Fauzi Achmad et al. [12] determined Sub grade improvement by the HDPE and waste squashed glass and examined the chemical element by help of Integrated

Electron Microscope and Energy-Dispersive X-Ray Spectroscopy (SEM-EDS).

3. Materials adopted

3.1. Black Cotton Soil

Black cotton soil is one of major soil deposits of India. They are formed by lava basaltic rocks. They contain high percentage of clay particles whose size less than 0.002mm, due to that they exhibit high rate of swelling and shrinkage characteristics when exposed to changes in moisture content and hence have been found to be most inconvenient for engineering consideration. Black cotton soil refers to the montmorillonite group for having expensiveness nature. Black cotton soil for study has been collected from Mahoba district which is situated in Bundelkhand region of the Indian state of Uttar Pradesh. The index properties of black cotton soil were evaluated by the standard procedures and calculated as per provision of IS codes of practice. Table 1 shows the index properties of black cotton soil.

Table 1. Properties of Black Cotton Soil

Properties	Values
Specific gravity	2.58
Liquid limit	49%
Plastic Limit	22%
Plasticity index	27%
Soil classification	Clay with intermediate plastic (CI)
Optimum moisture content	19.5%
Maximum dry density (g/cc)	1.71gm/cc
Free swell index	55%

3.2. Fly ash

Fly ash is a fine powder which is a by-product of burning pulverized coal in electric generation power plants. Fly ash has pozzolanic nature, a substance containing aluminous and siliceous material that produced cementitious property in the presence of water. Nowadays utilization of fly ash in geotechnical engineering also plays a pivotal role in consumption of fly ash. A soil like black cotton soil which has high swelling characteristics can be stabilized by fly ash and controlled its swelling characteristics. In this study, fly ash was collected from Usha Martin Limited. Usha Martin Limited is a steel plant which is situated in Jamshedpur, Jharkhand. The properties of fly ash is evaluated by standard procedure in laboratory as per Indian Standard.

3.3. Geotextile

Geotextile is a form of the largest group of geosynthetic materials. Geosynthetic includes eight main product- geotextile, geogrid, geonet, geomembrane, geosynthetic clay liner, geofoam, geocell and geocomposite. Now it is widely accepted and used in the several geotechnical application including- roads, airfields, railroads, embankments, retaining structures, reservoirs, canals, dams, bank protection, coastal engineering and construction site silt fences. In this study, a woven multifilament polypropylene geotextile fabric has been provided by Techno Fabric, Surat, Gujrat. The geotextile is stable within the pH range of 2 to 13. The properties of the geotextile was provided by Techno Fabric which was shown in table 2.

Table 2. Properties of Geotextile

Properties	Values
Mass per unit area	200 g/m^2
Tensile Strength	55 kN/m^2
Elongation at Break	25%
Puncture Resistance	700 N
Trapezoidal Tear	800 N
Pore Size	75 micron
Water Permeability (at 100mm WH)	7 L/m^2/s

4. Methodology

There are basically three type of laboratory test performed for the improvement of black cotton soil subgrade- 1) Differential swell index, 2) Modified proctor test and 3) California bearing ratio. All the mentioned tests were conducted as per provision of Indian standard [13-15].

4.1. Differential swell index

Differential free swell is defined as the increase in volume of soil without any external constrain when subjected to submerged in water. Before initiating the test two oven dried samples of 10 gram each passing through 425 micron sieve is prepared. After that pour each sample in to the two glass of measuring cylindern of 100ml capacity and fill one cylinder with kerosene and other with distilled water. Sufficient time, not less than 24 hours shall be allowed for soil specimen to attain equilibirium state of volume. Eq. 1 shows the mathematical formula to calculate swelling index.

$$DFS = \frac{V_d - V_k}{V_k} X\ 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, V_d = volume of soil in distilled water.
V_k = volume of soil in kerosene.

4.2. Modified proctor test

Compaction test is a laboratory test in which experimentally determined the optimal moisture content (OMC) at which given soil type will become the most dense and achieve its maximum dry density (MDD). Representative oven dried soil sample is compacted in standard mould of 100mm diameter and 1000cc volume by the rammer of weight 4.9kg and dropped from a height of 450mm above the soil. Soil is compacted in five layers of approximatily equal mass, each layer being given 25 blow. Adding suitable amount of water with soil and mix throughly. Genrally for cohesive soil, water to be added should be 8% to 12% below the plastic limit. Then a suitable incremnet of water is added in each trial. For cohesive soil, increment is generally 2% to 4%. Total number of determination made should be at least five times.

The dry densities will be obtained for each determination corresponding to moisture content. A smooth curve is drawn against moisture content on x-axis and dry densities on y-axis. Maximum value on y-axis is called as maximum dry density (MDD) and corresponding moisture content is defined as optimum moisture content (OMC).

4.3.California bearing ratio test

This is a penetration test developed by the California division of highways, as a method for evaluating the stability of soil subgrade and other flexible pavement materials. The test results have been correlated with flexible pavement thickness requirement for highways and air fields. The CBR tests may be conducted in the laboratory on a prepared specimen in a mould or field in-situ condition. The ratio of the force per unit area required to penetrate a soil mass with standard penetration plunger at a uniform rate of 1.25 mm/min., to the corresponding penetration load of the standard material or crushed stone is called CBR.

Before initiating the test calibration of the CBR proving ring was done. 4.5-5 kg of soil was taken and mixed it well with the required amount of water (OMC) or moisture content in the field available. The separator was placed on the bottom of the mould on the base plate and a coarse filter sheet was placed on the spacer disc. Wet soil was compressed by light or heavy compaction in the mould. The collar was removed and the extra soil was removed, the clamps were removed and the compressed soil mould was raised. The filter paper was placed on the base plate, the mould compacted, the bottom turned and placed on the plate. Base and clamps were fixed. The weight of 2.5 to 5 kg was placed on the top of the mould. The mould was installed on the base plate and the same pressure weights was applied to the test sample. A complete setup was placed under the loading machine. Penetration of the piston was applied to the soil surface by applying a 4 kg load. The dial gauge of the calibration ring and the penetration dial gauge was set to 0. The load was applied at a penetration rate of 1.25 mm/min. California bearing ratio can be calculated by the following mathematical formula as in Eq. 2.

$$\text{CBR} = \frac{P_t}{P_s} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, P_t = Corrected test load corresponding to 2.5mm penetration.

P_s = Total standard load for same depth of penetration.

The load value and the corresponding intervention value were stored. On the x-axis a graph was drawn against the penetration depth (mm) and on the y-axis against the load (kN). After calculating the CBR values, the optimum CBR value identified for corresponding amount of fly ash and location of geotextile.

4.4. Reinforcement Pattern

The soil which was collected from field and fly ash which was collected from Usha Martin were oven dried in the laboratory at 105^{o}C for 24 hours. The CBR test specimen were prepared in standard CBR mould of diameter 150mm and height 175mm. Black cotton soil was thoroughly mixed with fly ash of different proportion (i.e. 0%, 10%, 20% and 30% of dry weight of soil). Then the prepared samples was reinforced by a single layer of geotextile of 148mm diameter and it is placed at different depth of mould (i.e. top, middle and bottom). Prepared sample was compacted in CBR mould by modified proctor method. The reinforcement pattern of soil in mould is shown in fig 1.

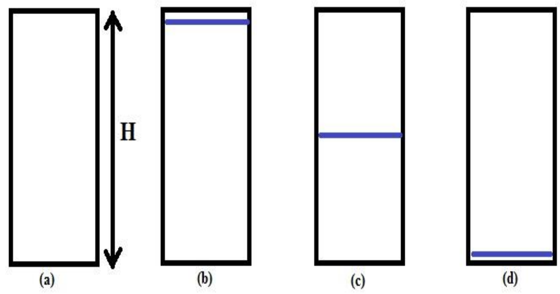

Figure 1. (a) without reinforcement (b) reinforcement at top (c) reinforcement at middle (d) reinforcement at bottom.

5. Result and discussion

Optimum value of fly ash and reiforcement depth of geotextile were investigted using a series of “california bearing ratio” test. At optimum moisture content (OMC). Samples were prepared with 0%, 10%, 20% and 30% of fly ash and reinforced by geotextile.

5.1. Differential free swell

Black Cotton is highly clay content soil, which is montmorillonite in structure. The clay mineral is responsible for the expansive character of black cotton soil. Hence that why black cotton soil shows high expansive character. Expansive nature of black cotton soil creates a hindrance in construction work. Hence it needs to be stabilize to create a smooth working condition. In this study, fly ash has been mixed with BCS to control its swelling character fot civil engineering purpose. Hence fly ash is mixed with BCS with different proportion of 0%, 10%, 20% & 30%. In fig. 2, the variation of differential free swell (DFS) showed.

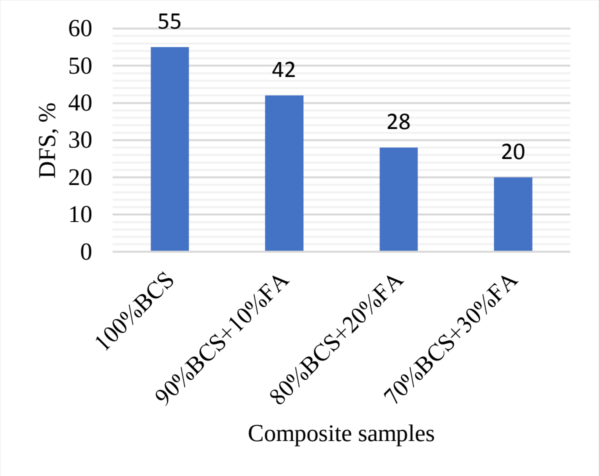

Figure 2. effect of fly ash on DFS of BCS.

From above results, it clearly describes that DFS is the highest at 0% of fly ash which is 55%. At 30% of fly ash, DFS is 20% which is moderate. At 30% of fly ash, DFS has decreased about 64% as compare to 0% fly ash. 20-30% swelling can be favourable for civil engineering works. Hence it can be concluded that by increasing the amount of fly ash differential free swell is continuously decreasing.

5.2. Modified proctor test

It is also known as heavy compaction. Modified proctor test is conducted on the expansive soil with different proportion of fly ash. Comparision of all conducted tests are reffering fig. 3 and result is discussed accordingly.

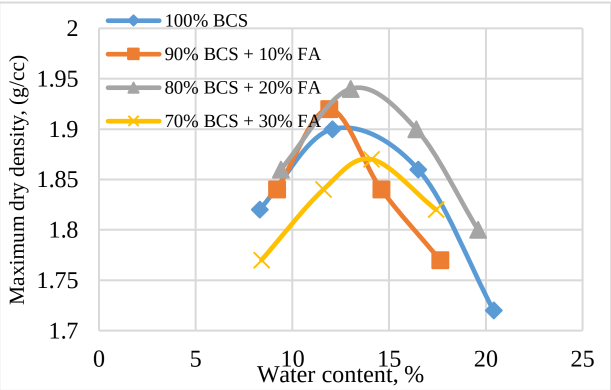

Figure 3. modified proctor test of BCS at different amount of fly ash.

From the modified proctor test response, it is visible that the use of fly ash on black cotton soil is significantly increase the value of maximum dry density (MDD) and after significant increase, it dcreases further mixing of fly ash in to the black cotton soil. The optimum value of maximum dry density of black cotton soil is obtained by mixing of 20% fly ash with black cotton soil. At 0% fly ash. Maximum dry density is 1.90g/cc, whereas the maximum dry density of the sample is increased to 1.94g/cc for 20% fly ash mix. Again it decreases to 1.87g/cc for 30% fly ash mix. It is notified that fly ash can increase the value of MDD for BCS upto a certain limit.

5.3. California bearing ratio

The california bearing ratio is penetration test which is used to evaluation of subgrade strength of roads and pavements. The results of these test are used to determine the thickness of flexible pavement and its component layers. Fig. 4 shows the relation between CBR value and thickness of flexible pavement according to IRC:37-2001. According to IRC:37-2001[16], CBR value of soil sample is low then thickness of flexible pavement is very high and vice versa.

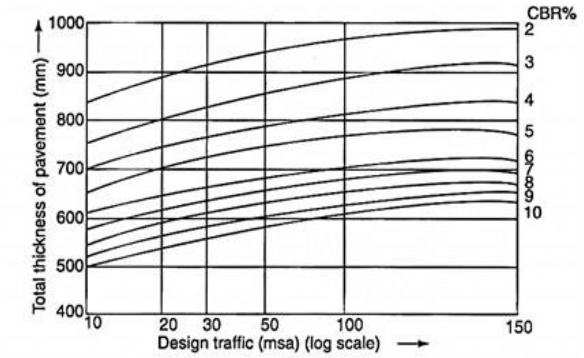

Figure 4. Pavement thickness design chart for traffic 10 to 150 msa (IRC 37-2001).

In present study, CBR test has been performed on prepared composite sample of black cotton soil and fly ash and reinforced with woven geotextile. All the laboratories CBR test is performed by the modified proctor test method. The CBR test is performed in both soaked as well as soaked condition as per relavent IS provision.

5.3.1. Unsoaked condition

In unsoaked condition, sample is compacted in mould and immediately tested for the CBR. Unsoaked state of CBR is discussed in following graphs. By the help of these tests, CBR test is obtained and the engineering properties of geotextile and fly ash is discussed and compared accordingly. From fig. 5 to fig. 8 represent the effect of fly ash on black cotton soil with reinforcement with geotextile at different depth. Table 3 shows the CBR value on prepared soil sample in unsoaked condition.

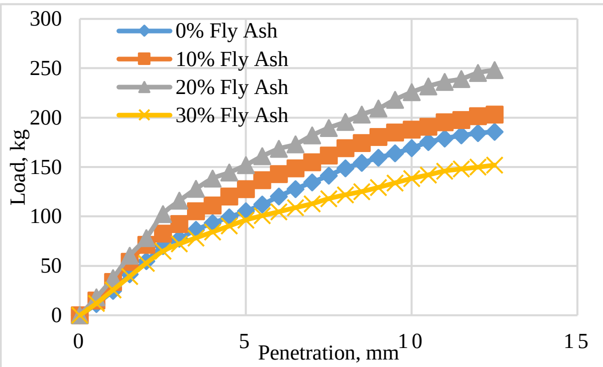

Figure 5. effect of fly ash on CBR of BCS of without geotextile in unsoaked condition.

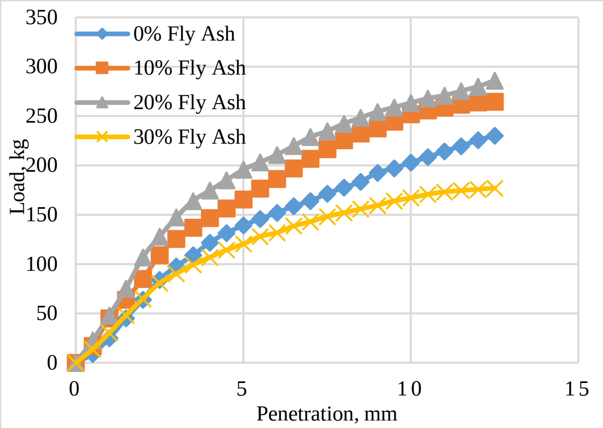

Figure 6. effect of fly ash on CBR of BCS reinforced at top with geotextile in unsoaked condition.

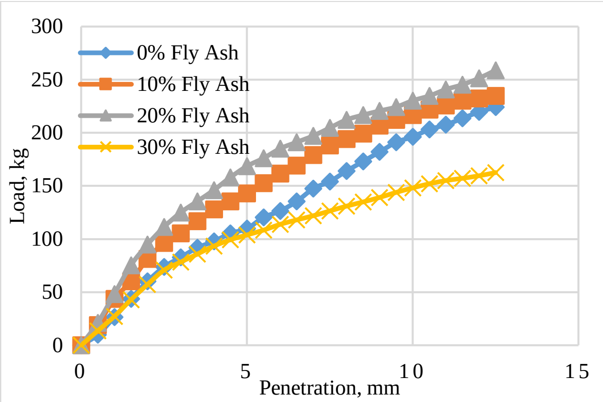

Figure 7. effect of fly ash on CBR of BCS reinforced at middle with geotextile in unsoaked condition.

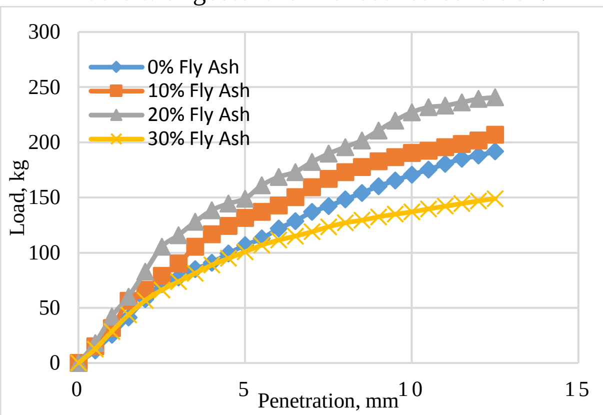

Figure 8. effect of fly ash on CBR of BCS reinforced at bottom with geotextile in unsoaked condition.

Table 3. Unsoaked CBR of prepared composite sample

Sample	Reinforcement	CBR,%
100% BCS	Without reinforcement	5.1
	Top	6.15
	Middle	5.38
	Bottom	5.21
90% BCS + 10% FA	Without reinforcement	6.04
	Top	7.9
	Middle	7.02
	Bottom	5.76
80% BCS + 20% FA	Without reinforcement	7.47
	Top	9.34
	Middle	8.13
	Bottom	7.68
70% BCS + 30% FA	Without reinforcement	4.72
	Top	5.89
	Middle	5.16
	Bottom	4.83

From the above result it can be concluded that CBR value of black cotton soil is increased up to 20% of fly ash. Further additio of fly ash into the soil led to a decrease in unsoaked CBR value. When the sample is reinforced at top by geotextile, it gives maximum value of CBR. When the prepared sample is reinforced at middle and bottom of CBR mould, it does not show any significant change. When sample is reinforced at bottom of mould, its result is as like as without reinforcement. The maximum value of unsoaked CBR achieved is 9.34% for the composite mixture of 80% black cotton soil & 20% of fly ash which is reinforced at top of the mould. Whereas the unsoaked CBR of virgin black cotton soil of without reinforcement is 5.1%. The CBR value is increased from 5.1% to 9.34% which is approx 85% increament of initial value. Hence 20% fly ash mix with reinforced at top is preferable.

5.3.2. Soaked Condition

In soaked condition, prepared sample is compacted in CBR mould and after that it is soaked in water for 96 hours. Mainly soaked CBR of soil is tested to identify the behaviour of soil sample in monsoon season. Black cotton soil has high swelling charecteristics when comes in contact with moisture. Hence soaked CBR test of black cotton soil is important. After conducting the all test on prepared sample, the engineering properties of fly ash and geotextile is discussed as a subgrade material. Soaked state of CBR is discussed in the following graph. Fig. 9, fig.10, fig.11 and fig.12 reffer the effect of fly ash on black cotton soil without geotextile and reinforcement at top, middle and bottom of mould respectively. Table 4 shows the CBR value of prepared composite sample in soaked condition.

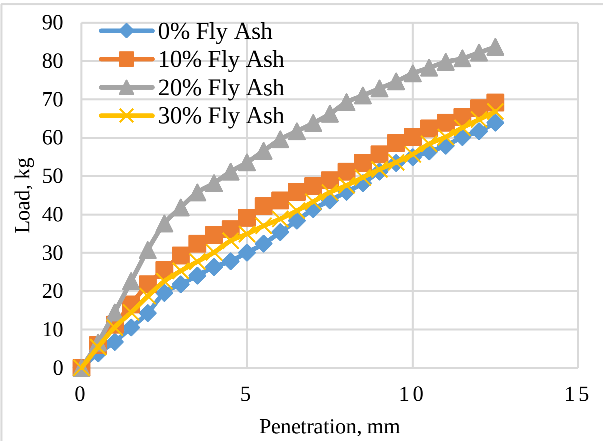

Figure 9. effect of fly ash on CBR of BCS without reinforcement in soaked condition.

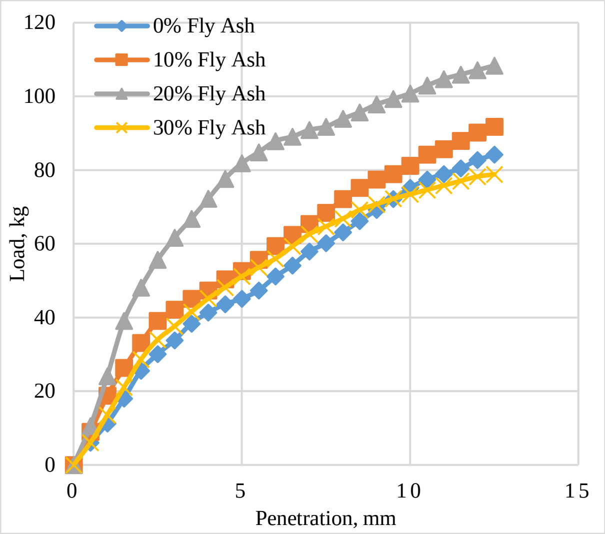

Figure 10. effect of fly ash on CBR of BCS reinforced at top with geotextile in soaked condition.

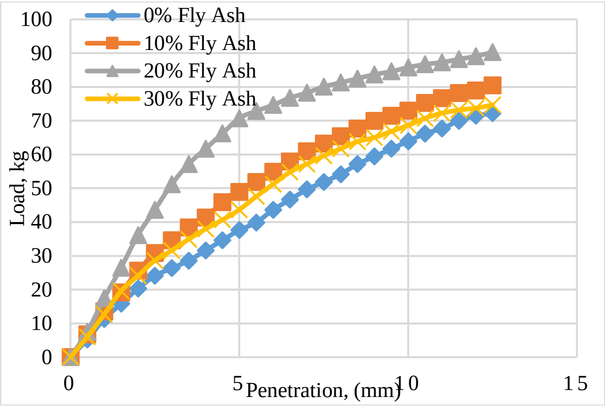

Figure 11. effect of fly ash on CBR of BCS reinforced at middle with geotextile in soaked condition.

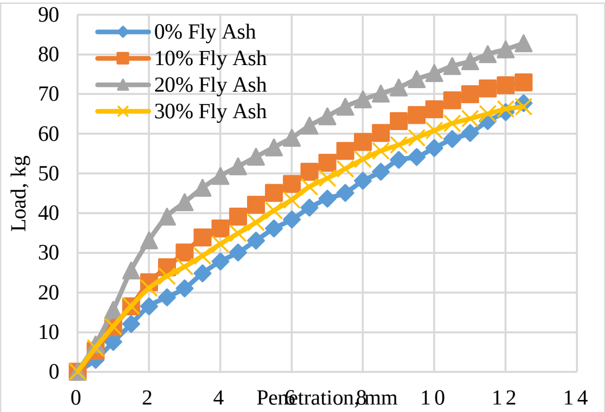

Figure 12. effect of fly ash on CBR of BCS reinforced at bottom with geotextile in soaked condition.

Table 4. Soaked CBR of prepared composite samples

Sample	Reinforcement	CBR,%
100% BCS	Without reinforcement	1.43
	Top	2.2
	Middle	1.75
	Bottom	1.4
90% BCS + 10% FA	Without reinforcement	1.82
	Top	2.85
	Middle	2.2
	Bottom	1.7
80% BCS + 20% FA	Without reinforcement	2.75
	Top	4.05
	Middle	3.18
	Bottom	2.8
70% BCS + 30% FA	Without reinforcement	1.65
	Top	2.5
	Middle	2.1
	Bottom	1.75

Utilization of fly ash and geotextile results in the significant improvement of soaked CBR value of black cotton soil. CBR value of black cotton soil is increased up to 20% of fly ash. Further addition of fly ash into the soil led to a decrease in soaked CBR value. When the sample is reinforced at top by woven geotextile, it gives the maximum value of CBR for black cotton soil. The maximum value of soaked CBR achieved is 4.05% for the composite mixture of 80% black cotton soil & 20% of fly ash which is reinforced at top of the mould. Whereas the soaked CBR of virgin black cotton soil of without reinforcement is 1.43%. Hence it is clealy shown the the use of fly ash and geotextile is quite effective to improve the CBR value of black cotton soil subgrade. The CBR value is increased from 1.43% to 4.05% which is approx 3 times increament of initial value. The optimum CBR value of soaked condition is able to retain its strength even in mansoon season. Reinforcing with geotextile at top can increase approx 80-90% CBR value as compare to without reinorcement. But the use of geotextile at middle and bottom do not give a significant change, hence reinforcing with geotextile at top is preferable.

6. Conclusion

In present study , a series of california bearing ratio (CBR) were conducted with composite samples of black cotton soil and fly ash which was reinforced with woven geotextile. The main motive of this study is to investigate the CBR value improvement on mixing of fly ash and intrusion of reinforcement layer of geotextile. The optimal percentage of fly ash and placing of geotextile for present study were evaluated and discussed. Based on the earlier chapters following conclusion can be described:

- Fly ash is pozzolanic in nature. Mixing of fly ash with black cotton soil can control the swelling and shrinkage characteristics of black cotton soil. By mixing of fly ash, differential free swell decreases gradually. In this study differential free swell decreases form 55% to 20% by the mixing of fly ash upto 30%.
- The maximum dry density of soil-fly ash mixture increases upto 20% mixing of fly ash by total weight of mixture. Further addition of fly ash in soil tends to decrease in maximum dry density of soil and optimum moisture content starts increasing.
- Utilization of fly ash and geotextile in expansive soil subgrade can be able to improve its strength. Black cotton soil has very low CBR value. But by the help of fly ash and geotextile its CBR value increases

significantly. The optimum value of combination is found to be 80% black cotton soil and 20% of fly ash which is reinforced at top of mould by geotextile for unsoaked and soaked both condition. For unsoaked CBR, the value of mix is found to be 9.34% which is 83% more than the CBR of soil alone. For soaked CBR, the value of optimum mix is 4.05 which is approx 3 times of CBR of soil alone.

- Fly ash gives its optimum value at by mixing of 20% of total mix. Geotextile givs its optimum CBR valu when it is reinforced at top of mould. Hence it can be used as a seprator between subgrade and base course.

7. Future scope

There is a vast scope of soil reinforcement through geotextiles. The present studies is limited to some laboratory work. Some following test can also be evaluated:

- Further experiments can be carried out on the soil sample to determined the shear strength parameters.
- In the further study, geotextile can be used in multiple layers and CBR value accordingly is evaluated.
- The sample can be tested for vulnerability towards excessive permeability which may cause problems in performance and service life of roads.
- Some other type of geotextile can also be used (i.e. geogrids, etc.) to know the effectiveness of the reinforcement.

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