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PERFORMANCE STUDIES ON BLACK COTTON SOIL USING LIME AND FLY ASH

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ABSTRACT

Foundations constructed on weak soils can cause significant distress due to moisture-induced volume changes and low strength, thereby reducing the foundation life. Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to obtain an improved soil material possessing the desired engineering properties. Subgrade soil may be stabilized to increase the strength and durability or to prevent erosion and dust generation. In the present study Black cotton soil was stabilized with lime and fly ash. These additives can be used with a variety of soils to improve their native engineering properties, but their effectiveness depends on amount of additive and nature of soil. The laboratory investigations were conducted for different curing days to determine the basic and engineering properties of soil such as Atterberg's limits, grain-size distribution, Maximum Dry Density, Optimum Moisture Content, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), Durability and Fatigue.Initially the lime was added in to the expansive soil from 1 % to 9 % by weight of dry soil with an increment of 1.5 % and studied the geotechnical characteristics. The optimum lime content was found from the results. Then fly ash was added at high percentages i.e, 10 % to 40 % by the dry weight of soil. The mixed samples were cured for 0, 7 and 28 days. And conducted UCS, CBR, Durability and fatigue tests. The experimental investigations indicate that there is a good improvement in engineering properties of the soils treated of soils treated with lime and flyash.

***Keywords:* Black cotton soil, Lime, fly ash, Density, Stabilization.**

1. INTRODCTION

Construction on natural soft soil deposits is still a challenge in geotechnical engineering. It gains even more important as urban areas all over the world become more and more congested. For socio-economic development today's construction projects are frequently built on those areas, which were considered unsuitable for construction work a couple of decades ago. Proper remedial measures are to be adopted to modify the soil or to reduce to its detrimental effects if non-swelling clay are identified in a project. The remedial measures can be different for planning and designing stages and post construction stages. Many stabilization techniques are in practice for improving non-swelling soils in which the characteristics of the soils are altered. Additives such as lime, cement, calcium chloride, rice husk, fly ash etc., are also used to alter the characteristics of the weak soils. The characteristics that are of concern to the design engineers are permeability, compressibility of soils and durability of the structures. The effects of the additives and the optimum amount of additives to the used are dependent mainly on mineralogical composition of the soils

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

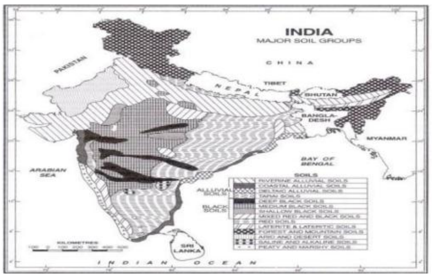

Figure 1.1: Geological map of Indian soils

Expansive soil (Black cotton soil) is mostly found in the arid and semi-arid regions and it cover very large area of the world. It covers nearly 30% of the land in India and includes approximately the entire Deccan Plateau. Andhra Pradesh, Karnataka, Maharashtra, Parts of Gujarat and Western Madhya Pradesh. The name “Black Cotton” as an agricultural origin. Most of these soils are black in colour and are good for growing Cotton. These soils can be used as a construction material when it possesses engineering properties such as high strength, low settlement and high Durability. Difficulty is often experienced while working with such soils particularly in its field compaction. These soils instead of replacing with new materials can improve the strength properties by using different methods. Stabilisation is one among the best alternative method to enhance the engineering properties.

1.1 OBJECTIVES OF THE PRESENT STUDY

The main objective is to investigate the stabilization mechanism of lime and fly ash to better understand their potential usage in Expansive soils. Experiments performed in the laboratory to determine improve properties of the soil.

1. To study the improvement of geotechnical and engineering properties of black cotton soil by stabilizing with combined application of fly ash and lime.
2. To qualitatively evaluated the durability of treated specimens with regard to wet-dry cycles and freeze-thaw.
3. To evaluate the fatigue behaviour of stabilised soil.

2. LITERATURE REVIEW

Expansive soils are residually derived soil that is abundantly found over the vast stretch of semi-arid regions across the world. Due to the presence of the montmorillonite mineral, these soils exhibit high affinity for water and therefore experience large moisture related volume changes (i.e. swell-shrink) during wet and dry seasons.

The following sections deal with the review of different works related to the property enhancement of soil by addition of lime and fly ash.

2.1 LIME TREATMENT OF EXPANSIVE SOIL

2.1.1 Mechanism

Use of lime for soil improvement in the modern age started in the beginning of 20th century. The actions of lime that lead to improvement of soils are, Cation exchange, flocculation and agglomeration, carbonation and pozzolanic reaction. These reactions contribute to physical, mineralogical and microstructural changes in the treated soils leading to reduction in plasticity and swell-shrink potential, improvement in strength and stability.

Comparing the effect of Portland cement and quicklime, Esrig (1999) reported that lime releases more heat and consumes more water in the hydration process in comparison to Portland cement, and hence, quicklime is more efficient in reducing moisture content of clay soil. This is equivalent to increase in consolidation pressure. For soils having natural water content of about 35-40%, are prone to large increase in undrained shear strength. However, for soils having very high water content e.g. expansive soils, the percentage loss of moisture being too small, more lime is required for adequate strength gain of the otherwise weak soil.

2.1.2 Effect on Plasticity Characteristics

Several researchers observed that the liquid limit of clayey soils decrease with addition of lime This was attributed to the reduction in thickness of the diffuse double layer, which takes place due to cation exchange and flocculation-agglomeration reactions (Lambe, 1962; Thompson, 1966 to bring about these changes in plasticity. Generally the amount needed varies from 1 to 3% depending on the amount and type of clay minerals present in the soil.

Addition of lime may have the following effects:

- An increase in the electrolyte concentration reduces the double layer, aiding to form clay clusters, which lead to a decrease in the liquid limit.
- If the exchangeable cations present in soil are monovalent, addition of lime decreases the thickness of the double layer due to the higher valence of calcium, which in turn brings down the liquid limit.
- If the cation present is divalent, cation exchange will have very little effect. However, replacement with calcium ions generally induces flocculation, which in turn increases the liquid limit
- If the exchangeable cations are more than divalent, partial replacement of higher-valence ions with calcium, increases the liquid limit.
- Addition of lime increases pH, which increases the cation exchange capacity and hence leads to an increase in liquid limit.
- Addition of lime causes flocculation of clay particles. When the fabric becomes more flocculent, the water-holding capacity increases and hence liquid limit increases.

2.1.3 Effect on Compaction

Different authors reported correlation of MDD and OMC with LL, PL and PI. However, the wide variety of soil properties makes it difficult to arrive at a generalised correlation. The Design Manual of U.S. Navy (1962) gives the following empirical relationships for estimation of OMC and MDD under Standard Proctor compaction:

$$OMC = 6.77 + 0.43LL - 0.21PI, \quad (2.1)$$

$$MDD = 20.48 - 0.13LL + 0.05PI \quad (2.2)$$

Hammond (1980) found the following relationship for black cotton soils:

$$OMC = 0.96PL - 7.7 \quad (2.3)$$

2.2 TREATMENT OF SOIL WITH FLY ASH

Based on the self-cementitious properties, fly ashes are divided in to two categories – Class C and Class F (ASTM C618-08a). Both types are pozzolanic. Class C fly ash has generally higher calcium content, measured as CaO, (more than 10%) and is self-cementitious. Although many investigators thought that the self-cementitious properties were the results of the presence of free CaO in fly ash, Joshi (2000) reported that it is the calcium in the glassy phase i.e. fly ash particles which produces cementitious compounds on hydration even without the presence of free lime. Expansive soils can thus be theoretically stabilized in an effective manner by cationic exchange with fly ash.

Addition of fly ash reduced the plasticity characteristics of the expansive soil. The liquid limit decreased and the plastic limit increased with increase in the fly ash content. With 20% fly ash, the free swell index could be reduced by about 50%. Both the swell potential and swell pressure were reduced by 50%. Kumar, P. and Sharma (2004).). When fly ash is added to soil-lime mixture, maximum dry density decreased further and optimum moisture content increased. With the increase in the percentage of fly ash keeping amount of lime as constant, strength increased and reached a certain maximum value and thereafter it started decreasing, but was always higher than that of the respective soil-lime mixture.

SUMMARY:

From literature review it is found that the individual application of fly ash and lime have been extensively studied, for the improvement of soils, but the combined application of both has not been dealt in detail. This aspect has been taken up under the present research work. The objective of the study is to develop an understanding of the performance improvement of expansive soil through combined application of fly ash and lime.

3. MATERIALS AND METHODS

3.1. Black Cotton Soil (BC Soil)

In Andhra Pradesh region the land under cultivation is mostly of BC soil. The effect of swelling and shrinkage of these soils are seen to be more critical when extreme environmental conditions prevail. These areas being extensively developed in the fields of transportation, irrigation, industrialization, etc., any method to improve the construction techniques in the soils is considered to be of vital importance from the view of economy in developing India. In a broad sense the engineering problem in BC soils is to identify the presence of expensive deposits and try to stabilize the using better materials or techniques.

3.2 STABILIZERS

3.2.1 Lime:

Lime is the burned by product of limestone. Lime can be used in the form of quicklime, hydrated lime, or lime slurry to stabilize the soil. Quicklime is manufactured chemically by transforming calcium carbonate (limestone – CaCO3) into calcium oxide.

Table 3.1: Technical specifications of Lime

Property	Description
Appearance	White powder
Chemical formula	Ca(OH)2
Specific Gravity	2.4
Solubility in water	1.73 g/L (20o C)
Flash point	Non flammable
Dosage	1.5, 3, 4.5% By weight of dry soil
pH	12.4

3.2.2 Fly ash

Fly ash is a marginal material, which is easily available at all thermal power stations, and can be utilized for road construction.

Table 3.2: Physical Properties of Fly ash

Properties	Test Value
Type	Class F
Specific Gravity	1.975
Water content (%)	0.16
Loss on Ignition (%)	0.43
Size	<45 µ
pH	8.12

3.3 METHODS USED

The basic tests for Specific Gravity (IS:2720, Part- III), Grain size distribution (IS:2720, Part-IV), Atterberg's limits (IS:2720, Part-V), Compaction characteristics (IS:2720, Part-VII, VIII), UCS (IS:2720, Part-X), CBR (IS:2720 Part-XVI), pH test (IS 2720, Part-XXVI),Durability (ASTM D 559, 560), Fatigue behaviour, etc. were performed.

3.3.1 Specific Gravity Test

Standard test equipment and procedure available for specific gravity test was used in the present work (IS: 2720 part3 -1980), "Determination of specific gravity, section1 fine grained soils"). In laboratory we used density bottle method to determine the specific gravity is shown in Fig.3.1

Fig 3.1: Density Bottle

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3.3.2 Grain size analysis test:

For determination of grain size distribution, the soils were passed through IS sieve size 75µ. Sieve analysis for coarser particles (i.e. portion retained on 75µ sieve) and sedimentation analysis for finer particles (i.e. portion passing 75µ sieve) were conducted.

The percentage of soil passing through 75µ IS sieve for black cotton soil was found to be 56%. The sedimentation analysis was done by hydrometer method using sodium hexa meta phosphate as the dispersing agent. The test was conducted as per IS 2720 (part4)-1985.The grain size analysis test results for the black cotton soil sample graphically presented in fig 4.1 Results of this test also tabulated in Table 4.2

3.2.3 Atterberg's Limits

The Atterberg's limits are a basic measure of the critical water contents of a fine-grained soil: Its plastic limit, liquid limit and shrinkage limit. Standard test equipment and procedure available for LL and PL test was used in the present work (IS: 2720 (part 5)-1985, "Determination of liquid limit and plastic limit"). The tests were conducted immediately on untreated soil and soil+ lime mixes after mixing water. The results of the tests are tabulated in Table 4.2.

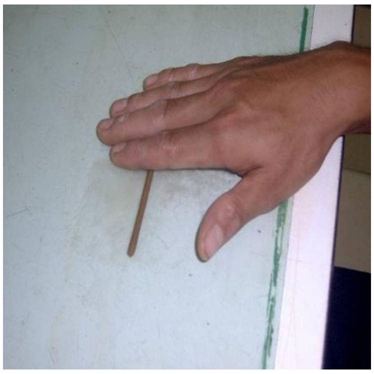

Fig 3.2: a) Casagrande Apparatus b) Thread Test

3.2.4 pH Test

The acidic or alkaline characteristics of a soil sample can be quantitatively expressed by hydrogen ion-activity commonly designated pH. The pH is measured electrically by means of an electrode assembly consisting of one glass electrode and one calomel reference electrode with saturated potassium chloride solution. The pH meter directly gives the pH value. The samples are sieved and tested as per IS 2720 (part26)-1987.

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Fig 3.3 : pH meter

3.2.5 Free Swell Index test (FSI)

Free swell is the increase in volume of soil, without any external constrains, on submergence in water. Tests for determination of free swell index were conducted as per IS 2720 Part XI. 10 gram oven dry soil passing throught 425µ IS sieve is taken.

$$FSI\ (\%) = \frac{Vd - Vk}{Vk} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \ (3.1)$$

Where, Vd = volume of sample in distilled water

Vk = volume of sample in kerosene

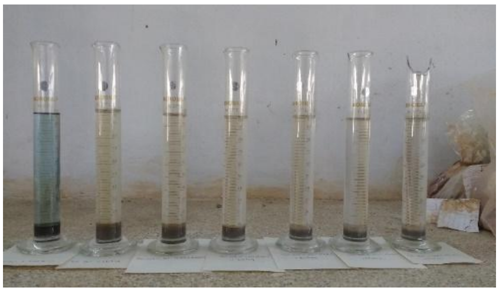

Fig 3.4: Test set up for FSI

3.2.6 Compaction Tests

Standard proctor test was conducted on soil to determine the maximum dry density and Optimum moisture content. The water content in the soil sample was determined by oven dry method. The dry density of soil sample determined by using equation 3.2.

$$Dry\ density = \frac{Bulk\ density}{1 + water\ content} \times 100 \qquad (3.2)$$

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3.2.7 Unconfined Compression Strength Test

The UCC test was conducted to find the angle of internal friction and cohesion value. Standard test equipment and procedure available for UCC test was used in the present work (IS: 2720 (part 10)-1973, "Determination of Unconfined Compression strength"). Results of conducted on basic soil are tabulated in table 3.1 after treating the soils with commercial stabilizer, the UCC test was carried as per prescribed standards (IS: 4332(part5) -1970, "Determination of Unconfined Compression strength").

The Unconfined compression test carried out for soil samples which cured for 0, 7 and 28 days are based on light and heavy compaction test results. The UCS testing machine and the failure pattern of UCS samples are shown in fig.

Fig 3.5: a) UCS testing setup **b) Failure Pattern of UCS samples**

3.2.8 California Bearing Ratio Test

The CBR test was conducted to evaluate the stability of the subgrade and materials used in the sub-base and base of flexible pavements. Standard test equipment and procedure available for California Bearing Ratio (CBR) test was used in the present work (IS 2720 (part 16)-1987, "Laboratory Determination of CBR"). The tests were conducted for both un-soaked and soaked condition for light and heavy compaction. Soaked tests were conducted after 4 days curing in water.

3.2.9 Durability test:

Durability is defined as the ability of amaterial to retain stability and integrity over years of exposure to destructive forces of weathering and hence it is one of the important factor for any stabiliser**.**

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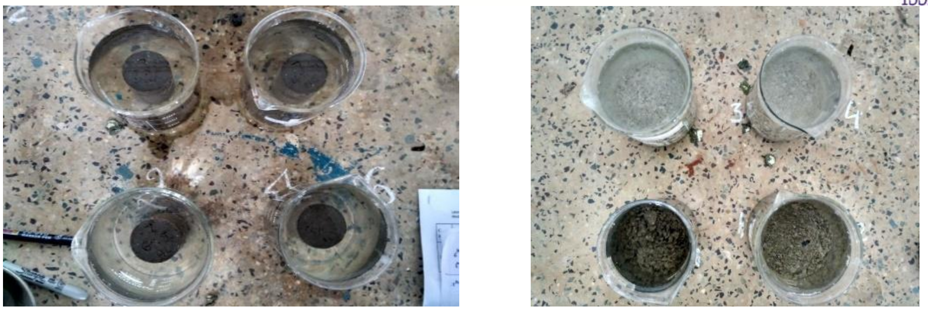

Fig 3.6: Wet Dry test sample before and after failure.

3.2.10 FATIGUE TEST

Fatigue failure is one of the main dis-stress mechanisms causing degradation of foundations and it is an important parameter related to structural failure of foundations. The untreated and treated soil specimens with 28 days curing period were tested for repeated loading with 1/3rd, 1/2 th and 2/3 rd of their UCS values.

Test procedure:

- The cylindrical sample was mounted on the loading frame and the Deflection sensing transducers (LVDT) are set to read the deformation of the specimen. The load cell is brought in contact with the specimen surface.
- In the control unit, through the dedicated software, the selected loading stress level, frequency of loading and the type of wave form are fed in to the loading device.
- The loading system and the data acquisition system is switched on simultaneously and the process of fatigue load application on the test specimen was initiated.
- The repeated loading, at the designated excitation level (i.e. at the selected stress level and frequency) is continued till the failure of the test specimen.
- The data acquisition system continuously record the vertical deformation of the test specimen with cycles of loading until the failure and the output file is given noted as a result file.
- The failure pattern of the test specimen is noted down manually.

Sl.No.	PROPERTIES	Test value
1	**Specific gravity**	2.6
2	**Grain size distribution**	
	Gravel size, %	2
	Sand size,%	41
	Silt size,%	32
	Clay size,%	25
3	**Consistency Limits**	
	Liquid limit, %	42
	Plastic limit %	21.5
	Shrinkage limit, %	9.7
	Plasticity Index,%	21
4	**IS soil classification**	**CI**
5	Free swell Index	55.5%
6	pH	7.05
7	**Engineering Properties**	
	IS Light Compaction	
	a. MDD, (g/cc)	1.74
	b. O.M.C %	17.3
	IS Heavy Compaction	
	a. MDD, (g/cc)	1.89
	b. O.M.C %	13.6
8	**Unconfined Compressive Strength, UCS (Kpa)**	
	a) Light Compaction	145
	b) Heavy Compaction	232
9	**California Bearing Ratio, CBR (%)**	
	IS Standard Compaction	
	a) Un-soaked Condition	4
	b) Soaked Condition	3
	IS Modified Compaction	
	a) Un-soaked Condition	13
	b) Soaked Condition	7

Fig 3.7: Fatigue Testing Machin

3.2.11 ESTIMATION OF LIME FIXATION

In stabilization of clayey soils with lime has shown that small amounts of lime considerably improve workability but contribute little to strength, whereas larger amounts of lime also improve the strength and bearing capacities of these soils. This suggests the possibility that lime added to soil must first satisfy an affinity of the soil for lime, an affinity referred to as "lime fixation." (Hilt, G. H. (1960)

$$Optimum\ lime\ content = \frac{\%\ of\ clay}{35} + 1.25 \qquad (3.4)$$

3.2.12 DOSAGE CALCULATION

Dosage rates can be specified in many different ways, but the most common way to define the dosage rate is based on the dry weight of soil to be treated. From the lime fixation, we fixed the optimum lime content and then replace different percentage amount of fly ash. Investigation carried out by conducting laboratory tests on these different mixes. Treated soil Mix contents used in the study are named as follows.

Table 3.1: Soil mix composition for treated soil sample

sl.no	Material proportion			Soil Mix name
	BC soil (%)	Lime (%)	Fly ash (%)	
1	100	0	0	S0-0-0
2	96	4	0	S1-L-0
3	86	4	10	S2-L-20
4	76	4	20	S3-L-20
5	66	4	30	S4-L-30

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Curing:

The samples were tested at various curing periods like 0, 7 and 28 days. All samples prepared were labelled according to the period of curing. The specimens are kept in desiccators maintain 100% humidity. The cured specimens are tested immediately after designated curing period.

4. RESULTS AND DISCUSSIONS

4.1. GEOTECHNICAL PROPERTIES OF BC SOIL

4.2. Effect on consistency limits:

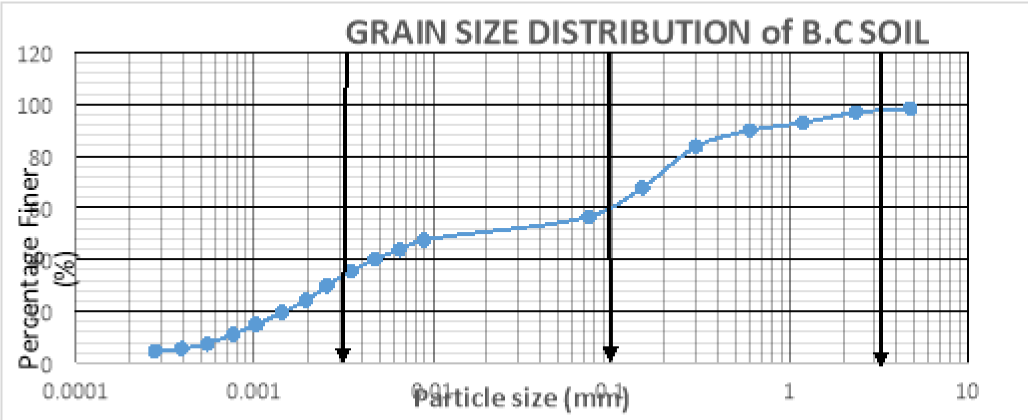

Fig 4.1: Grain size distribution curve for Black cotton soil

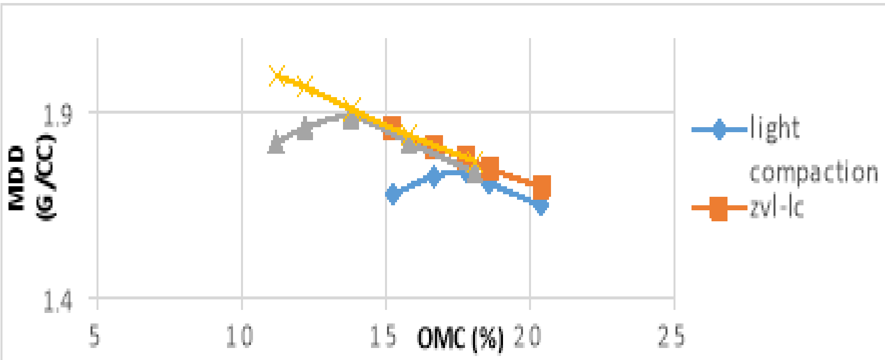

Fig4.2: MDD- OMC relation for B.C. soil on light and heavy compaction

4.3. BLACK COTTON SOIL STABILIZATION WITH LIME

4.3.1 Dosage of lime:

Trails were conducted by treating the soil at different lime percentages from 1.5% to

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9% by weight of dry soil and variations in engineering properties were studied. Lime added to the oven dry soil in dry form and mix thoroughly and perform laboratory

tests after adding required water content to the mix.

Table 4.1: Geotechnical Properties of Black Cotton Soil

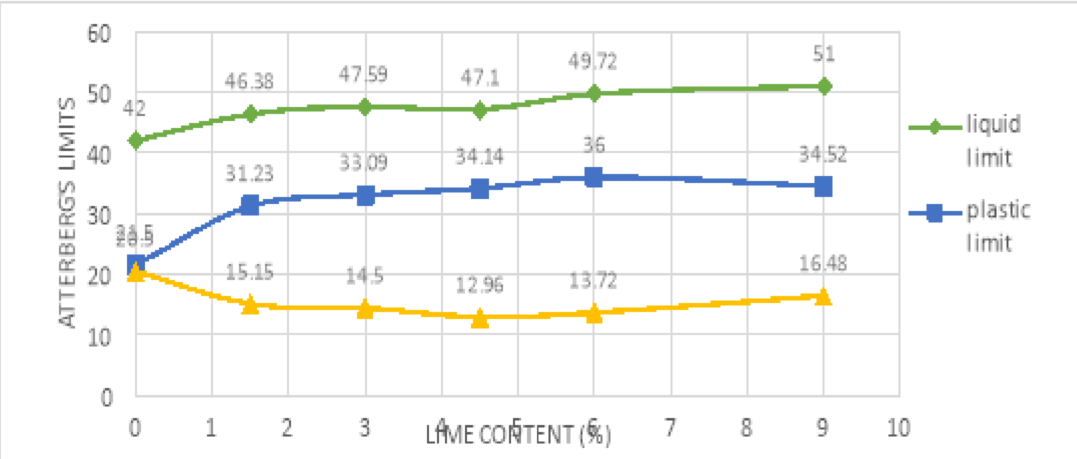

Fig 4.3: Variation of Atterberg's limits with Lime content.

4.3.2 Effect of Free Swell Index with Lime

Table 4.2: Free swell index variation with % lime content

% lime	0	1.5	3	4.5	6	9
Free swell Index (%)	55.5	42	27.7	22.2	16.6	16.6

4.3.3 Effect of Lime on Compaction

Table 4.3: Standard compaction test results for different lime content

Lime content (%)	MDD (KN/m³)	OMC (%)
0	17.07	17.3
1.5	16.8	18.05
3	16.32	18.8
4.5	16.04	19.3
6	15.9	19.93
9	15.6	21

Table 4.4.: Unconfined compression strength test results for lime treated soil

% lime	UCS in KN/m2		
	0 days	**7 days**	**28 days**
0	145	163	236
1.5	203	284	392
3	220.13	366	578
4.5	228	412	741
6	207	365	757
9	214	317	650

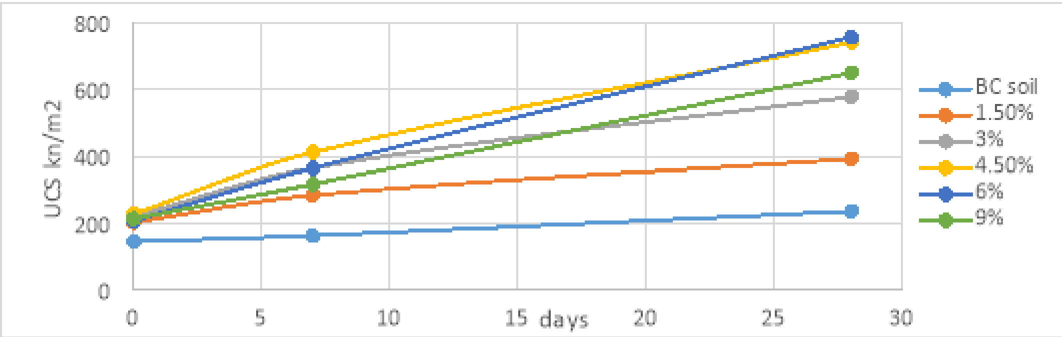

Fig 4.4: Variation of ucs with curing period for different %Lime on light compaction

4.4 STABILIZATION OF BC SOIL WITH FLYASH

4.4.1 Effect of Fly ash on Compaction Characteristics

Compaction characteristics have been studied by replacing fly ash in different percentages to with the soil and optimum lime content mix.

Table 4.5: Standard and Modified compaction test results for different fly ash content

Soil mix	IS light compaction		IS Heavy compaction	
	OMC (%)	MDD (KN/m³)	OMC (%)	MDD (KN/m³)
S0-0-0	17.3	17.07	13.6	18.5
S1-L-0	19.3	16	15.72	17.46
S2-L-10	18.59	17.12	14.9	18.32
S3-L-20	17.6	17.65	13.73	19.04
S4-L-30	17.84	17.41	13.7	18.82
S5-L-40	18.7	16.8	14.5	17.93

With increased fly ash content the clay mass effectively fills the voids formed by the relatively coarse fly ash, giving rise to a compact structure and hence increased density.

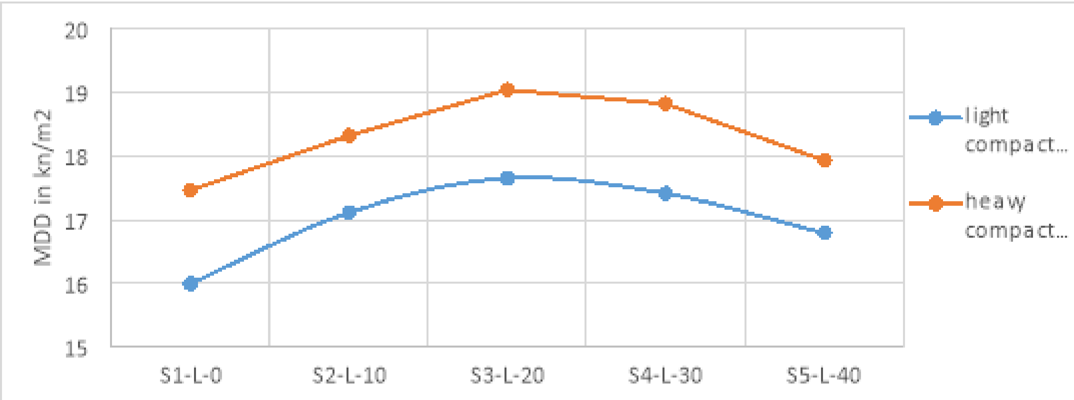

Fig 4.5: Variation of dry density with different fly ash content for the soil

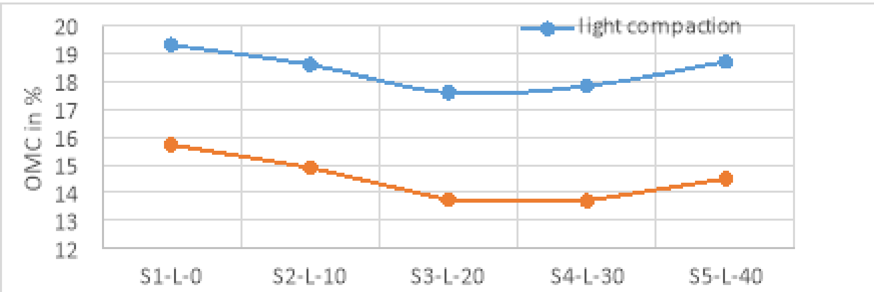

Fig 4.6: Variation of water content with different fly ash content for the soil

4.4.2 Effect of Fly ash on Unconfined Compressive Strength

Table4.6: UCS test results for different fly ash treated soil

Sl.No.	Soil-mix	UCC strength in KN/m²					
		IS Light compaction			IS Heavy compaction		
		0 Days	7 Days	28 Days	0 Days	7 Days	28 Days
1	S0-0-0	145	163	236	231.7	306	452
2	S1-L-0	228	412	741	310	497	1056
3	S2-L-10	220.13	555	883	345	766	1549
4	S3-L-20	274	508	964	355	714	1724
5	S4-L-30	252	461	857	314	546	1425
6	S5-L-40	218	385	693	280	448	1106

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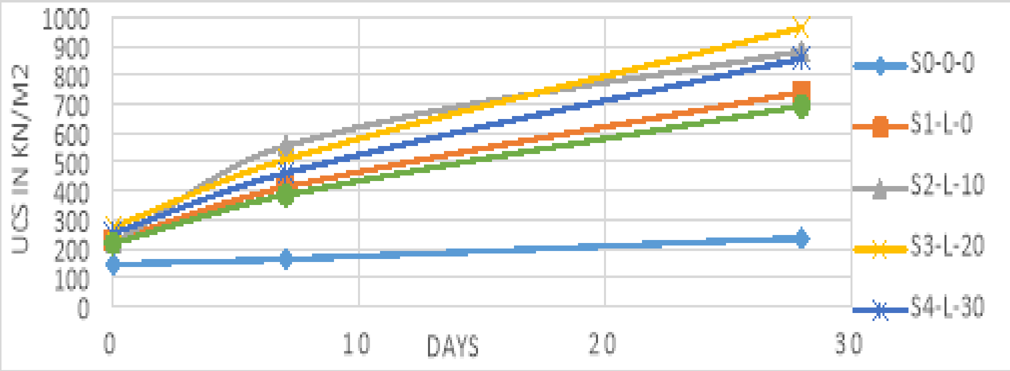

Fig 4.7: Variation of ucs with curing period for different %flyash on light compaction

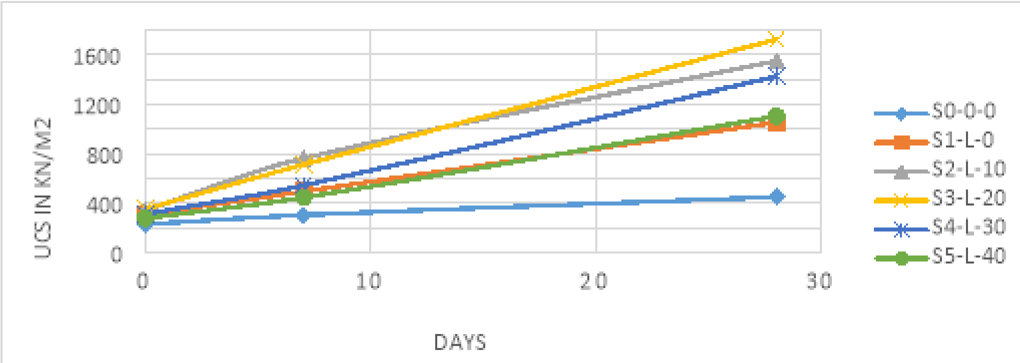

Fig 4.8: Variation of ucs with curing period for different % Flyash on heavy compaction

4.4.3 Effect of Fly ash on CBR Test

Table 4.7: CBR test results for different fly ash treated soil

Soil Mix	Light compaction		Heavy compaction	
	soaked	Un soaked	soaked	Un soaked
S0-0-0	3	4	7	13
S1-L-0	11	9	16	17
S2-L-10	13	9	25	21
S3-L-20	15	11	34	25
S4-L-30	22	17	37	30
S5-L-40	20	12	35	26

The results are presented in fig. for soil-lime-fly ash. The results showed a increased percentage of 600% black cotton soil with 30% fly ash content.

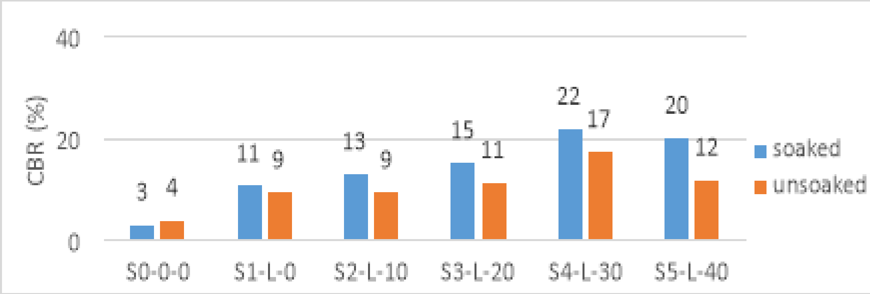

Fig 4.9: Variation of CBR results with different fly ash for light compaction

In soaked condition, as fly ash content increases CBR strength increased from 3% to 22%, 8% to 37% in light and heavy compaction respectively. Further increase beyond 30% fly ash content it decreases in both light compaction as well as heavy compaction.

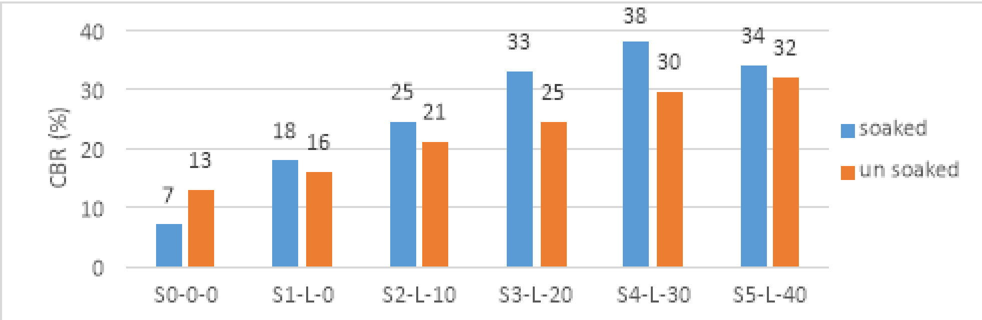

Fig4.10: Variation of CBR results with different fly ash for heavy compaction

4.5 DURABILITY TEST

Table 4.8: Percentage weight loss during alternate cycles of FT for untreated and treated soils

No.of cycles	BC soil		lime		S3-L-20	
	Freeze	Thaw	Freeze	Thaw	Freeze	Thaw
1	0.61	4.96	0.19	1.98	4.11	3.53
2	4.6	6.52	2.35	3.43	3.89	4.37
3	5.92	7.75	2.8	3.81	3.93	3.97
4	7.13	8.19	3.25	3.88	4.12	4.23
5	7.51	8.13	3.56	3.94	3.78	4.01
6	7.82	8	3.75	4.01	4.35	4.37
7	7.38	8.62	3.98	4.26	4.42	4.75
8	8	7.94	4.21	4.67	4.87	5.06
9	7.48	8.81	4.39	4.81	5.23	5.69
10	8.05	9	4.51	4.96	5.13	5.82
11	9.68	9.24	4.59	5.04	6.32	6.33
12	8.52	8.81	4.7	5.16	6.35	6.55

Table 4.9:

No. of cycles	BC soil		lime		S3-L-20	
	F	T	F	T	F	T
0	186		177		172	
1	184.87	176.77	176.66	173.50	164.93	165.93
2	177.44	173.87	172.84	170.93	165.31	164.48
3	174.99	171.59	172.04	170.26	165.24	165.17
4	172.74	170.77	171.25	170.13	164.91	164.72
5	172.03	170.88	170.70	170.03	165.50	165.10
6	171.45	171.12	170.36	169.90	164.52	164.48
7	172.27	169.97	169.96	169.46	164.40	163.83
8	171.12	171.23	169.55	168.73	163.62	163.30
9	172.09	169.61	169.23	168.49	163.00	162.21
10	171.03	169.26	169.02	168.22	163.18	161.99
11	168.00	168.81	168.88	168.08	161.13	161.11
12	170.15	169.61	168.68	167.87	161.08	160.73

Weight loss during alternate cycles of FT for untreated and treated soils

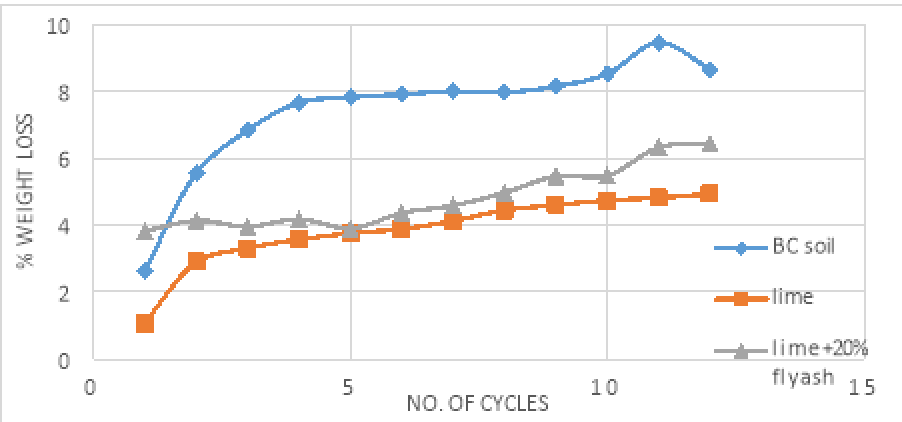

Fig4.11: Percentage weight loss during alternate cycles of FT for untreated and treated soils

4.6 FATIGUE LIFE TEST:

TABLE 4.9: fatigue life cycles for treated and untreated soils.

sample	UCS (kg)	Stress level	applied load (kg)	fatigue life (no. of cycles)
S0-0-0	52	0.33	17.16	2163
		0.5	26	1642
		0.66	34.32	971
S1-L-0	158	0.33	52.14	12857
		0.5	79	10694
		0.66	104.28	7352
S4-L-30	200	0.33	66	18547
		0.5	100	15628
		0.66	132	11734

5. CONCLUSIONS

The behaviour of black cotton soil varies widely with introduction of stabilizer. The amount of stabilizer required for appreciable stabilization depends on characteristics of soil.

- Compared to untreated soil, the soaked CBR increased by 5 times for 5% lime+ soil+ 30% fly ash. Therefore these combination can be used as modified basement layer for low and high volume constructions.
- Addition of 20% fly ash along with 5 % lime by weight of soil resulted significant increase in the UCS is 3 and 5 times for 7 and 28 curing days.
- Lime was observed to be an effective stabilizer and further addition of fly ash improves the soil strength properties.
- The lime stabilisation controlled the critical swelling problem of soil, by significantly reducing the FSI from 55.5% to 16% and further addition of fly ash reduces swelling effectively.
- From test results concluded that 2% lime is as lime fixation, 5% lime content as optimum For BC soil in present study.
- It was observed that the strength of lime treated soil depended on type of soil type, lime content, curing period and moisture content.
- At higher lime content and prolonged curing periods, the strength of the expansive soil exhibit an increasing trend, which is more prominent in case of expansive soil-fly ash mixes.
- Soaked CBR value is more than un soaked when more fly ash added to lime-soil mix

- Fatigue life of treated soil (4%lime+ 20% fly ash + soil) is better than the untreated soil for 28 days curing.
- In Durability test both untreated and treated, could not withstand wet and dry cycles. Whereas During FT cycles the entire samples passed 12 cycles and the weight loss was within 14%. It is observed that loss in weight of soil samples is less for treated soil when compared to untreated soil samples.

5.1 SCOPE FOR FUTURE STUDIES

1. This work can be extended for different combinations of stabilizers, which enzymes available in market with lime.

2. Studies to improve durability condition to pass through wet- dry cycles with different chemical composition can be taken up.

3. Fatigue test at different frequencies can be conducted to assess the dynamic characteristics of dynamic modulus.

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