Stabilization of Black cotton soils using Lime and Nylon Fibers

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Abstract:In The present study, an attempt is being made to stabilize the Highly Expansive soil Using the combination of oldest material i.e. Lime and the newly used recent material i.e. Randomly Distributed Nylon fibers.Lime improves the geotechnical properties of soil and Nylon fiber increases the strength properties. In the present study, an attempt has been made to combine both materials to improve geotechnical properties as well as to increase the strength of the expansive soil. In the present study, Lime is used in three different percentages (2%, 4%, 6%) and Nylon fibers are used as three different percentages (0.2%, 0.4%, 0.6%) in three aspect ratios i.e. L/D ratios (50, 100, 150). Atterberg Limits, standard proctor test, free swell index, swelling pressure, unconfined compressive strength test, California Bearing ratio test and expansion ratio test are performed on different combinations. The Soaked CBR, UCS and swelling pressure are improved more than satisfying limits.

***Keywords*–Black cotton soil, Lime, Nylon fibers, Stabilization, CBR, UCS**

I. INTRODUCTION

India has large tracks of expansive soil known as black cotton soil (BC soil), covering an area of 0.8 million square kilometer, which is about 20% of total land area. The occurrence of swelling soil is generally a result of geologic history, sedimentation and environmental conditions. Black cotton soil is a name believed to have first been used in India where the areas with black or dark grey soils were found quite suitable for growing cotton. Soils derived from the weathering of black trap rock, in particular, which are black, fine grained, heavy and climatologically suited to the growth of cotton, were called as black cotton soils (or regur). These soils occur in the states of Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamilnadu. The thickness of the black cotton soil cap is highly variable ranging from 30 cm. to 15 m., while the composition of the soil shows considerable variation with different depth horizons, especially in its clay content and lime segregation.

Black Cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. Black Cotton soil has a high percentage of clays, which is predominantly montmorillonite in structure and black or blackish grey in color. Because of its high swelling and shrinkage characteristics, the Black Cotton soil has been a challenge to geotechnical and highway engineers. The soil is very hard when dry, but loses its strength completely when in wet condition. The wetting and drying process causes vertical movement in the soil mass which leads to failure of a pavement, in the form of settlement, heavy depression, cracking and unevenness. Such soils may cause heavy damages in light loaded structures such as water canals, reservoirs, highways, railways and airport runways etc., unless appropriate measures are taken.

With the seasonal variation, polygonal cracks appear at the surface during the summer, which may extend to a depth of about 2m indicating the active zone in which volume change occurs called as active zone. The depth of active zone defined as the thickness of the soil below the ground surface within which moisture content variations occurs and hence volume changes do take place with the variation of seasons. Sustained efforts are being made all over the world onhighway research field to evolve more promising treatment methods for proper design and construction of pavements running over expansive soil sub grade.

Lime is the oldest and well known material to be used as a stabilizing material for Expansive Soils. With the introduction of lime into the soil environment, is dissolved in water and and are freed. Cation exchange occurs between cations linked to the clay layers and ; becomes the only interlamellar cations. Clay particles are surrounded by a diffuse hydrous layer which is modified by the ion exchange of calcium. This modifies the density of the electrical charge around the clay particles and attracts them closer to each other to form flocks (flocculation). This implies stronger attraction forces between layers and a stacking of a greater number of layers. These reactions change the clay texture, giving thicker particles, reducing plasticity and increasing the soil strength.The nylons are generally tough, strong, durable fibers and possess high tensile strength. So, in recent advancement, the nylon fibers are used as reinforcement in the expansive soil to increase the strength of fibers. When nylon fibers are introduced in the soil, it holds particles surrounded by it and helps to increase the strength.Lime improves the geotechnical properties of soil and Nylon fiber increases the strength properties. In the present study, an attempt has been made to combine both materials to improve geotechnical properties as well as to increase the strength of the expansive soil.

II. LITERATURE REVIEW

Yi Cai (2006) has used polypropylene fibers in three different percentage (i.e. 0.05%, 0.15%, 0.25% by weight of the parent soil) and three different percentage of lime (i.e. 2%, 5%, and 8% by weight of parent soil). Total nine groups of tests were performed.ZHANG Ji-ru (2002) has conducted soil stabilization using lime and fly-ash individually and admixed. Lime and fly ash were added to the expansive soil at 4% - 6% and 40% - 50% by dry weight of soil, respectively. P.Sowmya Ratna has made an attempt study the compaction and CBR characteristics tests of black cotton soil mixing with different percentages of lime and

Recron-3s Fiber with a view to determine the optimum percentage. Test results shows that stabilizing clayey soils with lime and imparting Recron 3s fibers enhance the strength.Kameshwar Rao Tallapragada has made an attempt to evaluate the benefits of fiber reinforced subgrade soil in flexible pavements. Two types of fibers 1) Monofilament, 2) Nylon Thread are selected for study. An attempt was made to investigate the strength behavior of locally available Black Cotton soil reinforced with randomly mixed (1) Monofilament and (2) Nylon Thread.

III. SAMPLE PREPARATION

3.1 Soil

The Black Cotton Soil of Highly Expansive nature was collected from Intola village near Jambusar, Gujarat from the depth of 0.5 m from the ground. The soil is black to blackish grey in color with high clay content. The soil is then oven dried, pulverized manually and soil passing through 4.75 mm size sieve was used. The geotechnical properties of the black cotton soil have enlisted in table 1. The chemical properties of the black cotton soil have enlisted in table 2 and EDS image of black cotton soil has shown below.

Table 3.1 Geotechnical properties of Expansive soil

No	Index and Engineering Properties	Value
1	**Specific gravity**	2.55
2	**Atterberg's limits** ➢ Liquid limit (%) ➢ Plastic limit (%) ➢ Plasticity index	 76.63 31.30 45.33
3	**IS Soil Classification**	CH
4	**Free swell index (%)**	120%
5	**Engineering Properties** Light Compaction ➢ Maximum Dry Density, (kN/m^3) ➢ Optimum Moisture Content (%)	 13.82 30.12%
6	**Swelling pressure (kN/m^2)**	312.30
7	**CBR value (%)** ➢ Unsoaked CBR (%) ➢ Soaked CBR (%) ➢ Expansion ratio (%)	 8.27 1.88 6.568
8	**Unconfined compression test (kN/m^3)**	243.95
9	**pH value**	7.1

Table 3.2 Results of EDS Analysis of Expansive Soil Sample

Element	Weight (%)	Atomic (%)	Formula
Na	0.85	0.81	Na_2O
Mg	1.50	1.25	MgO
Al	7.48	5.61	Al_2O3
Si	22.98	16.56	SiO_2
K	1.02	0.53	K_2O
Ca	1.10	0.56	CaO
Fe	7.94	2.88	FeO
O	57.12	72.26	
Ti	0.87	0.37	
Total	100.00		

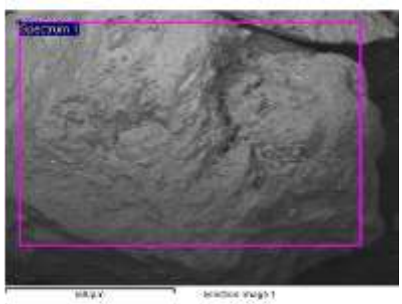


Fig. 3.1EDS Image of Expansive Soil

3.2 Lime

The commercial Birla lime has taken from market for the purpose of stabilizing soil, which imparts cementing property to the soil mix. Commercial grade lime mainly consisting of 58.67% of Cao and 7.4% Silica was used in the study as shown in the fig.2. The quantity of lime was 0%, 2%, 4% and 6% by dry weight of soil. The specific gravity of lime was 2.37. Lime in the form of lime stone CaCO3, was first sieved through 150 micron sieve and stored in airtight container for subsequent use.

3.3 Nylon Fibers

The nylon fiber which is used in the present study has brought from 'CENTURY ENKA, SURAT'. Nylon Fibers are distributed randomly with different aspect ratios (L/D ratio) (i.e. 50, 100 & 150) and with different percentages (i.e. 0.2%, 0.4% & 0.6%) as discussed in Chapter 3.

The Nylon Fibers used in the present research has following properties. 1. The type fiber used is 44/24. 24 stands for the number of filaments present in a single thread of nylon fiber. 44 stand for the Denier. A Denier is the weight in grams of 9000 m long nylon fiber. 2. It has a Trilobal cross section. 3. The Elongation of this fiber is 48%. 4. The Tenacity of fibers is 4.2. Tenacity is the specific tensile strength of fiber at breaking point.

		
Fig. 3.2 Black Cotton Soil	**Fig. 3.3 Lime**	**Fig. 3.4 Nylon Fibers**

3.4 Preparation of Sample

The remolded samples for different tests were prepared by compacting the black cotton soil at MDD with the addition of OMC. The predefined percentages of limewere added to soil at its dry state then soil is mixed with the OMC. After adding Optimum Moisture content required, the fibers were mixed randomly and then the soil was compacted at MDD.

IV. RESULT ANALYSIS AND DISCUSSION

4.1 Evaluation of effect of lime on geotechnical properties of expansive soil

4.1.1 Atterberg's Limits

Atterberg's Limit results are determined as per IS: 2720 (Part-5). These results are used to classify the soil as per IS soil classification (Plasticity Chart). Total four combinations have decided on which Atterberg's limit tests have conducted. In these combinations, one combination is untreated soil and in other threecombinations, soil is mixed with three different percentages of Lime i.e. 2%, 4% & 6%. The combinations are as follows.

1. $\boldsymbol{C_0 = BC}$
2. $\boldsymbol{C_1 = BC + L_1}$
3. $\boldsymbol{C_2 = BC + L_2}$
4. $\boldsymbol{C_3 = BC + L_3}$

Where, L_1= 2% lime, L_2= 4% lime, L_3= 6% lime and BC = Black cotton soil

Fig. 4.1shows the typical reduction in Liquid Limit and Plasticity Index and increase in Plastic Limit. The Liquid Limit, Plastic Limit and Plasticity Index of untreated soil are 76.63%, 31.30% & 45.33% respectively which show improvement up to 73.5%, 46.2% & 27.3% for $\boldsymbol{C_1}$respectively, 71.7%, 47.8% & 23.9% for $\boldsymbol{C_2}$ respectively and 66.2%, 49.8% & 16.4% for $\boldsymbol{C_3}$respectively.

As per IS soil classification, the pure BC soil has classified as **CH soil**. The combination $\boldsymbol{C_1}, \boldsymbol{C_2}$&$\boldsymbol{C_3}$are classified as **MH, MH & MH** respectively. So, the behaviour BC soil converts from High Plasticity Clay to High Plasticity Silt.

4.1.2 Free swell index

The purpose of determining free swell index is to know the behaviour of Black Cotton soil when water is added into the soil. **Fig. 4.2** shows the reduction in the free swell index with increase in lime percentages. The same combinations are considered as the Atterberg's limits (i.e.$\boldsymbol{C_0}, \boldsymbol{C_1}, \boldsymbol{C_2}$&$\boldsymbol{C_3}$). The free swell index of untreated soil has become 120% which reduces to 90% with addition of 6% lime to the soil.

4.1.3 Standard Proctor test

Standard Proctor test is conducted to determine the MDD and OMC of BC soil with and without Lime. The combinations are the same as above (i.e.$C_0, C_1, C_2 \& C_3$). The BC soil is mixed with three different percentages of lime which are 2%, 4%, and 6%. The MDD and OMC of pure BC soil are 13.82 kN/m^3 and 30.12% respectively (fig. 4.3). As shown in the fig. 4.4, as the percentage of lime increases, MDD has decreased and OMC has increased. MDD decreases up to 13.21 kN/m^3 and OMC increases up to 35.29%.

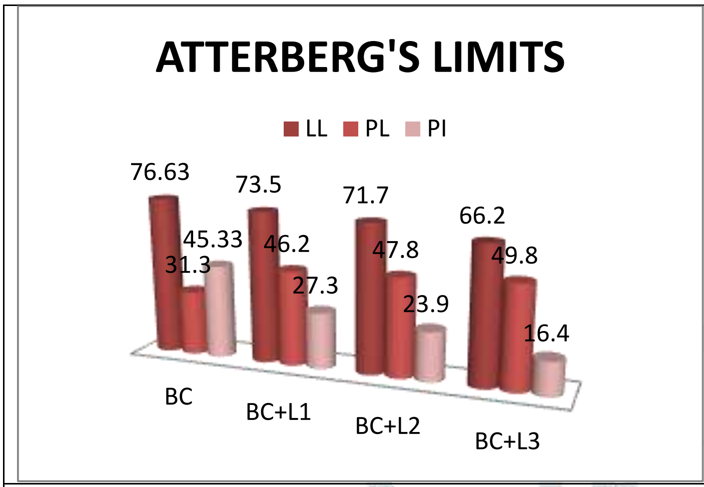


Fig. 4.1 Atterberg's Limits of BC soil with & without Lime

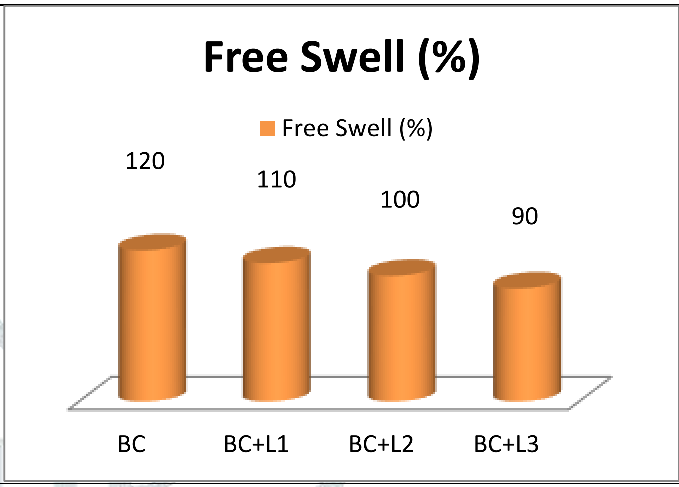


Fig. 4.2 Free Swell Index of BC soil with & without Lime

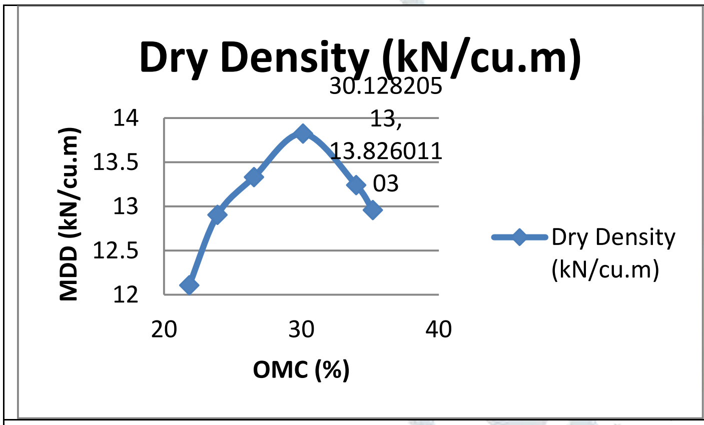


Fig. 4.3 MDD &OMC of BC soil

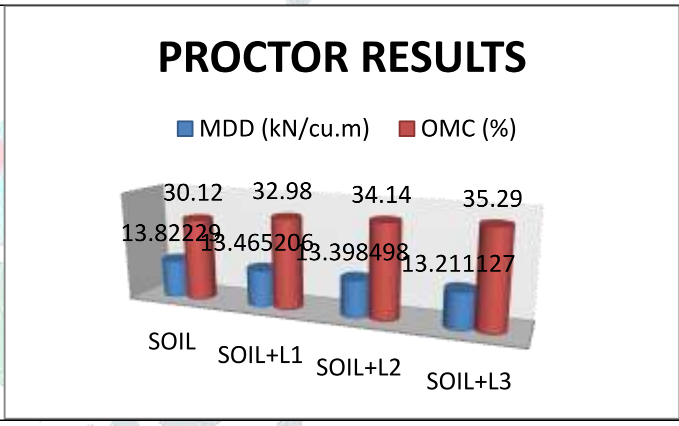


Fig. 4.4 MDD & OMC of BC soil with and without lime

4.2 Evaluation of effect of lime and nylon fibers on engineering & strength properties of soil

4.2.1 Sample preparation

The oven dried sample is mixed with the lime in the powder form. Then the mixture of soil and lime is mixed with enough quantity of water (equivalent to OMC) and then fibers are added. Then the soil sample is prepared by compacting the soil mixture at MDD. The combinations for these tests are shown in the table 4.1.

Table 4.1 Percentages of lime and nylon fibers

Sample	Fibers		Lime
	Aspect ratio	Percentages	Percentages
S1	50	0.2	2
S2		0.4	4
S3		0.6	6
S4	100	0.2	2
S5		0.4	4
S6		0.6	6
S7	150	0.2	2

S8		0.4	4
S9		0.6	6

4.2.2Swell Pressure Test

The Swell pressure test is conducted on BC soil mixed with and without Lime and Nylon fibers. Total 10 combinations have decided from which one is pure black cotton soil (**fig. 4.5**)and other are mixed with different percentages of lime and fibers as per their aspect ratios as discussed in chapter 4 (i.e. S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9). The 1 mm IS sieve passing oven dried expansive soil is taken for this purpose. **Fig. 4.6** shows the variation of swell pressure results of all the soil mixes mentioned above. The swell pressure of pure BC soil has resulted 312.30kN/m^2. As seen in the **fig. 4.6**, the swell pressure has reduced to 93.69kN/m^2 by adding of 6% lime and 0.6% fibers of aspect ratio of 100 (i.e.S_6).

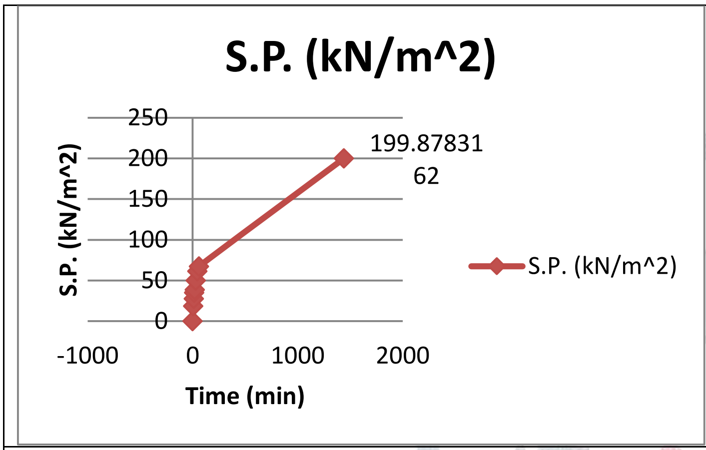


Fig. 4.5 Swell Pressure of BC soil

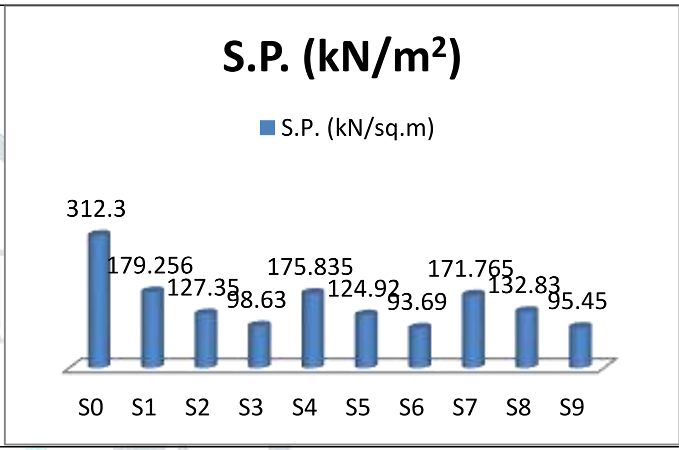


Fig. 4.6 Swell Pressure with and without Lime and Nylon fibers

4.2.3 California Bearing Ratio Test

The California Bearing Ratio test has conducted on the black cotton soil blended with Lime and Nylon fibers with different percentages. The Unsoaked and Soaked CBR have conducted on pure BC soil the value of which are 8.27% and 1.88% respectively. For other combinations, only soaked CBR has conducted (i.e.S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9). For each combination, two samples have made and tested and the average value of these two has considered. The 1 mm IS sieve passing oven dried expansive soil is taken for this purpose. The unsoaked CBR and soaked CBR of BC soil are 8.27% and 1.88% respectively. The soaked CBR has increased to 54.20% by adding 6% lime and 0.6% nylon fibers of aspect ratio 50 (S_3) which is about 2700% increment in CBR value which have shown in **fig. 4.7. Fig. 4.8** shows the variation of Expansion ratios. The expansion ratio of pure BC soil is 6.568% which has reduced to 0.032% of S_3, S_6, S_9.

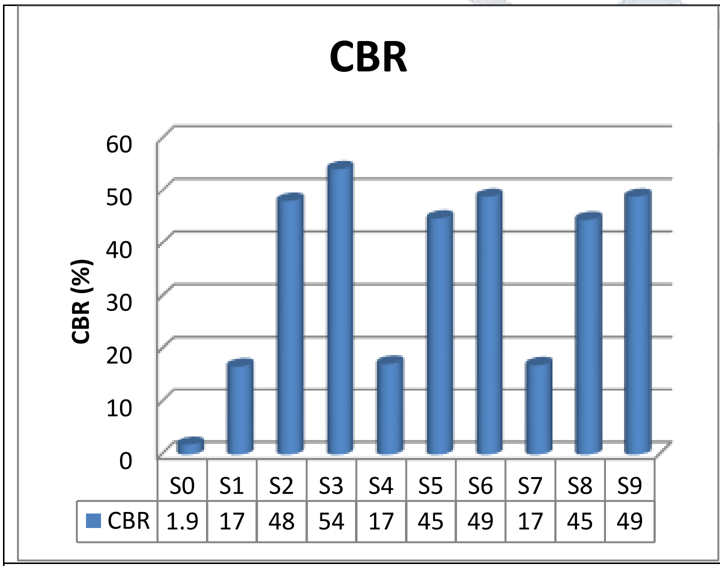


Fig. 4.7 Soaked CBR of soil with and without Lime and Nylon fibers

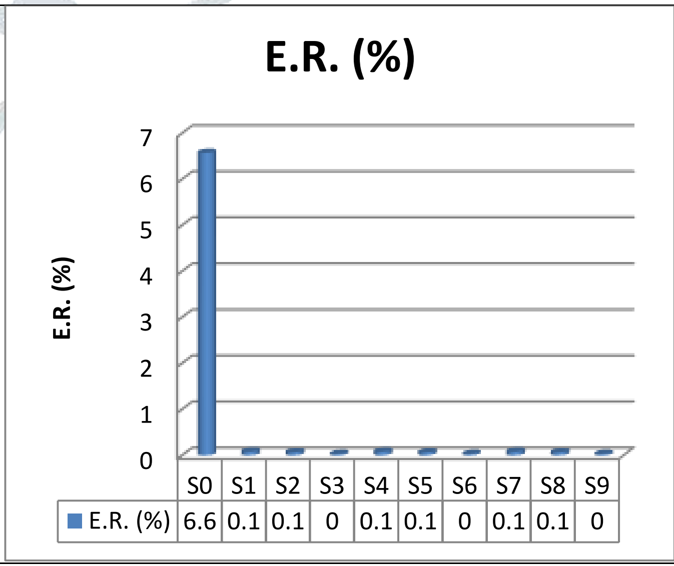


Fig. 4.8 E.R. of soil with and without lime and nylon fibers

4.2.4 Unconfined Compressive Strength Test

The purpose of conducting Unconfined Compressive strength test on expansive soil blended with lime and nylon fibers is to analyze the effect of stabilizing materials on strength characteristics of expansive soil. For this purpose, expansive soil passing through 1 mm IS sieve and oven dried is taken. The combinations to be tested are same as the above which is different percentages of lime and nylon fibers as per their aspect ratios (i.e.S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9). For pure BC soil, the soil sample is mixed with the water content equal to OMC and sample made by compacting it at MDD. For each combination, two samples have made and tested and the average value of these two has considered the UCS strength for that combination. The Average UCS strength of pure BC soil is 243.95kN/m^2. **Fig. 4.9** shows the stress vs. strain curve for pure BC soil. All combinations have cured for different curing periods of 1 day, 7 days and 14 days.

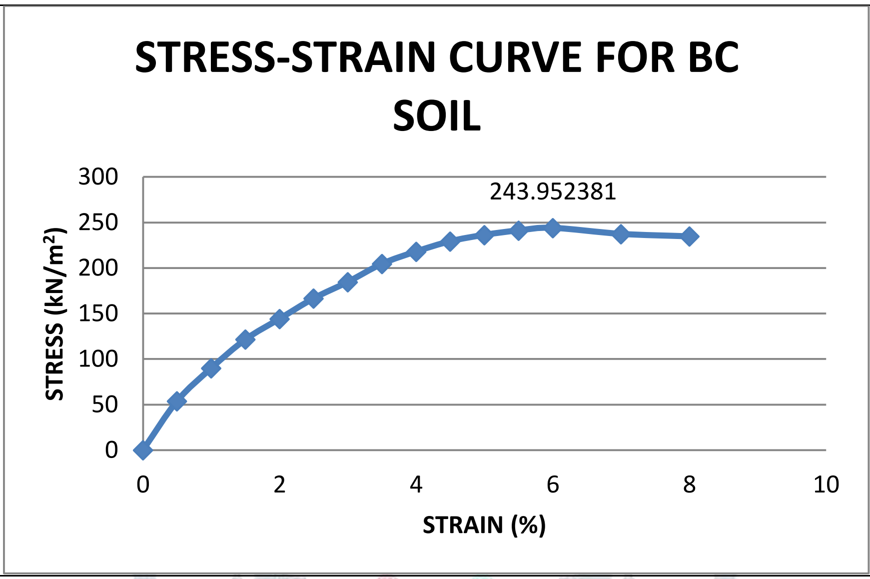


Fig. 4.9 Stress-Strain curve for pure BC soil

After 1 Day curing period

For 1 Day curing, two samples for each combination have made and cured. For soil mixed with 2% lime, the sample is prepared at the MDD-OMC of combination C_1 i.e. MDD = 13.46kN/m^3 and OMC = 32.98%. For soil mixed with 4% lime, the sample is prepared at the MDD-OMC of combination C_2 i.e. MDD = 13.39kN/m^3 and OMC = 34.14%. For soil mixed with 6% lime, the sample is prepared at the MDD-OMC of combination C_3 i.e. MDD = 13.21kN/m^3 and OMC = 35.29%. **Fig. 4.10**shows the UCS values of combinations. The UCS value of BC soil after 1 Day curing is same i.e. 243.95kN/m^2. The UCS values of combination S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 are 403.4453, 1057.318, 1397.65, 463.4818, 1042.834, 1123.883, 407.6479, 979.7958 and 907.752kN/m^2 respectively. The maximum UCS strength has resulted as 1123.883kN/m^2 which is of combination S_6. The minimum value of UCS strength has resulted as 403.4453kN/m^2 which is of combination S_1. **Fig. 4.11** shows the stress-strain curve for all combinations after curing of 1 Day.

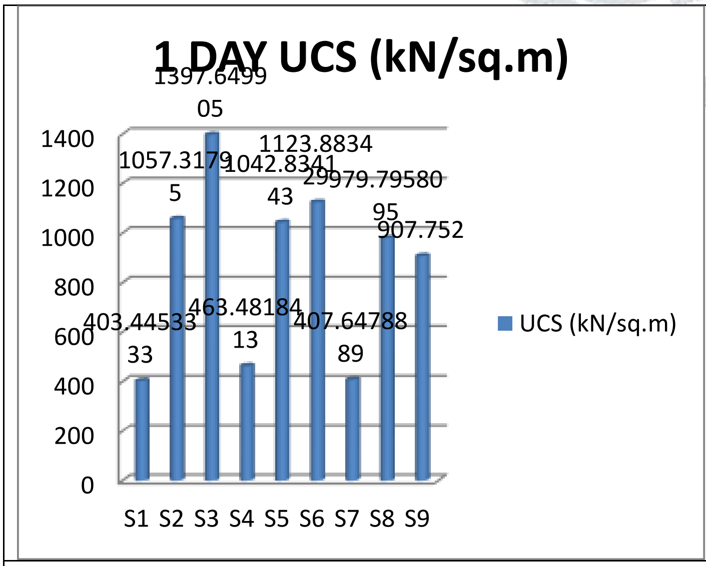


Fig. 4.10 UCS values of combinations after 1 Day curing

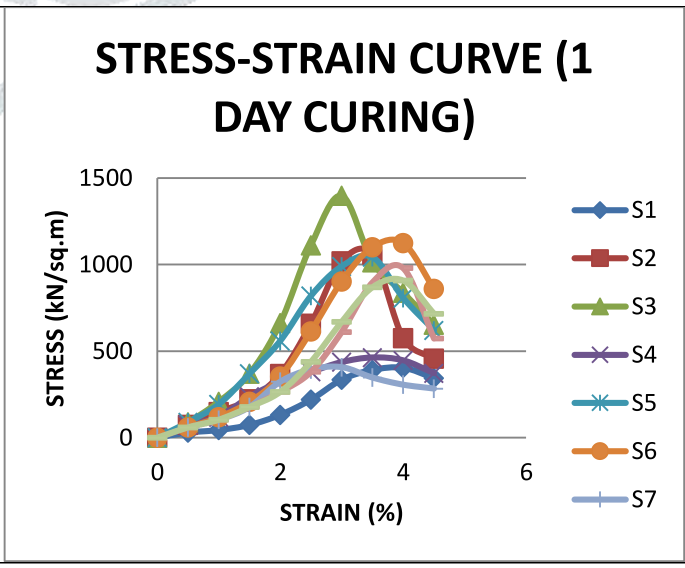
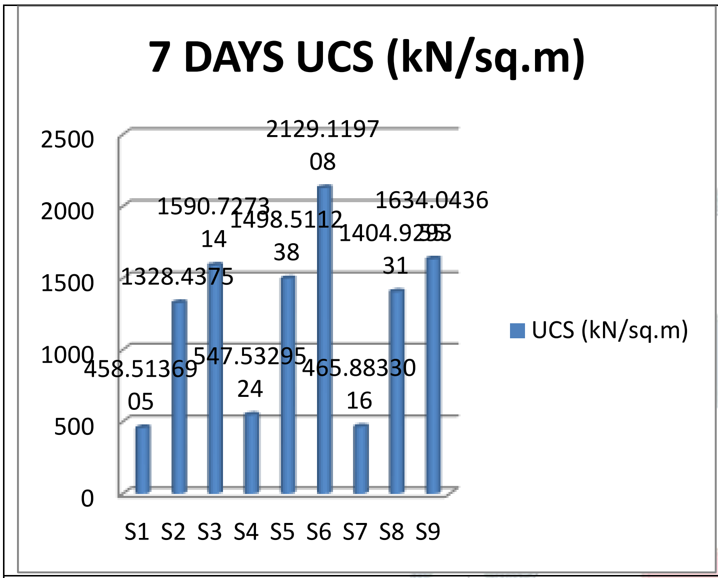


Fig. 4.11 Stress-Strain curves of combinations after 1 Day curing

After 7 Day curing period

For 7 Days curing, two samples for each combination have made and cured. For soil mixed with 2% lime, the sample is prepared at the MDD-OMC of combination C_1 i.e. MDD = 13.46kN/m^3 and OMC = 32.98%. For soil mixed with 4% lime, the sample is prepared at the MDD-OMC of combination C_2 i.e. MDD = 13.39kN/m^3 and OMC = 34.14%. For soil mixed with 6% lime, the sample is prepared at the MDD-OMC of combination C_3 i.e. MDD = 13.21kN/m^3 and OMC = 35.29%. **Fig. 4.12**shows the UCS values of combinations. The UCS value of BC soil after 7 Days curing is same i.e. 243.95kN/m^2. The UCS values of combination S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 are 458.5137, 1328.438, 1590.727, 547.533, 1498.511, 2129.12, 465.8833, 1404.929 and 1634.044kN/m^2 respectively. The maximum UCS strength has resulted as 2129.12kN/m^2 which is of combination S_6. The minimum value of UCS strength has resulted as 458.5137kN/m^2 which is of combination S_1. **Fig. 4.13** shows the stress-strain curve for all combinations after curing of 7 Days.



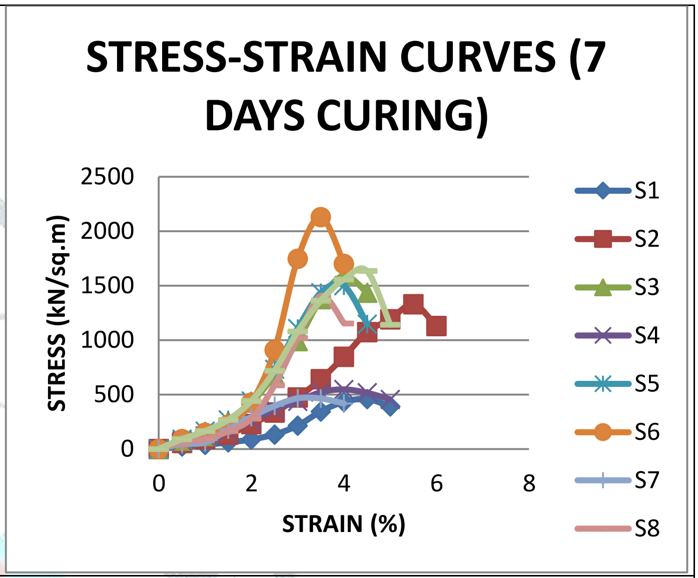
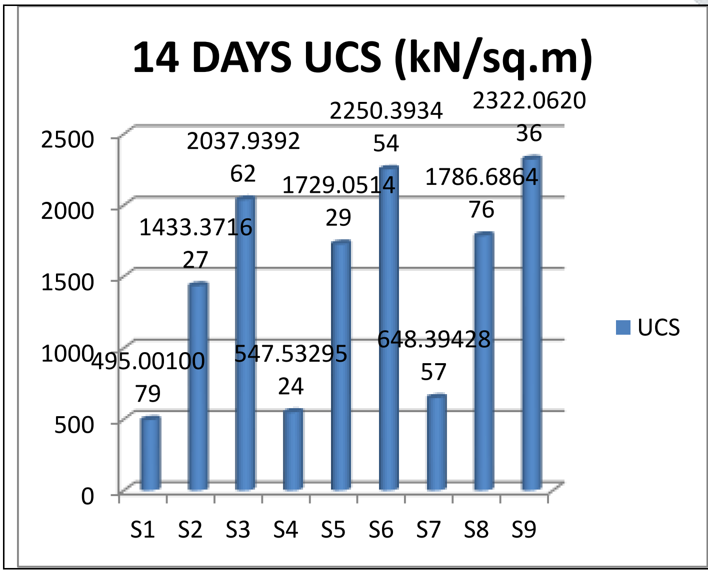


Fig. 4.12 UCS values of combinations after 7 Days curing

Fig. 4.13 Stress-Strain curves of combinations after 7 Days curing

After 14 Day curing period

For 14 Days curing, two samples for each combination have made and cured. For soil mixed with 2% lime, the sample is prepared at the MDD-OMC of combination C_1 i.e. MDD = 13.46kN/m^3 and OMC = 32.98%. For soil mixed with 4% lime, the sample is prepared at the MDD-OMC of combination C_2 i.e. MDD = 13.39kN/m^3 and OMC = 34.14%. For soil mixed with 6% lime, the sample is prepared at the MDD-OMC of combination C_3 i.e. MDD = 13.21kN/m^3 and OMC = 35.29%. **Fig. 4.14**shows the UCS values of combinations. The UCS value of BC soil after 14 Days curing is same i.e. 243.95kN/m^2. The UCS values of combination S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 are 495.001, 1433.372, 2037.939, 547.533, 1729.051, 2250.393, 648.3943, 1786.686 and 2322.062kN/m^2 respectively. The maximum UCS strength has resulted as 2322.062kN/m^2 which is of combination S_9. The minimum value of UCS strength has resulted as 495.001kN/m^2 which is of combination S_1. **Fig. 4.15** shows the stress-strain curve for all combinations after curing of 14 Days.



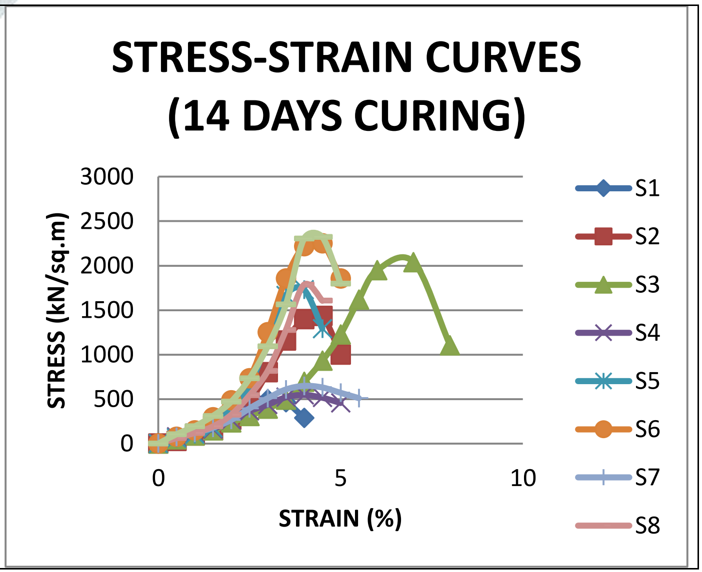


Fig. 4.14 UCS values of combinations after 14 Days curing	Fig. 4.15 Stress-Strain curves of combinations after 14 Days curing

4.2.5 Discussions

From the results shown above, following discussions can be made.

1. With addition of lime to Black Cotton soil, the L.L. and P.I. of soil decreases and P.L. of soil increases. The soil converts from CH to MH.
2. With addition of lime to Black cotton soil, the free swell index of the soil decreases.
3. With addition of Lime to Black Cotton soil, MDD decreases and OMC increases.
4. With addition of Lime and Nylon fibers to Black cotton soil, the swelling pressure decreases.
5. With addition of Lime and Nylon fibers to Black Cotton soil, the soaked CBR increases marvelously and the expansion ratio decreases almost too negligible.
6. With addition of Lime and Nylon fibers to Black Cotton soil, the UCS strength of soil after 14 Days curing increases beyond expectations.

The Lime and Nylon Fibers combination can be used for stabilizing any soil but it will give its best results in Highly Expansive soils.

V. CONCLUSIONS

In previous chapters, the laboratory investigations have been made to determine the potential of Lime and Nylon fibers as stabilizing materials. From the present study, following conclusions can be made.

1. Liquid Limit decreases from 76.63% to 66.2%, Plastic Limit improves from 31.3% to 49.8% and Plasticity Index improves from 45.33% to 16.4% with addition of lime varying from 0% to 6% in expansive soil as a result of cations from the lime which reduces the volumetric changes. From LL, PL and PI results, the expansive soil classification can be changed from CH to MH.
2. With addition of lime from 0% to 6%, the free swell index of expansive soil reduced from 120% to 90% as a result of reduction in volumetric changes.
3. MDD has decreased from 13.82kN/m^2 to 13.21kN/m^2 due to the agglomerated and flocculated particles of lime mix soil occupy large voids and the OMC has increased from 30.12% to 35.29% due to the action of lime which needed more water for pozzolanic action.
4. The swelling pressure has reduced by **70%** from pure BC soil after adding lime and nylon fibers. This is mainly because the fibre-reinforced soils behave like a composite materials in which the fibre having relatively high strength offering more tensile resistance to soil against swelling. The swelling pressure has reduced from 312.30kN/m^2 to 93.69kN/m^2 after adding 6% lime and 0.6% nylon fibers (aspect ratio = 100).
5. CBR values soaked sample has increased from 1.88% to 54.20% with addition of 6% lime and 0.6% nylon fibers (aspect ratio = 50) which is nearly **2780%** increment from the pure BC soil. The Expansion Ratio has decreased from 6.568% to 0.032% which is negligible. The overall CBR values increases due to the reason that lime has effectively bonded the soil particles to form a closely packed mass that resists the ingress of water and fibers have effectively reinforced soil mass and provided resistance against penetration.
6. The UCS strength of BC soil has increased from 243.95kN/m^2 to 2322.062kN/m^2 after 14 Days of curing by adding 6% lime and 0.6% nylon fibers (aspect ratio = 150). The increment in UCS value is about **850%** and it is because lime has effectively bonded the soil particles to form a closely packed mass which imparts greater strength and fibers have effectively reinforced soil mass and provided resistance against failure.

The field application of the lime and nylon fibers is feasible, economic and environmental friendly.

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