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Stabilization of Black Cotton Soil Using Lime and Bamboo Fiber Mixture as a Subgrade Material

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Abstract:** The design of pavements on black cotton soil has always been a difficult task for the engineers as the structure and pavement resting on black cotton soil cracks without any warning. Black cotton soil is most commonly found in Indian region. Soil proportion changes depending upon their constituents, i.e., water content, density, bulk density, compressive strength etc. The properties of black cotton soil can be modified by stabilizing the soil with the use of additives or by mechanical means. The aim of this project is to find the optimum percentage of lime separately and lime + bamboo fibre separately to be added in black cotton Soil and study the properties of soil. In this project an attempt has been made to stabilize the soil using lime and bamboo fibre. Initially lime is blended with black cotton soil in different proportions (2%, 4%, 6%, 8%). The experimental work included the tests carried out on virgin black cotton soil and lime added black cotton soil which are Liquid limit, Plastic limit, modified proctor, specific gravity, free swell index, C.B.R. test, unconfined compressive strength test. On the basis of the soaked CBR and Modified Proctor Values, it is determined that 6% of lime is an optimum percent which can be added to stabilize black cotton soil for road construction. So, 6% lime is added with black cotton soil and different percentages of bamboo fibres (2%, 4%, 6%, 8%). California Bearing Ration, modified proctor test, Unconfined Compressive strength test are performed on the soil mixture of 6% lime + Black Cotton Soil + different percent of Bamboo Fibre. On the basis of the soaked CBR, it is concluded that if 6% lime with 8% of bamboo fibre is blended in black cotton soil, engineering properties of BCS can be improved to such an extent that the pavements built on this soil can efficiently withstand the loads applied on it while vehicular movement. Hence, according to the results obtained from experimental study, pavement design is performed for CBR 5%, 6%, 8%. The evaluation of cost for each pavement design is carried out which shows the decrease in cost of construction of pavement as the CBR values increases.
***Keywords:** Lime, Bamboo Fibre, California Bearing Ratio, Unconfined Compressive strength, Modified Proctor, Black Cotton Soil, Pavement design.*

I. INTRODUCTION

The soils which show volumetric changes due to changes in their moisture content are referred to as swelling soils. Some partially saturated clayey soils are very sensitive to variations in water content and show excessive volume changes. Such soils, when they increase in volume because of an increase in their water contents, are classified as expansive soils. Problem of expansive soils has appeared as cracking and break-up of pavements, railways, highway embankments, roadways, building foundations, slab on-grade members and, channel and reservoir linings, irrigation systems, water lines, sewer lines. It is reported that damage to the structures due to expansive soils has been the costliest natural hazard in some countries. In the United States damage caused by expansive clays exceeds the combined average annual damage from floods, hurricanes, earthquakes, and tornadoes. Documented evidence of the problems associated with expansive clays is worldwide, having occurred in such countries as the United States, China, Australia, India, Canada, and regions in Europe.

It is reasonable that studies on the problem of expansive soils become more important day by day if the durative deficit of world resources and economy is taken into consideration. When geotechnical engineers are faced with expansive soils, the engineering properties of those soils may need to be improved to make them suitable for construction. A substantial literature has concluded this severity an extent of damage inflicted by soil deposits of swelling nature, to various structures, throughout the world. The loss caused due to damaged structures proved the need for more reliable investigation, of such soils and necessary methods to eliminate or reduce the effect of soil volume change.

Additives, including lime, fly ash, Portland cement, saw dust and more recently synthetics are available that will lessen these problems when mixed in the proper amounts with problem soils. These additives may be used separately or in combination and each has construction issues related to its performance Black cotton soil (BC Soil) represents a well-known category of problematic from civil engineering point of view.

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Figure.1 Black Cotton Soil

They exhibit large volumetric changes shrinkage and swelling behaviour if the moisture content changed. Due to this nature this type of soil is susceptible to damage to the structures and pavements founded on it. In India expansive soils cover about $0.8X10^6$ km^2 area approximately 20% of surface area. Structure founded in areas with soft or weak soil have need for improvement of soil properties by using additives. Soil stabilization techniques are used to improve shear strength, CBR, reducing expansive characteristics, etc. Silica fume also referred as micro-silica is a product resulting reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapour. It cools, condenses and is collected. It is fine grey coloured powder sometime similar to Portland cement or some flashes. Condensed silica fume is essentially silicon-dioxide (more than 90%) in non-crystalline form. Since it is an air borne material line flash it has spherical shape. It is extremely fine with a particle size less than 0.1 micron and specific surface area of about 20,000m^2/kg. Silica fume is used as an artificial pozzolanic admixture in concrete. As far as the production of silica fume is concerned nearly 100,000 tons of micro silica is produced each year worldwide. Iron also has a large amount of micro silica production. Steel Authority of India has provided necessary facilities to produced more than 3000 tons of Silica fume annually. Many waste materials are used to modify the characteristics of soft soils. Traditionally the soils are stabilized by lime, cement, etc. In recent year the uses of waste materials like flash, plastic, rice- husk ash, slag, etc. for soil stabilization is gaining importance. In this study attempts are made to find the influences of silica fume on engineering characteristics of black cotton soil. Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. Bamboo has a very long history with human kind. Bamboo is also one of the oldest building materials used by human kind. It has been used widely for household products and extended to industrial applications due to advances in processing technology. It has been used widely for household products and extended to industrial applications due to advances in processing technology.

A. The Effect of Lime Stabilization on Properties of Black Cotton Soil

Black soils have wide development in Bombay, western part of Madhya Pradesh, part of Gujarat, and in some parts of Madras. In Bombay, large area is occupied by soils derived from the Deccan trap. Black Cotton soils absorb water heavily, swell, become soft and lose strength. These soils are easily compressible when wet and possesses a tendency to heave during wet condition. Black Cotton soils shrink in volume and develop cracks during summer. They are characterized by extreme hardness and cracks when dry. These properties make them poor foundation soils and earth construction material. The stability and performance of the pavements are greatly influenced by the sub grade and embankment as they serve as foundations for pavements. For developing a good and durable road network in black cotton soil areas, the nature of soils shall be properly understood. On such soils suitable construction practices and sophisticated methods of design need to be adopted.

B. Lime Stabilization

Soil stabilization is a collective term for any physical, chemical, or biological method, or any combination of such methods that may be used to improve certain properties of a natural soil to make it serve adequately an intended engineering purpose. It is the process of blending and mixing materials with a soil to improve certain properties of the soil.

The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil. The main benefits of using lime to stabilize clays are improved workability, increased strength, and volume stability. Workability is improved because flocculation makes the clay more friable; this assists combination for effective mixing and compaction. Lime increases the optimum water content for compaction, which is an advantage when dealing with wet soil. The compaction curve for lime-treated clay is generally flatter, which makes moisture control less critical and reduces the variability of the density produced. In first few hours after mixing, lime additives cause a steady increase in strength, but at a slower rate than cement. The need for compaction immediately after mixing is therefore less critical for lime than cement. Lime increases the strength of clayey soil. Related to strength is improved durability under traffic or resistance to the action of water, wind, and freeze-thaw cycles. The shrinkage and swell characteristics of soil are reduced markedly. The lime stabilized layer forms a water-resistant barrier by impeding penetration of gravity water from above and capillary moisture from below. Lime stabilization of clay soils is achieved in the field by shallow/surface stabilization or deep stabilization methods. Shallow stabilization using lime is achieved by mechanical mixing of lime and black cotton soil, spreading the mix and then compacting it. Deep stabilization involves the use of lime columns, lime piles or lime injection methods. Mixing-spreading-compacting has the advantage over the lime pile technique that it ensures efficient contact between lime and clay mineral particles of the soil. A detailed study of the exact effects of lime addition to the properties of black cotton soil is needed so that it can be used as a reference in future construction works in such soils. Black soil specimens from the Latur district of Maharashtra were taken to study the effects of addition of lime on the properties of the soil.

II. MATERIAL AND PROPERTIES

A. Material Used for Stabilization

1) Black Cotton Soil

a) Black cotton soil is not suitable for the construction work because its volumetric changes.
b) Therefore, it is necessary to improve the properties of black cotton soil to avoid damage to the structures.
c) Collecting soil sample from site which is situated at Wagholi, Pune.

2) Lime

a) Lime has been mainly used for stabilizing the road bases and the subgrade.
b) Lime is very actual in treating heavy plastic clayey soils.
c) Lime may be used alone or in mixture with cement, bitumen or fly ash.

3) Natural Raw Bamboo Fibre

a) Bamboo is easily available, eco-friendly, and also cost effective.
b) Bamboo fiber is a regenerated cellulosic fiber produced from bamboo
c) Sources
d) Sapkal Bamboo Works, Loni Kalbhor, Pune.
e) Size Specification (length – 5-10mm)

B. Black Cotton Soil Engineering Properties

Table 1. Black Cotton Soil Properties

Property	Value
Dry Density	1300-1800 kg/cm^3
Liquid Limit	(40-120%)
Plastic Limit	(20-60%)
Specific Gravity	2.60-2.75
Maximum Density	(20-35%)
Compressive Index	0.2-0.5

C. Chemical Composition Black Cotton

Table 1 Chemical Composition Black Cotton

Mineral	Value
Alumina	10%
Iron Oxide	(9-10%)
Lime and Magnesium Carbonates	(6-8%)
Potash	<0.5%
Phosphate, Nitrogen, Humus	Low

III. METHODOLOGY

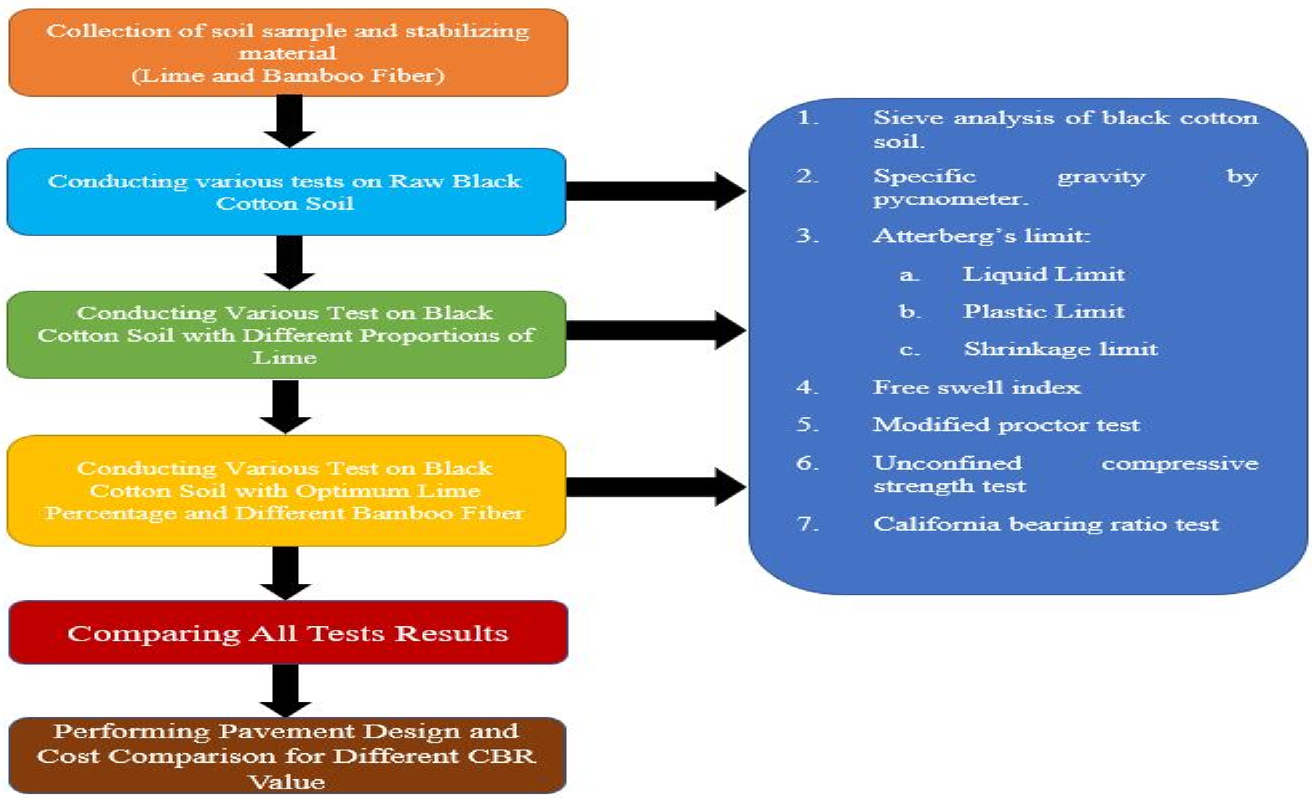

Figure.2 Methodology Flowchart

The Highway Research Board (HRB) classification of the soil strata like black cotton soil and are done using suitable sampling technique such as Core Cutter Method. To determine the characteristics like Grading by Sieve Analysis, Atterbergs Limits i.e. Liquid limit using Casagrande Method, Plastic limit by rolling the sample to 3mm diameter thread, Shrinkage limit using Shrinkage apparatus, Optimum Moisture Content and Maximum Dry Density using Standard Proctor Test and also California Bearing Ratio by conches determination of the properties such as liquid limit, plastic limit, shrinkage limit, optimum moisture content, maximum dry density, CBR value and shear strength for different concentration of lime and bamboo fiber with black cotton soil as IS:2720. The pavement thickness design will be done using pavement design catalogues published by IRC SP:20-2002. The estimation for the road is done by considering the item such as Jungle Cutting, Earthwork Excavation for Roadway and Drains, compacting and grading etc., as per SR 2020-21, PWD circle and suggestion of specification for the mixture of Bamboo fibres as Geo Synthetic material for stabilization. during four days soaked CBR Test and Shear using Unconfined Compression Test. The different tests were conducted in order to determine the different characteristics and properties of the soil. The procedure of each of the tests have been explained below.

A. *Tests Performed on Soil*

1) Sieve Analysis of black cotton soil.
2) Specific gravity by pycnometer.
3) Atterbergs limit:
   a) Liquid Limit
   b) Plastic Limit
   c) Shrinkage limit
4) Standard proctor test
5) Free Swell Test
6) Unconfined compression test
7) California bearing ratio test

IV. RESULTS AND DISSCUSSION

A. *Engineering Properties of Black Cotton Soil*

Table No-03 Black Cotton Soil Properties

Properties	Black Cotton Soil
Color	Greyish Black
Specific Gravity	2.46
Free Swell Index (%)	95
GRAIN SIZE DISTRIBUTION	
Gravel (%)	0.69
Sand (%)	6.39
Silt / Clay (%)	92.92
IS Classification	CH
ATTERBERG'S LIMIT	
Liquid Limit (%)	72.39
Plastic Limit (%)	33.06
Plasticity Index (%)	39.33
Shrinkage Limit (%)	27.03
COMPACTION CHARACTRISTIC	
Maximum Density (g/cc)	1.38
Optimum Moisture Content (%)	26.41
Unconfined Compressive Strength (Kg/cm^2)	0.445
CALIFORNIA BEARING RATIO (SOAKED)	
2.5mm penetration (%)	3.90
5mm penetration (%)	3.08

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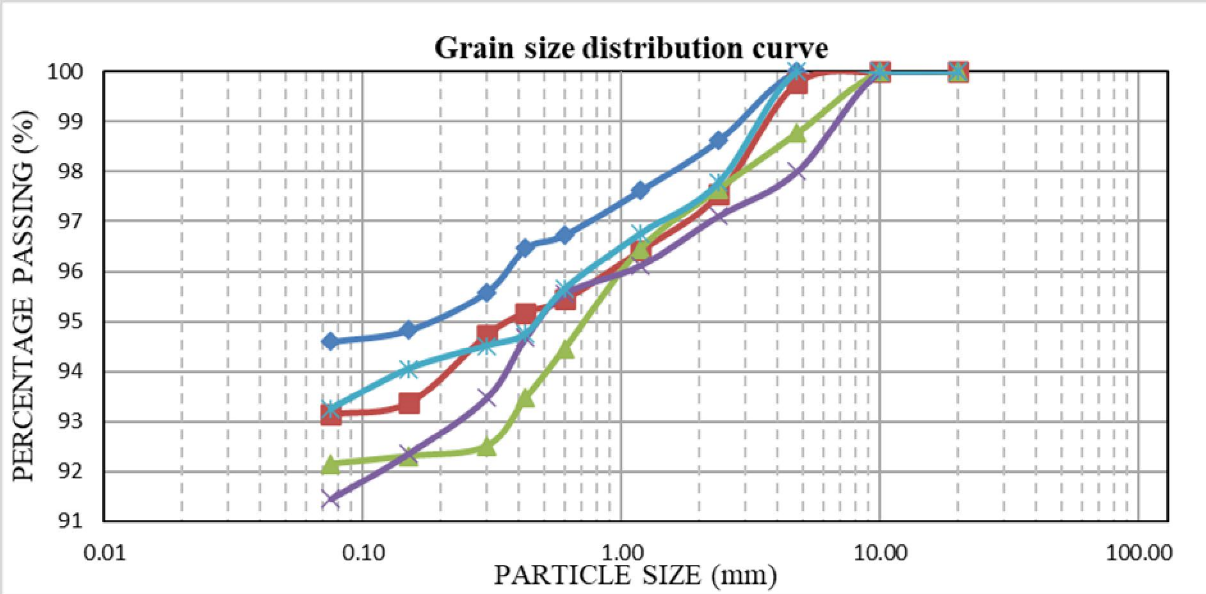
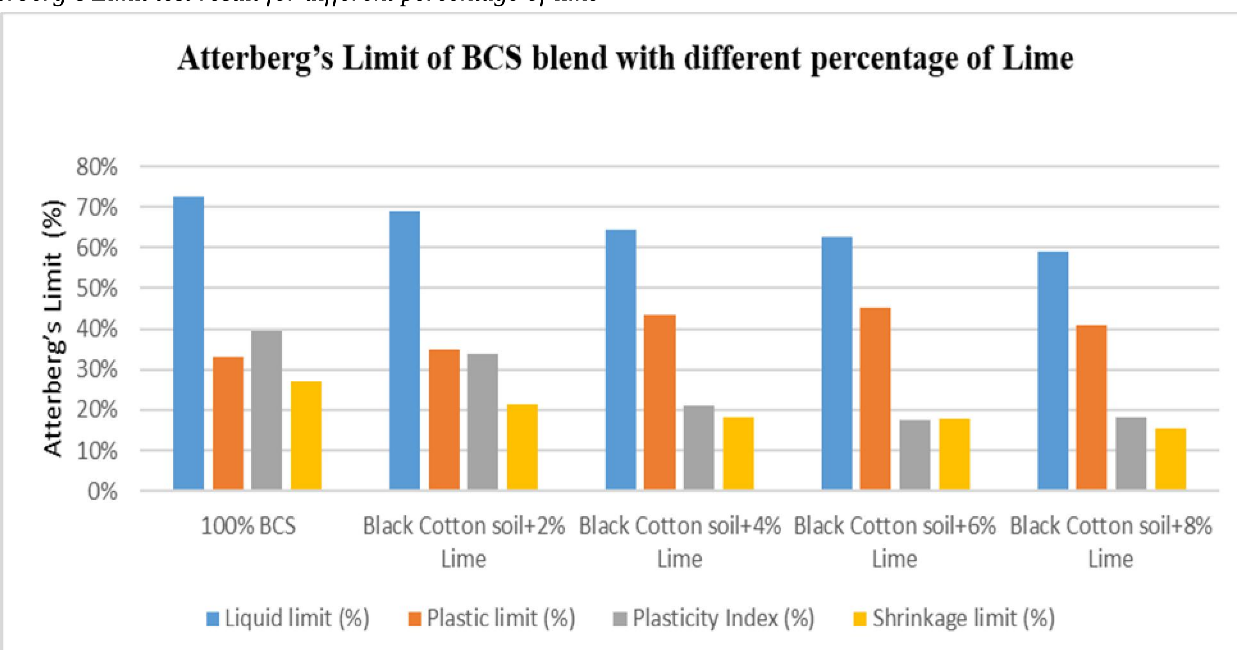
B. Sieve Analysis of Raw Black cotton Soil



Graph.1 Grain size distribution curve for black cotton soil

C. Tests on Lime Added Black Cotton Soil

1) Atterberg's Limit test result for different percentage of lime



Graph No.-02 Graphical comparison of Atterberg's Limits of BCS blend with different percentage of Lime

The outcome of graph on black cotton soil treated with different proportions of lime is showing that with raise in the proportion of lime, the liquid limit goes reducing from 72.39 % to 59.15 % of lime proportion increasing from 0 to 8 % whereas the plastic limit raises beginning 33.07 % to 45.06 % for 0 to 6% but slightly decreased to 41.05% for 8% of lime and shrinkage limit goes decreasing from 27.03% to 15.48% while lime proportion increasing from 0 to 8 % respectively as shown in graph-02.

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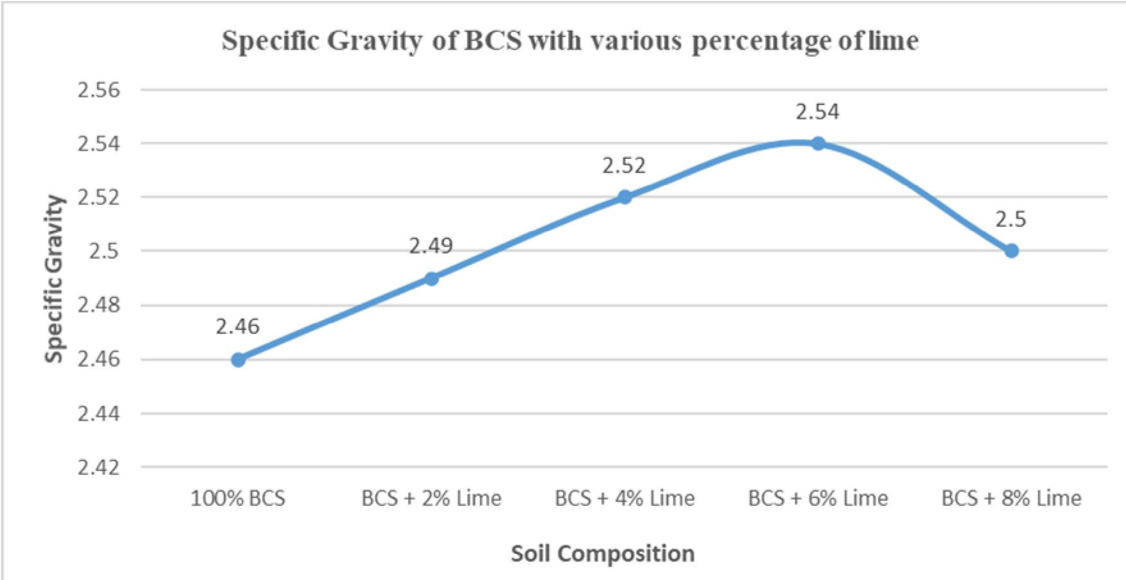
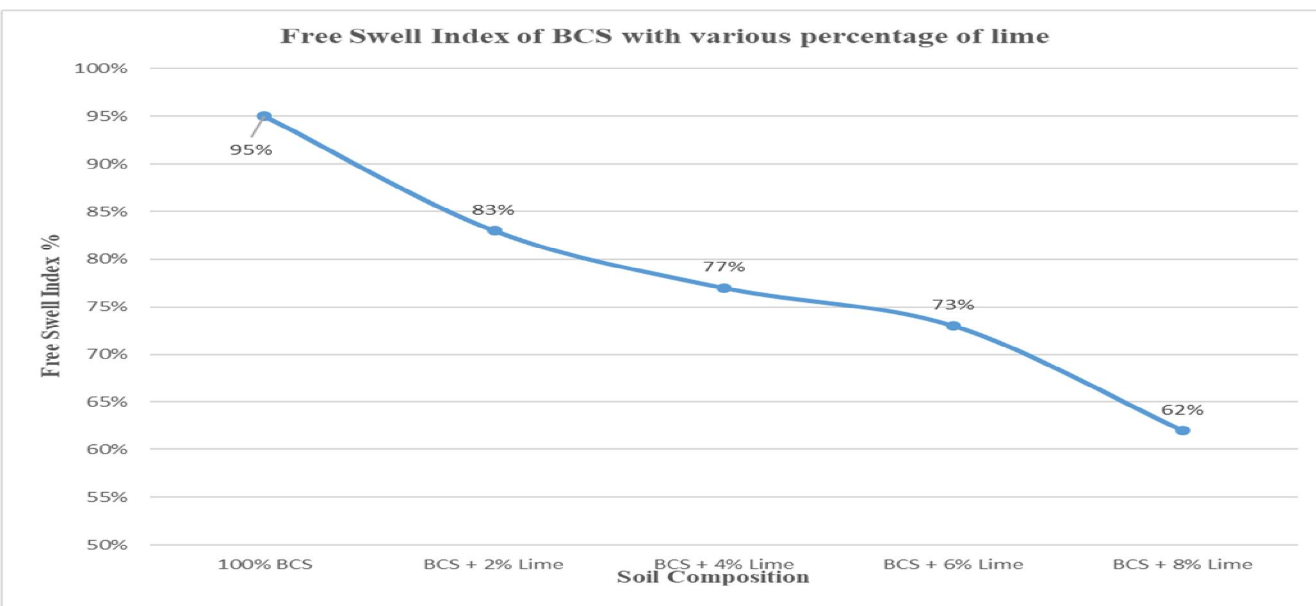
2) Specific Gravity



Graph No-03 Graphical Representation of BCS with various percentage of lime

Graph no.-03 shows the comparison of specific gravity of virgin BC soil with BC soil mixed with 2%, 4%, 6% and 8% brick powder. It can be seen that specific gravity of BC soil sample raised marginally when 6% brick powder was added in it. The bars of the virgin BC soil, 2%, 4% and 8% brick powder mixed BC soil are small as compared to the result bar of 6% brick powder mixed BC soil.

D. Free Swell Index



Graph No.-04 Graphical Representation of Free Swell Index of BCS with various percentage of lime

It has been observed that the free swell index value continuously decreases with increase of lime content from 0% to 8%. The FSI value decreases from 95% to 62% at 0 to 8% of lime. Hence lime blended soils will be more volumetrically stable than soil alone.

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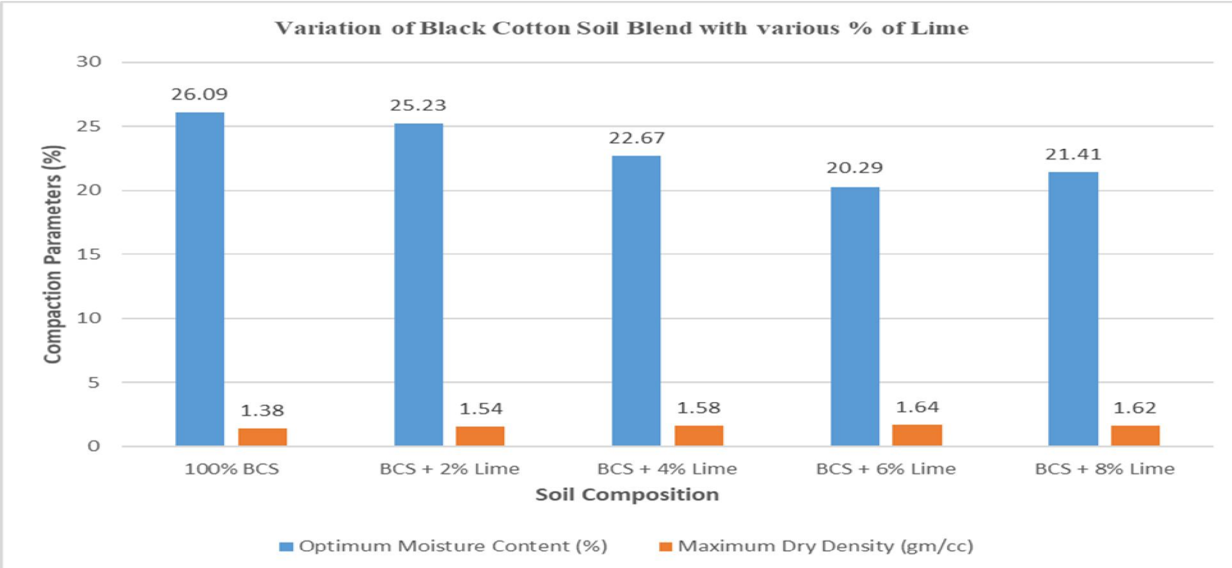
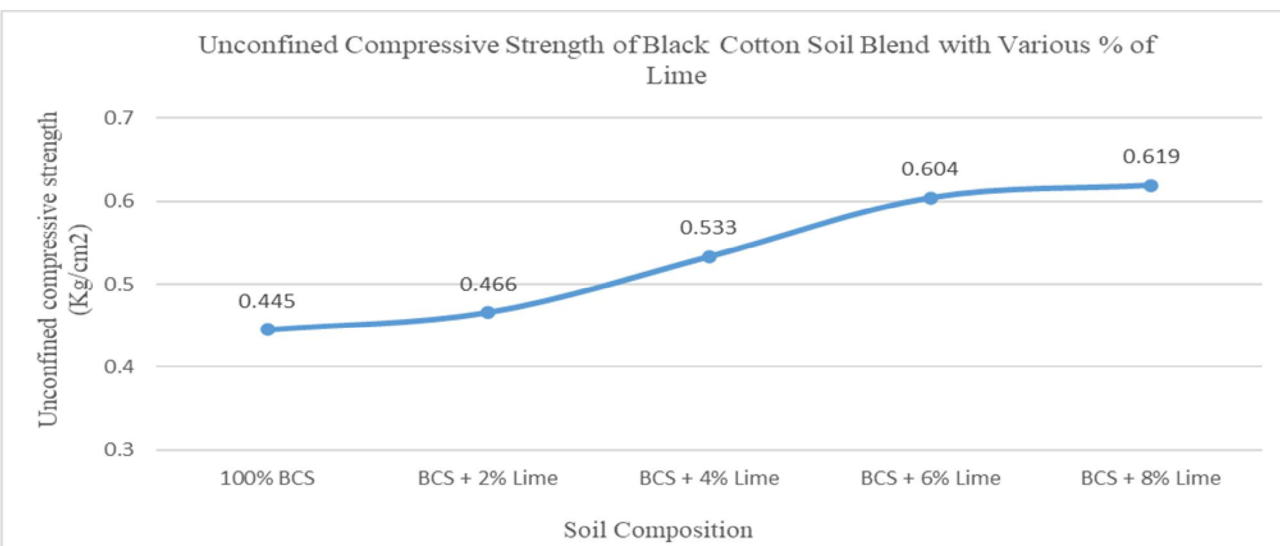
E. Modified Proctor Test



Graph No.-05 Graphical Variation of OMC and MDD of BCS with various percentage of lime

It has been observed that the black cotton soil is having 1.38 gm/cc maximum dry density and 26.07% optimum moisture content. With increasing the percentage of lime in black cotton soil, the maximum dry density of black cotton soil is 1.64 gm/cc and optimum moisture content is 20.29% with increasing the percentage of lime up to 6% but after that the value of maximum dry density and optimum moisture content is slightly decreased by increasing the percentage of lime up to 8%. and it is decreased up to 1.62gm/cc and 21.41%. The graphical presentation of percentage variation in MDD and OMC for BCS and mix specimen has shown in graph-5

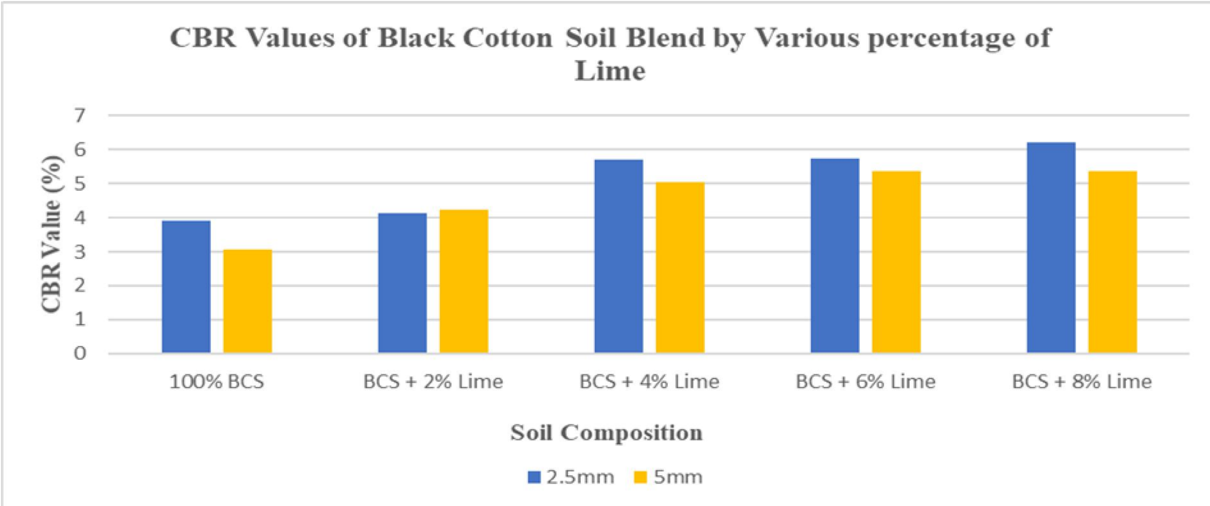
F. Unconfined Compressive Strength Test (UCS)



Graph-06 Graphical representation of UCS of BCS Blend with Various percentage of Lime

It has been observed that with increasing the percentage of lime in black cotton soil, the unconfined compressive strength increases. The value of unconfined compressive strength for black cotton soil is determined 0.455kg/cm^2 and in addition of lime it increase by 0.466kg/cm^2 to 0.619kg/cm^2 for 2% to 8% lime in soil.

G. California Bearing Ratio Test (CBR)

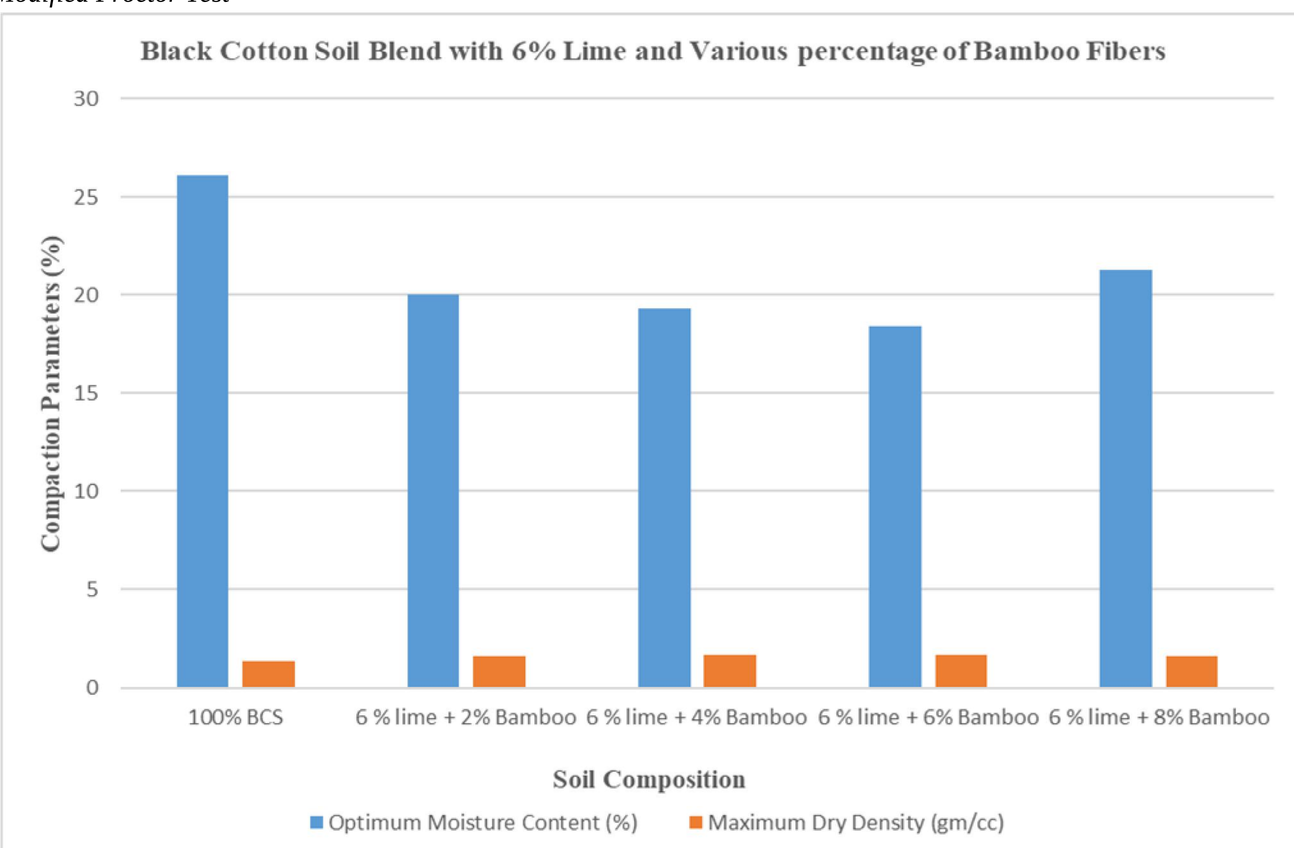


Graph No-07. Graphical representation of CBR Values of BCS Blend by Various percentage of Lime

The test has been conducted on the BC soil with different percentages of lime by weight of raw BC soil. In the Fig. 6 the load penetration bar (2.5mm and 5mm) of the BC soils with the addition of lime (0%, 2%, 4%, 6% and 8%) is formed which clearly depicts that as the lime content increases the load penetration value increases. The black cotton soil with 8% lime shows the highest limit of load bearing value of 6.21% and 5.38% at the penetration of 2.5mm and 5mm.

H. Bamboo + Lime Result

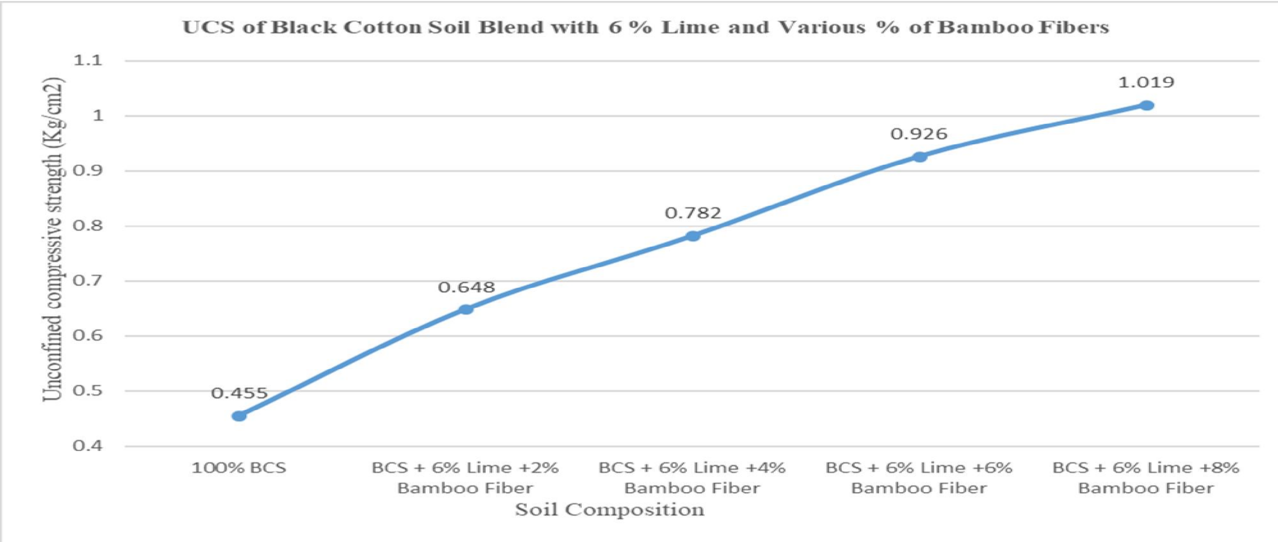
1) Modified Proctor Test



Graph No-08 Graphical Variation of OMC and MDD of BCS with 6% Lime and various percentage of Bamboo Fibers

It has been observed that the black cotton soil is having 1.38 gm/cc maximum dry density and optimum moisture content of 26.09%. With increasing the percentage of lime and bamboo fiber in black cotton soil, the maximum dry density and optimum moisture content is increased with increasing the optimum percentage of lime with different percentage bamboo fiber up to 6% lime + 8% bamboo fiber (1.69gm/cc and 18.25%).

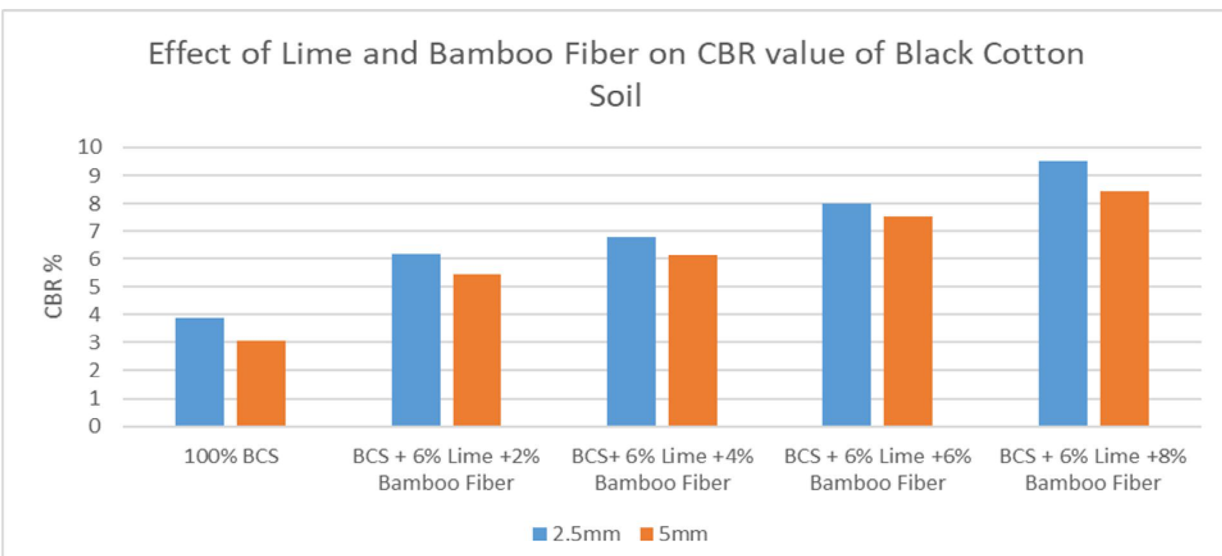
2) Unconfined Compressive Strength Test



Graph No-09 Graphical representation of Unconfined Compressive Strength of Black Cotton Soil Blend with 6% Lime and different percentage of Bamboo Fiber

It has been observed that with increasing the percentage of lime with different percentage of bamboo fiber in black cotton soil, the unconfined compressive strength increases. The value of unconfined compressive strength for black cotton soil is determined 0.455kg/cm2 and in addition of 6% lime with different proportion of bamboo fiber it increased by 0.648kg/cm2 to 1.019kg/cm2 for 6 lime + 2% bamboo fiber to 6%lime + 8% bamboo fiber in black cotton soil.

3) California Bearing Ratio Test



Graph No.-10 Graphical representation of CBR Values of BC Soil Blend by 6% Lime with Various percentage of Bamboo Fiber

V. PAVEMENT DESIGN

Pavement design is performed for rural roads, considering the subgrade soil with stabilization. For this purpose, 1 km rural road for a design period of 15 years has been considered. The total thickness of pavement crust has been designed with reference to pavement thickness plates in accordance with IRC 37-2018.

Flexible pavement crusts have been designed for two different stabilized soil compositions (i.e., lime and bamboo fiber) as a subgrade having CBR value more than 5% as per IRC 37-2018, for stabilized subgrade with optimum amount of lime (4%, 6%, and 8%) and lime with bamboo mixture (6% lime + 2%bamboo fiber, 6%lime + 4% bamboo fiber, 6%lime + 6%bamboo fiber and 6%lime + 8%bamboo fiber) having CBR values of lime (5.05%,5.36% and 5.38%) and for lime with bamboo fiber mixture (5.43%, 6.13%, 7.54% and 8.45%), respectively.

Designing of pavement for two lanes undivided/ single carriage way having 7m width for all CBR values.

Table No. 4 Pavement design for different % of lime and bamboo fiber with BCS

% of material added in BCS		4% lime	6% lime	8% lime	6%Lime+2%Bamboo fiber	6%Lime+4%Bamboo fiber	6%Lime+6%Bamboo fiber	6%Lime+8%Bamboo fiber
CBR (%)		5			5	6	8	
Cumulative traffic (msa)		30			30	30	30	
Pavement composition	Bituminous Concrete	40			40	40	40	
	Dense Bituminous Macadam	115			115	110	95	
	Wet Mix Macadam	250			250	250	250	
	Granular Sub Base	200			200	200	200	
Total thickness in mm		605			605	600	585	

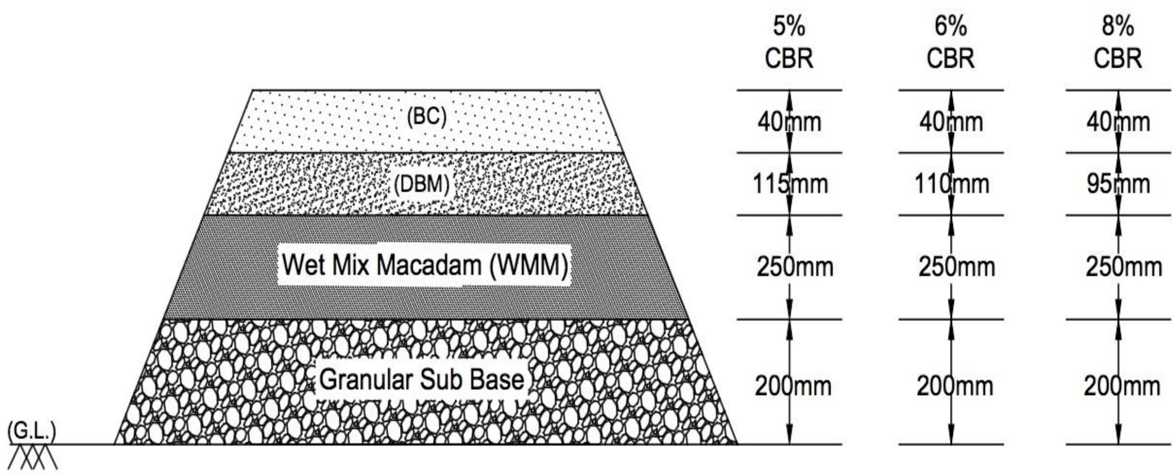


Figure- 22 Pavement composition with thickness of each layer for Different CBR values

A. Cost Evaluation of Pavements

The cost analysis of the designed pavements is carried out by considering the pavement to be double lane and by using the Public Works Department SSR (2022-23). The costs of pavement sections have been worked out for 10 km length considering width of pavement as 7 m. The details of cost analysis of designed pavement sections are presented in tables 5 and 6. Cost analysis of flexible pavements indicates that cost of the pavement decreases with increase in CBR value of the subgrade soil as the thickness of BC, DBM decreases.

Table No. 5 Summery Table for Conventional Road

Sr. No.	Particulars	Cost
1	Earthwork	9,17,30,387/-
2	Granular Sub Base	7,40,16,600/-
3	Water Bound Macadam	11,52,83,000/-
4	Dense Bituminous Macadam	25,30,06,250/-
5	Bituminous Concrete	7,74,45,480/-
6	Road Furniture	44,24,952/-
	Total Cost of Road	Rs 61,59,07,000/-

Table 14. Summery Table for Stabilized Road (BCS + 6%Lime + 8%Bamboo Fibre)

Sr. No.	Particulars	Cost (Rs)
1	Earthwork	10,31,21,509/-
2	Granular Sub Base	7,40,16,600/-
3	Water Bound Macadam	17,89,13,000/-
4	Dense Bituminous Macadam	15,64,41,250/-
5	Bituminous Concrete	7,74,45,480/-
6	Road Furniture	44,24,952/-
	Total Cost of Road	Rs 59,43,63,000/-

Comparative cost analysis is done on the grounds of pavement design for conventional roads and stabilized road. Above comparative cost analysis clearly reflects the decrease in cost of stabilized road by about 2.15 Cr i.e. 3.5% as compared to the cost of conventional road.

VI. CONCLUSION

The-following outcomes were made based on the experimentations carried out.

Adding of lime shows a falling graph in liquid-limit from 72.39% to 59.15%, as the lime % varies starting from 0 % to 8 % with an increment of 2 % added in Black Cotton soil and simultaneously improvement in plastic-limit starts from 33.07% to 45.06 % up to 6% lime content, and plastic limit reduced to 41.01% again at 8% lime content. Addition of lime to the black cotton soil up to 6% results in the rise in Maximum Dry Density value from 1.38 g/cc to 1.64 g/cc, whereas Optimum Moisture Content decreases from 26.09 % to 20.29 %. Unconfined compressive strength of treated black cotton soil with lime mix shows the increasing nature from 0.445 kg/cm^2 to 0.619 kg/cm^2 from 0% to 8% respectively. California Bearing ratio shows the increasing trend from 3.08% to 5.38%. Based on these results optimum lime content is considered as 6%.

Black Cotton soil with 6% lime and different proportions of bamboo fiber (2%, 4%, 6%, 8%) were tested for Unconfined compressive strength, California Bearing Ratio, Modified Proctor. Modified proctor test of this blend (BCS + 6% lime + varying proportion of Bamboo fiber) showed the increasing nature of Maximum Dry Density from 1.38 g/cc to 1.69 g/cc while Optimum Moisture Content decreases from 26.09 % to 18.25 % with the increasing proportion of Bamboo Fiber. Unconfined Compressive strength results shows the significant increase in UCS from 0.455kg/cm^2 to 1.019 kg/cm^2 at 8% bamboo fiber addition. Soaked CBR values are majorly increasing from 3.08 % to 8.45 % up to 8 % of bamboo fiber and 6% lime added to Black cotton soil. Under this examination, utilization of lime and bamboo fibers helps to develop strength in soil significantly. CBR values raise due to lime significantly bonded with soil particles that resist the entrance of water and adding fibers enhance the strength. Test results proved that the effect of lime and bamboo fibers in soil-stabilization can develop the strength significantly. From the trails, the optimum-proportion of lime-and Bamboo fibers are 6% and 8% correspondingly.

Overall, lime and bamboo fiber stabilized Black cotton soil can be used as subgrade for pavement construction from point of view of cost-effective concern for subgrade improvement. As per IRC 37-2018, design of pavement for 5%, 6%, 8% CBR shows that as the CBR value increases, the thickness of Dense Bituminous Macadam decreases by 5-15%. As per Public Works Department SSR (2022-23) with the increase in CBR, Comparative cost analysis is done on the grounds of pavement design for conventional roads and stabilized road. Comparative cost analysis clearly reflects the decrease in cost of stabilized road by about 2.15 Cr i.e., 3.5% as compared to the cost of conventional road.

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