A case study on Air-cooled Blast Furnace slag Blended with Black Cotton Soil for sustainable Engineering Applications

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Abstract: In Civil engineering the construction of Highways, Runways & Railways are major essential applications. Construction of Road or Railways requires the good sub grade material, obtaining such materials of required quality has become an issue. Construction of such structures on Black Cotton soil (BC soil), has become an challenge to engineers as it undergoes high rate of swelling and shrinkage in the presence and absence of water. Further, in this study, attempt has been made to stabilize weaker soil such as Black Cotton soil (BC soil) using suitable stabilizers, so that the soil strength can be increase.

To achieve this, Air Cooled Blast-furnace Slag (ACBS) has been selected has additives in the present study. Initially, BC soil and ACBS are characterized for its physical, chemical and Geotechnical properties respectively, to estimate its behaviour in various condition (with and without water). Later, blending of BC soil with ACBS has been done in two methods: In the First method, ACBS is added to the BC soil in the increment of 3%, 6%, 9%...20% by dry weight of soil, where as in second method ACBS is replaced with BC soil with same (as that of first method) percentage of replacement. These increments of additives and replacements are selected based on trial and error method. Further, for each increment of additives, Physical and Geotechnical characteristics of BC soil has been determined, to analyse the change in the properties of BC. Further, the post stabilization characteristics of BC soil are compared with its original characteristics and optimum dosage of stabilizer is worked out.

There are economic, environmental, and social benefits derived from the effective use of ACBS rather than disposing of it as waste. As a result, the valuable use of ACBS has broad positive impacts on sustainability, a consideration of increasing importance.

Keywords: Air-cooled Blast Furnace slag, Black Cotton soil, Characterization Blending of soil

1. INTRODUCTION: Black cotton soils (BC soils) are inorganic clays of medium to high compressibility and form a major soil group in India. They are characterized by high shrinkage and swelling properties. Moreover, such Black cotton soils covers approximately 20% of the total area of Indiaand occurs mostly in the central and western parts. Further, because of its high swelling and shrinkage characteristics, the Black cotton soils have been a challenge to the highway engineers. The Black cotton soils are very hard when dry, but lose its strength completely when in wet condition[3].

It is observed that on drying, the black cotton soil develops cracks of varying depth. Because of wetting and drying process, vertical movement takes place in the soil mass [2]. All these movements lead to failure of pavement, in the form of settlement, heavy depression, cracking and unevenness.

It is a well-known fact that water is the worst enemy of all structures, particularly in expansive soil areas. Water penetrates into the foundation from three sides viz. top surface, and from bottom layers due to capillary action [29]. Therefore, specifications in expansive soil areas must take these factors into consideration [5, 4]. The surfacing must be impervious, sides paved and soil beneath well treated to check capillary rise of water.

It has been found during handling of various investigation project assignments for assessing causes of structural failures that water has got easy access into the foundations [6, 8]. It saturates the soil and thus lowers its bearing capacity, ultimately resulting in heavy depressions and settlement. Water lubricates the soil particles and makes the mechanical interlock unstable. In the top surface, ravelling, stripping and cracking develop due to water stagnation and its seepage into the bottom layers [7, 9, 10].

Blast-furnace slag is defined by the American Society for Testing and Materials as "the non-metallic product consisting essentially of silicates and alumino-silicates of calcium and other bases that is "developed in a molten condition simultaneously with iron in a blast furnace." The blast furnace is the primary means for sinking iron oxides to molten, metallic iron. It is constantly stimulating with iron oxide sources (ores, pellets, sinter, etc.), flux stone (limestone and dolomite), and fuel (coke). Molten iron collects in the bottom of the furnace and the liquid slag floats on it. Both are regularly tapped from the furnace [30]. The slag consists primarily of the impurities from the iron ore (chiefly silica and alumina) mutual with calcium and magnesium oxides from the flux stone [28].

2. MATERIALS AND METHADOLOGY

The following are the materials which are used in the present work.

- Air-Cooled Blast furnace Slag and
- Black Cotton soil

2.1. Air-Cooled Blast furnace Slag (ACBS)

Blast furnace slag is improved by melting separation from blast furnaces that generate molten pig iron. It consists of non-ferrous components enclosed in the iron ore mutually with limestone as an auxiliary materials and ash from coke. Roughly about 290kg of slag will generated for each ton of pig iron. When it is expelled from blast furnace, the slag is molten at a temperature of approximately 1400˚C (Shown in Fig 2.2). Depending on the cooling method used, it is called as air-cooled slag or granulated slag. In the present study. The slag is obtained from Hospet steels limited steel plant, Hospet, Bellary District of Karnataka, India. Fig 2.1 shows the location of sample extraction for the study.

Fig 2.1 Location of site (Source: Google)

Fig 2.2 molten blast furnace slag being dumped into a cooling pit (Source: Google)

2.2 Black Cotton Soil

Black cotton soil is aexceedingly clayey soil. The Black cotton soil has a high percentage of clay, which is largely montmorillonite in composition. Expansive soils are the soils which enlarge when the moisture content of the soils is increased. The expansive soils are called swelling soils or black cotton soils. Such soil sample is collected from madugiri, Tumkur district, Karnataka, India. Sampling location is shown in fig 2.3

2.3 Methodology

Characterization of BC soil and ACBS are carried out to know the physical, chemical and geotechnical characteristics. The result obtained from these tests are requisite to know the various properties, which are important to conclude the quality of soil and ACBS, also its behaviour at different condition. The tests that are conducted are as follows;

Table 2.1 Physical Characterization tests

Physical Characterization	
Test Conducted	**Reference**
Water content determination	IS: 2720 Part 2 (1973)
Specific gravity	IS: 2720 PART 3 (1980)
Grain size analysis	IS: 2720 PART 4 (1985)
Hydrometer test	IS:3104 (1965)
Consistency limit	IS: 2720 Part 5 (1985)
Organic content test	ASTM D 2974-87
Free swell test	IS: 2720 Part 40 (1977)

Table 2.2 Chemical Characterization tests

Chemical Characterization	
Test Conducted	**Reference**
pH test	IS: 3025 (Part XXII)-1987
. Electrical Conductivity	IS: 3025 (Part XXVI)-1987
Total Dissolved Test	IS: 3025 (Part XXV)-1987
X-Ray florescence (XRF)	ASTM E572 - 13

Table 2.3 Geotechnical Characterization tests

Geotechnical Characterization	
Test Conducted	**Reference**
Standard Proctor test.	IS-2720 PART 7-1983
Un-soaked California bearing ratio test.	IS: 2720 (PART XVI) - 1979
Unconfined Compression Test.	IS 2720 (PART10) 1979

3. RESULTS AND DISCUSSION

Table 3.1 Physical properties of black cotton soils and ACBS

Name	W %	% Fraction				IS Classification	G	Organic content (%)	FSI (%)	Consistency Limit			C_u	C_c
		Gravel	Sand	Silt&	clay					W_L (%)	W_P (%)	SL (%)		
BC Soil	28.3	0	32	19	49	CH	2.62	4.74	50	55.7	35.41	12.3	NA	NA
ACBS	2.6	0	100	0	0	SW	3.15	1.45	0	Non Plastic			5.1	1.9

Table 3.2 Chemical properties of BC Soil and air-cooled blast furnace slag

Sl no	Parameters	BC Soil (% by weight)	ACBS (% by weight)
1	Water soluble chlorides as Cl	0.024	<0.010
2	Water soluble sulphates as SO4	<0.05	0.30
3	Water soluble alkalinity (total) as CaCO3	0.50	0.27
4	Total hardness as CaCO3	0.12	0.22

5	Total dissolved solids	311.6 µs/ppm	356.7 µs/ppm
6	pH of water extract	7.78	10.2
7	Electric conductivity	555.2 µs/ppm	576 µs/ppm
8	SiO_2	63.8	19.35
9	Al_2O_3	13.79	2.01
10	Fe_2O_3	7.68	43.95
11	CaO	1.64	24.25
12	MgO	1.33	4.36
13	MnO	0.12	1.48
14	Na_2O	1.12	0.30

Table 3.3 Geotechnical properties of black cotton soils

Sl no	Laboratory Test	BC Soil
1	Optimum Moisture Content (OMC)	20.5%
2	Maximum Dry Density (MDD)	1.63 gm/cc
3	CBR value @2.5mm Penetration	2.25
4	CBR value @5mm Penetration	2.18
5	Unconfined Compression Strength	5.49 KN/m^2

It can be concluded from the test results that, BC soil has higher water holding capacity and has high clay content with free swell Index (FSI) 0f 50% (refer table 3.1), which shows that soil is highly susceptible for high rate of swelling and shrinkage, in the presence and absence of water. Father, BC soil exhibits very less strength (refer table 3.3), which is not sufficient for any engineering applications. Therefore, the BC soil has to be stabilized with suitable stabilizing agent.

Furthermore, ACBS has also tested for its physical and chemical properties, and it is observed that, ACBS exhibits higher specific gravity and non-plastic in nature (refer table 3.1), moreover, ACBS is basic in nature, with higher content of iron oxide (refer table 3.2), which will help in increase strength of BC soil when it is used as stabilizing agent.

Blending of BC soil with ACBS has been done in two methods [22]: In the First method, ACBS is added to the BC soil in the increment of 3%, 6%, 9%...20% by dry weight of soil, where as in second method ACBS is replaced with BC soil with same (as that of first method) percentage of replacement. These increments of additives and replacements are selected based on trial and error method. Further, for each increment of additives, Physical and Geotechnical characteristics of BC soil has been determined, to analyse the change in the properties of BC.

3.1 Addition of ACBS to BC soil

ACBS is added to the dry BC soil in increments of 3% until mix proportion reaches 20%. Thereafter, its physical and geotechnical properties are determined for each of the mixer and optimum dosage of ACBS is determined whose strength is maximum.

Table 3.4 Variation of consistency limit with various percentage of addition of ACBS

Sl no	% Addition of ACBS	Liquid Limit (%)	Plastic Limit (%)	Shrinkage limit (%)
1	0%	55.7	35.41	12.3
2	3%	52.8	33.08	11.65
3	6%	48.5	31.17	11.0
4	9%	44.2	29.87	10.79
5	12%	41.5	28.34	10.42
6	15%	39.3	26.79	10.35
7	20%	37.4	25.44	10.22

From table 3.4 it can be concluded that, the addition of ACBS to the BC soil from 3 to 20 % has shown linear decrease in liquid limit plastic limit and shrinkage limit values. Further, with decrease in consistency values, the reactivity of soil get decreases and hence swell potential of the soil.

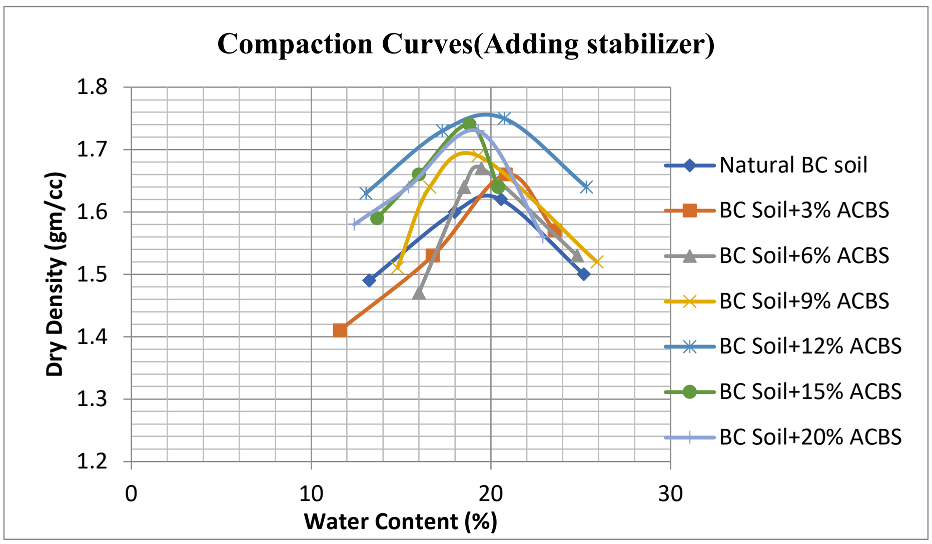

Fig 3.1 compaction curves for Black Cotton soil with percentage of addition of ACBS

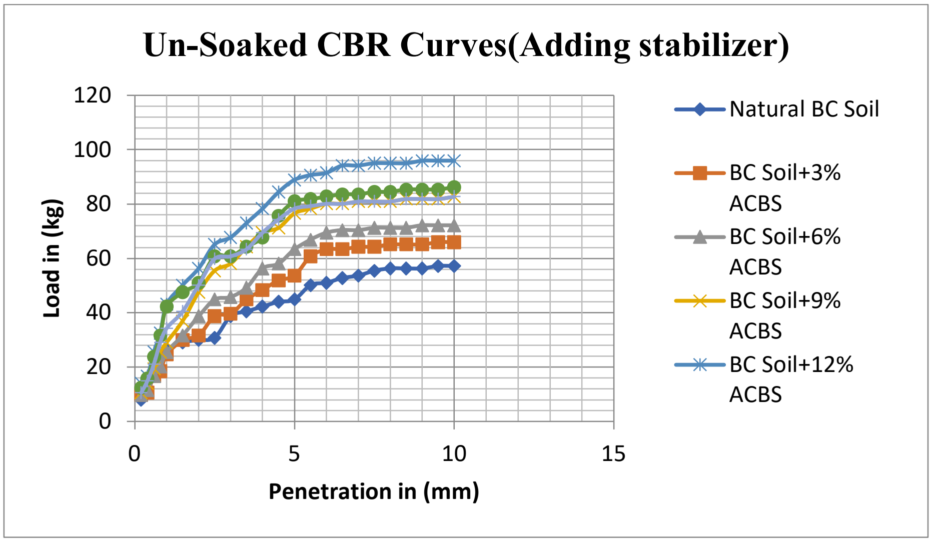

Fig 3.2 CBR for Black Cotton soil with percentage of addition of ACBS

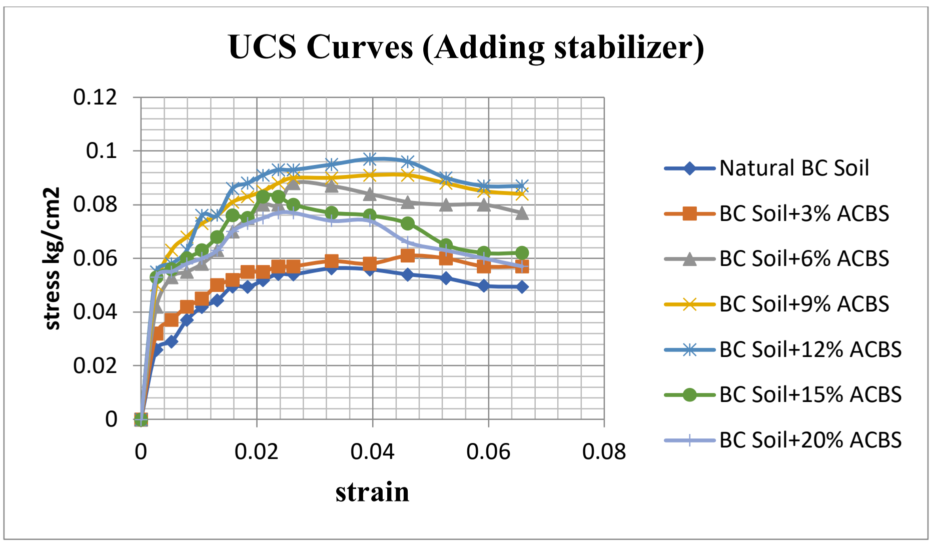

Fig 3.2 UCS for Black Cotton soil with percentage of addition of ACBS

Table 3.5 Geotechnical properties of BC soil with percentage addition of ACBS

Sl no	% of additive added to BC soil	OMC (%)	MDD (gm/cc)	CBR 2.5mm Penetration	CBR 5mm Penetration	UCS (KN/m^2)
1	0%	20.5	1.63	2.25	2.18	5.49
2	3%	19.6	1.67	2.83	2.61	5.98
3	6%	19.1	1.68	3.28	3.08	8.63
4	9%	18.2	1.71	4.05	3.73	8.92
5	12%	17.5	1.76	4.75	4.33	9.51
6	15%	16.8	1.75	4.43	3.94	8.14

7	20%	16.05	1.73	4.36	3.81	7.55

OMC=Optimum Moisture Content, MDD=Maximum Dry Density, CBR=California Bearing Ratio, UCS=Unconfined Compression Strength

It can be depicted from fig 3.1, 3.2 and 3.3 that, the strength properties of BC soil added with different percentage of ACBS has been analysed. Furthermore, it is very clear that, addition of 12% of ACBS yielded maximum strength (refer table 3.5) to the BC soil, and hence this percentage is concluded as optimum dosage, and the same can be implemented in the field for engineering application as per the direction of [26]

3.2 Replacement of ACBS with BC soil

ACBS is replaced with dry BC soil in increments of 3% until mix proportion reaches 20%. Thereafter, its physical and geotechnical properties are determined for each of the mixer and optimum dosage of ACBS is determined.

Table 3.6 Variation of consistency limit with various % of replacement of ACBS

Sl no	% replacement of ACBS	Liquid Limit (%)	Plastic Limit (%)	Shrinkage limit (%)
1	0%	55.7	35.41	12.3
2	3%	51.4	32.73	11.51
3	6%	47.8	30.05	10.88
4	9%	43.5	28.85	10.64
5	12%	40.7	27.56	10.34
6	15%	37.9	26.48	10.27
7	20%	35.6	24.33	10.19

From table 3.6 it can be concluded that, the replacement of ACBS with BC soil from 3 to 20 % has shown similar trend as that of addition of ACBS to BC soil (refer table 3.4), both methods has shown linear decrease in liquid limit plastic limit and shrinkage limit values. Further, with decrease in consistency values, the reactivity of soil get decreases and hence swell potential of the soil.

Table 3.7 Geotechnical properties of BC soil with percentage addition of ACBS

Sl no	% of additive added to BC soil	OMC (%)	MDD (gm/cc)	CBR 2.5mm Penetration	CBR 5mm Penetration	UCS (KN/m^2)
1	0%	20.5	1.63	2.25	2.18	5.49
2	3%	19.6	1.67	3.21	2.83	6.27
3	6%	19.1	1.68	4.56	3.38	8.82
4	9%	18.2	1.71	6.23	4.84	9.41
5	12%	17.5	1.76	7.07	5.31	10.0
6	15%	16.8	1.75	5.85	4.41	8.04
	20%	16.05	1.73	4.24	3.47	7.34

OMC=Optimum Moisture Content, MDD=Maximum Dry Density, CBR=California Bearing Ratio, UCS=Unconfined Compression Strength

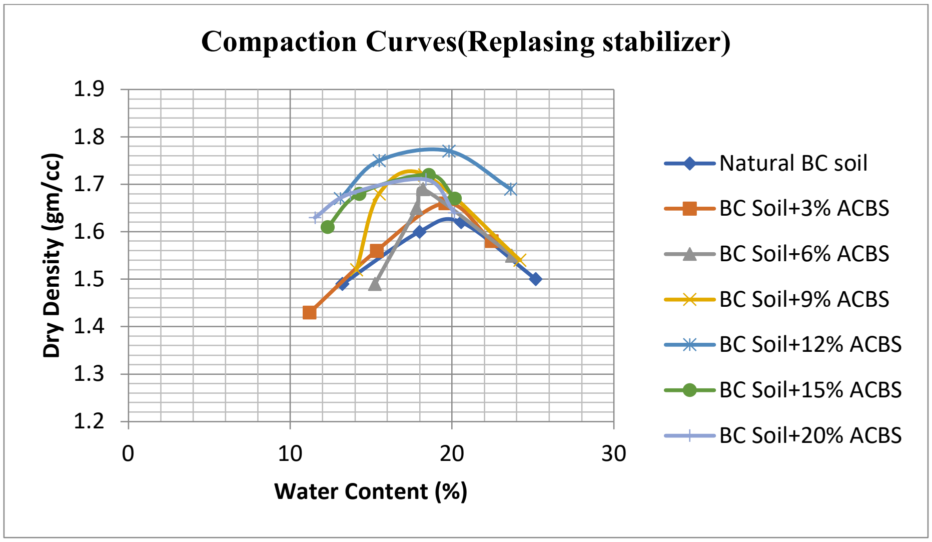

Fig 3.4 compaction curves for Black Cotton soil with percentage of Replacement of ACBS

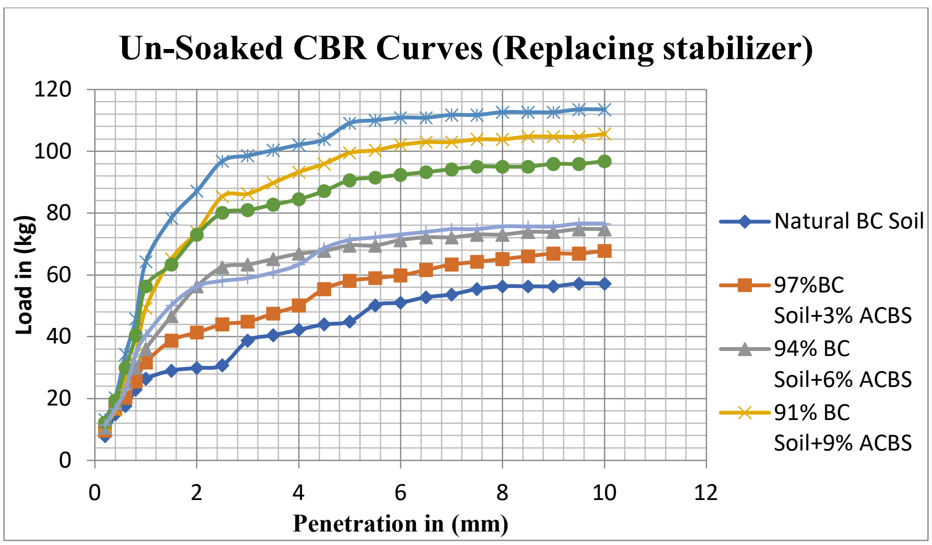

Fig 3.5 CBR for Black Cotton soil with percentage of Replacement of ACBS

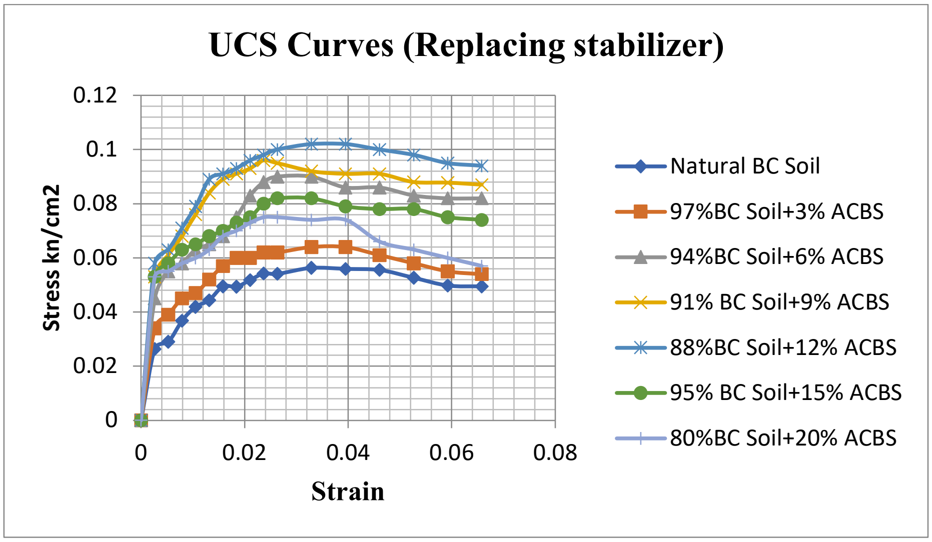

Fig 3.6 UCS for Black Cotton soil with percentage of Replacement of ACBS

It can be depicted from fig 3.4, 3.5 and 3.6 that, the strength properties of BC soil replaced with different percentage of ACBS has been analysed. Coincidently, percentage replacement and percentage addition of ACBS has yielded maximum strength at 12% of replacement and addition respectively with BC soil. Further, 12% of ACBS has been concluded as optimum dosage in both the methods.

3.3 Comparison of both the methods

BC Soil has been Blended with ACBS, blending has of ACBS is done by two methods. In first method, stabilizer ACBS is added to the BC soil in incremental percentage whereas in second method, ACBS stabilizer is replaced with equal percentage of BC soil. However, the percentage of addition in first method and percentage replacement in second method are maintained same (i.e., 3%, 6%, 9%, 12%, 15%, and 20%). The results of both the methods are compare in the following section.

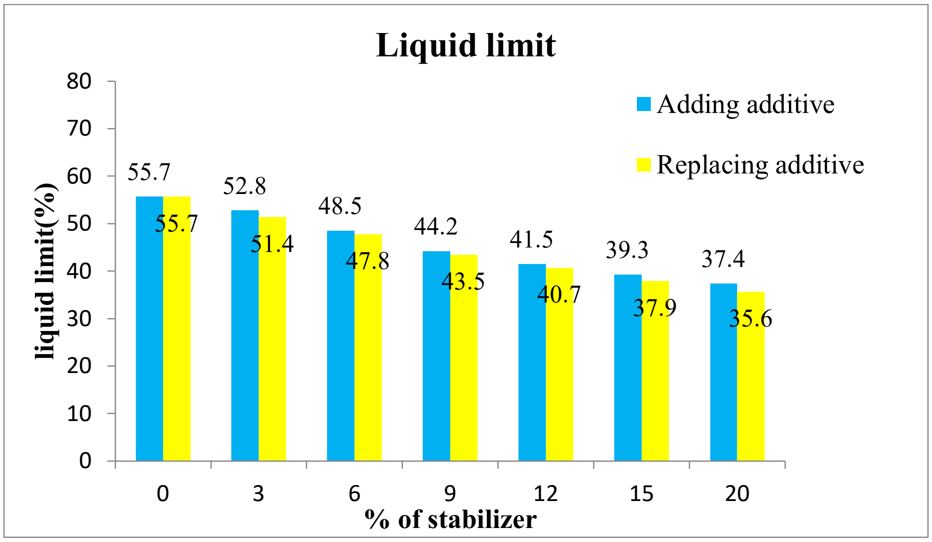

Fig 3.7 Comparison of Liquid Limit results between two methods

From Fig 3.7 it is evident that, with both methods the value of liquid limit has shown decreasing trend with increase in percentage of additive. However, by replacing ACBS with BC soil has shown comparatively lesser values than by adding stabilizer to the soil. Moreover, in difference in the change in liquid limit is less, and hence both the methods are recommended to use in the practice.

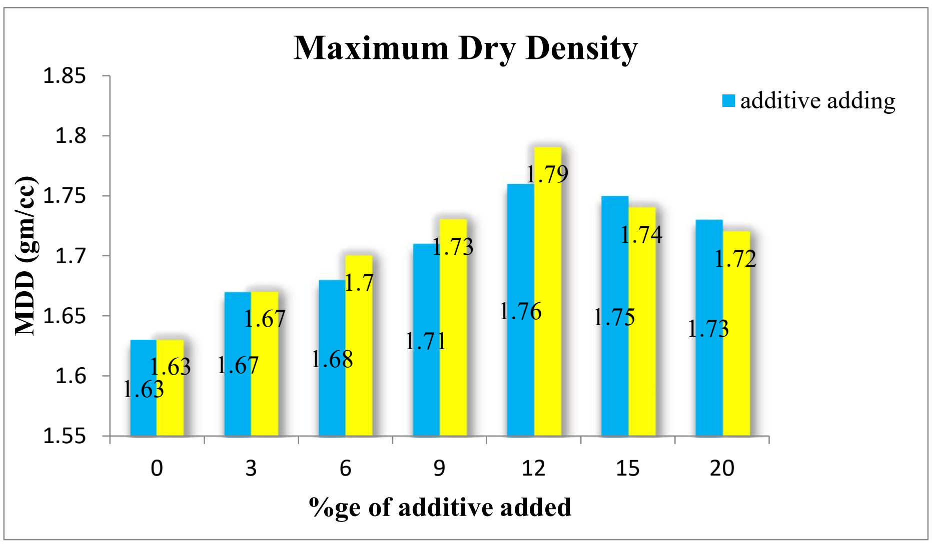

Fig 3.8 Comparison of MDD results between two methods

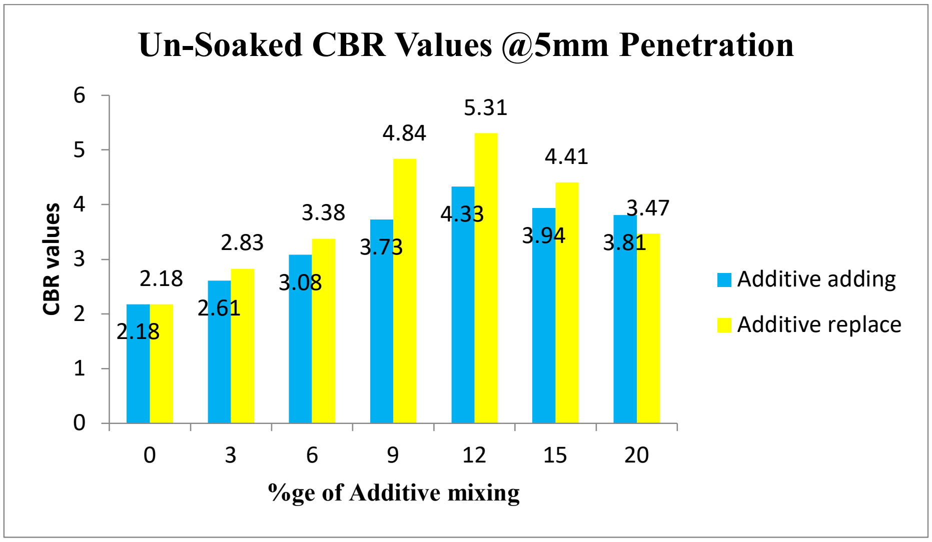

Fig 3.9 Comparison of CBR results between two methods

The strength parameters such as density and CBR values are compared and results are displayed in Fig 3.8 and Fig 3.9. It is evident from these results that, with both the methods soil yielded maximum strength at 12% of stabilizer. However, by comparing both the methods it can be concluded that, by replacing stabilizer with BC soil yielded more strength than by adding stabilizer.

4. CONCLUSION

- From the present study, it is concluded that, the optimum additive content of 12% yielded maximum strength to the BC soil in both the methods by adding and replacing the BC soil.
- Addition of ACBS leads to the increase in the maximum dry density (1.63 to 1.76gm/cc) and decrease in the optimum moisture content (20.5 to 16.5).
- Replacement of ACBS leads to the increase in the maximum dry density (1.63 to 1.79gm/cc) and decrease in the optimum moisture content (20.5 to 15.1). The addition of ACBS individually improves the properties of BC soil.
- The CBR value at OMC for natural BC Soil was 2.25, which is increased to 4.75 by the addition of 12% optimum stabilizer, and the same was increase to 7.07 by the replacement of 12% optimum stabilizer.
- The UCS value at OMC for natural BC Soil was 5.49KN/m^2 which is increased to 9.51KN/m^2 by the addition of 12% optimum stabilizer, and the same was increase to 10. KN/m^2 by the replacement of 12% optimum stabilizer.

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