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An Experimental Investigation on the Behaviour of BC Soil Stabilized with Cement

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Abstract-Expansive soils show the significant geotechnical and structural challenges. Worldwide the costs associated with expansive behaviour are estimated at several billions per year. Expansive soils are those soils that experience volume changes related to changes in water content. These volume changes can be either in the form of swelling or in the form of shrinkage and are therefore sometimes known as swell/shrink soils. When working with large land areas include: soil properties, suction/water conditions, temporal and spatial changes in water content, e.g. generated by the trees and geometry/stiffness of foundations and related structures. Expansive soils can be found in wet environments where expansive problems occur with soils with a high index of plasticity (Ip) or in arid/semi-arid areas where both soils and medium expansions can cause significant damage. In Belagavi district of Karnataka state, damage often occurs as a direct result of interaction with vegetation and associated changes in water content. The lands experience swelling/shrinkage problems in Belagavi. However, a slight swelling/shrinking potential may occur in many parts of the country.

The main objective of this experimental investigation is to study the behaviour of BC soil stabilized with cement.

Key words: BC soil, Stabilization, cement, Atterberg limits, expansive.

1. INTRODUCTION

The soil has a solid mineral and organic phase, as well as a porous phase that stores gases and water. The pore space allows for penetration and the movement of air and water. Consistency, a common soil problem, reduces this space. If sufficient time is given, the bare soil will alter the soil profile consisting of two or more layers, referred to as soil patches, varying in one or more properties such as their composition, inclination, consistency, colour, and functionality. They vary widely in size and usually have no sharp edges; their development depends on the type of parent material. Biological influences on soil properties are much stronger than surface, while geological influences on soil properties increase with depth. Water is a critical agent in soil development because of its involvement in degradation, rainfall, erosion, transport, and the characterization of soil materials. Cement stabilization is a cost-effective and worldwide method for pavement and earth structure works. Stabilization begins by mixing the in-situ soil in a very relatively dry state with cement and water specified for compaction. The soil, within the presence of moisture and a cementing agent becomes a modified soil, i.e., particles group together due to physical-chemical interactions among soil, cementing material and water. Compaction is required to create soil particles slip over one another and move in a densely packed state. During this state, the soil particles will be welded by chemical (cementation) bonds and become an engineered material.

Puzzolonic reactions occur when siliceous and aluminous materials react chemically with hydroxide at regular temperatures to create cementitious compounds (Grytan Sarkar.et al 2012) [1]. On the opposite hand, a cation exchange occurs when the soil is in a position to exchange free cations available within the exchange locations. When water is mixed with cement, hydration occurs, meaning cementing compounds of calcium–silicate–hydrate (C–S–H) and calcium–aluminate–hydrate (C–A–H) are formed and excess calcium hydrate (CaOH) is released, approximately 31% by weight. Formation of C–S–H and C–A–H occurs when crystals begin forming in few hours after the water and cement are mixed (Sankar Bhattacharjaet.al 2003) [15]; crystals will still form as long as unreacted cement particles and free water remain within the mixture (Gregory E. Halsted et.al 2008) [9]. Soils that have a PI value beyond 30 are difficult to combine with cement. Increase of plastic limit implies that cement treated soil required more water to vary its plastic state to semisolid state. This modification of Atterberg limit is due to the cation exchange reaction and flocculation–aggregation for presence of more amount of cement, which reduces plasticity index of soil. A reduction in plasticity index causes a big decrease in swell potential and removal of some water which will be absorbed by clay minerals. (M. Bayat.et.al 2013) [12].

The main objective of this experimental work is to study the behaviour of BC soil stabilized with different percentages of cement. Different properties studied are Specific gravity, Permeability, Atterberg limits, OMC, UCS and CBR.

2 MATERIALS AND METHODOLOGY

2.1 Materials used

2.1.1 Black cotton soil

Black cotton soil used in the study is obtained from Belagavi in the state of Karnataka. It is smooth in texture. For the purpose of tests, the soil is collected at a depth of 1mt below the ground level. It is pulverised, dried, sieved through different sieves for the required tests and stored in polythene bag in the laboratory. The chemical compositions of BC soil are as shown in Table:1

Fig: 1 BC soil used in research work.

Table: 1 Chemical composition of BC soil.

Chemical present	Available percentage.
Ca O	1.05
SiO_2	79.93
Al_2O_3	10.59
Fe_2O_3	5.07
MgO	2.11
Na	0.6
K	1.11

2.1.2 Ordinary Portland cement (OPC-43 grade)

OPC is procured commercially and is used for research work. The chemical compositions of cement is shown in Table: 2

Fig:2 Cement used in research work.

Table: 2 Chemical composition of cement

Chemical present	Available percentage.
Ca O	63
SiO_2	21.9
Al_2O_3	6.9
Fe_2O_3	3
MgO	2.5
SO_3	1.7

2.2. Methodology: This describes about the experimental programme with BC soil which is used for investigation and different experiments to be carried using cement as stabilizer.

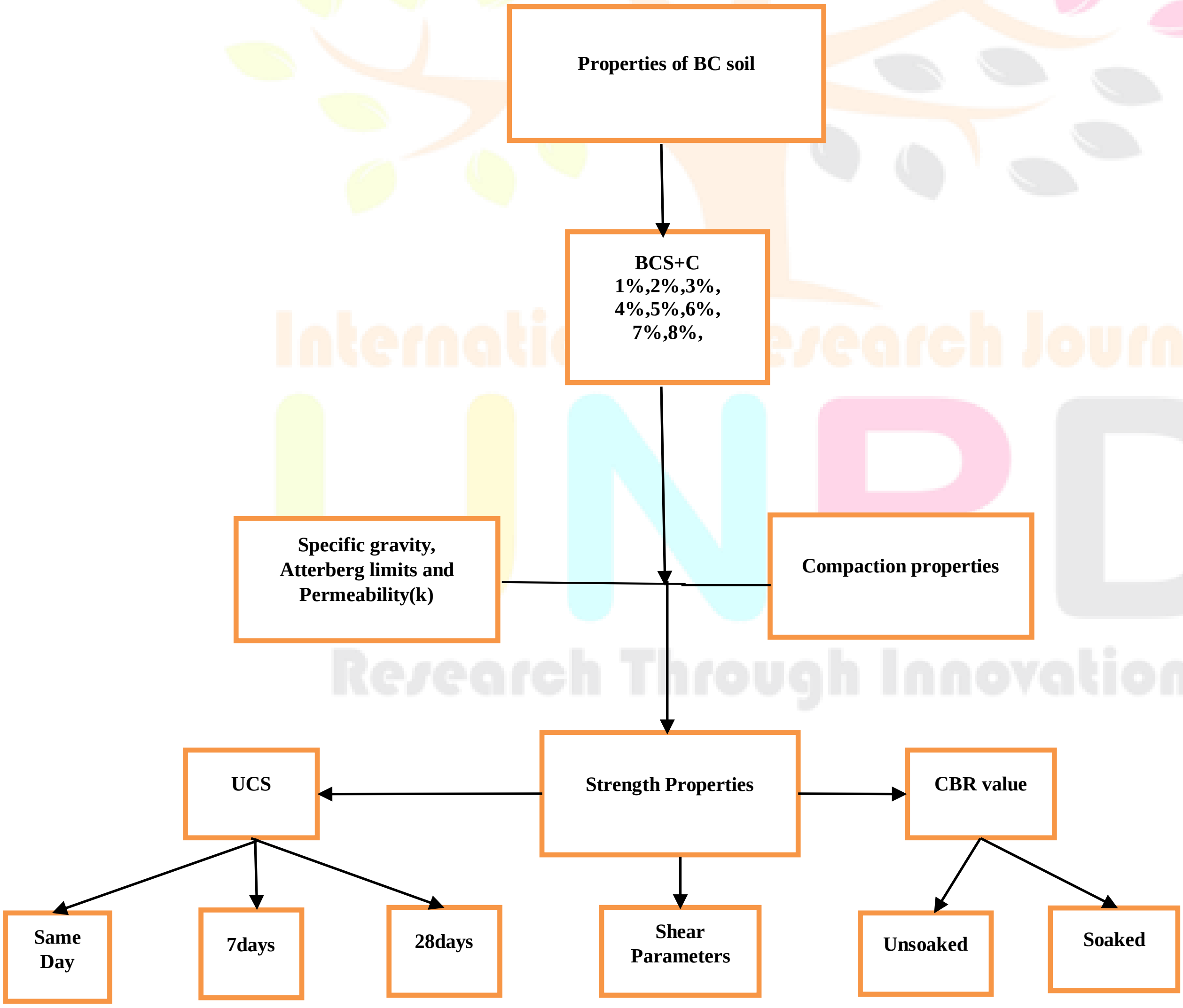

Fig: 3 Experimental programmes.

3. TEST RESULTS

3.1 Properties of BC soil: **T**his section deals with the test results as obtained from the experimentations. Table: 3 shows the properties of the black cotton soil which explains the behaviour when it comes in contact with water.

Table: 3 Properties of BC soil.

Sl No	Laboratory tests	Results
1	Grain size distribution; Fine sand fraction (%) Silt fraction (%) Clay fraction (%)	 15.2 17.6 67.2
2	Specific gravity(G)	2.72
3	Liquid limit, wL (%)	65
4	Plastic limit (wp) (%)	27
5	Plasticity index, IP (%)	38
6	Shrinkage limit (ws) (%)	11
7	Unified soil classification	CH
8	Optimum moisture content (OMC) %	22
9	Max dry density (MDD) gm/cc	1.57
10	Cohesion (C), kg/cm^2	0.33
11	Angle of internal friction (Φ) ^{o}	23^o
12	UCS, kg/cm2	0.66 for day-1 0.95 for day-7 1.24 for day-28
13	CBR Value	
	Unsoaked 2.5mm	5.62 %
	5.0mm	2.18%
	Soaked 2.5mm	3.25%
	5.0mm	2.06%

3.2 Mix design

The mix design is decided on the basis of trial and error method and from literature review, where it is decided to keep cement percentage varying from 1% to 8%.

Table: 4 Mix design details.

Soil type	Mix proportions
Black cotton soil + Cement	BCS99%+1%C
	BCS98%+2%C
	BCS97%+3%C
	BCS96%+4%C
	BCS95%+5%C
	BCS94%+6%C
	BCS93%+7%C
	BCS92%+8%C

3.3: Index properties of BC soil stabilized with cement

Following tables give the index properties of the soil stabilized with various percentages of cement. The variation of index properties is depicted in the form of graphs.

Table: 5 Index properties of BC soil stabilized with cement.

Percentage replacement of BC soil by cement	Specific gravity	Coefficient of permeability cm/sec	Liquid limit (%)	Plastic limit (%)	Plasticity index	Shrinkage limit (%)
0% (Ref mix)	2.72	2.12E-06	65.00	27.00	38.00	11.00
1.0%	2.74	2.00E-06	64.60	27.80	36.80	10.82
2.0%	2.77	1.90E-06	63.70	28.60	35.10	10.32
3.0%	2.80	1.80E-06	63.00	29.50	33.50	9.85
4.0%	2.82	1.60E-06	62.50	30.70	31.80	9.35
5.0%	2.83	1.50E-06	61.70	31.60	30.10	8.85
6.0%	2.85	1.30E-06	60.40	32.50	27.90	8.21
7.0%	2.88	1.12E-06	59.30	33.20	26.10	7.68
8.0%	2.90	1.00E-06	58.40	34.30	24.10	7.09

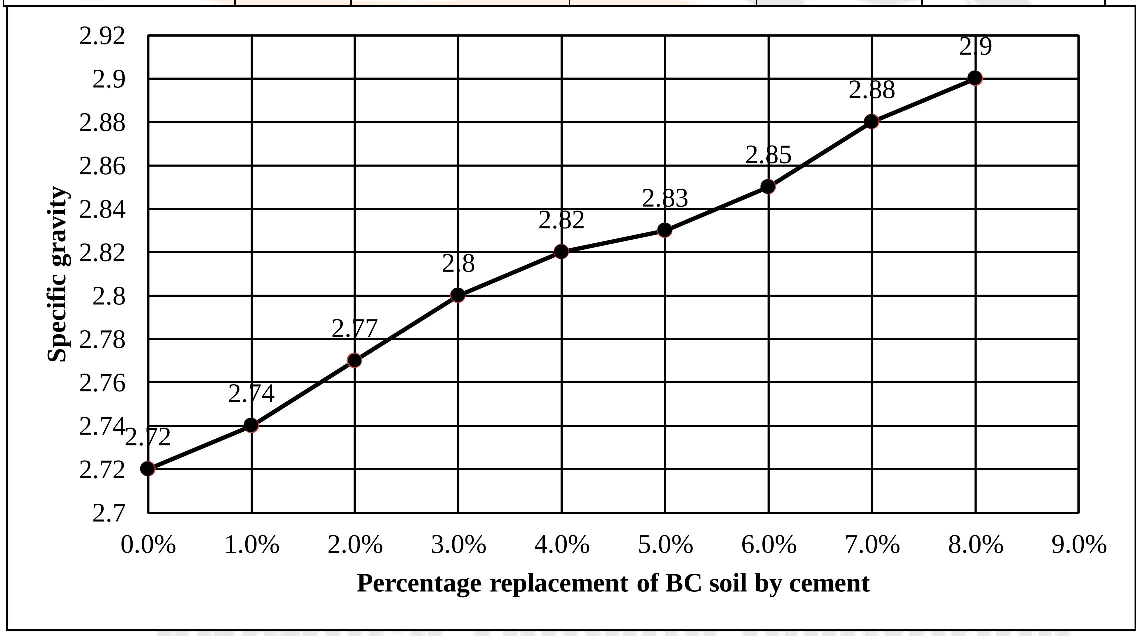

Fig: 4 Variation of specific gravity for different percentage replacement of BC soil by cement.

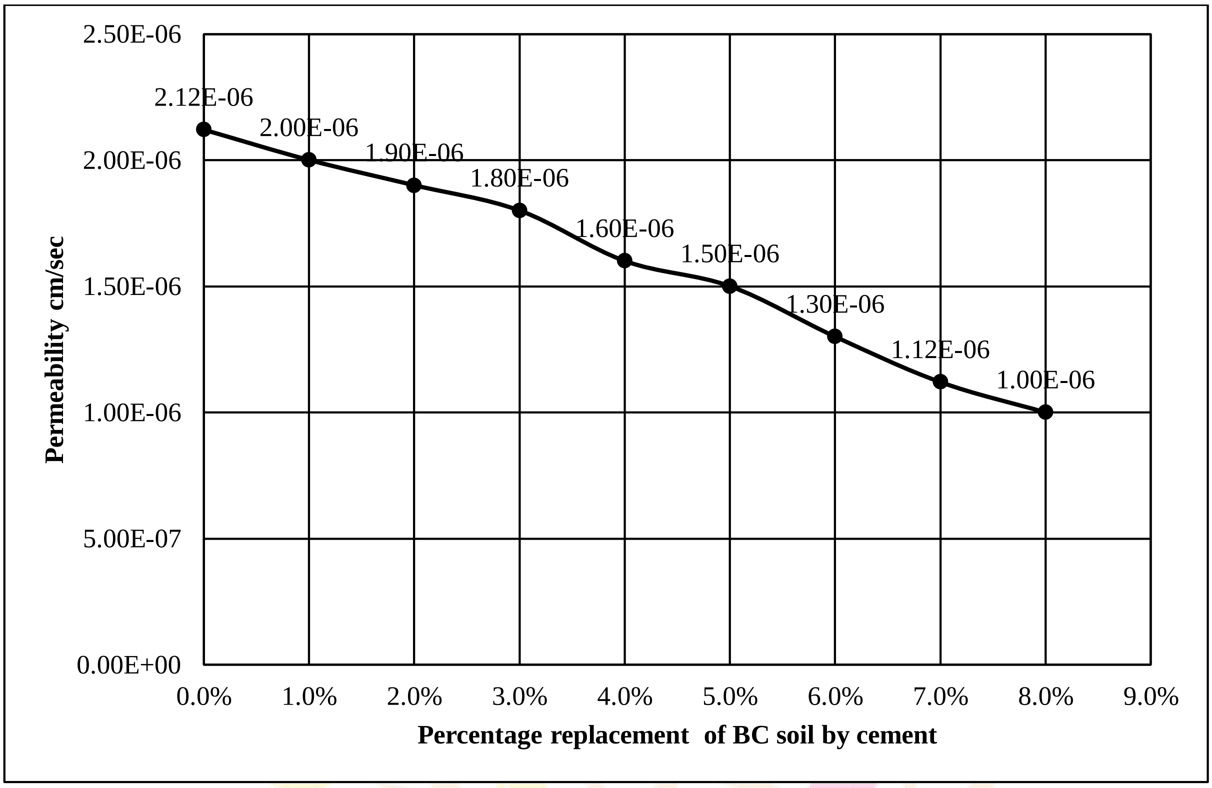

Fig: 5 Variation of permeability for different percentage replacement of BC soil by cement.

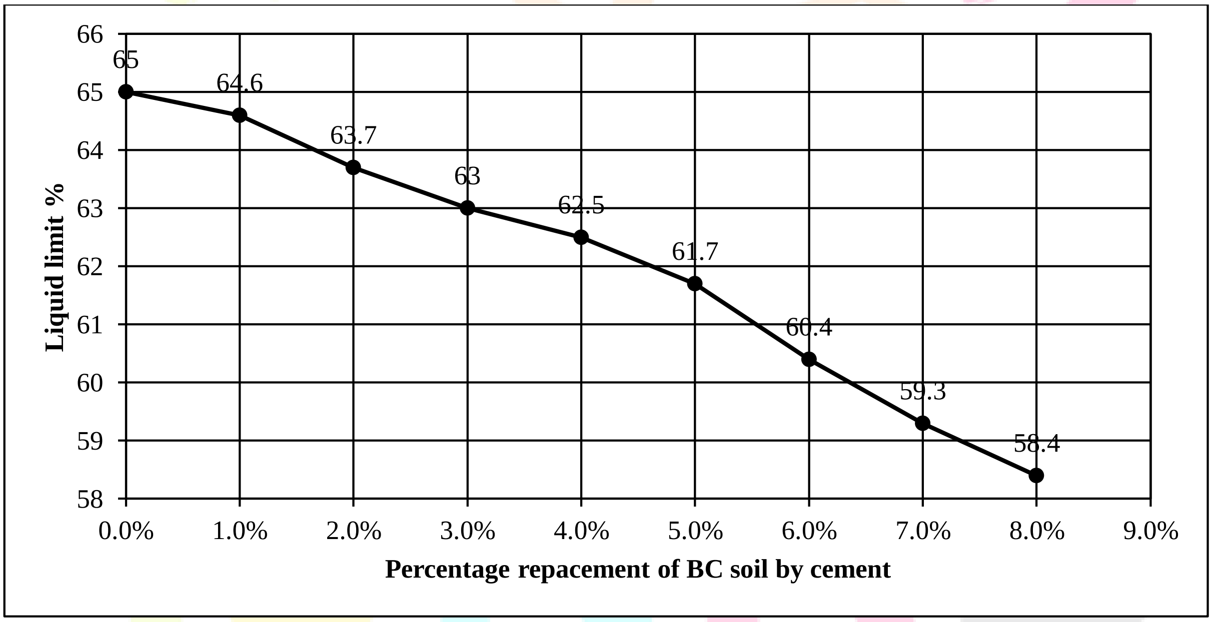

Fig: 6 Variation of liquid limit for different percentage replacement of BC soil by cement

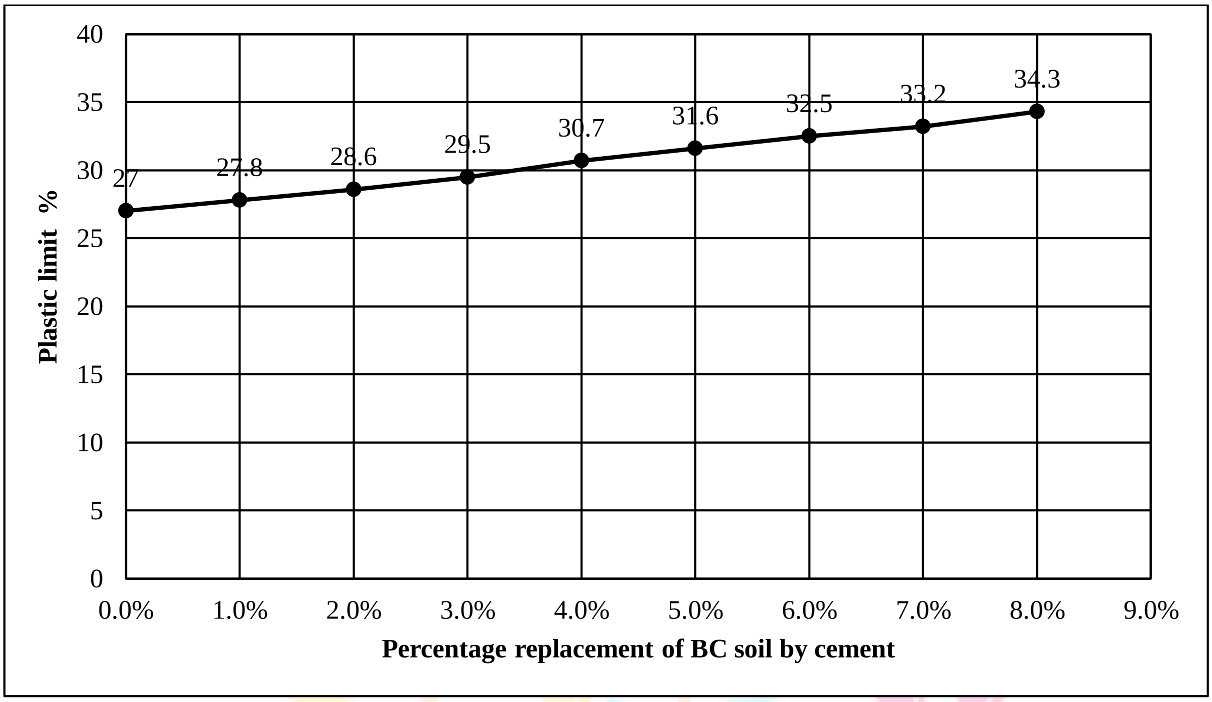

Fig: 7 Variation of plastic limit for different percentage replacement of BC soil by cement.

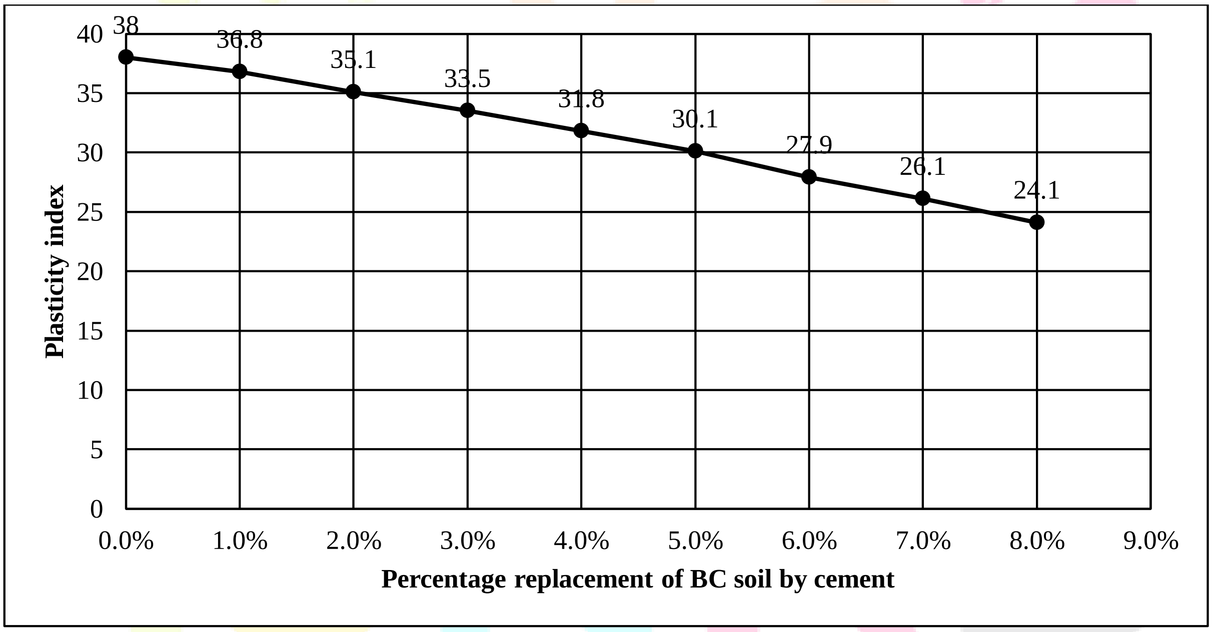

Fig: 8 Variation of plasticity index for different percentage replacement of BC soil by cement.

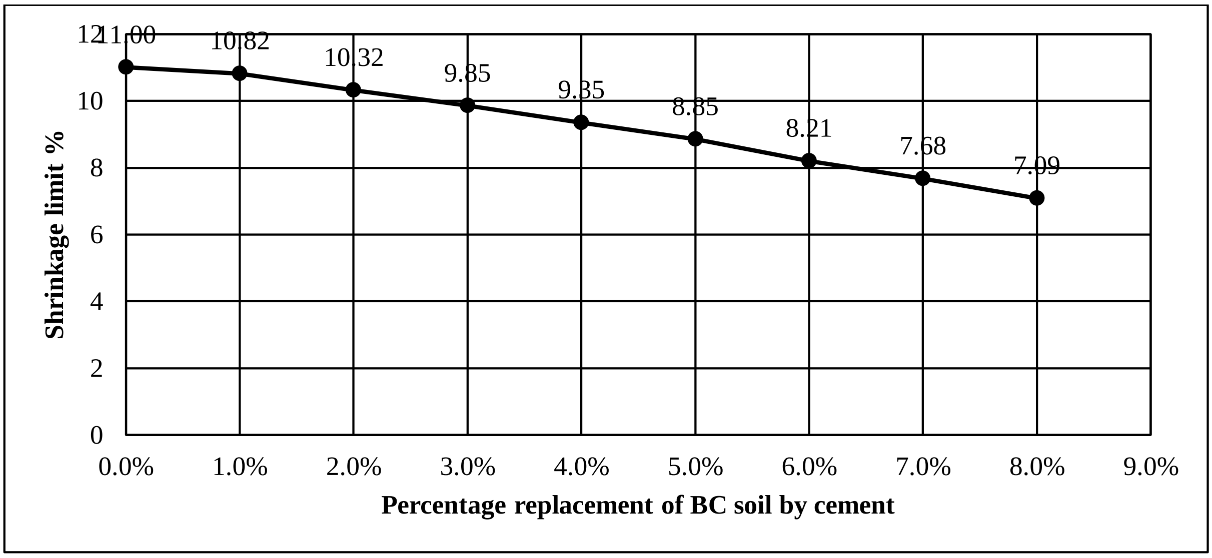

Fig: 9 Variation of shrinkage limit for different percentage replacement of BC soil by cement.

3.4 Test results on compaction properties of BC soil stabilized with cement

Table 6 gives the results of compaction properties of BC soil when cement is used as stabilizing material in different percentages. The variation of maximum dry density and optimum moisture content are shown in figures.

Table: 6 Compaction properties of BC soil stabilized with cement.

Percentage replacement of BC soil by cement	Maximum dry density gm/cc	OMC %
0% (Ref mix)	1.57	22.00
1.0%	1.58	21.00
2.0%	1.59	20.50
3.0%	1.61	20.10
4.0%	1.62	19.60
5.0%	1.63	18.80
6.0%	1.64	18.30
7.0%	1.65	17.80
8.0%	1.66	17.30

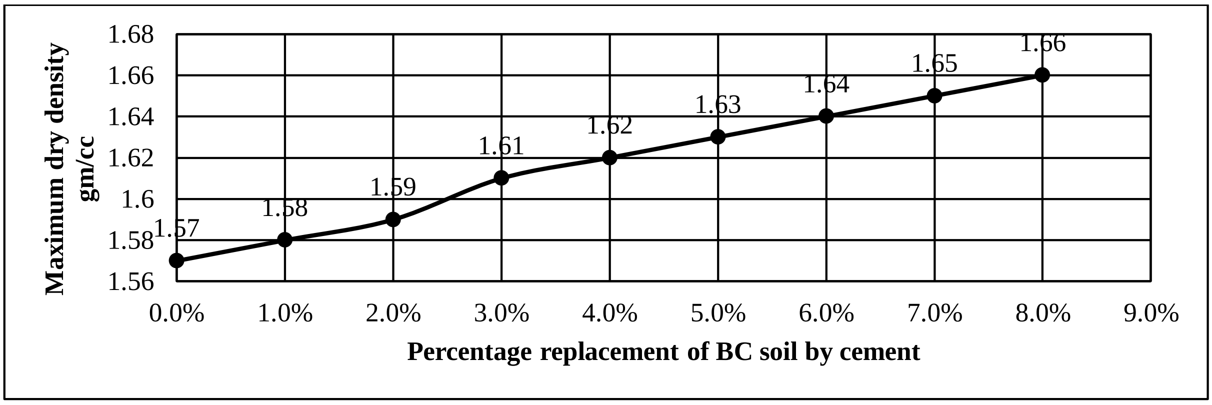

Fig: 10 Variation of maximum dry density for different percentage replacement of BC soil by cement.

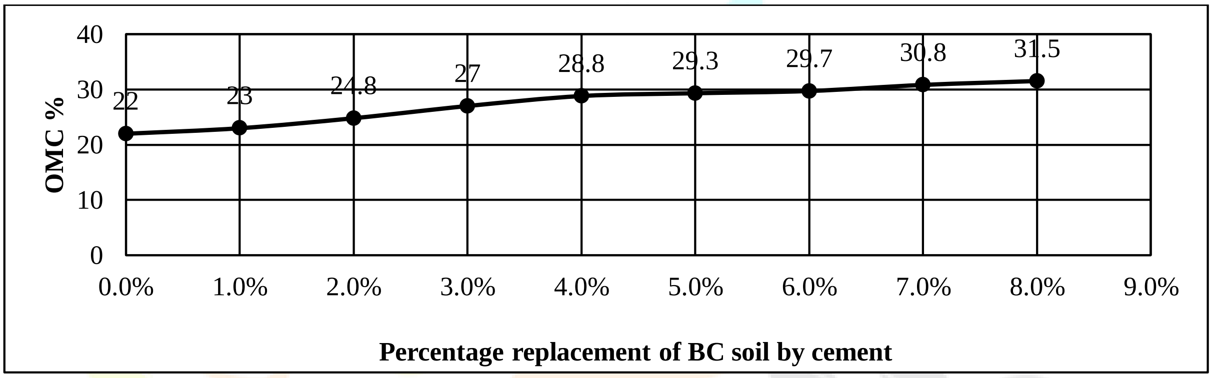

Fig: 11 Variation of optimum moisture content for different percentage replacement of BC soil by cement.

3.5 Test results on strength properties of BC soil stabilized with cement

Table 7 gives the results of strength properties of BC soil, when cement is used as stabilizing material in different percentages. The variation of UCS, C, Ø and CBR values are shown in figures.

Table: 7 Strength properties of BC soil stabilized with cement.

Percentage replacement of BC soil by cement	Unconfined compressive strength kg/cm2			Cohesion (C) kg/cm^2	Angle of internal friction $(\Phi)^o$	CBR %	
	Day1	7 days	28 days			Unsoaked	Soaked
0% (Ref mix)	0.66	0.95	1.24	0.33	23.00	5.62	3.25
1.0%	1.86	2.55	3.67	0.31	24.50	7.50	4.86
2.0%	3.56	5.34	6.50	0.30	25.20	8.80	6.17
3.0%	4.45	6.58	7.66	0.27	25.60	10.70	8.00
4.0%	4.61	6.65	7.86	0.25	25.80	11.30	9.60
5.0%	5.23	6.71	8.30	0.23	26.00	11.56	10.13
6.0%	5.56	6.85	8.70	0.22	26.30	11.87	10.70
7.0%	6.00	6.95	8.87	0.20	26.70	12.05	11.12
8.0%	6.50	7.24	9.15	0.18	27.00	12.25	11.75

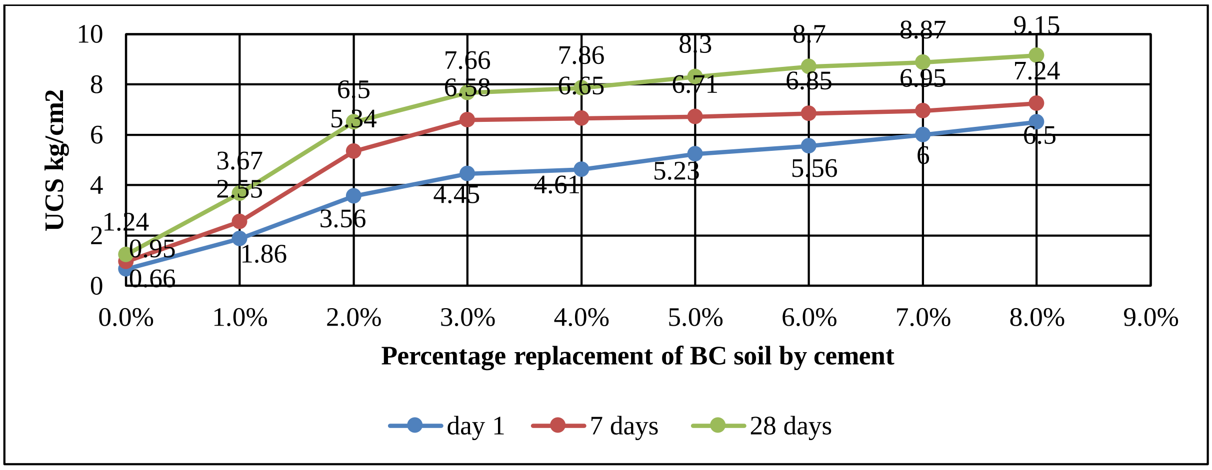

Fig: 12 Variation of UCS for different percentage replacement of BC soil by cement for different days of curing.

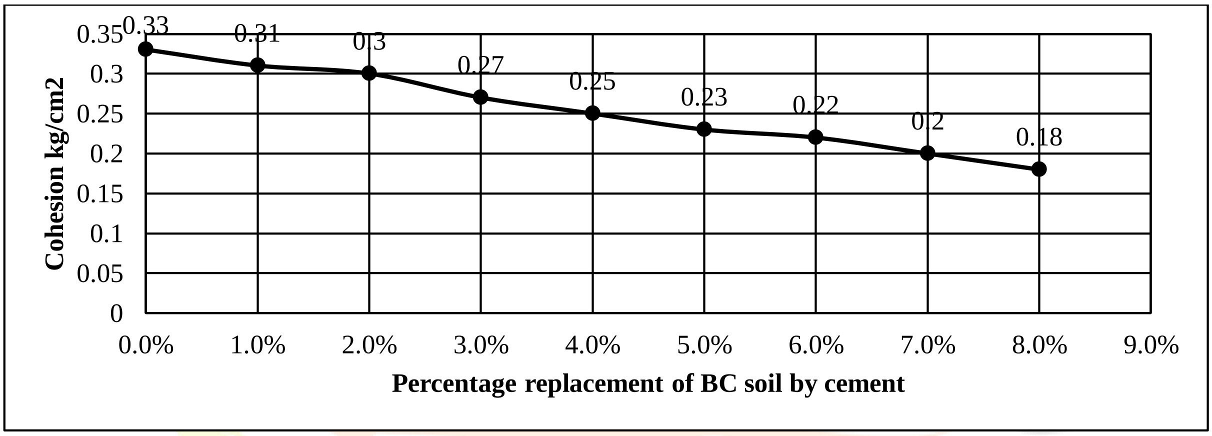

Fig: 13 Variation of cohesion for different percentage replacement of BC soil by cement.

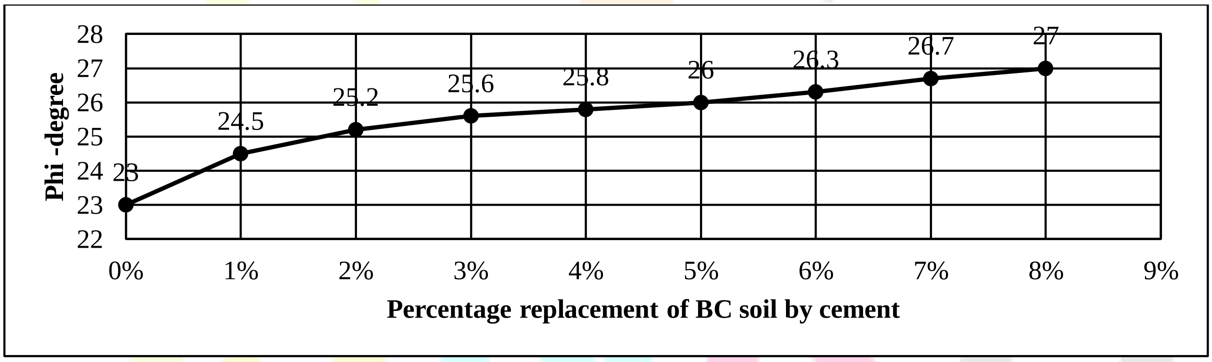

Fig: 14 Variation of angle of internal friction for different percentage replacement of BC soil by cement.

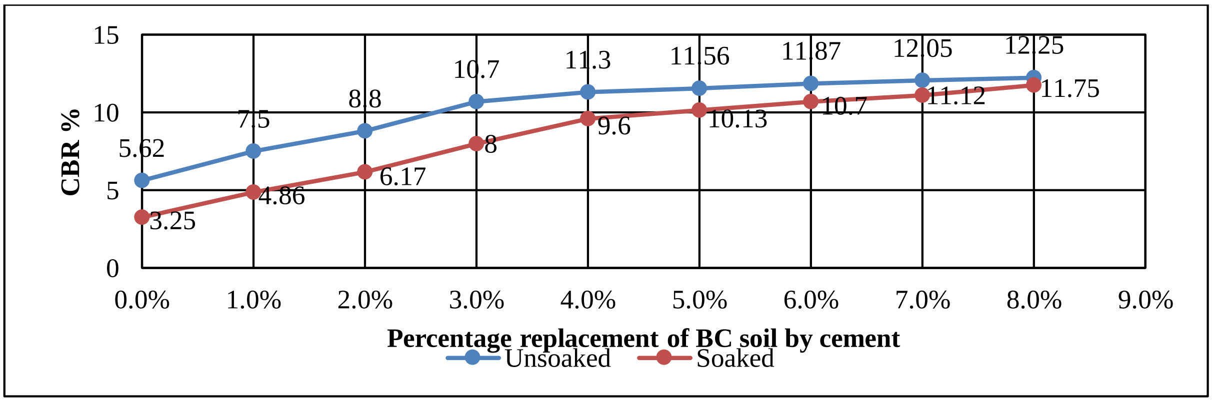

Fig: 15 Variation of unsoaked and soaked CBR values for different percentage replacement of BC soil by cement.

4.0: OBSERVATIONS AND DISCUSSIONS

Fig: 4 shows the variation of specific gravity of BC soil stabilized with different percentages of cement. The specific gravity values show increasing trend from 0% to 8% replacement levels. At 8% replacement level the value of specific gravity is found to be highest and its value is 2.9. This is due to molecular reshuffling of soil matrix due to the higher density of cement than BC soil. Also, it is due to hydration of cement.

Fig: 5 indicates the variation of permeability values. It is observed that the permeability of BC soil decreases as the cement replacement level increases. The reduction of permeability is due to the chemical composition of cement. When water in soil comes in contact with cement, hydration occurs, i.e. cementing compounds of calcium –silicate-hydrate (C-S-H) and calcium –aluminate –hydrate (C-A-H) are formed and excess calcium hydroxide (CaOH) is released. Formation of C-S-H and C-A-H makes the matrix denser Hence due to the formation of such cementing compounds, permeability gets reduced.

Fig: 6 shows the variation of liquid limit of BC soil. It is observed that liquid limit reaches the least value of 58.40% at 8 % replacement level. The decrease in liquid limit is due to the agglomeration (particle size enlargement) of the clayey particles in presences of sufficient quantity of water.

Fig: 7 shows variation in plastic limit. It is observed that the plastic limit goes on increasing with increase in cement content. The highest value of plastic limit is attained at 8% replacement level and its value is 34.30%. This is due to the fact that cement treated soil require more water to change its plastic state to semisolid state.

Fig: 9 shows the variation of shrinkage limit. It is observed that shrinkage limit reaches the least value of 7.09 % at 8 % replacement of BC soil by cement. This can be due to the fact that with increase in percentage of cement level flocculation takes place.

From table 6 and figures 10 and 11 it is observed that the maximum dry density is obtained at 8% replacement of BC soil with cement. At 8% replacement level the maximum dry density is found to be 1.66 gm/cc and corresponding optimum moisture content is found to be 17.3 %. Addition of cement to BC soil mixture results in an increase of MDD and OMC. The specific gravity of cement particles is higher than that of BC soil. Replacement of a certain percentage of BC soil by cement will increase its mass density. Also, cement particles are comparatively finer than the soil particles. These finer particles occupy the void space in the compacted mixture, thus increasing the MDD of the mixture.

Table 7 and figures 12,13, 14 and 15 show the variation of unconfined compressive strength, cohesion, angle of internal friction and CBR values for BC soil at different percentage replacement by cement. There is rapid increase of unconfined compressive strength up to 3% replacement level. After 3% the unconfined compressive strength values start increasing gradually. At 8% replacement level, the 28 days unconfined compressive strength is found to be 9.15 kg/cm^2.This is due to the fact that at 3% replacement of BC soil by cement, the moisture available, in the system is such that, it reacts with the available cement and produces the hydration products such as C_3S and C_2S which ultimately result in C-S-H gel and this is responsible for binding the particles more effectively. Thus, it can be concluded that the rapid increase in the value of unconfined compressive strength is obtained when 3 % BC soil is replaced with cement. Hence 3% of cement can be considered as optimum value for stabilization, even further increase in cement content increases the UCS value gradually, it may not prove to be economical.

It is observed from figures 13 and 14 that the cohesion value reaches its least value (0.18 kg/cm^2) and angle of internal friction (Φ) reaches its higher value (27^o) when 8 % of BC soil is replaced with cement. This is due to the fact of formation of more sand like particles during stabilization process. Also, up to 3% replacement of BC soil by cement the graph indicates steep increase later it gradually increases.

Table 7 and fig: 15 illustrates the variation of CBR values. It is observed that soaked and unsoaked CBR values reach their higher values when 8% BC soil is replaced by cement. Also, at 3% replacement the graph shows steep increase. This is attributed to the increase in the contact area and adhesion between cement and soil which will create a dense network of interconnected particles. The increase in CBR value may be due to the shear transfer mechanism between the soil and cement and the improvement in the strength is due to the pozzolanic action of BC soil-cement mix.

5.0 CONCLUSIONS

From the above observations the following conclusions may be drawn.

- Specific gravity of BC soil stabilized with cement increases as the percentage replacement by cement increases.
- Permeability of BC soil decreases as the percentage replacement by cement increases.
- The liquid limit of BC soil stabilized with cement decreases as the percentage replacement by cement increases.
- Plastic limit of BC soil stabilized with cement increases as the percentage replacement by cement increases.
- Shrinkage limit of BC soil stabilized with cement decreases as the percentage replacement by cement increases.
- Maximum dry density of BC soil stabilized with cement increases as the percentage replacement by cement increases.
- Rapid increase in the value of UCS is obtained when 3% BC soil is replaced in the cement. Hence 3% of cement can be considered as optimum value for stabilization. Even though further increase in cement content increases the UCS value gradually, but it may not prove to be economical.
- Even though the cohesion value reaches its least value and phi reaches its higher value at 8% replacement 3% replacement may be considered as the best because of economic aspects.
- Even though the CBR values reach their higher value when 8% BC soil is replaced by cement,3% replacement is considered as the best because of economic aspects and steep rise at 3%.
- Finally, the optimum value of cement can be considered as 3% as this gives good strength results along with workability, and economic construction.

6.0 ACKNOWLEDGEMENTS

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