Research Article

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Effect of Calcium Chloride on Geotechnical Properties of Black Cotton Soil Ramya

Ramya HN[1], Umesha TS[2] and Lalithamba HS[2]

[1]*Channabasaveshwara Institute of Technology, Gubbi, 572 216, India*

[2]*Siddaganga Institute of Technology, Tumakuru, 572 103, India*

***Corresponding author**
Ramya HN, Channabasaveshwara Institute of Technology, Gubbi, 572 216, India, Email: ramya.hn@cittumkur.org

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Abstract
The objective of the present study was to understand the effect of calcium chloride on geotechnical properties of black cotton soil. Black cotton soil collected from Siraguppa taluk, Bellary. It was subjected to various concentrations of calcium chloride viz. 0.1 N, 0.5 N, 1.0 N, 2.0 N and 4.0 N. Attempt was made to understand the effect of calcium chloride on index properties and engineering properties of black cotton soil. It was observed that the values of liquid limit, plastic limit and plasticity index of the soil treated with calcium chloride was decreasing with increase in concentration. Further the treated soil was investigated for compaction test. It was observed that the maximum dry density of the soil was increasing at higher concentrations. However, no remarkable changes were observed in the values of optimum moisture content with increase in concentration of calcium chloride. The laboratory investigation was made to obtain the unconfined compression strength (UCS) of treated soil. The soil was cured for 1 day, 7, 14 and 28 days. It was observed that the values of UCS were increasing with increase in concentration at any curing period. The soil was further tested to obtain the effect of calcium chloride on permeability of treated soil. It was observed that the permeability is increasing with increase in concentrations of 0 N, 0.5 N, and 4.0 N.

Keywords: Calcium chloride, Black cotton soil, Compaction, Unconfined compression strength

Introduction
The increasing use of chemicals such as pesticides, fertilizers and insecticides are the major source of pollutants of soil. Also, the soil contamination arises from radioactive fallouts, leaching of wastes from landfills and direct discharge of industrial wastes to the soil. Hence, the geotechnical properties of soil get modified in the vicinity of industries. Chlorides are one of the pollutants from the industries like Tannery, Textiles and Battery. The attempt is made here to understand the effect of one such chlorides i.e. calcium chloride.

The control of alkali induced heave in black cotton soil using potassium and magnesium salts was observed by Hariprasad Reddy, and noticed that the swelling characteristics of treated soil was in controlled condition when compared to untreated soil [1]. However the swelling here occurs in two stages, first stage can be controlled but the second stage of swelling cannot be controlled. The study was carried to investigate the effect of certain electrolytes on expansive soil by G. V. R. Prasada Raju et al. [2]. Potassium chloride, ferric chloride and calcium chloride were used as electrolytes. It was observed that the maximum improvement in the properties of expansive soil was found when treated with ferric chloride when compared to potassium chloride and calcium chloride. Strength and F O S Performance of Black Cotton Soil Treated with Calcium Chloride was carried out by Manoj Krishna and H N Ramesh, the investigation revealed that the addition of 3% calcium chloride has shown higher factor of safety with higher curing periods for an embankment slope of 1:2.5.The effect of certain industrial effluent on swelling characteristics of black cotton soil was investigated by Narasimha Rao, et al. [3,4]. Textile, Tannery and Battery effluent were considered as the contaminants, it was observed that the Textile and Tannery effluent decrease the plasticity and swelling of expansive soil, whereas Battery effluent increases the same. The effect of industrial effluents with soil was represented by Narasimha Rao and Chittaranjan [5]. The effluent sample collected from an area around the textile industry in Manipal shows, higher metal concentration of Sodium, Calcium, Magnesium, Potassium and Iron was studied by Poornima K and Vasudevan K [6]. The effect of calcium chloride and Na_2SiO_3 on CH properties of soil, was studied by Ramadasu [7]. He noticed that, the liquid limit, plastic limit , plasticity index and swelling characteristics of soil has reduced with the increase in concentration of calcium chloride Na2SiO3, whereas the strength of the soil has increased with the increase in concentration of same. Further the effect of sodium chloride on geotechnical properties of black cotton soil was studied by Srikanth and Harnadh [8]. They reported that the plasticity characteristics, swelling characteristics and strength of the soil decreases with the increase in concentration of sodium chloride. Hence, an attempt is made here, to know the effect of one such effluent i.e. sodium chloride on black cotton soil.

Materials and Methods
The Black cotton soil is collected near Siraguppa Taluk, Bellary district from a cotton cultivated land. Table 2.1.shows the properties

of black cotton soil used in the test. Calcium chloride is ionic compound of calcium and chlorine. It is solid at room temperature and highly soluble in water .Because of its hygroscopic nature, it must be kept in air tight containers. The anhydrous salt is deliquescent. Calcium chloride is directly obtained from limestone. Calcium chloride is used to increase the water hardness in swimming pool; this avoids the erosion of concrete in the pool. It is used in aquariums, ass a preservative and also in concrete to speed up the initial setting time. Other applications of calcium chloride includes, as additive in plastics, in fire extinguisher, waste water treatment and oil industries. The molecular weight of the calcium chloride used in the present study was 110.98 g/mol.

Table 2.1 Properties of Black cotton soil

Sl No	Property	Value
1	**Grain size distribution**	
	Sand (%)	12
	Silt (%)	24
	Clay (%)	64
2	**Atterberg's Limits**	
	Liquid Limit (%)	63
	Plastic Limit (%)	28
	Plasticity Index (%)	35
3	**Compaction Properties**	
	Optimum Moisture Content [OMC(%)]	19
	Maximum Dry Density [MDD (KN/m^3)]	15
4	**Specific Gravity**	2.61
5	**IS classification**	CH
6	**Permeability (mm/sec)**	$1.55 X 10^{-5}$

Tests on the index properties and engineering properties of soil are carried out for contaminated and uncontaminated soil conforming to IS code. Specific gravity test is conducted conforming to IS: 2720 (Part 3/Sec 1) – 1980. The wet sieve analysis is carried out for uncontaminated soil conforming to IS: 2720 (Part 4) – 1985. According to IS: 2720 (Part 5) – 1985, tests on Atterberg's limits are carried out. Standard proctor test is conducted conforming to IS: 2720 (Part 7) – 1980. The unconfined Compression Strength of soil is conducted conforming to IS: 2720(Part 10)-1973.The treated and untreated soil is subjected to consolidation test conforming to IS: 2720 (Part 15) – 1986.

Experimental Investigation

Specific Gravity

The specific gravity test is conducted on untreated and treated black cotton soil. The test is conducted using density bottle for fine grained soil particles. Table 3.1 reveals the values of specific gravity test conducted for treated and untreated BC soil.

Fig 3.1 shows the behaviour of specific gravity of black cotton soil treated with calcium chloride. It is noted that the dissolved salts present in the pore fluid will start precipitating and add the weight and volume to the soil solids itself. Also, when the sample is heated,

Table 3.1 Specific Gravity of soil treated with calcium chloride

Concentration	Specific Gravity
0N	2.61
0.1N	2.36
0.5N	2.29
1.0N	2.26
2.0N	2.22
4.0N	2.15

certain salts undergo dehydration and lose their crystallization. Therefore the obtained specific gravity may not represent its true specific gravity [8].

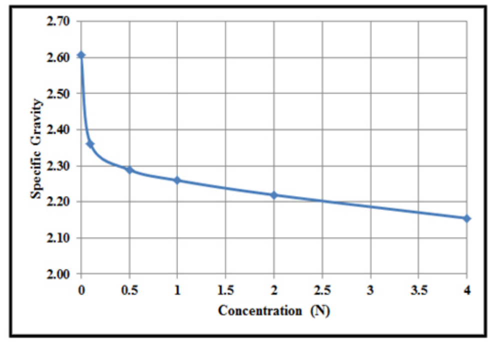

Figure 3.1: Effect of Calcium chloride on specific gravity of BC soil

Soil Classification

Fine grained soils are classified on the basis of their grain and gradation characteristics. The classification of soil contaminated with calcium chloride can also be obtained by the values of liquid limit and plastic limit. The plasticity chart is drawn between liquid limit and plasticity index to find out the nature of soil. Table 3.2, shows the values of plasticity chart, where the soil is changing from CH to CI. Fig 3.2 shows the grain size distribution curve of black cotton soil. It shows the behaviour of grain size of soil when treated with 4 N calcium chloride. Table 3 shows the comparison between the effect of water and calcium chloride on grain size distribution of black cotton soil. It was observed that the percentage of clay reduced from 64% to 47 % and percentage silt increased from 24 % to 41 %. Fig 3.3 represents the effect of calcium chloride on the plasticity property represented on IS plasticity chart. Black cotton soil with a liquid limit of 63 % and plasticity index of 34 % lies in CH zone. But, with the addition of calcium chloride there is transformation in the plasticity property, the liquid limit reduces to 43 % and plasticity index reduces to 20 % and the nature of soil is transformed from CH to CI, which indicates the reduction in clay content.

Table 3.2 Effect of calcium chloride on plasticity properties of soil

Concentration of the solution in normality	Liquid Limit (%)	Plasticity Index (%)	Soil Classification
0	63	28	CH
0.1	58	28	CH
0.5	46	21	CH
1.0	46	21	CH
2.0	46	21	CI
4.0	43	20	CI

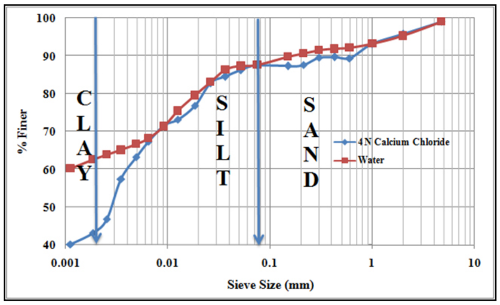

Figure 3.2: Effect of Calcium chloride on grain size of BC soil

Table 3.3: Comparison between the effect of water and 4 N calcium chloride on grain size of soil

Particulars	Water	4N Calcium chloride
Clay (%)	64	47
Silt (%)	24	41
Sand	12	12

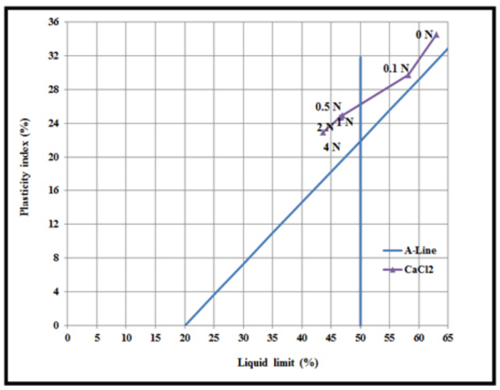

Figure 3.3: Effect of calcium chloride on plasticity properties of black cotton soil

Atterberg's Limits

Test on Liquid limit and Plastic limit was carried out for treated and untreated black cotton soil .Figure 3.4 shows the effect of calcium chloride on Atterberg's limits of black cotton soil. It was observed that the liquid limit, Plastic limit and plasticity index was decreasing with the increase in concentration of calcium chloride. Decrease in liquid limit, plastic limit and plasticity index is said to be, due to decrease in the diffused double layer with increase in concentration. [9].

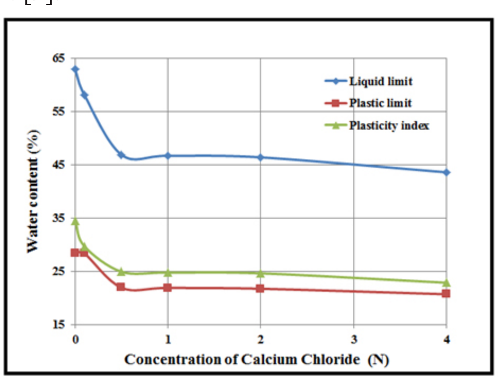

Figure 3.4: Effect of Calcium chloride on consistency limits of black cotton soil

Compaction

The standard proctor test was conducted for treated and untreated soil sample. Fig 3.5 shows the effect of calcium chloride on compaction characteristics of black cotton soil. It was observed that, with the increase in concentration the maximum dry density increases. The optimum moisture content increases with increase in concentration. The increase in the maximum dry density attributed by calcium chloride at low moisture content is because the soil structure tends to change from edge-to-face type of flocculation to face-to-face flocculation with the increase in salt concentration [10]. This increase in OMC indicates that the soil has got more affinity or more absorption capacity for water due to increase in electrolyte concentration in pore fluid [11].

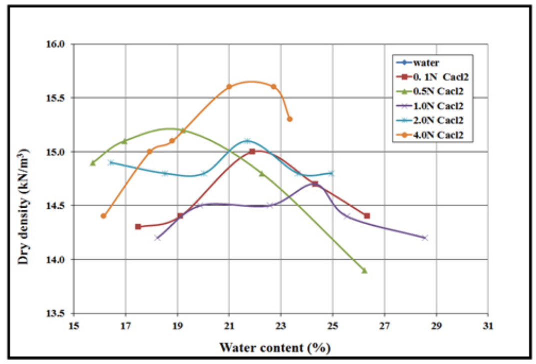

Figure 3.5: Effect of calcium chloride on compaction characteristics of black cotton soil

Solid volume occupation

During compaction the volume of a three phase system consisting of solids, water and air is reduced by expulsion of air without changing the quantity of water or solids. Hence, compaction is a volume change phenomenon. Water content is conventionally expressed as weight of water to weight of solids (W_w/W_s). But, with respect to the volume, water content can be expressed as volume of water per unit volume of solids (V_w/V_s).Solid volume occupation is the volume of solids per unit volume of compacted specimen (V_s/V).

Table 3.4 shows the values of solid volume occupation (P) and Water volume content (e_w) at varying concentrations of calcium chloride. Fig 3.6 shows the compaction curve plotted with respect to solid volume occupation and water volume content. It was observed that, with the increase in the concentration of calcium chloride, the solid volume occupation is increasing with decrease in the values of water volume content. It was observed that at dry side of optimum the particles come closer to each other due to decrease in negative pore water pressure. Whereas, at wet side of optimum the compaction energy is resisted by positive pore water pressure, which prevents the particles from coming closer to each other. Therefore, reduces the solid volume occupation. Table 3.5 shows the variation in the values of water volume content and void ratios with increase in concentration of calcium chloride. Fig 3.7 shows the behaviour of void ratios and water volume content with respect to the concentrations of calcium chloride. It was observed that, with the increase in the concentrations of calcium chloride the water volume content and void ratios decreases.

Table 3.6 shows the variation in the values of water volume content and percentage air voids. Fig 3.8 shows the effect of calcium chloride on water volume content and percentage air voids of black cotton soil. It is observed that the water volume content decreases with increase in concentration. Also, the percentage air voids decreases with increase in concentration. When compared to Fig. 3.5 and Fig. 3.6, it was observed that the interpretation of compaction characteristics made with respect to solid volume occupation shows real order compaction. But, the conventional method of expressing compaction curves gives misleading picture. This is also supported by the thesis of Ph.D. submitted by Prashanth [7].

Table 3.4: Solid volume occupation and Water volume content at various concentrations of Calcium Chloride

Concentration	e_w	P	Concentration	e_w	P
0	42.05	0.537	1	41.20	0.629
	46.66	0.560		44.94	0.642
	51.59	0.580		51.02	0.639
	55.26	0.573		54.97	0.652
	60.30	0.561		57.74	0.635
0.1	41.30	0.606		64.55	0.628
	45.11	0.610	2	36.46	0.673
	51.71	0.636		41.11	0.666
	57.40	0.623		44.48	0.667
	62.18	0.61		48.17	0.682
0.5	36.03	0.65		52.51	0.666
	38.83	0.66		55.39	0.66
	43.98	0.66	4	34.75	0.672
	50.98	0.65		38.58	0.698
	60.03	0.61		40.44	0.702
				45.18	0.728
				48.88	0.723
				50.21	0.710

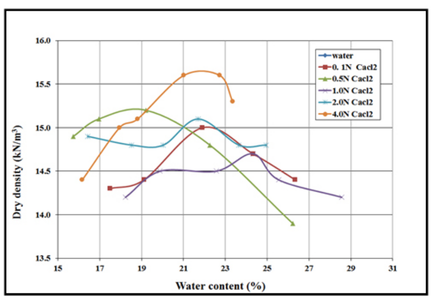

Figure 3.6: Effect of Calcium Chloride on water volume content and solid volume occupation

Table 3.5: Water volume content and void ratios of soil treated with Calcium Chloride

Concentration (N)	e_w	e	Concentration (N)	e_w	E
0	42.05	0.862	1	41.20	0.591
	46.66	0.785		44.94	0.559
	51.59	0.725		51.02	0.564
	55.26	0.746		54.97	0.534
	60.30	0.783		57.74	0.574
0.1	41.30	0.651		64.55	0.593
	45.11	0.640	2	36.46	0.485
	51.71	0.572		41.11	0.502
	57.40	0.605		44.48	0.499
	62.18	0.64		48.17	0.466
0.5	36.03	0.540		52.51	0.502
	38.83	0.519		55.39	0.505
	43.98	0.506	4	34.75	0.488
	50.98	0.548		38.58	0.433
	60.03	0.643		40.44	0.424
				45.18	0.374
				48.88	0.382
				50.21	0.408

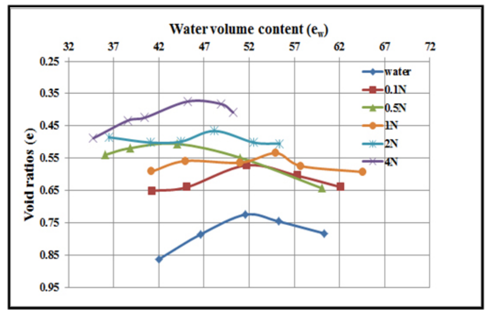

Figure 3.7: Effect of Calcium Chloride on water volume content and void ratios

Consolidation

Consolidation test was carried out for treated and untreated soil. The sample treated at 0.5 N Calcium Chloride and 4 N Calcium Chloride. The soil sample here is subjected to various increments of stress viz. 0 kg/cm^2, 0.25 kg/cm^2, 1.0 kg/cm^2, 2.0 kg/cm^2 and 4.0 kg/cm^2. The sample was subjected to each stress under 24 hrs, after which the stress is incremented. After the increment of 4.0 kg/cm^2 the soil sample is subjected to unloading and allowed to swell for duration of 24 hrs. The value of permeability is then obtained. Table 3.7 shows the values of permeability at 0.5 N and 4.0 N Calcium Chloride. It was observed that, the values of co-efficient of permeability are increasing with increase in concentration of calcium chloride. This increase in permeability is due to decrease in the thickness of diffused double layer resulting in flocculation of clay particles. Clay mineral in contact with certain chemical might undergo large interlayer shrinkage. This event could be accompanied by considerable reduction in the thickness of diffuse double layer, potential cracking and increase in hydraulic conductivity values. Also according to the Gouy-Chapman theory by increasing the ion concentration, the thickness of diffuse double layer decreases which leads to flocculation of the clay particles, creating large pore channels which flow can occur [12].

Table 3.6: Water volume content and percentage air voids of soil treated with Calcium Chloride

Concentration (N)	ew	n	Concentration (N)	ew	n
0	42.05	0.463	1	41.20	0.371
	46.66	0.440		44.94	0.358
	51.59	0.420		51.02	0.361
	55.26	0.427		54.97	0.348
	60.30	0.439		57.74	0.365
0.1	41.30	0.394	2	64.55	0.372
	45.11	0.390		36.46	0.327
	51.71	0.364		41.11	0.334
	57.40	0.377		44.48	0.333
	62.18	0.39		48.17	0.318
0.5	36.03	0.351		52.51	0.334
	38.83	0.342		55.39	0.336
	43.98	0.336		34.75	0.328
	50.98	0.354		38.58	0.302
	60.03	0.391	4	40.44	0.298
				45.18	0.272
				48.88	0.277
				50.21	0.290

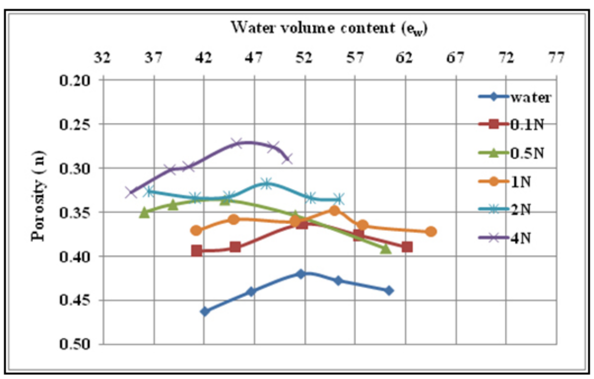

Figure 3.8: Effect of Calcium Chloride on water volume content and porosity of black cotton soil

Table 3.7 Permeability value

Concentration (N)	K (mm/s)
0 N	0.0000155
0.5 N	0.0000149
4 N	0.0000158

Table 3.8, shows the values of void ratios under increments of loadings. Fig 3.9 shows the effect of calcium chloride on void ratios of black cotton soil. It is observed that, the void ratio is decreasing with increase in stress.

Table 3.8: Variation of void ratios of treated soil at different stress increments

Stress Increment (kN/m^2)	Void Ratios		
	Water	0.5 N	4 N
24.515	0.65	0.71	0.67
49.03	0.61	0.66	0.60
98.06	0.48	0.55	0.51
196.12	0.41	0.48	0.41
392.24	0.29	0.29	0.31

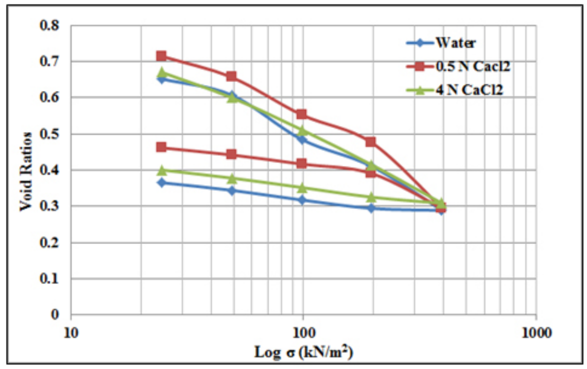

Figure 3.9: Effect of Calcium chloride on void ratios of black cotton soil (e-log σ)

Fig 3.10 shows the effect of calcium chloride on co-efficient of consolidation and compression index of black cotton soil. It is observed that the co-efficient of consolidation increases with increase in concentration. The compression index decreases with increase in concentration. The compressibility of clays is primarily governed by the physico-chemical forces present in clay water electrolyte system. The type of clay minerals, the type and amount of exchangeable cations and the properties of the fluid to which the clay is exposed to and interacts with, are some of the physico-chemical forces. The clay phase dominates the compression and consolidation behaviour, with non-clayey material playing a passive role as relative inert filter. The more compressible the clay, the more pronounced the influence of cation type and electrolyte concentration on compressibility (Mitchell 1993) [11].

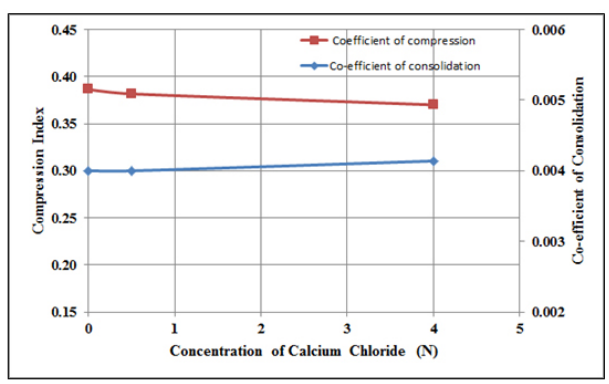

Figure 3.10: Concentration Vs Compression Index and Co-efficient of volume change

Unconfined compression Strength

Unconfined compression test was carried out on treated and untreated soil. The samples are subjected to curing for durations of 1 day, 7 days, 14 days and 28 days. Table 5.15 shows the values of strength of black cotton soil treated with calcium chloride. Fig 3.11, 3.12 and 3.13 show the stress strain behavior of black cotton soil at various concentrations of calcium chloride subjected to 7 days, 14 days and 28 days curing period respectively. It is observed that the stress bearing capacity of soil increases with increase in concentrations, also with the number of curing days.

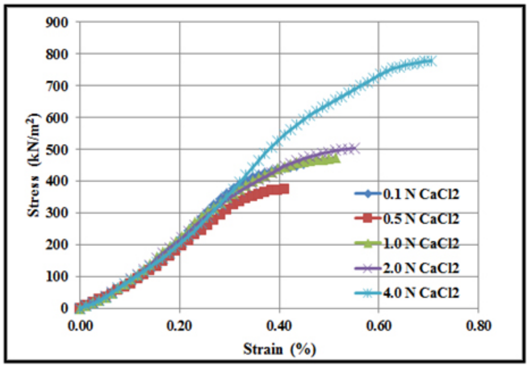

Figure 3.11: Stress Strain behaviour of treated soil cured for 7 days curing

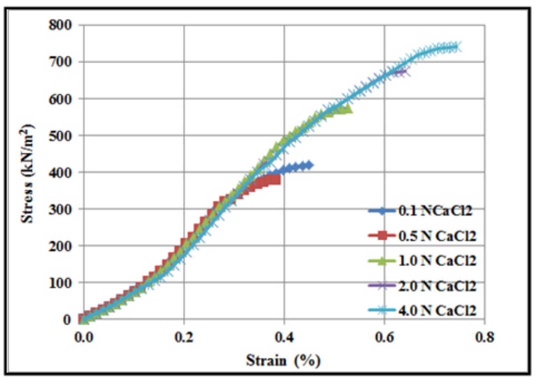

Figure 3.12: Stress Strain behaviour of treated soil cured for 14 days

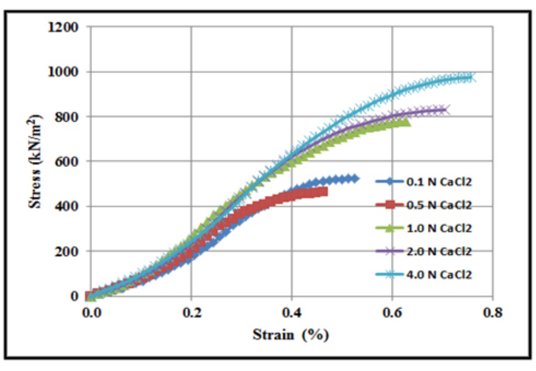

Figure 3.13: Stress Strain behaviour of treated soil cured for 28 days

Fig 3.14 and 3.15 show the effect of calcium chloride on unconfined compression strength of black cotton soil. It was observed that the strength of the soil is increasing with increase in concentration at any curing period. As the concentration increases, soil in presence of water forms cluster, this cluster will hold the soil particles together thereby increases the strength of soil [2]. The increase in strength could be due to cation exchange between the mineral layers and due to silicate gel formation [3].

Mechanism of calcium chloride with black cotton soil

Calcium chloride is an ionic compound of calcium and chlorine. It is obtained on a large scale as a by product during ammonia-soda process. It behaves as a solid ionic halide at room temperature and highly dissolves in water. It releases large amount of heat while reacting with water. Experimental results of black cotton soil treated with calcium chloride showed decrease in plasticity and increase in strength and permeability. These changes in the properties of clayey soils are due to the reaction between the calcium chloride, silicate and aluminates present in the black cotton soil. The following equation represents the reaction developed.

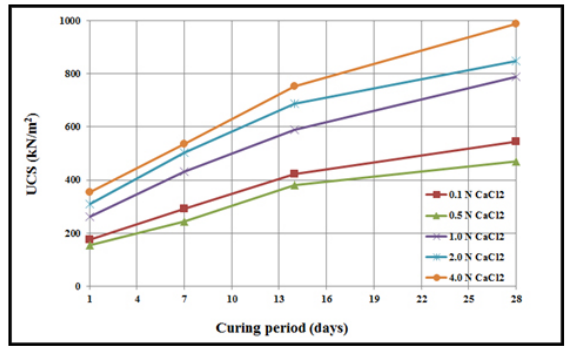

Figure 3.14: Effects on UCS of Black cotton treated by Calcium Chloride

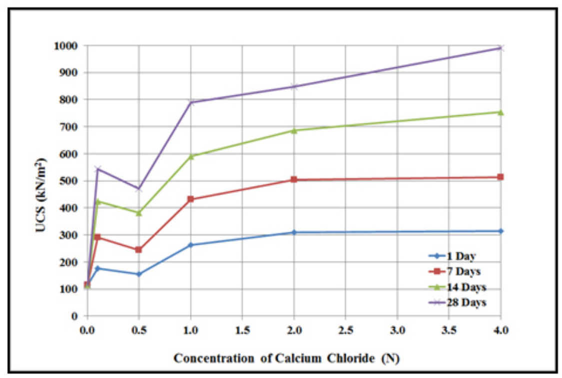

Figure 3.15: Concentration Vs UCS of BC soil treated with Calcium Chloride

$$CaCl_2 + H_2O \longrightarrow Ca^{2+} + 2Cl^- \quad (5.1)$$

$$Ca^{2+} + OH^- + \text{soluble clay silica} \longrightarrow \text{calcium silicate hydrate} \quad (5.2)$$

$$Ca^{2+} + OH^- + \text{soluble clay alumina} \longrightarrow \text{calcium aluminates hydrates} \quad (5.3)$$

Calcium chloride when dissolved in water, Ca^{2+} and $2Cl^-$ ions are formed in the solution. The addition of calcium chloride to black cotton soil supplies an excess of Ca^{2+} and the cation exchange occurs with Ca^{2+} replacing dissimilar cations from the exchange complex of the soil. This causes flocculation and aggregation of the clay fraction. The clay particles clump together into larger sized aggregates. The influence of cation exchange, flocculation and aggregation are mainly responsible for the change in plasticity of soil. During this process, the silicate and alumina reacts with calcium to produce cementitious compounds; calcium silicate hydrate (CSH) and calcium aluminate hydrates (CAH). The strength of the treated soil increases with time is primarily due to these cementitious compounds. Furnishing the fact that, CAH is main binding agent of OPC would strongly justify that it acts as a binding agent for clayey soils also [13].

Conclusion

Following are the conclusions drawn from the above discussions

1. The plasticity properties decrease with increase in concentration.
2. The liquid limit was gradually decreased by 31 %, plastic limit was gradually decreased by 28 % and plasticity index by 35 % at 4 N concentration.
3. Soil treated with 4 N calcium chloride was subjected to grain size distribution analysis, showed reduction in the percentage of clay from 64 % to 47 % and increase in the percentage of silt by 24 % to 41 %. Also, the soil showed transformation from CH to CI.
4. The maximum dry density increased gradually from 15.1kN/m^3 to 15.6kN/m^3 at 0 N to 4 N.
5. Permeability of the treated soil varies as 1.55 X 10^{-5} mm/s^2, 1.49 X 10^{-5} mm/s^2 and 1.58 X 10^{-5} mm/s^2 at 0 N, 0.5 N and 4 N respectively [14,15].
6. Strength of the soil increased with increase in concentration and curing period. It was observed that the strength is increased 3 times from 1 curing day to 28 days of curing at 0.1 N, 0.5 N, 1.0 N and 2.7 times at 2.0 N and 4.0 N of calcium chloride.

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