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Effect of Sodium Chloride on Geotechnical Properties of Black Cotton Soil

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Abstract

Rapid industrialization in the various fields of urbanization has resulted in massive pollution of environment. Pollution occurring in soil and ground water table is alarmingly increasing day by day. Thus, a sincere attention is required, to control the effect of pollutants on the soil and water table. An attempt was made here to know the effect of one such pollutant, i.e. Sodium chloride (NaCl) on black cotton soil. The soil was collected from Siraguppa taluk, Bellary district. It was subjected to the various concentrations of sodium chloride viz, 0.1normality (N), 0.5N, 1.0N, 2.0N, and 4.0N, and the effect on the index properties and engineering properties of soil was observed. It, was observed that the, values of liquid limit, plastic limit and plasticity index are decreasing with increase in the concentration of NaCl. The variation in the values of Optimum Moisture Content (OMC) was not well pronounced with the increase in the concentration of NaCl. However, the values of Maximum Dry Density (MDD) at higher concentrations are found to be increased. Also, the strength of the soil was found to be increased with increase in concentration of NaCl. Further, the consolidation test was conducted on black cotton soil with various concentration of NaCl viz. 0N, 0.5N, and 4.0N; to know the permeability of soil, and it was observed that the permeability was increasing with increase in concentration.

Keywords: Sodium chloride; Black cotton soil; Atterberg's limits; Compaction

Introduction

Industrialization is very important for the socio economic development of the country. But, increase of industrialization causes lot of environmental hazards. Municipal solid waste and industrial solid waste placed on or beneath the ground surface are the two most important sources for subsurface contamination. During rains, water infiltrates into the waste and reacts physically, chemically and biologically with the waste to produce leachate. The leachate infiltrates into the ground causing subsoil and ground water contaminations. Generally, the solid waste continues to stay at the location where it is placed over the years, hence the process of leachate infiltration into the subsurface environment continues, slowly and for several years. Liquid wastes also seep or leak into the sub-surface soil and contaminate the subsurface soil and the ground water. Such industrial effluents either treated or untreated are discharged over the soil which may change the properties of soil. Therefore, it becomes very important to understand the effect of chemicals that are ejected out of the industries. If there is an improvement in engineering behavior of soil, there is a value addition to the industrial wastes serving the three benefits of safe disposal of effluent, using as a stabilizer and return of income on it. If there is degradation of engineering behavior of soil then solution for decontamination is to be thought of. 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 effect of certain industrial effluent on swelling characteristics of black cotton soil was investigated by Narasimha Rao *et al.* [3]. 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 [4]. 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 [7]. The effect of calcium chloride and Na2SiO3 on CH properties of soil, was studied by Ramadasu [9]. 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

[10]. 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 1 shows the properties of black cotton soil used in the test.

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.	**Indian Standards (IS) classification**	Clay of high plasticity (CH)
6.	**Permeability (mm/sec)**	1.55×10^{-5}

Table 1: Properties of Black Cotton Soil

Sodium chloride is a common salt which readily dissolves in water. The solution is odorless but has a characteristic taste. It is hygroscopic in nature and has wide industrial applications. Sodium chloride is an ionic compound made up of equal numbers of positively charged sodium and negatively charged chloride. It is used on the roads and bridges to prevent the building of ice when temperature reduces to freezing. It is used in the production of several metals like copper, steel and aluminum. Other use of sodium chloride includes glass production, rubber production and hardening of soil during construction. For the present work Sodium Chloride was used in the form of solution at various concentrations viz. 0N, 0.1N, 0.5N, 1.0N, 2.0N, and 4.0N. The solution for each concentration was prepared using distilled water. The molecular weight of sodium chloride used was 58.44 g/mol.

Experimental Investigations

Tests on the index properties and engineering properties of soil were carried out for treated and untreated soil conforming to IS code. Specific gravity test was conducted conforming to IS: 2720 (Part 3/Sec 1)-1980. The test is conducted using density bottle method. Objective is to determine the specific gravity of soil fraction. The wet sieve analysis was carried out for untreated soil conforming to IS: 2720 (Part 4)-1985. The objective of the test is to determine the amount of sand, silt and clay fraction present in the soil. According to IS: 2720 (Part 5)-1985, tests on Atterberg's limits were carried out. The objective is to determine the liquid limit and plastic limit of the soil mass. Standard proctor test was conducted conforming to IS: 2720 (Part 7)-1980. The objective is to determine the maximum dry density and optimum moisture content of the soil. The unconfined Compression Strength of soil was conducted conforming to IS: 2720(Part 10)-1973. The objective is to determine the compressive strength of the soil. The treated and untreated soil was subjected to consolidation test conforming to IS: 2720 (Part 15)-1986. The objective is to determine the compression index, coefficient of consolidation and permeability of soil.

Specific Gravity

The specific gravity test was conducted on black cotton soil using density bottle for fine grained soil particles. Figure 1 shows the effect of sodium chloride on specific gravity of black cotton soil. It was observed, that the values of specific gravity is decreasing with the increase in concentration of sodium chloride. The IS code specifies the procedure to obtain the specific gravity of untreated soil. The same procedure was adopted to obtain the specific gravity of treated soil. It was further noted that the dissolved salts present in the pore fluid will start precipitating and added the weight and volume to the soil solids itself. Also, when the sample was heated, certain salts undergo dehydration and lose their crystallization. Therefore, the obtained specific gravity may not represent its true specific gravity [6].

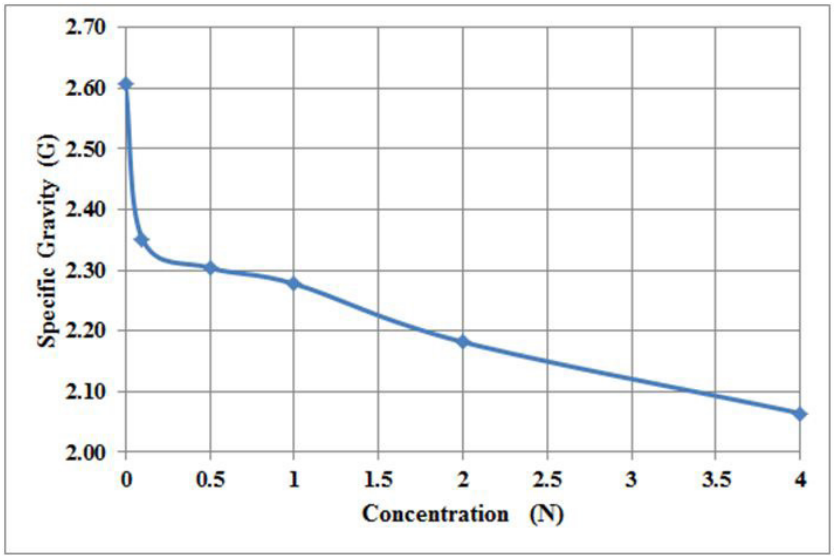

Figure 1: Effect of sodium chloride on specific gravity of black cotton soil

Effect of Sodium Chloride on Soil Classification

Fine grained soils are classified on the basis of their grain and gradation characteristics. The classification of soil treated with sodium 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 2 shows the values of plasticity chart, where the soil is changing from clay of high plasticity (CH) to clay of medium plasticity (CI). Figure 2 shows the grain size distribution curve of black cotton soil. It shows the percentage of silt, sand and clay present in the soil. Also it shows the effect of 4 N sodium chloride on grain size of black cotton soil. Table 3 shows the comparison between the effect of water and sodium chloride on grain size distribution of black cotton soil. It was observed that the percentage of clay reduced from 64% to 48% and percentage silt increased from 24% to 40%.

Concentration	Liquid Limit	Plasticity Index	Soil Classification
0 N	63	34	CH
0.1 N	61	33	CH
0.5 N	57	32	CH
1.0 N	51	27	CH
2.0 N	**47**	23	CI
4.0 N	42	18	CI

Table 2: The effect of sodium chloride on plasticity properties of soil

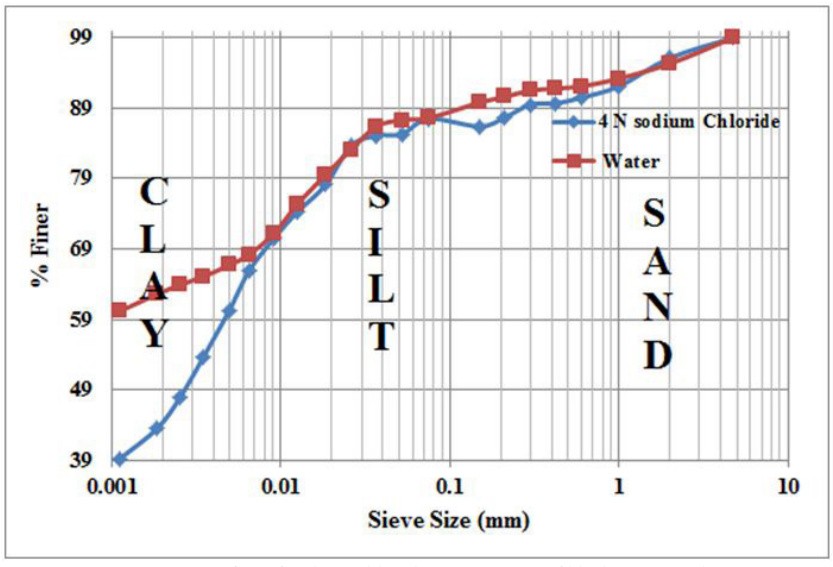

Figure 2: Effect of sodium chloride on grain size of black cotton soil

Particulars	Water	4N Sodium chloride
Clay (%)	64	48
Silt (%)	24	40
Sand (%)	12	12

Table 3: Comparison between the effect of water and 4 N NaCl on grain size of soil

Figure 3 represents the effect of sodium chloride on the plasticity property represented on IS plasticity chart. Black cotton soil with a liquid limit of 63.05% and plasticity index of 34.58% lies in CH zone. But, with the addition of sodium chloride there is transformation in the plasticity property, the liquid limit reduces to 42.54% and plasticity index reduces to 18.87% and the nature of soil is transformed from CH to CI, which indicates the reduction in clay content.

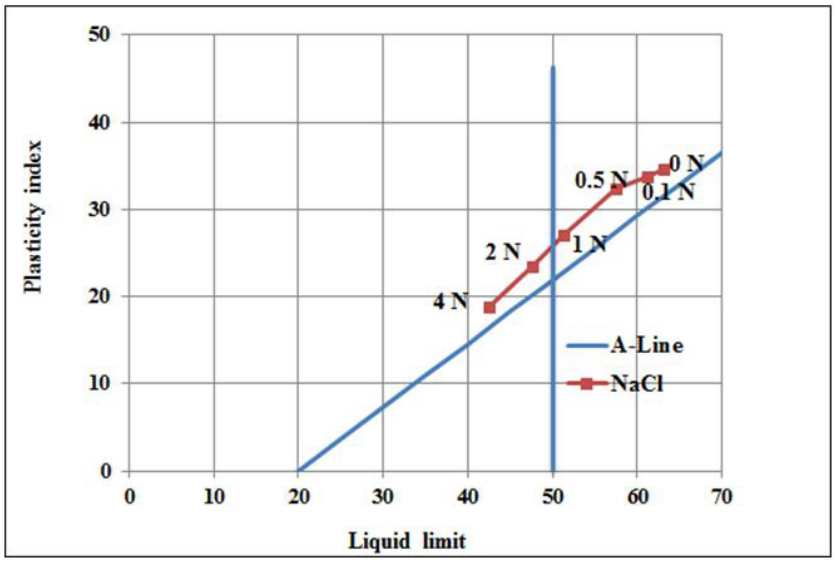

Figure 3: Effect of sodium chloride on plasticity properties of black cotton soil

Atterberg's Limits

Test on liquid limit and Plastic limit was carried out for treated and untreated black cotton soil. Figure 4 shows the effect of sodium 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 sodium chloride. The intervention of sodium chloride dissolved in distilled water would result in change in the ion exchange capacity, perhaps due to adsorption. The ion concentration reduces the repulsive forces and increases the effective stress leading to flocculation of clay particles which reduces the plasticity [10].

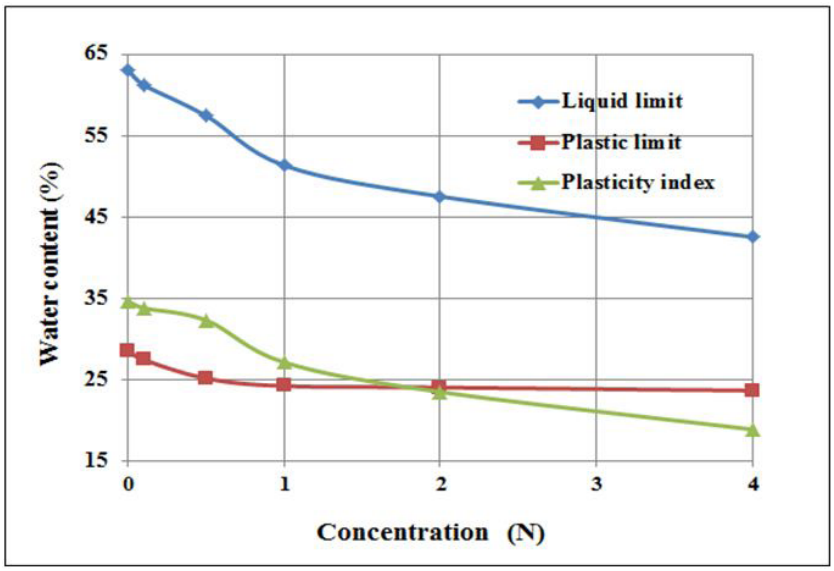

Figure 4: Effect of sodium chloride on consistency limits of black cotton soil

Compaction Test

The standard proctor test was conducted for treated and untreated black cotton soil. Figure 5 shows the effect of sodium chloride

on compaction properties of black cotton soil. By adding salt to the pore fluid, the thickness of diffuse double layer decrease. Therefore using the same compaction energy, the particles pack better together and the dry density increases [5].

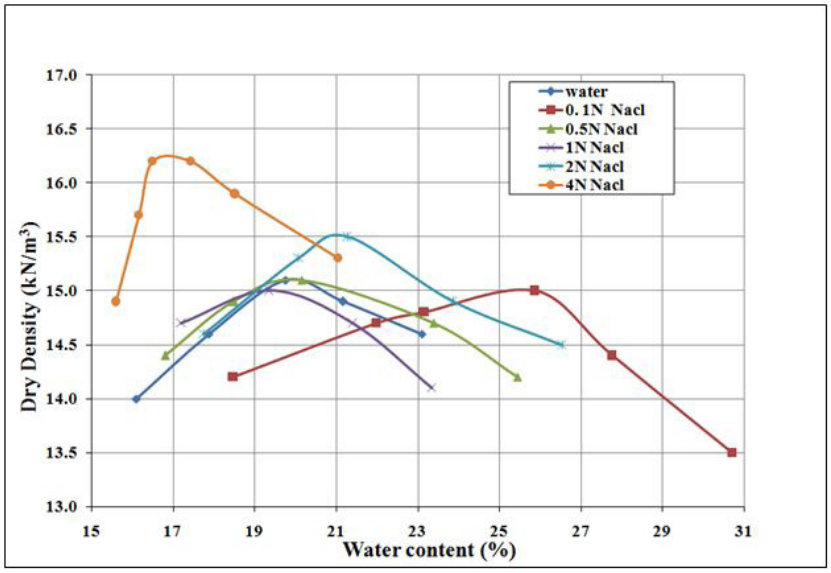

Figure 5: Effect of sodium chloride on compaction characteristics of black cotton soil

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 4 shows the values of solid volume occupation (P) and Water volume content (e_w) at varying concentrations of sodium chloride. Figure 6 shows the compaction curve plotted with respect to solid volume occupation and water volume content. It is observed that, the behavior of black cotton soil shows a precise trend in the variation of curve with increase in concentration. With the increase in the concentration of sodium chloride, the solid volume occupation increases and water volume content decreases.

Concentration (N)	e_w	P	Concentration (N)	e_w	P
0	42.05	0.54	1	39.22	0.64
	46.66	0.56		44.13	0.66
	51.59	0.58		48.8	0.64
	55.26	0.57		53.23	0.62
	60.3	0.56			
0.1	36.33	0.61			
	42.69	0.63			
	45.53	0.63	2	38.7	0.67
	51.34	0.64		43.76	0.7
	56.97	0.61		46.36	0.71
	60.82	0.57		52	0.68
	36.19	0.62		57.86	0.67
	39	0.65		33.86	0.72
	44.18	0.66			
0.5	51.2	0.64	4	40.23	0.76
				42.22	0.79
	60.29	0.62		43.97	0.79
				45.57	0.77
				47.28	0.74

Table 4: Values of Solid Volume Occupation And Water Volume Content At Various Concentrations Of Sodium Chloride

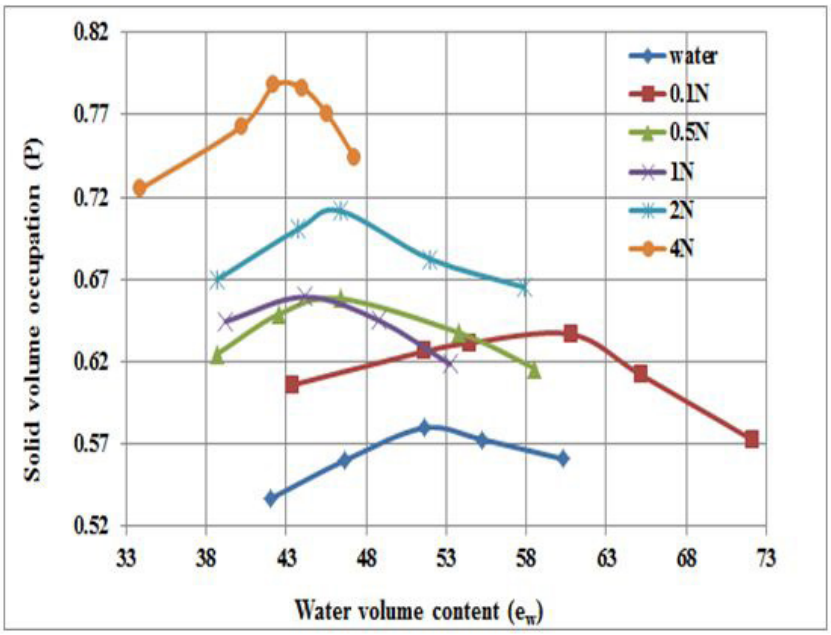

Figure 6: Effect of Nacl on Water Volume Content and Solid Volume Occupation

Water Volume Content and Voids Ratio: Table 5 shows the variation in the values of water volume content and voids ratio with reference to the concentration of sodium chloride. Figure 7 shows the behavior of voids ratio and water volume content with respect to the concentrations of sodium chloride. It can be clearly noticed that, with the increase in the concentrations of sodium chloride the water volume content is decreasing and also the voids ratio decreasing. This property aids to the process of compaction, therefore increasing the bonding between the particles. Figure 8 shows the behavior of black cotton soil with respect to the water volume content and percentage air voids. The curve indicates the decrease in the water volume content with increase in concentration of sodium chloride. Also, decrease in percentage air voids with increase in concentration.

Concentration (N)	e_w	e	Concentration (N)	e_w	e
0	42.05	0.862		39.22	0.551
	46.66	0.785		44.13	0.517
	51.59	0.725		48.8	0.55
	55.26	0.746	1	53.23	0.617
	60.3	0.783			
0.1	36.33	0.711		38.7	0.492
	42.69	0.642			
	45.53	0.618			
	51.34	0.625		43.76	0.427
	56.97	0.685		46.36	0.405
	60.82	0.718	2	52	0.466
0.5	36.19	0.546		57.86	0.503
	39	0.526			
	44.18	0.512	4	33.86	0.379
	51.2	0.555		40.23	0.310
	60.29	0.65		42.22	0.270
				43.97	0.272
				45.57	0.299
				47.28	0.345

Table 5: Values of Water volume content and percentage voids

Consolidation

Consolidation test was carried out for treated and untreated soil. The sample was treated at 0.5 N NaC l and 4 N NaCl. The soil sample here is subjected to various increments of stress viz. 0 kg/cm^2, 0.25 kg/cm2, 1.0 kg/cm2, 2.0 kg/cm^2 and 4.0 kg/cm^2. The sample subjected to each stress under 24 hrs, after which the stress is incremented. After the increment, the soil sample was subjected to unloading and allowed to swell for duration of 24 hrs. The value of permeability was then obtained. Table 6 below

shows the values of permeability at 0.5 N and 4.0 N NaCl. It is observed that, the co-efficient of permeability is increasing with increase in concentration of sodium chloride.

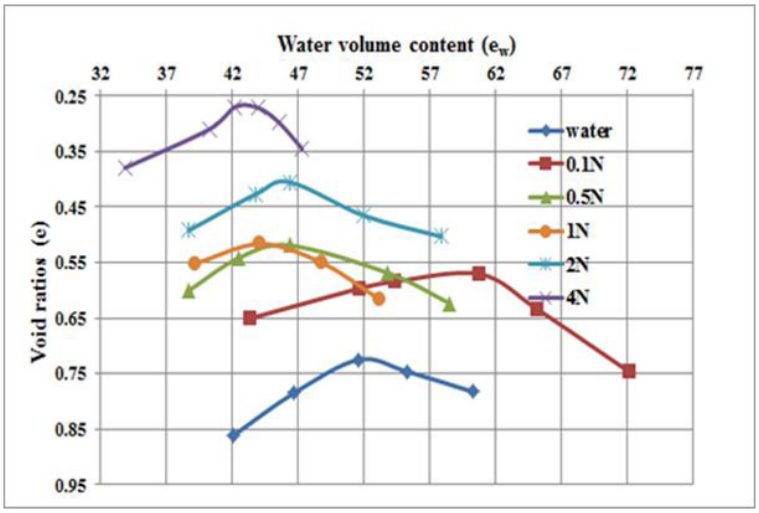

Figure 7: Effect of Nacl on Water Volume Content and Voids Ratio

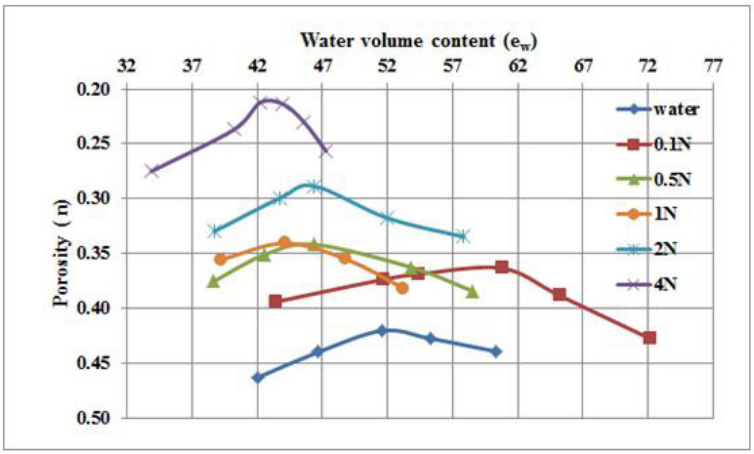

Figure 8: Effect of Nacl on Water Volume Content and Porosity

Concentration (N)	K (mm/s)
0 N	0.0000155
0.5 N	0.0000261
4 N	0.0000257

Table 6: Permeability values

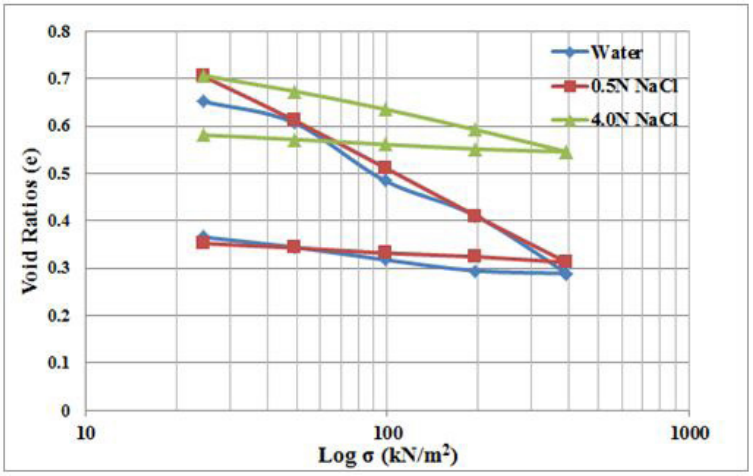

Figure 9: Steady state thermal contour of embossed fin

Figure 9 shows the effect of sodium chloride on voids ratio of black cotton soil. It is observed that, the voids ratio is decreasing with increase in stress. Figure 10 behavior of Cc and Cv of black cotton soil. It is observed that compression index decreases with increase in concentration and co-efficient of consolidation increases from with increase in concentration.

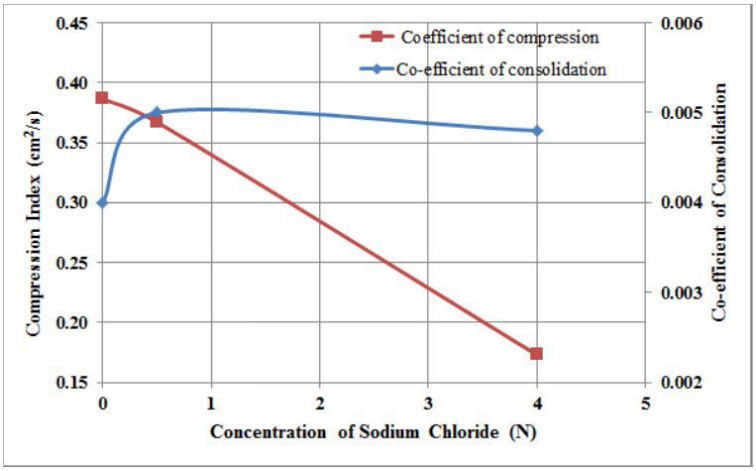

Figure 10: Concentration Vs Compression Index and Co-Efficient of Volume Change

Unconfined Compression Strength

Unconfined compression strength test was carried out on treated and untreated black cotton soil. The samples are subjected to curing for durations of 1 day, 7 days, 14 days and 28 days. Figures 11, 12 & 13 show the stress strain behavior of black cotton soil at

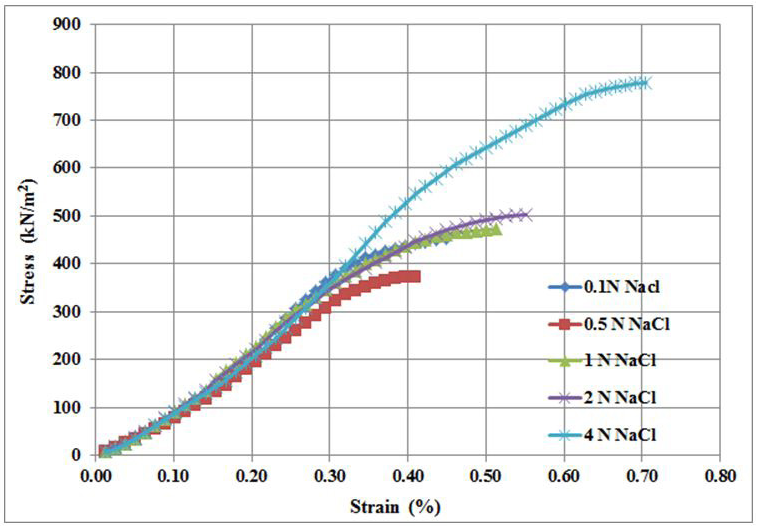

Figure 11: Stress Strain Behavior of Soil Cured For 7 Days Curing

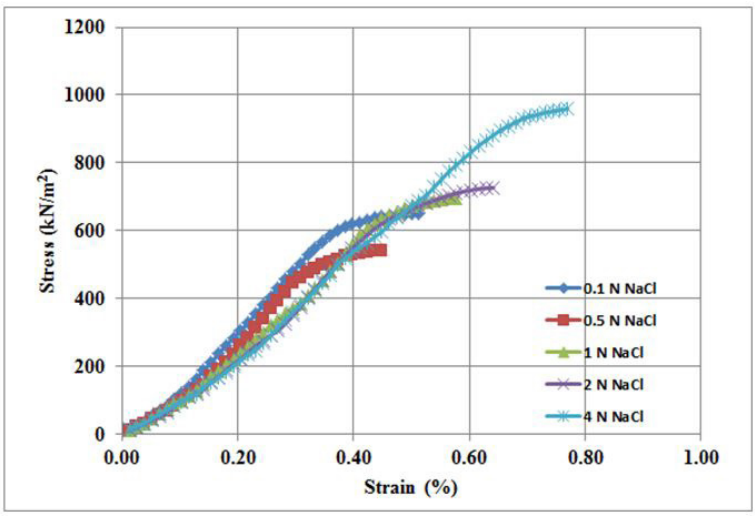

Figure 12: Stress Strain Behavior of Soil Cured For 14 Days

various concentrations of sodium chloride subjected to 7 days, 14 days and 28 days curing period respectively. Figure 14 shows the effect of sodium chloride on unconfined compression strength of black cotton soil with increase in curing period. It was observed that at any curing period the strength increases with increase in sodium chloride concentration. The increase in the strength with addition of chemicals may be attributed to the cation exchange of NaCl between mineral layers and due to the formation of silicate gel [8].

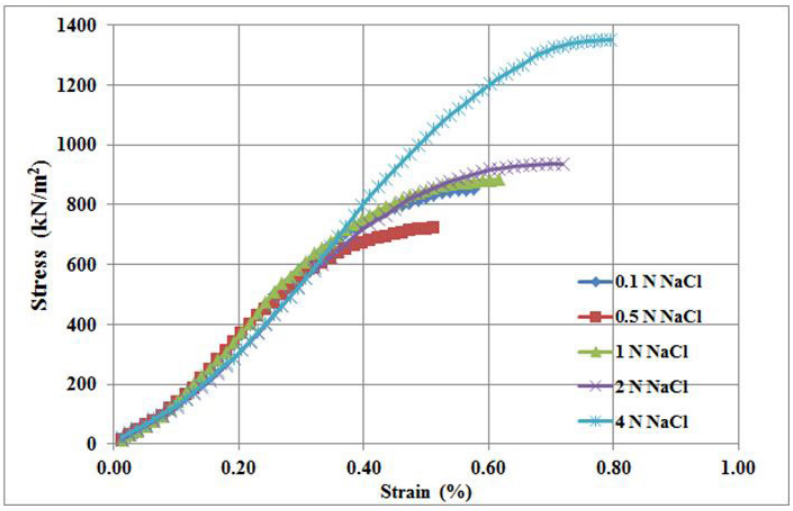

Figure 13: Stress Strain Behavior of Soil Cured For 28 Days

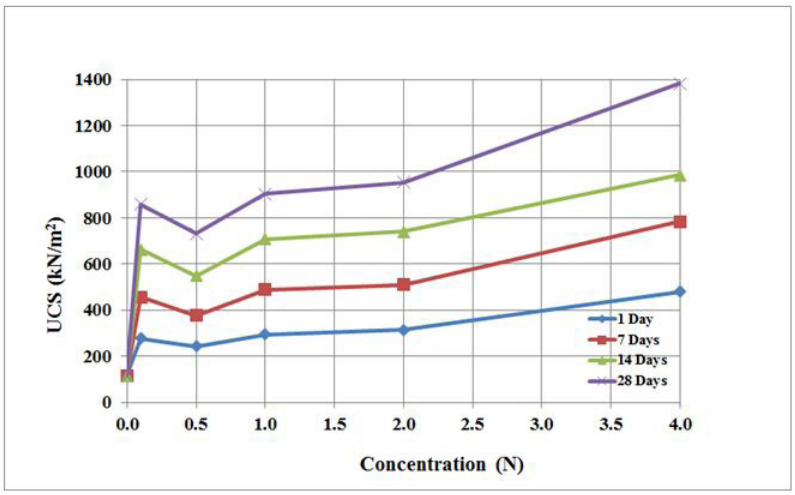

Figure 14: Effect of Sodium Chloride on Unconfined Compression Strength of Black Cotton

Mechanism of Sodium Chloride with Black Cotton Soil

After the conduction of tests, it was observed that the black cotton soils treated with sodium chloride leads to decrease in plasticity and increase in strength and permeability. Such changes in the properties of clayey soils are due to the reaction between the sodium chloride, silicate and aluminates present in the black cotton soil. The following equation represents the reaction developed.

$$NaCl + H_2O \rightarrow Na^+ + Cl^-$$

$$Na^+ + OH^- + \text{soluble clay silica} \rightarrow \text{sodium silicate hydrate}$$

$$Na^+ + OH + \text{soluble clay alumina} \rightarrow \text{sodium aluminates hydrate}$$

Sodium chloride when dissolved in water, Na^+ and Cl^- ions are formed in the solution. The addition of sodium chloride to black cotton soil creates alkaline environment, which leads to the solubility of silicate and aluminum ions at high rate. During this process, the silicate and alumina reacts with sodium to produce cementitious compounds; sodium silicate hydrate (SCH) and sodium aluminates hydrates (SAH). Untreated clays have a molecular structure similar to some polymers, and give plastic properties. The structure can trap water between its molecular layers, causing volume and density changes. Whereas, in the treated soils the cementitious compounds are trapped between the molecular layers causing flocculation by bonding adjacent soil particles together and strengthen the soil with curing time.

Conclusions

Following are the conclusions drawn from the above discussions

1. Addition of sodium chloride on black cotton soil reduces the specific gravity with increase in concentration.
2. Sodium chloride has the property of transforming the soil from CH zone to CI zone.
3. It is observed that, with increase in concentration of sodium chloride, the liquid limit, plastic limit and plasticity index of black cotton soil decreases.
4. Coefficient of consolidation increases with increase in concentration. Coefficient of compression decreases with increase in concentration.
5. It is observed that the permeability of black cotton soil increase with increase in concentration of sodium chloride
6. Black cotton soil treated with sodium chloride shows increase in strength with increase in concentration at any curing period.

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