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Geotechnical Properties of Clayey Soils Induced by the Presence of Sodium Chloride

Falah H Rahil¹, Kawther Y H Al-Soudany¹, Narjis S Abbas¹, Luay Y Hussein¹

¹University of Technology, Building and Construction Engineering Department /Baghdad, Iraq

Abstract: The presence of appreciable quantities of soluble salt indicates that engineering properties of clayey soils may change in the presence of percolating water. Hence, an attempt was made in laboratory investigation to study the geotechnical properties of clayey soils mixed with (0%, 5%, 10% and 15% by weight) of sodium chloride. Three type of clayey soils used having plasticity indices (12, 26 and 44%) were taken from three sites in Baghdad. Test Atterberg limits, unconfined compression, specific gravity, compaction and consolidation test, were conducted to investigate the effect of salt content on soil properties. The results showed that the plasticity index, optimum moisture contents, compression index, and unconfined compressive strength decrease with increasing salt content. The max dry unit weight slightly increases with increase salt content while it increases up to 5% salt then decreases for high plasticity.

1. Introduction

In many regions of the world, especially in arid and semi-arid zones, large areas are covered with soil, containing varying quantities of soluble salts mostly sodium chloride (NaCl) [1]. The saline soil in Iraq is situated in central and southern parts. The presence of appreciable quantities of soluble salt indicates that the engineering properties may change in the presence of percolating water.

The compaction characteristics of a cohesive soil were affected by gypsum content. The maximum dry unit weight increases with increase of gypsum content up to 5% then decreases, while the optimum moisture content increases as gypsum content increase. This behavior was attributed to the dispersion effect and soil volume increase [2]. The effect of adding gypsum contents which varying between (5-20%) on the properties of cohesive subgrade, soil brought from a site in Baghdad was investigated. The maximum dry density decreases and the optimum moisture content increases as the gypsum content increase [3].

Al-Heaty studied the effect of three types of soluble salts (NaCl, Na₂SO₄ and CaSO₄.2H₂O) on the compressibility, shear strength and stiffness of a subgrade soil. The results showed that the low percentages of soluble salts increased the compressibility of soil through the increase in maximum dry density while high percentages reduced it and the sodium chloride indicates a significant reduction in the compressibility and strength [4]. Abood investigated the effect of adding different chloride compounds including (NaCl, MgCl₂, CaCl₂) with various amount of salts (2%, 4% and 8%) on the properties of cohesive soil. The study showed that the increase in the percentage of each the chloride compound increased the maximum dry density and decrease the optimum moisture content [5]. Amu studied the effect of common salt (NaCl on the compaction and CBR properties) of eggshell stabilized lateritic soils with various amount of salt (2, 4, 6, 8 and 10%), the results showed that the addition of common salt improved the compaction and CBR characteristics of soils [6].

The effect of adding sodium chloride increase the dry density and decrease the optimum moisture content [7] [8], while the results obtained by [9] showed that the type and amount of soil salinity has no significant impact on the compaction characteristics.



Various researches have conducted scattered and diverse reaches on investigating and determining the effect of sodium chloride on the engineering properties of clayey soils. Hence, this paper describes the effect of addition NaCl on engineering properties of clayey soil having different plasticity indices.

2. Experimental Work

2.1. Soils used

The soil samples were obtained from three different locations in Baghdad area at a depth about 1.5m below natural ground surface. The grain size distribution of these soils is shown in Figure 1 and its property are given in Table 1.

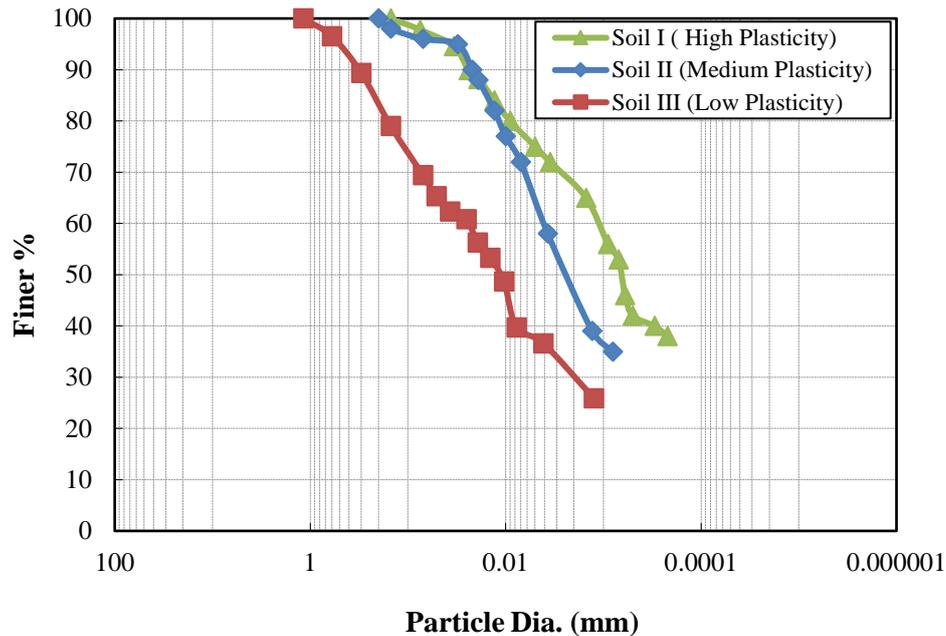


Figure 1. Grain size distribution curves of the soils used.

Table 1. The physical properties of the soils used.

Index Properties	Soil I (High)	Soil II (Medium)	Soil III (Low)
L.L (Liquid Limit)	65	42	34
P.L (Plastic Limit)	21	16	22
P.I (Plasticity Index)	44	26	12
Gs (Specific Gravity)	2.70	2.69	2.65
Sand	2.2%	4%	30.6%
Silt	22.8%	33%	31.4%
Clay	75%	63%	38%
O.M.C (Optimum Moisture Content)	23.2	19	16.4
γ_{dry} maximum dry density	15.71	17.21	17.43
Soil Classification according to USC	CH	CL	CL

2.2. Salt used

The sodium chloride salt used is common, non-iodized stable salts, white in color and is in the form of crystals, obtained from S.E. of Geological Survey and mining, passing through a No.50 (0.3 mm) sieve. The purity of NaCl used was 99% and the degree of solubility equal to 360gm/l.

2.3. Experimental program and samples preparation

The experimental program involves investigating the influence of sodium chloride on geotechnical properties of clayey soils, namely specific gravity, Atterberg's limit, compaction characteristics, unconfined compressive strength, consolidation properties. Tests were performed using samples prepared at 17.21 kN/m^3 dry unit weight (γ_{dry}) and 19% water content.

The soil samples were prepared by air drying, pulverizing and sorting on a No.4 (4.75mm) sieve. Individual quantities of salt and soil were weighed in separate containers according to predetermined levels to minimize the time required for sample preparation.

The samples were prepared by first measuring the desired quantity of distilled water, selecting the proper reweighed quantities of salt and soil, dissolving the salt with water, adding water, and blending by hand for 5 minutes. The sample was thoroughly mixed to ensure even distribution of moisture throughout until a uniform appearance was attained. The wet sample, were placed in a plastic bag and allowed to stand prior to test (24 –hr. Waiting period) to enhance moisture equilibrium and to enable excess pore pressure to dissipate. The salt contents were used in levels of (5% to 15%) by weight of dry soil. All tests were conducted depending on the ASTM (2002) specification.

3. Results and analyses

3.1. Specific gravity

In order to investigate the influence of sodium chloride content on specific gravity of the soils, specific gravity tests were carried out on soil samples containing different salt contents. The results are presented in Figure 2. The results demonstrate a decrease in the specific gravity values as the salt content increases. This decrement is attributed to the low value of specific gravity of NaCl (2.1).

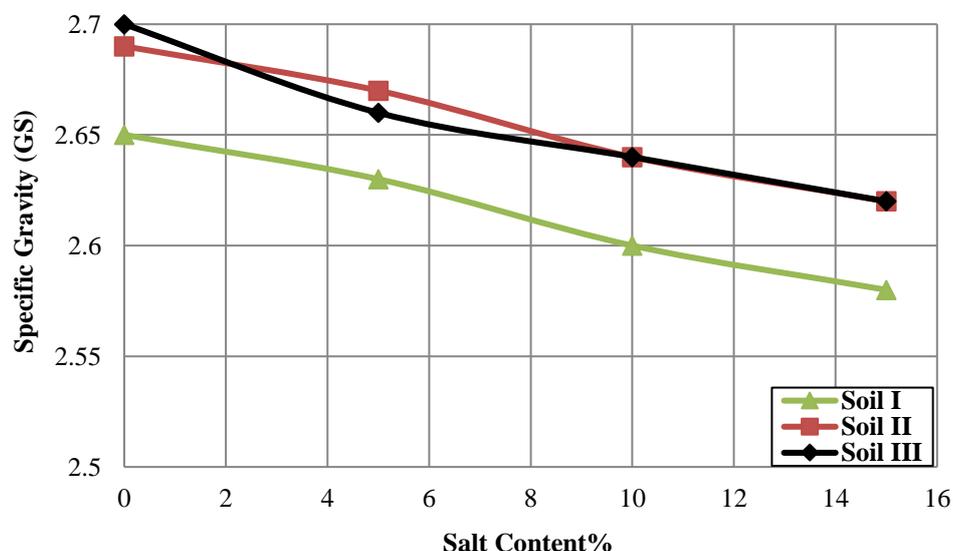


Figure 2. Variation of specific gravity with increasing salt content.

3.2. Atterberg's Limits:

The influence of salt content on the liquid limit, plastic limit and plasticity index of the soils are shown in Figures 3, 4 and 5 respectively. The Figures show that the increase of salt content decreases the liquid limit and has no effect on plastic limit. The reduction in L.L is attributed to the flocculation and agglomeration of the soil particles due to the presence of salt. The presence of high sodium ions in the soil water causes dispersion of fine particles. The Na^+ is a reactive ion and inherently has positive electrical charge while the clay particles have a negative electrical charge acting as exchange site on which the positive charge cations Na^+ try to attach. As a result, an excess of cation leads to a deficiency

of water and decrease in thickness of diffused double layer. Table 2 present values of liquid, plastic limits and plasticity index for all soils tested in this research.

Table 2. Atterberg's limit of tested soils.

Soil type	Salt content (%)	L.L (%)	P.L (%)	P.I (%)
I	0	65	21	44
	5	49	21.5	27.5
	10	33	22	11
	15	31	21	10
II	0	42	16	26
	5	37	16	21
	10	36	17	19
	15	35	18	17
III	0	37	15	22
	5	35	14	21
	10	32	14	18
	15	25	13	12

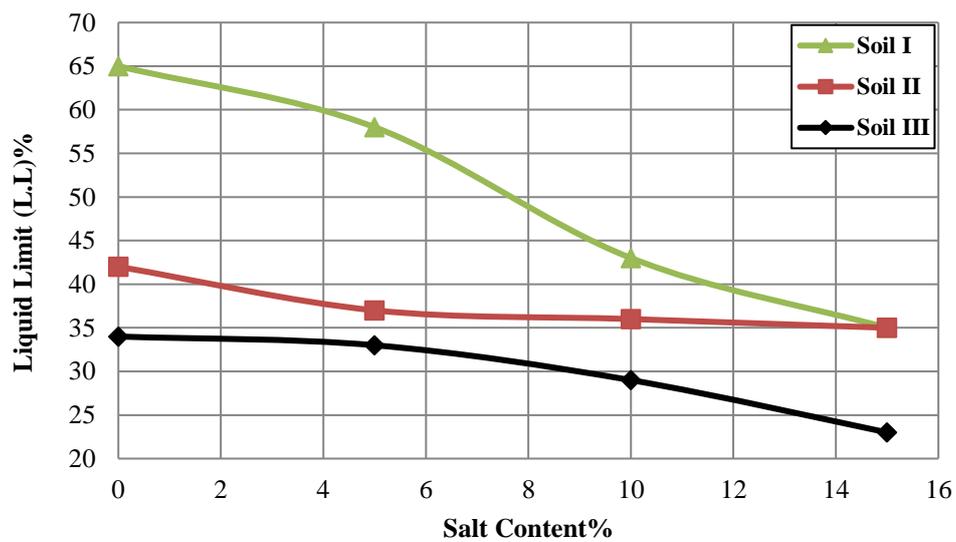


Figure 3. Variation of liquid limit (L.L.) with increasing salt content.

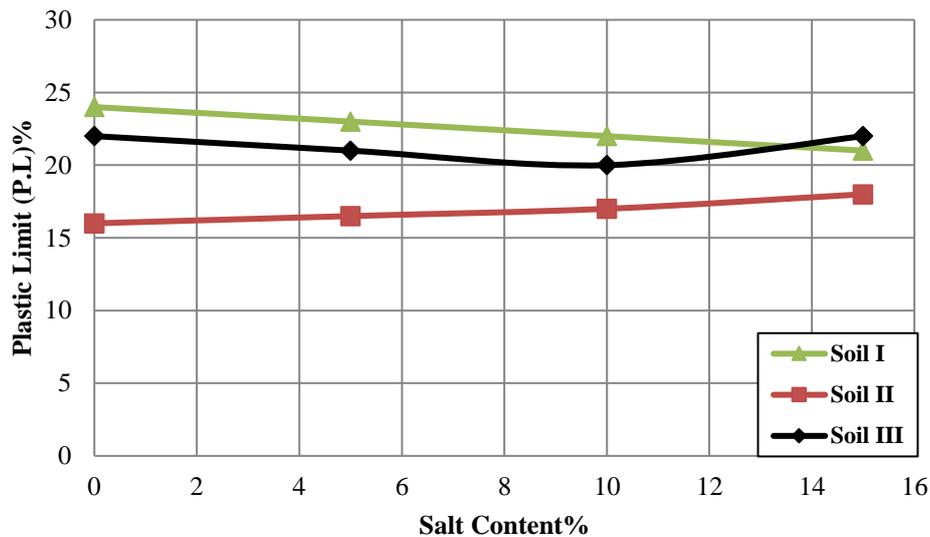


Figure 4. Variation of plastic Limit (P.L) with increasing salt content.

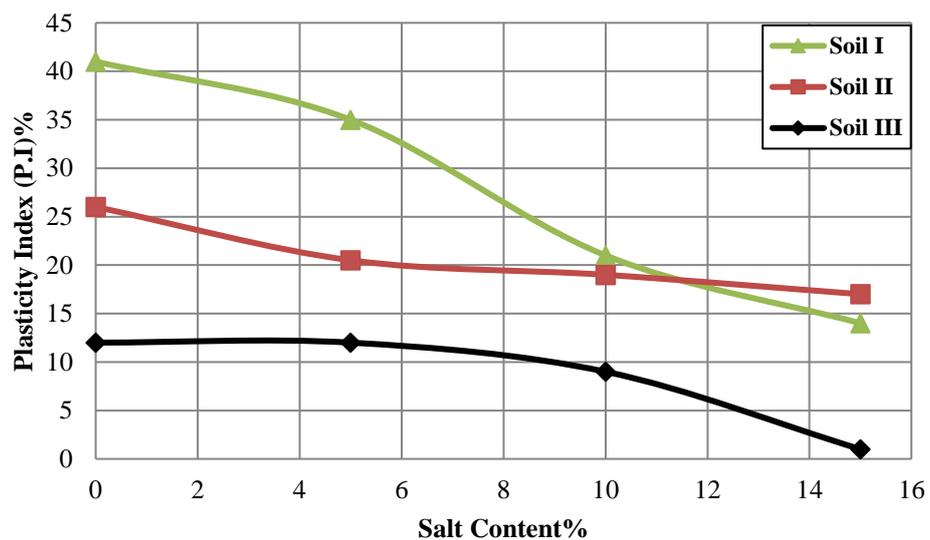


Figure 5. Variation of plasticity index (P.I) with increasing salt content.

3.3. Compaction tests

The results of maximum dry unit weight - salt content are shown in Figure 6 and the results of optimum moisture content - salt content are shown in Figure 7 it can be observed that by increasing the salt content for the soil types, the samples exhibit slight increase in maximum dry unit weight for low plasticity soil while it increase up to 5% then decrease for high plasticity soil. The same results were obtained by [10], [11] and [12]. This behavior may be attributed to aggregation of salt which fill the pores between soil particles. At low salt content, the soil structure tends to change from edge-to-face type of flocculation, and this leads to a decrease in the repulsive forces because of replacement of ions in the pore water and a mildly flocculated soil structure is produced. Table 3 present Proctor test results for used soil.

Table 3. The compaction characteristics for tested soils.

Soil type	Salt content (%)	O.M.C (%)	$\gamma_{dry\ max}$
I	0	23.2	15.71
	5	20.5	16.23
	10	18	15.70
	15	18.2	15.32
II	0	19	17.21
	5	17.8	17.31
	10	16.63	17.37
	15	15.93	17.39
III	0	19	17.43
	5	16.15	17.93
	10	14.7	17.98
	15	12.4	18.20

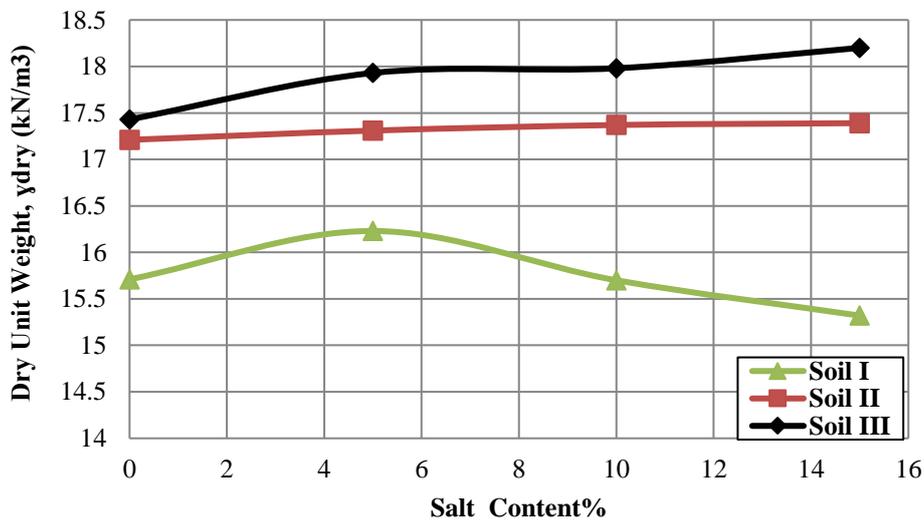


Figure 6. Variation of maximum dry density with increasing salt content.

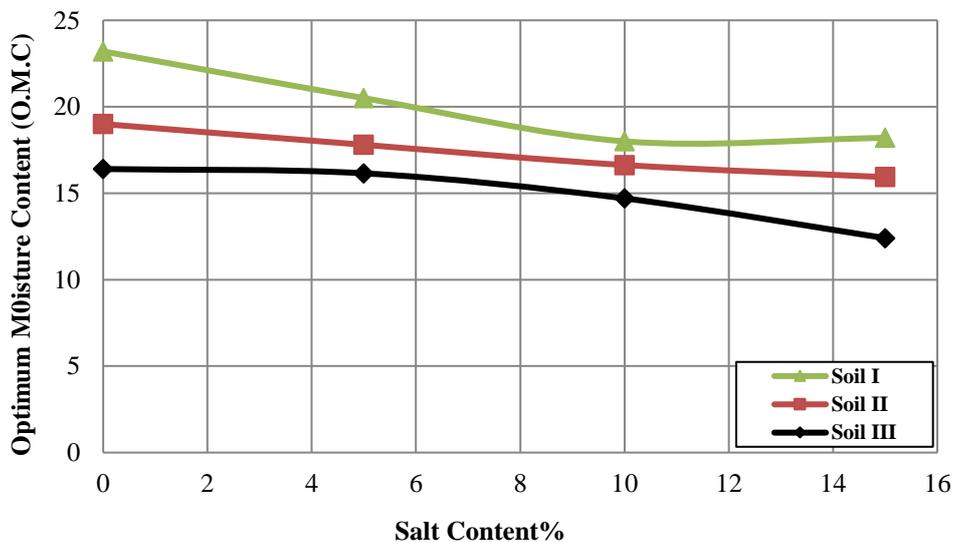


Figure 7. Variation of (O.M.C) with increasing salt content.

3.4. Shear strength

In order to determine the shear strength of three soils, unconfined compressive tests were used. All samples were tested at dry unit weight (γ_{dry}) 17.21kN/m^3 and water content 19%. Figures 8 to 11 shows the results of the unconfined compressive tests for different contents of salt for soils used. This behavior could be attributed to the fact that chlorides are good soil lubricant and that the excess quantity of salt recrystallizes in the bonds between soil particles, which may disrupt the crystalline structure of the soil fabric and reduce the unconfined strength. The reduction in shear strength by increasing salts content comes about as a result of the destruction of the chemical bond, resulting in reducing rigidity of the sample. Figure 11 represent the relationship between unconfined compressive strength and salt content for three soils. The Figure 11 show that the values of shear strength (C_u) is high for high plasticity and low for low plasticity since three soils are tested at the same dry unit weight (γ_{dry}) and water content this mean the soil is tested at dry unit weight greater than its maximum unit weight and water content less than it's optimum moisture content, also another reason, depend on the percentage of sand in each soil. When the percentage of sand increases the shear strength decreases.

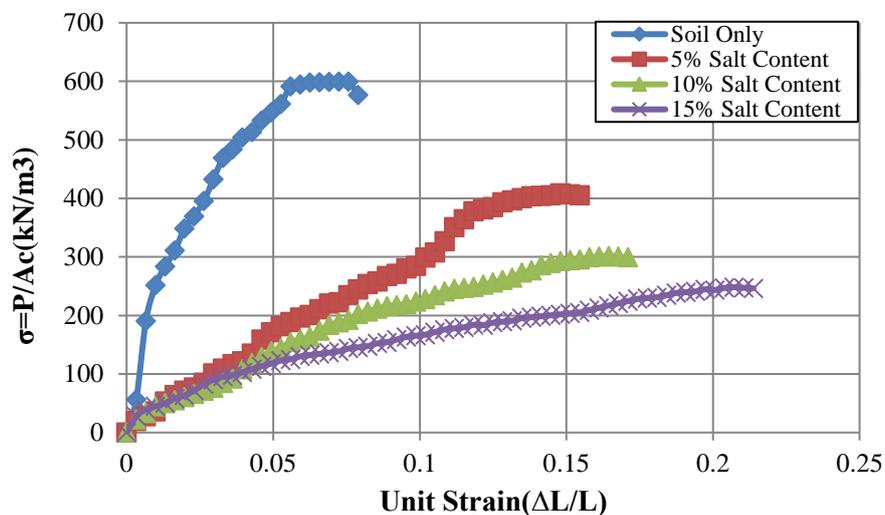


Figure 8. Stress – strain relationship from unconfined compressive test results for soil I.

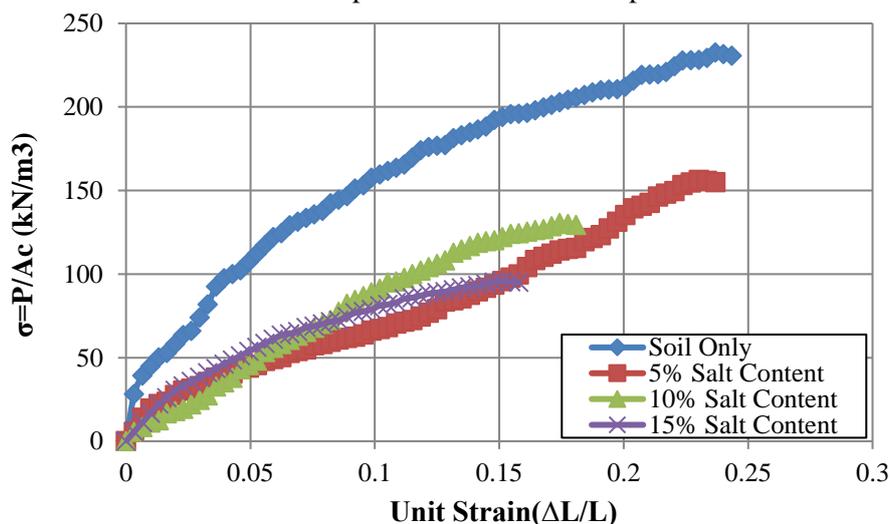


Figure 9. Stress – strain relationship from unconfined compressive test results for soil II.

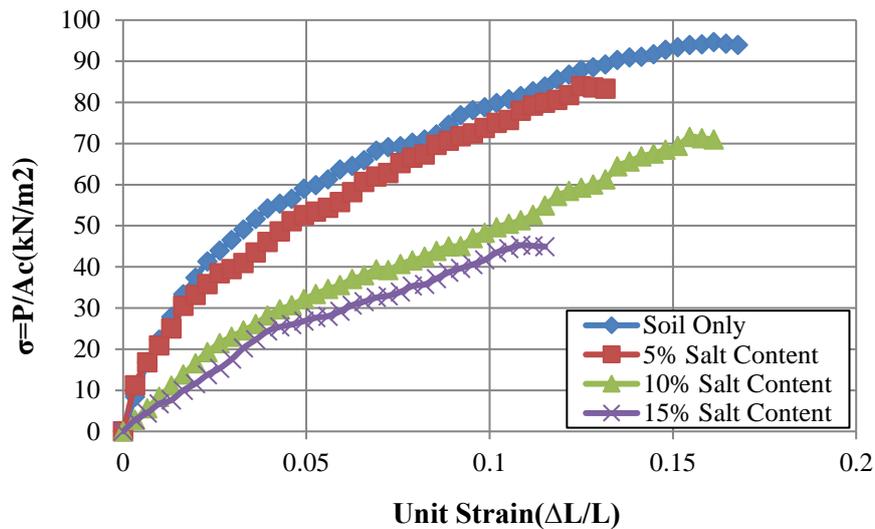


Figure 10. Stress – strain relationship from unconfined compressive test results for soil III.

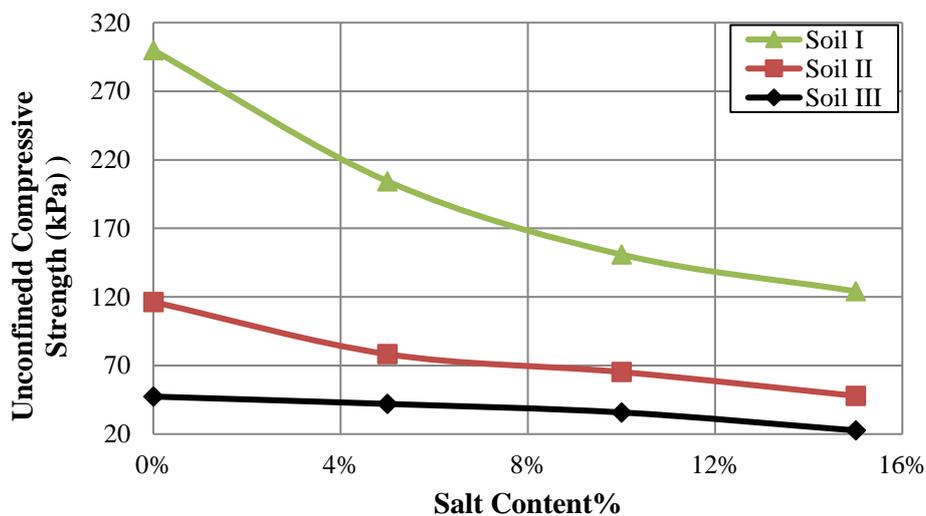


Figure 11. Variation of the unconfined shear stress for three soils with increasing salt content.

3.5. Compressibility

The variation of compression index with salt content is shown in Figure 12 for the three types of soils. It's clear that the compression index decreases with increase in plasticity index and decrease with increase in salt content for three types of soil. This reduction may be attributed to the thickness of diffuse double layer, which decreases with increasing salt content. Table 4 presents the values of compression indices for three soils with the variation of salts content.

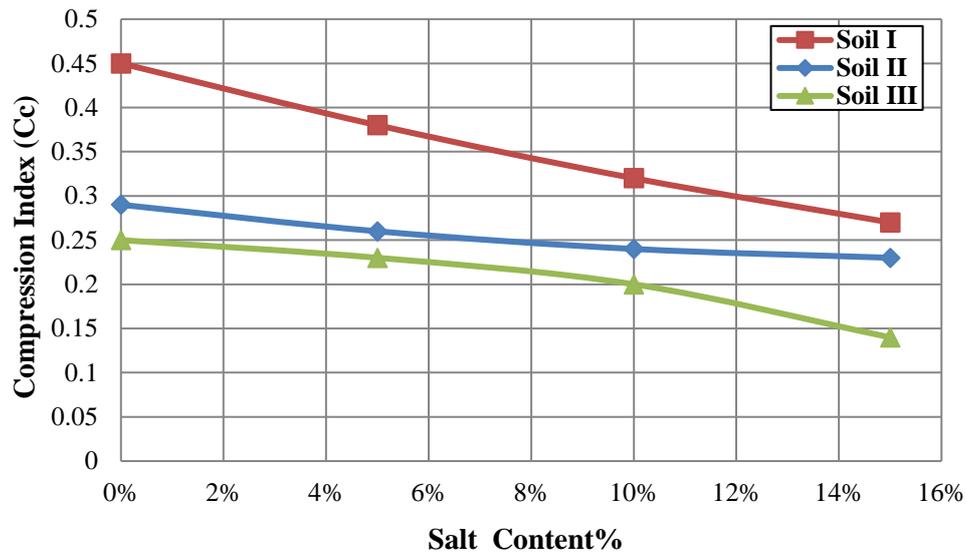


Figure 12. The variation of compression index with salt contents.

Table 4: Compression index for all soils tested in research.

Salt content (%)	Compression index		
	Soil I	Soil II	Soil III
0	0.45	0.29	0.25
5	0.38	0.26	0.23
10	0.32	0.24	0.20
15	0.27	0.23	0.14

4. Conclusions

Based on the experimental study carried out in this research, the following were conducted from drawn:-

1. The liquid limit decrease with increase in salt content but the rate of reduction decrease with decrease plasticity index and same trend for the plasticity index.
2. No effect of salt content on plastic limit for three type of soils.
3. Slight increase in maximum dry unit weight for low plasticity soil while it increase up to 5% then decrease for high plasticity soil. The optimum moisture content decreases with increasing salt content.
4. The unconfined shear strength and the compression index decreases with increasing salt content. A significant reduction is obtained for high plasticity soil.

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