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Research Article

Study on Osmotic Consolidation and Hydraulic Conductivity Behavior of an Expansive Soil Inundated with Sodium Chloride Solution

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Canals are a very imperative source of irrigation for the agricultural sector in India. Seepage causes major water loss in canals, and hence, the installation of liners becomes necessary. Compacted clay soils are commonly used as liners in the canals. This structure will most probably be subjected to salinization and desalinization cycles throughout its life. Because of the interaction between the pore liquid and clay particles, physico-chemical influences considerably impact the behavior of clay barriers. In this paper, the effect of interacting fluid on volume change, consolidation parameters, and hydraulic conductivity of compacted clay soil is investigated with the help of a one-dimensional consolidation test. The compacted clay specimens were immersed alternatively with distilled water (DW) and sodium chloride (NaCl) solutions (SW) at constant loading of 10 kPa, which replicates the load conditions in the field canal due to 1 m head of water and incremental loading as per IS 2720 part 15 standards. The experimental results proved that there is a percentage volume change increase of about two times for each stage inundated with 4M NaCl solution than its preceding stages inundated with distilled water at constant loading of 10 kPa. The consolidation rate was accelerated with 4M NaCl solution than the normal consolidation at incremental loading. The permeability coefficient in the salt water-induced sample increased by 217% more than the distilled water-induced sample at incremental loading. Therefore, the soil specimen subjected to alternate salinization and desalinization cycles significantly affects the volumetric and consolidation behavior, leading to decreased life of clay barrier structures.

1. Introduction

India is a country with the most irrigated land, second only to China. The irrigated area is constantly increasing to ensure a continuous food supply and avoid crop failures due to famines and water scarcity [1]. This country has invested a lot of money in irrigation projects to secure the benefits of irrigated land. Around Rs. 1,15,000 crores have been expended on major and medium irrigation projects from 1947 to 2002, i.e., up to the end of the ninth five-year plan. These data confirm that irrigation water is a valuable commodity, so there should be no wastage while storing and transporting it from the reservoirs to the fields [1]. Canals are India's second most important source of irrigation, next only to wells and tube wells, which contribute about 24% of the total irrigation water to cultivable lands. The canals irrigate those areas with large plains, fertile soils, and perennial rivers. The plains of North India are primarily irrigated by canals. The canal irrigated area used to be 8.3 million hectares in 1950-51, but it was 16.18 million hectares in 2014-15, showing an increased canal irrigation trend in the country [2]. As most irrigation canals in India are unlined, a large portion of the costly irrigation water is lost due to percolation and absorption as seepage loss. Excessive water usage for irrigation leads to increased salinity, nutrient pollution, and damage to floodplains and swamplands [2]. India is experiencing a persistent water shortage due to its poor water resource management system and climate change. There are certainly areas where the soil conditions are such that seepage losses are minimal and the lining is unnecessary. But still, there are other areas where the lining is necessary as they experience 25 to 50% water loss due to seepage [1]. If the liners are applied to canals, they are subjected to adverse environmental changes, and so their efficiency decreases. Therefore, the reasons for the deterioration of clay liner should be studied, and suitable solutions must be provided to improve canal lining techniques and materials to minimise the water losses in the canal and improve their performance.

The compacted clay soil is not only utilized in clay liners but also finds use in a variety of geo-environmental applications such as coverings, earthen dams, subgrades of highway pavements and runways, embankments as they have low permeability, high specific surface area, increased shear strength, mechanical stability, high adsorption capacity, low compressibility, resistance to freezing, thawing, and desiccation. The clay particles have a high specific surface area due to their smaller particle size and structure [3]. The fact that compacted soils may not be fully saturated and defined by the phenomenon of soil suction is widely recognized [4, 5]. Matric and osmotic suction are two types of soil suction. The dissolved salt content in pore water affects osmotic suction. Pore fluid composition of clays may be subjected to alteration due to infiltration of chemical solutions from chemical spillages during industrial operations, seepage of irrigation water mixed with fertilizers into the canal, and inundation of clay liners in brine ponds [6, 7]. Leachates from municipal and hazardous waste dumps and near-surface nuclear waste sites also generate osmotic suction gradients when they come into contact with compacted clay barriers [8, 9].

Due to osmotic gradients, water flows out of clay, causing osmotic consolidation to occur and thereby creating a negative pore water pressure within the void spaces of unsaturated clay that increases the effective stress; the associated volume decrease is termed as osmotically induced consolidation [10]. Osmotic suction is found to alter due to changes in pore fluid composition as a result of groundwater pollution [11]. Because of changes in diffuse double-layer thickness, pore fluid osmotic suction substantially impacts the physical and hydraulic behavior of compacted clays [12]. The difference in ion concentration between the double layer's interior and exterior acts as a semipermeable membrane, allowing water to pass through it and expanding the soil's volume [13, 14]. The diffuse double-layer thickness changes the cluster size and pore size, thereby affecting the soil structure and, subsequently, the mechanisms of compacted clays [12, 15]. Physico-chemical impacts altogether affect the behavior of clay barriers because of the interaction between the pore liquid and clay particles, and they pose a great challenge on the grounds that the effectiveness of clay barriers might be altered [16, 17]. Alternate wetting and drying cycles bring out volumetric changes, disrupting the microstructure of compacted clays [18].

As a result, in geo-environmental engineering applications, recognizing the influence of osmotic consolidation on clay behavior is critical. During the formation of clay materials, dissolved salts are spontaneously acquired in the pore water [19]. Clay soils often have pore water salt concentrations (or pore water salinity) ranging from 0 to 900 ppm for nonsaline soils and 3700 to 7300 ppm for saline soils [20]. However, their natural pore water salinity may be altered when clays are used as impermeable barriers in waste disposal facilities. Infiltration of leachates and brine solutions in compacted clay liners installed in landfills and brine ponds [21], seepage of fertilizer mixed water into the canal linings, infiltration of saline groundwater into compacted bentonite barriers in underground nuclear waste repositories [22], and repositories for low-level radioactive wastes and chemical wastes in salt formations [23] are examples of situations that alter the pore water salt concentrations of clay barriers. Highly concentrated 4 molar sodium chloride (TDS = 2,34,000 ppm) solutions make up brine solutions in brine ponds [24]. Total dissolved salt concentrations in slightly saline groundwater range from 1000 to 3000 ppm, while TDS in very saline groundwater ranges from 10000 ppm to 35000 ppm [25]. Encroachment of seawater in coastal places during current or geologic eras, as well as salt dissolving in salt domes/salt beds, may result in saline water in aquifers [20, 26]. When nonsaline clays (pore water salt concentrations ranging from 0 to 900 ppm) are utilized to build impermeable clay barriers, their pore water salinity may be lower than that of external chemical reservoir solutions [20, 27]. Variances cause the osmotic suction difference between the two-solution phase dissolved salt content between the pore water of clay barriers and the chemical reservoir solution [3, 28].

This paper elucidates the behavior of (a) osmotic consolidation in expansive clayey soils exposed to salinization and desalinization cycles at alternate stages of incremental loading and constant loading with 4M NaCl solution and (b) the effect on the microstructure of expansive clay in a compacted state and during wetting cycles of salinization and desalinization and (c) examines the changes in hydraulic conductivity of expansive clay during each cycle.

2. Structure of Compacted Clay

Various researchers have investigated the structure of compacted clay using scanning electron microscopy (SEM) and mercury intrusion porosimetry (MIP) tests in order to incorporate the double structure at the microstructural and macrostructural levels [29–37]. Silicate clays are blended in a definite proportion of one aluminium or magnesium octahedral sheet sandwiched between two silica tetrahedral sheets. During chemical weathering, feldspar and amphiboles break down into two-dimensional silicate sheets and constituent cations. The layers are formed by combining two to four sheets which make up the smallest unit cell of a clay mineral. Silica sheets consist of four oxygen atoms with silicate at the centre. Three of the four oxygen atoms are shared during layer formation, with one oxygen atom left unbalanced [3]. Octahedral sheet consists of magnesium or aluminium with oxygen or hydroxyls in an octahedral pattern. In some cases, other cations such as Fe^{2+}, Fe^{3+}, Mn^{2+}, Ti^{4+}, Ni^{2+}, Cr^{3+}, and Li^{+} may be present.

Bonding between octahedral and two tetrahedral sheets is very strong due to primary valence bonding. Nevertheless, weak Vander Waals bonding exists between unit layers and is susceptible to separation. The physical and chemical behavior of clay is influenced by the interlayer cations that arise due to prevailing environmental conditions [3]. Generally, clay mineral surfaces always have a negative charge due to isomorphous substitution. Isomorphous substitution in the octahedral sheet with lower valence ions results in a net negative charge. To maintain electrical equilibrium, the clay surface attracts cations and holds between the layers on surfaces and edges of clay particles. The cations adhered to clay minerals are mainly exchangeable cations that may be replaced by cations of either lower valence or higher valence, based on their abundance [3].

Montmorillonite may occur as tinny equidimensional fragments making it appear as thin films. The thickness of the particles ranges from 1 nm to 1/100 of width. The specific surface area of montmorillonite minerals may be large. The primary surface area is about 50 to 1220 m^2/g, while the second surface area, including interlayer zones due to penetration of water molecules, may rise up to 840 m^2/g [3]. In the smectite group of minerals, the silicate layers instantly absorb water molecules due to moderate surface charge density, and the adsorbed positively charged ions hydrate, causing the separation of layers and bringing about the expansion of clay. The interlayer bond has low strength and is strongly influenced by charge distribution, ion hydration energy, surface ion configuration, and the polar molecule's structure [3]. As the pore fluid electrolyte concentration increases, double layer thickness decreases causing a reduction in intra-aggregate pore size and an increase in interaggregate pore size, explaining the increased permeability as pore fluid concentration rises due to the impact of physicochemical interactions [38]. Changes in macrovoids predominated during loading at constant water content, while changes in microvoids predominated with changes in water content, according to the MIP experiments [12].

3. Materials and Methods

3.1. Materials. The representative soil sample was collected from the GCT Coimbatore campus, Thadagam Road, Coimbatore, Tamil Nadu, from a depth of 3 m below ground level. The sample was identified and confirmed to be clayey soil. Before laboratory testing, the representative soil was air-dried, pulverized, and sieved through a 425 μ sieve, a representative soil size for conducting index properties tests. Distilled water (DW) and 4M NaCl solution (SW) were used for consolidation tests.

3.2. Properties of Soil. The laboratory tests were conducted to determine the index properties of the soil sample to understand its nature and characteristics. The tests conducted were strictly adhered to the Indian standard code of practice. The properties are summarised in Table 1.

3.3. Methodology. Generally, a consolidation test is carried out to determine the amount of settlement mainly due to primary consolidation and the time taken for settlement by loading the soil axially and confining the soil laterally. The consolidation parameters thus obtained are also used in the design of ground improvement techniques. This study investigates the effect of interacting fluid on volume change, consolidation parameters, and hydraulic conductivity of compacted clay soil through a one-dimensional consolidation test. The test was conducted as per IS: 2720 (Part 15)–1965 [39], and the square root of the time method was adopted to find the coefficient of consolidation. The loadings and time intervals used for the experiment were adopted from IS: 2720 (Part 15) [39]. The soil sample was loaded with a constant pressure of 10 kPa, which replicated the load conditions in the field canal due to a 1 m head of water. This constant loading of the soil sample yielded volumetric changes and average axial strain variations. The soil sample was also loaded with incremental pressure according to IS: 2720 (Part 15)-1965 [39] in order to obtain the consolidation properties and hydraulic conductivity of the soil sample. The whole experimental program was divided into 4 stages with variations in inundation and loading: sample 1–Soil inundated with distilled water (DW) with constant loading of 10 kPa; sample 2–Soil inundated with distilled water (DW) and 4M NaCl solution (SW) at alternate stages with constant loading; sample 3–Soil inundated with distilled water (DW) with incremental loading; Sample 4-Soil inundated alternatively with 4M NaCl solution (SW) and distilled water (DW) with incremental loading.

3.4. Consolidation Test. The clay soil specimen (passing through 425 μ) was completely hand-mixed with a predetermined volume of distilled water to achieve an optimum water content of 20% and then moved to a desiccator for 48 hours to equilibrate the soil. The required mass of moisture-equilibrated soil was carefully transferred to a standard proctor mould, and the soil specimen was compacted to achieve a maximum dry density of 1.931 g/cc. Then, the remolded specimen of clay was extruded by a sample extractor into the oedometer ring, and the excess soil was trimmed off. The specimen was placed between two dry and clean porous stones and placed in a fixed ring oedometer cell with filter papers (double drainage condition). The dial gauge readings were recorded at prescribed intervals until the readings barely changed. On completion of the experiment, water was drained out of the

Table 1: Index properties of collected soil sample.

S. no.	Properties	Value	IS standards
1	Initial moisture content	11.02%	IS 2720–part 2
2	Consistency limits		
	Liquid limit	61%	IS 2720–part 5
	Plastic limit	33%	
	Shrinkage limit	17%	IS 2720–part 6
3	Mechanical sieve analysis		
	Percentage of gravel	0.05%	IS 2720–part 4
	Percentage of sand	33%	
	Percentage of fines	66.95%	
4	Specific gravity (Gs)	2.8	IS 2720–part 3
5	Standard proctor compaction test		
	Maximum dry density	1.931	IS 2720–part 7
	Optimum moisture content	20%	
6	Grain size distribution		
	Silt	28.95%	IS 2720–part 4
	Clay	38%	
7	Unified soil classification symbol	CH	

cell, the ring was kept in a hot air oven for 24 hours, and the dry mass of the soil was taken. Based on the dial readings taken after 24 hours of the corresponding pressures, the thickness in each stage was calculated based on the difference between the initial and final dial readings. Using height of solids method, void ratio (e) at each stage was calculated. The final results obtained from the experiment are represented in Tables 2–5 for sample 1, 2, 3, and 4, respectively.

The parameters, namely compression index (C_c), coefficient of compressibility (a_v), coefficient of volume compressibility (m_v), coefficient of consolidation (C_v), and coefficient of permeability (k), were determined for samples 3 and 4. The slope of the straight line portion of the e-logP curve is termed as compression index. Another term, coefficient of compressibility (a_v), is the ratio between the change in void ratio and the change in effective pressure. Coefficient of volume compressibility (m_v) is a term relating the change in void ratio and the corresponding change in pressure to the void ratio corresponding to the initial effective pressure. The rate at which soil undergoes consolidation is given by the coefficient of consolidation (C_v).

3.5. Scanning Electron Microscopy Test (SEM). SEM studies were performed on soil samples inundated with distilled water and on soil samples inundated with saltwater and distilled water at alternate stages of loading. The soil samples were compacted at a maximum dry density of 1.931 g/cc and optimum moisture content of 20%. The scanning electron micrographs were obtained at 1 μm magnification using a Carl Zeiss (USA), Model: Sigma with Gemini Column, Resolution 1.5 Nm high-resolution scanning electron microscope. The compacted specimens were freeze-dried before SEM examinations to retain the soil structure.

4. Results and Discussion

When subjected to alternate salinization and desalinization cycles, the behavior of clay liners was analyzed by studying the microstructural changes, volumetric changes, the axial strain developed, hydraulic conductivity changes, and changes in consolidation parameters. It could be seen in Figure 1 that the percentage volume change was below 25% in all stages of constant loading for sample 1 except the initial and final stages. The reason is that sample 1 was inundated with distilled water at all stages of loading, and the soil does not show any cation exchange mechanisms, so the soil compressed steadily.

From Figure 1, it could be observed that, for sample 2, the percentage volume change showed an increase of about two times for each stage inundated with 4M NaCl solution than its preceding stages inundated with distilled water. This shows that soil specimen volume changes significantly when exposed to saltwater and supports the osmotic consolidation phenomenon. This also proves that the soil undergoes a cation exchange mechanism in which the NaCl is attracted between the unit layers of clay particles and weakens the bond between them to cause great volumetric changes when it is subjected to loading, thereby showing high consolidation and compression rates [18].

The oedometer test was conducted with two samples at incremental loading as per IS 2720 (part 15) [39]; sample 3 was inundated with distilled water; sample 4 was inundated with salt water and distilled water at the alternate stage of loading. The recordings were obtained from an oedometer at time intervals, confirming the square root of the time method. From the observations, the consolidation properties of two soils were computed. The void ratio of soil at each stage of the test was calculated using the height of solids method (equations (1) and (2)).

$$e = \frac{H}{\mathrm{Hs}} - 1, \tag{1}$$

$$\mathrm{Hs} = \frac{\mathrm{Vs}}{A}. \tag{2}$$

In equation (1), the void ratio at different stages could be obtained by substituting the value of the height of specimen (H) at the corresponding stage. The height of solids (Hs) in (2) was calculated with the help of the volume of soil solids (vs) and the area of soil specimen (A). The initial void ratio was computed with 20 mm as the height of the specimen and is found to be 0.5860 for sample 3 and 0.6131 for sample 4. The final void ratio was obtained by using the value of the height of the soil specimen at the end of the test and was found to be 0.3548 for sample 3 and 0.4995 for sample 4. The change in void ratio was observed to be lesser for sample 3 compared to sample 4, as seen in Table 6. The compression index is an important parameter that represents the settlement of the soil specimen. The compression index was obtained by finding the slope of e vs. $\log p$ graph. In Table 6, the compression index in the distilled and salt water-induced samples yielded a value of 0.0130 and 0.0335, which indicated that the compression index in salt water-induced

Table 2: Experimental data for sample 1–soil inundated with distilled water at constant loading of 10 kPa.

Stage no.	Inundated water	Initial reading (mm)	Final reading (mm)	Compression ΔH (mm)	Specimen height (mm)	e	Percentage volume change (%)
1	DW	4.456	4.425	0.031	19.969	0.6106	0.1550
2	DW	4.425	4.378	0.047	19.922	0.6068	0.2354
3	DW	4.378	4.341	0.037	19.885	0.6038	0.1857
4	DW	4.341	4.297	0.044	19.841	0.6003	0.2213
5	DW	4.297	4.254	0.043	19.798	0.5968	0.2167
6	DW	4.254	4.222	0.032	19.766	0.5942	0.1616
7	DW	4.222	4.193	0.029	19.737	0.5919	0.1467
8	DW	4.193	4.182	0.011	19.726	0.5910	0.0557

Table 3: Experimental data for sample 2–soil inundated with distilled water and 4M NaCl solution at alternate stages with constant loading of 10 kPa.

Stage no.	Inundated water	Initial reading (mm)	Final reading (mm)	Compression ΔH (mm)	Specimen height (mm)	e	Percentage volume change (%)
1	DW	6.935	6.896	0.039	19.961	0.6100	0.1950
2	SW	6.896	6.729	0.167	19.794	0.5965	0.8366
3	DW	6.729	6.689	0.04	19.754	0.5933	0.2021
4	SW	6.689	6.6	0.089	19.665	0.5861	0.4505
5	DW	6.6	6.549	0.051	19.614	0.5820	0.2593
6	SW	6.549	6.465	0.084	19.53	0.5752	0.4283
7	DW	6.465	6.426	0.039	19.491	0.5721	0.1997
8	SW	6.426	6.325	0.101	19.39	0.5639	0.5182

Table 4: Experimental data for sample 3–soil inundated with distilled water at incremental loading.

Stage no.	Applied pressure P (kg/cm^2)	Compression ΔH (mm)	e	de	a_v (cm^2/kg)	m_v (cm^2/kg)	C_v (cm^2/min)	k (cm/sec)	C_c (cm^2/kg)
1	0.1	0.063	0.581	0.005	0.05	0.03	0.0183	$9.63E-09$	0.013
2	0.2	0.063	0.576	0.005			0.0051	$2.70E-09$	
3	0.4	0.115	0.567	0.009			0.0320	$1.68E-08$	
4	0.800	0.253	0.547	0.020			0.0302	$1.59E-08$	
5	1.600	0.408	0.514	0.032			0.0152	$8.03E-09$	
6	3.200	0.548	0.471	0.043			0.0089	$4.67E-09$	
7	6.400	0.678	0.417	0.054			0.0161	$8.50E-09$	
8	12.800	0.787	0.355	0.062			0.0080	$4.21E-09$	

Table 5: Experimental data for sample 4–soil inundated with 4M NaCl solution and distilled water at the alternate stage of incremental loading.

Stage no.	Applied pressure P (kg/cm^2)	Compression ΔH (mm)	e	de	a_v (cm^2/kg)	m_v (cm^2/kg)	C_v (cm^2/min)	k (cm/sec)	C_c (cm^2/kg)
1	0.1	0.034	0.610	0.003	0.04	0.03	0.018	$9.30E-09$	0.030
2	0.2	0.055	0.606	0.004			0.125	$6.33E-08$	
3	0.4	0.291	0.583	0.023			0.064	$3.24E-08$	
4	0.800	0.244	0.563	0.020			0.026	$1.30E-08$	
5	1.600	0.184	0.548	0.015			0.055	$2.77E-08$	
6	3.200	0.166	0.535	0.013			0.006	$3.13E-09$	
7	6.400	0.182	0.520	0.015			0.016	$8.35E-09$	
8	12.800	0.252	0.500	0.020			0.022	$1.12E-08$	

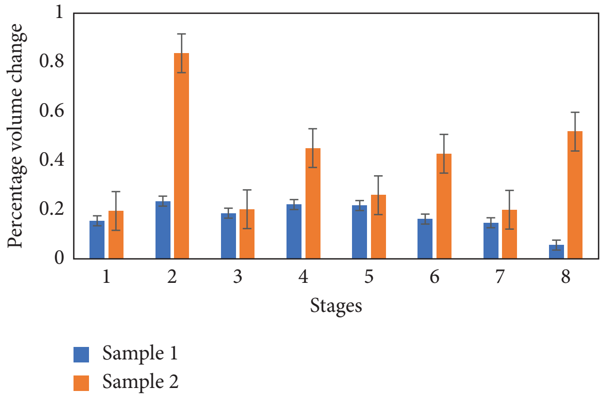


Figure 1: Comparison of samples 1 and 2 results of percentage volume change at different stages where sample 1 is soil inundated with distilled water with constant loading of 10 kPa; sample 2 is soil inundated with distilled water and 4M NaCl solution at alternate stages with constant loading.

samples increased by 158% more than in the distilled water-induced sample.

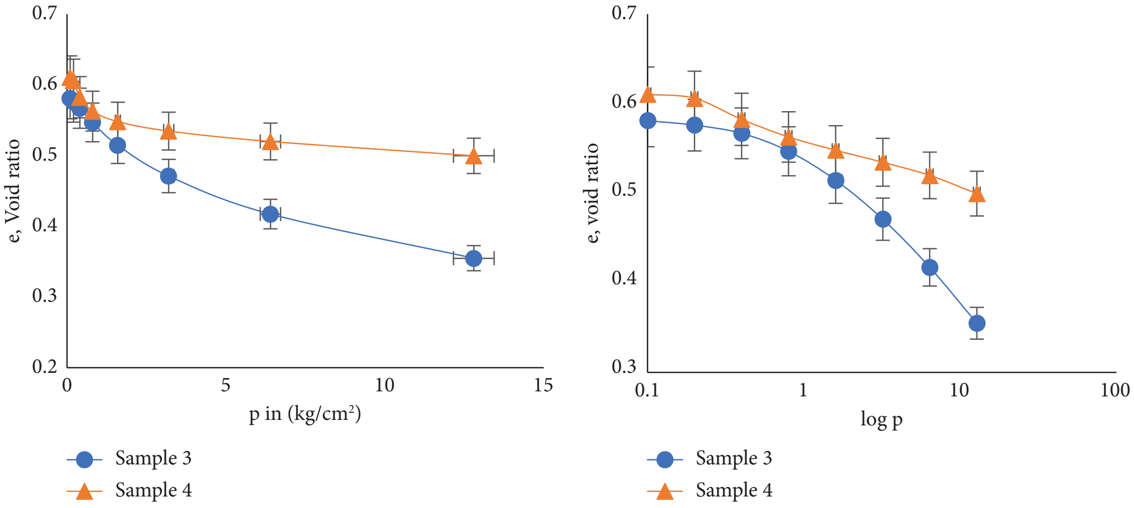
The coefficient of permeability (k) of soil was calculated with the help of the coefficient of consolidation, coefficient of volume compressibility, and unit weight of water obtained from the oedometer test. Table 6 shows that the value in the salt water-induced sample increased by 217% more than the distilled water-induced sample, which represents that the permeability is increased due to salt water exposure in clay soil specimen. Figure 2(a) represents the void ratio vs. pressure graph from which the value of the compressibility coefficient for samples 3 and 4 is obtained. Therefore, from Table 6, the compressibility coefficient in salt water-induced sample decreased slightly by 1.83% compared to distilled water-induced sample.

From Table 5, it could be seen that the coefficient of permeability values increased at the beginning stages of consolidation for alternate salinization and desalinization cycles, whereas from Table 4, it could be noticed that there was an insignificant change in the value of the coefficient of permeability value for clay saturated with distilled water. The coefficient of consolidation value, an important parameter to discuss the consolidation rate, increased to 0.0414 cm^2/min for sample 3 from 0.01257 cm^2/min for sample 4, as indicated in Table 6. From the data obtained, this experimental result showed reversible consolidation properties developed during salinization cycles.

From Figure 3(a), it could be observed from the scanning electron micrographs of the sample inundated with distilled water that the surface was compacted well and showed uniform and homogeneous particle arrangement. The SEM images of the sample inundated with sodium chloride solutions and distilled water at alternate stages represent a well-oriented dispersed structure (Figure 3(b)). In Figure 3(b), it could be observed that the number of micropores and the size of macropores increased. Researchers reported similar observations [21, 40, 41] and also found that saline solutions enhanced the double-structure arrangement through osmotic and osmotic-induced consolidation.

Table 6: Results of consolidation test of sample 3 and sample 4 at incremental loading where sample 3 is the soil inundated with distilled water at incremental loading; sample 4 is the soil inundated with salt water and distilled water at the alternate stage of incremental loading.

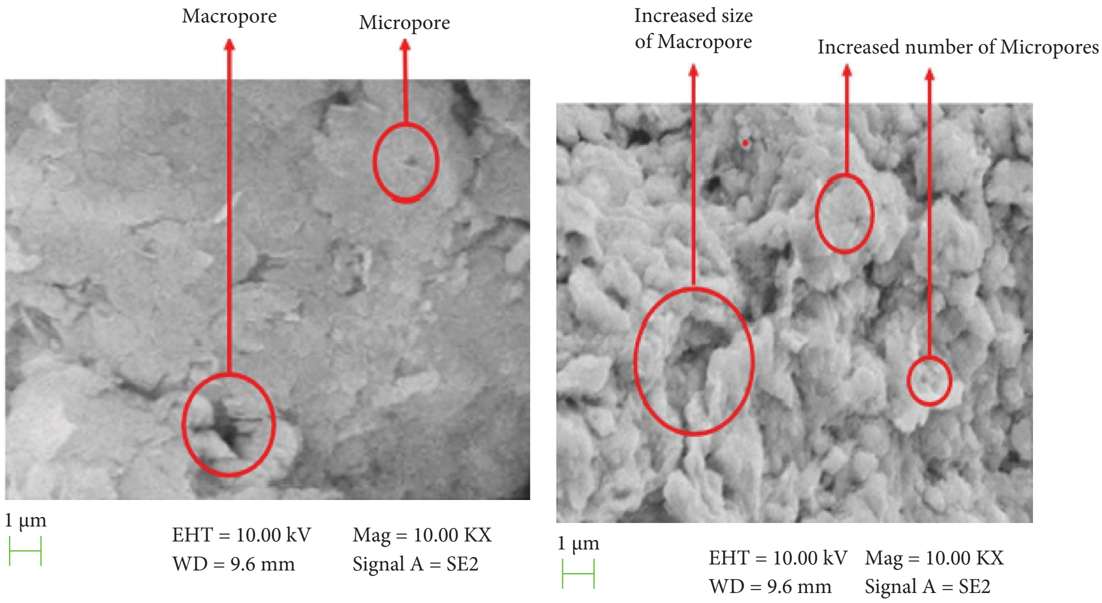
Results	Sample 3	Sample 4
Compression index, C_c	0.013	0.0335
Coeff. of compressibility, a_v (cm^2/kg)	0.0501	0.0492
Coeff. of volume compressibility, m_v (cm^2/kg)	0.0316	0.0305
Coeff. of consolidation, C_v (cm^2/min)	0.01257	0.0414
Permeability of soil, k (cm/sec)	$6.62E-09$	$2.10E-08$
Initial void ratio	0.586	0.6131
Final void ratio	0.3548	0.4995
Change in void ratio	0.2311	0.1135



(a)

(b)

Figure 2: (a) e vs. p graph of samples 3 and 4; (b) e vs. log p graph of samples 3 and 4.



(a)

(b)

Figure 3: (a) Scanning electron micrographs of sample inundated with distilled water; (b) scanning electron micrographs of sample inundated with sodium chloride solution.

5. Conclusions

It could be observed that the clay liners were greatly influenced when exposed to salinization and desalinization cycles, and from the experimental results, the following conclusions were drawn.

(i) The constant loading of the sample inundated with distilled water and 4M NaCl solution at alternate stages showed that the percentage of volume change increased by 124% when compared to the sample inundated with distilled water at all stages. This weakens the bond between the unit layers and causes the structure of clay particles to distort.

(ii) The structure of the clay was affected when it was exposed to salt water containing different cations as the clay particles adsorb cations to balance its negative charge, which leads to layer separation and expansion, affecting the microstructure and physical properties of the soil.

(iii) From the overall results obtained from soil sample at incremental loading, the coefficient of consolidation of soil sample inundated with distilled water and 4M NaCl solution at alternate stages showed a 3.2-fold increase than the sample inundated with distilled water at all the stages.

(iv) Furthermore, the coefficient of permeability increased by 217% when the soil was exposed to salinization than the soil exposed to distilled water which caused leakages in clay barriers.

(v) The compression index of soil inundated with distilled water and 4M NaCl solution at alternate stages showed an increase of 158% than the soil inundated with distilled water at all stages. This increase in compression index showed that soil compressibility increased, thereby increasing the settlement of the structure.

Therefore, the soil specimen subjected to alternate salinization and desalinization cycles significantly affects the volumetric and consolidation behavior, leading to decreased life of clay barrier structures.

Data Availability

The underlying data supporting the results of this study have been included in the paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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