Journal of Engineering Sciences

Vol 11, Issue 7,July/2020

ISSN NO:0377-9254

Effect of Salt on the behaviour of Compacted Bentonite

Iqbal Jabbar Mir[1], Himanshu Kumar Sadhya[2] and Shashivendra Dulawat[3]

[1]*M Tech Scholar, Department of Civil Engg, Mewar University, India*

[2]*Assistant Professor, Department of Civil Engg, Mewar University, India*

[3]*Assistant Professor, Department of Civil Engg, Mewar University, India*

***Abstract*— In the early 1980s when compacted clay liners began to be used for lining waste containment systems, there was a great upraised in research into understanding the interaction between clays and various chemical fluids. This study has focused mainly on the conditions under which the hydraulic conductivity could increase as the pore water in the liner is replaced with the landfill leachate. The study mainly deals with the physicochemical interaction of soil caused by leaching and some changes in the basic properties of soil due to the permeation of chemical fluids. From this study it was found that when leaching with chemical fluids the hydraulic conductivity increases by two to three orders of magnitude. Clay (especially montmorillonite and bentonite) are widely used as barriers in landfills to prevent contamination of subsoil groundwater by leachates containing hazardous chemical components containing organic matter, salts, heavy metals etc. The laboratory tests enable to distinguish the different processes, making their interpretation easier, and provide with fundamental data concerning the parameters to be used in the models. The presence of chemical fluids containing some salts and heavy metal ions in the pore water will alter the physico-chemical characteristics of the clay–water system, resulting in changes in the short- and long-term mechanical and chemical behavior of the clay soil barrier materials. This study investigates bentonite-contaminant interaction at different concentrations of salts and heavy metals ions and their resultant effect on the mechanical and properties changed behavior of bentonite soil. A set of physico-chemical experiments including Atterberg limits, consolidation, unconfined compression test were performed to investigate the fundamental mechanism of soil-contaminant interaction from a rheological point of view. Consolidation tests were performed to study hydraulic conductivity and volume change behavior of soil. One of the primary objective of this study is to evaluate potential relationships between the consolidation properties and the hydraulic conductivities of compacted bentonite.**

Keywords—*Bentonite; compressibility; unconfined compressive strength; hydraulic conductivity; landfill liner; compaction.*

1. INTRODUCTION

Compacted clays are widely used as barriers in industrial waste landfills. The liners are exposed to various chemical, biological and physical events and they are affected by the resulting leachate. There are many kinds of pollutants in the wastes and it is important to know the interactions between clay and pollutants to be able to predict the long-term behavior of the barrier. The present study focuses on the effect of salts on the behaviour of bentonite. Egloffstein (2001) also reports example of cation exchange from sodium to calcium in a bentonite resulted in a change in the fabric of the soil from smaller finely distributed clay flakes to larger crystals, which leads to higher permeability. In this study special focus is given on the physico-chemical factors which effect permeability of clay. The mobility and concentration of heavy metals in soils have been widely studied in the last decades. Heavy metals are present in municipal waste in a small amount, but most of them become toxic at high concentrations. Montmorillonite can adsorb heavy metals in two different mechanisms: (i) cation exchange in the interlayers resulting from the interactions between ions and negative permanent change and (ii) formation of inner- sphere complexes through Si-O-and Al-O groups a the clay particle edges(Baileyetal,1999).Both mechanisms are pH dependent because in acid conditions (pH < 4) most silanol and aluminol groups are protonated; therefore, an acidification can lead to an increase in mobility of metals bound to soil (Batchelor, 1998). For municipal waste disposals, the in situ compaction of soil is usually achieved to obtain engineered clay barriers. Expansive clays are of great importance because of their low permeability and their excellent performance in pollutant retention. Previous studies, laid by Olson and Mesri (1971) have shown that the behavioral characteristics of expansive clay soils can be directly related to the physical and chemical properties of the pore fluid and the microstructure of the soils. The equilibrium established between applied external forces and interparticle forces can be affected when changes occur in the chemistry of the pore fluid. Numerous studies have been undertaken to analyze the physico- chemical behavior of expansive soils as a result of changes in the internal forces. However,there has been little focused on the effect of heavy metalions concentration on the behavior of soils.

Atterberg limit tests, standard Proctor compaction tests, unconfined compression tests, hydraulic conductivity tests and one-dimensional consolidation tests were performed to study the behaviour of bentonite with varying concentrations of salts and heavy metal ions (HMs). The liquid limit behavior of a montmorillonite soil is controlled essentially by diffuse double layer forces and that of kaolinitic soil by shearing resistance at particle level. In the case of lateritic soils, because of its low cation exchange capacity, the effects due to changes in diffuse double layer are negligible. However the increase in liquid limit (w_L) of the lateritic soil are mainly due to increase in clay content of the lateritic soil. Saturated bentonite can absorb water up to 5 times its own mass to form a gel up to 15 times its own dry volume (Abeele, 1986) and this can be factor which bentonite is having high swelling potential. Characteristics of permeant liquids that tend to compress the diffuse double layer and, therefore, to cause an increase in hydraulic conductivity are: (i) a low dielectric constant (e.g., concentrated organic liquids and petroleum hydrocarbons); (ii) a high electrolyte concentration (e.g., very salty water or brine); and (iii) a preponderance of multivalent cations (e.g. Ca^{2+} and Mg^{2+}). Furthermore, the present study investigates the influence of NaCl and $CaCl_2$ concentrations as a permeating liquid on the plasticity, swelling, hydraulic conductivity, shear strength and compressibility behavior of bentonite, because it is considered that leachate contains highest amount of NaCl and $CaCl_2$ salts. Clayey soils are more vulnerable to attenuation in hydraulic conductivity at low effective confining stress than at high confining stress(BroderickandDaniel,1990).Knowledge of basic consolidation properties of clay liner is required to provide an improved understanding of the state of existing stress within when overburden stress comes after dumping of waste.

1.1 Objective and scope of the study

Based on the critical appraisal presented above, the following scope of the study has been defined:

1) Determination of compaction, compressibility and permeability characteristics of bentonite.
2) To study the effect of salt solution on the compressibility, hydraulic conductivity, swelling pressure of the compacted bentonite.
3) To study the effect of compaction water content on the compressibility, hydraulic conductivity, swelling pressure of the compacted bentonite.
4) Determination of consolidation characteristics of bentonite in the presence of various kinds of salts with different concentrations at different initial compaction conditions state.
5) To study the unconfined compressive strength of bentonite in its worst natural condition after the sample is flooded to saturate at lowest vertical confining pressure.
6) To study various stages of swelling potential and degree of swelling.

Vol 11, Issue 7,July/2020

ISSN NO:0377-9254

2.0 MATERIALS AND METHODS

2.1 Materials

The bentonite used in this study was a locally procured powdered form and the main source was from Rajasthan, India. The physical properties of bentonite are listed in Table 1.

TABLE 2.1 Physical properties and classification of materials used in this study.

Properties	Bentonite
Liquide Limit	217%
Plastic Limit	42.8%
Plasticity Index	174.2
Shrinkage Limit	16.3%
Specific Gravity	2.8
Specific Surface Area	503 m^2/g
Clay Content	64%
Silt Content	36%
USCS Clasification	High plasticity clay(CH)

2.2 Methods

2.2.1 Unconfined Compression Tests (IS: Part10)

This test was carried out in accordance with Indian Standard (IS: Part 10). Unconfined compressive strength (UCS) test were performed on cylindrical specimens 38.1mm in diameter and length of 76.2 mm. Soil was compacted 5 % of the optimum moisture content (OMC) and maximum dry density and also another at OMC and MDD. After each compaction, the soil was extruded from the mould and sealed in polythene bag to minimize moisture loss, and kept for a period of 24 hours to allow for uniform moisture distribution, at a constant temperature of 25 ± 2ºC. After reaching equilibrium moisture content, they were placed in a load frame UCS machine driven strain controlled at1.5 mm/min until failure occurred. Two specimens were averagely prepared for each test. The objective of the unconfined compression test is to determine the UU (unconsolidated, undrained) strength of a cohesive soil in an inexpensive manner. It is the load per unit area at which an unconfined cylindrical specimen of soil will fail in the axial compression test.

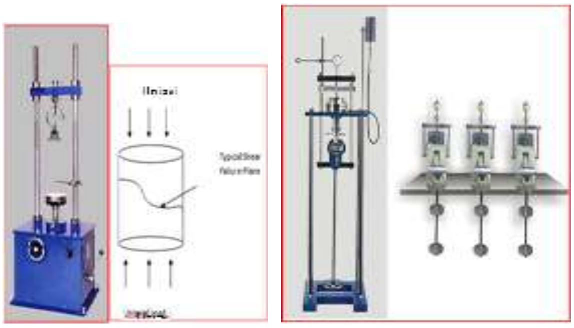

Figure 2.2.1 : UCC machine as per IS: Part 10 (left Figure) and schematic diagram of Unconfined Compressive Strength Test and Typical Shear Failure Plane of specimen (right Figure).

2.2.2 Consolidation test (ASTM D2435)

In order to assess the hydraulic conductivity and compressibility, consolidation test was carried out of the soil. Indirect determination of the hydraulic conductivity from fixed ring consolidation test has several advantages and disadvantages over permeability tests, which are as follows:

(1) can apply vertical pressure simulating those infield;
(2) can measure vertical deformations;
(3) can test sample under a range of vertical stresses;
(4) thin samples allow short testing time;
(5) cost effective method for obtaining hydraulic conductivity data over a range of sample states;

However it has also some disadvantages over other methods. Those are,

(1) Some soil types may be difficult to trim into consolidation ring, especially undisturbed sample;
(2) Thin samples may not be representative;
(3) It under-estimates slightly the hydraulic conductivity value because of secondary consolidation takes place.

Despite of some disadvantages, the consolidation permeability test is potentially the most useful tool among the other methods viz. rigid-wall and flexible-wall (triaxial) permeability test because of the flexibility which it offers for testing specimens under a range of confining stresses and for accurate determination of the change in sample thickness as a result of both seepage forces and chemical influence on the soil structure. Pore fluid

JES Journal of Engineering Sciences
Vol 11, Issue 7,July/2020
ISSN NO:0377-9254

replacement can be achieved quickly, as in this method the sample thickness is thin compared to other test.

Figure 2.2.2.1: Consolidometer as per ASTM D 2435

Fig: 2.2.2.2 Fixed ring consolidation cell (left figure) and schematic diagram of Fixed ring consolidation cell (Humboldt Mfg. Co, 2013), right figure

3.0 RESULTS AND DISCUSSIONS

3.1 Atterberg's Limit Tests

Table:3.1 Atterberg's limit of bentonite in presence of salt solutions at different concentrations

Concentration, N	Liquid Limit, %		Plastic Limit, %		Plasticity Index		Shrinkage Limit, %	
	NaCl	$CaCl_2$	NaCl	$CaCl_2$	NaCl	$CaCl_2$	NaCl	$CaCl_2$
0	217.5	217.5	42.8	42.8	174.7	174.7	16.3	16.3
0.01	174.7	159.0	41.8	41.2	132.9	117.8	16.7	16.9
0.1	128.3	116.2	40.0	39.8	88.3	76.4	14.8	15.6
1	95.0	90.0	38.0	37.5	57.0	52.5	13.3	13.5

3.2 Free swell

The effect of various concentrations of NaCl and $CaCl_2$ on free swelling of bentonite is shown in Figure 5.1. Figure 5.1 shows that the swelling of bentonite decreased with increasing the concentration of NaCl and $CaCl_2$and higher swelling is observed for NaCl solutions compared to the $CaCl_2$ solutions. For NaCl solutions, osmotic as well as hydration swelling takes place which allows the interlayer spacing to become large, resulting in higher swelling (Mishra et al., 2009).

On the other hand, the amount of osmotic swelling decreases in the presence of $CaCl_2$ solution, resulting in less swelling of bentonite compared to the swelling at same concentration of NaCl solution (Zhang et al., 1995). For NaCl solution, the swelling of the bentonites decreased considerably for an increase in the concentration from 0 to 0.1 N. But, with an increased in the concentration from 0.1 to 1 N, swelling decreases marginally. In contrast to this, the swelling of bentonite decreased uniformly with an increase in the concentration from 0 to 1 N of $CaCl_2$ solution.

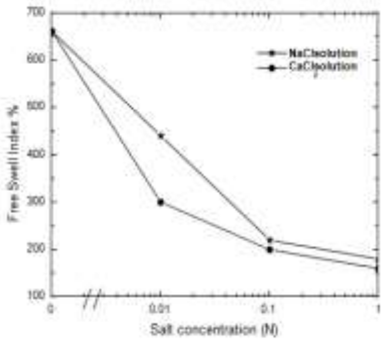

Figure: 3.2.1 Plot for the free swelling of bintonite at various concentration of NaCl and CaCl2 Solution

3.3 Swell Pressure

Swell pressure is defined here as the pressure required to compress the specimen that has been soaked and completed the swell under 0.05 kg/cm^2 pressure, back into its original configuration (before swell). Swell pressure decreases with increased chemical concentration. However, relatively large rate of change in swell pressure is occurred with varying concentrations of salts. Relatively large rate of change in swell pressure with concentration is observed at lower concentration. Figure 5.2 shows a relationship between swelling pressure and various salt concentrations for varying compaction conditions. The results show swelling pressure decreased gradually when the concentration of salts changed from 0 to 0.01 N but there is a rapid decreased when salt concentration changed from 0.01 to 0.1 N. Again the swelling pressure is more for NaCl solution than $CaCl_2$ solution. These plots show that the swelling pressure curves are dependent on the salt concentrations as well as on the type of cations.

Journal of Engineering Sciences
Vol 11, Issue 7,July/2020
ISSN NO:0377-9254

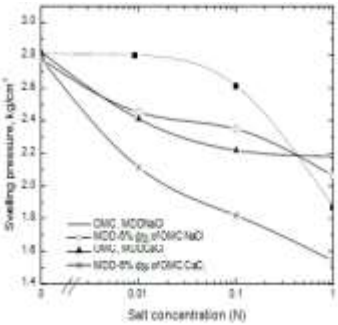

Fig: 3.3.1 Effect of Swelling pressure at various salt concentration for different compaction Condition

3.4 Swelling potential

The swelling potential was defined as the percentage swell of a laterally confined sample, which has soaked under a surcharge pressure of 0.05 kg/cm^2 after being compacted at to maximum density at optimum moisture content according to the compaction test. The results obtained are presented in Figures 5.3(a,b,c and d) for different compaction conditions in the presence of different salt solutions with various concentrations in the form of percentage of swelling versus time of bentonite soil. Here from the graph it can be seen that swelling percent is highest in case for DI water and when concentration goes on increasing swelling also decreases. The swell is expressed as a percentage increase in sample height. It has been observed that for all the mixtures, increase in swelling with log time is slow initially, increases steeply, and then reaches an asymptotic value. Figure 5.4(a,b,c and d) replots the time-degree of swelling relationship as percentage of the maximum swelling. Here, the percent swelling at a particular time is calculated as the ratio of amount of swelling of the mixture at that time to the total swelling and is denoted as a percentage. In this plot also the trend of all curves are following the same trend as described earlier.

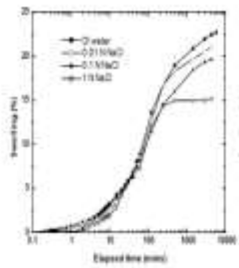

Figure (a): Swelling behavior (aspercent initial height) of bentonite compacted at MDD and OMC forNaCl solutions

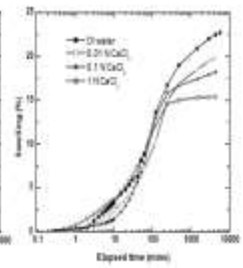

Figure (b): Swelling behavior (aspercent of of initial height) of bentonite compacted at MDD and OMC for $CaCl_2$ solutions

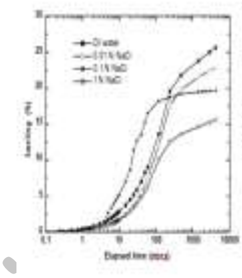

Figure (c): Swelling behavior(aspercent initial height) of bentonite compacted at MDD and 5% dry of OMCforNaCl solutions

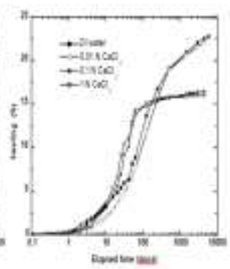

Figure (d): Swelling behavior (aspercent of of initial height) of bentonite compacted at MDD and 5% dry of OMC forCaCl₂ solutions

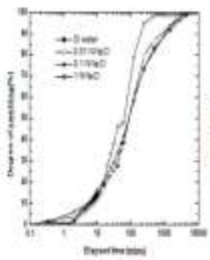

Figure (a): Swelling behavior(as percent total swell) of bentonitecompacted at MDD and OMC forNaCl solutions

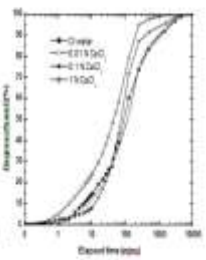

Figure (b): Swelling behavior (as percent of of total swell) of bentonite compacted at MDD and OMC for $CaCl_2$ solutions

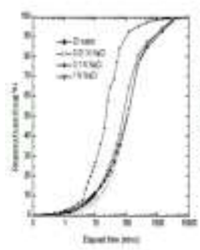

Figure (c): Swelling behavior(aspercent total swell) of bentonite compactedatMDD and 5% dry of OMC forNaClsolutions

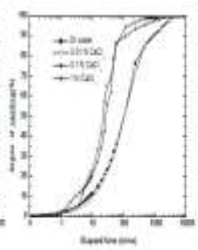

Figure (d): Swelling behavior (as percent of of total swell) of bentonite compacted atMDD and 5% dry of OMC for $CaCl_2$ solutions

3.5 Determination of the consolidation behaviour of bentonite

Results of the consolidation tests performed on test specimens of different salt solutions are shown in Figure 5.7 to 5.10 in the form of traditional plots of

Vol 11, Issue 7,July/2020

ISSN NO:0377-9254

void ratio *e* versus logarithm of the effective consolidation stress, *p*, or *e*–log *p* curves.

Because all the test specimens were remolded, a pre consolidation stress is not evident in the loading portions of the *e*–log *p* curves shown in Figure (5.7 to 5.10) (Lambe and Whitman1969).

Figure5.7to5.10 shows the relationship between the void ratio(*e*) and consolidation pressure(*p*)for different compaction conditions at different concentrations of various salt solutions. The results show that with increase in overburden pressure, the void ratio at different compaction conditions for various salt solutions also decreased. The increase in the overburden pressure on different compaction conditions with various salt concentrations can be correlated with the increase in the pressure on the liner due to the increase in the weight of the overburden weight due to dumping of more and more waste materials. The result shows that the decrease in the void ratio with an increase in the pressure. However, with an increase in the load the different compaction conditions at various salt concentrations get compressed significantly. Results show that the entire compaction conditions void ratio will be lowest at 0.1 N concentration means void ratio will decrease with increase in salt concentration. This can be attributed to the thick double layer has formed in case of water and double layer will be collapsed when salt concentration increases.

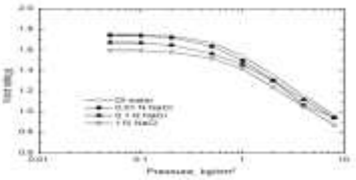

***Fig: 3.5.1: e*-log *p* plots of bentonite for MDD and OMC at various concentrations of NaCl solution**

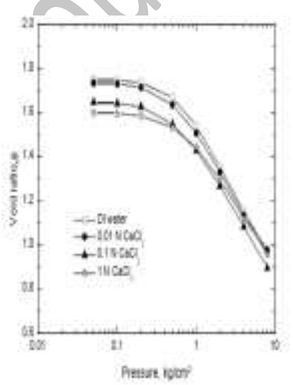

***Fig: 3.5.2 e*-log *p* plots of bentonite for MDD and OMC at various concentrations of $CaCl_2$ solution.**

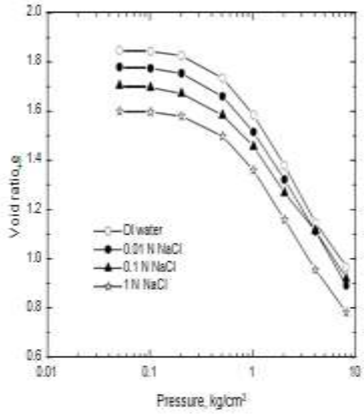

***Fig: 3.5.3 e*-log *p* plots of bentonite for MDD and 5% dry of OMC conditions at various concentrations of NaCl solution.**

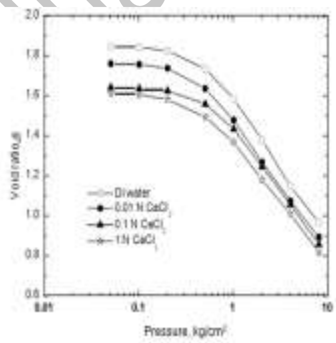

***Fig: 3.5.4 e*-log *p* plots of bentonite for MDD and 5% dry of OMC conditions at various concentrations of $CaCl_2$ solution**

3.6 Unconfined Compression Tests

Unconfined compression tests were conducted to study the effect of various concentrations of salts on the properties of bentonite on unconfined compression strength of soil. Graph is drawn through the data points to study the effect of various concentrations of salts on the properties of bentonite on unconfined compression strength of the soil. A low confining stress of 0.05 kg/cm^2 was taken as the effective overburden pressure though an effective stress of 35 KPa is considered to be the lowest practical value (Ruhl and Daniel, 1997) for liner; and flooded with deionised water up to saturation at room temperature (22 ± 3^{0}C)was selected to simulate worst case- conditions. Daniel and Wu (1993) arbitrarily selected a minimum

Vol 11, Issue 7,July/2020
ISSN NO:0377-9254

unconfined compressive strength of 200 kN/m^2 to support the maximum bearing stress in a landfill even though, the minimum required strength of soil to be used in compacted soil liners is not specified. The high value of the effective confining stress was taken as representative of the stresses applied in-situ on the clay layer at the bottom of a repository, under 20 m of wastes (Souli et al., 2008). The 200 KPa stress value is recommended for the determination of the permeability of clay in the Belgian guide line for the construction of sanitary landfills (Marcoenetal.,2000).

Unconfined compression strength versus strain for all soil samples compacted at OMC and MDD and the other at MDD and 5% dry of OMC in presence of various concentrations of NaCl and $CaCl_2$ solutions. And the individual ultimate unconfined compressive strength for every sample is tabulated in Table5.3.

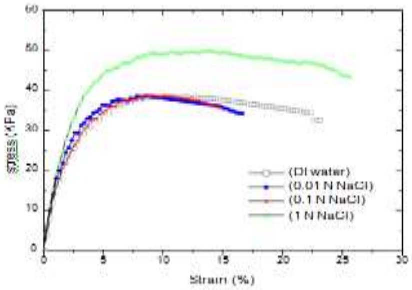

Fig: 3.6.1 Stress versus strain in unconfined compression tests after swelling for bentonite initially compacted at OMC and MDD in presence of various concentrations of NaCl solution

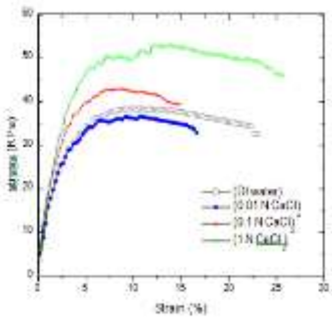

Fig:3.6.2 Stress versus strain in unconfined compression tests after swelling for bentonite initially compacted at MDD and OMC in presence of various concentrations of $CaCl_2$ solution

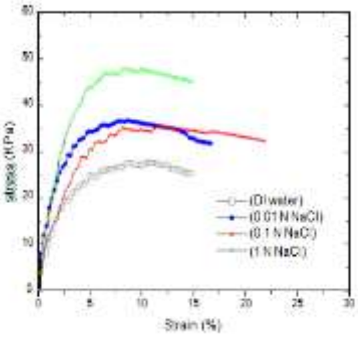

Fig: 3.6.3 Stress versus strain in unconfined compression tests after swelling for bentonite initially compacted at MDD and 5% dry of OMC in presence of various concentrations of NaCl solution.

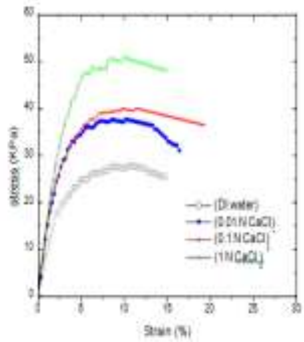

Fig: 3.6.4 Stress versus strain in unconfined compression tests after swelling for bentonite initially compacted at MDD and 5% dry of OMC in presence of various concentrations of $CaCl_2$ solution.

From Figure 5.12 to 5.15, it is seen that with increased in salt solution concentrations there is a slight improvement in strength which is attributed due to the relatively denser particle arrangement in higher salt concentration as diffuse double layer thickness gets compressed in higher electrolyte concentration when soil is fully submerged inside water.

3.7 Volumetric shrinkage

Volumetric shrinkage value of bentonite was found and tabulated below for two different compaction conditions.

Volumetric shrinkage at OMC and MDD compaction condition = 16.24%

Volumetric shrinkage at 5% dryof OMC and MDD compaction condition = 12.24%

4.0 CONCLUSIONS AND FUTURE SCOPE

A number of laboratory physicochemical tests have been conducted to determine the effect on the interaction of soil particles of bentonite and chemical fluids with different concentrations on the engineering behavior of compacted bentonite for their use as compacted clay barriers for municipal waste landfills. The physicochemical tests investigated in this study included Atterberg limit, unconfined compression strength, hydraulic conductivity, consolidation property and compressibility behavior. Based on the physicochemical interaction test results, the following general conclusions have been drawn:

- When the salt concentration was increased from 0 to 0.01 N, there was a marginal change in both hydraulic conductivity and compressibility, but increased significantly with further increase in salt concentration for both NaCl and $CaCl_2$. The hydraulic conductivity at a given void ratio exhibited slight increase in a range of 0 to 0.01 N but significantly increase in a higher salt concentration range.
- For any given compaction condition, the increase in salt concentration increased the hydraulic conductivity and decreased compression index.
- At a given compaction condition density, the hydraulic conductivity and compression index decreased with an increase in the initial compaction water content.
- Liquid limit and free swell of bentonite was found decreasing for the increased in salt solution concentrations.

REFERENCES

Abeele, W.V. (1986). “The influence of Bentonite on the Permeability of SandySilts”, *Nuclear and Chemical Waste Management*, 6, 81-88.

Abollino, O., Aceto, M., Malandrino, M., Sarzanini, C. and Mentasti, E. (2003). “Adsorption of heavy metals on Na-montmorillonite. Effect of pH and organic substances”, *Water Research*, 37, 1619–1627.

Anandarajah, A. (2003). “Mechanism Controlling Permeability Change in Clays due to Changes in Pore Fluid”, *Journal of Geotechnical and Geoenvironmental Engineering, ASCE* 129(2),163–172.

Arasan, S. and Yetimoglu, T. (2008). “Effect of Inorganic Salt Solutions on the Consistency Limits of Two Clays”, *Turkish J. Eng. Env. Sci.* 32, 107 – 115.

ASTM D 2487-93 (2000). “Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)”, Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA,USA.

ASTM D 2435 (1996).“Standard Test Methods for One-Dimensional Consolidation Properties of Soils”, Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA,USA.

ASTM D 427-04(2008).“Standard Test Method for Shrinkage Factors of Soils by the Mercury Method”, Annual Book of ASTM Standards, Vol. 04.08, ASTM International, West Conshohocken, PA,USA.

Bailey, S.E., Olin, T.J., Bricka, R.M., and Adrian, D.D. (1999). “A review of potentially low- cost sorbents for heavy metals”, *Water Res.*, 33(11),2469–79.

Batchelor, B. (1998). “Leach models for contaminants immobilized by pH-dependent mechanisms”, *J. of Environ. Sci. Technol.*, 32(11),1721–6.

Benefield, L.D., Judkins, J.F. and Weand, B.L., (1982). Process Chemistry for Water and Wastewater Treatment. Prentice-HallInc.

Benson, C., Zhai, H., and Wang, X. (1994). “Estimating Hydraulic Conductivity of Compacted Clay Liners”, *Journal of Geotech. Engrg., ASCE*,120(2),366–387.

Bohn, H.L., McNeal, B.L., O’Connor, G.A., 1979. Soil Chemistry. *John Wiley and Sons*, New York. 329pp.

Boynton,S.S.andDaniel,D.E.(1985).“Hydrauliccon ductivitytestsoncompactedclay”,*Journal of Geotechnical Engineering, ASCE*, 111(4), 465-478.

Broderick, G.P., and Daniel, D.E.(1990). “Stabilizing compacted clay against chemical attack”, *Journal of Geotechnical Engineering, ASCE*, 116(10),1549-1567.

Carter, D. L., Heilman, M. D., and Gonzalez, C. L., 1965, “Ethylene Glycol Monoethyl Ether for Determining Surface Area of Silicate Minerals”, *Soil Science*, 100(5),356–360.

Daniel, D. E. (1994). “State-of-the-art: Laboratory hydraulic conductivity tests for saturated soils”.*Hydraulic Conductivity and Waste Contaminant Transportin Soil*,

ASTMSTP1142,D.E. Daniel and S. J. Trautwein,

Daniel, D.E. and Benson, C.H. (1990). “Water Content-Density Criteria for Compacted Soil Liners”, *Journal of Geotechnical Engineering*, ASCE, 116(12),1811-1830.

Daniel, D.E., Shan, H.Y. and Anderson, J.D. (1993). “Effects of partial wetting on the performance of the bentonite component of a geosynthetic clay liner”, Proc., *Geosynthetics ’93*, Industrial Fabrics Assn. Int., St. Paul, Minn., 3,1483-1496.

Daniel, D.E. and Wu, Y.K. (1993). “Compacted Clay Liners and Covers for AridSites”,*Journal of Geotechnical Engineering, ASCE*, 119(2), pp: 223-237.

Demetracopoulos, A.C., et al. (1984). “Modeling for design of landfill bottomliners”,*Journal of Environmental Engineering, ASCE*, 110(6), 1084-1098.

Dyal, R. S. and Hendricks, S. B., 1950, “Total Surface of Clays in Polar Liquids as a Characteristic Index”, *Journal of Soil Science*, 69,421–432.

Egloffstein, T.A. (2001). “Natural bentonites — influence of the ion exchange and partial desiccation on permeability and self heating capacity of bentonites used in GCLs”, *Geotext. Geomembr.*, 19,427–444.

Elsbury, B.R., Daniel, D.E., Sraders, G.A. and Anderson, D.C. (1990). “Lessons Learned from Compacted Clay Liner”, *Journal of Geotechnical Engineering, ASCE*, 116(11),1641-1660.

Holtz, W.G. (1965). Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling; American Society of Agronomy, Soil Science Society ofAmerica.

IS 2720, Part II, (1973). “Methods of Test for Soils: Determination of water content”, Indian Standards Institute, New Delhi,India.