World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:5, No:1, 2011

Effect of Salt Solution and Plasticity Index on undrain Shear Strength of Clays

S .A. Naeini, M. A. Jahanfar

International Science Index, Materials and Metallurgical Engineering Vol:5, No:1, 2011 waset.org/Publication/3054

***Abstract*—**Compacted clay liners (CCLs) are the main materials used in waste disposal landfills due to their low permeability. In this study, the effect on the shear resistant of clays with inorganic salt solutions as permeate fluid was experimentally investigated. For this purpose, NaCl inorganic salt solution at concentrations of 2, 5, 10% and deionized water were used. Laboratory direct shear and Vane shear tests were conducted on three compacted clays with low, medium and high plasticity. Results indicated that the solutions type and its concentration affect the shear properties of the mixture. In the light of this study, the influence magnitude of these inorganic salts in varies concentrations in different clays were determined and more suitable compacted clay with the compare of plasticity were found.

***Keywords*—**landfill liner, shear resistant, plasticity, salt solution

I. Introduction

CLAYEY soils are commonly used as barriers in municipal and industrial waste sites to isolate ground water from contaminants. With migration of contaminated fluids and replacement of pore fluids of soil, the chemistry as well as physic-chemical properties of the pore fluid is changed, and soil is contaminated. Great stress caused by stacked up wastes in landfill will be tolerated by clay liner and when heavy rain fall passed through the refuse to form leachate, the clay liner will be contaminated by advection and diffusion. This can change soil properties, such as hydraulic conductivity and shear strength behavior and make the soil collapsible. Increased stresses in soil and the reduction of shear strength by contamination together make the clay liner more prone to failure, leading to underground water pollution. Under these conditions, the overall stability of the landfill structure and those around it may also be reduced.

A significant body of literature addresses the effects of various chemicals on the permeability and other hydraulic properties of soils, while the influence of hazardous wastes and contaminated water on the shear strength has been practically neglected. Bjerrum and Rosenquist [1] investigated the leaching effects on artificial marine clay. Authors reported that leaching of the salt resulted in the decrease of the undrained strength. Olson [2] focused on the effect of pore water electrolyte concentration on the effective shear strength of three clay minerals and demonstrated the different results with various solutions. Rashid [3] reported the properties of marine clay were affected by high organic contamination. The results of their study indicated that an increase in the organic contents caused a decrease in remolded undrained shear strengths. Yong [4] investigated the leaching effects of chemicals on the shear strength of sensitive clay. Substantial reductions in the undisturbed and remolded strength were observed. The experimental study that recently done by Singh [5], has shown the effects of inorganic and organic chemical on bentonite soil geotechnical properties. Results indicate that with the addition of inorganic chemical (Aluminium hydroxide), the cohesion (C_u) decreased by about 50% whereas the angle of internal friction (Φ_u) remained unchanged. With the addition of organic chemical (Acetic acid), the behavior of bentonite was almost same as that with inorganic chemical (Aluminum hydroxide).

S. A. Naeini is with department of civil engineering of Imam Khomeini International university, Ghazvin, Iran (corresponding author to provide phone: 281-336-8413; fax: 281-378-0073; e-mail: naeini.hasan@ yahoo.com).

M. A. Jahanfar, was with Imam Khomeini International university, Ghazvin, Iran. (e-mail: enjahanfar@yahoo.com).

The influence of pore fluid chemistry on the engineering behavior of clay soil in many respects is still unclear and is even controversial in some cases. In view of the above, in this study undrained shear strength behavior of low, medium and high plasticity clay have been studied by varying ion concentrations, to determine best compacted clay plasticity to endure the shear strength reduction due to salt solutions.

II. Materials

A. Clay with different plasticity index

In this investigation, three clays with different plasticity index were used. Physical properties of clays such as liquid limit and plastic limit were tested according to ASTM-D4318 [6].

Grain-size distribution tests were carried out according to the unified soil classification and two first soils sequenced in CL and third soil classified in CH.

Compaction tests were done according to ASTM-D1557 [7] to discover the dry density and optimum moisture content of three clays.

Table. 1 shows the physical properties of investigated clays. The grain-size distribution curves for the three soils tested are

TABLE I
THE PHYSICAL PROPERTIES OF CLAYS INVESTIGATED

Clays	Clay 1	Clay 2	Clay 3
Liquid limit (%)	30.4%	39.5%	58.8%
Plastic limit (%)	20.5%	22.8%	26.1%
Plasticity index (%)	9.9%	16.7%	32.7%
Dry Density (KN/m^3)	18.5	17.4	16.9
Optimum Moisture (%)	12.9%	15.2%	16%

shown in Fig. 1.

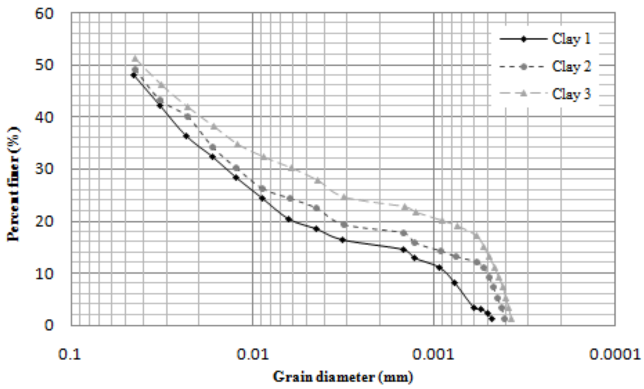

Fig. 1 Grain size distribution of soils studied.

B. Salt Concentration

Among the important parameters that vary significantly in the reclamation of compacted clays liner (CCLs) are concentration of salts. The main caution present in the pore medium is NaCl in order of its magnitude.

The magnitude of salt concentration in leachate varies significantly depending upon the time, temperature, moisture and host of other factors due to waste [8].Distilled water and different salt solutions were used in this study to understand the geotechnical behavior of clays. Three different salt level solutions (2%, 5% and 10 % NaCl solutions) were used in this study and deionized water is indicated as 0% salt solution. Commercial NaCl crystals from Germany Chemical Merck were used to prepare the different saline pore fluids. The pore fluid salinity depends on the mass of the NaCl in the solution i.e., 2% NaCl concentration represents 2 g of NaCl in 100 ml of deionized water. Salt solutions were prepared by adding NaCl to deionized water and it was thoroughly mixed to form a uniform solution. In view of the above, this article demonstrates the effect of salt concentration on undrained strength behavior.

III. Methods and Techniques

A. Specimen preparation

An experimental program was performed on different clay plasticity mixed with various percentages of predominant waste salt contents. After the mixing, the specimens were saturated for 72 hour with low normal load just in support of swell prevent, after which they were subjected to compaction at optimum water content by hand remolding taking care not to entrap air in direct shear squire mould and laboratory vane shear cylinder mould. Remolded undrained shear strength was measured on saturated clays using both the Laboratory vane shear and direct shear tests.

B. Laboratory Vane Shear Test

The undrained remolded shear strength is determined by the vane shear test (ASTM-4648) [9]. A typical laboratory vane of 12.5mm high (h), and 12.5mm in diameter (d), with blade thickness of 0.05 mm, has been used for samples. The gap between the specimen and the mold were filled with paraffin wax to keep the specimen in position and to prevent lateral expansion during shearing. After pushing the vanes gently into the soil mold, the torque rod is rotated at a uniform speed at 10 per minute until failure took place and the maximum torque, τ_{max}, was noted. The rotation of the vane, shears the soil along a cylindrical surface, and the undrained shear resistance, C_u can be calculated from the following equation:

$$C_u = \frac{\tau_{max}}{\pi \times d^2 \times \left(\frac{h}{2} + \frac{d}{6}\right)} \tag{1}$$

C. Direct Shear Test

In this study, a direct shear apparatus was used to simulate undrain unconsolidated conditions in the laboratory scale to measure the undrain shear strength value (ASTM-3080) [10]. A direct shear box having a length of 15.2 cm and width of 13.2 cm with a squire sample holder of 6×6 cm^2 dimensions and 2 cm depth, all made of steel to preventing corrode, was used to study the shear behavior of the remolded clay samples. To minimize drainage, the normal load was kept low equal to 5Kpa and shearing commenced after the application of the normal load at constant value of 0.9mm/min.

IV. Results and Discussion

Undrained unconsolidated (UU) tests were conducted to study the effect of salt solution and plasticity index on undrained shear strength of clay. In this study undrained unconsolidated condition were simulated by direct shear and laboratory vane shear tests. Two series of undrained unconsolidated tests with different concentrations of waste main content salt (NaCl) were conducted. First series of undrained unconsolidated tests included four tests on clays with varied NaCl contents of 0, 2, 5, and 10% with direct shear test. Second series of this test were carried out same as series one with varied NaCl contents by means of laboratory vane shear test. In later sections, the results were investigated in two categories. First section shown the salt solution change effects on each clay, and second section were illustrated the plasticity index alter effects on each salt contents.

A. Salt Solution Changes

The plot of undrained shear resistance versus percent salt content for direct shear tests is shown in Fig 2. A best-fit line was drawn through the data points to study the effect of addition of salt solution on undrained shear strength of the soil.

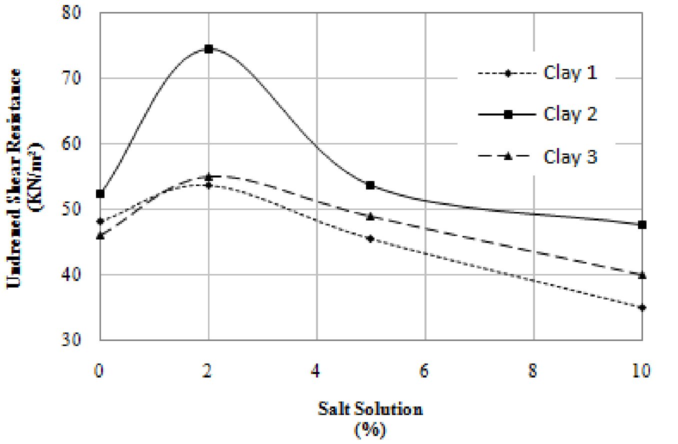

Fig. 2 Undrained shear resistance versus percent salt content with direct shear tests.

Fig. 3 shows undrain shear resistance versus salt solution percents for vane shear test. As shown in Fig. 3, a best-fit straight line was drawn through the data points to determine the relationship between salt solution and undrained shear strength. The observations made from Fig. 3 are consistent with those made from direct shear tests (Fig. 2).

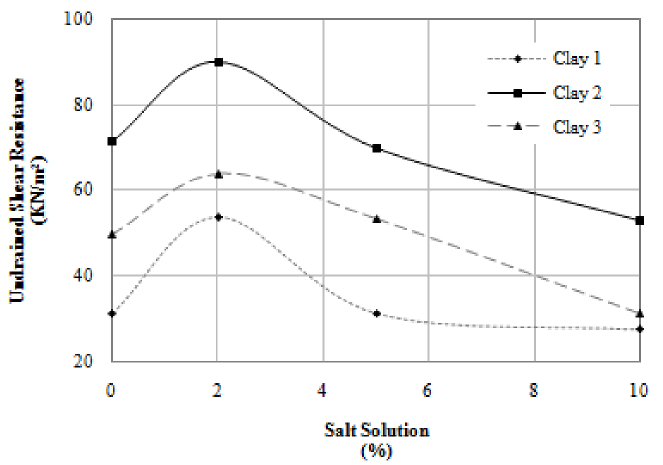

Fig. 3 Undrained shear resistance versus percent salt content with Laboratory vane shear test.

Most clay mixtures showed an increase in their undrained shear resistance values with the increasing NaCl concentration in the pore fluid until 2% and then sharply decreasing to 10 % (Fig. 2 and Fig. 3).

According to Fig 2 and Fig. 3 medium plasticity clay (clay 2) showed comparatively higher undrained shear resistance value compared to other clay mixtures in all of NaCl concentrations, and the low plasticity clay (clay 1) showed the least undrained shear resistance value with various pore fluid salinity levels. At a normal load level of 20 Kg, clay 2 showed a peak stress value of 74.5 KPa with 2% NaCl concentration pore fluid, and clay 1 showed a least peak shear stress value of 35 KPa with 10% NaCl concentration pore fluid in direct shear test.

B. Plasticity Index Changes

The relationship between the percentage of plasticity and undrained shear resistance for four salt-clay mixtures (0, 2, 5, 10% salt concentration) show in Fig. 4 and Fig. 5.

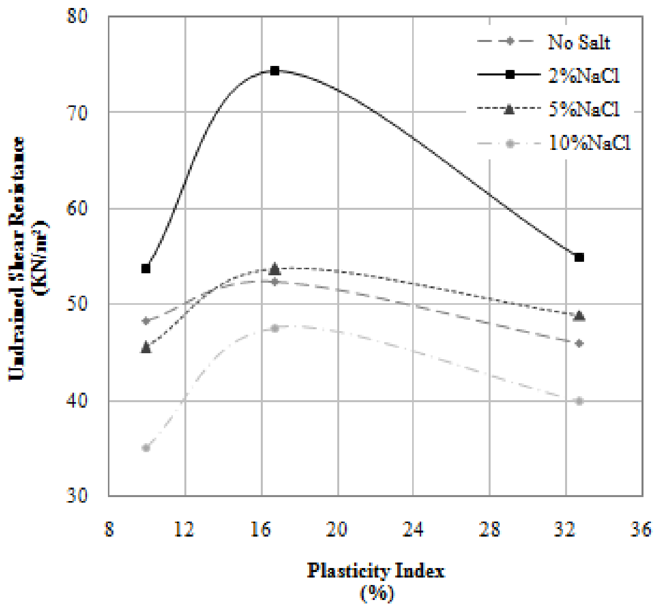

Fig. 4 Undrained shear resistance versus Plasticity index with direct shear test.

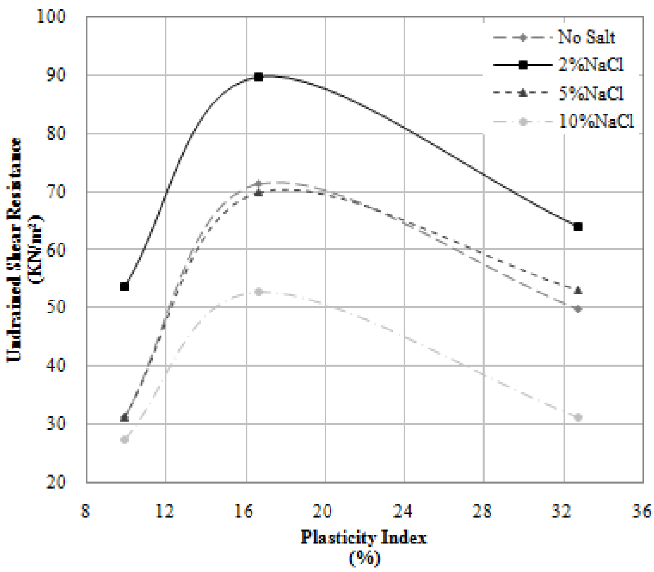

Fig. 5 Undrained shear resistance versus Plasticity index with vane shear test.

As the percentage of plasticity index increases up to medium plasticity (16.7%), the undrained shear resistance sharply increases and then slightly decreases near to high plasticity. Accordance between Fig. 4 and Fig. 5 is visible for 2% and 10% salt solution, but this coordination is not enough for 5% salt and deionized water contents.

Therefore, it is concluded that descending linear variation of undrained shear strength with salt content is misappropriate and in 2% salt solution, undrained shear resistance would increased in all plasticity.

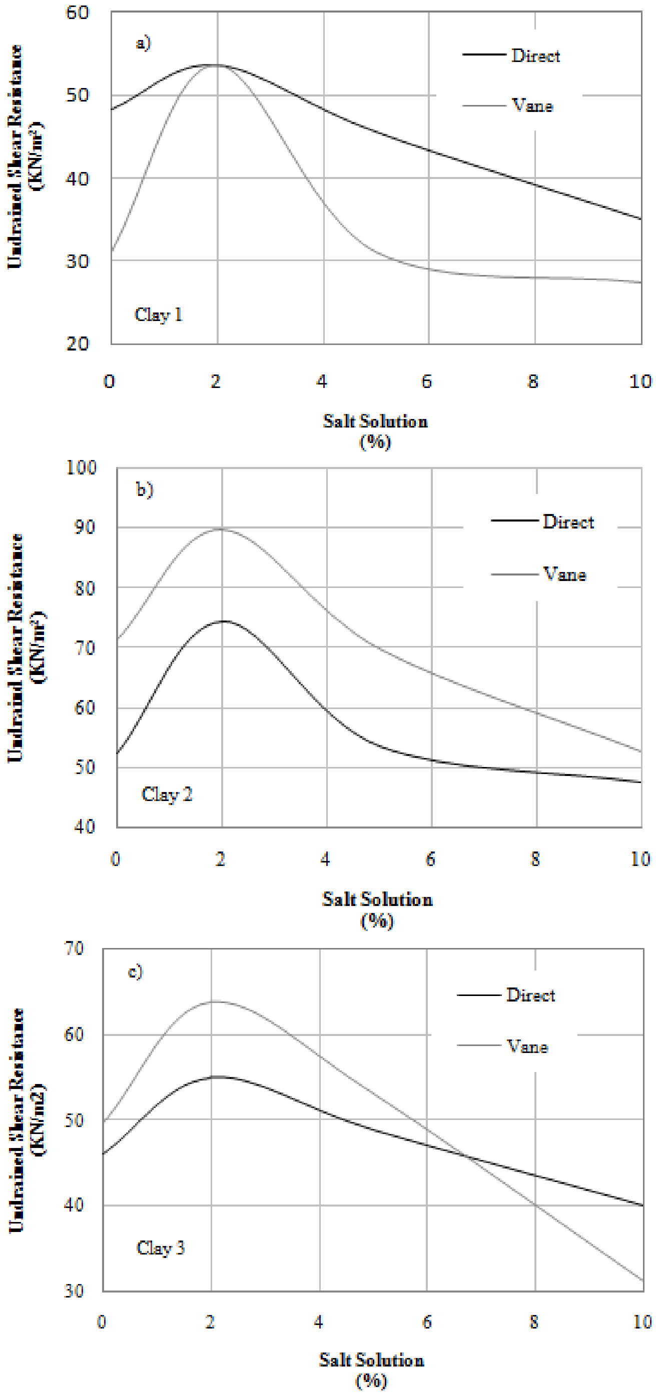

Fig. 6 Undrained shear resistance-salt solutions relationships for direct and vane shear tests for3 clays.

C. Comparative Discussion

Fig. 6a to Fig. 6c present the undrained strength versus different salt consolidation levels for clay 1, clay 2, and clay 3, respectively, at various plasticity indexes.

It may be seen that, for each clay, the undrained strength has been measured by both vane test and direct shear test.

According to Fig. 6a, the results of direct shear tests is over than vane shear test results, whereas based on Fig. 6b and Fig. 6c, approximately in all cases undrained shear resistance in vane shear has higher value than this parameter in direct shear test. Fig. 6b shown that vane shear results overestimated by 24% than direct shear results in clay 2 and Fig. 6c illustrated that this difference approximately equal to 11% for clay 3.

V. CONCLUSION

Two series of laboratory tests have been conducted to determine the effect of plasticity and salt solutions on the engineering behavior of compacted clay for their use as compacted clay barriers for municipal waste landfills. Based on the laboratory test results, the following general conclusions have been drawn:

1. Addition of salt solution sharply increases the undrained shear resistance of compacted up to 2% NaCl, due to changes in chemical structure of clay and then decreases up to 10% NaCl slightly owing to salt flocculation as discussed by Bolt (1956) to decrease the attractive forces in compare with deionized water contents.

2. Within the percent range of salt solution investigated in this study (0 to 10%), it is concluded that undrained shear resistance increase nonlinearly with increase in plasticity index. This is important because the flexibility of compacted clay liners is directly related to plasticity index. It concluded that medium plasticity clay (clay 2) has most shear resistance in all salt concentrations. These changes in strength can be best explained by theory on factors influencing shear strength of compacted clays developed by Lambe [11]. In one hand, when plasticity is build up, the soil structure becomes flocculated due to reduction in interparticle repulsion. Lambe reported that greater repulsion results in lower shear strength. In the other hand, when plasticity developed incredibly, this caused increase in void volume, and thus decreased undrained shear resistance.

3. In compare of direct shear and laboratory vane shear tests, it was found that as the plasticity of soils increases, undrained shear resistance obtained by vane shear tests may give overestimated results. This subject will confirm Bjerrum [1] theory. He concluded that the overestimation was caused by a viscous effect and the speed of vane rotation. The magnitude of the overestimation increased with increasing plasticity index. He suggested some factors to modify the vane shear results in higher plasticity.

REFERENCES

[1] L. Bjerrum, I. Rosenquist, "Some experiments with artificially sedimented clays" *Geotechnique 6, pp. 124-136, 1974.*

[2] R. E. Olson, "Effective shear strength of clays with various pore water electrolyte" *v.100, Journal of the Soil Mechanics and Foundation, May 1974.*

[3] M. A. Rashid, J. D. Brown, "Geochemistry of marine humic compounds," *Springer, 1985*.

[4] R. N. Yong, "Selective leaching effects on some mechanical properties of a sensitive clay," *1sth International Symposium on Environmental Geotechnology, V. 1, pp. 99-110, 1986.*
[5] S. Singh, "Effects of chemicals on compacted clay liner" *EJGE*, vol. 12, Bund. D, 2007.
[6] American Society for Testing and Materials (ASTM),"Standard test method for liquid limit, plastic limit and plastic index of soils", *Designation D 4318*, 1995.
[7] American Society for Testing and Materials (ASTM),"Standard test method for Laboratory Compaction Characteristics of Soil Using Modified Effort", *Designation D 1557*, 1995.
[8] P. Agamuthu, "Solid waste principles and management with Malaysian case studies" *Kuala Lumpur: University of Malaya Press*, 2001.S. Singh, "Effects of chemicals on compacted clay liner" *EJGE*, vol. 12, Bund. D, 2007.
[9] American Society for Testing and Materials (ASTM)," Standard test method for laboratory miniature vane shear test for saturated fine grained clayey soil", *Designation D 4648*, 1995.
[10] American Society for Testing and Materials (ASTM),"Standard test method for direct shear test", *Designation D 3080*, 1995.
[11] Lambe T. W. (1958), "The Structure of Compacted Clay", *J. of Soil Mechanics and Foundation Division, ASCE, Vol. 84, 1-35.*