ANALYZING THE EFFECT OF INORGANIC SALT SOLUTION AND PLASTICITY INDEX ON THE UNDRAINED SHEAR STRENGTH OF SOILS IN A COASTAL CITY OF BANGLADESH

Moumita Paul Aishi*[1], Tasfia Mehedi[2] and Md. Humayun Kabir[3]

[1]*Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: mou.aishi@gmail.com*
[2] *Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: tasfiamehedi82@gmail.com*
[3]*Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh, e-mail: mhkabir@ce.kuet.ac.bd*

***Moumita Paul Aishi**

ABSTRACT

In this study, the effect of inorganic salt solution and plasticity index on the undrained shear strength of soils have been investigated. The soil has been collected from multiple locations of Khulna, a coastal city of Bangladesh. The research includes several steps: a collection of samples from four different locations, determination of basic properties of the samples, and shear strength by using two unique methods. The basic soil tests performed are specific gravity tests, moisture content tests, liquid limit, and plastic limit tests. Direct shear and vane shear apparatus have been used to measure the undrained shear strengths. Variations of shear strength from direct shear and vane shear methods due to the presence of different salt solutions for highly plastic and low plastic clays have been compared. NaCl solutions have been added as the salt solution at four different concentrations. Soil samples were kept for proper soaking and penetration in the salt solutions. Variations due to the presence of different concentrations of admixtures have been analyzed. Results show that both salt solution and plasticity index have a great impact on the undrained shear strength of the soil.

Keywords: *Inorganic soil, undrained shear strength, salt solution, vane shear, direct shear*

1. INTRODUCTION

Soil mechanics is a crucial field for soil engineers. To evaluate different problems related to soil mechanics, for instance, seepage through an earth dam, bearing capacity of foundations, footing settlement, etc., soil engineers must keep deep understanding of different soil parameters. Among them, cohesion (c) and angle of friction (φ) are shear strength parameters, which are needed to solve various soil mechanics problem e.g., to evaluate the bearing capacity of soil, assessment of the slope stability etc. Due to the high cost and lengthy procedure, some of the soil properties are estimated from Atterberg limits, especially for plastic, clayey soils (Obasi, 2005). Water salinity has a significant role on these properties, thus gaining attention of researchers around the world. Salt can be found in soil in different ionized form like sulphate, chloride, magnesium, etc. It is reported that presence of a cation increases dry density of soil and decreases water content (Ören & Kaya, 2003). These salts can affect the nature of soil particles and thus chemical reactions might happen among these particles and the ions present in the pore water of soil (Al-Obaidi, 2018). Salt creates the loss of physical and chemical bonds exhibiting the physic-chemical effect of pore water on the shear strength of the clay. (Bjerrum & Rosenqvist, 1974). In this work, we have selected soils from Khulna, a coastal city of Bangladesh where the effect of salinity on soil is more prominent. To evaluate the effects of the salt content on the physical properties of soil, NaCl solution was used. Chloride ions can absorb water according to their hydration radius (Flatt, 2002; Konyai et al., 2006). Microstructures of soil may alter due to the adverse effect of its presence and thus reducing shear strength. Finally, we have established and explained the correlation between plasticity and shear strength of soil from their physical significance.

2. METHODOLOGY

2.1 Collection of Samples

The test procedure includes a collection of samples from four different locations. We collected samples from the sides of the highway, the Bhairab riverbank, lake side of the campus and from the premises of Department of Civil Engineering, KUET. These soils will be identified as sample1,2,3, and 4 respectively. The soil textures were different, and one sample contained quartz. The soil was oven dried, sieved, and stored properly for the later works.

2.2 Sample Preparation

Before adding NaCl salt solution, specific gravity, moisture content, grain size analysis, liquid limit, plastic limit, and plasticity index were determined for the abovementioned samples at natural conditions. Then salt solutions at four different concentrations (1%, 3%, 6%, 10%) were mixed with the four samples. Deionized water is indicated as a 0% salt solution. After the mixing, the specimens were kept at rest for 72 hours with a lower and normal load for saturation to prevent any kind of swelling. During the hand-remolding, we should be careful that air shouldn't be entrapped in direct shear square mold and laboratory vane shear cylindrical mold. Plastic limit, liquid limit, shear strength tests were done for all these samples mixed with the admixtures.

2.3 Calculations

2.3.1 Specific Gravity

The term specific gravity of soil refers to the specific gravity of the solid matter of the soil, which is designated as G_s. Specific gravity of solids is only applied to the fraction of the soil sample that passes through the No. 4 sieve. We followed ASTM D854-02 to determine specific gravity here. The specific gravity of soil can be obtained from:

$$G_S = \frac{W_S G_T}{W_{S-} w_1 + w_2} \quad (1)$$

G_T = Specific Gravity of distilled water at temperature T
W_s= Dry weight of soil
w_1= Total weight of pycno-meter, soil, and water
w_2= weight of pycno-meter, and water

2.3.2 Moisture Content

Moisture content refers to the water content present in moist soils. The water content 'W' of a soil is defined as the ratio of the weight of water (W_W) to the weight of dry soil grains in the mass (W_s). (ASTM D2216-90)

$$W(\%) = \frac{W_W}{W_S} * 100 \quad (2)$$

2.3.3 Grain Size Analysis

Grain size analysis is a fundamental tool for classifying unconsolidated materials and sediments, sedimentary rocks, and sedimentary environments. Quantitative analysis of the percentages of different particulate size yields one of the most fundamental physical properties of clastic sediments and sedimentary rocks. The purpose behind sizing grains is to obtain a frequency distribution of particle sizes (López, 2016). We followed ASTM D422-63 for this analysis.

2.3.4 Liquid Limit

Liquid Limit (LL) is the water content, in percent, of soil at the boundary between the semiliquid and plastic states. We determined the liquid limit according to ASTM D4318-10 (2010).

2.3.5 Plastic Limit

Plastic Limit (PL) is the water content, in percentage, of soil at the boundary between the plastic and semi-solid state. We followed ASTM D4318-10 (2010) here as well.

2.3.6 Plasticity Index

Plasticity Index (PI) can be defined as the range of moisture content where the soil deforms plastically. (ASTM D4318-10, 2010). Plasticity index can be expressed as:

$$PI = LL - PL \tag{3}$$

2.3.7 Direct Shear Test

A direct shear test is a laboratory or field test used by geotechnical engineers to measure the shear strength properties of soil or rock materials, or discontinuities in soil or rock masses. The U.S. and U.K. standards defining how the test should be performed are ASTM D3080, AASHTO T236, and BS 1377-7:1990, respectively. Figure 1 refers to the schematic diagram of a direct shear box (IIT Gandhinagar, 2015).

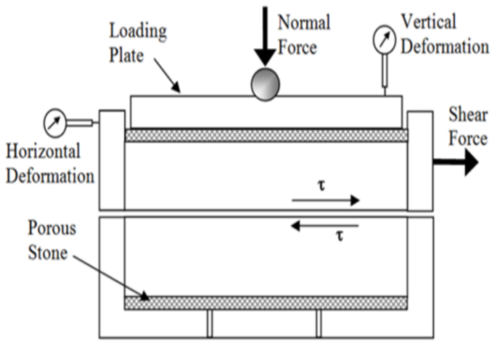


Figure 1: Direct shear test machine (Block Diagram)

2.3.8 Vane Shear Test

Vane shear test is a useful method of measuring the shear strength of clay. It is a cheaper and quicker method. The test can also be conducted in the laboratory. The laboratory vane shear test for the measurement of shear strength of cohesive soils is useful for soils of low shear strength (less than 0.3 kg/cm^2) for which triaxial or unconfined tests cannot be performed. The test gives the undrained strength of the soil. The undisturbed and remolded strength obtained is useful for evaluating the sensitivity of soil. They can be used during both field and laboratory tests. (Vaneshear Test, 2015). Figure 2 shows the equipment used for the laboratory vane shear test (ASTM D2573-08, 2010). The equation for calculating the shear strength is:

$$\boldsymbol{S} = \frac{\boldsymbol{T}}{\boldsymbol{\pi}(\boldsymbol{D}^2\frac{\boldsymbol{H}}{2} + \boldsymbol{D}^3)} \tag{4}$$

Here,
S= Shear Strength
T= Torque in cm kg
D= Overall diameter of vane in cm
T= Spring Constant/ 180x difference in degrees

Figure 2: Vane shear test machine blade

3. RESULTS AND DISCUSSIONS

3.1 Physical Properties

Table 1 Properties of soil for the different samples

Soil Property	Sample 1	Sample 2	Sample 3	Sample 4
Specific Gravity G_S	2.6	2.65	2.7	2.62
Moisture Content, %	20	22.96	26.13	24.75
Liquid Limit	36.2	52.3	38.2	44.1
Plastic Limit	25.4	34.6	28.5	32.4
Plasticity Index	10.7	27.6	9.7	11.7
Classification	CL	CH	CL	CL

3.2 Grain Size Analysis

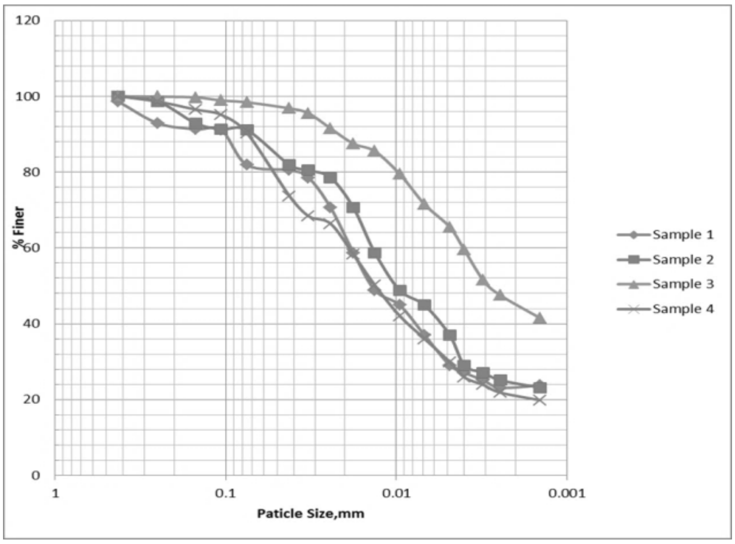
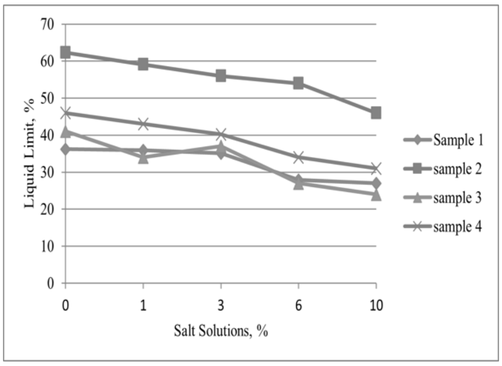


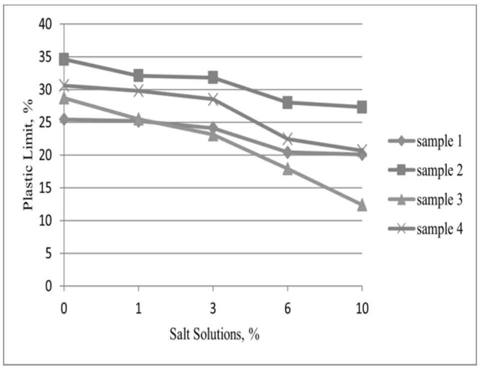
Figure 3: Particle Size Distribution Curve

Particle distribution curve in Figure 3 shows the relative amount of different sized particles that was present in the samples.

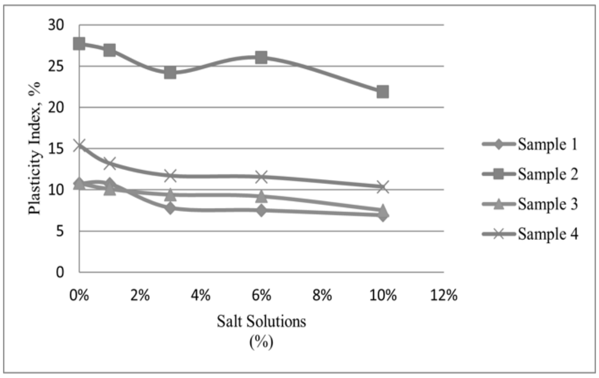
3.3 Effect of Salt Content on Consistency Indices



(a)



(b)



(c)

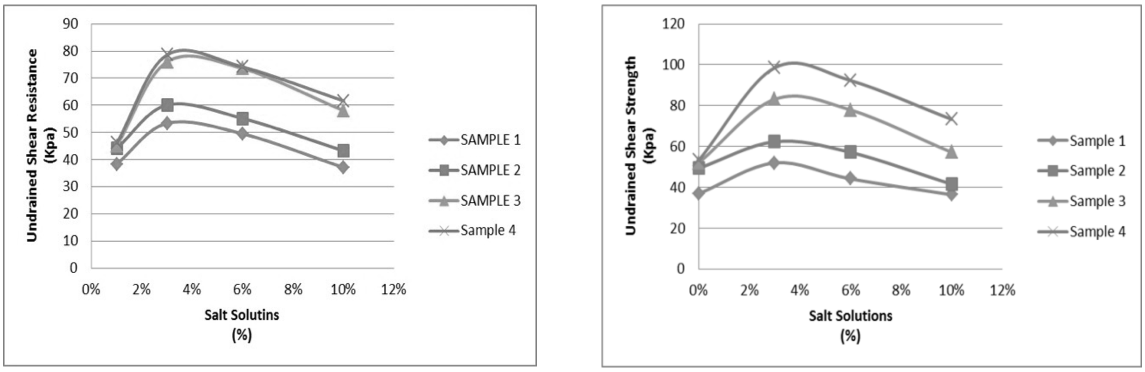
Figure 4: Effect of Salt Content Solution on (a) Liquid Limit of the Soil Samples (b) Plastic Limit of the Soil Samples (c) Plasticity Index of soil

The parameters of liquid limit and plastic limit decreased gradually for the increasing amount of salt solutions. For the plasticity index, the changes were not uniform, and they fluctuated for different samples (Figure 4). Changes in water film thickness and double electric layer are likely the causes of these fluctuations (Xing et al.,2009). Salt crystallization helps to increase coarse particles and thus decrease the total surface area. The decrease of the total surface area contributes to the thinning of the water film. Because the interparticle repulsion in the soil becomes diminished because of the presence of electrolytes from the increasing amount of salt content, the particles become free to move at a less interparticle distance. The rise of salt concentration in the samples assist the soils to get flocculated and forming clusters, causing a decrease in liquid and plastic limit (Li et al., 2016).

3.4 Effect of Salt Content on Mechanical Properties of Soils

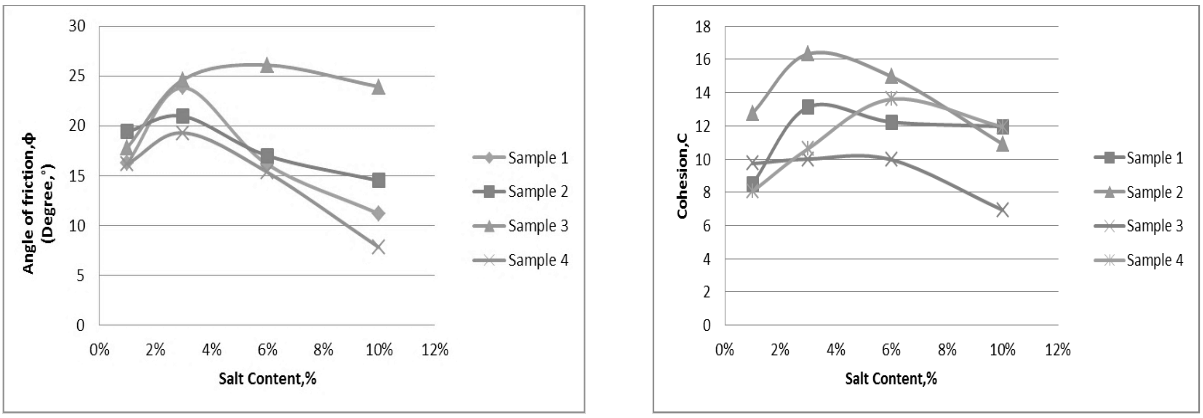
3.4.1 Shear Strength

Figure 5 shows the effect of salt content on the undrained shear strength of the soil. It shows that undrained shear strength becomes the highest at around 3% salt content. The shear strength decreases significantly afterward with the increasing amount of salt contents. It is a general tendency of soil to reduce its shear strength with an increasing level of salinity. The formation of brine from salt content and water might be the reason for this change. This brine can generate a film around each soil particle which has weaker surface tension than regular moisture. This tendency tends to decrease the strength. (Al-Obaidi, 2018)



(a) (b)

Figure 5: Effect of Salt Solution on Undrained Shear Strength of the soil samples from (a) Direct Shear test (b) Vane Shear test



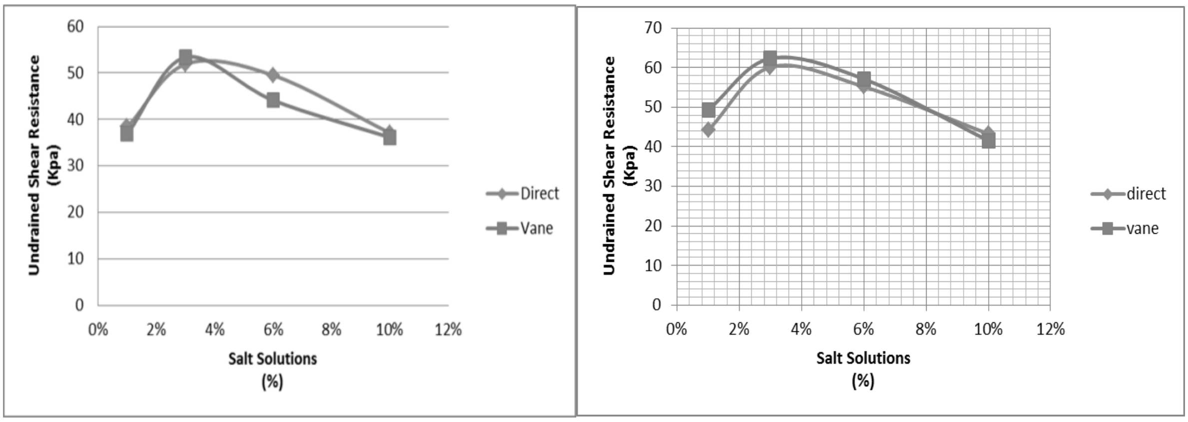
(a) (b)

Figure 6: (a) Effect of Salt Solution on Angle of Friction (b) Effect of Salt Content on Cohesion

In the experiment, the angle of friction and cohesion were used to evaluate the direct shear test (ASTM D6528-00, 2007). As the salt content rises from 1% to 3%, they increased rapidly. From figure 6(a) and (b), it became evident that for samples 1, 2, 3, cohesion increases up to 3% of salt content, and then starts decreasing to 10% of the solution. But sample 4 cohesion increases up to 6% of salt content, then decreases by 10%. it is shown that for Sample 1, 2, 4, the angle of friction increases up to 3% of salt content, then starts to decrease up to 10% of salt content. For sample 4, the Angle of friction increases up to 6% of salt content, then decreases for 10% salt content. As high salt content leads to salt crystallization, change of both cohesion and internal friction angle are both subject to change of the combination of these factors (Li et al., 2016). In general, the salt solutions have visible effects on the shear strength of the soil.

3.4.2 Comparison of a Mechanical Property:

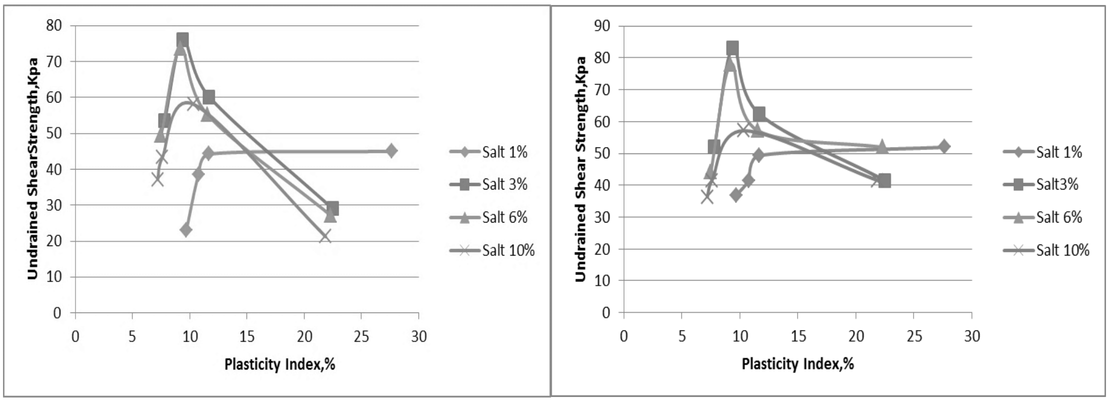
Figure 7 indicates that soils with high plasticity show a higher value of shear strength for the vane shear test. Undrained shear strength varies in direct shear and vane shear tests due to the direct shear test failure plane being horizontal and vane shear test the failure plane is perpendicular to the direction of the applied torque. Lower plasticity soils show a lower value of shear strength during the vane shear test. Though the change is not very much significant.



(a) (b)

Figure 7: (a) Comparison of direct & vane shear test result for sample CH Soil (b) CL soil

3.5 Effect of Plasticity Index on Shear Strength



(a) (b)

Figure 8: (a) Effect of Plasticity Index on Undrained Shear Strength of Soil for Direct Shear Test (b) Vane Shear Test

If the plasticity index increases, the plastic range of the soil increases. Friction between layers of soils increases in a wider range of moisture content. That contributes to the increase of undrained shear strength. There is an opposing effect where the change is subjected to the particle size. Highly plastic soils have small particles and relatively high surface area per unit weight. On the other hand, low plasticity soils have larger particles with less contact area. When an external load is applied, the soils with more surface area would generate low horizontal shear stress i.e. low undrained shear strength (Obasi, 2005). As seen in figure 8, for lower plasticity index, the first effect dominates. At higher plasticity variation from the second effect is more prominent. As a result, we get non-monotonic change with plasticity index. The presence of different amounts of salt content also affects this variation. More samples would give us a solid conclusion on the validity of this effect.

4. CONCLUSIONS

The chemicals significantly affect the geotechnical properties of clay and clay liners. The behavior of the low plasticity clays (CL) is different from the high plasticity clay (CH). Liquid Limit, Plastic Limit and Plasticity Index decrease with the increase of salt solution. Undrained Shear Strength increases up to salt content percentage of 3% for our samples and starts decreasing afterwards till 10%. Friction angle and cohesion are also affected by salt content. Lastly, undrained shear strength shows non-monotonic change with plasticity index of soil particularly at low percentage of salt.

ACKNOWLEDGEMENTS

We would like to express our heartiest gratitude to the faculty members and other staff of the Department of Civil Engineering at Khulna University of Engineering & Technology for providing us necessary supports and instruments to conduct the research work.

REFERENCES

Ajam, M., Sabour, M. R., and Dezvareh, G. A. (2015). "Study of water salinity effect on geotechnical behavior of soil structure using response surface method (RSM)." Case study: Gotvand Dam.

Al-Obaidi, A., Ihssan A. and Allawi, H. (2018) "Studying of the combined salts effect on the engineering properties of clayey soil." MATEC Web of Conferences, Baghdad, Iraq, Vol. 162, 01011.

Arasan, S. (2010). "Effect of Chemicals on Geotechnical Properties of Clay Liners." *Research Journal of Applied Sciences, Engineering and Technology*, 2(8): 765-775.

Arasan, S. and Yetimoglu, T. (2007). "Effect of Inorganic Salt Solutions on the Consistency Limit of Two Clays." *Turkish Journal of Engineering and Environmental Science*, 32(2008), 07-115.

ASTM D4318-10, 2010. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. West Conshohocken, PA.

ASTM D854-14, 2010. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. West Conshohocken, PA.

ASTM D422-63, 2007. Standard Test Method for Particle-Size Analysis of Soils. West Conshohocken, PA.

ASTM D 2216-90, 2007. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil. West Conshohocken, PA.

ASTM D1556-00, 2007. Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method. West Conshohocken, PA.

ASTM D2166, 2010. Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. West Conshohocken, PA.

ASTM D4648-05, 2010. Standard Test Method for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil. West Conshohocken, PA.

Bjerrum, L. and Rosenqvist, I. T. (1974). "Some Experiments with Artificially Sedimented Clays." *Geotechnique*, Vol. 6, Issue 3, 124-136.

Flatt, R.J., 2002. Salt damage in porous materials: how high super saturations are generated. *J. Cryst. Growth* 242 (3), 435–454.

IIT Gandhinagar. (2015, January 1). *IIT Gandhinagar*. Retrieved January 1, 2015, from IIT gandhinagar website: http://research.iitgn.ac.in.

Konyai, S., Sriboonlue, V., Trelo-ges, V., Muangson, N., 2006. "Hysteresis of water retention curve of saline soil". *Unsaturated Soils*. pp. 1394–1404.

Li, M., Chai, S., Du, H. and Wang, C. (2016). "Effect of chlorine salt on the physical and mechanical properties of inshore saline soil treated with lime." *Soils and Foundations*, Vol. 56(3), 327–335

López, G. I. (2016, August 1). *Researchgate*. Retrieved August 1, 2016, from Researchgate web site: https://www.researchgate.net

Mun, W., Teixeira, T., Balci, M. C., Svoboda, J. and McCartney, J.S. (2016). "Rate effects on the undrained shear strength of compacted clay." *Soils and Foundation*, 56(4), 719-731.

Obasi, N. L. and Anyaegbunam, A. J. (2005). "Correlation of the Undrained Shear Strength and Plasticity Index of Tropical Clays." *Nigerian Journal of Technology*, Vol. 24, No. 2.

Ören, A. H., Kaya, A., 2003. "Some engineering aspects of homoionized mixed clay minerals." *Environmental Monitoring and Assessment*, 84:85–98.

Singh, S., A. Prasad, 2007. "Effects of chemicals on compacted clay liner." *Electronic Journal of Geotechnical Engineering*, 12; 1-15.

Vaneshear Test. (2015, February 2). *Geotechdata.infio*. Retrieved February 2, 2015, from Geothechdata.info website: http://geothechdata.info.

Xing, H.F., Yang, X.M., Xu, C., Ye, G.B., 2009. "Strength characteristics and mechanisms of salt-rich soil-cement." *Eng. Geol.* 103 (1), 33–38.