AN INVESTIGATION ON THE STRENGTH AND MOISTURE DENSITY RELATIONSHIPS OF SOILS TREATED WITH ORGANO SILANES AS A FUNCTION OF MOISTURE AND SALT CONTENT

by

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ABSTRACT

MACKENZIE MALISHER. An Investigation on the Strength and Moisture Density Relationships of Soils Treated with Organo Silanes as a Function of Moisture and Salt Content. (Under the direction of Dr. John Daniels)

Organo silanes (OS) are chemical agents that can be mixed with soil to induce water repellency by coating the surfaces of particles. As a means to mitigate the effect of frost heaving, the current research has been conducted to determine the effectiveness of using chemical agents to make soil water-repellent. The effect of salt, known to lower the temperature at which the surrounding water freezes has also been investigated. These treatment processes are expected to change the mechanical properties of soil. Laboratory tests were carried out to determine the compaction properties, shear strength, and penetration resistance of the untreated and treated soils, with and without the addition of salt. TerraSil (from Zydex industries) was used as the OS in the treatment process at a ratio of 1:100 (OS: Water) batched gravimetrically. It was determined that a reduction in moisture content occurred in all soils treated with OS, ranging from 0.20 to 2.70%. In soils with increased salinity, the difference in optimum moisture content was less for treated and untreated soils, ranging from 0 to 0.9%. The change in shear strength for treated soils was found to be dependent on soil. For the Fairbanks, Alaska (AK-F) soil, changes in shear strength were minimal at optimum moisture. For the Hanover, New Hampshire (NH-H) soil, the peak shear stress for the sample treated with TerraSil dropped to approximately 6 kPa. For the pocket penetrometer, the maximum drop in penetration resistance when considering treated and untreated soils at a particular moisture content was 1.83 kg/cm^2.

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CHAPTER 1: INTRODUCTION

1.1 Background

Frost heaving is the rise of the ground surface due to the volumetric expansion of water that occurs when ice is formed. There is typically less resistance above the forming ice, therefore the expansion occurs in the upward direction (Murton 2021). Frost heaving occurs in frost susceptible soils where a water supply and freezing temperatures are present. Silty soils tend to be frost susceptible due to their small particle size which promotes capillary action to occur. Capillary action occurs when small "tube" like formations pull water upward. If freezing conditions continue, ice lenses are formed parallel to the ground surface. This process may occur seasonally or persist for longer periods of time.

This deformation in ground surface causes detrimental damage to roads, structures, and underground utilities. During the spring seasons, as the ice melts, thaw weakening occurs. The water is not able to immediately drain as it thaws, resulting in a weaker subgrade and a lower bearing capacity. This thawing can occur either in the upward or downward direction. When surface temperatures begin to increase, the thawing occurs from top downward, which creates poor drainage conditions by limiting the drainage by the frozen section underneath (Zang 2016).

Capillary barriers can be used by substituting frost-susceptible soils for granular materials such as sands, which offer better drainage (Rengmark, 1963). Plastic foams as heat insulating materials that restrict the propagation of the freezing front (Gandahl, 1982). To restrict the supply of water, capillary barriers such as geotextiles (Henry, 1990) and geocomposite drainage nets (Evans *et al*. 2002) have traditionally been used. A comparably lesser-known method to mitigating frost heaving is the use of water-repellent soils. This comes in the form of chemical agents which are mixed with the soil to create a water-repellent layer.

In engineering applications, the reduction in expansion of swelling clays (Hernandez *et al*. 2005) and the reduction of flow during capillary rise (Orozco and Caicedo, 2017), have previously been considered with the use of water-repellent soils. Additionally, their implementation as capillary barriers in a geotechnical context for infiltration control in landfills (Keatts *et al*. 2018) and as slope covers (Lourenço *et al*. 2017) have also been investigated.

Chamberlain (1983) explains how salt effects the freezing behavior of soils, beyond just lowering the freezing point. Ice crystals that are formed in the soil do not contain the surrounding salts and therefore push the salt into any surrounding pore fluid. This accumulation of salt lowers the segregation temperature and can in return reduce ice formation. The segregation temperature refers to the point where growth or stagnation can occur in an ice lens formation, because it is the warmest point of the ice lens (Fu *et al*. 2022). Consequently, pockets of brine might develop in the unfrozen pore water space. Soil salinity has the potential to decrease frost heaving while also improving the shear strength of soils.

1.2 Problem Statement

Frost heaving requires the following three conditions to be present: freezing temperatures, frost susceptible soils (generally fine-grained soils), and water availability. A method used to prevent frost heaving would be the implementation of chemical agents for the purpose of creating water repellent soil. If these chemical agents were to be used in field applications, it would be necessary to know how the mechanical properties of the soil will change as a result. This research is part of the preliminary work to determine the changes in compaction and strength properties of soils which are artificially made hydrophobic. The chemical agent used in this research is an organo silane (OS) in the commercial form known as TerraSil.

Additionally, increased soil salinity may reduce the frost heave potential while also impacting the mechanical properties of soil. Therefore, the mechanical properties of the combined effect of increased soil salinity with OS treatment should be investigated.

1.3 Research Objectives

The purpose of this research is to compare the mechanical properties of untreated soils to the properties of soils treated with the OS based chemical, known as TerraSil. This research encompasses lab testing on the moisture density relationships, shear strength, and the resistance to penetration. The scope of this research will include four soils from the following four locations: Keokuk County, Iowa (IA-KC), Ashe County, North Carolina (NC-AC), Hanover, New Hampshire (NH-H), and Fairbanks, Alaska (AK-F). Preliminary testing was done on these soils to determine the soil properties and classifications. The soils were then tested for water repellency using the water drop penetration test (WDPT), with multiple concentrations of TerraSil mixed with water. A concentration was selected and used for the compaction, direct shear, and pocket penetrometer tests. The compaction and direct shear tests were also tested increasing the soil salinity to 1 mole of NaCl per liter of water. The salinity of the soil was expected to change the mechanical properties of the soils. Therefore, a combined effect of salinity and treatment with TerraSil was investigated. Additionally, the compaction, direct shear, and pocket penetrometer tests were done varying the moisture content.

CHAPTER 2: LITERATURE REVIEW

2.1 Water Repellency

Water will spread on a solid when the adhesive forces between the solid and water molecules are larger than the cohesive forces within the water (Doerr 2000). For naturally occurring water repellent soils, the water repellency induced have been reported to be transient and non-uniformly distributed (Morley *et al*. 2005; Jackson and Roering 2009). Soils are considered to have water repellent properties when water is unable to flow through porous soils, either from weak adhesion to the soil particles or from entrapped air bubbles (Roberts and Carbon 1972).

Chemical agents can be used to introduce water repellency to varying soil types. Lime and cement are used for soil stabilization to decrease permeability and increase the strength of the soil. As a result, frost heaving and shrink/swell potential is decreased (Cuisinier 2011). Lime is used to create cementitious bonds with naturally occurring Pozzolans in soils, such as silica and alumina. Limitations to this process exist when the soil contains chemical compounds that alter the effects of lime and cement. For example, sulfates and organic matter have been known to alter soil stabilization (Cuisinier 2011).

To meet needs beyond typical soil stabilization methods, commercial products have been developed to introduce water repellency in soils. Uduebor *et al*. (2022) lists some of the products as the following: Dimethyldichlorosilane, Wax, Zycosoil (Trimethyloxysilyl), Stearic acid, and Tung Oil. Dimethyldichlorosilane has been used for water repellency in dry soils by reacting with water or water vapor to form polydimethylsiloxane and hydrogen chloric fumes (Ng and Lourenco 2016). The polydimethylsiloxane is then able to interact with the soil particle surface creating an outward-oriented hydrophobic methyl group. Dimethyldichlorosilane was found to be less effective and have a delayed development of water repellency when organic matter, residual water, and other non-mineral matter were present (Ng and Lourenco 2016).

Wax-coated soils have been identified as having hydrophobic properties by forming a thin film around the soil particles of sandy soils. Due to the mechanical properties of hydrophilic soils being dependent on water content, coating the soil in wax limits the loss of strength in the soil that would result from an increase in water content (Bardet *et al*. 2011). Stearic acid is considered a common organic acid found in soils, which can also be artificially introduced to the soil by mixing the acid with diethyl ether, due to the acid being insoluble with water (Leelamanie *et al*. 2008). Tung oil is a type of vegetable oil that comes from the Tung tree. Tung oil has been found to decrease the hydraulic conductivity of soil by creating a film around the particles (Zhang *et al*. 2016).

Daniels (2009) describes the use of an OS chemical agent to generate hydrophobic surfaces on silica-based materials. This process occurs through covalent bonding in the surface of a material, creating almost permanent modification. Daniels (2009) suggests that OS has the potential to decrease swell potential and hydraulic conductivity, while also increasing the strength of a soil. Choi (2016) used OS (Zycosoil, Zydexindustries, Vadodara, India) on kaolin clay and found that the soil-water contact angle increased up to a concentrated treatment of 2.5% (weight of OS to weight of water).

The degree of water repellency can be measured by the water-drop penetration time (WDPT) and the contact angle measurement of wetting. The WDPT test consists of placing a water droplet on a soil surface while measuring the time it takes for the drop to completely penetrate the surface (Doerr 1998). The water will not immediately penetrate the surface if the surface tension of the soil is higher than that of the water droplet which is around 72 mN/m. Multiple classifications exist relating time to level of hydrophobicity e.g., Charts by Doerr (2006). Through a study done by Leelamanie *et al.* (2008), the WDPT has been related to contact angle measurements with contact angles from 11° to 69° for WDPT less than 1 second. A gradual increase in penetration time was then observed for contact angles above between 69° and 88 and a sharp increase was observed for angles 88° to 93°. The WDPT was then over an hour for contact angles above 93°.

2.2 Mechanical Tests

2.2.1 Compaction

Lin *et al*. (2021) investigated the effects the Tung oil (a commercially available water-repellent product) had on the compaction properties of completely decomposed granite. Samples were compacted using a modified compaction test with a controlled energy per unit volume that was kept similar to the Standard Proctor Test. These compaction tests were completed immediately after mixing the soil with the Tung oil, due to the hardening effects the oil has. It was found that a higher concentration of Tung oil reduced the optimum moisture content while increasing the maximum dry density. For example, the soil's natural optimum moisture content was found to be 23%, this value reduced to 17% after mixing with 5% Tung Oil.

Choi *et al*. (2016) compared the compaction properties of kaolin clay that was modified with the OS Zycosoilin (Zydex industries, Vadodara, Indi, in concentrations ranging from 0.5% to 10% batched gravimetrically. It was found that the maximum dry weight decreased with increasing concentrations of OS. Additionally, the treated clays were further away from the ZAV curves and therefore had a harder time reaching full saturation.

Bardet *et al*. (2011) used a manufactured blend of poorly graded sand mixed with 3% in weight of a petroleum wax. It was found that wax coated samples had a flatter compaction curve, and therefore was less sensitive to changes in moisture. Because of this it also had less variations in shear strength among different moisture contents.

2.2.2 Direct Shear Test

From the few studies in literature aiming to understand the mechanical behavior of water-repellent soils compared to untreated soils, multiple studies have found conflicting results when examining shear strength. Byun *et al*. (2011) used glass beads with a median diameter of 0.25 mm to minimize the effect of particle shape and size. To make the particles hydrophobic, the glass beads were modified using a silica silanization process. After treatment, the glass beads were oven dried. Water was added at 5% and 10% degrees of saturation for both the hydrophobic and hydrophilic samples. During the sample preparation for direct shear, it was noted that the packing density was higher for the hydrophobic glass beads. It was concluded that the internal friction angles of the hydrophilic and hydrophobic samples were 40° and 29° respectively. It was noted that even with the higher packing density of the hydrophobic sample, the shear strength was still smaller than that of the hydrophilic samples. This led to the conclusion that the shear strength of the sample was more influenced by the interparticle friction effect compared to the high packing density.

Bardet *et al*. (2011) investigated the shear strength of wax coated sands. It was determined that the wax coated samples had a slightly increased shear strength cohesion at a low pressure and an insignificant effect on internal friction. It was also noted that wax coating increased the cohesion of the samples. Karim *et al* (2018) studied sand particles made water repellent with an organic silane under dry and submerged conditions. The hydrophobic samples were treated then oven dried before being compacted in the direct shear box in three layers and then sheared. For submerged samples, 15 minutes was allowed for the sample to equilibrate with the added water. All samples were then sheared at a rate of 0.5 mm/min. It was determined that in the dry condition the peak shear stress of the hydrophobic sand was reduced by 26% and the friction angle reduced from 36.9° to 29.7° compared to the hydrophilic sample. For the submerged test, the peak shear stress reduction was 34% and the reduction in friction angle was 38.7° to 26.1°. This suggest that for hydrophobic samples the degree of saturation has less of an impact on shear stress. It was also recommended that since the study was done on naturally hydrophilic soil, it should be recreated on naturally hydrophobic samples.

Discrepancies in literature on shear strength of water-repellent soils may depend on the chemical agents used. It may be that the resulting mechanical characteristics of water-repellent soils are not only dependent on the type of chemicals and inherent soil properties (e.g., particle size) but also on the sample preparation method. Therefore, determining the mechanical behavior of water-repellent soils is necessary prior to deployment in ground engineering.

2.3.3 Pocket Penetrometer

Mousavi *et al*. (2021) used the pocket penetrometer (PP) device to create a model that compares the results to the results of the unconfined compressive strength (UCS) test on fine grained soils. It was determined that with a non-linear relationship the PP can be used to estimate the UCS with reasonable accuracy at a R^2 coefficient of 0.99. The UCS of water-repellent soils

Lin *et al.* (2021) compared the UCS of untreated soil samples to those with increased water repellency due to treatment a process using Tung oil. Concentrations of 5% and 10% were used and samples were prepared at optimum moisture content. It was found that the Tung oil increased the UCS of the soil due to the hardening and bonding effects of the oil. Higher concentrations of oil and longer time intervals were found to continually increase the UCS. For example, the untreated control sample was tested 3 days after being prepared and had a UCS of 632 kPa. The same soil treated at 5% Tung oil reached 1853 kPa after three days. Additionally, after 28 days there was no difference in the untreated control sample, while the UCS of the treated sample increased to 2136 kPa.

2.3 Soil Salinity

Total suction has been shown to be dominated by osmotic suction, even with moderate concentrations of salt (Miller and Nelson 2006). Equation (1) relates total suction in soils (Ψ) to the density of salt solution (ρ_f), where (R) is the gas constant per mole, (T) is temperature in Kelvin, (M) is molecular weight of the solution, and the relative humidity ratio is denoted by the ratio (P_A/P^*_A).

$$\Psi = \frac{\rho_f}{M} RT \ln \frac{P_A}{P^*_A} \tag{1}$$

Total suction is a function of both osmotic and matric suction. Osmotic suction is a result of the pore water salt content, while matric suction is associated with capillary effects. Osmotic suction has been shown to affect the shear strength of materials, such as fly ash where an increase of 32% in peak shear stress for fly ash samples was reported in Saulick *et al.* (2022) due to salinization. Direct shear tests were conducted on coal fly ash samples targeting an optimum water content. For samples with an increased osmotic suction, a 1-molar solution of NaCl was used. Jayathilaka *et al.* (2020) found that for unsaturated soil specimens, an increase in osmotic suction resulted in a significant increase of peak shear strength, at around 75%. Additionally, peak shear strength for saturated specimens with increased osmotic suction was close to double the strength. A total of 147 direct shear tests were conducted or remolded and recompacted clay specimens. A separate study done by Leong and Abuel-Naga (2018) found that shear strength was unaffected by osmotic suction of around 5000 kPa in unsaturated high plasticity silty soil samples. This study used unconfined compression tests to measure the strength at dry of optimum, optimum, and wet of optimum.

Salinity has also been shown to have an impact on the compaction soils. Ning *et al*. (2016) investigated the influence water, density, and salt had on the frost heaving characteristics of soil. The critical water content of frost heaving saline soils was analyzed at varying water contents, compaction degrees, and salt contents. It was found that frost heaving favored higher density and water content values. Additionally, shrinkage was found at lower density and water content values. A close to linear relationship was found between frost heaving quantity and water content. Therefore, Ning *et al*. (2016) suggests that a critical water content for frost heaving exists.

Otoko (2014) found that when mixed with salt water, maximum dry unit weight decreased in clay samples, but increased in clayey sand and base course samples. Using soils with different clay fractions and mineral compositions, Ying *et al*. (2021) found that soils with a higher salt content had a lower dry density and higher optimum water content. After a certain point of salinity these properties were no longer impacted with increasing amounts of salt.

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Soils

Table 1 presents the soils used for lab testing. These soils were identified as frost susceptible based on their classification.

Table 1. Soil Properties

Soils	UCS	AASHTO	Specific Gravity	Liquid Limit	Plastic Limit	Percent Passing No. 4 (%)	Percent Passing No. 200 (%)
(NH-H)	SM	A-5	2.68	41.8	NP	79.8	42.41
(NC-AC)	SM/SC	A-4	2.67	38.4	NP	96.5	38.2
(IA-KC)	CL	A-6	2.74	42.95	18.3	92.7	81.4
(AK-F)	ML	A-5	2.67	41.0	NP	90.4	81.8

3.1.2 Chemical Agent

The chemical agent used is a commercially available product, known as TerraSil (from Zydex industries). This OS is water soluble and non-leachable (Uduebor *et al*. 2022). The chemical consists of ethylene glycol, benzyl alcohol, and hydroxyalkyl-alkoxy-alkyl (Pandagre and Rawat, 2016).

3.2 Methods

3.2.1 Sample Preparation

Samples were prepared as follows: A batch of the individual soil samples were first oven dried at 121° Celsius, after which they were discretely separated by hand. The resulting soil was then sieved through a No. 4 sieve (4.75 mm), followed by proper mixing to ensure an even particle size distribution before separation of the batch into smaller samples.

To induce water repellency in the soils, a commercially available product (TerraSil from Zydex Industries) containing approximately 65% of alkoxy-alkylsilyl compounds was used. The chemical agent is water soluble and has a density of 1.01 g/cm3. For hydrolysis to occur, TerraSil is first diluted in a ratio of 1:100 (batched gravimetrically). For samples which the effect of salinity was investigated; a 1 mole solution was prepared using NaCl and water. For treated samples, this was then used to mix with the TerraSil at the same a ratio of 1:100 (batched gravimetrically). The solution prepared from the salt water and TerraSil was then mixed with a handheld mixer. Once fully mixed, the TerraSil and water solution was added to the oven dried soil sample depending on the targeted moisture content. For direct shear testing, samples were prepared at the optimum moisture content, as well as 4% above and below optimum. For compaction testing a range of moisture contents was used. The soils were manually mixed and placed in a plastic bag ensure proper conditioning according to the minimum standing time required in ASTM 3080.

3.2.2 Water Drop Penetration Time Test

After sample preparation of the TerraSil treated soil with the same 1:100 (batched gravimetrically) ratio, the soil was compacted using the Harvard miniature apparatus. Samples were compacted at optimum moisture content with the intent of reaching the maximum dry density. In field applications of TerraSil, it is assumed that the soil would be air-dried after treatment to increase the water repellency. Therefore, the samples used for the (WDPT) test were air dried before placing the water droplet.

3.2.3 Compaction

Compaction characteristics of the soils were determined using a Harvard miniature apparatus. The procedures followed are presented in “Suggested Method of Test for Moisture-Density Relations of Soils Using Harvard Compaction Apparatus” from Wilson (1970). After sample preparation, the mold was weighed, and the apparatus was setup with screws holding it in place. A total of 5 soil layers were used for each test. Once a layer was placed, the soil was slightly pressed down so that the surface of the soil was level and not loose. The tamper was set to 17 kg and a total of 25 tamps were done for each layer. The first 4 tamps were applied in separate quadrants of the mold and the fifth tamp was applied in the center. This was repeated until the number of tamps reached 25. Layers with approximately equal thickness were used and each layer was scarified before the following layer was placed. Once compacted, the mold was isolated from the base and collar and excess soil was carefully trimmed away. The soil and mold were then weighed and extruded with a sample ejector. The moisture content of the soil was then tested.

3.2.4 Direct Shear

The friction angle and soil cohesion strength parameters were determined through direct shear tests under consolidated drained conditions (ASTM D 3080). The following direct shear tests were performed:

- Untreated soils at optimum moisture content
- TerraSil treated soil at optimum moisture content

- TerraSil treated soil at optimum moisture content with salt

The shearing rate was determined using ASTM recommendations. Consolidation testing was completed to obtain the time required for the specimen to reach 50% consolidation using the same normal force as the direct shear testing. The following equations are from ASTM D698.

$$\text{Time of failure } (t_f) = 50t_{50} \tag{2}$$

$$\text{Displacement rate } (d_r) = d_f/t_f \tag{3}$$

The shear box was assembled and a moist porous stone was placed at the bottom with a filter paper above. After sample preparation, the amount of soil needed to reach a particular unit weight was determined and weighed out. The shear box had a diameter of 63.27 mm and a height of 33.01 mm. Specimens were molded into the shear box by tamping multiple layers and scarifying the soil surface in between each layer. Once the shear box was prepared, the specimens were loaded at 25 kPa, 50 kPa, and 100 kPa. The sample then went through primary consolidation before being sheared.

To determine the unsaturated shear strength (τ'_u) at varying normal stresses (kPa) of 25, 50 and 100, the equations proposed by Khabbaz and Khalili (1998) and Jayathilaka *et al*. (2021) were used to respectively investigate the effect of matric and osmotic suction on the unsaturated shear strength.

$$\tau'_u = [(\sigma_N - u_a) + x_1(u_a - u_w)]\, tan\, \phi' + c' \tag{4}$$

$$x_1 = \left(\frac{u_a - u_w}{AEV}\right)^{-0.55} \tag{5}$$

In equation 4, σ_N is the total normal stress, (u_a) is the pore air pressure, (x_1) is the effective stress parameter dependent on matric suction, (u_w) is the pore water pressure, (ϕ') is the effective friction angle, and c' is the effective cohesion. The strength parameter (ϕ' and c') are assumed to be independent of the matric suction and salinity based osmotic suction. In equation 5, $(u_a - u_w)$ is the matric suction and AEV is the air entry value. For the samples tested with an added salinity, the shear strength of the osmotically induced unsaturated soil (τ'_{us}) was given as the following equation.

$$\tau'_{us} = [(\sigma_N - u_a) + x_1(u_a - u_w) + x_2\pi]\,tan\,\phi' + c' \tag{6}$$

Where (π) is the osmotic suction and (x_2) is representative of the pore water salinity. Lange (1967), relates the NaCl concentration to in the following equation, with (C) representing the concentration.

$$\pi(\text{kPa}) = 4937.9(\text{C}) - 192.01 \tag{7}$$

With a NaCl concentration of 1 mol/L, equation 6 gives a (π) value of 4,745.89 kPa. The suction and air entry values were obtained from the soil water characteristic curves (SWCC) for each soil tested using gravimetric water content (Uduebor, n.d.). See Figures 17 and 18 in

Appendix D for SWCC results. Table 2 below shows the matric suction and air entry value at optimum moisture content for each soil type.

Table 2. Suction and Air Entry Values

Soil Type	Matric Suction (kPa) $u_a - u_w$	Air Entry Value (kPa) AEV
NH-H	8.9	12.3
AK-F	81.6	17.0

3.5 Pocket Penetrometer

Procedural guidelines from Davidson (1965) were used to test soil's resistance to vertical penetration by use of a pocket penetrometer. A pocket penetrometer is a hand operated device with a measurement range of 0 to 4.5 kg/cm2. The soil was prepared with target moisture contents and compacted to target density values. Once compacted, the mold was placed on a flat surface and the needle was placed on the top of the soil in the vertical position, away from the edge of the mold. The penetrometer was steadily pushed through the sample until it reached the black line on the needle of the penetrometer, indicating the stopping point. The value on the penetrometer was then recorded and the sample moisture content was taken. This was repeated two more times on the same sample and the measurements were then averaged.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Water Drop Penetration Time Test

The WDPT varied depending on the soil type and the moisture content it was treated with. The TerraSil mixture was created at a ratio of 1:00 (OS: water) batched gravimetrically. Therefore, samples with higher moisture contents had higher dosages of TerraSil. Table 3 shows the time frames in which the water droplet was present on the soil surface. These samples were tested below, above, and at optimum.

Table 3. WDPT Test Results

Soils	Below Optimum	At Optimum	Above Optimum
NH-H	0.5 - 1 hr	>1 hr	>1 hr
NC-AC	0 – 0.25 hr	0.25 - 0.5 hr	0.5 – 1 hr
IA-KC	0.5 – 1 hr	>1 hr	>1 hr
AK-F	0.5 – 1 hr	>1 hr	> 1 hr

4.2 Compaction of Soils

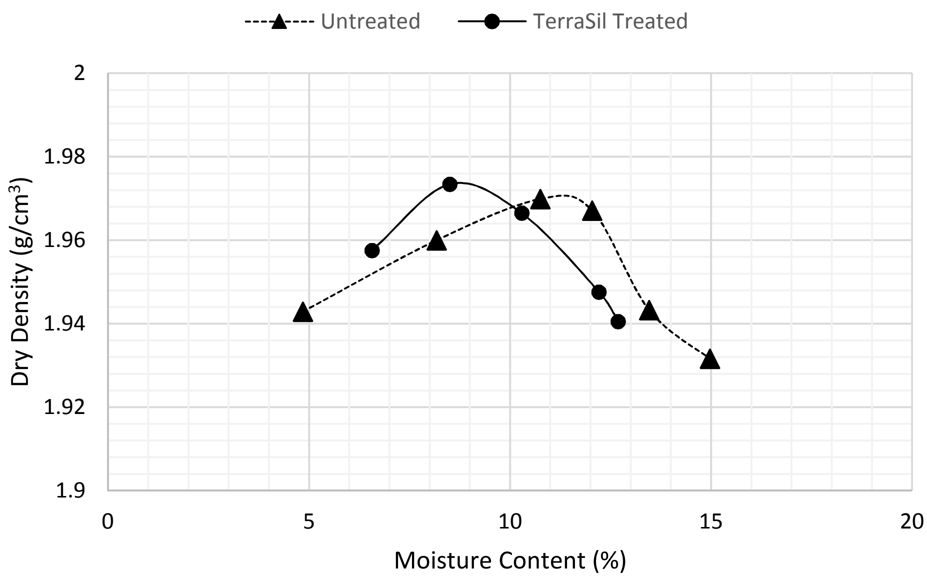

Figure 1. Compaction of Soil (NH-H) Treated vs. Untreated

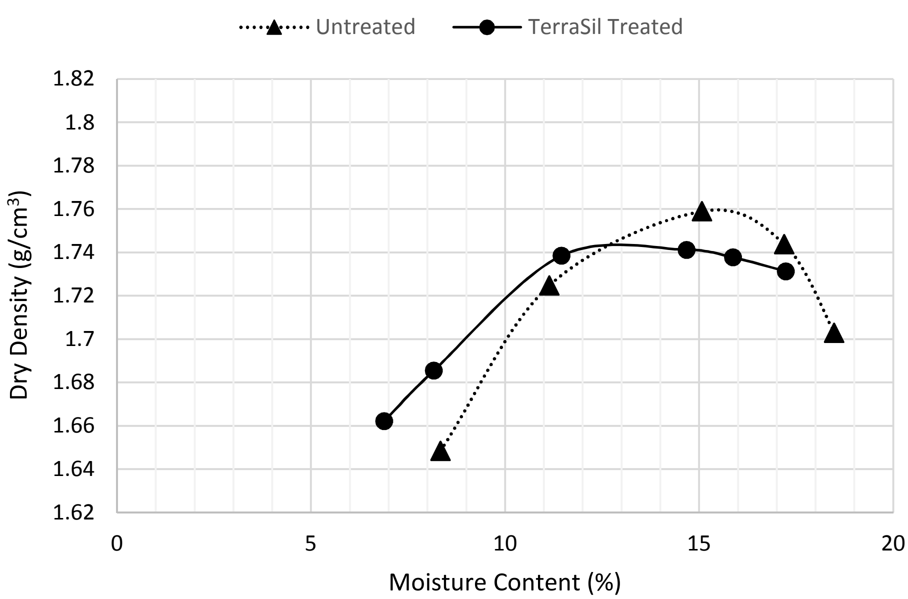

Figure 2. Compaction of Soil (NC-AC) Treated vs. Untreated

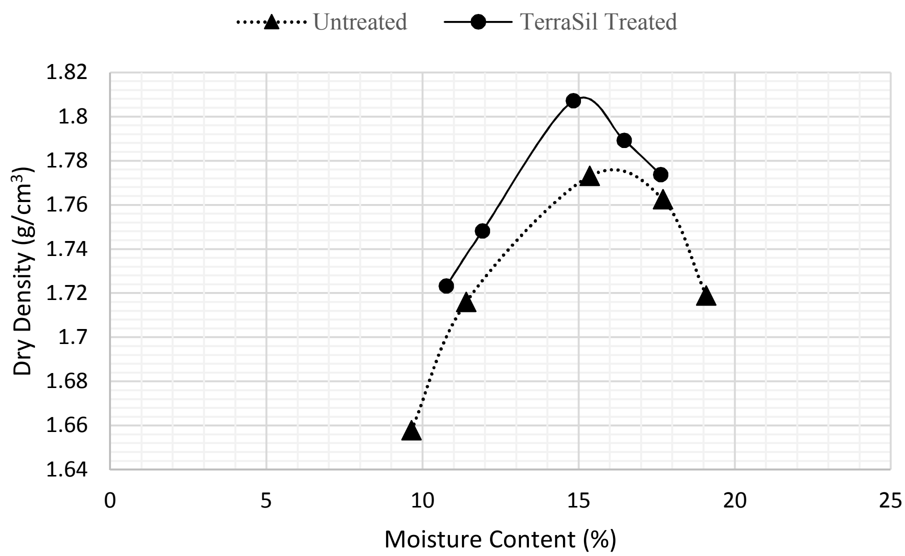

Figure 3. Compaction of Soil (IA-KC) Treated vs. Untreated

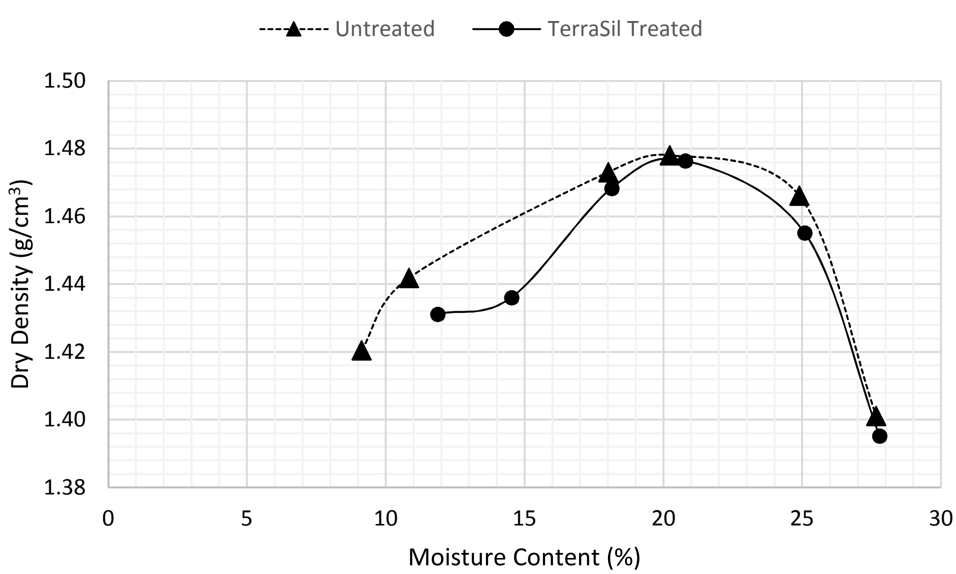

Figure 4. Compaction of Soil (AK-F) Treated vs. Untreated

The effect of TerraSil on the compaction properties of the AK-F soil was modest. Optimum moisture content remained relatively the same after treatment. Maximum dry density values for both samples fell within a range of 0.003 g/cm^3.

Table 4. Compaction Properties of Treated and Untreated Soils

	Treated with TerraSil		Untreated	
Soils	Opt. MC (%)	Max. Dry Density (g/cm^3)	Opt. MC (%)	Max. Dry Density (g/cm^3)
NH-H	8.80	1.975	11.30	1.970
NC-AC	12.80	1.744	15.50	1.760
IA-KC	15.20	1.808	16.22	1.776
AK-F	20.20	1.475	20.40	1.478

4.2.1 Compaction of Soils with Salt Content

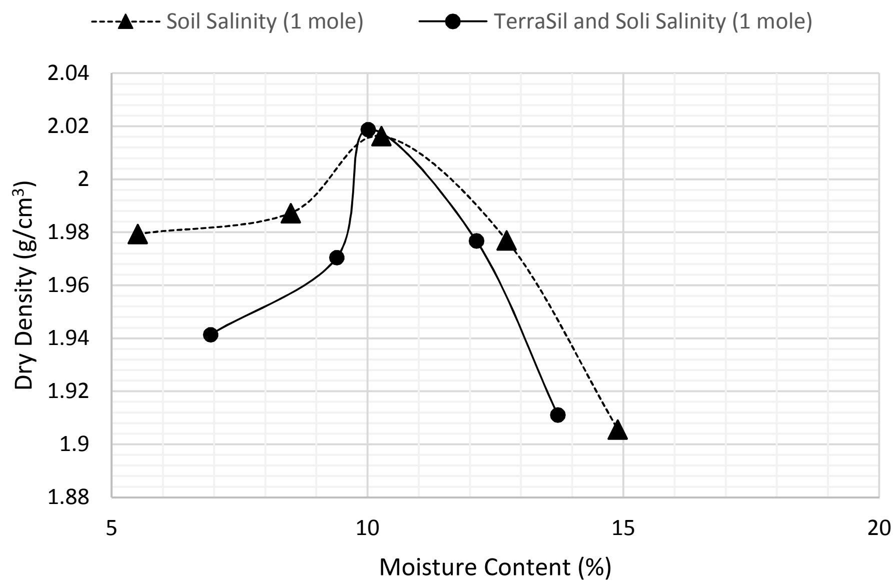

Figure 5. Compaction of Soil (NH-H) with Salt Treated vs Untreated

The addition of TerraSil to a sample with soil salinity had minimal effects on the compaction properties of the NH-H soil. For the treated sample, the decrease in optimum moisture content was 2.1% and the increase maximum dry density was 0.04 g/cm^3.

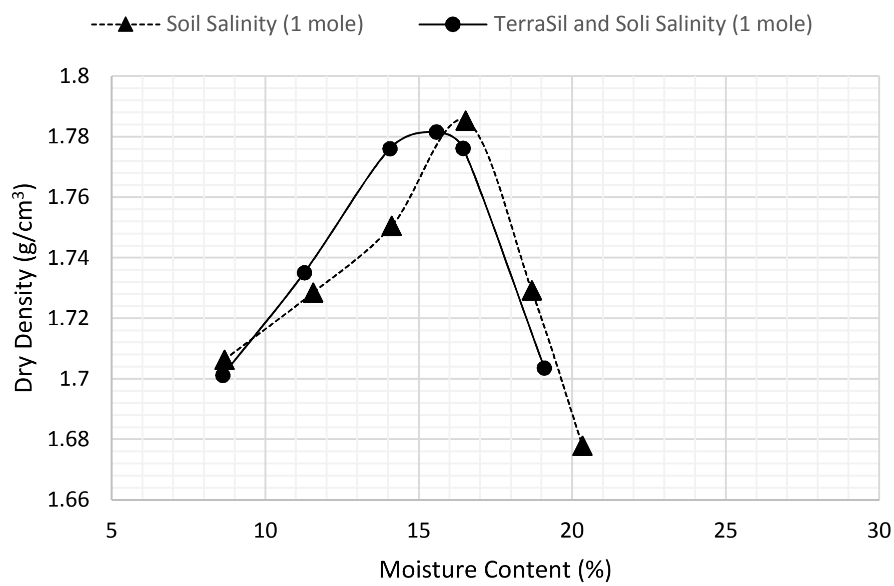

Figure 6. Compaction of Soil (NC-AC) with Salt Treated vs Untreated

The addition of TerraSil to a sample with soil salinity had minimal effects on the compaction properties of the NC-AC soil. For the treated sample, the decrease in optimum moisture content was 0.94% and the decrease in maximum dry density was less than 0.01 g/cm^3.

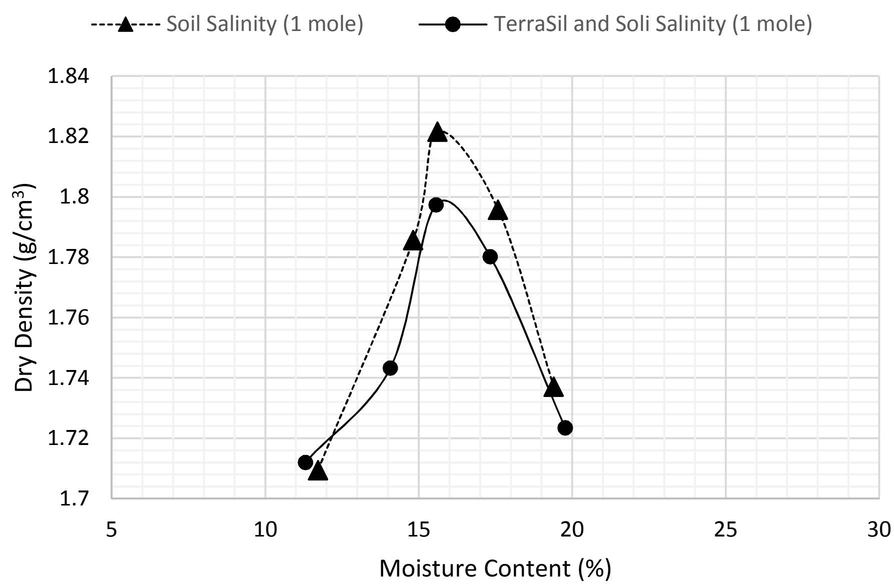

Figure 7. Compaction of Soil (IA-KC) with Salt Treated vs Untreated

The addition of TerraSil to a sample with soil salinity had minimal effects on the compaction properties of the IA-KC soil. For the treated sample, the change in optimum moisture content remained the same and the change in maximum dry density was less than 0.02 g/cm^3.

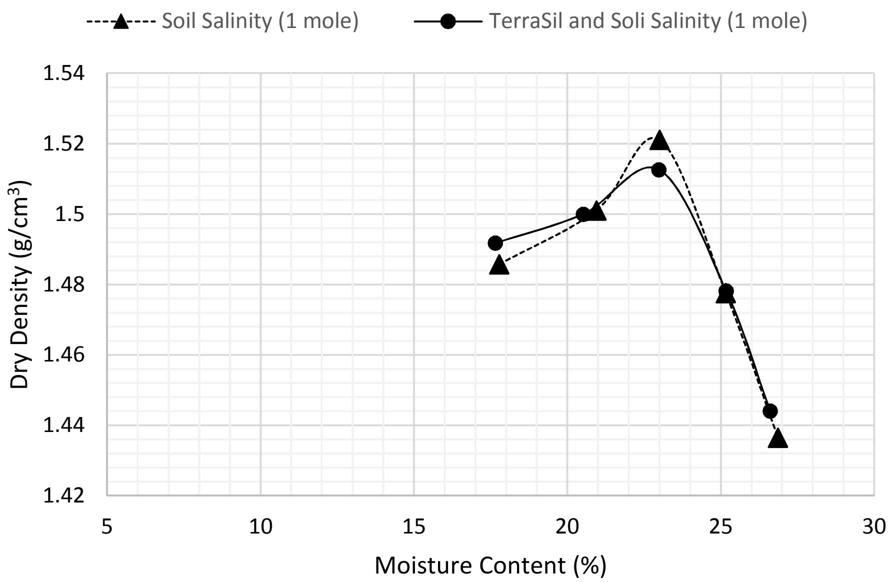

Figure 8. Compaction of Soil (AK-F) with Salt Treated vs Untreated

The addition of TerraSil to a sample with soil salinity had minimal effects on the compaction properties of the AK-F soil. For the treated sample, the decrease in optimum moisture content was 0.01% and the decrease in maximum dry density was less than 0.01 g/cm^3.

Table 5. Compaction Properties of Treated and Untreated Soils with added Salinity

	Treated with TerraSil		Untreated	
Soils	Opt. MC (%)	Max. Dry Density (g/cm^3)	Opt. MC (%)	Max. Dry Density (g/cm^3)
NH-H	10.01	2.010	10.26	2.020
NC-AC	15.5	1.780	16.4	1.786
IA-KC	15.8	1.790	15.8	1.822
AK-F	22.8	1.520	22.9	1.522

4.3 Direct Shear

Unsaturated shear stress values were compared at similar normal loads and saturated friction angles were estimated from suction values. The following figure shows the TerraSil treated sample with added salt as the highest peak shear stress at 60.0 kPa for the (NH-H) soil.

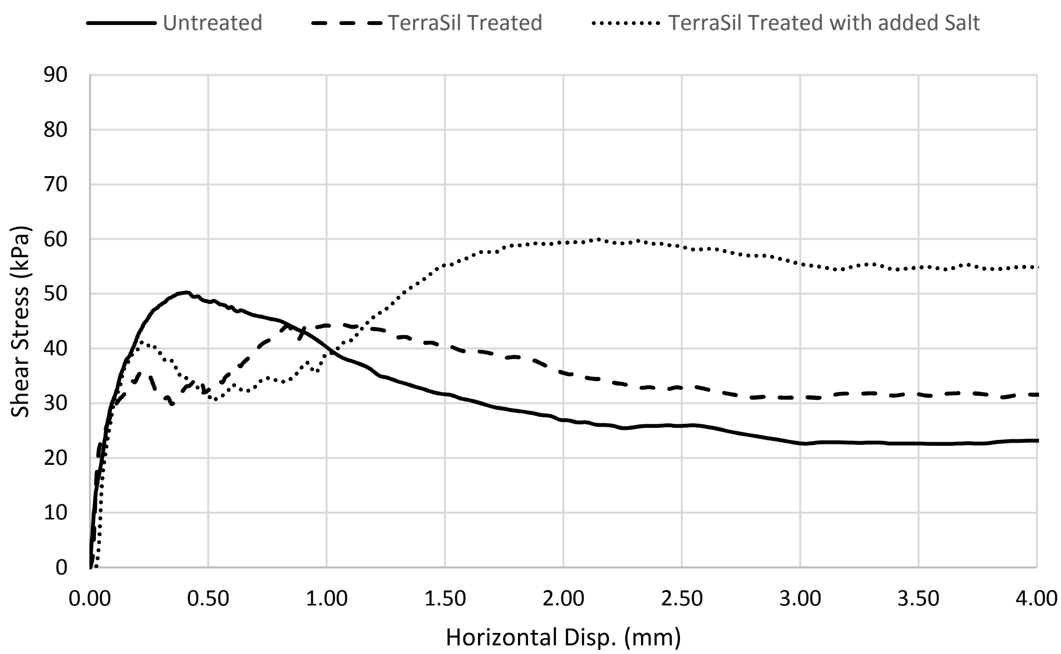

Figure 9. Soil (NH-H) Untreated, Treated, and Treated with Salt at 50 kPa

Table 6. Soil (NH-H) Maximum Shear Stress and Friction Angle

Soil: NH-H	Untreated	TerraSil Treated	TerraSil Treated with added Salinity
Max Shear Stress (kPa)	50.22	44.47	60.00
ϕsat' (˚)	39.63	36.26	47.00

A sample calculation for the untreated and the TerraSil Treated with added Salinity is shown below.

$$\phi' = \tan^{-1}\left[\frac{\tau'_u - c'}{(\sigma_N - u_a) + x_1(u_a - u_w)}\right]$$

$$\mathrm{x}_1 = \left(\frac{\mathrm{u_a} - \mathrm{u_w}}{\mathrm{AEV}}\right)^{-0.55} = \left(\frac{10.75}{10.57}\right)^{-0.55} = 0.9908$$

$$\phi' = \tan^{-1}\left[\frac{50.2\,kPa - 0\,kPa}{(50\,kPa - 0) + 0.9908(10.75\,kPa)}\right]$$

$$\phi sat' = 39.63^{\circ}\ for\ untreated\ sample$$

$$\phi' = \tan^{-1}\left[\frac{\tau'_u - c'}{(\sigma_N - u_a) + x_1(u_a - u_w) + x_2\pi}\right]$$

$$\phi' = \tan^{-1}\left[\frac{60.0\,kPa - 0kPa}{(50kPa - 0) + 0.9908(10.75\,kPa) + 0.001(-4700\,kPa)}\right]$$

$$\phi sat' = 47.00^{\circ}\ for\ treated\ sample\ with\ added\ salinity$$

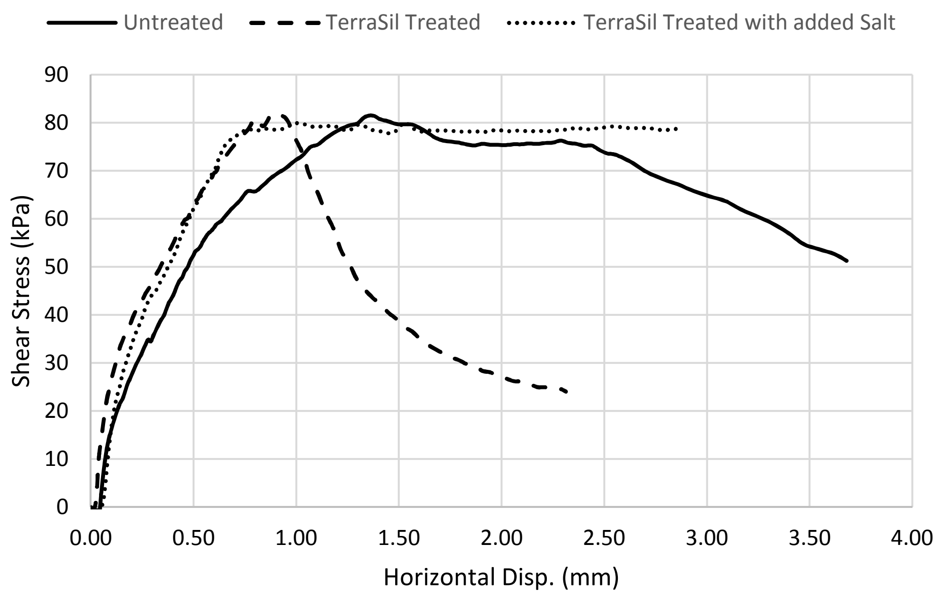

Figure 10. Soil (AK-F) Untreated, Treated, and Treated with Salt at 50 kPa

Table 7. Soil (AK-F) Maximum Shear Stress and Friction Angle

Soil: AK-F	Untreated	TerraSil Treated	TerraSil Treated with added Salinity
Max Shear Stress (kPa)	81.47	81.65	80.04
ϕsat' (˚)	43.98	44.04	45.11

4.4 Pocket Penetrometer

The figures below display the penetrometer test results, indicating a reduction in compressive strength for two of the treated samples. The IA-KC soil did not see a decrease in compressive strength for the treated sample. The AK-F soil had around half of the treated samples having a lower compressive strength and the other half being higher.

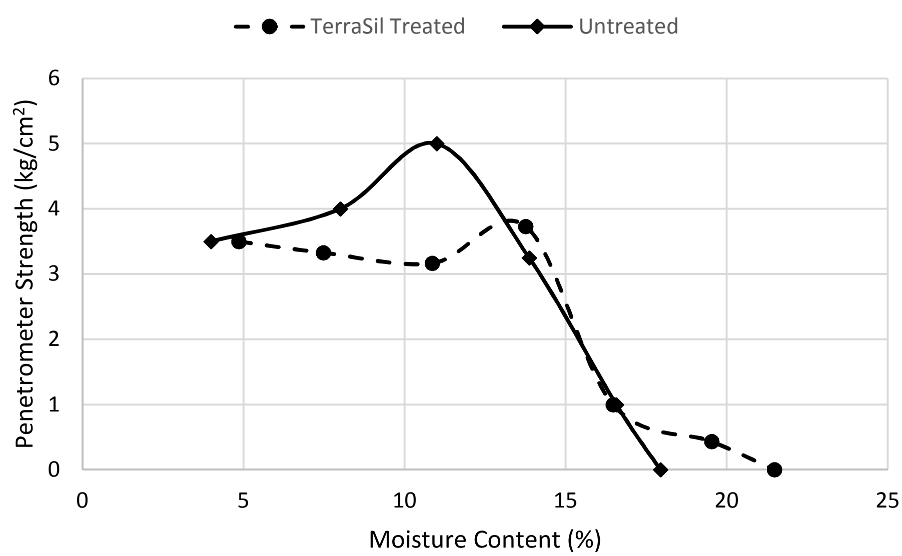

Figure 11. Penetrometer Results (NH-H) Treated vs Untreated

For the NH-H soil, the maximum strength value reached for the untreated test was 5.0 kg/cm^2, while the treated test was 3.73 kg/cm^2. The largest difference in strength occurred around a moisture content of 11%, this difference in value was 1.83 kg/cm^2.

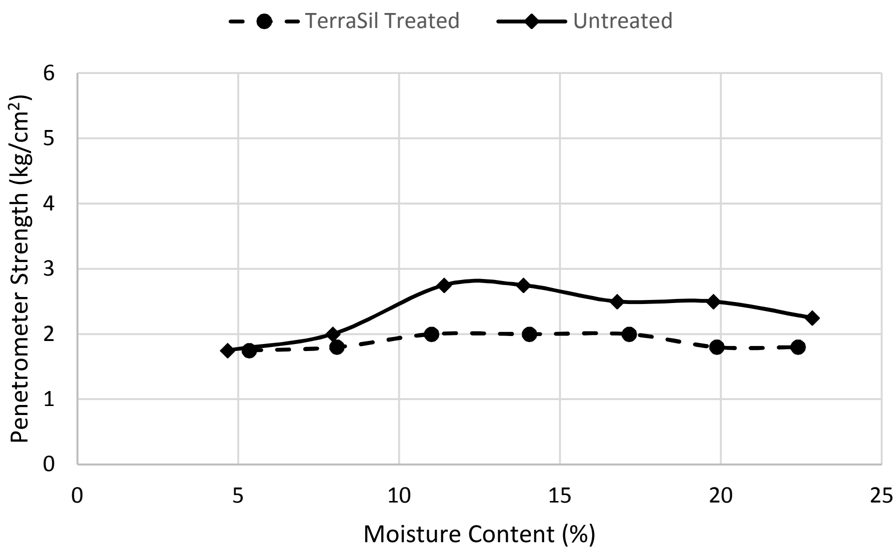

Figure 12. Penetrometer Results (NC-AC) Treated vs Untreated

For the NC-AC soil, the maximum strength value reached for the untreated test was 2.75 kg/cm^2, while the treated test was 3.73 kg/cm^2. The largest difference in strength occurred between a moisture content of 11% and 14%, this difference in value was 0.75 kg/cm^2.

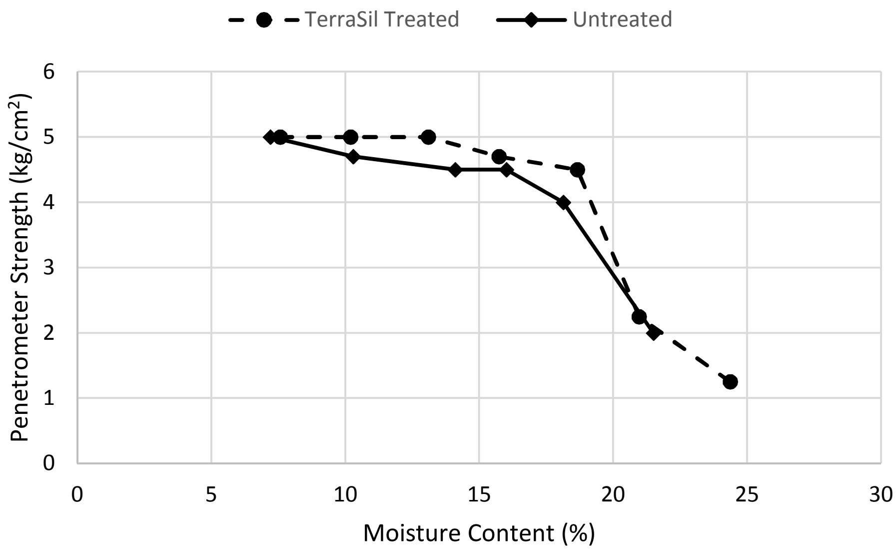

Figure 13. Penetrometer Results (IA-KC) Treated vs Untreated

For the IA-KC soil, the maximum strength value reached for the untreated and treated samples was 5 kg/cm^2. The largest difference in strength occurred around a moisture content of 14%, this difference in value was 0.5 kg/cm^2.

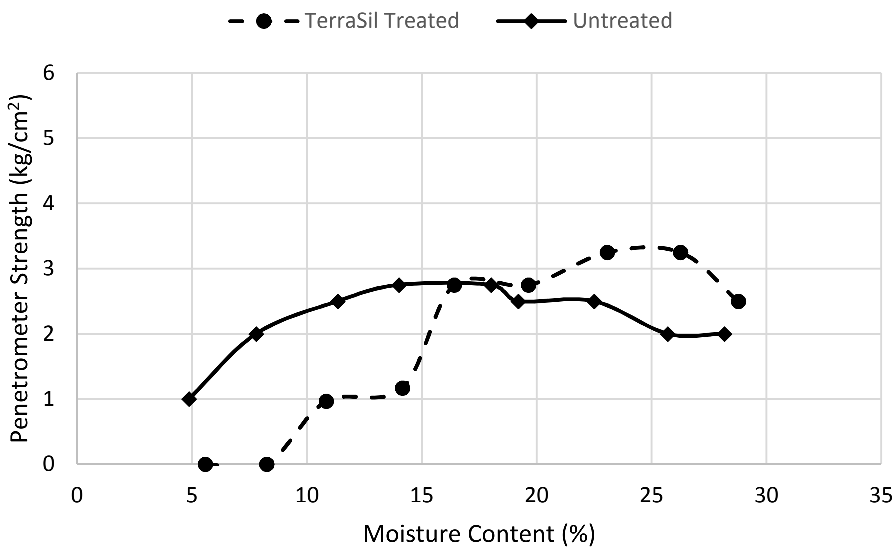

Figure 14. Penetrometer Results (AK-F) Treated vs Untreated

For the AK-F soil, the maximum strength value reached for the untreated soil was 2.75 kg/cm^2 and 3.25 kg/cm^2 for the treated sample. The largest difference in strength occurred around a moisture content of 14%, this difference in value was 1.583 kg/cm^2.

The pocket penetrometer results are limited to a reliability of ± 20% according to Davidson (1965). Therefore, the tests completed may be a better indicator of if the penetration resistance increases or decreases with TerraSil, as opposed to using the results for exact strength values. For field applications these results are expected to be useful. When treating the soil with an OS water must first be mixed with the chemical. As a result, when mixing the solution with the in-situ soil, the moisture content will increase. Therefore, it is important to know the extent at which the solution and increased moisture content will affect the workability of the soil. It may be determined that higher concentrations of the chemical are needed so that less water is mixed into the soil. For low volume roads compaction criteria is not always met, and therefore more of a focus is on the extent to which heavy machinery can operate on the subgrade without excessive deformation or rutting. A pocket penetrometer test would work well in these field conditions because of the simplicity of the test.

CHAPTER 6: CONCLUSIONS

6.1 Compaction

An overall decrease in moisture content occurred for samples that were treated with TerraSil. The maximum dry density values stayed relatively similar and no clear trends were determined. For the samples with an added salt content, the differences between the optimum moisture contents and dry densities for the treated and untreated soils, was less in comparison to the samples without added salinity.

6.2 Direct Shear

The direct shear results appear to be primarily dependent on soil type. A higher variation in max shear stress was determined for the (NH-H) soil, which is classified as a silty sand (SM). Additionally, the sample with added salinity had an increase in peak shear stress around 10 kPa. The (AK-F) soil which is classified as a silt (ML) did not see this same improvement with added salinity. Minimal difference was found between the untreated, treated, and treated with added salinity samples. Further testing on a wider range of soil types and under different conditions is recommended.

6.3 Pocket Penetrometer

The pocket penetrometer results appear to be a function of soil type. (IA-KC) and (NC-AC) soils followed similar trends for the treated and untreated samples, and had minimal difference in the compressive strength. The (NH-H) saw the largest overall drop in compressive strength, at a value of 1.83 kg/cm^2.

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APPENDIX A: SAMPLE PREPERATION

Figure 15. TerraSil Mixing Process

APPENDIX B: WATER DROP PENETRATION TIME TEST

Figure 16. WDPT Samples

APPENDIX C: COMPACTION

Table 8. Compaction Data (NH-H) TerraSil Treated

Weight of Empty Mold (g)	420.56	420.57	420.87	420.89	420.91
Weight of Mold + Soil (g)	550.73	554.17	556.2	557.26	557.36
Weight of Soil (g)	130.17	133.6	135.33	136.37	136.45
Moist Density (g/cm^3)	2.086058	2.141026	2.16875	2.185417	2.186699
Dry Density (g/cm^3)	1.957574	1.973404	1.966498	1.947616	1.94053
Dry Density (kg/m^3)	1957.574	1973.404	1966.498	1947.616	1940.53
Dry Unit Weight (kN/m^3)	19.2038	19.3591	19.29135	19.10611	19.0366
Can Id	4*	B	1	43	45
Weight of Can (g)	30.26	31.33	6.54	38.83	6.37
Can + Wet Soil (g)	160.31	164.68	141.65	174.66	142.19
Can + Dry Soil (g)	152.3	154.24	129.05	159.88	126.9
Actual MC (%)	6.563422	8.49402	10.28487	12.20983	12.68564

Table 9. Compaction Data (NH-H) Untreated

Weight of Empty Mold (g)	420.91	421.67	419.961	420.5	419.93	421.58
Weight of Mold + Soil (g)	548.02	553.97	556.1	558.03	557.5	560.143

Weight of Soil (g)	127.11	132.3	136.139	137.53	137.57	138.563
Moist Density (g/cm^3)	2.03702	2.12019	2.18171	2.20401	2.20465	2.22056
Dry Density (g/cm^3)	1.94295	1.96005	1.96994	1.96714	1.94326	1.93168
Dry Density (kg/m^3)	1942.95	1960.05	1969.94	1967.14	1943.26	1931.68
Dry Unit Weight (kN/m^3)	19.0604	19.2281	19.3251	19.2977	19.0633	18.9498
Can Id	CCI	4	351	45	2010	2010
Weight of Can (g)	6.32	50.44	36.55	6.36	38.99	38.99
Can + Wet Soil (g)	133.22	182.17	174.39	143.7	175.71	175.89
Can + Dry Soil (g)	127.36	172.22	161.01	128.94	159.5	158.08
Actual MC (%)	4.84137	8.17047	10.7504	12.0411	13.4512	14.9551

Table 10. Compaction Data (NH-H) TerraSil Treated with Salt

Weight of Empty Mold (g)	420.04	420.04	420.04	421.03	419.89
Weight of Mold + Soil (g)	548.72	553.66	557.71	558.42	554.6
Weight of Soil (g)	128.68	133.62	137.67	137.39	134.71
Moist Density (g/cm^3)	2.076	2.156	2.221	2.216	2.173
Dry Density (g/cm^3)	1.941	1.970	2.019	1.977	1.911
Dry Density (kg/m^3)	1941.421	1970.460	2018.857	1976.752	1911.108
Dry Unit Weight (kN/m^3)	19.045	19.330	19.805	19.392	18.748
Can Id	20	c	R4L4	19	B
Weight of Can	41.47	39.56	32.89	32.33	31.85
Can + Wet Soil (g)	170.15	173.18	169.46	169.72	166.32
Can + Dry Soil (g)	161.81	161.7	157.03	154.86	150.1

Actual MC (%)	6.930	9.399	10.013	12.128	13.717

Table 11. Compaction Data (NH-H) Untreated with Salt

Weight of Empty Mold (g)	420.04	420.04	420.04	420.04	420.04
Weight of Mold + Soil (g)	549.49	553.69	557.86	558.17	555.75
Weight of Soil (g)	129.45	133.65	137.82	138.13	135.71
Moist Density (g/cm^3)	2.088	2.156	2.223	2.228	2.189
Dry Density (g/cm^3)	1.979	1.987	2.016	1.977	1.906
Dry Density (kg/m^3)	1979.442	1987.318	2016.349	1977.029	1905.640
Dry Unit Weight (kN/m^3)	19.418	19.496	19.780	19.395	18.694
Can Id	*4A	*2A	*3A	2A2	*4A
Weight of Can (g)	1.72	1.7	1.72	16.16	1.72
Can + Wet Soil (g)	66.51	77.56	80.21	76.88	62.6
Can + Dry Soil (g)	63.13	71.62	72.9	70.03	54.71
Actual MC (%)	5.504	8.495	10.270	12.716	14.890

Table 12. Compaction Data (NC-AC) TerraSil Treated

Weight of Empty Mold (g)	420.51	420.88	421.67	420.51	421.66
Weight of Mold + Soil (g)	531.37	534.64	542.58	545.111	548.31
Weight of Soil (g)	110.86	113.76	120.91	124.601	126.65
Moist Density (g/cm^3)	1.7766	1.82308	1.93766	1.99681	2.029647
Dry Density (g/cm^3)	1.66216	1.68547	1.73851	1.74122	1.731299
Dry Density (kg/m^3)	1662.16	1685.47	1738.51	1741.22	1731.299
Dry Unit Weight (kN/m^3)	16.3058	16.5345	17.0548	17.0814	16.98404
Can Id	PC1	4	4	kk1	B

Weight of Can (g)	6.26	50.39	50.38	6.45	31.32
Can + Wet Soil (g)	116.95	163.93	169.18	130.67	156.29
Can + Dry Soil (g)	109.82	155.36	156.97	114.77	137.92
Actual MC (%)	6.8849	8.16424	11.4551	14.6787	17.23265

Table 13. Compaction Data (NC-AC) Untreated

Weight of Empty Mold (g)	419.96	420.91	420.41	420.92	420.52
Weight of Mold + Soil (g)	531.4	540.53	546.72	548.44	546.42
Weight of Soil (g)	111.44	119.62	126.31	127.52	125.9
Moist Density (g/cm^3)	1.7859	1.91699	2.0242	2.04359	2.01763
Dry Density (g/cm^3)	1.64852	1.72486	1.75904	1.74377	1.70296
Dry Density (kg/m^3)	1648.52	1724.86	1759.04	1743.77	1702.96
Dry Unit Weight (kN/m^3)	16.172	16.9208	17.2562	17.1064	16.706
Can Id	2010	4*	4*	45	B
Weight of Can (g)	38.98	30.25	30.25	6.38	31.33
Can + Wet Soil (g)	144.54	149.68	155.6	133.5	156.94
Can + Dry Soil (g)	136.42	137.71	139.18	114.85	137.35
Actual MC (%)	8.33333	11.139	15.0739	17.1937	18.4776

Table 14. Compaction Data (NC-AC) TerraSil Treated with Salt

Weight of Empty Mold (g)	420.04	420.04	420.04	419.87	420.04	419.89
Weight of Mold + Soil (g)	534.58	539.72	545.61	547.5	548.24	545.65
Weight of Soil (g)	114.54	119.68	125.57	127.63	128.2	125.76
Moist Density (g/cm^3)	1.848	1.931	2.026	2.059	2.068	2.029

Dry Density (g/cm^3)	1.701	1.735	1.776	1.782	1.776	1.704
Dry Density (kg/m^3)	1701.201	1735.125	1776.071	1781.552	1776.100	1703.581
Dry Unit Weight (kN/m^3)	16.689	17.022	17.423	17.477	17.424	16.712
Can Id	50	70	92	c	33	4
Weight of Can (g)	31.18	30.43	27.69	39.24	39.91	32.29
Can + Wet Soil (g)	145.97	147.57	153.59	163.46	168.34	157.41
Can + Dry Soil (g)	136.86	135.7	138.07	146.72	150.2	137.35
Actual MC (%)	8.620	11.276	14.061	15.575	16.448	19.094

Table 15. Compaction Data (NC-AC) Untreated with Salt

Weight of Empty Mold (g)	420.04	420.04	420.04	420.04	419.89	419.9
Weight of Mold + Soil (g)	534.98	539.57	543.87	548.99	547.1	545.05
Weight of Soil (g)	114.94	119.53	123.83	128.95	127.21	125.15
Moist Density (g/cm^3)	1.854	1.928	1.998	2.080	2.052	2.019
Dry Density (g/cm^3)	1.706	1.729	1.751	1.785	1.729	1.678
Dry Density (kg/m^3)	1706.394	1728.532	1750.560	1785.392	1729.243	1677.925
Dry Unit Weight (kN/m^3)	16.740	16.957	17.173	17.515	16.964	16.460
Can Id	*2B	4B	*2A	*3A	50	19
Weight of Can	1.72	1.72	1.71	1.73	31.15	32.32
Can + Wet Soil (g)	63.15	63	55.54	70.22	158.03	156.92
Can + Dry Soil (g)	58.25	56.65	48.88	60.51	138.06	135.87
Actual MC (%)	8.668	11.560	14.119	16.519	18.679	20.328

Table 16. Compaction Data (IA-KC) TerraSil Treated

Weight of Empty Mold (g)	420.49	420.87	420.52	420.863	420.52

Weight of Mold + Soil (g)	539.59	542.96	550.01	550.89	550.71
Weight of Soil (g)	119.1	122.09	129.49	130.027	130.19
Moist Density (g/cm^3)	1.90865	1.95657	2.07516	2.08377	2.08638
Dry Density (g/cm^3)	1.72324	1.74817	1.80715	1.78915	1.77368
Dry Density (kg/m^3)	1723.24	1748.17	1807.15	1789.15	1773.68
Dry Unit Weight (kN/m^3)	16.905	17.1496	17.7282	17.5516	17.3998
Can Id	4	20	B	50	45
Weight of Can (g)	50.37	40.81	31.34	35.83	6.36
Can + Wet Soil (g)	164.951	151.69	126.5	162.08	136.2
Can + Dry Soil (g)	153.82	139.88	114.21	144.23	116.74
Actual MC (%)	10.7598	11.9209	14.8305	16.4668	17.63

Table 17. Compaction Data (IA-KC) Untreated

Weight of Empty Mold (g)	421.66	421.67	421.59	419.95	421.4
Weight of Mold + Soil (g)	535.08	540.95	549.22	549.39	549.13
Weight of Soil (g)	113.42	119.28	127.63	129.44	127.73
Moist Density (g/cm^3)	1.817628	1.911538	2.045353	2.074359	2.046955
Dry Density (g/cm^3)	1.657865	1.716015	1.77308	1.762476	1.71893
Dry Density (kg/m^3)	1657.865	1716.015	1773.08	1762.476	1718.93
Dry Unit Weight (kN/m^3)	16.26366	16.8341	17.39391	17.28989	16.8627
Can Id	BHI	B	4	35	4*
Weight of Can (g)	54.39	31.31	50.42	36.57	30.33
Can + Wet Soil (g)	167.25	150.29	177.3	164.67	156.57
Can + Dry Soil (g)	157.33	138.12	160.41	145.41	136.34

Actual MC (%)	9.636682	11.39406	15.35594	17.6957	19.08311

Table 18. Compaction Data (IA-KC) TerraSil Treated with Salt

Weight of Empty Mold (g)	421.01	421.01	419.87	421.01	419.88
Weight of Mold + Soil (g)	539.14	544.28	548.63	550.48	547.83
Weight of Soil (g)	118.13	123.27	128.76	129.47	127.95
Moist Density (g/cm^3)	1.906	1.989	2.077	2.089	2.064
Dry Density (g/cm^3)	1.712	1.743	1.797	1.780	1.723
Dry Density (kg/m^3)	1712.107	1743.310	1797.448	1780.254	1723.481
Dry Unit Weight (kN/m^3)	16.796	17.102	17.633	17.464	16.907
Can Id	*2B	98	43	MS5	20
Weight of Can	1.73	27.89	36.83	36.33	41.4
Can + Wet Soil (g)	32.63	151.16	165.41	165.8	167.78
Can + Dry Soil (g)	29.49	135.95	148.09	146.68	146.92
Actual MC (%)	11.311	14.076	15.567	17.327	19.769

Table 19. Compaction Data (IA-KC) Untreated with Salt

Weight of Empty Mold (g)	421.04	421.04	419.86	421.04	419.91
Weight of Mold + Soil (g)	539.42	548.13	550.4	551.93	548.47
Weight of Soil (g)	118.38	127.09	130.54	130.89	128.56
Moist Density (g/cm^3)	1.910	2.050	2.106	2.112	2.074
Dry Density (g/cm^3)	1.710	1.786	1.822	1.796	1.737
Dry Density (kg/m^3)	1709.553	1785.725	1821.741	1795.875	1737.159
Dry Unit Weight (kN/m^3)	16.771	17.518	17.871	17.618	17.042
Can Id	*3B	#PC	*4A	98	R4L4
Weight of Can	1.72	1.73	1.72	27.89	32.86
Can + Wet Soil (g)	81.26	38.77	68.7	158.3	160.55
Can + Dry Soil (g)	72.92	33.99	59.66	138.8	139.81
Actual MC (%)	11.713	14.817	15.602	17.582	19.392

Table 20. Compaction Data (AK-F) TerraSil Treated

Weight of Empty Mold (g)	420.89	420.89	420.82	420.89	419.87	419.87
Weight of Mold + Soil (g)	520.79	523.52	529.06	532.17	533.45	531.12
Weight of Soil (g)	99.9	102.63	108.24	111.28	113.58	111.25
Moist Density (g/cm^3)	1.601	1.645	1.735	1.783	1.820	1.783
Dry Density (g/cm^3)	1.431	1.436	1.468	1.476	1.455	1.395
Dry Density (kg/m^3)	1431.180	1436.091	1468.332	1476.443	1455.167	1395.220
Dry Unit Weight (kN/m^3)	14.040	14.088	14.404	14.484	14.275	13.687
Can Id	4	4*	51	51	MS5	921
Weight of Can (g)	50.4	30.26	36.8	36.81	36.22	31.32
Can + Wet Soil (g)	150.07	132.67	144.87	146.87	150.61	142.44
Can + Dry Soil (g)	139.5	119.68	128.28	127.93	127.67	118.28
Actual MC (%)	11.863	14.527	18.135	20.786	25.085	27.783

Table 21. Compaction Data (AK-F) Untreated

Weight of Empty Mold (g)	420.900	420.910	420.060	420.820	420.820	419.870
Weight of Mold + Soil (g)	517.630	520.630	528.540	531.710	535.080	531.490
Weight of Soil (g)	96.730	99.720	108.480	110.890	114.260	111.620
Moist Density (g/cm^3)	1.550	1.598	1.738	1.777	1.831	1.789
Dry Density (g/cm^3)	1.421	1.442	1.473	1.478	1.466	1.401
Dry Density (kg/m^3)	1420.579	1441.900	1473.137	1478.093	1466.189	1401.216
Dry Unit Weight (kN/m^3)	13.936	14.145	14.451	14.500	14.383	13.746
Can Id	4	15	4	51	4*	10

Weight of Can (g)	50.4	12.67	50.38	36.8	30.26	1.74
Can + Wet Soil (g)	146.94	112.13	158.95	147.47	144.22	92.11
Can + Dry Soil (g)	138.87	102.41	142.38	128.85	121.51	72.53
Actual MC (%)	9.122	10.831	18.011	20.228	24.888	27.659

Table 22. Compaction Data (AK-F) TerraSil Treated with Salt

Weight of Empty Mold (g)	419.89	419.89	419.89	419.89	419.89
Weight of Mold + Soil (g)	528.68	531.95	535.2	534.58	533.22
Weight of Soil (g)	108.79	112.06	115.31	114.69	113.33
Moist Density (g/cm3)	1.755	1.808	1.860	1.850	1.828
Dry Density (g/cm^3)	1.492	1.500	1.513	1.478	1.444
Dry Density (kg/m^3)	1491.735	1500.005	1512.602	1478.117	1444.048
Dry Unit Weight (kN/m^3)	14.634	14.715	14.839	14.500	14.166
Can Id	19	1D4	c	50	20
Weight of Can	32.33	1.74	39.24	31.16	41.41
Can + Wet Soil (g)	140.96	46.96	154.44	145.71	154.55
Can + Dry Soil (g)	124.66	39.26	132.91	122.67	130.77
Actual MC (%)	17.654	20.522	22.985	25.178	26.611

Table 23. Compaction Data (AK-F) Untreated with Salt

Weight of Empty Mold (g)	421.01	421.01	421.01	421.01	419.89
Weight of Mold + Soil (g)	529.47	533.54	536.98	535.64	532.85
Weight of Soil (g)	108.46	112.53	115.97	114.63	112.96
Moist Density (g/cm^3)	1.750	1.815	1.871	1.849	1.822
Dry Density (g/cm^3)	1.486	1.501	1.521	1.478	1.437
Dry Density (kg/m^3)	1485.741	1501.068	1521.123	1477.595	1436.529
Dry Unit Weight (kN/m^3)	14.575	14.725	14.922	14.495	14.092

Can Id	JJ	* 1A	QQ	2D	70
Weight of Can	1.75	1.73	1.72	1.74	30.44
Can + Wet Soil (g)	62.39	51.28	63.71	57.81	143.23
Can + Dry Soil (g)	53.24	42.7	52.12	46.54	119.35
Actual MC (%)	17.770	20.942	22.996	25.156	26.859

APPENDIX D: DIRECT SHEAR

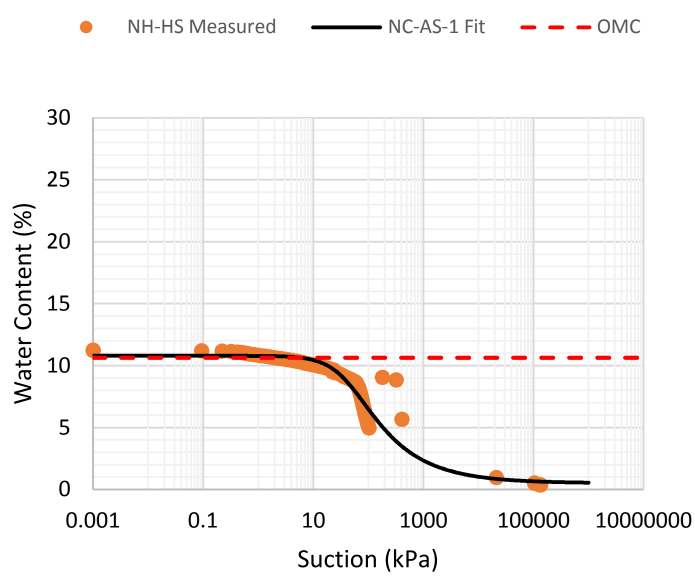

Figure 17. SWCC of Soil (NH-H) (Source: Uduebor, n.d.)

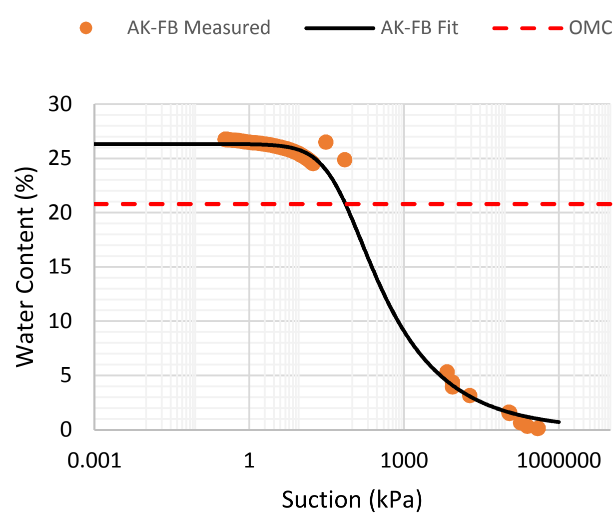

Figure 18. SWCC of Soil (AK-F) (Source: Uduebor, n.d.)

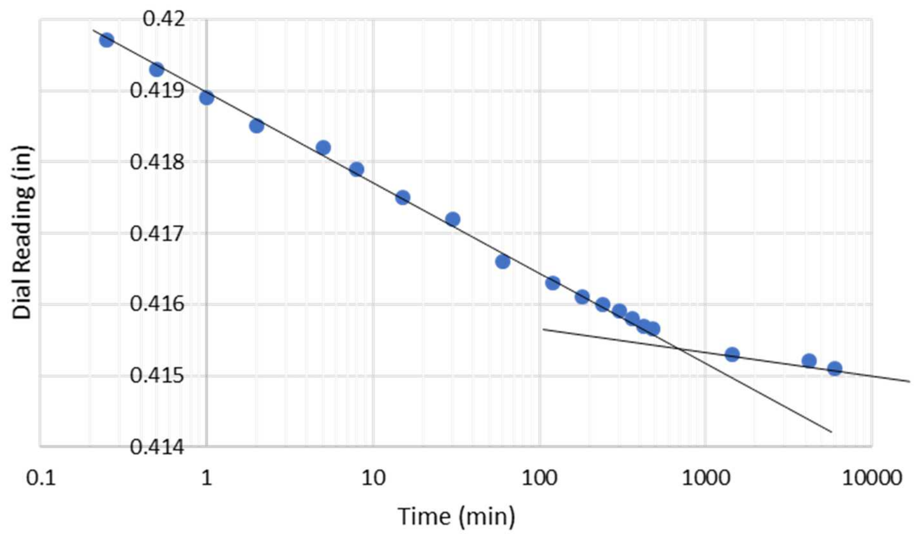

Figure 19. Consolidation Graph of (NH-H)

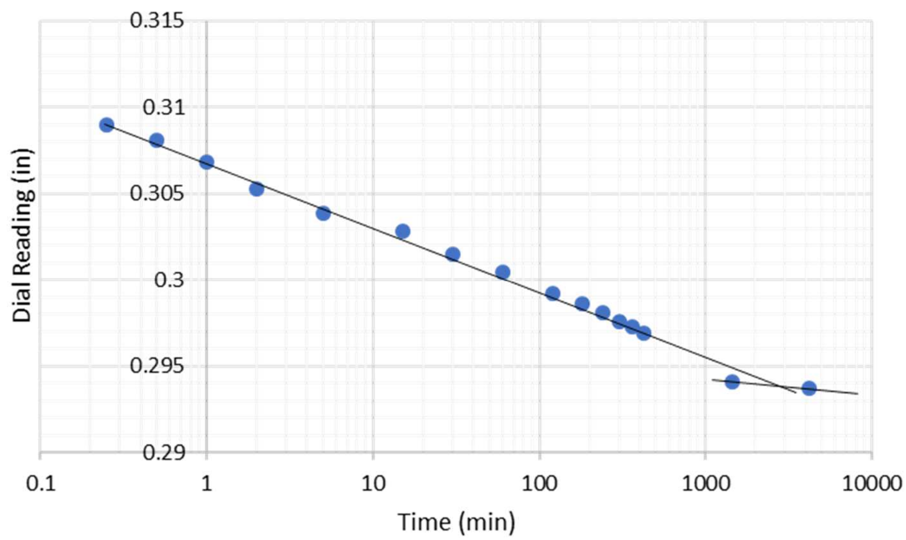

Figure 20. Consolidation Graph of (AK-F)

Table 24. Displacement Rates

Soil	Rate (mm/min)
(NH-H)	0.0167
(AK-F)	0.009

Table 25. Untreated (NH-H) at 50 kPa

Elapsed Time (min.)	Vertical Load (N)	Vertical Disp. (mm)	Horizontal Disp. (mm)	Horizontal Load (N)	Nominal Shear Stress (kPa)	Normal Stress (kPa)
0.00	156.95	0.00	0.00	0.00	0.00	24.96
0.65	160.37	0.00	0.01	24.07	7.65	25.50
1.28	160.03	0.00	0.03	43.58	13.86	25.45
1.92	155.84	0.00	0.04	53.14	16.90	24.78
2.55	156.99	0.00	0.05	62.48	19.87	24.97
3.20	157.32	0.00	0.06	74.30	23.63	25.02
3.83	155.31	0.00	0.08	84.79	26.97	24.70
4.47	158.02	0.00	0.09	92.82	29.52	25.13
5.10	156.95	0.00	0.10	97.50	31.01	24.96
5.75	152.12	0.00	0.11	102.44	32.58	24.19
6.38	156.99	0.00	0.13	109.70	34.89	24.97
7.02	158.02	0.00	0.14	114.12	36.30	25.13
7.65	159.46	0.00	0.15	119.18	37.91	25.36
8.28	157.03	0.00	0.17	121.20	38.55	24.97
8.93	160.37	0.00	0.18	125.11	39.79	25.50
9.57	157.16	0.00	0.19	128.97	41.02	24.99
10.20	157.33	0.00	0.20	133.76	42.54	25.02
10.83	157.45	0.00	0.22	136.74	43.49	25.04

11.47	158.52	0.00	0.23	140.19	44.59	25.21
12.12	157.94	0.00	0.24	142.34	45.27	25.12
12.75	155.97	0.00	0.25	145.21	46.18	24.80
13.38	156.15	0.00	0.27	147.63	46.96	24.83
14.02	155.76	0.00	0.28	148.72	47.30	24.77
14.65	158.32	0.00	0.29	150.28	47.80	25.18
15.30	156.86	0.00	0.31	151.52	48.19	24.95
15.93	156.40	0.00	0.32	152.67	48.56	24.87
16.57	154.90	0.00	0.33	154.33	49.09	24.63
17.20	157.43	0.00	0.34	155.20	49.36	25.04
17.85	157.64	0.00	0.36	156.06	49.64	25.07
18.48	160.03	0.00	0.37	157.11	49.97	25.45
19.12	156.10	0.00	0.38	157.39	50.06	24.83
19.75	156.18	0.00	0.39	157.70	50.16	24.84
20.38	155.59	0.00	0.41	157.91	50.23	24.74
21.02	156.36	0.00	0.42	157.60	50.13	24.87
21.67	156.99	0.00	0.43	155.72	49.53	24.97
22.30	157.21	0.00	0.45	155.50	49.46	25.00
22.93	159.86	0.00	0.46	155.63	49.50	25.42
23.57	156.39	0.00	0.47	153.99	48.98	24.87
24.20	159.05	0.00	0.48	153.25	48.74	25.29
24.83	155.67	0.00	0.50	152.79	48.60	24.76
25.47	157.24	0.00	0.51	152.39	48.47	25.01
26.12	159.39	0.00	0.52	153.16	48.71	25.35
26.75	159.05	0.00	0.53	152.50	48.50	25.29
27.38	156.96	0.00	0.55	151.22	48.10	24.96
28.02	154.81	0.00	0.56	150.90	48.00	24.62
28.65	155.68	0.00	0.57	150.34	47.82	24.76
29.30	155.62	0.00	0.59	148.98	47.38	24.75
29.93	155.37	0.00	0.60	149.62	47.59	24.71

30.57	158.31	0.00	0.61	147.74	46.99	25.18
31.20	158.01	0.00	0.62	147.03	46.77	25.13
31.85	156.36	0.00	0.64	147.70	46.98	24.87
32.48	158.19	0.00	0.65	147.19	46.82	25.16
34.38	156.69	0.01	0.69	145.09	46.15	24.92
36.28	156.32	0.01	0.73	143.98	45.79	24.86
38.20	157.03	0.00	0.76	142.71	45.39	24.97
40.10	160.53	0.01	0.80	141.72	45.08	25.53
42.00	159.73	0.00	0.84	139.16	44.26	25.40
43.92	155.24	0.00	0.88	136.59	43.44	24.69
45.82	156.69	0.00	0.92	134.33	42.72	24.92
47.72	156.36	0.00	0.95	131.10	41.70	24.87
49.63	155.04	0.00	0.99	127.35	40.51	24.66
51.53	160.92	0.00	1.03	123.45	39.26	25.59
53.43	156.40	0.00	1.07	120.29	38.26	24.87
55.35	156.27	0.01	1.11	118.51	37.70	24.85
57.25	158.64	0.00	1.14	116.62	37.09	25.23
59.17	156.56	0.01	1.18	114.16	36.31	24.90
61.07	156.13	0.01	1.22	110.24	35.06	24.83
62.98	158.36	0.01	1.26	108.92	34.64	25.18
64.88	157.68	0.00	1.30	106.95	34.02	25.08
66.80	155.55	0.00	1.34	105.44	33.54	24.74
68.70	158.05	0.01	1.37	103.82	33.02	25.14
70.60	155.38	0.01	1.41	102.33	32.55	24.71
72.52	157.45	0.01	1.45	100.62	32.00	25.04
74.42	155.89	0.01	1.49	99.59	31.68	24.79
76.33	156.60	0.01	1.53	99.00	31.49	24.91
78.23	157.08	0.01	1.56	97.12	30.89	24.98
80.15	154.95	0.01	1.60	96.07	30.56	24.64
82.05	157.64	0.01	1.64	94.76	30.14	25.07

83.95	157.46	0.01	1.68	93.18	29.64	25.04
85.87	158.96	0.01	1.72	91.77	29.19	25.28
87.77	155.45	0.01	1.76	90.95	28.93	24.72
89.68	158.01	0.01	1.79	90.09	28.65	25.13
91.58	158.31	0.01	1.83	89.48	28.46	25.18
93.50	156.26	0.01	1.87	88.63	28.19	24.85
95.40	158.24	0.01	1.91	87.54	27.84	25.16
97.30	157.30	0.01	1.95	87.01	27.68	25.02
99.22	156.60	0.01	1.98	84.86	26.99	24.91
101.12	156.39	0.01	2.02	84.41	26.85	24.87
103.03	152.55	0.01	2.06	83.31	26.50	24.26
104.93	160.45	0.01	2.10	83.34	26.51	25.52
106.83	158.74	0.01	2.14	82.02	26.09	25.24
108.75	158.11	0.01	2.17	81.80	26.02	25.14
110.65	157.13	0.01	2.21	81.28	25.85	24.99
112.55	156.82	0.01	2.25	79.95	25.43	24.94
114.47	157.64	0.01	2.29	80.38	25.57	25.07
116.37	158.41	0.01	2.33	81.04	25.77	25.19
118.28	157.12	0.01	2.37	81.32	25.86	24.99
120.18	158.15	0.01	2.40	81.33	25.87	25.15
122.08	157.43	0.01	2.44	81.64	25.97	25.04
124.00	157.25	0.01	2.48	81.25	25.84	25.01
125.90	158.52	0.02	2.52	81.41	25.89	25.21
127.82	158.11	0.01	2.56	81.64	25.97	25.14
131.63	156.87	0.01	2.63	80.11	25.48	24.95
135.43	155.76	0.01	2.71	77.88	24.77	24.77
139.25	156.96	0.01	2.78	76.03	24.18	24.96
143.07	155.93	0.01	2.86	74.34	23.65	24.80
146.87	157.03	0.02	2.94	72.64	23.10	24.97
150.68	157.03	0.02	3.01	71.08	22.61	24.97

154.50	156.29	0.02	3.09	71.86	22.86	24.86
158.30	156.70	0.02	3.17	71.87	22.86	24.92
162.12	157.93	0.01	3.24	71.59	22.77	25.12
165.93	156.74	0.01	3.32	71.76	22.82	24.93
169.73	157.03	0.02	3.39	71.12	22.62	24.97
173.55	155.97	0.02	3.47	71.14	22.63	24.80
177.37	156.49	0.01	3.55	71.01	22.59	24.89
181.17	156.18	0.02	3.62	70.92	22.56	24.84
184.98	158.23	0.02	3.70	71.31	22.68	25.16
188.80	157.85	0.02	3.78	71.16	22.63	25.10
192.62	158.05	0.02	3.85	72.27	22.99	25.14
196.42	157.76	0.02	3.93	72.70	23.12	25.09
200.23	157.77	0.02	4.00	72.74	23.14	25.09
204.05	158.11	0.02	4.08	72.63	23.10	25.14
207.85	156.26	0.02	4.16	73.59	23.41	24.85
211.67	158.27	0.02	4.23	74.36	23.65	25.17
215.48	156.26	0.02	4.31	74.26	23.62	24.85
219.30	156.40	0.02	4.39	73.11	23.25	24.87
223.10	157.80	0.02	4.46	73.51	23.38	25.10
226.92	156.01	0.02	4.54	72.74	23.14	24.81
230.73	156.60	0.02	4.61	71.80	22.84	24.91
234.53	159.39	0.02	4.69	71.29	22.68	25.35
238.35	157.03	0.02	4.77	70.78	22.51	24.97
242.17	156.53	0.02	4.84	69.77	22.19	24.89
245.98	156.42	0.02	4.92	69.52	22.11	24.88
249.78	156.39	0.02	5.00	68.60	21.82	24.87
253.60	155.51	0.02	5.07	68.16	21.68	24.73
257.42	158.32	0.02	5.15	68.77	21.87	25.18
261.23	156.35	0.02	5.22	68.19	21.69	24.86
265.05	156.87	0.02	5.30	67.81	21.57	24.95

268.85	155.55	0.02	5.38	67.70	21.53	24.74
272.67	157.08	0.02	5.45	68.25	21.71	24.98
276.48	156.93	0.02	5.53	68.39	21.75	24.96
280.28	158.83	0.02	5.61	68.86	21.90	25.26
284.10	157.41	0.02	5.68	67.67	21.52	25.03
287.92	155.89	0.02	5.76	67.04	21.32	24.79
291.72	157.03	0.02	5.83	66.34	21.10	24.97
295.53	156.86	0.03	5.91	66.49	21.15	24.95
299.35	156.82	0.03	5.99	66.48	21.15	24.94
303.17	157.54	0.03	6.06	64.14	20.40	25.05
306.97	156.53	0.03	6.14	63.61	20.23	24.89
310.78	156.48	0.03	6.22	63.86	20.31	24.88
314.60	157.51	0.03	6.29	63.46	20.18	25.05
317.53	157.11	0.03	6.35	63.76	20.28	24.98

Table 26. Treated (NH-H) at 50 kPa

Elapsed Time (min.)	Vertical Load (N)	Vertical Disp. (mm)	Horizontal Disp. (mm)	Horizontal Load (N)	Nominal Shear Stress (kPa)	Normal Stress (kPa)
0.00	152.29	0.00	0.00	0.00	0.00	48.44
0.75	153.27	0.00	0.01	7.20	2.29	48.75
1.52	159.13	0.00	0.02	46.79	14.88	50.61
2.28	170.72	0.00	0.04	67.61	21.50	54.30
3.03	159.29	-0.01	0.05	73.87	23.49	50.66
3.80	156.82	0.00	0.06	78.38	24.93	49.88
4.57	157.49	0.00	0.08	83.67	26.61	50.09
5.33	155.82	0.00	0.09	87.05	27.69	49.56

6.08	157.89	0.00	0.10	91.78	29.19	50.22
6.85	157.29	0.00	0.11	94.72	30.13	50.03
7.62	155.49	0.00	0.13	96.99	30.85	49.46
8.37	157.11	0.00	0.14	98.69	31.39	49.97
9.13	157.96	0.00	0.15	100.91	32.10	50.24
9.90	157.46	0.00	0.16	103.52	32.92	50.08
10.67	161.25	0.00	0.18	106.99	34.03	51.29
11.42	150.12	0.00	0.19	106.58	33.90	47.75
12.18	156.74	-0.01	0.20	110.34	35.09	49.85
12.95	156.68	0.00	0.22	112.19	35.68	49.84
13.72	155.93	-0.01	0.23	112.55	35.80	49.59
14.47	155.87	-0.01	0.24	112.86	35.90	49.58
15.23	158.47	-0.01	0.25	109.59	34.86	50.41
16.00	156.99	0.00	0.27	105.37	33.51	49.93
16.75	157.45	0.00	0.28	100.49	31.96	50.08
17.52	157.11	0.00	0.29	97.93	31.15	49.97
18.28	155.46	-0.01	0.30	97.24	30.93	49.45
19.05	157.16	0.00	0.32	97.16	30.90	49.99
19.80	155.15	-0.01	0.33	97.69	31.07	49.35
20.57	155.80	-0.01	0.34	94.12	29.94	49.55
21.33	154.34	0.00	0.36	95.00	30.22	49.09
22.08	157.66	0.00	0.37	97.67	31.06	50.15
22.85	156.61	-0.01	0.38	99.07	31.51	49.81
23.62	156.68	-0.01	0.39	102.04	32.46	49.84
24.38	156.68	-0.01	0.41	104.05	33.09	49.84
25.13	156.48	-0.01	0.42	104.45	33.22	49.77
25.90	158.31	0.00	0.43	105.86	33.67	50.35
26.67	156.77	-0.01	0.44	106.31	33.81	49.86
27.42	158.82	-0.01	0.46	106.92	34.01	50.51
28.18	157.61	-0.01	0.47	107.50	34.19	50.13

28.95	161.09	-0.01	0.48	101.01	32.13	51.24
29.72	155.19	0.00	0.50	101.59	32.31	49.36
30.47	159.83	0.00	0.51	102.90	32.73	50.84
31.23	155.16	0.00	0.52	104.03	33.09	49.35
32.00	157.67	-0.01	0.53	106.33	33.82	50.15
32.77	155.50	-0.01	0.55	107.14	34.08	49.46
33.52	157.29	0.00	0.56	106.39	33.84	50.03
34.28	157.97	0.00	0.57	109.42	34.80	50.25
35.05	156.61	0.00	0.58	110.90	35.27	49.81
35.80	156.52	0.00	0.60	112.99	35.94	49.78
36.57	156.09	0.00	0.61	114.27	36.34	49.65
37.33	156.95	0.00	0.62	116.83	37.16	49.92
38.08	156.71	0.00	0.64	115.65	36.79	49.85
38.85	158.05	0.00	0.65	117.80	37.47	50.27
41.13	158.31	0.00	0.69	122.60	38.99	50.35
43.42	157.38	0.00	0.72	128.21	40.78	50.06
45.70	156.82	0.00	0.76	131.20	41.73	49.88
47.98	159.47	0.00	0.80	135.29	43.03	50.72
50.27	156.98	0.00	0.84	138.67	44.11	49.93
52.55	98.24	0.00	0.88	130.67	41.56	31.25
54.83	158.82	0.00	0.92	139.82	44.47	50.51
57.12	163.00	0.00	0.95	138.11	43.93	51.84
59.40	158.57	0.00	0.99	139.03	44.22	50.44
61.68	156.64	0.01	1.03	138.75	44.13	49.82
63.97	158.01	0.00	1.07	139.50	44.37	50.26
66.25	156.39	0.00	1.11	138.33	44.00	49.74
68.53	157.75	0.00	1.14	138.71	44.12	50.17
70.82	158.14	0.00	1.18	137.26	43.66	50.30
73.10	160.53	0.00	1.22	136.80	43.51	51.06
75.38	152.97	0.00	1.26	135.34	43.05	48.65

77.67	156.26	0.00	1.30	132.40	42.11	49.70
79.95	158.21	0.00	1.33	132.44	42.12	50.32
82.23	156.43	0.00	1.37	130.11	41.38	49.75
84.52	158.53	0.00	1.41	129.13	41.07	50.42
86.80	156.82	0.00	1.45	129.09	41.06	49.88
89.08	156.27	0.00	1.49	126.85	40.35	49.70
91.37	158.10	0.00	1.53	126.74	40.31	50.29
93.65	157.12	0.00	1.56	124.78	39.69	49.97
95.93	157.24	0.00	1.60	123.90	39.41	50.01
98.22	159.34	0.00	1.64	124.12	39.48	50.68
100.50	157.03	0.00	1.68	123.48	39.28	49.95
102.78	159.47	0.00	1.72	122.09	38.83	50.72
105.08	154.69	0.00	1.75	120.62	38.36	49.20
107.37	157.42	0.00	1.79	121.03	38.49	50.07
109.65	156.84	0.00	1.83	120.39	38.29	49.89
111.93	156.17	0.00	1.87	119.30	37.94	49.67
114.22	156.86	0.00	1.91	117.16	37.27	49.89
116.48	159.34	0.00	1.95	114.52	36.43	50.68
118.77	156.05	0.00	1.98	112.62	35.82	49.64
121.05	158.22	0.00	2.02	111.02	35.31	50.32
123.33	157.72	0.00	2.06	111.35	35.42	50.16
125.62	156.60	0.00	2.10	109.06	34.69	49.81
127.90	157.59	0.00	2.14	108.36	34.46	50.12
130.18	157.38	0.00	2.17	108.20	34.41	50.06
132.47	157.08	0.00	2.21	106.20	33.78	49.96
134.75	157.29	0.01	2.25	105.44	33.54	50.03
137.03	157.25	0.01	2.29	104.18	33.13	50.01
139.32	155.69	0.00	2.33	103.25	32.84	49.52
141.60	156.68	0.00	2.36	103.63	32.96	49.84
143.88	158.60	0.01	2.40	102.70	32.67	50.45

146.17	158.74	0.00	2.44	102.55	32.62	50.49
148.45	156.82	0.00	2.48	103.55	32.94	49.88
150.73	156.22	0.01	2.52	102.85	32.71	49.69
153.02	158.18	0.00	2.56	103.77	33.01	50.31
157.58	155.91	0.00	2.63	101.54	32.30	49.59
162.15	156.39	0.01	2.71	99.65	31.69	49.74
166.72	156.95	0.00	2.78	97.73	31.08	49.92
171.28	157.97	0.01	2.86	98.14	31.21	50.25
175.85	157.67	0.00	2.94	97.59	31.04	50.15
180.40	157.74	0.01	3.01	97.93	31.15	50.17
184.97	156.74	0.00	3.09	97.59	31.04	49.85
189.53	154.82	0.00	3.17	99.76	31.73	49.24
194.10	158.77	0.01	3.24	99.89	31.77	50.50
198.67	156.39	0.00	3.32	100.06	31.83	49.74
203.23	148.28	0.00	3.39	98.80	31.43	47.16
207.78	156.81	0.01	3.47	100.02	31.81	49.88
212.35	157.07	0.00	3.55	98.69	31.39	49.96
216.92	157.83	0.01	3.62	99.93	31.78	50.20
221.48	156.98	0.00	3.70	100.21	31.87	49.93
226.05	157.53	0.01	3.77	99.63	31.69	50.10
230.62	159.13	0.01	3.85	97.82	31.11	50.61
235.18	156.65	0.00	3.93	99.33	31.59	49.83
239.75	156.48	0.01	4.00	99.31	31.59	49.77
244.30	158.57	0.01	4.08	99.71	31.72	50.44
248.87	156.47	0.01	4.16	98.71	31.40	49.77
253.43	157.15	0.01	4.23	99.16	31.54	49.98
258.00	157.16	0.01	4.31	100.27	31.89	49.99
262.57	156.65	0.01	4.38	98.69	31.39	49.83
267.13	157.19	0.01	4.46	98.86	31.44	50.00
271.68	156.71	0.01	4.54	97.68	31.07	49.85

276.25	157.24	0.01	4.61	98.29	31.26	50.01
280.82	156.98	0.01	4.69	99.31	31.59	49.93
285.38	157.16	0.01	4.77	98.11	31.21	49.99
289.95	157.11	0.01	4.84	98.03	31.18	49.97
294.52	156.74	0.01	4.92	97.22	30.92	49.85
299.07	158.90	0.01	4.99	97.58	31.04	50.54
303.63	157.16	0.01	5.07	96.11	30.57	49.99
308.20	157.71	0.01	5.15	96.92	30.83	50.16
312.77	157.25	0.01	5.22	97.65	31.06	50.01
317.33	156.73	0.01	5.30	97.20	30.92	49.85
321.88	156.91	0.01	5.38	96.92	30.83	49.91
326.45	156.85	0.01	5.45	96.41	30.66	49.89
331.02	156.91	0.01	5.53	96.66	30.75	49.91
335.15	156.98	0.01	5.60	95.22	30.29	49.93

Table 27. Treated with Salt (NH-H) at 50 kPa

Elapsed Time (min.)	Vertical Load (N)	Vertical Disp. (mm)	Horizontal Disp. (mm)	Horizontal Load (N)	Nominal Shear Stress (kPa)	Normal Stress (kPa)
0.00	154.57	0.00	0.00	0.00	0.00	49.16
0.77	157.16	0.00	0.01	-0.45	-0.14	49.99
1.52	157.58	0.00	0.02	-0.05	-0.01	50.12
2.28	157.17	0.00	0.04	13.59	4.32	49.99
3.05	157.34	0.00	0.05	48.66	15.48	50.04
3.82	157.58	0.00	0.06	63.85	20.31	50.12
4.57	157.47	0.00	0.08	75.17	23.91	50.09
5.33	156.92	0.00	0.09	85.16	27.08	49.91
6.10	157.26	0.00	0.10	95.49	30.37	50.02
6.87	157.10	0.00	0.11	99.80	31.74	49.97

7.62	157.14	0.00	0.13	104.48	33.23	49.98
8.38	157.87	0.00	0.14	112.44	35.76	50.21
9.15	157.44	0.00	0.15	116.69	37.12	50.08
9.92	157.56	0.00	0.16	118.88	37.81	50.11
10.67	157.76	0.00	0.18	122.33	38.91	50.18
11.43	157.13	0.00	0.19	123.65	39.33	49.98
12.20	157.65	0.00	0.20	125.70	39.98	50.14
12.97	157.29	0.00	0.22	129.10	41.06	50.03
13.72	157.53	0.00	0.23	128.93	41.01	50.10
14.48	157.79	0.00	0.24	127.39	40.52	50.19
15.25	157.38	0.00	0.25	128.24	40.79	50.06
16.02	157.42	0.00	0.27	127.86	40.67	50.07
16.77	156.91	0.00	0.28	125.32	39.86	49.91
17.53	157.48	0.00	0.29	123.87	39.40	50.09
18.30	157.28	0.00	0.30	120.99	38.48	50.03
19.05	157.73	0.00	0.32	119.05	37.87	50.17
19.82	157.78	0.00	0.33	119.29	37.94	50.18
20.58	157.39	0.00	0.34	119.09	37.88	50.06
21.33	157.57	0.00	0.36	115.99	36.89	50.12
22.10	157.32	0.00	0.37	113.56	36.12	50.04
22.87	157.39	0.00	0.38	110.11	35.02	50.06
23.63	157.51	0.00	0.39	109.94	34.97	50.10
24.40	157.10	0.00	0.41	108.83	34.61	49.97
25.15	157.43	0.00	0.42	107.80	34.29	50.07
25.92	157.76	0.00	0.43	106.59	33.90	50.18
26.68	157.78	0.00	0.44	106.32	33.82	50.18
27.43	157.48	0.00	0.46	102.43	32.58	50.09
28.20	157.57	0.00	0.47	100.98	32.12	50.12
28.97	157.70	0.00	0.48	100.19	31.87	50.16
29.73	157.91	0.00	0.50	99.35	31.60	50.23

30.48	157.35	0.00	0.51	97.50	31.01	50.05
31.25	158.06	0.00	0.52	95.92	30.51	50.27
32.02	158.27	0.00	0.53	97.03	30.86	50.34
32.77	157.54	0.00	0.55	97.63	31.05	50.11
33.53	157.76	0.00	0.56	98.75	31.41	50.18
34.30	157.67	0.00	0.57	100.24	31.88	50.15
35.05	157.63	0.00	0.58	101.92	32.42	50.14
35.82	157.88	-0.01	0.60	104.55	33.25	50.22
36.58	157.34	0.00	0.61	104.72	33.31	50.05
37.35	157.55	0.00	0.62	103.49	32.92	50.11
38.10	157.55	0.00	0.64	102.45	32.59	50.11
38.87	157.40	-0.01	0.65	101.32	32.23	50.06
41.15	157.20	0.00	0.69	102.62	32.64	50.00
43.43	157.43	0.00	0.72	107.64	34.24	50.07
45.72	157.04	-0.01	0.76	108.86	34.63	49.95
48.00	157.54	-0.01	0.80	106.78	33.96	50.11
50.28	157.16	-0.01	0.84	107.70	34.26	49.99
52.57	157.68	-0.01	0.88	112.09	35.65	50.15
54.85	157.81	-0.01	0.92	117.77	37.46	50.19
57.13	157.20	-0.01	0.95	112.10	35.65	50.00
59.42	157.67	-0.01	0.99	121.80	38.74	50.15
61.70	157.44	0.00	1.03	123.74	39.36	50.08
63.98	157.28	-0.01	1.07	129.04	41.04	50.03
66.27	157.26	0.00	1.11	130.87	41.62	50.02
68.55	158.04	-0.01	1.14	136.66	43.47	50.27
70.83	157.82	-0.01	1.18	142.23	45.24	50.20
73.12	157.53	-0.01	1.22	145.99	46.43	50.10
75.40	157.52	-0.01	1.26	149.42	47.52	50.10
77.68	157.50	0.00	1.30	154.31	49.08	50.09
79.97	157.98	0.00	1.33	158.96	50.56	50.25

82.25	157.55	-0.01	1.37	162.37	51.65	50.11
84.53	157.46	-0.01	1.41	165.72	52.71	50.08
86.82	157.78	-0.01	1.45	169.90	54.04	50.18
89.10	157.77	-0.01	1.49	173.31	55.12	50.18
91.38	157.48	-0.01	1.53	174.02	55.35	50.09
93.67	157.46	-0.01	1.56	176.43	56.12	50.08
95.95	157.56	0.00	1.60	178.22	56.69	50.11
98.23	157.39	-0.01	1.64	180.97	57.56	50.06
100.52	157.37	0.00	1.68	181.31	57.67	50.05
102.80	157.27	-0.01	1.72	181.37	57.69	50.02
105.08	157.60	0.00	1.75	184.15	58.57	50.13
107.37	157.79	0.00	1.79	185.11	58.88	50.19
109.65	157.45	0.00	1.83	185.13	58.88	50.08
111.93	157.63	0.00	1.87	186.21	59.23	50.14
114.22	157.53	0.00	1.91	186.06	59.18	50.10
116.50	157.48	0.00	1.94	185.88	59.12	50.09
118.78	157.39	0.00	1.98	186.71	59.39	50.06
121.07	157.00	0.00	2.02	186.69	59.38	49.94
123.35	157.51	0.00	2.06	187.03	59.49	50.10
125.63	157.80	0.00	2.10	186.99	59.47	50.19
127.90	157.71	0.00	2.14	188.65	60.00	50.16
130.18	157.35	0.00	2.17	187.60	59.67	50.05
132.47	157.23	0.00	2.21	186.60	59.35	50.01
134.75	157.34	0.00	2.25	186.27	59.24	50.04
137.05	157.42	0.00	2.29	186.79	59.41	50.07
139.32	157.57	0.00	2.33	187.75	59.72	50.12
141.60	157.47	0.00	2.36	185.96	59.15	50.09
143.88	157.68	0.00	2.40	186.27	59.24	50.15
146.17	158.09	0.00	2.44	185.24	58.92	50.28
148.45	157.23	0.00	2.48	184.88	58.80	50.01

150.75	157.67	0.00	2.52	183.65	58.41	50.15
153.03	157.36	0.00	2.56	182.66	58.10	50.05
157.58	157.62	0.00	2.63	183.07	58.23	50.13
162.15	157.28	0.00	2.71	180.93	57.55	50.03
166.72	157.41	0.00	2.78	179.18	56.99	50.07
171.28	157.27	0.00	2.86	179.01	56.94	50.02
175.85	157.78	0.00	2.94	176.58	56.16	50.18
180.42	157.55	0.00	3.01	174.09	55.37	50.11
184.98	157.09	0.00	3.09	172.71	54.93	49.96
189.55	157.53	0.00	3.17	171.18	54.45	50.11
194.12	157.44	0.00	3.24	173.46	55.17	50.08
198.67	156.97	0.00	3.32	174.13	55.38	49.93
203.23	157.54	0.00	3.39	171.28	54.48	50.11
207.80	157.58	0.00	3.47	172.06	54.73	50.12
212.37	157.45	0.00	3.55	172.65	54.91	50.08
216.93	157.59	0.00	3.62	171.31	54.49	50.12
221.50	157.45	0.00	3.70	174.00	55.34	50.08
226.07	157.60	0.00	3.77	171.80	54.64	50.13
230.62	157.48	0.00	3.85	171.65	54.60	50.09
235.18	157.22	0.00	3.93	172.70	54.93	50.01
239.75	157.65	0.00	4.00	172.51	54.87	50.14
244.32	157.90	0.00	4.08	172.72	54.94	50.22
248.88	157.63	0.00	4.16	172.54	54.88	50.14
253.45	157.36	0.00	4.23	171.16	54.44	50.05
258.02	157.59	0.00	4.31	171.31	54.49	50.12
262.57	157.24	0.00	4.38	170.67	54.28	50.01
267.13	157.82	0.00	4.46	169.75	53.99	50.20
271.70	157.85	0.00	4.54	170.37	54.19	50.21
276.27	157.27	0.00	4.61	170.56	54.25	50.02
280.83	157.55	0.00	4.69	171.29	54.48	50.11

285.40	157.87	0.00	4.77	170.79	54.32	50.21
289.97	157.17	0.00	4.84	171.91	54.68	49.99
294.52	157.41	0.00	4.92	172.61	54.90	50.07
299.08	157.42	0.00	4.99	172.55	54.88	50.07
303.65	157.40	0.00	5.07	172.89	54.99	50.06
308.22	157.41	0.00	5.15	173.29	55.12	50.07
312.78	157.53	0.00	5.22	172.76	54.95	50.10
317.35	157.62	0.00	5.30	172.97	55.02	50.13
321.92	157.50	0.00	5.38	172.89	54.99	50.09
326.48	157.38	0.00	5.45	171.18	54.45	50.06
331.03	157.32	0.00	5.53	170.59	54.26	50.04
335.60	157.67	0.00	5.60	171.11	54.43	50.15
340.17	157.07	0.00	5.68	170.61	54.26	49.96
344.73	157.14	0.00	5.76	169.41	53.88	49.98
349.30	157.68	0.00	5.83	168.88	53.71	50.15
353.87	158.05	0.00	5.91	169.63	53.95	50.27
358.43	157.76	0.00	5.99	168.75	53.67	50.18
363.00	157.49	0.00	6.06	169.61	53.95	50.09
367.55	157.36	0.00	6.14	168.54	53.61	50.05
372.12	157.92	0.00	6.21	168.22	53.50	50.23
376.68	157.76	0.00	6.29	168.30	53.53	50.18
380.22	157.18	0.00	6.35	168.30	53.53	49.99

Table 28. Untreated (AK-F) at 50 kPa

Elapsed Time (min.)	Vertical Load (N)	Vertical Disp. (mm)	Horizontal Disp. (mm)	Horizontal Load (N)	Nominal Shear Stress (kPa)	Normal Stress (kPa)
0.00	154.38	0.00	0.00	0.00	0.00	49.10
1.40	157.40	0.00	0.01	-4.38	-1.39	50.06
2.82	157.23	0.00	0.03	-10.39	-3.30	50.01
4.23	156.69	0.00	0.04	-8.82	-2.80	49.84
5.63	156.84	0.00	0.05	9.50	3.02	49.89
7.05	155.97	-0.01	0.06	25.00	7.95	49.61
8.47	156.91	0.00	0.08	36.82	11.71	49.91
9.88	156.51	0.00	0.09	45.16	14.36	49.78
11.28	156.34	0.00	0.10	51.81	16.48	49.72
12.70	156.87	0.00	0.11	57.32	18.23	49.89
14.12	156.63	0.00	0.13	62.42	19.85	49.82
15.53	156.82	0.00	0.14	67.37	21.43	49.88
16.95	156.65	0.00	0.15	70.41	22.40	49.82
18.35	157.12	0.00	0.16	75.13	23.90	49.97
19.77	156.61	0.00	0.18	80.37	25.56	49.81
21.18	156.12	0.00	0.19	83.98	26.71	49.66
22.60	155.97	0.00	0.20	87.97	27.98	49.61
24.00	157.04	0.00	0.22	91.83	29.21	49.95
25.42	156.20	0.00	0.23	95.56	30.39	49.68
26.83	156.91	0.00	0.24	98.85	31.44	49.91
28.25	156.42	0.00	0.25	102.79	32.69	49.75
29.67	155.91	0.00	0.27	106.48	33.87	49.59
31.07	156.97	0.00	0.28	109.65	34.87	49.93
32.48	156.45	0.00	0.29	108.43	34.49	49.76
33.90	157.16	0.00	0.30	112.43	35.76	49.99

35.32	157.42	0.00	0.32	116.01	36.90	50.07
36.72	157.01	0.00	0.33	119.71	38.08	49.94
38.13	155.84	0.00	0.34	122.81	39.06	49.57
39.55	156.83	0.00	0.36	125.32	39.86	49.88
40.97	156.16	0.00	0.37	129.82	41.29	49.67
42.37	157.04	0.00	0.38	133.98	42.61	49.95
43.78	156.69	0.00	0.39	136.82	43.52	49.84
45.20	156.80	0.00	0.41	140.52	44.70	49.87
46.62	156.21	0.00	0.42	144.86	46.08	49.68
48.03	157.17	0.00	0.43	148.15	47.12	49.99
49.45	156.46	0.00	0.44	150.23	47.78	49.76
50.85	156.34	0.00	0.46	154.29	49.07	49.72
52.27	156.46	0.00	0.47	156.78	49.87	49.77
53.68	156.61	0.00	0.48	161.01	51.21	49.81
55.10	156.21	0.00	0.50	163.83	52.11	49.68
56.50	157.96	0.00	0.51	167.20	53.18	50.24
57.92	157.23	0.00	0.52	168.73	53.67	50.01
59.33	156.95	0.00	0.53	170.63	54.27	49.92
60.75	156.51	0.00	0.55	174.02	55.35	49.78
62.15	157.52	0.00	0.56	176.62	56.18	50.10
63.57	156.99	0.00	0.57	179.07	56.96	49.93
64.98	156.38	0.00	0.58	180.50	57.41	49.74
66.40	155.74	0.00	0.60	182.43	58.02	49.53
67.80	156.27	0.00	0.61	184.87	58.80	49.70
69.22	156.12	0.00	0.62	186.16	59.21	49.66
70.63	156.65	0.00	0.64	187.16	59.53	49.82
72.05	157.65	0.00	0.65	189.46	60.26	50.14
76.28	155.80	0.00	0.69	195.35	62.14	49.55
80.52	156.71	0.00	0.72	200.38	63.73	49.85
84.75	156.31	0.00	0.76	206.60	65.71	49.72

89.00	156.78	0.00	0.80	206.55	65.70	49.87
93.23	156.68	0.00	0.84	210.64	67.00	49.83
97.47	156.48	0.00	0.88	215.34	68.49	49.77
101.70	156.86	0.00	0.92	218.95	69.64	49.89
105.93	156.84	0.00	0.95	222.16	70.66	49.89
110.17	156.65	0.00	0.99	226.48	72.03	49.82
114.40	155.92	0.00	1.03	229.93	73.13	49.59
118.63	156.50	-0.01	1.07	235.39	74.87	49.78
122.87	156.72	0.00	1.11	237.25	75.46	49.85
127.12	157.72	0.00	1.14	241.34	76.76	50.16
131.35	156.76	0.00	1.18	244.74	77.84	49.86
135.58	156.66	0.00	1.22	247.55	78.74	49.83
139.82	156.44	-0.01	1.26	249.77	79.44	49.76
144.05	156.44	0.00	1.30	250.90	79.80	49.76
148.28	157.49	0.00	1.33	255.26	81.19	50.09
152.52	156.29	0.00	1.37	256.15	81.47	49.71
156.75	157.10	0.00	1.41	253.63	80.67	49.97
160.98	156.50	0.00	1.45	252.37	80.27	49.78
165.22	156.27	0.00	1.49	250.66	79.72	49.70
169.45	158.13	0.00	1.53	250.36	79.63	50.29
173.68	156.42	0.00	1.56	250.34	79.62	49.75
177.93	156.16	0.00	1.60	248.04	78.89	49.67
182.17	157.63	0.00	1.64	244.97	77.92	50.14
186.40	156.05	0.00	1.68	241.62	76.85	49.63
190.63	156.66	0.00	1.72	239.80	76.27	49.83
194.87	156.76	0.00	1.75	239.04	76.03	49.86
199.10	156.80	0.00	1.79	238.42	75.83	49.87
203.33	155.78	0.00	1.83	237.25	75.46	49.55
207.57	156.46	0.00	1.87	236.63	75.26	49.77
211.80	157.27	0.00	1.91	237.70	75.60	50.02

216.05	156.18	0.00	1.94	237.04	75.39	49.67
220.28	156.19	0.00	1.98	236.95	75.37	49.68
224.52	157.12	0.00	2.02	236.84	75.33	49.97
228.75	156.66	0.00	2.06	237.35	75.49	49.83
232.98	156.84	0.00	2.10	237.35	75.49	49.89
237.22	156.72	0.00	2.14	237.88	75.66	49.85
241.45	156.67	0.00	2.17	237.58	75.57	49.83
245.68	156.37	0.00	2.21	238.19	75.76	49.73
249.93	156.86	0.00	2.25	238.44	75.84	49.89
254.17	158.83	0.01	2.29	239.74	76.25	50.52
258.40	156.88	0.00	2.33	238.22	75.77	49.90
262.63	156.80	0.00	2.36	237.65	75.59	49.87
266.87	156.88	0.01	2.40	236.41	75.19	49.90
271.10	159.30	0.01	2.44	236.52	75.23	50.67
275.33	157.40	0.01	2.48	233.47	74.26	50.06
279.57	156.46	0.00	2.52	231.28	73.56	49.76
283.80	156.97	0.00	2.55	230.56	73.33	49.93
292.27	156.25	0.00	2.63	225.70	71.79	49.70
300.73	157.03	0.00	2.71	219.19	69.72	49.95
309.22	157.06	0.00	2.78	214.68	68.28	49.96
317.68	157.38	0.01	2.86	211.12	67.15	50.06
326.15	157.21	0.00	2.94	206.80	65.78	50.00
334.62	156.50	0.00	3.01	203.29	64.66	49.78
343.08	156.83	0.00	3.09	200.32	63.71	49.88
351.55	156.76	0.00	3.16	194.79	61.96	49.86
360.02	156.44	0.01	3.24	190.44	60.57	49.76
368.48	156.31	0.01	3.32	185.71	59.07	49.72
376.95	156.59	0.01	3.39	179.70	57.16	49.81
385.42	157.08	0.01	3.47	172.19	54.77	49.96
393.88	157.40	0.01	3.55	168.69	53.65	50.06

402.35	157.52	0.01	3.62	165.51	52.64	50.10
408.88	156.69	0.01	3.68	161.11	51.24	49.84

Table 29. Treated (AK-F) at 50 kPa

Elapsed Time (min.)	Vertical Load (N)	Vertical Disp. (mm)	Horizontal Disp. (mm)	Horizontal Load (N)	Nominal Shear Stress (kPa)	Normal Stress (kPa)
0.00	158.88	0.00	0.00	0.00	0.00	50.53
1.40	157.85	0.00	0.01	-1.86	-0.59	50.21
2.82	157.52	0.00	0.02	4.76	1.51	50.10
4.23	157.30	0.00	0.04	31.72	10.09	50.03
5.65	156.87	0.00	0.05	44.97	14.30	49.90
7.07	157.74	0.00	0.06	58.00	18.45	50.17
8.47	157.95	0.00	0.08	69.62	22.15	50.24
9.88	157.17	0.00	0.09	77.14	24.54	49.99
11.30	158.07	0.00	0.10	84.98	27.03	50.28
12.72	157.01	0.00	0.11	91.28	29.03	49.94
14.13	157.85	0.00	0.13	97.52	31.02	50.21
15.55	157.17	0.00	0.14	103.95	33.06	49.99
16.95	156.66	0.00	0.15	108.58	34.54	49.83
18.37	157.57	0.00	0.16	112.77	35.87	50.12
19.78	156.80	0.00	0.18	115.83	36.84	49.87
21.20	156.84	0.00	0.19	119.46	38.00	49.89
22.60	157.68	0.00	0.20	124.15	39.49	50.15
24.02	159.94	0.00	0.22	127.82	40.66	50.87
25.43	158.29	0.00	0.23	130.62	41.54	50.35

26.85	157.04	0.00	0.24	133.99	42.62	49.95
28.27	156.10	0.01	0.25	136.60	43.45	49.65
29.68	157.26	0.00	0.27	140.12	44.57	50.02
31.08	156.87	0.00	0.28	142.71	45.39	49.90
32.50	156.52	0.00	0.29	145.78	46.37	49.78
33.92	156.40	0.00	0.30	148.90	47.36	49.75
35.33	158.41	0.00	0.32	152.43	48.48	50.38
36.73	158.11	0.00	0.33	155.27	49.39	50.29
38.15	158.16	0.00	0.34	158.69	50.47	50.31
39.57	158.59	0.00	0.36	162.87	51.80	50.44
40.97	156.88	0.00	0.37	165.74	52.72	49.90
42.38	156.66	0.00	0.38	167.83	53.38	49.83
43.80	158.55	0.00	0.39	170.96	54.38	50.43
45.22	157.73	0.01	0.41	174.51	55.50	50.17
46.62	157.44	0.00	0.42	178.53	56.78	50.08
48.03	156.97	0.00	0.43	181.83	57.83	49.93
49.45	157.09	0.01	0.44	185.37	58.96	49.96
50.87	158.55	0.00	0.46	188.10	59.83	50.43
52.27	157.43	0.00	0.47	189.08	60.14	50.07
53.68	159.26	0.00	0.48	192.71	61.29	50.66
55.10	157.43	0.00	0.50	195.76	62.26	50.07
56.52	158.21	0.00	0.51	199.96	63.60	50.32
57.92	157.51	0.01	0.52	201.81	64.19	50.10
59.33	158.49	0.00	0.53	205.36	65.32	50.41
60.75	157.99	0.00	0.55	208.69	66.38	50.25
62.17	158.12	0.00	0.56	210.37	66.91	50.29
63.58	158.84	0.00	0.57	213.10	67.78	50.52
65.00	156.97	0.00	0.58	214.75	68.30	49.93
66.40	155.21	0.00	0.60	218.29	69.43	49.37
67.82	157.65	0.00	0.61	219.80	69.91	50.14

69.23	158.08	0.00	0.62	223.74	71.16	50.28
70.65	158.21	0.00	0.64	227.20	72.26	50.32
72.05	156.53	0.00	0.65	228.61	72.71	49.79
76.30	159.52	0.00	0.69	235.16	74.80	50.74
80.53	157.64	0.01	0.72	241.60	76.84	50.14
84.77	155.68	0.00	0.76	246.76	78.49	49.52
89.00	157.81	0.00	0.80	254.37	80.91	50.19
93.23	156.57	0.01	0.84	249.32	79.30	49.80
97.47	159.17	0.01	0.88	256.70	81.65	50.62
101.70	157.64	0.01	0.91	256.57	81.61	50.14
105.93	157.09	0.01	0.95	253.74	80.71	49.96
110.17	157.90	0.00	0.99	242.32	77.07	50.22
114.40	159.06	0.00	1.03	231.64	73.68	50.59
118.63	156.66	0.01	1.07	215.72	68.61	49.83
122.88	162.81	0.00	1.11	205.16	65.25	51.79
127.12	158.65	0.01	1.14	192.40	61.20	50.46
131.35	157.44	0.00	1.18	181.98	57.88	50.08
135.58	154.31	0.01	1.22	167.26	53.20	49.08
139.82	159.32	0.01	1.26	159.37	50.69	50.67
144.05	156.07	0.01	1.30	148.60	47.26	49.64
148.28	157.18	0.00	1.33	142.24	45.24	49.99
152.52	157.22	0.01	1.37	136.88	43.54	50.01
156.75	157.38	0.01	1.41	132.87	42.26	50.06
160.98	153.98	0.01	1.45	127.18	40.45	48.98
165.23	156.45	0.00	1.49	123.27	39.21	49.76
169.47	155.35	0.01	1.52	118.05	37.55	49.41
173.70	158.28	0.00	1.56	115.09	36.61	50.34
177.93	157.04	0.00	1.60	110.28	35.08	49.95
182.17	155.73	0.01	1.64	106.47	33.86	49.53
186.40	154.49	0.01	1.68	103.39	32.89	49.14

190.63	157.78	0.01	1.72	100.67	32.02	50.18
194.87	156.93	0.01	1.75	98.02	31.18	49.91
199.10	158.50	0.01	1.79	96.22	30.61	50.41
203.33	157.17	0.00	1.83	93.63	29.78	49.99
207.57	157.57	0.01	1.87	92.28	29.35	50.12
211.80	158.58	0.01	1.91	89.27	28.39	50.44
216.03	157.64	0.00	1.94	88.30	28.08	50.14
220.27	156.16	0.01	1.98	85.86	27.31	49.67
224.50	157.13	0.01	2.02	84.30	26.81	49.98
228.73	155.56	0.01	2.06	82.49	26.24	49.48
232.97	158.65	0.01	2.10	82.30	26.18	50.46
237.22	156.74	0.01	2.13	80.77	25.69	49.85
241.45	156.37	0.01	2.17	78.63	25.01	49.74
245.68	157.78	0.01	2.21	78.50	24.97	50.18
249.92	155.21	0.01	2.25	77.43	24.63	49.37
254.15	156.63	0.01	2.29	77.28	24.58	49.82
256.88	156.84	0.01	2.31	75.70	24.08	49.89

Table 30. Treated with Salt (AK-F) at 50 kPa

Elapsed Time (min.)	Vertical Load (N)	Vertical Disp. (mm)	Horizontal Disp. (mm)	Horizontal Load (N)	Nominal Shear Stress (kPa)	Normal Stress (kPa)
0.00	157.31	0.00	0.00	0.00	0.00	50.03
1.42	155.45	0.00	0.01	-2.36	-0.75	49.44
2.83	157.29	0.00	0.03	-2.12	-0.67	50.03
4.25	156.57	0.00	0.04	-1.40	-0.44	49.80
5.67	157.42	0.00	0.05	0.14	0.04	50.07
7.07	157.36	0.00	0.06	7.46	2.37	50.05
8.48	155.75	0.00	0.08	24.59	7.82	49.54

9.90	157.10	0.00	0.09	41.35	13.15	49.97
11.32	157.22	-0.01	0.10	54.39	17.30	50.01
12.73	157.42	0.00	0.11	65.56	20.85	50.07
14.13	156.82	0.00	0.13	72.86	23.18	49.88
15.55	157.40	0.00	0.14	79.09	25.15	50.06
16.97	157.61	0.00	0.15	87.17	27.73	50.13
18.38	157.76	0.00	0.17	92.60	29.45	50.18
19.80	157.22	0.00	0.18	97.95	31.15	50.01
21.20	156.80	0.00	0.19	103.18	32.82	49.87
22.62	158.02	0.00	0.20	108.76	34.59	50.26
24.03	158.35	0.00	0.22	113.41	36.07	50.37
25.45	157.35	0.00	0.23	117.64	37.42	50.05
26.85	156.70	0.00	0.24	121.11	38.52	49.84
28.27	153.90	0.00	0.25	126.30	40.17	48.95
29.68	157.55	0.00	0.27	131.23	41.74	50.11
31.10	157.27	0.00	0.28	135.04	42.95	50.02
32.50	157.31	0.00	0.29	138.01	43.90	50.03
33.92	156.78	0.00	0.31	141.08	44.87	49.87
35.33	156.57	0.00	0.32	142.22	45.24	49.80
36.75	157.35	0.00	0.33	145.90	46.41	50.05
38.15	157.44	0.00	0.34	148.33	47.18	50.08
39.57	157.91	0.00	0.36	152.00	48.34	50.22
40.98	156.89	0.00	0.37	155.52	49.47	49.90
42.40	157.25	0.00	0.38	159.02	50.58	50.01
43.80	157.38	0.00	0.39	162.00	51.53	50.06
45.22	156.93	0.00	0.41	165.80	52.74	49.91
46.63	157.73	0.00	0.42	170.26	54.15	50.17
48.05	157.46	0.00	0.43	175.34	55.77	50.08
49.47	157.93	0.00	0.45	179.51	57.10	50.23
50.87	157.29	0.00	0.46	183.79	58.46	50.03

52.28	157.74	0.00	0.47	186.32	59.26	50.17
53.70	156.67	0.00	0.48	190.50	60.59	49.83
55.10	156.75	0.00	0.50	194.43	61.84	49.86
56.52	156.61	0.00	0.51	197.50	62.82	49.81
57.93	157.86	0.00	0.52	200.59	63.80	50.21
59.35	157.06	0.00	0.53	203.52	64.73	49.95
60.77	157.17	0.00	0.55	208.04	66.17	49.99
62.17	157.71	0.00	0.56	211.39	67.24	50.16
63.58	157.31	0.00	0.57	214.05	68.08	50.03
65.00	157.74	0.00	0.59	216.96	69.01	50.17
66.42	157.42	0.00	0.60	220.51	70.14	50.07
67.82	157.14	0.00	0.61	223.03	70.94	49.98
69.23	157.37	0.00	0.62	228.67	72.73	50.05
70.65	157.71	0.00	0.64	232.50	73.95	50.16
72.07	157.42	0.00	0.65	236.18	75.12	50.07
76.30	156.99	0.00	0.69	241.36	76.77	49.93
80.53	156.50	0.00	0.72	244.37	77.72	49.78
84.77	157.70	0.00	0.76	247.54	78.74	50.16
89.00	157.56	0.01	0.80	246.15	78.29	50.11
93.23	157.39	0.00	0.84	247.62	78.76	50.06
97.47	156.16	0.00	0.88	247.20	78.62	49.67
101.70	157.59	0.00	0.92	247.01	78.57	50.12
105.95	157.10	0.00	0.95	248.63	79.08	49.97
110.18	157.44	0.00	0.99	251.15	79.88	50.08
114.42	157.10	0.00	1.03	250.94	79.81	49.97
118.65	157.98	0.00	1.07	249.16	79.25	50.25
122.88	156.37	0.00	1.11	249.00	79.20	49.74
127.12	157.18	0.00	1.14	249.20	79.26	49.99
131.35	157.12	0.00	1.18	249.48	79.35	49.97
135.58	158.04	0.01	1.22	247.25	78.64	50.27

139.82	156.50	0.00	1.26	246.63	78.44	49.78
144.05	156.03	0.00	1.30	250.18	79.57	49.63
148.28	156.87	0.00	1.33	249.06	79.22	49.89
152.52	156.34	0.00	1.37	246.69	78.46	49.73
156.75	157.74	0.00	1.41	245.90	78.21	50.17
160.98	157.85	0.00	1.45	244.68	77.82	50.21
165.22	157.72	0.00	1.49	246.39	78.37	50.17
169.45	158.25	0.00	1.53	251.66	80.04	50.33
173.70	155.01	0.00	1.56	248.12	78.92	49.30
177.93	156.93	0.00	1.60	245.84	78.19	49.91
182.17	157.23	0.00	1.64	246.41	78.38	50.01
186.40	156.90	0.00	1.68	246.47	78.39	49.91
190.63	158.10	0.00	1.72	246.47	78.39	50.29
194.87	157.94	0.00	1.75	246.24	78.32	50.24
199.10	157.14	0.00	1.79	245.82	78.19	49.98
203.35	156.66	0.00	1.83	245.71	78.15	49.83
207.58	159.26	0.00	1.87	246.01	78.25	50.65
211.82	157.21	-0.01	1.91	245.41	78.06	50.00
216.05	156.97	0.00	1.94	246.26	78.33	49.93
220.28	156.56	0.00	1.98	246.84	78.51	49.80
224.53	157.89	0.00	2.02	245.94	78.22	50.22
228.77	156.54	0.00	2.06	246.33	78.35	49.79
233.00	157.48	-0.01	2.10	246.39	78.37	50.09
237.23	156.74	0.00	2.14	245.88	78.20	49.85
241.47	157.18	0.00	2.17	246.32	78.35	49.99
245.70	157.09	0.00	2.21	245.94	78.23	49.96
249.93	156.50	0.00	2.25	246.20	78.31	49.78
254.17	156.99	0.00	2.29	247.08	78.59	49.93
258.40	157.59	0.00	2.33	247.05	78.58	50.12
262.63	158.03	0.00	2.36	248.52	79.05	50.27

266.87	157.08	0.00	2.40	246.98	78.56	49.96
271.12	157.27	0.00	2.44	247.79	78.81	50.02
275.35	157.25	0.00	2.48	247.93	78.86	50.02
279.58	157.05	0.00	2.52	248.91	79.17	49.95
283.82	157.02	-0.01	2.55	249.07	79.22	49.94
292.28	157.27	0.00	2.63	247.99	78.88	50.02
300.75	157.75	0.00	2.71	248.15	78.93	50.18
309.22	154.82	-0.01	2.78	246.77	78.49	49.24
316.82	157.70	0.00	2.85	247.59	78.75	50.16

APPENDIX E: POCKET PENETROMETER

Figure 21. Pocket Penetrometer

NH-H	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	50	68	47.8	173.59	30.43	347.86	4.86	3.50	343.27	3.339609553	3.50	333.16	>5	1.74
8%	921	68.7	48.3	179.04	31.32	360.55	7.47	3.33	353.97	5.324149638	4.10	337.66	>5	1.71
11%	33	75.1	49.1	217.50	39.04	430.5	10.86	3.17	423.6	8.903488899	4.83	392.16	>5	1.62
14%	70	70.6	47.7	186.73	30.17	423.3	13.76	3.73	415.4	11.4734649	>5	375.75	>5	1.85
17%	98	70	48.1	185.11	26.89	420.1	16.47	1.00	415.4	15.07315917	3.35	364.51	>5	1.82
20%	B	62.7	42.9	132.46	31.31	311.4	19.53	0.43	304.64	16.64817344	1.50	265.63	>5	1.77
23%	14	62.4	44.2	135.17	31.48	321.3	21.48	0.00	311.32	17.29890598	1.50	270.05	>5	1.76

AK-F	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	2	75.7	51.8	233.14	38.75	252.92	5.58	0.00	250.11	4.195218141	0	241.6	0	0.87
8%	9?	70.5	47.8	186.59	27.37	197.32	8.24	0.00	194.32	6.330806955	0	184.38	0	0.84
11%	20	75.5	50.8	227.43	40.16	291.34	10.83	0.97	287.12	8.970568768	0.8	266.79	0.7	1.00
14%	Ms5	80.1	52	262.03	32.37	331.7	14.15	1.17	326.12	12.01998246	1.8	294.6	1.25	1.00
17%	19	62.51	43.98	134.97	32.36	220.41	16.41	2.75	209.79	9.836572985	3	193.9	3.5	1.20
20%	14	62.37	44.43	135.74	32.47	204.42	19.64	2.75	196.3	13.99248539	3.25	176.19	3.6	1.06
23%	A-2	62.52	44.3	136.00	32.9	232.08	23.06	3.25	221.57	16.56369702	4	194.76	5	1.19
26%	33	74.35	47.76	207.36	39.44	351.56	26.25	3.25	344.01	23.19796133	3.75	286.66	5	1.19
29%	A53	62.16	43.87	133.13	31.85	233.28	28.77	2.50	225.29	23.65914467	2.75	188.28	5	1.18

NC-AC	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	2	75.7	51.8	233.14	38.74	347.2	5.34	1.75	343.85	4.193559403	1.5	331.57	3.25	1.26
8%	33	75.1	51.1	226.36	39.44	351	8.06	1.80	345.59	6.187783983	1.5	327.75	4	1.27
11%	921	68.7	47.96	177.78	31.33	299.3	11.01	2.00	291.56	7.8003314	2.5	272.73	4.5	1.36
14%	50	68	47.8	173.59	30.43	315.4	14.04	2.00	306.58	10.51304626	3	280.31	>5	1.44
17%	70	70.6	47.9	187.51	31.67	325.1	17.15	2.00	316.24	13.60986905	3	282.15	>5	1.34
20%	98	70	47.79	183.92	28.05	341.1	19.86	1.80	330.19	15.68710036	2.75	289.22	>5	1.42
23%	14	62.7	44.46	137.28	32.67	259.75	22.40	1.80	250.53	17.42575325	2.75	218.2	>5	1.35

IA-KC	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	33	75.1	47.1	208.64	39.32	351.42	7.57	5.00	347.85	6.334654489	5	329.47	>5	1.39
8%	2	75.7	46.8	210.63	38.85	356.11	10.20	5.00	351.04	8.440723888	5	326.74	>5	1.37
11%	50	68	48.1	174.68	30.71	322.08	13.09	5.00	315.49	10.53407856	5	288.35	>5	1.47
14%	98	70	47.79	183.92	28.21	349.44	15.73	4.70	339.65	12.20636979	5	305.77	>5	1.51
17%	70	70.6	48.6	190.25	31.61	368.4	18.66	4.50	356.27	14.38537153	5	315.44	>5	1.49
20%	921	71.01	46.08	182.49	31.38	380.16	20.97	2.25	369.05	17.11233656	5	319.71	>5	1.58
23%	C	74.8	39.82	174.98	38.81	392.3	24.36	1.25	383.66	21.31926121	2.75	323.06	>5	1.62

Figure 22. Pocket Penetrometer Data for Treated Soils

NH-H	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	50	68	48.19	175.01	30.43	366.92	3.99	3.5	361.45	2.30	4.25	354.00	>5	1.85
8%	33	75.1	45.87	203.19	39.04	439.90	8.00	4	431.40	5.71	>5	410.20	>5	1.83
11%	c	74.19	44.08	190.56	39.6	439.50	10.99	5	409.30	2.61	>5	399.89	>6	1.89
14%	98	70.96	47.44	187.61	28.3	424.60	13.87	3.25	386.92	3.04	>5	376.34	>7	1.86
17%	50	68	48.07	174.57	30.63	439.70	16.57	1	400.20	5.32	>5	381.54	>8	2.01
20%	A-2	62.82	44.28	137.24	32.96	331.43	17.94	0	299.60	5.36	>5	286.03	>9	1.84

AK-F	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	98	69.32	42.9	161.9063622	28.22	232.80	4.87	1	230.81	3.85	1.75	223.30	1	1.20
8%	50	68	44.8	162.6991762	30.43	240.62	7.79	2	237.70	6.29	2.00	225.43	1	1.20
11%	921	68.7	48.3	179.0400207	31.32	247.06	11.34	2.5	243.04	9.26	3.00	225.09	3.25	1.08
14%	c or 17	75.52	40.38	180.8755196	39.81	259.85	14.00	2.75	256.03	12.03	3.50	232.82	4	1.07
17%	B	62.59	43.68	134.3946706	31.45	212.47	18.01	2.75	205.67	13.58	3.50	184.84	5	1.14
20%	14	62.6	44.38	136.5920675	32.5	206.64	19.19	2.5	196.01	11.92	3.50	178.60	5	1.07
23%	20	73.45	51.06	216.3485183	41.07	354.49	22.50	2.5	335.85	15.21	3.25	296.93	5	1.18
26%	92	69.01	48.35	180.8464749	27.52	280.91	25.70	2	263.47	17.04	2.50	229.11	5	1.11
29%	Ms5	80	52.85	265.6528504	32.37	392.92	28.16	2	371.94	20.71	2.50	313.69	5	1.06

NC-AC	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	70	69.6	48.13	183.1149722	30.44	276.63	4.67	1.75	272.66	2.98	1.25	265.65	3	1.28
8%	33	75.57	51.29	230.0493752	40.25	349.26	7.94	2	340.02	4.71	1.75	326.54	4.5	1.24
11%	A-2	62.5	44.27	135.8185442	32.96	234.44	11.39	2.75	223.06	5.10	3.75	213.84	5	1.33
14%	98	69.41	47.19	178.5597547	28.3	311.61	13.85	2.75	292.73	6.27	4.25	277.14	5	1.39
17%	50	70.08	48.14	185.6879779	30.82	325.84	16.77	2.5	306.60	9.15	4.00	283.47	5	1.36
20%	c	75.34	45.27	201.813977	39.29	383.16	19.76	2.5	366.14	13.83	4.00	326.42	5	1.42
23%	921	69.28	47.65	179.6255775	30.97	348.66	22.83	2.25	328.67	15.10	4.00	289.62	5	1.44

IA-KC	Can ID	Diam. (mm)	Height (mm)	Volume (cm^3)	Can weight (g)	Can + Wet soil (g)	Water Content Immediately After	UC Strength Immediately After	Can + Damp soil (g)	Water Content Air Dried	UC Strength Air Dried	Can + Dry soil (g)	UC Strength Oven Dried	Dry Density (g/cm^3)
5%	19	62.77	44.38	137.3349487	32.33	241.95	7.20	5	239.83	6.12	5.00	227.87	>5	1.42
8%	14	62.64	44.15	136.0578865	32.52	229.01	10.29	4.7	225.57	8.36	5.00	210.68	>5	1.31
11%	70	67.76	48.42	174.6067763	30.57	313.69	14.10	4.5	307.84	11.74	5.00	278.70	>5	1.42
14%	A-2	62.64	43.73	134.7635646	33	259.30	16.01	4.5	253.12	12.84	5.00	228.07	>5	1.45
17%	2	75.55	48.18	215.985824	38.8	449.40	18.14	4	440.20	15.49	5.00	386.36	>5	1.61
20%	43	76.4	42.01	192.5878626	37.2	453.10	21.50	2	443.70	18.76	4.25	379.50	>5	1.78
23%	921	68.7	48.3	179.0400207	31.49	392.47	25.93936434	1	382.96	22.62	2.75	318.12	>5	1.60

Figure 23. Pocket Penetrometer for Untreated Soils