SURFACTANT IMPACTS ON SOIL PROPERTIES AND FEASIBILITY FOR IN-SITU REMEDIATION OF HEAVY METALS

By

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CHAPTER I

BACKGROUND, REVIEW, AND OBJECTIVES

Problem Statement

Heavy metal contamination of soil is one of the most widespread environmental problems today. The toxicity of the metal contaminated soils poses a threat to both humans and animals, and ex-situ methods such as excavation and acid washing are expensive and impractical. In-situ methods are currently being explored, namely enhanced in-situ soil washing. Surfactants have been used in such a capacity for the remediation of petroleum products and other organic contaminants in recent years. Previous studies have shown that cationic surfactants were effective in the desorption of heavy metals such as cadmium, lead, and zinc from soils. Consequently, it has been reasoned that surfactants could also be applied in the removal of heavy metals from contaminated soils.

Another concern stems from the use of surfactants for in-situ remediation. Understanding the engineering properties of a soil is important in structural design, whether it be a commercial, an agricultural, or a residential structure. Future landuse is an important parameter in choosing a remediation for a particular site, and, therefore, it is important to study the effects of surfactants on soil properties.

The two objectives of this study are:

- to explore the feasibility of using a cationic surfactant for the removal of cadmium, lead, and zinc from a contaminated soil in a laboratory setting, and
- to study the effects of three surfactants, two cationic and one anionic, on the mechanical properties, namely plasticity, compaction, consolidation, and shear strength of two soils.

As detailed in the Research Focus, the first objective is addressed in Chapter II, and the second objective is addressed in Chapter III. It will be shown in the following chapters that these objectives have not been adequately studied in any previous research.

Description of Surfactant Properties

A surfactant is an organic compound consisting of a hydrophilic head and a hydrophobic tail. This amphiphilic structure causes a tendency for these molecules to concentrate at phase boundaries and alter interfacial properties such as surface tension. Surfactant molecules also have a tendency to spontaneously self-assemble into micellar structures at a certain concentrations known as critical micelle concentrations (CMC). Micelles can take on different shapes such as globules, rods, disks, and vesicles, depending on the area occupied by a surfactant molecule at a micellar or bulk interphase (Hoffman, 1994). It is the structure of the micelle that makes it possible for surfactants to act as a sink for contaminants that are normally insoluble in water. Surfactant ability to decrease surface tension at concentrations above the CMC may also affect the behavior of soil, either by making a structural breakdown more probable or by "lubricating" the soil particles and allowing them to obtain a denser, stronger structure.

Surfactants are classified according to the charge carried by the hydrophilic head. Four categories of surfactants are nonionic, anionic, cationic, and amphoteric (containing both positive and negative charges). The hydrophilic component of the surfactant molecule has a definite influence on the physical and chemical behavior of the molecule (Allred, 1995).

Research Focus

The research focus of Chapter II was to study the feasibility of using surfactants to enhance in-situ removal of heavy metals from a contaminated soil. This study focused on saturated and low flow conditions to simulate the conditions for in-situ soil washing. Isostearamidopropyl Morpholine Lactate (ISML) was chosen based on studies by Kornecki et al. (1998). It has a tendency to lower the pH of a soil solution to approximately 4, which generally, mobilizes lead. Lead is mobilized because at pH 4, the lead, since it is reduced to Pb^{+2}, and should be easily desorbed from the soil matrix. Once desorbed, the surfactant is believed to compete for adsorption sites, which should increase lead mobility.

Chapter III concentrated on the effects of surfactants on the engineering properties of soil. These included plasticity, compaction, consolidation, and shear strength. Two different soils were observed in combination with three surfactants (one anionic and two cationic). The first soil was comprised of mostly fines, particularly silt. The second had a high percentage of sand in its composition. The surfactants had surprisingly little effect on the finer, more cohesive soil. The anionic surfactant caused the sandy soil to behave like a liquid at a lower water content than an unaltered sample of the same soil.

Future Recommendations

The overall objectives of this research were to explore the feasibility of using surfactants for the removal of cadmium, lead, and zinc from a contaminated soil in a laboratory setting, and to study the effects of surfactants on soil properties such as plasticity, compaction, consolidation, and shear strength. These objectives have been accomplished and are detailed in the following chapters.

Future research should be focused in several areas. First, more study should be done to understand why the cationic surfactant, ISML, was unable to remove significant amounts of the heavy metals from the Blackwell soil. The low pH of the surfactant solution normally would mobilize such metals. Likewise, the strange behavior of cadmium in the soil should be investigated. It appears that the cationic surfactant inhibits the desorption of cadmium from the soil causing low removal rates despite the large percentage of cadmium that is readily available. Research to explain differences in removal rates between historically contaminated and spiked soils should also be considered. Future research on anionic surfactant impacts on soil strength and consolidation should address the mechanism of soil-surfactant interactions.

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CHAPTER II

SURFACTANT ENHANCED IN-SITU SOIL WASHING FOR THE REMOVAL OF HEAVY METALS FROM CONTAMINATED SOIL

Abstract

The feasibility of in-situ soil washing using a cationic surfactant to enhance the removal of heavy metals was evaluated. Saturated laboratory column experiments using an influent with various concentrations of the surfactant ISML were conducted on a contaminated soil taken from Blackwell, Oklahoma. The Blackwell Loam contains high levels of cadmium, lead, and zinc, 296 ppm, 497 ppm, and 12,740ppm, respectively. Column effluent was analyzed for metal content, surfactant concentration, and pH. ISML did not significantly enhance the removal of the heavy metals from the soil. Only 2.1% of lead and 4.5% of zinc were leached after 21 pore volumes of 0.05M ISML were passed through the column. Increased concentration of the surfactant increased the removal efficiencies of lead and zinc but not enough to justify further interest. Removal efficiency of cadmium was reduced by the addition of ISML. Cadmium removal efficiencies decreased from 4.4%, where a standard soil solution without ISML was the influent, to 2.1%, where the influent was a 0.05M ISML solution. These findings are in contrast to studies performed on spiked soils, previously reported and indicate that the heavy metals were in chemical forms not susceptible to surfactant leaching.

Introduction

Heavy metal contamination of soil is one of the most wide spread environmental cleanup problems today. The toxicity of metal contaminated soils pose a threat to both animals and humans, especially those soils contaminated by metal smelting which were then used as fill material for residential purposes such as yards and driveways (Beiergrohslein, 1998). At present, there is no economically effective or efficient technology for removing heavy metals from soil. Ex-situ methods such as excavation and transport of the contaminated soil to landfills have been standard practice. Other practices such as acid washing significantly change the soil matrix and may create new problems.

Over the years, several approaches to in-situ methods for removing heavy metals from soil have been studied. One approach is the use of a chelating agent such as EDTA as an additive to soil flushing. Batch tests and saturated column experiments have shown EDTA to be effective for the removal of heavy metals such as lead. However, EDTA is not biodegradable and would accumulate in the environment (Hering, 1995).

Another approach is the use of surfactants for the in-situ remediation of soil. A surfactant is an organic compound consisting of a hydrophilic head and a hydrophobic tail. This amphiphilic structure causes a tendency for these molecules to concentrate at phase boundaries and alter interfacial properties such as surface tension. At certain concentrations, known as the critical micelle concentration (CMC), surfactant molecules also have a tendency to self-assemble into aggregates called micelles. It is the structure of the micelles that makes it possible for the surfactants to act as a sink for contaminants that are normally insoluble in water, such as metals. Surfactants are classified according to the charge of the hydrophobic head group as being cationic, anionic, nonionic, and amphoteric.

Beveridge and Pickering (1983) showed, using batch tests, that cationic surfactants were effective in the desorption of copper, lead, cadmium, and zinc from montmorillonite clay. This was a result of the competition between metal ions and the cationic organic species for negative sites on clay surfaces since most counter ions associated with montmorillonite are retained by electrostatic attraction and are available to participate in cation exchange. In 1998, Kornecki et al., in the first of two studies, investigated the use of cationic surfactants to desorb lead from a soil spiked with Pb $(NO_3)_2$. These experiments explored the effectiveness of 10 cationic surfactants. Isostearamidopropyl Morpholine Lactate (ISML), Lapyrium Chloride (LC), and Dodecyl Pyridinium Chloride desorbed 83, 78, and 68%, respectively, of the lead at a concentration of 0.025 moles/liter and at pH 4. Promising results led to a saturated column feasibility study by Kornecki et al. (1999) using two cationic surfactants, ISML and LC. Flushing tests were conducted on saturated columns containing a sandy loam that was spiked with lead nitrate. ISML and LC desorbed 94% and 92% of the lead, respectively. However, only 20 pore volumes of 0.025 mol/l ISML was required to remove 50% of the lead, as opposed to 230 pore volumes of 0.025 mol/l LC to remove the same amount. In both studies, Kornecki et al. showed that the lower pH enhanced the mobility of Pb by reducing it to soluble Pb^{+2} forms and subsequent competition for cation exchange sites.

Following on Kornecki's success, this study attempts to determine the feasibility of using the cationic surfactant, ISML, to remove lead, cadmium, and zinc from a historically contaminated smelter soil.

Materials

Surfactants

Isostearamidopropyl morpholine lactate (ISML), is a cationic surfactant obtained from the Witco Corporation (Dublin, OH). Its molecular formula is $C_{25}H_{50}N_2O_2{*}C_3H_6O_3$ and has a molecular weight of 503g/mol. ISML, as produced by the manufacturer, is 24.7% active, has a solution pH of 4.16, a solution viscosity of 1.0526 mm^2/s at 0.025M concentration and at 22°C, and a critical micelle concentration (CMC) of 0.02mM.

Percentage active ingredient, solution pH, and solution viscosity were measured by Kornecki et al. (1998). Critical micelle concentration was taken from Beiergrohslein (1998). All other property information was obtained from the Witco Corporation (1999).

Soil

The soil used in this study is Blackwell Loam taken from an abandoned zinc-smelting site in Blackwell, Oklahoma. This soil contains high concentrations of zinc, cadmium, and lead. Soil properties were measured by Gradwohl (1994). Blackwell Loam is a neutral soil with a pH of 6.4. Its electrical conductivity is 2.9 dSm^{-1}, and the organic content is 1.88%. Total metal concentrations were measured using the USEPA Method 3050B. A potentially bioavailable assessment sequential extraction (PBASE) procedure was also performed by Gradwohl (1994) to determine what soil fraction the metals are associated with and the desorption potential of the metals. The sequential extraction observed four fractions from the most readily available fraction to the least soluble fraction. The first fraction is the exchangeable or readily soluble fraction and is measured by the amount of metal extracted with a 0.5M $Ca(NO_3)_2$ solution at 25° C. The second fraction, acid-soluble, is metal that is extracted by a weak acid solution. In this case, the solution is 1M NaOAc at the same temperature as before. The metals that are associated with this soil fraction are generally those that have formed weak surface complexes with the soil particles and are associated with carbonates in the soil. A solution of 0.1M Na_2EDTA is used for the third fraction. This fraction includes all surface complexes and precipitates that are not as readily available as the metals associated with the first two fractions. The third fraction generally consists of metals associated with organic matter in the soil. Finally, the very insoluble or occluded metals are extracted by a heated digestion with 4M HNO_3 at 80° C. This fraction is usually referred to as the residual fraction, because the metals in this fraction are not expected to be removed within a reasonable amount of time under natural conditions. The results of the PBASE analysis are listed in Table 1. The total original concentrations of metals are 296 mg/kg, 497 mg/kg, and 12,740 mg/kg for Cd, Pb, and Zn, respectively.

Table 1. PBASE – Soil Fraction Content

Metal	Exchangeable (% Readily Soluble)	Acid Soluble (% Weak Surface Complexes)	Surface Complexes (% Precipitates)	Very Insoluble (% Occluded)
Cd	60	30	3	7
Pb	1	59	24	16
Zn	10	52	18	20

Experimental Procedures

Soil Sample Preparation

Three saturated column experiments were conducted with Blackwell soil contaminated with zinc, cadmium, and lead. The soil was air dried and sieved through a standard No. 20 sieve (< 0.85mm) to remove any debris. It was then oven dried at 105 degrees Celsius for 24 hours to reduce microbial activity. Finally, deionized water was added to the soil to produce five- percent moisture content for column packing.

Surfactant Solution Preparation

Three column experiments were performed. The first experiment used a standard soil solution, without ISML, as the influent. The soil standard solution is a 0.1N $CaSO_4$ solution made up of one part saturated $CaSO_4$ solution and two parts deionized water. The other two columns were flushed with 0.025 mol/L and 0.05 mol/L ISML solutions. The 0.025 mol/L concentration is based on the cationic surfactant solution concentrations used by Kornecki et al. (1999), and the 0.05 mol/L concentration was selected to determine the effects of concentration on the removal of the heavy metals from the soil. The ISML solutions were prepared by adding deionized water to the surfactant by weight to achieve the desired concentrations.

Columns

Column ends and barrel were made of clear acrylic, and the barrel was lined with neoprene to prevent sidewall leaking. A 39.6 mm inside diameter by 152 mm length column was used, and soil was packed in 50 g lifts. Column densities and porosities for the three tests are listed in Table 2. Vacuum saturation was performed on the column using standard soil solution for 24 hours. Surfactant was pumped into the column through Tygon ® tubing connected to a peristaltic pump at a flow rate of 0.5 mL/minute, while an automated fraction collector sampled column effluent.

Table 2. Column Properties

Column	Density (g/cm^3)	Porosity
0.1N $CaSO_4$	1.70	0.294
0.025M ISML	1.58	0.313
0.05M ISML	1.50	0.347

Sample Analysis

The effluent from the column was analyzed for zinc, cadmium, lead, pH, and surfactant concentration. The effluent samples were divided into four groups. Every fourth sample was filtered through a 45µm syringe filter and measured by inductively coupled plasma (ICP) to ascertain zinc, cadmium, and lead concentrations. Most samples were diluted by a factor of ten to enable measurement of high zinc concentrations. The second group of samples was used to measure pH, using a pH probe. The third group of samples was analyzed by a colorimetric method using methyl orange and adapted from Kornecki et al. (1999) to determine the surfactant concentration in the effluent. Colorimetric measurements were obtained using a spectrophotometer at a wavelength of 418 nm. The fourth group of samples was used for the quality control tests performed at the end of the study to determine whether or not some of the metal was being sorbed onto the filters. This was accomplished by wet digestion of unfiltered effluent samples with perchloric acid.

Experimental Results

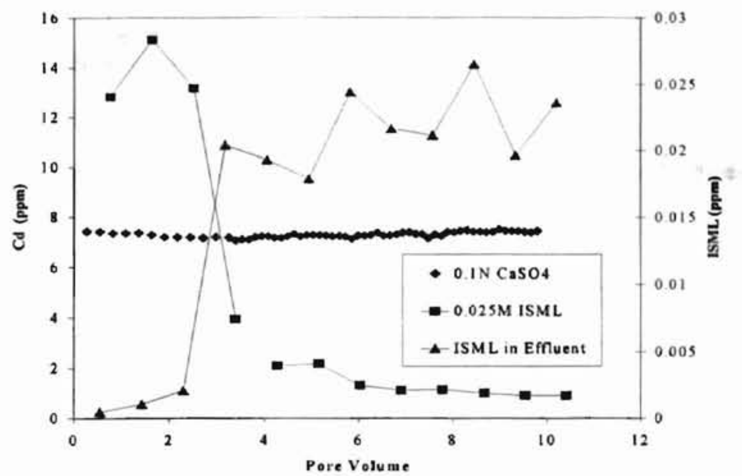
A comparison of the results of all three columns after 10 pore volumes with three solutions is presented in Table 3. The standard soil solution, 0.1N $CaSO_4$ removed only 4.4, 0.04, and 1.4% of Cd, Pb, and Zn, respectively. Figure 1 shows a steady metal concentration in the column effluent. They were only approximately 7.5, 100, and 0.12 ppm for Cd, Zn, and Pb, respectively.

Table 3. Comparison of Removal Efficiencies of Columns After 10 Pore Volumes

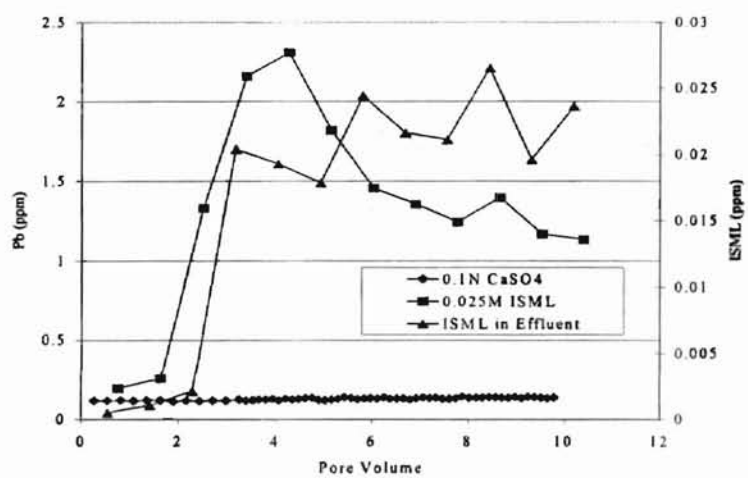
		Column		
	Metal	0.1N $CaSO_4$	0.025M ISML	0.05M ISML
Original Content (mg)	Cd	89.5	83.2	79.6
	Pb	150.3	139.7	133.7
	Zn	3854	3580	3427
Amount Removed (mg)	Cd	3.93	3.22	1.66
	Pb	0.066	0.764	1.48
	Zn	54.5	93.9	92.6
Percent Removed (%)	Cd	4.4	3.9	2.1
	Pb	0.04	0.55	1.1
	Zn	1.4	2.6	2.7

The addition of 0.025M ISML decreased the amount of Cd removed from the column. Only 3.9% was removed after 10 pore volumes and a total of 4.8% was removed after 25 pore volumes. Removal of Pb and Zn was increased to 0.55 and 2.6% after 10 pore volumes, and after 25 pore volumes, 1.3 and 3.3% of Pb and Zn were removed. A drop from 6.5 to 4 in the pH was observed just after 2 pore volumes as shown in Figure 2. This coincides with the peaks of concentration for Cd and Zn in the

a)



b)



c)

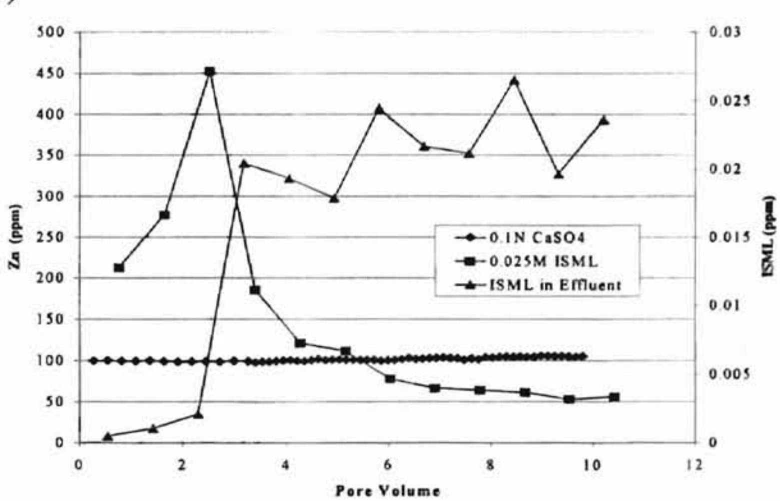


Figure 1. Effluent metal concentrations for water only and 0.025M ISML leachate. Effluent ISML Concentrations are also shown: a) Cd, b) Pb, and c) Zn.

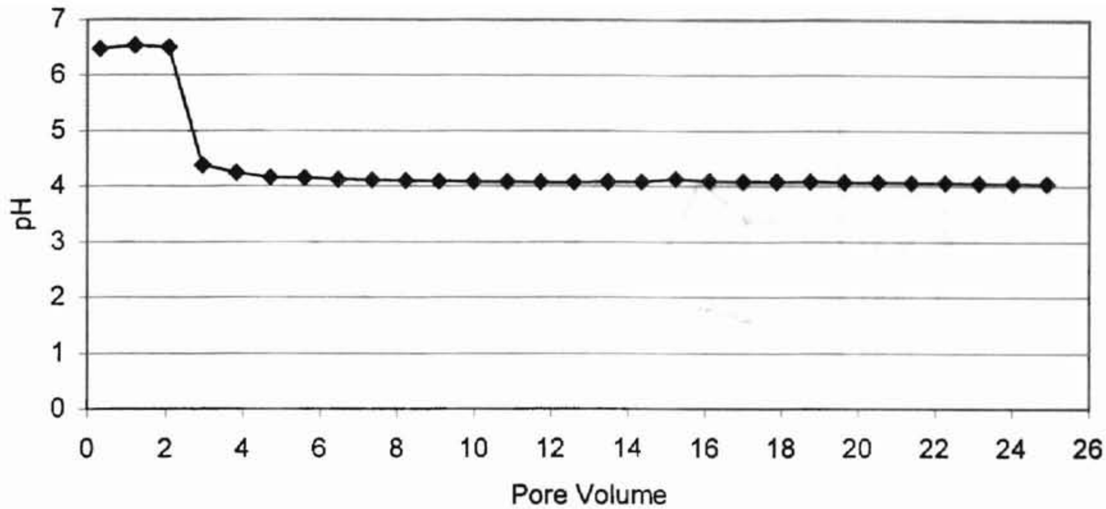
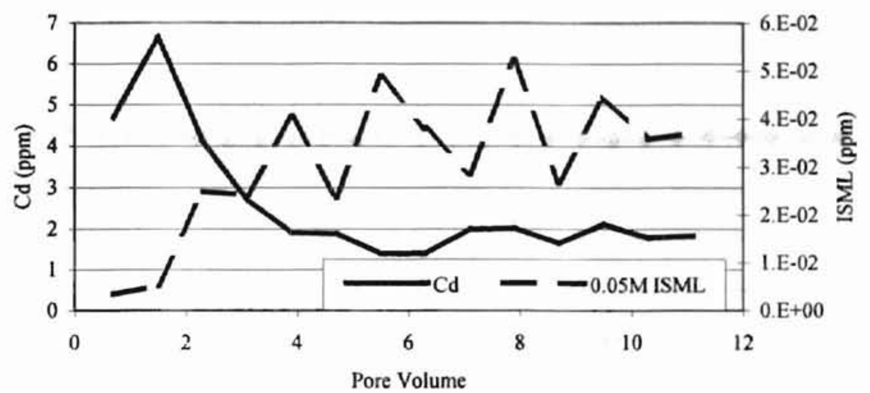


Figure 2. pH vs. Pore Volume for 0.025M ISML

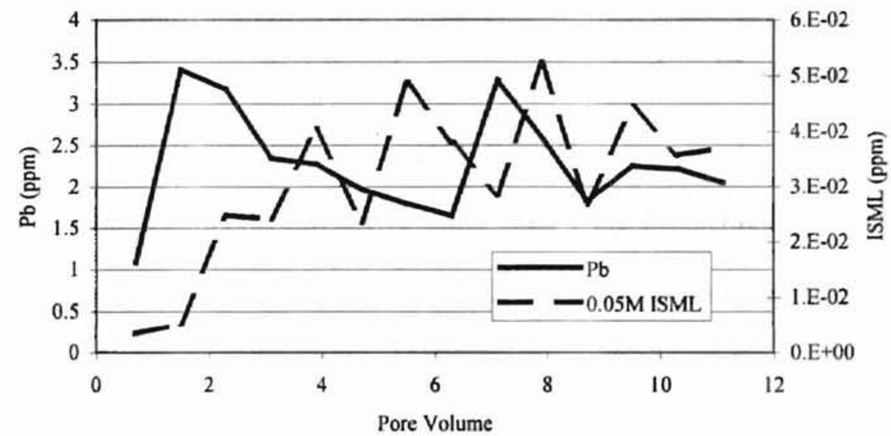
effluent. The concentrations then drop off as the concentration of the surfactant increases and levels off as shown in figures 1a and 1c. Lead does not peak until 4 pore volumes. Lead seems to follow the same basic trend as the other two metals, but the portion after the peak does not drop off as quickly. The Pb concentration appears to level off along with the surfactant concentration.

Figure 3 presents the effluent concentrations for the 0.05M ISML leachate. Once again, the amount of Cd removed decreased with an increase in the concentration of the cationic surfactant, ISML. At 10 pore volumes, only 2.1% of the Cd was removed, and 21 pore volumes of influent removed 3.5%. The amount of Pb and Zn removed from the soil increased again. At 10 pore volumes, 1.1 and 2.7% of Pb and Zn were removed. At 21 pore volumes, 2.1 and 4.5% of Pb and Zn were removed. The pH dropped from 6.8 to 4 within 1 pore volume with the increased surfactant concentration as shown in Figure 4. The peak concentrations for Cd and Zn remained at approximately 2 pore volumes.

a)



b)



c)

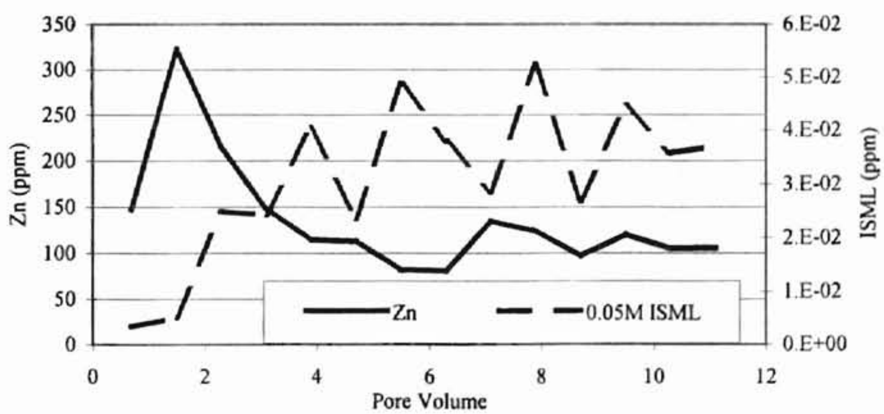


Figure 3. Effluent metal concentrations for 0.05M ISML leachate. Effluent ISML concentrations are also shown: a) Cd, b) Pb, and c) Zn.

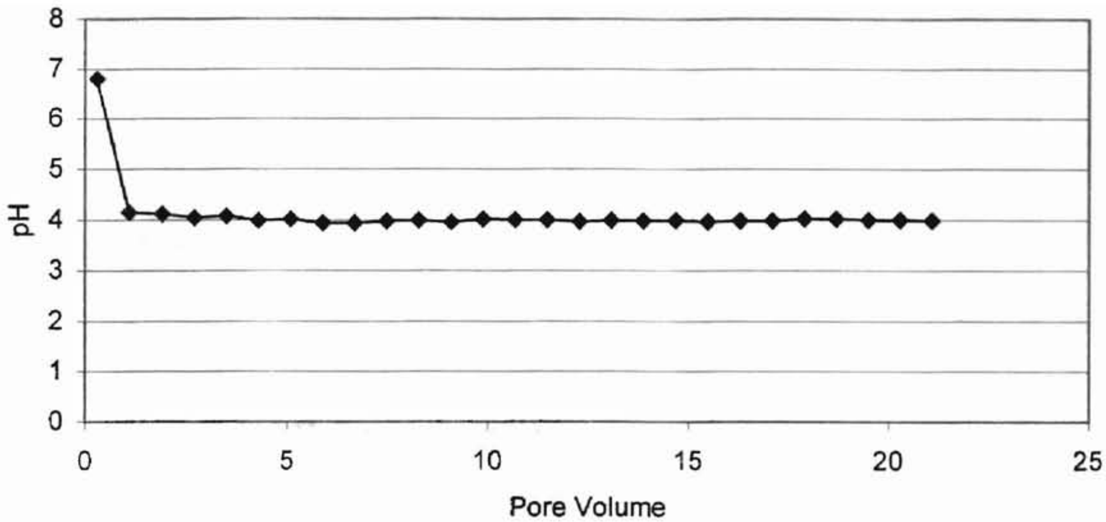
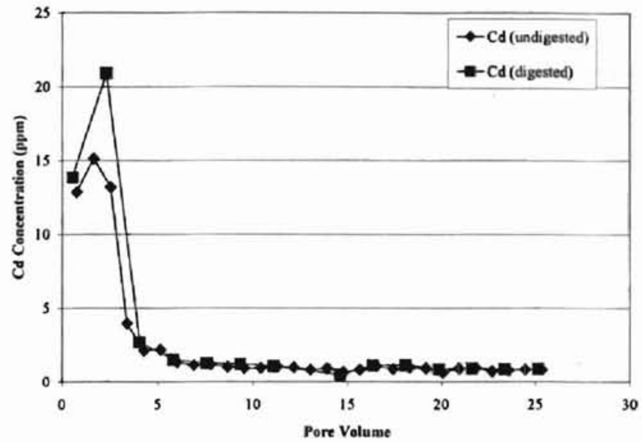


Figure 4. pH vs. Pore Volume for 0.05M ISML

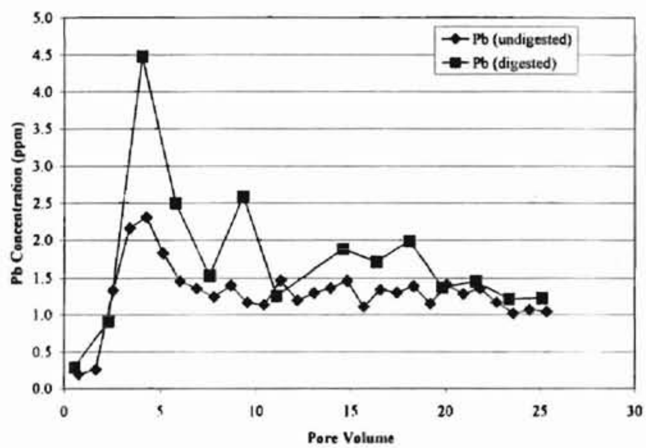
However, Figure 3c shows that the Pb concentration in the effluent had more than one peak at 2 pore volumes and again at 7.5 pore volumes.

Due to small removal rates, two other tests were performed in order to determine the source of any possible errors. The objective of the first test was to make sure that no significant amounts of surfactant and dissolved metals were being adsorbed onto the filters. This was achieved by digesting unfiltered 0.025M ISML effluent samples with perchloric acid, measuring metal concentrations using the ICP, and comparing the results with the original effluent concentrations for the same surfactant concentration. In Figure 5a, the digested sample concentrations of Cd were higher than for the filtered. However, they both followed the same basic trend, and the greatest difference between the two was approximately 7 ppm at 2 pore volumes. Figure 5b shows the comparison of digested and filtered for the concentration of Pb in the effluent samples. The digested series shows a peak at 4.5 ppm at approximately 4 pore volumes, and the filtered series shows a

a)



b)



c)

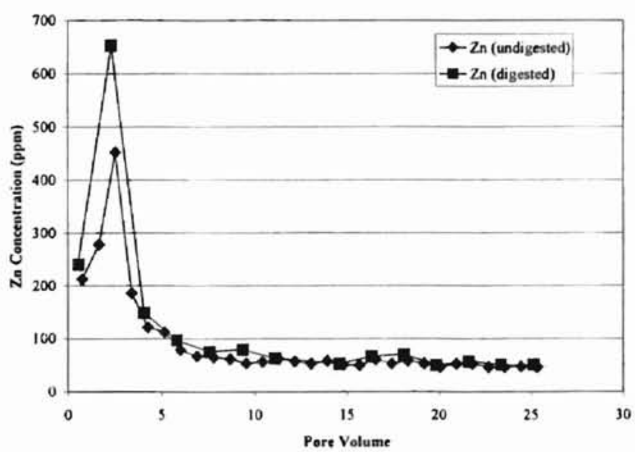


Figure 5. Effluent Metal Concentration comparing digested and undigested 0.025M ISML samples: a) Cd, b) Pb, and c) Zn.

peak of 2.3 ppm at the same pore volume. Once again, these series follow similar trends. The Zn concentrations for both series are shown in Figure 5c, and are almost identical after 5 pore volumes. There is a 200 ppm difference in concentrations at the peaks found at 2.5 pore volumes.

The objective of the second test was to determine whether or not there was a problem measuring actual metal content, as may occur if the metals were in forms that were not measurable by the instrumentation used to analyze the data. This was accomplished by spiking solutions with known concentrations of Cd, Pb, and Zn. The spiked solutions were allowed to equilibrate for 2 hours and then metal concentrations were measured by ICP as before. The original concentrations of the metals in the spiked solutions were as follows: Cd concentration was 0.9485μg/ml, Pb concentration was 0.9387 μg/ml, and Zn concentration was 0.9467μg/ml, and average recovery percentages are listed in Table 4, below. This test was performed in quadruplicate. The solution with the higher surfactant concentration had a slightly lower recovery rate than the 0.025M ISML solution. Pb had the highest recovery percentage of the three metals and Zn had the lowest.

Table 4. Results of Spike Recovery.

Sample	% Cd Recovered	% Pb Recovered	% Zn Recovered
0.025M ISML	87.5	90.0	85.4
0.05M ISML	81.4	83.8	77.2

Discussion

Overall, the addition of ISML to the flushing solution did increase the mobility of lead and zinc. However, it did not perform as well as anticipated from the results of the experiments by Kornecki et al. (1999). Less than 5% of each of the heavy metals was removed after passing 20 pore volumes through both of the columns that contained ISML in the flushing solution. Kornecki et al. (1999) were able to remove over 50% of the lead from an artificially contaminated soil after 20 pore volumes. Using batch testing, Beiergrohslein (1998) only removed 0.05 and 2.6% of Pb and Zn from a historically contaminated soil, from another zinc smelting site in Oklahoma, with a 0.02mM ISML solution. His results agree with the findings of this study. The amount of lead and zinc that is readily available according to the potentially bioavailable assessment sequential extraction (PBASE) by Gradwohl (1994) equates to 1% and 10% of the total content of each metal in the soil, respectively. An increase in the surfactant concentration did cause an increase in the removal efficiency, but ISML did not remove a significant amount of any of the metals. It seems that the drop in the pH, as a result of adding ISML to the flushing solution, is what mobilized the lead and the zinc, as opposed to the cationic surfactant causing desorption of the metals based on competition for sites and the CEC of the soil.

The removal of cadmium was inhibited by the addition of ISML. Approximately 60% of the Cd was in the readily available soil fraction according to PBASE results shown in Table 3 (Gradwohl, 1994), which would explain why the 0.1N $CaSO_4$ solution was able to remove 4.4% of the Cd in 10 pore volumes. According to a study by Doong et al. (1998), cationic surfactants decrease the desorption of Cd, Pb, and Zn from the soil under neutral pH conditions. The removal of Cd was somehow decreased by the addition of ISML, since the columns using 0.025M and 0.05M solutions of ISML as the influent removed 3.9 and 2.1% after 10 pore volumes. Beiergrohslein (1998) was able to remove 6.1% of the Cd at pH 4 with a 0.02mM ISML solution in a batch study. Beiergrohslein (1998) also found that the highest removal efficiency for Cd occurs at pH 7, which may partially explain the decrease in removal efficiency with the addition of the cationic surfactant. Studies by Doong et al. (1998) and Beiergrohslein (1998) also showed that chelating agents such as EDTA and citric acid were more successful in removing the heavy metals from other types of contaminated soil.

The tests performed to ascertain whether or not there was some error in measuring metal concentration, either by adsorption of surfactants and metals onto the filter or by complex forms of the metals not measurable by the ICP did illuminate some measuring error. However, it was not enough to explain the low removal rates or the why the soil standard soil solution alone was able to remove more Cd than influents with surfactants.

Potential explanations for the behavior of the metals in the soil are uncertain at this time. One possibility may be found in the results of the PBASE process shown in Table 3. The existing forms of the metals allow them to remain sorbed onto the soil despite the decrease in pH. In other words, the lower pH did not produce soluble Pb^{+2} forms. Perhaps this is further complicated by the complexes formed by ISML at the soil particle surface, and instead of acting as a sink for the insoluble metals, the surfactant traps the metal in the pores of the soil particles.

Conclusions

ISML did not significantly enhance the removal of the heavy metals from the soil. ISML leaching removed only 2.1 and 4.5% of Pb and Zn, respectively, from the column flushed with a 0.05M solution of ISML after 21 pore volumes. Increased concentration of the surfactant did remove more of the metals Pb and Zn, but did not perform as well as anticipated from the results obtained by Kornecki et al. (1999). On the other hand, the removal efficiency of Cd was decreased by the addition of ISML to the flushing solution. The column using only a standard soil solution as the influent, removed 4.4% of the Cd after 10 pore volumes, whereas, the column using a 0.05M ISML solution as the influent removed 2.1% in the same number of pore volume. Thus, the chemical form of the metal in the soil is critical to the evaluating its potential removal by surfactants. This is in strong contrast to studies performed on artificially contaminated soils.

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CHAPTER III

EFFECTS OF SURFACTANTS ON SOIL PROPERTIES

Abstract

The effects of surfactants on soil mechanical properties were evaluated. Three surfactants, two cationic and one anionic, were added to two soils, Teller loam and Slaughterville sandy loam. Soil properties including plasticity, compaction, consolidation, and shear strength were evaluated for altered and unaltered samples of both soils. The Liquidity Index indicated that Teller loam exhibits more plastic behavior as a result of added surfactants, while plastic limits for the Slaughterville sandy loam were unavailable due to low cohesive nature of material. The surfactants had no notable effects on the compaction properties or settlement of the Teller loam. However, preconsolidation stress measurements showed a notable increase for one cationic surfactant and decreases for the anionic and the other cationic. Surfactant addition caused lower optimum moisture contents and a sharp drop in dry bulk density just wet of optimum for Slaughterville sandy loam series. Settlement estimates were decidedly smaller than that in Teller loam. Unaltered samples consistently experienced greater amounts of consolidation than samples with surfactant additives. The anionic surfactant decreased shear strength of both soils, though with catastrophic effects in Slaughterville sandy loam. Surfactant concentration had no notable effects on soil strength.

Introduction

Increased use of surfactants for in-situ remediation has prompted some concerns about their effects on soil properties. Previous studies have studied the effects of surfactants on soil hydraulic conductivity. Allred and Brown (1994) studied surfactant-induced reductions in hydraulic conductivity to determine the feasibility of using surfactants in soil flushing operations. Tumeo (1997) studied the various causes of surfactant-induced changes on hydraulic conductivity. Others have studied adsorption of surfactants onto the soil matrix. However, very little work has been conducted toward characterizing the effects of surfactants on properties that effect soil strength. Allred et al. (1998) studied the effects of surfactants on mechanical compaction and found that, while the maximum dry bulk density of the soil was not affected by the presence of surfactants, the corresponding optimum moisture content was. Soil strength is a concern on remediation sites where future land use becomes an issue. This study explores the effects of three surfactants, two cationic and one anionic, on the plasticity, compaction, consolidation, and direct shear of two different soils.

Soil engineering properties are affected by characteristics including a) the clay minerals present in the soil; b) the ions in the pore water; and c) the stress history of the soil. Plasticity of a soil is governed by the moisture content of the soil. This is important since the presence of water in the soil voids can affect the behavior of fine-grained soils (Holtz and Kovacs, 1981). For example, some soils are sensitive to the breakdown of the soil structure. As long as they remain undisturbed, they are relatively strong, but if they are sheared and the soil structure breaks down they may flow like a liquid (Holtz and Kovacs, 1981).

Compaction is a function of four variables: dry bulk density, water content, compactive effort, and soil type. The objective of compaction is to stabilize soils and improve engineering behavior. Some of the advantages of compaction are that detrimental settlements may be reduced or prevented, soil strength and stability may be improved, bearing capacity may be improved, and undesirable volume changes may be controlled. The point of studying soil compaction for this study is to determine the change in optimum water content by surfactants, if any are incurred. Optimum water content is the water content that corresponds with the maximum dry bulk density achieved by the compaction test.

Consolidation is an important consideration when studying soil properties, also. When materials are loaded or stressed, they deform or strain. This may happen instantaneously or over a long period of time. Vertical deformation is referred to as settlement, and engineers are interested in the possible amount of settlement that will occur for a given external load and its rate of occurrence for design purposes. According to Holtz and Kovacs (1981), total settlement consists of three components: immediate settlement, consolidation, or time-dependent settlement, and secondary compression, which is also time-dependent. Consolidation occurs in fine-grained soils and is dependent upon the rate of pore water drainage, which in turn is dependent upon the permeability of the soil.

Shear strength of a soil is one of the most important parameters in structural design, since failure of a foundation or earth-fill structure may be a result of excessive shear force applied to the soil (Das, 1984). "Failure" can be defined as that point at which the applied load or stress causes the deformation of the soil to become unacceptably large (Holtz and Kovacs, 1981).

Materials

Surfactants

Surfactants, short for surface-active agent, are organic molecules consisting of a hydrophilic head and a hydrophobic tail. This amphiphilic structure causes a tendency for these molecules to concentrate at phase boundaries and to alter interfacial properties such as surface tension. They are classified according to the charge carried by the hydrophilic head group. Thus, anionic, cationic, and nonionic surfactants are all possible. At a certain concentration known as the critical micelle concentration (CMC), surfactant molecules have the ability to self-assemble into aggregates called micelles. Their ability to decrease surface tension at phase boundaries at concentrations above the CMC may affect the behavior of soil. This may occur either by making a structural breakdown more likely, or by "lubricating" the soil particles and allowing them to obtain a denser structure, thereby increasing the strength of the soil.

In this study, three surfactants were used including two cationic and one anionic. All are listed in Table 5 along with their various properties.

CMC measurements were determined by Allred et al (1998) from surface tension measurements of aqueous surfactant solutions at 22° Celsius. Surfactants C1 (cat#: 86,042-5) and A1 (cat#: 28,995-7) were obtained from Aldrich Chemical Company, Milwaukee, WI, and C2 (trade name EMCOL CC-9) was obtained from Witco, Greenwich, CT.

Table 5. Surfactant Properties

Symbol	Chemical Name	Classification	Molecular Weight (g/mol)	CMC (mol/L)	Surface Tension (dynes/cm)
C1	Tetradecyl Trimethyl Ammonium Bromide	Cationic	336	$2.4 * 10^{-3}$	37.8
C2	Polyoxypropylene Methyl Diethyl Ammonium Chloride	Cationic	600	$1.2 * 10^{-3}$	40
A1	Sodium Dodecyl Benzene Sulfonate	Anionic	348	$5.4 * 10^{-3}$	35.7

Soils

Two soils were used in this study: Teller loam and Slaughterville sandy loam. Both were taken from a field site near Perkins, Oklahoma. Soil properties are listed in Table 6.

Table 6. Soil Properties

Soil	% Sand	% Silt	% Clay	pH	EC	CEC	% OM
Teller Loam	35	43	22	6.02	0.45	11.46	1.88
Slaughterville Sandy Loam	70	25	5	7.52	0.295	5.87	0.16

The Teller loam is a fine-grained, neutral soil with a moderate organic matter content (OM) and cation exchange capacity (CEC). The low electrical conductivity (EC) indicates that the soil is not salt affected. The Slaughterville sandy loam is composed of a relatively high percentage of sand. Its pH of 7.52 indicates that this is a calcareous soil, and thus, has free calcium and magnesium carbonates. The EC is smaller than that of the Teller loam, and the CEC is also relatively small. The low OM% indicates that this soil has low organic matter adsorption. Soil grain size distribution was measured by a mechanical sieve analysis in accordance with ASTM D 421 and ASTM D 422. The soil chemical properties: pH, EC, CEC, and OM were determined by the SWAT Laboratory, New Mexico State University, Las Cruces, New Mexico.

Experimental Methods

Soil Preparation

Both the Slaughterville and Teller soils were observed in this study at concentrations of 0.5% and 1% for each A1, C1, and C2. Unaltered samples of each soil were tested as controls. Soils were prepared by adding a ten percent (by weight) aqueous surfactant solution to a 2 kilogram sample of dry soil. Surfactant solution was added by evenly spraying the soil with a fine mist in 25 gram increments to obtain concentrations of 0.5% or 1.0%. After adding the surfactant solution, the soil was then saturated with distilled water and allowed to air dry for 48 hours. Once the soil was dried, a mortar and pestle were used to break up any soil aggregates that passed through a 2 mm sieve.

Atterberg Limits

Atterberg limits are water contents at critical stages in soil behavior including: the upper limit of viscous flow, where the soil behaves as a liquid; the liquid limit, which is the critical point where soil behavior begins to act as a plastic material and stops behaving as a liquid; the sticky limit, which is where clay loses its adhesion to a metal blade; the cohesion limit, point where soil grains no longer adhere to each other; the plastic limit, which is the point at which the soil begins to behave as a semisolid; and the shrinkage limit, which is the critical point where soil behaves as a brittle solid (Holtz and Kovacs, 1981). These limits are used with other soil properties to correlate with engineering behaviors such as compressibility, permeability, compactibility, shrink-swell, and shear strength. Atterberg limits are also used to classify soils, specifically the composition of the fines in a soil. Of the five limits, two were measured in this study: the liquid limit and the plastic limit. The range between the liquid limit and the plastic limit is called the plasticity index and can be defined as the range of water contents where the soil is plastic. Liquid and plastic limits were determined for both soils in accordance with ASTM Designation 04318.

Compaction

Compaction tests, also referred to as Proctor tests, provide the basis for determining the percent compaction and the water content required to achieve the acceptable shear strength, compressibility, and permeability for a given situation. Compaction is used to stabilize soils, and as a result, prevent or reduce detrimental settlements and improve soil strength and stability. Bearing Capacity may also be improved, and undesirable volume changes may be controlled through compaction. All compaction tests were performed according to ASTM Designation 698.

Consolidation

Consolidation tests are used to estimate the magnitude and rate of both differential and total settlement of a structure or earth fill. Testing followed ASTM Designation 2435 to measure settlement data. Normally, consolidation tests are performed on undisturbed samples. Samples for this experiment have been completely remolded. All samples were exposed to uniform conditions, thereby showing trends that would be applicable to field conditions. However, more experiments should be performed on undisturbed samples, if possible.

Shear Strength

The direct shear test is used to assess the strength of a soil in a field situation where complete consolidation has occurred under existing normal stress. It is a relatively quick test for consolidated drained strength properties since the drainage paths through the test sample are so short, as compared with the triaxial test. Shear strength data was also measured in accordance with ASTM Designation 3080.

Results and Discussion

Atterberg Limits

Results for liquid and plastic limits are shown in Table 7. Each soil exhibited very different qualities. The plasticity index (*PI*) of the Teller loam was affected by the addition of surfactant. Samples containing A1 and C1 both had lower PI's as well as lower liquid limits (*LL*). The *PI* for the sample where 1% C2 was applied was 5% larger than that of the unaltered sample. The plastic limit for the sample with C1 was 5% higher than that of the unaltered sample.

All of the Slaughterville sandy loam samples were nonplastic. No plastic limits were determined, with the exception of the sample containing C1. Plastic limits were not determinable due to the uncohesive nature of this soil. The *LL* for the unaltered sample was also unattainable. However, the *LL*'s, for A1 and C1 samples were similar. The *LL* for the C2 sample was higher than the other two by approximately 5%.

Table 7. Atterberg Limit results.

Soil	Treatment	Plastic Limit Moisture Content (%)	Liquid Limit Moisture Content (%)	Plasticity Index (%)
Teller Loam	Unaltered	18.02	31.29	13.27
	1% A1	17.70	26.58	8.88
	1% C1	23.07	30.26	7.19
	1% C2	17.77	36.20	18.43
Slaughterville Sandy Loam	Unaltered	N/A	N/A	Nonplastic
	1% A1	N/A	11.38	Nonplastic
	1% C1	14.09	11.09	Nonplastic
	1% C2	N/A	15.99	Nonplastic

Given the original moisture contents of the soil samples, unaltered and treated, the liquidity index for the Teller loam samples was determined. This property indicates the probable behavior of a soil being sheared and is expressed as:

$$LI = \frac{w_n - PL}{PI} \tag{1}$$

where LI is the liquidity index, w_n is the natural water content, PL is the plastic limit, and PI is the plasticity index (Holtz and Kovacs, 1981). In soils where $LI < 0$, the soil will have a brittle fracture if sheared. If $LI > 1$, then the soil will behave as a viscous liquid if sheared. Otherwise, it will behave as a plastic, which is ideal since the fabric of a plastic soil will gradually alter and adjust as the stress applied to the soil increases (Holtz and Kovacs, 1981). The liquidity indices for the Teller loam samples are listed in Table 8 along with w_n, below. The water contents were measured in accordance with ASTM Designation 2216. From Table 8, it can be seen that all three samples with surfactant additives would most likely behave as plastic materials. The LI for the unaltered sample is slightly greater than zero, but is still much less than 1 and would probably behave like a plastic material also.

Table 8. Liquidity Indices for Teller Loam

Soil Treatment	Water Content (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index (%)
Unaltered	19.14	18.02	13.27	0.08
1% A1	17.70	17.07	8.88	0.00
1% C1	23.07	23.07	7.19	0.00
1% C2	17.77	17.77	18.43	0.00

Compaction

Compaction test results for the Teller loam samples are shown in Figure 6. No notable effects were observed by the addition of surfactant to the soil. All four samples followed the same basic trend with maximum dry bulk densities between 1.78 and 1.83 g/cm^3. Optimum moisture contents fell between 12% and 14% for samples containing 1% surfactant concentrations. Compaction tests were also performed on soil samples containing a 0.5% surfactant concentration. The results of these test samples also followed the same trend. The maximum dry bulk density was between 1.8 and 1.83g/cm^3, and the optimum moisture content was approximately 13% for all four samples.

The addition of surfactants had a more pronounced affect on the Slaughterville sandy loam than on the Teller loam. These results are summarized in Table 9. As shown in Figure 7a, only C2 follows the trend of the unaltered sample and has a slightly lower dry bulk density. This soil is nonplastic, as was revealed by the results of the Atterberg limits, causing the density to drop off quickly just wet of optimum. The addition of A1 and C1 to the soil caused the maximum dry bulk density to occur at a much lower moisture content and the density to drop more rapidly on the wet side of optimum than in an unaltered state. The maximum bulk densities of the samples containing the surfactants were all slightly higher, 1.79, 1.81, and 1.81 g/cm^3 for A1, C1, and C2, than that of the unaltered sample, 1.79 g/cm^3. The samples containing 0.5% surfactant concentrations had similar results. All samples had maximum dry bulk densities of approximately 1.8 g/cm^3, and, once again, the optimum moisture contents for the samples containing A1 and C1 were lower than those for the unaltered sample and the sample containing C2. The only visible difference, as can be seen in Figure 7b, is that the density of the sample containing 0.5% A1 decreases much more rapidly than it did at a 1% concentration of A1.

Table 9. Compaction Test Results for Slaughterville Sandy Loam.

Soil Treatment	Optimum Moisture Content (%)	Maximum Dry Bulk Density (g/cm^3)
Unaltered	11.5	1.77
1.0% A1	9.14	1.79
1.0% C1	8.96	1.81
1.0% C2	11.37	1.81
0.5% A1	9.1	1.81
0.5% C1	8.4	1.80
0.5% C2	11.41	1.81

Consolidation

Teller Loam

Consolidation test results for Teller loam samples are summarized in Table 10 and Table 11 below. H_o is the initial height of the sample and was approximately one inch for all samples, and H_s is the height of solids. The initial void ratio, e_o, the decrease in void ratio, Δe, and H_o are used to estimate the settlement of the soil layer, s, using equation (2) (Holtz and Kovacs, 1981)

$$s = \frac{\Delta e}{1 + e_o} Ho \tag{2}$$

From Table 10, the estimated settlement for the unaltered, 1% A1, and 1% C1 samples were approximately 0.1 inches and not significantly different. If the void ratio is plotted against the effective vertical stress, σ_v, provided by the various external loads placed on the samples, as shown in Figure 8, the slope of the resulting curve is called the coefficient of compressibility, a_v. It is represented by

$$a_v = \frac{\Delta e}{\Delta \sigma_v} \tag{3}$$

where Δe is the decrease in void ratio and $\Delta \sigma_v$ is the difference in effective stress or pressure in the vertical direction (Holtz and Kovacs, 1981).

Table 10 shows the values of a_v for A1 and C1 are similar and slightly smaller than those for the unaltered and C2 cases. Using the Casagrande procedure, the preconsolidation pressure, p_c, was graphically determined for each sample and is listed in Table 10. Considering that in reality, the samples all originally had the same preconsolidation pressure, it is interesting to note that the p_c for C1 was significantly higher than that for the unaltered sample. This may indicate a potential for the C1 sample to bear a larger overburden pressure. Both A1 and C2 exhibit a smaller capacity for overburden pressure as indicated by their p_c. It may also be noted that the initial densities of the samples, as indicated by H_s in Table 10, are different. This may account for the differences attained in the settlement estimates and those visible in Figure 8.

Table 10. Consolidation Test Results for Teller Loam

Soil Treatment	Unaltered	1% A1	1% C1	1% C2
H_o (inches)	0.998	1.001	0.997	N/A
H_s (inches)	0.576	0.621	0.578	0.594
e_o	0.7326	0.6119	0.725	N/A
Δe_o	0.1788	0.1691	0.1678	0.1983
s (inches)	0.103	0.0970	0.105	N/A
a_v (psi^{-1})	0.0133	0.0124	0.0125	0.0147
p_c (psi)	2.450	1.860	3.500	2.090

The time rate of consolidation is an important parameter in structural design. By plotting the actual dial readings from a consolidometer against real time for a given load, as shown in Figures 9 through 13, one can graphically determine the coefficient of consolidation, c_v (Holtz and Kovacs, 1981). This was done for Teller loam samples using Casagrande's logarithm-of-time method, where c_v is determined at a time, t_{50}, that represents the deformation of the soil at 50% primary consolidation (Das, 1994) and can be expressed as

$$c_v = \frac{0.197 H_{dr}^2}{t_{50}} \tag{4}$$

where H_{dr} is the length of the longest drainage path in the sample. The values of c_v for given external loads of 1,3,7, and 15 kg are summarized in Table 11 below. A1 had consistently smaller values for c_v for all of the given external loads, and therefore, a slower rate of consolidation than the other samples. The unaltered samples had the highest consolidation rates for 1 and 7 kg loadings. C1 maintained the same c_v for 1 and 3 kg load increments. However, the c_v of the 7 kg load for C1 was undeterminable because distinguishing between primary consolidation and secondary compression was difficult due to the linear nature of plotted data as can be seen in Figure 11.

Table 11. Coefficient of Consolidation for Teller Loam Series

Soil Treatment	Unaltered	1% A1	1% C1	1%C2
c_{v1} (in^2/min)	0.0181	0.00369	0.00935	0.01613
c_{v3} (in^2/min)	0.00751	0.00113	0.00935	0.0084
c_{v7} (in^2/min)	0.0156	0.00133	N/A	0.00794
c_{v15} (in^2/min)	0.0146	0.00197	0.0160	0.01132

Slaughterville Sandy Loam

Table 12 summarizes the results of the settlement calculations for the Slaughterville sandy loam series of this study, and Figure 14 is a graphical representation of decrease in void ratio with respect to effective stress (pressure). Beginning with the actual estimates for settlement for this series, it may be noted that the values of s are considerably smaller than those estimated for the Teller loam as well as a_v. Estimated settlement was determined to be 0.0329, 0.0252, and 0.0258 inches for the unaltered, A1, and C1 samples, respectively. The surfactant treated soils had a slightly smaller potential for settlement, and A1 treated soil had the smallest estimated s as it did in the Teller loam series. The preconsolidation pressure for the Slaughterville sandy loam is also less than that of the Teller loam. Once again, the initial densities as indicated by H_s in Table 12, of the samples are varied and may account for some the differences in settlement estimates.

Table 12. Consolidation Test Results for Slaughterville Sandy Loam

Soil Treatment	Unaltered	1% A1	1% C1	1% C2
H_o (inches)	0.998	1.005	0.998	N/A
H_s (inches)	0.635	0.652	0.664	0.656
e_o	0.5720	0.5414	0.5030	N/A
Δe_o	0.0518	0.0386	0.0388	0.0412
s (inches)	0.0329	0.0252	0.0258	N/A
a_v (psi^{-1})	0.00384	0.00288	0.00286	0.00305
p_c (psi)	1.780	2.000	1.1811	1.865

The time rate of consolidation for the Slaughterville sandy loam was determined by the Taylor's Square Root of Time method as described by Holtz and Kovacs (1981). Using this method, dial readings from the consolidometer are plotted against the square root of real time as shown in Figures 15-19, and c_v is determined at t_{90}, which is the time that represents the deformation of the soil at 90% primary consolidation and is represented by

$$c_v = \frac{0.848 H_{dr}^2}{t_{90}} \tag{5}$$

where H_{dr} is the length of the drainage path (Das, 1994). Taylor's method for determining c_v was used for analyzing the Slaughterville sandy loam data instead of the Casagrande method used on the Teller loam data because plotting the data using the logarithm of time gave a linear representation of the data and it was difficult to distinguish between primary consolidation and secondary as is necessary for Casagrande's method. Table 13 lists the values of c_v for 1, 3, 7, and 15 kg loads for all four sample types. By looking at Figures 15 through 19, it can be seen that the unaltered samples all experienced a greater amount of consolidation, even if the c_v is smaller than that of the surfactants as occurs for the 3 kg and 15 kg loadings.

Table 13. Coefficient of Consolidation for Slaughterville Sandy Loam Series

Soil Treatment	Unaltered	1% A1	1% C1	1%C2
c_{v1} (in^2/min)	0.0392	0.0507	0.0193	0.0342
c_{v3} (in^2/min)	0.0247	0.0826	0.0356	0.0653
c_{v7} (in^2/min)	0.0427	0.0351	0.0240	0.0563
c_{v15} (in^2/min)	0.0302	0.0739	0.0347	0.1247

Shear Strength

Teller Loam

Data obtained from the direct shear test was analyzed using the Mohr-Coulomb failure criteria as described by Das (1994) as

$$\tau_f = c + \sigma_f \tan\phi \qquad (6)$$

where τ_f is shear stress at failure, σ_f is normal stress at failure, c is cohesion, and ϕ is the angle of internal friction. From the data presented in Table 14, it may be noted that the addition of the anionic surfactant, A1, slightly decreased the soil strength. However, the concentration of that surfactant does not appear to have had any significant effects since the differences between the parameters for both samples are less than 5%. The addition of C1 slightly increased soil strength, and, once again, the concentration did not have any significant effects on soil strength. The addition of 0.5% C2 increased soil strength, while the addition of 1.0% C2 to the soil decreased soil strength slightly. Overall, the added surfactants had no significant effects on the strength of this soil. This may be due, in part, to the cohesive nature of this material.

Table 14. Shear and Normal Forces at Failure for Teller Loam soil

Soil Treatment	τ (kPa) at σ_n = 6.19 kPa	τ (kPa) at σ_n = 12.38 kPa	τ (kPa) at σ_n = 30.95 kPa	Slope	ϕ (degrees)	c
Unaltered	40.31	47.86	64.15	0.9431	43.32	35.204
0.5% A1	35.23	41.62	59.66	0.9832	44.51	29.275
1.0% A1	34.30	41.62	59.48	1.0011	45.03	28.642
0.5% C1	41.31	47.41	73.79	1.3369	53.20	32.102
1.0% C1	41.66	47.78	71.02	1.2009	50.21	33.663
0.5% C2	41.40	50.31	66.93	0.9997	44.99	36.378
1.0% C2	37.47	43.67	63.66	1.0621	46.72	30.735

Slaughterville Sandy Loam

The results summarized in Table 15 show that the Slaughterville sandy loam is a much less cohesive soil than the Teller loam, due to amount of sand in its composition. The addition of 0.5%C1, 1.0% C1, and 0.5% C2 to the soil slightly decreased soil strength. The 1.0% C2 sample showed slightly increased soil strength with a larger angle of internal friction and a higher cohesion parameter. The addition of the anionic surfactant had catastrophic effects. The soil failed quickly, and therefore, data was unavailable for a sample with a concentration of 1.0% A1. The soil lost almost all of its cohesion and had a small angle of internal friction.

Table 15. Shear and Normal Forces at Failure for Slaughterville Sandy Loam soil

Soil Treatment	τ (kPa) at $\sigma_n = 6.19$ kPa	τ (kPa) at $\sigma_n = 12.38$ kPa	τ (kPa) at $\sigma_n = 30.95$ kPa	Slope	ϕ (degrees)	c
Unaltered	19.88	25.07	40.61	0.8371	39.93	14.702
0.5% A1	3.66	4.00	N/A	0.0549	3.14	3.32
0.5% C1	17.75	23.65	39.68	0.8805	41.36	12.492
1.0% C1	16.55	21.83	38.78	0.9013	42.02	10.813
0.5% C2	18.08	23.75	39.08	0.8429	40.13	13.056
1.0% C2	21.85	27.69	44.42	0.9091	42.27	16.314

Conclusions

In this study, the concerns of surfactant effects on soil properties were addressed by observing the soil parameters, such as plasticity, compaction, consolidation, and shear strength, under various conditions. The effects of three surfactants including one anionic and two cationic, were observed on two different soils using the properties mentioned above.

A decreased *PI* was observed for A1 and C1 and an increased *PI* was observed for C2, as compared with the *PI* for the unaltered Teller loam sample. The liquidity indicates the Teller loam has slightly more plastic behavior as a result of the added surfactants.

Plastic limits for Slaughterville sandy loam were unattainable due to the low cohesive properties of the soil. The soil was found to be nonplastic for all Slaughterville samples.

There were no significant effects on the compaction data for the Teller loam samples. As with the study by Allred et al (1998), the addition of surfactants affected the optimum moisture contents. A1 and C1 samples exhibited lower optimum moisture concentrations and steep drop in the maximum dry bulk density just wet of optimum.

The addition of surfactants to the Teller loam did not affect the estimates for settlement, and the measured change in void ratio was similar for all four treatments. The p_c was significantly increased for C1 and significantly decreased for A1 and C2, while the coefficient of consolidation was noticeably smaller for A1 at all given external loads for the Teller loam. On the other hand, the estimates for the Slaughterville settlements were decidedly smaller than those for the Teller, and A1 and C1 had significantly smaller settlements than that for the unaltered sample. The unaltered samples of the Slaughterville samples consistently experienced greater amounts of consolidation than samples with surfactant additives. This may be due in part to the differences in the initial densities of the samples.

Finally, the addition of A1 significantly decreased the shear strength of both the Teller loam and Slaughterville sandy loam, although the effects were more pronounced in the Slaughterville data due to the uncohesive nature of the material. A1 caused catastrophic failure in the Slaughterville sandy loam. The cationic surfactants had no significant effects on the Teller loam, and surfactant concentrations had no notable effects on soil behavior except when C2 was increased in both soils.

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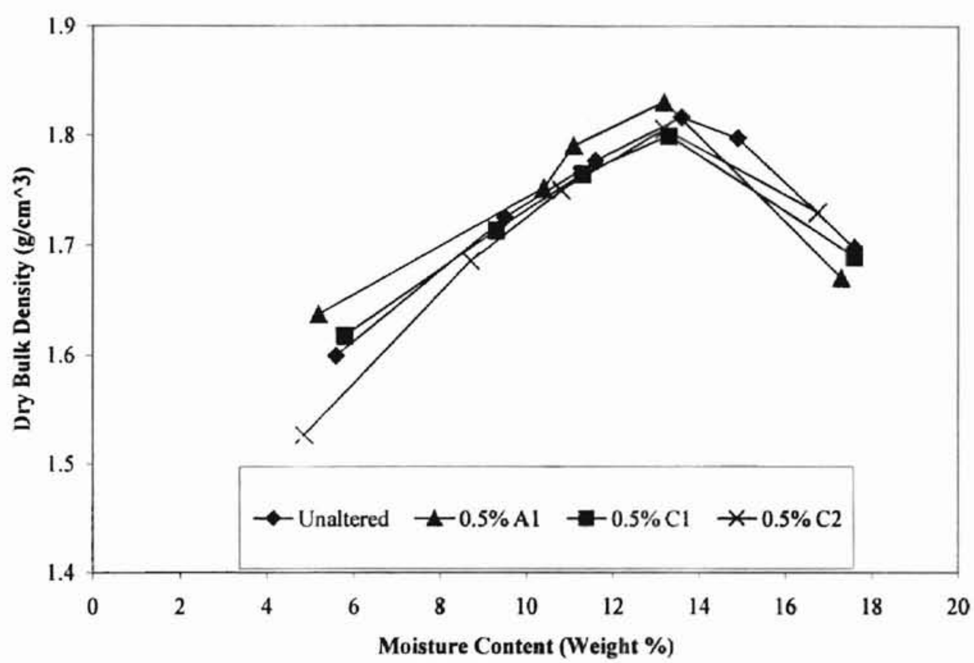


b)

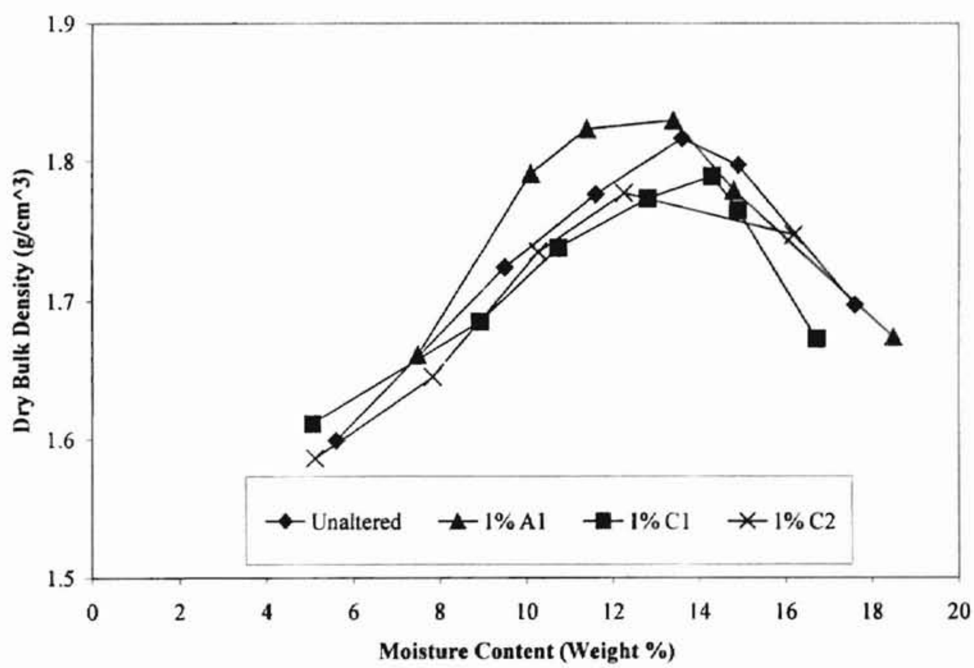
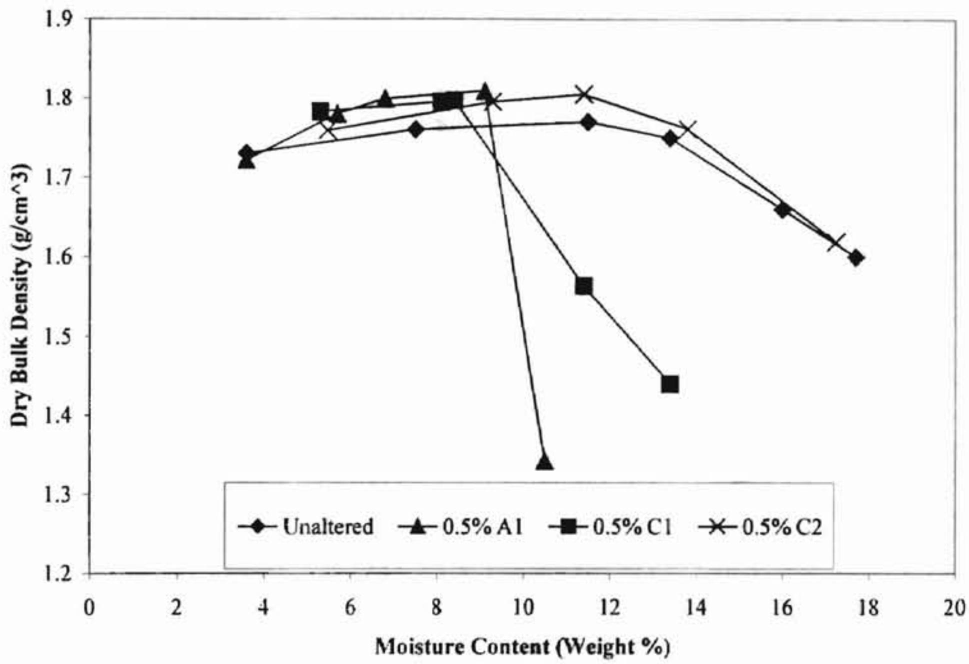


Figure 6.. Compaction test results for Teller loam a) at 0.5% surfactant concentration and b) at 1.0% surfactant concentration.

a)



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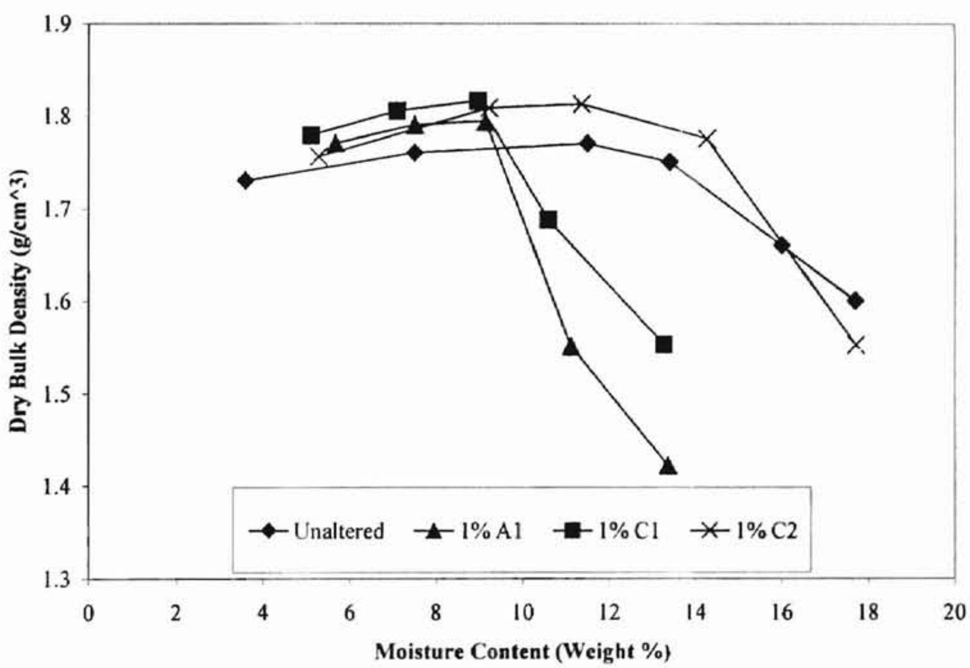

Figure 7. Compaction test results for Slaughterville sandy loam a) at 0.5% surfactant concentration and b) at 1.0% surfactant concentration

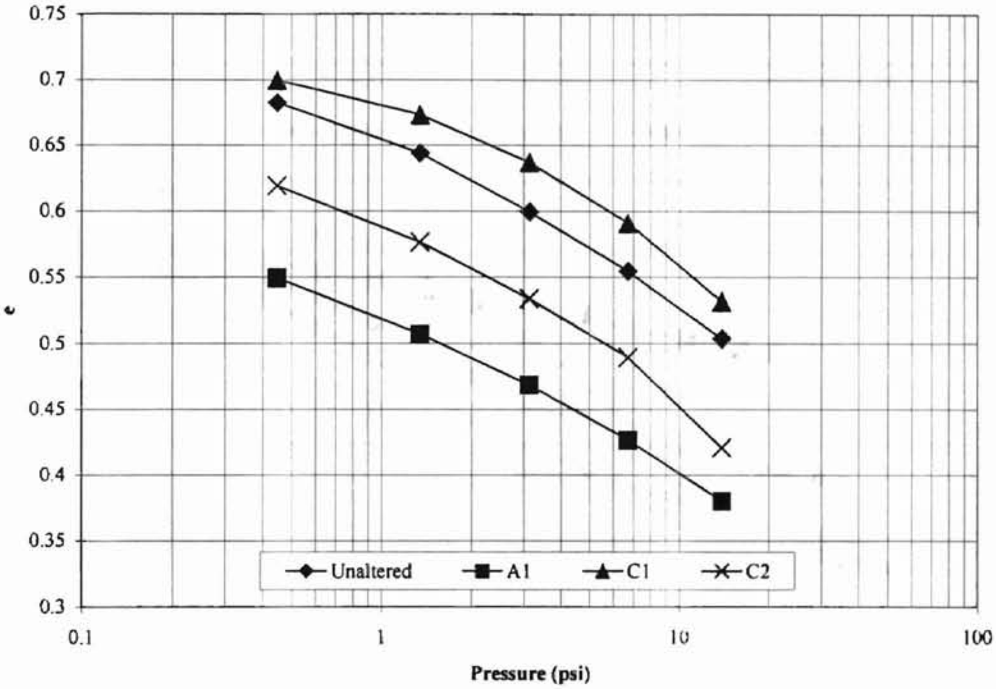

Figure 8. Void Ratio – Pressure Plot for Teller Loam Series

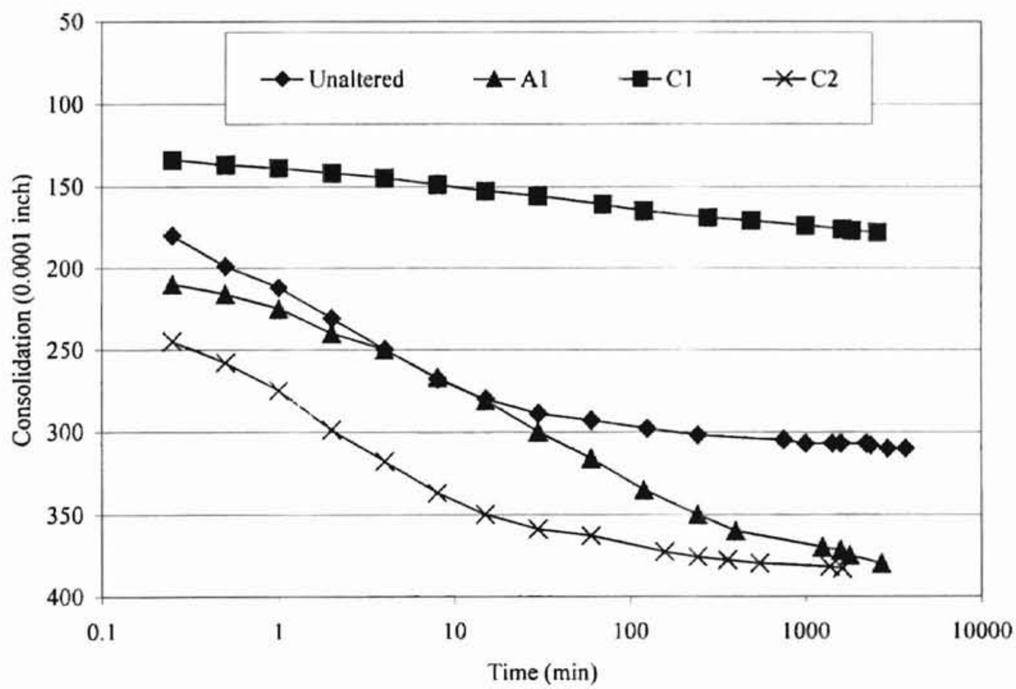

Figure 9. Consolidation Teller Loam – 1 kg Load

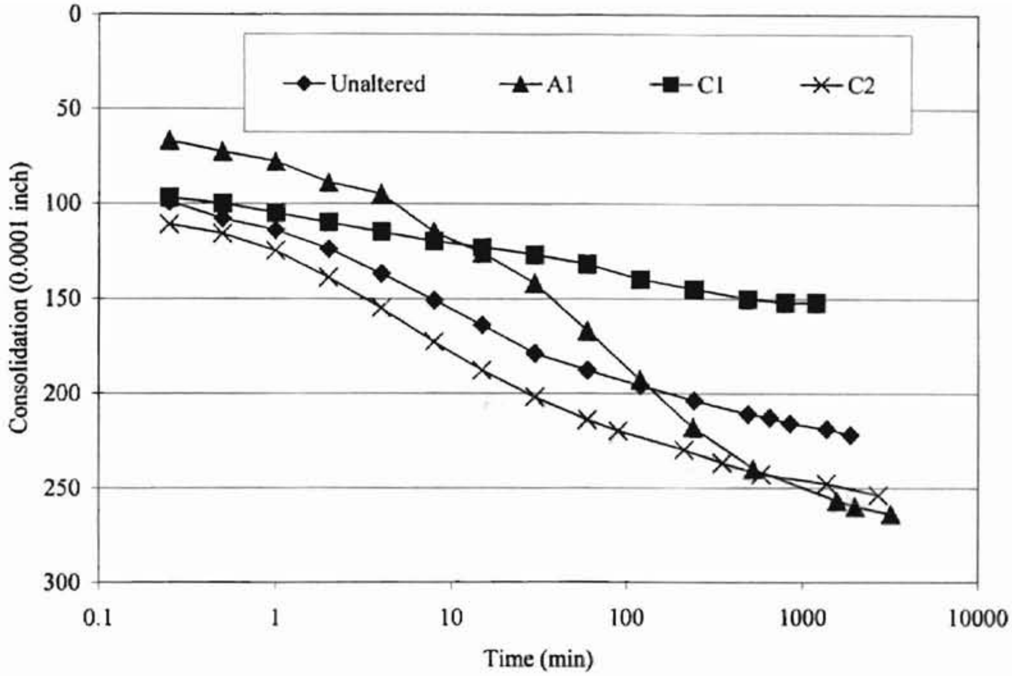

Figure 10. Consolidation Teller Loam – 3 kg Load

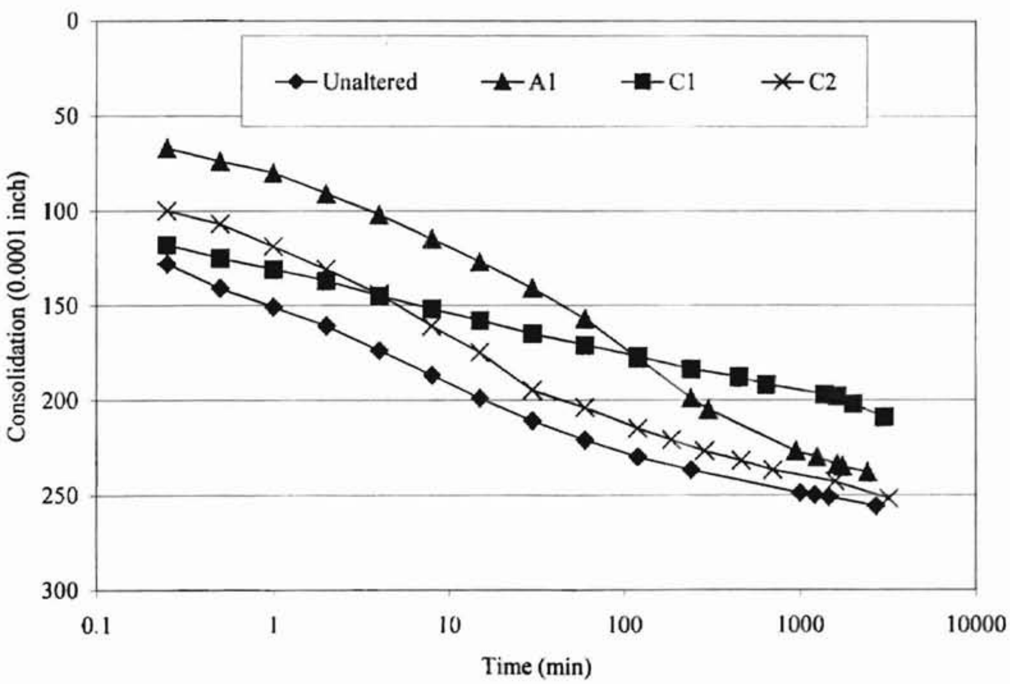

Figure 11. Consolidation Teller Loam – 7 kg Load

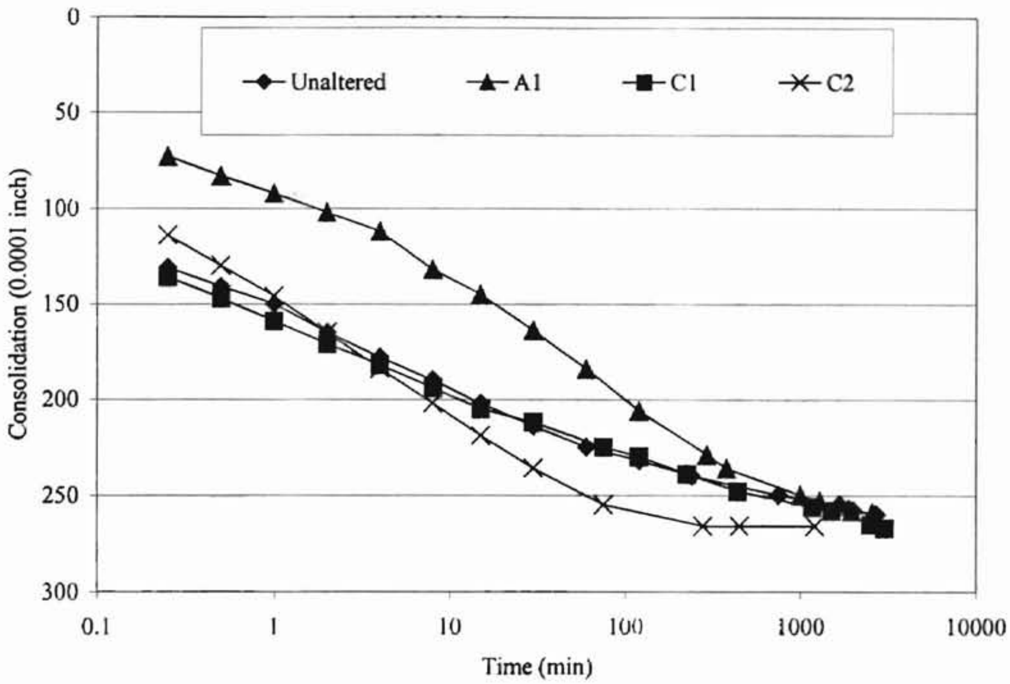

Figure 12. Consolidation Teller Loam – 15 kg Load

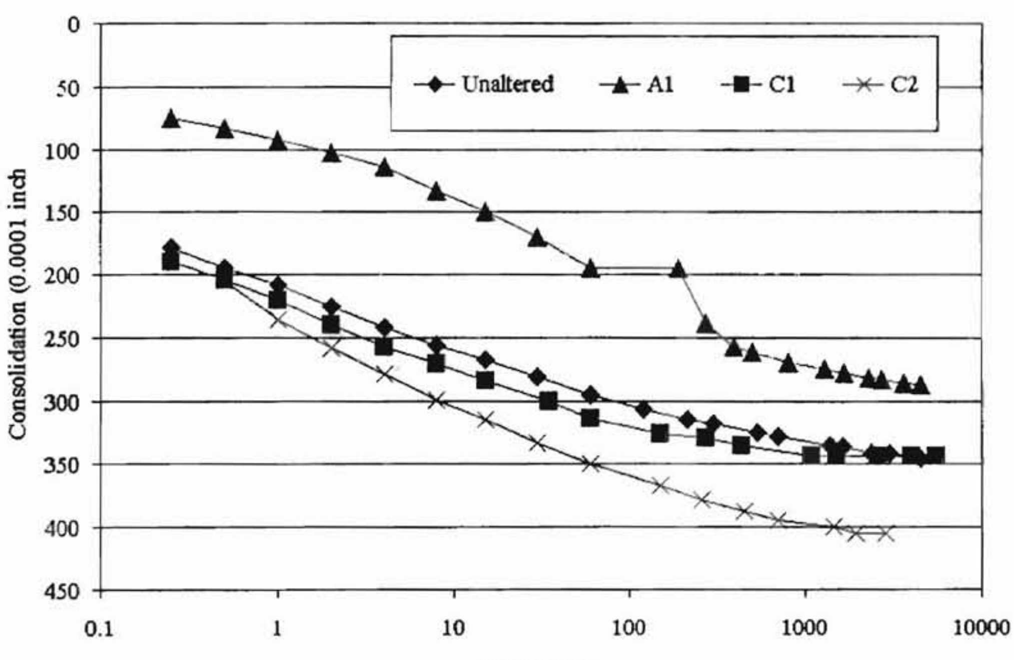

Figure 13. Consolidation Teller Loam – 31 kg Load

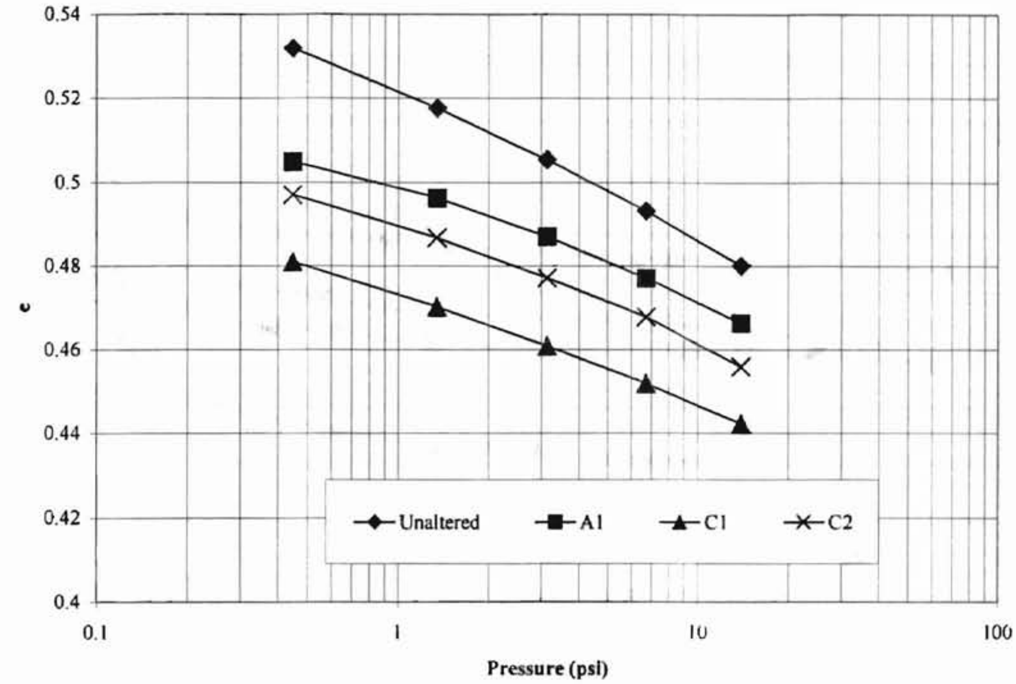

Figure 14. Void Ratio – Pressure Plot for Slaughterville Sandy Loam Series

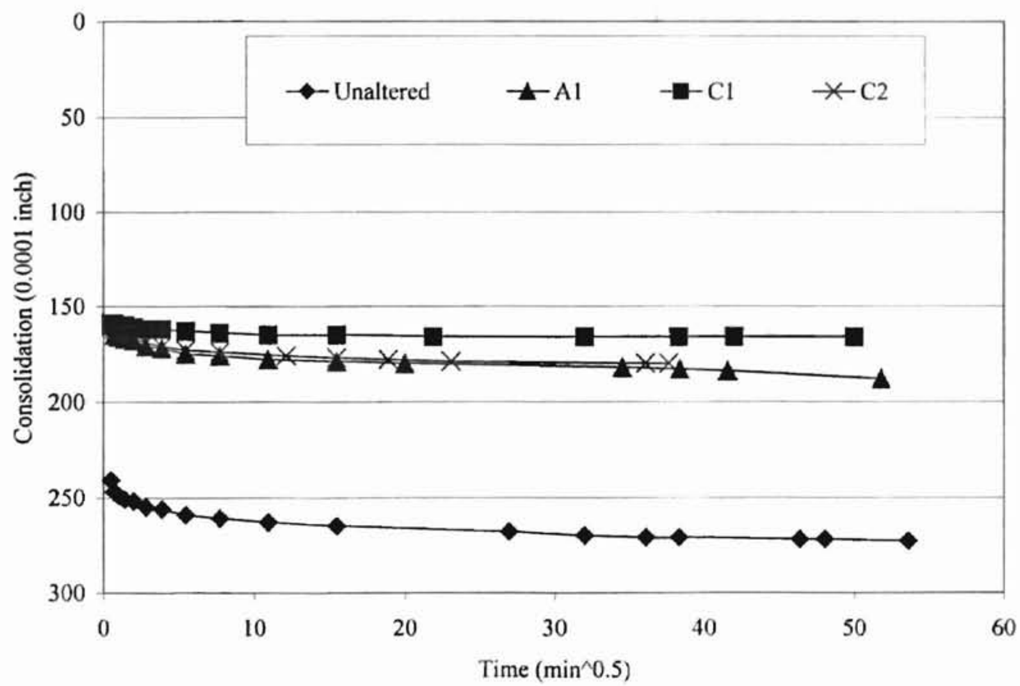

Figure 15. Consolidation Slaughterville Sandy Loam – 1 kg Load

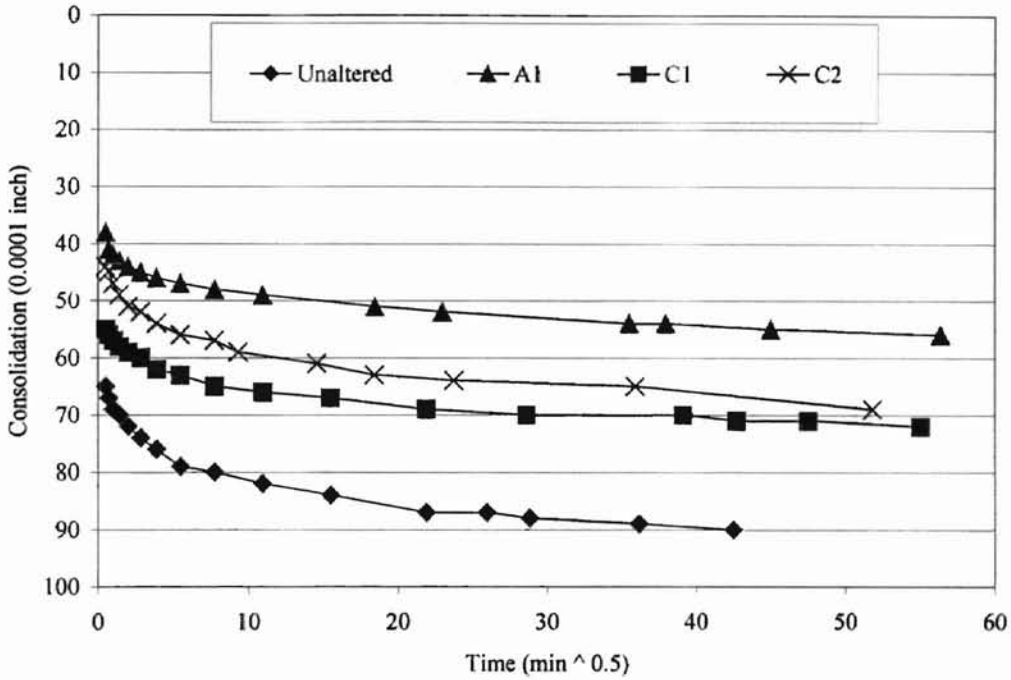

Figure 16. Consolidation Slaughterville Sandy Loam – 3 kg Load

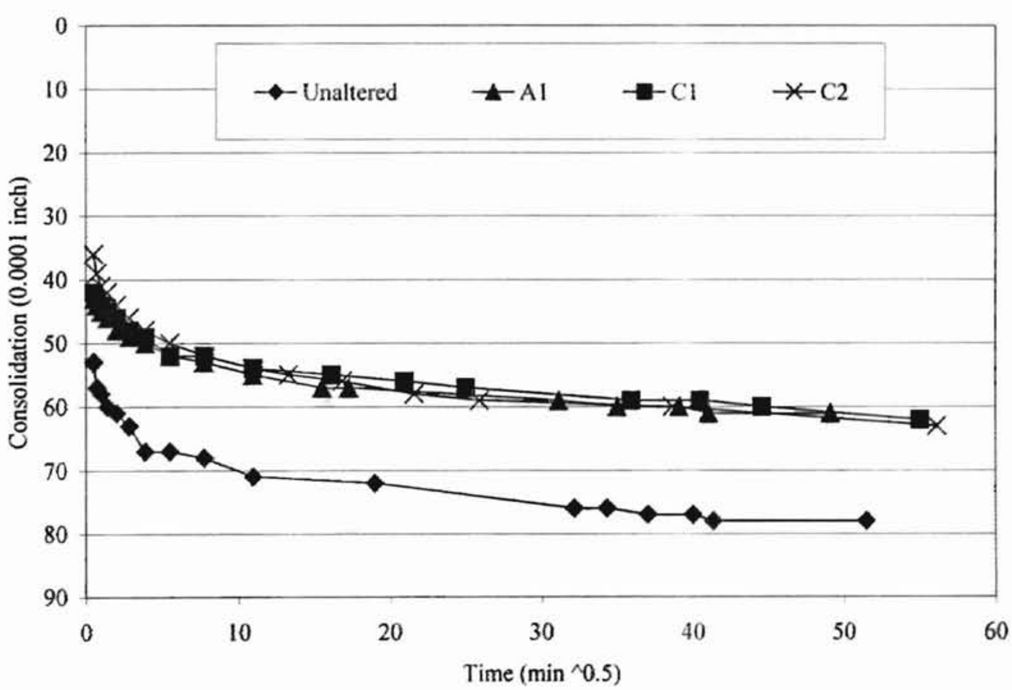

Figure 17. Consolidation Slaughterville Sandy Loam – 7 kg Loam

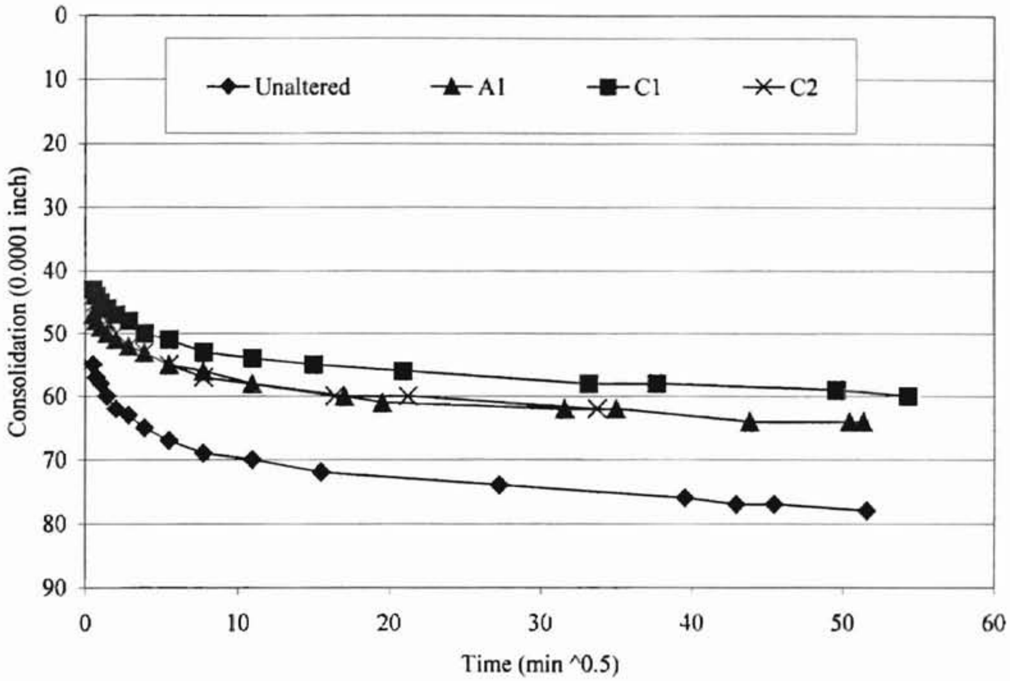

Figure 18. Consolidation Slaughterville Sandy Loam – 15 kg Loam

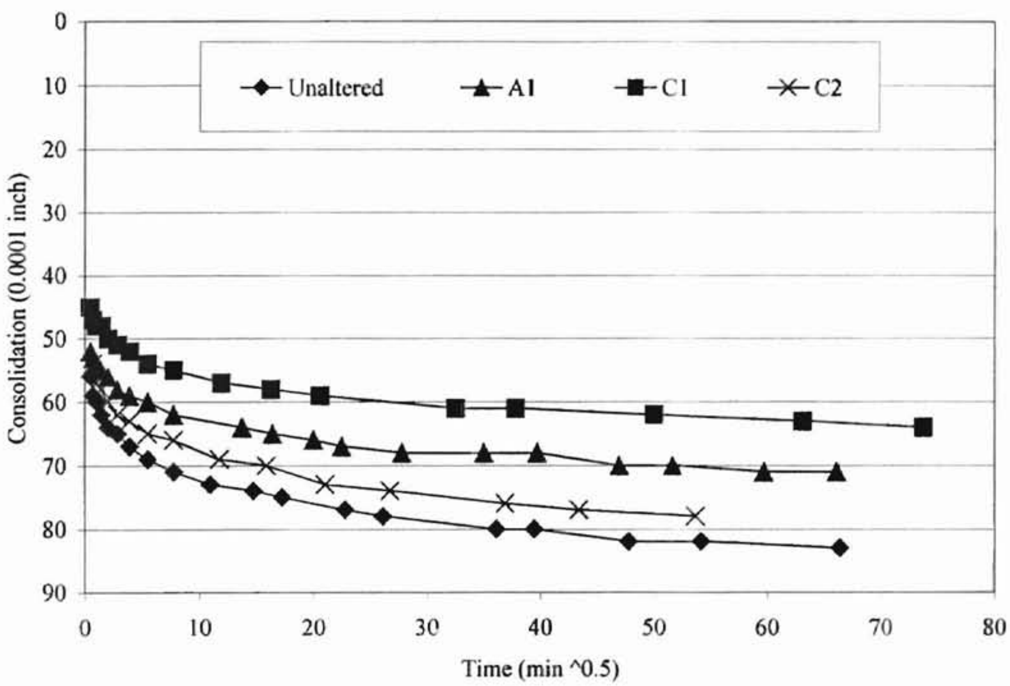

Figure 19. Consolidation Slaughterville Sandy Loam – 31 kg Load

APPENDICES

Appendix A

Data from Blackwell Saturated Soil Column Experiments

LIST OF TABLES

Table A-1. Metal Concentrations in Saturated Soil Column Effluent with 0.025M ISML Solution as Influent

Sample Name	Cumulative Time mid-interval (min)	Cumulative Effluent Volume mid-interval(ml)	Pore Volume	Cd (mg/L)	Pb (mg/L)	Zn (mg/L)
1-4	91	45.5	0.768	12.838	0.192	212.367
1-8	195	97.5	1.646	15.118	0.254	277.367
1-12	299	149.5	2.524	13.178	1.328	451.967
1-16	403	201.5	3.402	3.942	2.155	185.267
1-20	507	253.5	4.280	2.097	2.305	121.067
1-24	611	305.5	5.158	2.172	1.820	111.467
1-28	715	357.5	6.036	1.312	1.455	77.917
1-32	819	409.5	6.914	1.120	1.354	66.087
1-36	923	461.5	7.792	1.146	1.241	63.997
1-40	1027	513.5	8.670	0.994	1.395	61.207
1-44	1131	565.5	9.548	0.908	1.163	52.717
1-48	1235	617.5	10.425	0.914	1.131	56.067
1-52	1339	669.5	11.303	1.011	1.459	61.537
1-56	1443	721.5	12.181	0.956	1.194	56.517
1-60	1547	773.5	13.059	0.804	1.294	52.057
1-64	1651	825.5	13.937	0.874	1.361	57.247
1-68	1755	877.5	14.815	0.637	1.457	49.847
1-72	1859	929.5	15.693	0.798	1.106	49.387
1-76	1963	981.5	16.571	1.047	1.336	60.087
1-80	2067	1033.5	17.449	0.850	1.298	52.377
1-84	2171	1085.5	18.327	0.953	1.384	57.597
1-88	2275	1137.5	19.205	0.903	1.146	52.047
1-92	2379	1189.5	20.083	0.604	1.405	45.957
1-96	2483	1241.5	20.961	0.875	1.282	51.427
1-100	2587	1293.5	21.839	0.916	1.356	51.997
1-104	2691	1345.5	22.717	0.684	1.172	45.207
1-108	2795	1397.5	23.594	0.754	1.015	45.457
1-112	2899	1449.5	24.472	0.818	1.065	47.117
1-116	3003	1501.5	25.350	0.800	1.039	45.187

Table A-2. pH of Saturated Column Effluent with 0.025M ISML Solution as Influent

Sample #	Cumulative Time mid-interval (min)	Cumulative Effluent Volume mid-interval(ml)	Pore Volume	pH
1-2	39	19.5	0.3	6.48
1-6	143	71.5	1.2	6.54
1-10	247	123.5	2.1	6.50
1-14	351	175.5	3.0	4.38
1-18	455	227.5	3.8	4.23
1-22	559	279.5	4.7	4.16
1-26	663	331.5	5.6	4.15
1-30	767	383.5	6.5	4.12
1-34	871	435.5	7.4	4.11
1-38	975	487.5	8.2	4.10
1-42	1079	539.5	9.1	4.09
1-46	1183	591.5	10.0	4.08
1-50	1287	643.5	10.9	4.08
1-54	1391	695.5	11.7	4.07
1-58	1495	747.5	12.6	4.07
1-62	1599	799.5	13.5	4.08
1-66	1703	851.5	14.4	4.08
1-70	1807	903.5	15.3	4.13
1-74	1911	955.5	16.1	4.09
1-78	2015	1007.5	17.0	4.08
1-82	2119	1059.5	17.9	4.08
1-86	2223	1111.5	18.8	4.08
1-90	2327	1163.5	19.6	4.07
1-94	2431	1215.5	20.5	4.07
1-98	2535	1267.5	21.4	4.06
1-102	2639	1319.5	22.3	4.06
1-106	2743	1371.5	23.2	4.05
1-110	2847	1423.5	24.0	4.05
1-114	2951	1475.5	24.9	4.04

Table A-3. Surfactant Concentration in Effluent with 0.025M ISML Solution as Influent.

Sample #	Cumulative Time mid-interval (min)	Cumulative Volume Effluent mid-interval (mL)	Pore Volume	Spectrophotometer Reading	Concentration (M)	Dilution Factor	Actual Concentration (M)
1-3	65.00	32.50	0.55	0.011	2.40E-06	200	4.80E-04
1-7	169.00	84.50	1.43	0.018	5.20E-06	200	1.04E-03
1-11	273.00	136.50	2.30	0.031	1.04E-05	200	2.08E-03
1-15	377.00	188.50	3.18	0.260	1.02E-04	200	2.04E-02
1-19	481.00	240.50	4.06	0.246	9.64E-05	200	1.93E-02
1-23	585.00	292.50	4.94	0.228	8.92E-05	200	1.78E-02
1-27	689.00	344.50	5.82	0.310	1.22E-04	200	2.44E-02
1-31	793.00	396.50	6.69	0.274	1.08E-04	201	2.16E-02
1-35	897.00	448.50	7.57	0.269	1.06E-04	200	2.11E-02
1-39	1001.00	500.50	8.45	0.336	1.32E-04	200	2.65E-02
1-43	1105.00	552.50	9.33	0.250	9.80E-05	200	1.96E-02
1-47	1209.00	604.50	10.21	0.300	1.18E-04	200	2.36E-02

Table A-4. Metal Concentration in Effluent of Saturated Soil Column with 0.05M ISML Solution as Influent

Sample Name	Cumulative Time Mid-Interval (min)	Cumulative Effluent Volume (ml)	Cumulative Effluent Volume (L)	Pore Volumes	Cd (mg/L)	Pb (mg/L)	Zn (mg/L)
2-4	91	45.5	0.0455	0.7	4.689	1.088	147.300
2-8	195	97.5	0.0975	1.5	6.650	3.404	322.500
2-12	299	149.5	0.1495	2.3	4.093	3.170	214.700
2-16	403	201.5	0.2015	3.1	2.701	2.344	147.700
2-20	507	253.5	0.2535	3.9	1.913	2.268	114.400
2-24	611	305.5	0.3055	4.7	1.869	1.963	112.500
2-28	715	357.5	0.3575	5.5	1.399	1.794	81.680
2-32	819	409.5	0.4095	6.3	1.394	1.650	80.640
2-36	923	461.5	0.4615	7.1	1.984	3.278	134.400
2-40	1027	513.5	0.5135	7.9	2.014	2.591	123.500
2-44	1131	565.5	0.5655	8.7	1.649	1.827	97.170
2-48	1235	617.5	0.6175	9.5	2.106	2.246	119.500
2-52	1339	669.5	0.6695	10.3	1.777	2.211	104.700
2-56	1443	721.5	0.7215	11.1	1.823	2.049	105.500
2-60	1547	773.5	0.7735	11.9	1.649	1.933	93.000
2-64	1651	825.5	0.8255	12.7	1.626	2.286	93.360
2-68	1755	877.5	0.8775	13.5	1.582	1.805	84.330
2-72	1859	929.5	0.9295	14.3	1.576	1.957	85.320
2-76	1963	981.5	0.9815	15.1	1.285	1.663	71.540
2-80	2067	1033.5	1.0335	15.9	1.443	1.808	79.010
2-84	2171	1085.5	1.0855	16.7	1.348	1.380	68.090
2-88	2275	1137.5	1.1375	17.5	1.284	1.441	67.380
2-92	2379	1189.5	1.1895	18.3	1.628	1.751	89.190
2-96	2483	1241.5	1.2415	19.1	1.478	1.623	83.810
2-100	2587	1293.5	1.2935	19.9	1.427	2.106	89.440
2-104	2691	1345.5	1.3455	20.7	1.262	2.224	84.190
2-108	2795	1397.5	1.3975	21.5	1.013	1.294	63.110

Table A-5. pH of Saturated Column Effluent with 0.05M ISML Solution as Influent

Sample Number	Cumulative Time - Mid-Interval (min)	Cumulative Effluent Volume (ml)	Pore Volumes	pH
2-2	39	19.5	0.3	6.79
2-6	143	71.5	1.1	4.14
2-10	247	123.5	1.9	4.11
2-14	351	175.5	2.7	4.04
2-18	455	227.5	3.5	4.07
2-22	559	279.5	4.3	3.98
2-26	663	331.5	5.1	4.01
2-30	767	383.5	5.9	3.93
2-34	871	435.5	6.7	3.93
2-38	975	487.5	7.5	3.97
2-42	1079	539.5	8.3	3.98
2-46	1183	591.5	9.1	3.95
2-50	1287	643.5	9.9	4.01
2-54	1391	695.5	10.7	3.99
2-58	1495	747.5	11.5	3.99
2-62	1599	799.5	12.3	3.96
2-66	1703	851.5	13.1	3.98
2-70	1807	903.5	13.9	3.97
2-74	1911	955.5	14.7	3.98
2-78	2015	1007.5	15.5	3.96
2-82	2119	1059.5	16.3	3.97
2-86	2223	1111.5	17.1	3.97
2-90	2327	1163.5	17.9	4.02
2-94	2431	1215.5	18.7	4.02
2-98	2535	1267.5	19.5	4.00
2-102	2639	1319.5	20.3	4.00
2-106	2743	1371.5	21.1	3.98

Table A-6. Surfactant Concentration in Saturated Column Effluent with 0.05M ISML Solution as Influent

Sample Name	Cumulative Time Mid-Interval (min)	Cumulative Effluent Volume (ml)	Pore Volumes	Spectrophotometer Reading	Concentration	Dilution Factor	Actual Concentration
2-4	91	45.5	0.7	0.026	8.40E-06	400.0	3.36E-03
2-8	195	97.5	1.5	0.037	1.28E-05	400.0	5.12E-03
2-12	299	149.5	2.3	0.160	6.20E-05	400.0	2.48E-02
2-16	403	201.5	3.1	0.159	6.16E-05	392.1	2.42E-02
2-20	507	253.5	3.9	0.260	1.02E-04	396.0	4.04E-02
2-24	611	305.5	4.7	0.152	5.88E-05	400.0	2.35E-02
2-28	715	357.5	5.5	0.309	1.22E-04	400.4	4.87E-02
2-32	819	409.5	6.3	0.242	9.48E-05	400.0	3.79E-02
2-36	923	461.5	7.1	0.183	7.12E-05	400.0	2.85E-02
2-40	1027	513.5	7.9	0.332	1.31E-04	400.0	5.23E-02
2-44	1131	565.5	8.7	0.172	6.68E-05	400.2	2.67E-02
2-48	1235	617.5	9.5	0.283	1.11E-04	400.0	4.45E-02
2-52	1339	669.5	10.3	0.229	8.96E-05	398.4	3.57E-02
2-56	1443	721.5	11.1	0.236	9.24E-05	400.0	3.70E-02
2-60	1547	773.5	11.9	0.122	4.68E-05	396.0	1.85E-02

Appendix B

Data from Teller Loam Soil Property Measurements

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Table B-1. Teller Loam Consolidation Test Data for 1 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
1	0.25	180	0.25	134	0.25	210	0.25	245
1	0.5	199	0.5	137	0.5	216	0.5	258
1	1	212	1	139	1	225	1	275
1	2	231	2	142	2	240	2	299
1	4	250	4	145	4	250	4	318
1	8	268	8	149	8	267	8	337
1	15	280	15	153	15	281	15	350
1	30	289	30	156	30	300	30	359
1	60	293	70	161	60	316	60	363
1	125	298	120	165	120	335	158	373
1	243	302	280	169	243	350	243	376
1	750	305	490	171	400	360	360	378
1	1000	307	1000	174	1250	370	550	380
1	1417	307	1625	176	1583	372	1375	382
1	1583	307	1833	177	1792	375	1625	383
1	2214	307	2571	178	2714	380		
1	2357	308						
1	2928	310						
1	3700	310						

Table B-2. Teller Loam Consolidation Test Data for 3 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
3	0.25	99	0.25	97	0.25	67	0.25	111
3	0.5	108	0.5	100	0.5	73	0.5	116
3	1	114	1	105	1	78	1	125
3	2	124	2	110	2	89	2	139
3	4	137	4	115	4	95	4	155
3	8	151	8	120	8	115	8	173
3	15	164	15	123	15	126	15	188
3	30	179	30	127	30	142	30	202
3	60	188	60	132	60	167	60	214
3	120	196	120	140	120	193	90	220
3	243	204	243	145	240	218	214	230
3	490	211	487	150	525	240	350	237
3	650	213	800	152	1583	257	583	243
3	850	216	1200	152	2000	260	1375	248
3	1375	219			3200	264	2714	254
3	1875	222						

Table B-3. Teller Loam Consolidation Test Data for 7 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
7	0.25	128	0.25	118	0.25	67	0.25	100
7	0.5	141	0.5	125	0.5	74	0.5	107
7	1	151	1	131	1	80	1	119
7	2	161	2	137	2	91	2	131
7	4	174	4	145	4	102	4	144
7	8	187	8	152	8	115	8	161
7	15	199	15	158	15	127	15	175
7	30	211	30	165	30	141	30	195
7	60	221	60	171	60	157	60	204
7	120	230	120	177	120	178	120	215
7	240	237	240	184	240	199	187	221
7	1000	249	450	188	300	205	286	227
7	1208	250	640	192	950	227	462	232
7	1458	251	1375	197	1250	230	700	237
7	2714	256	1625	198	1625	234	1583	243
7			2000	202	1750	235	3200	252
7			3000	209	2428	238		

Table B-4. Teller Loam Consolidation Test Data for 15 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
15	0.25	131	0.25	136	0.25	73	0.25	114
15	0.5	141	0.5	147	0.5	83	0.5	130
15	1	150	1	159	1	92	1	146
15	2	165	2	171	2	102	2	165
15	4	178	4	182	4	112	4	184
15	8	190	8	194	8	132	8	202
15	15	202	15	205	15	145	15	219
15	30	214	30	212	30	164	30	236
15	60	225	75	225	60	184	75	255
15	120	232	120	230	120	206	278	266
15	240	240	225	239	293	229	450	266
15	750	250	440	248	380	236	1208	266
15	1667	255	1167	256	1000	250		
15	1875	257	1500	258	1292	253		
15	2000	258	2500	265	1958	258		
15	2714	260	3000	267	2571	259		
15					2643	260		

Table B-5. Teller Loam Consolidation Test Data for 31 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
31	0.25	178	0.25	190	0.25	75	0.5	205
31	0.5	195	0.5	204	0.5	83	1	236
31	1	208	1	220	1	92	2	258
31	2	225	2	240	2	103	4	279
31	4	242	4	257	4	114	8	299
31	8	256	8	271	8	133	15	315
31	15	268	15	284	15	150	30	333
31	30	281	35	300	30	170	60	350
31	60	295	60	314	60	195	150	367
31	120	306	150	326	190	195	257	378
31	214	315	270	329	270	239	450	387
31	300	318	437	335	390	257	700	395
31	533	325	1083	343	500	261	1458	400
31	700	328	1500	343	800	270	1917	405
31	1375	335	2571	343	1292	275	2857	405
31	1625	336	4000	343	1667	278		
31	2357	341	5500	343	2286	282		
31	3000	341			2714	283		
31	4500	345			3600	286		
31					4500	287		

Table B-6. Unaltered Teller Loam Direct Shear Data for 2 kg Loading – Test A.

Teller - Unaltered 1 19-Mar-97 Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	12.18	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	25	38.25	12.07	
2.5	0	46	68.10	21.48	
6	1	57	83.73	26.41	
10	2	66	96.52	30.45	
13	4	72	105.05	33.14	
16	6	78	113.57	35.83	
20	8.5	82.5	119.97	37.85	
23	11	86.5	125.65	39.64	
26	14	89	129.21	40.76	
32	18	89.5	129.92	40.98	
37	20	82	119.26	37.62	
41	21	77	112.15	35.38	
46	22	70	102.21	32.24	
51	24	65	95.10	30.00	
57	24	58	85.15	26.86	
77	25	46	68.10	21.48	
86	27	43	63.83	20.14	
95	28	41	60.99	19.24	
99	29	40	59.57	18.79	
108.5	30	39	58.15	18.34	
138	35	35	52.46	16.55	

Table B-7. Unaltered Teller Loam Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.8	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	5	9.83	3.10	
0	0	5	9.83	3.10	
1	0	17	26.88	8.48	
4	0	23	35.41	11.17	
5	0	50	73.78	23.28	
8	2	63	92.26	29.10	
12	2	67	97.94	30.90	
15	3	75	109.31	34.48	
18	4	80	116.42	36.72	
21	5	84	122.10	38.52	
25	10	86	124.94	39.41	
29	12	86	124.94	39.41	
35	14	81	117.84	37.17	
38	17	79	115.00	36.28	
42	19	77	112.15	35.38	
48	22	75	109.31	34.48	
52	24	72	105.05	33.14	
62	30	65	95.10	30.00	
77	34	55	80.89	25.52	
90	37	48	70.94	22.38	
100	40	44	65.26	20.59	

Table B-8. Unaltered Teller Loam Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	12	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	6	11.25	3.55	
0	0	5.5	10.54	3.33	
0	0	4	8.41	2.65	
1	0	14	22.62	7.14	
3	0	30	45.36	14.31	
6	0	46	68.10	21.48	
9	0	55	80.89	25.52	
13	1	64	93.68	29.55	
17	3	71	103.63	32.69	
21	5	76	110.73	34.93	
24	7	81	117.84	37.17	
28	9	85	123.52	38.97	
31	11	87.5	127.08	40.09	
35	15	88.5	128.50	40.54	
42	20	83	120.68	38.07	
52	25	75	109.31	34.48	
63	29	66	96.52	30.45	
71	31	60	87.99	27.76	
81	33	55	80.89	25.52	
91	34	49	72.36	22.83	
100	35	44	65.26	20.59	

Table B-9. Unaltered Teller Loam Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Teller - Unaltered 2 19-Mar-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	11.92	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	6	11.25	3.55	
0	0	6	11.25	3.55	
0	0	12	19.78	6.24	
2	0	40	59.57	18.79	
4	0.5	60	87.99	27.76	
6	0.5	70	102.21	32.24	
9	1.5	80	116.42	36.72	
13	3.5	90	130.63	41.21	
16	5	95	137.73	43.45	
20	7.5	100	144.84	45.69	
24	9	105	151.95	47.93	
29	13	108	156.21	49.28	
35	17	105	151.95	47.93	
46	21	90	130.63	41.21	
56	24	84	122.10	38.52	
73	27.5	73	106.47	33.59	
87.5	31	66.5	97.23	30.67	
98	33	64	93.68	29.55	
108	35.5	63	92.26	29.10	

Table B-10. Unaltered Teller Loam Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.95	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	15	24.04	7.58	
1	0	35	52.46	16.55	
3.5	0	55	80.89	25.52	
6	1	67	97.94	30.90	
9	2	77	112.15	35.38	
12.5	3	84	122.10	38.52	
18	6	95	137.73	43.45	
29	12	103.5	149.81	47.26	
36	15	95	137.73	43.45	
48	19	80	116.42	36.72	
63	25	71	103.63	32.69	
81	28.5	66	96.52	30.45	
95	31.5	63	92.26	29.10	
104	33.5	62	90.84	28.65	

Table B-11. Unaltered Teller Loam Direct Shear Data for 4 kg Loading – Test C.

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	11.95	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	0	47	69.52	21.93	
10	2	83	120.68	38.07	
13	2.5	91	132.05	41.66	
16	4	96	139.16	43.90	
18	5	100	144.84	45.69	
26	9	103	149.10	47.04	
32	13	95	137.73	43.45	
42	19	85	123.52	38.97	
51	23	79	115.00	36.28	
71	29	69	100.78	31.79	
88	33	58	85.15	26.86	
101.5	35	54	79.47	25.07	
102	36	53	78.05	24.62	
110	36	52	76.62	24.17	

Table B-12. Unaltered Teller Loam Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Teller - Unaltered 3 19-Mar-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	11.8	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	27	41.10	12.96	
3	0	47	69.52	21.93	
6	0	72	105.05	33.14	
8	0	85	123.52	38.97	
11	0	95	137.73	43.45	
14	1	105	151.95	47.93	
17	1.5	110	159.05	50.17	
21	2.5	120	173.26	54.66	
24	3.5	125	180.37	56.90	
28	5.5	130	187.48	59.14	
54	16.5	138	198.84	62.73	
61	19	137	197.42	62.28	
77.5	26	130	187.48	59.14	
92.5	29.5	115	166.16	52.42	
106.5	32.5	105	151.95	47.93	
118.5	34	100	144.84	45.69	
133	35.5	95	137.73	43.45	
149	37.5	93	134.89	42.55	

Table B-13. Unaltered Teller Loam Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	11.65	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	14	22.62	7.14	
1	0	41	60.99	19.24	
3	0	64	93.68	29.55	
5	0.5	83	120.68	38.07	
8	1	100	144.84	45.69	
11	1.5	110	159.05	50.17	
14.5	2.5	120	173.26	54.66	
20	4	130	187.48	59.14	
24	6	135	194.58	61.38	
27	9	140	201.69	63.62	
35	11	140.5	202.40	63.85	
44	15	135	194.58	61.38	
56	20	130	187.48	59.14	
68	24	125	180.37	56.90	
86	29	115	166.16	52.42	
110.5	34.5	105	151.95	47.93	
122	36.5	100	144.84	45.69	
137.5	38.5	95	137.73	43.45	
143	39.5	93	134.89	42.55	

Table B-14. Unaltered Teller Loam Direct Shear Data for 10 kg Loading – Test C.

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	11.35	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	16	25.46	8.03	
1	0	42	62.41	19.69	
2	0	65	95.10	30.00	
5	0	80	116.42	36.72	
7	0	95	137.73	43.45	
9	0.5	105	151.95	47.93	
12.5	1.5	120	173.26	54.66	
16	2.5	125	180.37	56.90	
18.5	4	135	194.58	61.38	
22	5	140	201.69	63.62	
31	10	145	208.79	65.87	
43	16	143	205.95	64.97	
50	20	140	201.69	63.62	
65	25.5	135	194.58	61.38	
72	28.5	130	187.48	59.14	
96	36	115	166.16	52.42	
129	43	105	151.95	47.93	
145	45	100	144.84	45.69	
162	47.5	95	137.73	43.45	

Table B-15. Teller Loam with 0.5% A1 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Teller - 0.5% A1 Added -1 25-Mar-97					
Test A (2kg)					
			Sample Dimensions		
Soil Moisture	10.83	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear stress (kPa)	
1	0	22	33.99	10.72	
3	0	38	56.73	17.90	
6	0	47	69.52	21.93	
10	1	54	79.47	25.07	
12	2	60	87.99	27.76	
16	4	65	95.10	30.00	
22	6	71	103.63	32.69	
25	9	72.5	105.76	33.36	
28	12	69	100.78	31.79	
36	16	65	95.10	30.00	
74	30	44	65.26	20.59	
99	35	36	53.89	17.00	
120	36.5	35	52.46	16.55	
150	41.5	33	49.62	15.65	

Table B-16. Teller Loam with 0.5% A1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	10.83	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	0	33	49.62	15.65	
6	1	49	72.36	22.83	
9	2	59.5	87.28	27.53	
11	3	67	97.94	30.90	
14	4	72	105.05	33.14	
19	6.5	79	115.00	36.28	
28	12	85	123.52	38.97	
45	24	64	93.68	29.55	
61	28	50	73.78	23.28	
71	30	44	65.26	20.59	
100	36.5	38	56.73	17.90	
126	41.5	36.5	54.60	17.22	
153	45.5	34.5	51.75	16.33	

Table B-17. Teller Loam with 0.5% A1 Direct Shear Data for 2 kg Loading – Test C.

Test C (2kg)					
			Sample Dimensions		
Soil Moisture	10.76	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Sress (kPa)
3	0	35	52.46	16.55
5	0.5	40	59.57	18.79
8	1.5	49	72.36	22.83
15	5	66	96.52	30.45
18	6.5	69	100.78	31.79
25	11	72.5	105.76	33.36
38	20	68	99.36	31.34
59.5	33.5	63	92.26	29.10
83	43.5	50	73.78	23.28
98	47	43	63.83	20.14
130	53	39	58.15	18.34
152.5	57.5	38	56.73	17.90

Table B-18. Teller Loam with 0.5% A1 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Teller - 0.5% A1 Added -2 25-Mar-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	10.66	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0.5	0	14	22.62	7.14
2	0.5	34	51.04	16.10
4	1	51	75.20	23.72
7	2	63	92.26	29.10
9	3	71	103.63	32.69
14	5	80	116.42	36.72
21	9	90	130.63	41.21
27	13	91	132.05	41.66
48	25	80	116.42	36.72
66	33	70	102.21	32.24
86.5	38.5	60	87.99	27.76
101	41	55	80.89	25.52
127	45	50	73.78	23.28
150	48	48.5	71.65	22.60

Table B-19. Teller Loam with 0.5% A1 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	10.67	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	0	35	52.46	16.55	
4	0	52	76.62	24.17	
7	1	65	95.10	30.00	
10	1.5	71	103.63	32.69	
17	4.5	85	123.52	38.97	
28	11	89.75	130.27	41.10	
49	24	85	123.52	38.97	
73	38	80	116.42	36.72	
92.5	46.5	70	102.21	32.24	
107	51	60	87.99	27.76	
117	53	55	80.89	25.52	
147	58	50	73.78	23.28	
150	59	50	73.78	23.28	

Table B-20. Teller Loam with 0.5% A1 Direct Shear Data for 4 kg Loading – Test C.

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	10.19	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	18	28.30	8.93	
2	0	39	58.15	18.34	
4	1	55	80.89	25.52	
7.5	1.75	66	96.52	30.45	
10	3	75	109.31	34.48	
12	4	80	116.42	36.72	
15	5	85	123.52	38.97	
23	11	92	133.47	42.10	
33	18	85	123.52	38.97	
44	25	80	116.42	36.72	
59	32	75	109.31	34.48	
67.5	35	70	102.21	32.24	
87.5	42	60	87.99	27.76	
104	45	55	80.89	25.52	
152	54	50	73.78	23.28	

Table B-21. Teller Loam with 0.5% A1 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Teller - 0.5% A1 Added -3 25-Mar-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	10.32	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0	0	19	29.73	9.38
1	0	42	62.41	19.69
3	0	62.5	91.55	28.88
5	0.5	78	113.57	35.83
9	1	92	133.47	42.10
11	1.75	100	144.84	45.69
16	3	110	159.05	50.17
21	5	120	173.26	54.66
24.5	6.5	125	180.37	56.90
32	10.5	130	187.48	59.14
42	15	131	188.90	59.59
73	28	120	173.26	54.66
131	40	90	130.63	41.21
150	42.5	86	124.94	39.41
163	43.5	85	123.52	38.97

Table B-22. Teller Loam with 0.5% A1 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	10.14	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	31	46.78	14.76	
2	-3	57	83.73	26.41	
8	-14	95	137.73	43.45	
13	-18	11	18.36	5.79	
19	2	120	173.26	54.66	
25	3	130	187.48	59.14	
30	6.5	131.5	189.61	59.81	
38	11	131	188.90	59.59	
48	16	130	187.48	59.14	
67	25	125	180.37	56.90	
77.5	30	120	173.26	54.66	
98.5	36	105	151.95	47.93	
105	37.5	100	144.84	45.69	
136	42	90	130.63	41.21	
157	44	85	123.52	38.97	

Table B-23. Teller Loam with 0.5% A1 Direct Shear Data for 10 kg Loading – Test C.

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	9.73	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	15	24.04	7.58	
1	0	42	62.41	19.69	
2.5	0	66	96.52	30.45	
5	0	83	120.68	38.07	
7	1	96.5	139.87	44.12	
11	2	110	159.05	50.17	
13	2.5	115	166.16	52.42	
18	4.75	125	180.37	56.90	
22	6.5	130	187.48	59.14	
27	10	131	188.90	59.59	
37.5	15	125	180.37	56.90	
56	23.5	120	173.26	54.66	
78	30	105	151.95	47.93	
86	32	100	144.84	45.69	
101.5	34.5	90	130.63	41.21	
118	35.5	85	123.52	38.97	
150	39.5	81.5	118.55	37.40	

Table B-24. Teller Loam with 1% A1 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Teller - 1% A1 Added -1 26-Mar-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	12	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	7	12.67	4.00	
2	0	36	53.89	17.00	
4	1	48	70.94	22.38	
8	1.5	56.5	83.02	26.19	
11	2.5	63	92.26	29.10	
14	4.5	68	99.36	31.34	
24	11.75	75.75	110.38	34.82	
41	25.5	68	99.36	31.34	
49	31.5	60	87.99	27.76	
68	37.5	45	66.68	21.03	
80	40	40	59.57	18.79	
108	45	36.5	54.60	17.22	
176	56	34	51.04	16.10	

Table B-25. Teller Loam with 1% A1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	12	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	15	24.04	7.58	
2	0	35	52.46	16.55	
6.5	0.5	54	79.47	25.07	
7.5	1.5	60	87.99	27.76	
11	2.5	65	95.10	30.00	
14	4.5	70	102.21	32.24	
20	8.5	73	106.47	33.59	
26.5	14.5	70	102.21	32.24	
37	23	65	95.10	30.00	
43	27	60	87.99	27.76	
48	30	55	80.89	25.52	
53	31	50	73.78	23.28	
57	32	45	66.68	21.03	
65	33	40	59.57	18.79	
82.5	35.5	35	52.46	16.55	
100	37	32	48.20	15.21	
150	41.5	30	45.36	14.31	

Table B-26. Teller Loam with 1% A1 Direct Shear Data for 2 kg Loading – Test C

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	12	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.75	0	19	29.73	9.38	
2.5	0	39	58.15	18.34	
11	3	69	100.78	31.79	
14	5	73	106.47	33.59	
19	9	75	109.31	34.48	
28	18	70	102.21	32.24	
38	26	65	95.10	30.00	
47	32	60	87.99	27.76	
53	35	55	80.89	25.52	
57.5	37	50	73.78	23.28	
66	38.5	45	66.68	21.03	
85	41.5	40	59.57	18.79	
127	49.5	35	52.46	16.55	
150	53	32.5	48.91	15.43	

Table B-27. Teller Loam with 1% A1 Direct Shear Data for 4 kg Loading – Test A

Shear Test Data Teller - 1% A1 Added -2 26-Mar-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	10.83	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	17	26.88	8.48	
2	0	35	52.46	16.55	
4	0	49	72.36	22.83	
6.5	0	60	87.99	27.76	
9.5	1	68.5	100.07	31.57	
16	3	80	116.42	36.72	
19	5	85	123.52	38.97	
27	9.5	90	130.63	41.21	
33	13	85	123.52	38.97	
36	15.5	80	116.42	36.72	
42	18.5	75	109.31	34.48	
45.5	21	70	102.21	32.24	
56	25	62	90.84	28.65	
69	29	60	87.99	27.76	
77.5	31.5	55	80.89	25.52	
89	33	50	73.78	23.28	
133.5	39	45	66.68	21.03	
150	41	44	65.26	20.59	

Table B-28. Teller Loam with 1% A1 Direct Shear Data for 4 kg Loading – Test B

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	12	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	14	22.62	7.14	
1	0	34	51.04	16.10	
3	0	53	78.05	24.62	
6	1	65	95.10	30.00	
7.5	1.5	70	102.21	32.24	
10	2.5	75	109.31	34.48	
12.5	3.5	80	116.42	36.72	
15	5	85	123.52	38.97	
22	10	91.5	132.76	41.88	
34	18	85	123.52	38.97	
43	24	80	116.42	36.72	
60	32	75	109.31	34.48	
72	36.5	70	102.21	32.24	
85	41	65	95.10	30.00	
104	46	60	87.99	27.76	
121	48.5	55	80.89	25.52	
140	52	50	73.78	23.28	
150	52.5	46	68.10	21.48	

Table B-29. Teller Loam with 1% A1 Direct Shear Data for 4 kg Loading – Test C.

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	12	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	8	14.09	4.45	
3	0	37	55.31	17.45	
5	0	52	76.62	24.17	
7	1	65	95.10	30.00	
10	2	74	107.89	34.03	
12.5	3	81	117.84	37.17	
14	4	85	123.52	38.97	
17.5	6	90	130.63	41.21	
22.5	10	91.25	132.41	41.77	
40	22	85	123.52	38.97	
56	34	80	116.42	36.72	
64	37.5	75	109.31	34.48	
73	40.5	65	95.10	30.00	
80	42	60	87.99	27.76	
91	44	55	80.89	25.52	
121	48.5	50	73.78	23.28	
150	53	48	70.94	22.38	

Table B-30. Teller Loam with 1% A1 Direct Shear Data for 10 kg Loading – Test A

Shear Test Data Teller - 1% A1 Added -3 26-Mar-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	10.83	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	15	24.04	7.58	
1.5	0	40	59.57	18.79	
3.5	0	60	87.99	27.76	
6.5	0.5	78	113.57	35.83	
9	1	90	130.63	41.21	
11.5	1.5	95	137.73	43.45	
14.5	2.5	105	151.95	47.93	
17	4.5	110	159.05	50.17	
20	4.5	115	166.16	52.42	
21.5	5	120	173.26	54.66	
25	6.5	125	180.37	56.90	
33	11	129	186.05	58.69	
46	17.5	125	180.37	56.90	
62	24	120	173.26	54.66	
84	32.5	110	159.05	50.17	
115	39.5	95	137.73	43.45	
142	42.5	85	123.52	38.97	
150	43	84	122.10	38.52	

Table B-31. Teller Loam with 1% A1 Direct Shear Data for 10 kg Loading – Test B

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	10.83	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	16	25.46	8.03	
1.5	0	40	59.57	18.79	
3	0	63	92.26	29.10	
5	0.5	80	116.42	36.72	
8	1	93	134.89	42.55	
11	2	105	151.95	47.93	
13	3	110	159.05	50.17	
17	5	120	173.26	54.66	
33	13	134.3	193.59	61.07	
42	18	130	187.48	59.14	
56	25	125	180.37	56.90	
68	29.5	120	173.26	54.66	
92	38	110	159.05	50.17	
118	43.5	100	144.84	45.69	
127	45.5	95	137.73	43.45	
139	47.5	90	130.63	41.21	
150	48.5	87.5	127.08	40.09	

Table B-32. Teller Loam with 1% A1 Direct Shear Data for 10 kg Loading – Test C

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	10.83	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	18	28.30	8.93	
1.5	0	41	60.99	19.24	
3	0	63	92.26	29.10	
4.5	0	79	115.00	36.28	
8.5	1	95	137.73	43.45	
12	2	105	151.95	47.93	
16	3.5	115	166.16	52.42	
19	5	120	173.26	54.66	
22	6	125	180.37	56.90	
33	11	129	186.05	58.69	
42	16	125	180.37	56.90	
50	19	120	173.26	54.66	
69	26	115	166.16	52.42	
81	29	110	159.05	50.17	
108	38	100	144.84	45.69	
120	40	95	137.73	43.45	
129	41.5	90	130.63	41.21	
150	44	86	124.94	39.41	

Table B-33. Teller Loam with 0.5% C1 Direct Shear Data for 2 kg Loading – Test A

Shear Test Data Teller - 0.5% C1 Added -1 27-Mar-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	10.85	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	20	31.15	9.83	
1	0	47	69.52	21.93	
3	1	66	96.52	30.45	
6	2.5	78	113.57	35.83	
9	5	90	130.63	41.21	
14	8	95.25	138.09	43.56	
28	20	75	109.31	34.48	
32	23	60	87.99	27.76	
40	24	55	80.89	25.52	
45	25	50	73.78	23.28	
50	27	45	66.68	21.03	
57	28	40	59.57	18.79	
77	31.5	35	52.46	16.55	
100	35	33.25	49.98	15.77	
120	37.5	34	51.04	16.10	

Table B-34. Teller Loam with 0.5% C1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	10.68	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	20	31.15	9.83	
3	0.5	60	87.99	27.76	
5	1	70	102.21	32.24	
6.5	2	80	116.42	36.72	
9	3.5	90	130.63	41.21	
14	6.5	93.5	135.60	42.78	
21	12.5	80	116.42	36.72	
26	16.5	75	109.31	34.48	
30	20	70	102.21	32.24	
36	24	65	95.10	30.00	
40	25	60	87.99	27.76	
45	27.5	55	80.89	25.52	
52	29	50	73.78	23.28	
62	32	45	66.68	21.03	
90	40	40	59.57	18.79	
120	46.5	35.75	53.53	16.89	
135	49.5	35	52.46	16.55	

Table B-35. Teller Loam with 0.5% C1 Direct Shear Data for 2 kg Loading – Test C

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	10.86	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	32	48.20	15.21	
3	0	53	78.05	24.62	
5	1	62	90.84	28.65	
7	1	75	109.31	34.48	
8.5	2	80	116.42	36.72	
16	9	82	119.26	37.62	
34	24	75	109.31	34.48	
41	28	70	102.21	32.24	
48	31.5	65	95.10	30.00	
59	38	55	80.89	25.52	
65	39.5	50	73.78	23.28	
74	41.5	45	66.68	21.03	
100	48.5	41	60.99	19.24	
120	52.5	38.5	57.44	18.12	

Table B-36. Teller Loam with 0.5% C1 Direct Shear Data for 4 kg Loading – Test A

Shear Test Data Teller - 0.5% C1 Added -2 27-Mar-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	10.49	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	10	16.94	5.34	
1	0	30	45.36	14.31	
1	0	40	59.57	18.79	
1.5	0	50	73.78	23.28	
2	0	60	87.99	27.76	
3	0	70	102.21	32.24	
5	1	80	116.42	36.72	
6	1.5	85	123.52	38.97	
9	3	95	137.73	43.45	
14	6	97.5	141.29	44.57	
40	25	83	120.68	38.07	
51	28.5	65	95.10	30.00	
55	29	60	87.99	27.76	
65	31	55	80.89	25.52	
86	34.5	50	73.78	23.28	
125	39	45	66.68	21.03	

Table B-37. Teller Loam with 0.5% C1 Direct Shear Data for 4 kg Loading – Test B

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	10.47	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	14	22.62	7.14	
0.5	0	37	55.31	17.45	
1	0	60	87.99	27.76	
2.5	0	70	102.21	32.24	
4	0.5	80	116.42	36.72	
6	1	90	130.63	41.21	
15	6.5	107.5	155.50	49.05	
20	11	99	143.42	45.24	
26	17	95	137.73	43.45	
31	20	90	130.63	41.21	
38	23.5	85	123.52	38.97	
48	28.5	80	116.42	36.72	
53	30	75	109.31	34.48	
58	31.5	70	102.21	32.24	
69	34	65	95.10	30.00	
90	38.5	54.5	80.18	25.29	
120	43	51	75.20	23.72	
140	46.5	50	73.78	23.28	

Table B-38. Teller Loam with 0.5% C1 Direct Shear Data for 4 kg Loading – Test C

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	10.43	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	15	24.04	7.58	
1	0	40	59.57	18.79	
1	0	50	73.78	23.28	
1.5	0	60	87.99	27.76	
2	0	70	102.21	32.24	
3.5	0.5	80	116.42	36.72	
5.5	1	90	130.63	41.21	
8.5	2.5	100	144.84	45.69	
14	5.5	106.5	154.08	48.60	
27.5	16.5	104	150.52	47.48	
32	20	100	144.84	45.69	
36	22.5	95	137.73	43.45	
41	24.5	85	123.52	38.97	
45	25.5	75	109.31	34.48	
50	28	65	95.10	30.00	
65	30	60	87.99	27.76	
79	33	55	80.89	25.52	
105	37	49	72.36	22.83	
125	40.5	47	69.52	21.93	

Table B-39. Teller Loam with 0.5% C1 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Teller - 0.5% C1 Added -3 27-Mar-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	10	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	15	24.04	7.58	
1	0	38	56.73	17.90	
2	0	67	97.94	30.90	
2.5	0.5	90	130.63	41.21	
4	1	110	159.05	50.17	
5	1.5	120	173.26	54.66	
7	2.5	135	194.58	61.38	
20	9	162	232.95	73.49	
29	14	145	208.79	65.87	
34	16	135	194.58	61.38	
39	18	130	187.48	59.14	
50	21	126	181.79	57.35	
105	33	100	144.84	45.69	
130	36.5	94	136.31	43.00	
150	38.5	93.5	135.60	42.78	

Table B-40. Teller Loam with 0.5% C1 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	10.24	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	15	24.04	7.58	
1	0	30	45.36	14.31	
1.5	0	60	87.99	27.76	
2	0	80	116.42	36.72	
4	0.5	100	144.84	45.69	
6	1	120	173.26	54.66	
9	2	140	201.69	63.62	
11	3.5	150	215.90	68.11	
20	7.5	165	237.22	74.83	
27	12.5	155	223.00	70.35	
32	15	145	208.79	65.87	
43	20	135	194.58	61.38	
52	23	130	187.48	59.14	
110	32	86.5	125.65	39.64	
130	34	85	123.52	38.97	
150	34.5	84	122.10	38.52	

Table B-41. Teller Loam with 0.5% C1 Direct Shear Data for 10 kg Loading – Test C.

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	10.09	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	20	31.15	9.83	
0.5	0	40	59.57	18.79	
1.5	0	70	102.21	32.24	
4	0	90	130.63	41.21	
5.5	0	100	144.84	45.69	
8	1	120	173.26	54.66	
8.5	1.5	130	187.48	59.14	
13	2.5	145	208.79	65.87	
18.5	4.5	155	223.00	70.35	
26	9.5	161	231.53	73.04	
36	15	150	215.90	68.11	
41.5	18	140	201.69	63.62	
46	20	135	194.58	61.38	
51	22	130	187.48	59.14	
63	25.5	120	173.26	54.66	
100	29.5	89	129.21	40.76	
120	31	85.5	124.23	39.19	
150	31.5	83	120.68	38.07	

Table B-42. Teller Loam with 1% C1 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Teller - 1% C1 Added -1 31-Mar-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	10.56	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1.5	0.5	50	73.78	23.28	
2	1	65	95.10	30.00	
4	1.5	75	109.31	34.48	
6	3	85	123.52	38.97	
12	9	96.5	139.87	44.12	
18	16	85	123.52	38.97	
22	20	80	116.42	36.72	
29.5	25.5	70	102.21	32.24	
34	27	60	87.99	27.76	
42	29	50	73.78	23.28	
46	30	45	66.68	21.03	
57	32	40	59.57	18.79	
102	39	35	52.46	16.55	
130	43	33	49.62	15.65	

Table B-43. Teller Loam with 1% C1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	10.56	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1.5	0	50	73.78	23.28	
3	0.25	65	95.10	30.00	
5	0.5	75	109.31	34.48	
7	2.5	85	123.52	38.97	
12.5	7.5	91.5	132.76	41.88	
21	15	80	116.42	36.72	
24	19	75	109.31	34.48	
28	21	70	102.21	32.24	
35	25	60	87.99	27.76	
41	26	50	73.78	23.28	
46	26.5	45	66.68	21.03	
52	27	40	59.57	18.79	
71	29.5	35	52.46	16.55	
130	36.25	31.5	47.49	14.98	

Table B-44. Teller Loam with 1% C1 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	10.56	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1.5	0	50	73.78	23.28	
2.5	0	60	87.99	27.76	
5	1	75	109.31	34.48	
8	2.5	80	116.42	36.72	
11	5	81.5	118.55	37.40	
24.5	7.5	85	123.52	38.97	
28	20	70	102.21	32.24	
33	23	60	87.99	27.76	
38	24.5	50	73.78	23.28	
48	26.5	40	59.57	18.79	
71	31	35	52.46	16.55	
130	39.5	32.5	48.91	15.43	

Table B-45. Teller Loam with 1% C1 Direct Shear Data for 4 kg Loading – Test A

Shear Test Data Teller - 1% C1 Added -2 31-Mar-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	10.34	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1	0	40	59.57	18.79	
2.5	0	60	87.99	27.76	
4	0.5	75	109.31	34.48	
5.5	1	85	123.52	38.97	
7.5	1.5	95	137.73	43.45	
11	2.5	105	151.95	47.93	
16	6	112.5	162.60	51.29	
18	8	110	159.05	50.17	
23	12.5	105	151.95	47.93	
29.5	16.5	95	137.73	43.45	
41.5	21	85	123.52	38.97	
71	28.5	60	87.99	27.76	
94	32.5	55	80.89	25.52	
130	37.5	51.5	75.91	23.95	

Table B-46. Teller Loam with 1% C1 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	10.3	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	30	45.36	14.31	
0.75	0	50	73.78	23.28	
1.5	0	65	95.10	30.00	
2.5	0.25	75	109.31	34.48	
4	0.5	85	123.52	38.97	
12	5	101.5	146.97	46.36	
21	11	99	143.42	45.24	
26	15	95	137.73	43.45	
30	18	90	130.63	41.21	
39	22	85	123.52	38.97	
82.5	35.5	60	87.99	27.76	
95	38	55	80.89	25.52	
130	44	51.5	75.91	23.95	

Table B-47. Teller Loam with 1% C1 Direct Shear Data for 4 kg Loading – Test C.

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	10.38	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1	0	50	73.78	23.28	
2	0	60	87.99	27.76	
2.75	0.5	70	102.21	32.24	
4.5	0.5	80	116.42	36.72	
7	1.5	90	130.63	41.21	
8	2.5	95	137.73	43.45	
14	6	100	144.84	45.69	
23	14	95	137.73	43.45	
28	17	90	130.63	41.21	
49	26	75	109.31	34.48	
69	31	60	87.99	27.76	
77	32.5	55	80.89	25.52	
92	35	50	73.78	23.28	
130	40	47.5	70.23	22.15	

Table B-48. Teller Loam with 1% C1 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Teller - 1% C1 Added -3 31-Mar-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	10.23	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	30	45.36	14.31	
1.5	0	50	73.78	23.28	
2.25	0	70	102.21	32.24	
3	0.5	85	123.52	38.97	
4.5	0.5	95	137.73	43.45	
6.5	1	110	159.05	50.17	
11	2.5	125	180.37	56.90	
32	14	142	204.53	64.52	
56	24	120	173.26	54.66	
76	29	105	151.95	47.93	
125	36	85	123.52	38.97	
150	39	83	120.68	38.07	

Table B-49. Teller Loam with 1% C1 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	10.11	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1	0	50	73.78	23.28	
1.25	0	65	95.10	30.00	
2	0.25	80	116.42	36.72	
4	0.5	100	144.84	45.69	
6	1	120	173.26	54.66	
8	1.5	130	187.48	59.14	
26	10	161	231.53	73.04	
30	13	155	223.00	70.35	
38	16	145	208.79	65.87	
46	20	140	201.69	63.62	
62	26	120	173.26	54.66	
77	29	100	144.84	45.69	
96	30.5	90	130.63	41.21	
140	33	85.25	123.88	39.08	
160	34	84	122.10	38.52	

Table B-50. Teller Loam with 1% C1 Direct Shear Data for 10 kg Loading – Test C.

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	9.86	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1	0	60	87.99	27.76	
2	0	80	116.42	36.72	
3	0	95	137.73	43.45	
4	0	110	159.05	50.17	
5.5	0	120	173.26	54.66	
7	1	130	187.48	59.14	
9	1	140	201.69	63.62	
12	2	150	215.90	68.11	
12.5	2	155	223.00	70.35	
14	3	160	230.11	72.59	
17	4.5	165	237.22	74.83	
23	8.5	166.5	239.35	75.50	
31	13	155	223.00	70.35	
37	17	145	208.79	65.87	
67	28.5	120	173.26	54.66	
95	33	100	144.84	45.69	
140	39	89.5	129.92	40.98	
160	41.5	89	129.21	40.76	

Table B-51. Teller Loam with 0.5% C2 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Teller - 0.5% C2 Added -1 1-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	10.3	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
3	0	30	45.36	14.31
5	0.5	50	73.78	23.28
7	1	65	95.10	30.00
9	2.5	75	109.31	34.48
12	4	80	116.42	36.72
14	6	85	123.52	38.97
22	12	90.25	130.98	41.32
25	14	85	123.52	38.97
30	18	80	116.42	36.72
40	24.5	70	102.21	32.24
56	33	60	87.99	27.76
74	41.5	50	73.78	23.28
85	44.5	45	66.68	21.03
97	48	40	59.57	18.79
130	53	32	48.20	15.21

Table B-52. Teller Loam with 0.5% C2 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	10.23	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
5	0.5	50	73.78	23.28	
6	1	60	87.99	27.76	
8	1.75	70	102.21	32.24	
12	4.5	80	116.42	36.72	
15	6.75	85	123.52	38.97	
23	11.75	90	130.63	41.21	
29	20	80	116.42	36.72	
34	24	75	109.31	34.48	
41	29	65	95.10	30.00	
45	30.5	60	87.99	27.76	
52	32	50	73.78	23.28	
58	32.5	45	66.68	21.03	
68	33.5	40	59.57	18.79	
113	39	35	52.46	16.55	
130	41.5	34.5	51.75	16.33	

Table B-53. Teller Loam with 0.5% C2 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	10.29	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1.5	0	30	45.36	14.31	
4	0	50	73.78	23.28	
5.5	0.5	60	87.99	27.76	
7.5	1	70	102.21	32.24	
10.5	3	80	116.42	36.72	
12	4	85	123.52	38.97	
16.5	7.5	90	130.63	41.21	
20	11.5	91	132.05	41.66	
24	15	85	123.52	38.97	
27	19	80	116.42	36.72	
32	23.5	75	109.31	34.48	
38	28	70	102.21	32.24	
45	31.5	60	87.99	27.76	
61	36	50	73.78	23.28	
74	39	45	66.68	21.03	
101	44	40	59.57	18.79	
130	47.5	34.5	51.75	16.33	

Table B-54. Teller Loam with 0.5% C2 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Teller - 0.5% C2 Added -2 1-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	10.27	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
2.5	0	50	73.78	23.28	
4.5	0	70	102.21	32.24	
6.5	0.5	80	116.42	36.72	
9	1	90	130.63	41.21	
13	2.5	100	144.84	45.69	
20	6	109	157.63	49.73	
26	10	100	144.84	45.69	
30	12	95	137.73	43.45	
35	15	90	130.63	41.21	
41	18	85	123.52	38.97	
47	20	80	116.42	36.72	
63	26	70	102.21	32.24	
96	35	60	87.99	27.76	
117	39.5	55	80.89	25.52	
130	42.5	52.25	76.98	24.28	
150	46	49	72.36	22.83	

Table B-55. Teller Loam with 0.5% C2 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	10.19	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	0	30	45.36	14.31	
3	0.5	50	73.78	23.28	
5	0.5	70	102.21	32.24	
6	0.75	80	116.42	36.72	
8.5	1.5	90	130.63	41.21	
12	4	100	144.84	45.69	
13	5	105	151.95	47.93	
19	10	109.9	158.91	50.13	
24	15	100	144.84	45.69	
27	13	95	137.73	43.45	
31	20	85	123.52	38.97	
37	22	75	109.31	34.48	
48	24.5	60	87.99	27.76	
54	25.5	55	80.89	25.52	
66.5	26.5	50	73.78	23.28	
112	30	45	66.68	21.03	
150	32.5	42.5	63.12	19.91	

Table B-56. Teller Loam with 0.5% C2 Direct Shear Data for 4 kg Loading – Test C.

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	9.82	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	0	30	45.36	14.31	
4	0	50	73.78	23.28	
5	0.5	60	87.99	27.76	
6.5	0.75	70	102.21	32.24	
7	1	80	116.42	36.72	
9	2	90	130.63	41.21	
10	2.75	95	137.73	43.45	
12	3.5	100	144.84	45.69	
14	5	105	151.95	47.93	
17	7.5	110	159.05	50.17	
22	11	112	161.89	51.07	
24	13.5	105	151.95	47.93	
27	16	100	144.84	45.69	
34	20	90	130.63	41.21	
40	23.5	80	116.42	36.72	
49.5	26.5	70	102.21	32.24	
70	30	60	87.99	27.76	
130	37	44.5	65.97	20.81	
150	38.5	43.5	64.54	20.36	

Table B-57. Teller Loam with 0.5% C2 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Teller - 0.5% C2 Added -3 1-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	10.05	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1	0	50	73.78	23.28	
2	0	60	87.99	27.76	
3	0.5	80	116.42	36.72	
4.5	0.5	90	130.63	41.21	
6	1	100	144.84	45.69	
8	1.5	110	159.05	50.17	
12	2.5	120	173.26	54.66	
14	3	125	180.37	56.90	
16	4	130	187.48	59.14	
20	5	135	194.58	61.38	
24	7	136.25	196.36	61.94	
50	17	125	180.37	56.90	
65	22.5	115	166.16	52.42	
83	27	100	144.84	45.69	
120	31	85.5	124.23	39.19	
140	32.5	84.5	122.81	38.74	

Table B-58. Teller Loam with 0.5% C2 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	10.08	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
3.5	0	50	73.78	23.28	
4.5	0	70	102.21	32.24	
6	0.5	90	130.63	41.21	
9	0.5	110	159.05	50.17	
11.5	1	120	173.26	54.66	
14	1.5	130	187.48	59.14	
16	2.5	135	194.58	61.38	
18	3.5	140	201.69	63.62	
20	5	145	208.79	65.87	
25	7	150	215.90	68.11	
29	10	151.25	217.67	68.67	
46	18	140	201.69	63.62	
62	24	135	194.58	61.38	
84	31.5	125	180.37	56.90	
140	45	97.5	141.29	44.57	

Table B-59. Teller Loam with 0.5% C2 Direct Shear Data for 10 kg Loading – Test C.

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	9.94	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	0	30	45.36	14.31	
1	0	50	73.78	23.28	
2	0	70	102.21	32.24	
4	0.5	90	130.63	41.21	
5	0.5	100	144.84	45.69	
6	1	110	159.05	50.17	
8.5	1.5	120	173.26	54.66	
10.5	2	130	187.48	59.14	
15	3	140	201.69	63.62	
19	5.25	150	215.90	68.11	
29	11.5	155.5	223.71	70.57	
36	16	150	215.90	68.11	
61.5	28	140	201.69	63.62	
89	39	125	180.37	56.90	
118	46	110	159.05	50.17	
140	48.5	97.5	141.29	44.57	

Table B-60. Teller Loam with 1% C2 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Teller - 1% C2 Added -1 7-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	10.05	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
1	0	30	45.36	14.31
4	1	50	73.78	23.28
5	1	55	80.89	25.52
7	2	60	87.99	27.76
9	3	65	95.10	30.00
12	5	70	102.21	32.24
15	7	75	109.31	34.48
20	10	80	116.42	36.72
27	14	81	117.84	37.17
22	20	75	109.31	34.48
39	24	70	102.21	32.24
45	28	65	95.10	30.00
50	31	60	87.99	27.76
57.5	34.5	55	80.89	25.52
67	37.5	50	73.78	23.28
82	40.5	45	66.68	21.03
130	49	36.5	54.60	17.22

Table B-61. Teller Loam with 1% C2 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.24	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
3	0	40	59.57	18.79	
5	0.5	50	73.78	23.28	
7	1	55	80.89	25.52	
8	1.5	60	87.99	27.76	
10	2.5	65	95.10	30.00	
14	4	70	102.21	32.24	
17	5.5	75	109.31	34.48	
22	8.5	80	116.42	36.72	
30	14	82.5	119.97	37.85	
33	17.5	80	116.42	36.72	
38	20	75	109.31	34.48	
43	24	70	102.21	32.24	
51	29	65	95.10	30.00	
55	31.5	60	87.99	27.76	
61	34	55	80.89	25.52	
65	35	50	73.78	23.28	
73	36	45	66.68	21.03	
90	38	40	59.57	18.79	
130	44	36.5	54.60	17.22	

Table B-62. Teller Loam with 1% C2 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	12.52	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
3.5	0	45	66.68	21.03	
7	0.5	55	80.89	25.52	
8	1	60	87.99	27.76	
11	2	65	95.10	30.00	
14	3	70	102.21	32.24	
18	5	75	109.31	34.48	
24	8.5	80	116.42	36.72	
30	12	81.5	118.55	37.40	
35	18	75	109.31	34.48	
40	21	70	102.21	32.24	
45	24	65	95.10	30.00	
51	27	60	87.99	27.76	
59	30	55	80.89	25.52	
69	33	50	73.78	23.28	
78	35	45	66.68	21.03	
101	39	40	59.57	18.79	
130	43.5	37.5	56.02	17.67	

Table B-63. Teller Loam with 1% C2 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Teller - 1% C2 Added -2 7-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	11.07	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0.75	0	30	45.36	14.31
2	0	50	73.78	23.28
3.5	0	60	87.99	27.76
6	1	70	102.21	32.24
8	1.5	75	109.31	34.48
11	2.5	80	116.42	36.72
13	4	85	123.52	38.97
16	5	90	130.63	41.21
21	7.5	95	137.73	43.45
30	13	98.5	142.71	45.02
36	17	95	137.73	43.45
41	20.5	90	130.63	41.21
47	24	85	123.52	38.97
51	26.5	80	116.42	36.72
57	28.5	75	109.31	34.48
61	30	70	102.21	32.24
67	31	65	95.10	30.00
77	33	60	87.99	27.76
90.5	35	55	80.89	25.52
113	37.5	50	73.78	23.28
140	39.5	48	70.94	22.38

Table B-64. Teller Loam with 1% C2 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.18	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	0	30	45.36	14.31	
4	0	40	59.57	18.79	
6	0	50	73.78	23.28	
8.5	0	60	87.99	27.76	
11	0.5	70	102.21	32.24	
14	1	75	109.31	34.48	
16	1.5	80	116.42	36.72	
20	2.5	85	123.52	38.97	
25	4	90	130.63	41.21	
35	8	94	136.31	43.00	
48	14.5	90	130.63	41.21	
67	19	85	123.52	38.97	
65	22.5	80	116.42	36.72	
72	25	75	109.31	34.48	
80	28	70	102.21	32.24	
90	31	65	95.10	30.00	
100	33.5	60	87.99	27.76	
127	39.5	55	80.89	25.52	
140	42	54	79.47	25.07	

Table B-65. Teller Loam with 1% C2 Direct Shear Data for 4 kg Loading – Test C.

Test C (4 kg)					
			Sample Dimensions		
Soil Moisture	11.11	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
2	0	40	59.57	18.79	
3	0.25	50	73.78	23.28	
5	0.5	60	87.99	27.76	
7	1	65	95.10	30.00	
8	1	70	102.21	32.24	
11	1.5	75	109.31	34.48	
14	2.5	80	116.42	36.72	
17	3.5	85	123.52	38.97	
21	4.5	90	130.63	41.21	
31	9.5	94	136.31	43.00	
50	18.5	90	130.63	41.21	
57.5	23	85	123.52	38.97	
67	27	80	116.42	36.72	
78	32	75	109.31	34.48	
89.5	35.5	70	102.21	32.24	
104	40	65	95.10	30.00	
121	43.5	60	87.99	27.76	
140	47.5	56.5	83.02	26.19	

Table B-66. Teller Loam with 1% C2 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Teller - 1% C2 Added –3 7-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	10.96	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	98.1	N	Volume	88.4	cm^3
Proving Ring Constant	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
1.5	0	40	59.57	18.79	
2	0	50	73.78	23.28	
2.5	0	60	87.99	27.76	
4	0	70	102.21	32.24	
5	0	80	116.42	36.72	
7.5	0.25	90	130.63	41.21	
11	0.75	100	144.84	45.69	
12	1	105	151.95	47.93	
14	1.75	110	159.05	50.17	
16	2.25	115	166.16	52.42	
19	2.75	120	173.26	54.66	
22	3.5	125	180.37	56.90	
25	4.5	130	187.48	59.14	
31	6.5	135	194.58	61.38	
43	11	138	198.84	62.73	
53.5	15	135	194.58	61.38	
68	20	130	187.48	59.14	
85	24.5	125	180.37	56.90	
96	27	120	173.26	54.66	
103	28.5	115	166.16	52.42	
108.5	29.5	110	159.05	50.17	
118	31.5	105	151.95	47.93	
139	33.5	100	144.84	45.69	
150	34.5	94.75	137.38	43.34	

Table B-67. Teller Loam with 1% C2 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	10.92	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	0	30	45.36	14.31	
2	0	50	73.78	23.28	
3	0	65	95.10	30.00	
4	0	75	109.31	34.48	
5.5	0	80	116.42	36.72	
7.5	0.5	90	130.63	41.21	
10	1	100	144.84	45.69	
12	1	105	151.95	47.93	
18	2	115	166.16	52.42	
20	2.75	120	173.26	54.66	
23	3.5	125	180.37	56.90	
26	4.5	130	187.48	59.14	
31	6	135	194.58	61.38	
45	12.5	139	200.27	63.18	
56	16.5	135	194.58	61.38	
74	22.5	130	187.48	59.14	
81	28	125	180.37	56.90	
103	31	120	173.26	54.66	
120	34.5	115	166.16	52.42	
150	40	111	160.47	50.62	

Table B-68. Teller Loam with 1% C2 Direct Shear Data for 10 kg Loading – Test C.

Test C (10 kg)					
			Sample Dimensions		
Soil Moisture	10.84	%	Diameter	6.35	cm
Soil Weight	179	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	0	30	45.36	14.31	
1	0	50	73.78	23.28	
2.5	0	70	102.21	32.24	
4	0	80	116.42	36.72	
6	0	90	130.63	41.21	
10	0.5	100	144.84	45.69	
13	1	110	159.05	50.17	
17	2	120	173.26	54.66	
20	2.75	125	180.37	56.90	
23	3.5	130	187.48	59.14	
26	5	135	194.58	61.38	
48	14	141	203.11	64.07	
55	16	140	201.69	63.62	
73	24	135	194.58	61.38	
81	27	130	187.48	59.14	
89	30	125	180.37	56.90	
95	31.5	120	173.26	54.66	
105	33.5	115	166.16	52.42	
117.5	36	110	159.05	50.17	
132.5	38.75	105	151.95	47.93	
150	40.5	88	127.79	40.31	

Appendix C

Data from Slaughterville Sandy Loam Soil Property Measurements

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Table C-1. Slaughterville Sandy Loam Consolidation Test Data for 1 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
1	0.25	241	0.25	159	0.25	160	0.25	160
1	0.5	247	0.5	159	0.5	165	0.5	162
1	1	249	1	160	1	166	1	163
1	2	251	2	160	2	167	2	165
1	4	252	4	161	4	168	4	167
1	8	255	8	162	8	171	8	169
1	15	256	15	162	15	172	15	171
1	30	259	30	163	30	175	30	173
1	60	261	60	164	60	176	60	174
1	120	263	120	165	120	178	148	176
1	240	265	240	165	240	179	240	177
1	729	268	480	166	400	180	357	178
1	1024	270	1024	166	1193	182	534	179
1	1304	271	1469	166	1475	183	1303	180
1	1469	271	1764	166	1729	184	1418	180
1	2152	272	2500	166	2685	188		
1	2309	272						
1	2874	273						

Table C-2. Slaughterville Sandy Loam Consolidation Test Data for 3 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
3	0.25	65	0.25	55	0.25	38	0.25	44
3	0.5	67	0.5	56	0.5	41	0.5	45
3	1	69	1	57	1	42	1	47
3	2	70	2	58	2	43	2	49
3	4	72	4	59	4	44	4	51
3	8	74	8	60	8	45	8	52
3	15	76	15	62	15	46	15	54
3	30	79	30	63	30	47	30	56
3	60	80	60	65	60	48	60	57
3	120	82	120	66	120	49	87	59
3	240	84	240	67	340	51	212	61
3	480	87	480	69	527	52	339	63
3	674	87	820	70	1260	54	564	64
3	832	88	1528	70	1440	54	1289	65
3	1307	89	1825	71	2025	55	2685	69
3	1806	90	2256	71	3177	56		
3			3025	72				

Table C-3. Slaughterville Sandy Loam Consolidation Test Data for 7 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
7	0.25	53	0.25	42	0.25	43	0.25	36
7	0.5	57	0.5	43	0.5	44	0.5	39
7	1	58	1	44	1	45	1	41
7	2	60	2	45	2	46	2	42
7	4	61	4	46	4	48	4	44
7	8	63	8	48	8	49	8	46
7	15	67	15	49	15	50	15	48
7	30	67	30	52	30	52	30	50
7	60	68	60	52	60	53	60	52
7	120	71	120	54	120	55	120	54
7	360	72	260	55	240	57	177	55
7	1034	76	437	56	298	57	283	56
7	1178	76	625	57	969	59	466	58
7	1372	77	1289	59	1225	60	671	59
7	1600	77	1637	59	1528	60	1493	60
7	1710	78	1984	60	1683	61	3151	63
7	2650	78	3025	62	2410	61		

Table C-4. Slaughterville Sandy Loam Consolidation Test Data for 15 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
15	0.25	55	0.25	43	0.25	47	0.25	44
15	0.5	57	0.5	44	0.5	48	0.5	45
15	1	58	1	45	1	49	1	47
15	2	60	2	46	2	50	2	48
15	4	62	4	47	4	51	4	50
15	8	63	8	48	8	52	8	52
15	15	65	15	50	15	53	15	53
15	30	67	30	51	30	55	30	55
15	60	69	60	53	60	56	60	57
15	120	70	120	54	120	58	269	60
15	240	72	225	55	290	60	451	60
15	744	74	437	56	382	61	1139	62
15	1564	76	1101	58	998	62		
15	1845	77	1423	58	1225	62		
15	2066	77	2455	59	1924	64		
15	2662	78	2950	60	2546	64		
15					2638	64		

Table C-5. Slaughterville Sandy Loam Consolidation Test Data for 31 kg Loading.

	Unaltered		1% TDTMAB		1% SDBS		1% CC-9	
Load (kg)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)	Time (min)	Dial Reading (0.0001 inches)
31	0.25	56	0.25	45	0.25	52	0.5	54
31	0.5	59	0.5	47	0.5	53	1	57
31	1	60	1	48	1	54	2	58
31	2	62	2	48	2	55	4	60
31	4	64	4	50	4	56	8	62
31	8	65	8	51	8	58	15	63
31	15	67	15	52	15	59	30	65
31	30	69	30	54	30	60	60	66
31	60	71	60	55	60	62	138	69
31	120	73	141	57	189	64	252	70
31	217	74	264	58	269	65	442	73
31	297	75	425	59	400	66	716	74
31	519	77	1056	61	506	67	1362	76
31	682	78	1430	61	772	68	1882	77
31	1304	80	2500	62	1225	68	2881	78
31	1556	80	3985	63	1578	68		
31	2283	82	5439	64	2204	70		
31	2934	82			2669	70		
31	4407	83			3567	71		
31					4371	71		

Table C-6. Unaltered Slaughterville Sandy Loam Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Slaughterville - Unaltered 1 8-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	11.57	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	0.5	20	31.15	9.83	
4.5	0.75	25	38.25	12.07	
9	1.5	30	45.36	14.31	
15	3	35	52.46	16.55	
27	7	40	59.57	18.79	
49	15.5	43.25	64.19	20.25	
59	20	42	62.41	19.69	
62	21	41	60.99	19.24	
64	22	40	59.57	18.79	
72	24	35	52.46	16.55	
79	25	30	45.36	14.31	
102.5	26	25	38.25	12.07	
130	28.25	24.5	37.54	11.84	

Table C-7. Unaltered Slaughterville Sandy Loam Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.51	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	0	20	31.15	9.83	
6	0	25	38.25	12.07	
11	0	30	45.36	14.31	
19	1.75	35	52.46	16.55	
26	3.5	37	55.31	17.45	
32	6	39	58.15	18.34	
35	7	40	59.57	18.79	
41	9.5	41	60.99	19.24	
49	12	40	59.57	18.79	
59	15	35	52.46	16.55	
67.5	16	30	45.36	14.31	
88	18	25	38.25	12.07	
130	20	23.75	36.48	11.51	

Table C-8. Unaltered Slaughterville Sandy Loam Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	11.76	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
4	0	20	31.15	9.83	
7.5	0	25	38.25	12.07	
14	0	30	45.36	14.31	
22	0.25	35	52.46	16.55	
28	1	38	56.73	17.90	
30	1.5	39	58.15	18.34	
33	1.75	40	59.57	18.79	
37	2.5	41	60.99	19.24	
40	3.5	42	62.41	19.69	
44	4	43	63.83	20.14	
52	6	42	62.41	19.69	
55	7	40	59.57	18.79	
59	8	37	55.31	17.45	
62	8.5	35	52.46	16.55	
67	9.5	33	49.62	15.65	
71	10	30	45.36	14.31	
130	14	26	39.67	12.52	

Table C-9. Unaltered Slaughterville Sandy Loam Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Slaughterville - Unaltered2 9-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	11.47	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2.5	0	20	31.15	9.83	
5	-1	25	38.25	12.07	
8	-1.25	30	45.36	14.31	
11	-1.5	35	52.46	16.55	
15.5	-1.5	40	59.57	18.79	
21	-1	45	66.68	21.03	
24	0	47	69.52	21.93	
27	1	50	73.78	23.28	
31	2	53	78.05	24.62	
34	2.75	55	80.89	25.52	
45	6	57	83.73	26.41	
49	7	56	82.31	25.96	
52	8	55	80.89	25.52	
60	10	50	73.78	23.28	
67	11	45	66.68	21.03	
76	12	40	59.57	18.79	
96	13	35	52.46	16.55	
130	13.75	34.25	51.40	16.21	

Table C-10. Unaltered Slaughterville Sandy Loam Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.59	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.25	0	10	16.94	5.34	
2	-0.5	20	31.15	9.83	
6	-1	30	45.36	14.31	
10	-1.5	35	52.46	16.55	
15	-1	40	59.57	18.79	
22.5	0	45	66.68	21.03	
27	0.5	47	69.52	21.93	
30	1	48	70.94	22.38	
31.5	1.5	49	72.36	22.83	
34.5	2	50	73.78	23.28	
40	3	52	76.62	24.17	
45	5	53	78.05	24.62	
56	7	51	75.20	23.72	
59	8	50	73.78	23.28	
64	8.5	47	69.52	21.93	
68	9.5	45	66.68	21.03	
77.5	10	40	59.57	18.79	
103	10.75	35	52.46	16.55	
130	10.75	34	51.04	16.10	

Table C-11. Unaltered Slaughterville Sandy Loam Direct Shear Data for 4 kg Loading – Test C.

Test C (4kg)					
			Sample Dimensions		
Soil Moisture	11.34	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
7	-2.25	30	45.36	14.31	
12	-3.5	35	52.46	16.55	
18	-4.5	40	59.57	18.79	
26	-5	45	66.68	21.03	
38	-4	50	73.78	23.28	
42	-3.5	51	75.20	23.72	
46	-2.75	52	76.62	24.17	
54	-1	51	75.20	23.72	
57	0	50	73.78	23.28	
62	1	48	70.94	22.38	
68	1.75	45	66.68	21.03	
74	2	42	62.41	19.69	
78	2.5	40	59.57	18.79	
110	2.75	36	53.89	17.00	
130	3	35	52.46	16.55	

Table C-12. Unaltered Slaughterville Sandy Loam Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Slaughterville - Unaltered 3 9-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	11.79	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0	-1	10	16.94	5.34
1	-1	15	24.04	7.58
1.5	-1	20	31.15	9.83
4	-2	30	45.36	14.31
6.5	-2	40	59.57	18.79
8.5	-3	50	73.78	23.28
1.5	-3	55	80.89	25.52
16	-3.75	65	95.10	30.00
20	-4	70	102.21	32.24
24	-4	75	109.31	34.48
29	-3.25	80	116.42	36.72
37	-2.75	85	123.52	38.97
43	-2	88	127.79	40.31
53	-1	89	129.21	40.76
64	0	85	123.52	38.97
69	0.5	80	116.42	36.72
77	0.75	70	102.21	32.24
84	1	65	95.10	30.00
112	0	61	89.41	28.21
130	-0.25	62	90.84	28.65

Table C-13. Unaltered Slaughterville Sandy Loam Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	11.25	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1.5	-1	10	16.94	5.34	
2.5	-1	15	24.04	7.58	
3.5	-1.75	20	31.15	9.83	
6	-2.5	30	45.36	14.31	
7	-3	35	52.46	16.55	
9	-4	40	59.57	18.79	
13	-4.75	45	66.68	21.03	
16.5	-5	50	73.78	23.28	
20	-5.5	55	80.89	25.52	
27	-6.75	60	87.99	27.76	
32.5	-7.5	65	95.10	30.00	
35	-8	70	102.21	32.24	
39	-8	75	109.31	34.48	
47.5	-8.5	80	116.42	36.72	
56	-8.5	85	123.52	38.97	
69	-8	88.5	128.50	40.54	
75	-8	86	124.94	39.41	
83	-7.25	80	116.42	36.72	
89	-7.25	75	109.31	34.48	
97	-7.25	70	102.21	32.24	
120	-7.5	65	95.10	30.00	
130	-7.5	64.5	94.39	29.78	

Table C-14. Unaltered Slaughterville Sandy Loam Direct Shear Data for 10 kg Loading – Test C.

Test C (10kg)					
			Sample Dimensions		
Soil Moisture	11.19	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-1	15	24.04	7.58	
1.75	-1.25	20	31.15	9.83	
3.25	-2	30	45.36	14.31	
6.5	-3.5	40	59.57	18.79	
10.5	-5	50	73.78	23.28	
12.5	-6	55	80.89	25.52	
17	-6.25	60	87.99	27.76	
22	-7.25	65	95.10	30.00	
24.5	-7.75	70	102.21	32.24	
29	-8	75	109.31	34.48	
37	-8.25	80	116.42	36.72	
46	-8.25	85	123.52	38.97	
62	-7.75	88.5	128.50	40.54	
68.5	-7.5	86	124.94	39.41	
76	-7	80	116.42	36.72	
81	-6.75	75	109.31	34.48	
85	-6.75	70	102.21	32.24	
97	-7	65	95.10	30.00	
115	-7.5	62.5	91.55	28.88	
130	-7.75	62.5	91.55	28.88	

Table C-15. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% A1 Added 1 10-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	11.18	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
8	-1	3	6.99	2.20	
11	-1.25	2.75	6.63	2.09	
16	-2	4.5	9.12	2.88	
20	-2.25	4.5	9.12	2.88	
29	-3.5	5	9.83	3.10	
38	-4	6.25	11.61	3.66	
49	-4.25	6	11.25	3.55	
66	-5	5.75	10.90	3.44	
84	-5.5	6.75	12.32	3.89	
101	-6.25	6	11.25	3.55	
120	-6.33	8	14.09	4.45	
130	-6.5	7.8	13.81	4.36	

Table C-16. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.1	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
6	-0.5	3.5	7.70	2.43	
9	-1.25	4.25	8.76	2.76	
12	-1.5	5	9.83	3.10	
19	-2	5.25	10.19	3.21	
26	-3	6.25	11.61	3.66	
36	-4	6.1	11.39	3.59	
46	-5	7.1	12.81	4.04	
63	-6	7.5	13.38	4.22	
82	-7	8.25	14.45	4.56	
101	-7.25	8.25	14.45	4.56	
118	-8	9	15.51	4.89	
130	-8	9	15.51	4.89	

Table C-17. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	10.93	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
4	-1	2.5	6.28	1.98	
9	-1.25	3.75	8.05	2.54	
14	-2	4	8.41	2.65	
19	-2	4.75	9.47	2.99	
27	-2	4.75	9.47	2.99	
35	-2.5	5.25	10.19	3.21	
45	-2.5	6	11.25	3.55	
61	-3	6.25	11.61	3.66	
81	-3	7	12.67	4.00	
100	-2.5	7.1	12.81	4.04	
117	-4	7.9	13.95	4.40	
130	-4.5	8.5	14.80	4.67	

Table C-18. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% A1 Added 2 10-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	11.33	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
3	-1	4	8.41	2.65
6	-2	5	9.83	3.10
14	-3.75	5	9.83	3.10
24	-6	5	9.83	3.10
32	-7	5	9.83	3.10
38	-7.25	6	11.25	3.55
50	-7.5	6.5	11.96	3.77
61	-8.5	5	9.83	3.10
73	-10	5.25	10.19	3.21
80	-11	6	11.25	3.55
100	-12.5	7	12.67	4.00
115	-13.5	7.5	13.38	4.22
130	-14	7.25	13.03	4.11

Table C-19. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.31	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
4	-1	4	8.41	2.65	
9	-1.75	5	9.83	3.10	
14	-2.25	6.5	11.96	3.77	
18	-2.5	6.25	11.61	3.66	
23	-3	6.75	12.32	3.89	
26	-3.5	6.25	11.61	3.66	
30	-4	6	11.25	3.55	
35	-4	6	11.25	3.55	
40	-4.5	6.25	11.61	3.66	
50	-5	7	12.67	4.00	
63	-5	7.5	13.38	4.22	
77	-5.5	8	14.09	4.45	
111	-6	8.25	14.45	4.56	
130	-6.5	9	15.51	4.89	

Table C-20. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 4 kg Loading – Test C.

Test C (4kg)					
			Sample Dimensions		
Soil Moisture	11.25	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
5	-1.5	5.5	10.54	3.33	
8.5	-2	5.75	10.90	3.44	
14	-3	6	11.25	3.55	
18	-3.5	6.75	12.32	3.89	
36	-4.5	7	12.67	4.00	
35	-5.25	7.75	13.74	4.33	
50	-6.25	7	12.67	4.00	
63	-7	8.25	14.45	4.56	
71	-7.5	8.25	14.45	4.56	
90	-8.5	8.75	15.16	4.78	
110	-8.5	8.75	15.16	4.78	
130	-9.5	8.75	15.16	4.78	

Table C-21. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% A1 Added 3 10-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	11.29	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
4	-1.5	-0.5	2.01	0.64	
9	-3	11.25	18.71	5.90	
13	-4	12	19.78	6.24	
18	-4.75	12.5	20.49	6.46	
26	-6	15	24.04	7.58	
52	-9	13.5	21.91	6.91	
60	-9.5	15	24.04	7.58	
80	-10.25	15.25	24.40	7.70	
100	-10.75	17.25	27.24	8.59	
115	-11	17.75	27.95	8.82	
130	-11	16	25.46	8.03	

Table C-22. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	11.09	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-1	8	14.09	4.45	
7	-1.75	9.5	16.22	5.12	
11	-2.5	11	18.36	5.79	
14	-3	12	19.78	6.24	
23	-4	13	21.20	6.69	
31	-5	14	22.62	7.14	
45	-5.5	15	24.04	7.58	
60	-6	15.25	24.40	7.70	
79	-6.5	16	25.46	8.03	
99	-7.25	16	25.46	8.03	
113	-8	16.5	26.17	8.26	
130	-8.5	17	26.88	8.48	

Table C-23. Slaughterville Sandy Loam with 0.5% A1 Direct Shear Data for 10 kg Loading – Test C.

Test C (10kg)					
			Sample Dimensions		
Soil Moisture	11.19	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3.5	-1.5	10	16.94	5.34	
8	-2.5	11.25	18.71	5.90	
12.5	-3.25	12.75	20.84	6.58	
18	-3.25	13.25	21.55	6.80	
26	-5	12.75	20.84	6.58	
35	-5.75	13.5	21.91	6.91	
46	-7	13.5	21.91	6.91	
62	-7.5	13.75	22.26	7.02	
80	-9	14.25	22.98	7.25	
98	-9.5	14.75	23.69	7.47	
115	-10.5	16	25.46	8.03	
130	-10.5	16.25	25.82	8.14	

Table C-24. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% C1 Added1 11-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	11.64	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-1.5	5	9.83	3.10	
6	-2.5	13.5	21.91	6.91	
9	-3	16.25	25.82	8.14	
14	-3.5	18	28.30	8.93	
22	-4	22.5	34.70	10.95	
31	-4.5	25.75	39.32	12.40	
40	-3.75	28.75	43.58	13.75	
47	-3	31.25	47.14	14.87	
57	-2	33.1	49.76	15.70	
66	-0.5	35.25	52.82	16.66	
75	1.25	36.5	54.60	17.22	
85	3	35.75	53.53	16.89	
93	4.5	35.75	53.53	16.89	
102	5.25	33.25	49.98	15.77	
111	6	31.1	46.92	14.80	
120	6	30	45.36	14.31	
130	6.25	28.75	43.58	13.75	
139	6.5	28.5	43.23	13.64	
148	6.75	27.75	42.16	13.30	

Table C-25. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.6	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
5	-7.25	8	14.09	4.45	
10	-7.5	17	26.88	8.48	
14	-8	20	31.15	9.83	
18	-8	23	35.41	11.17	
27	-7.5	27	41.10	12.96	
35	-6.75	30	45.36	14.31	
44	-5.5	33	49.62	15.65	
53	-3.5	36.25	54.24	17.11	
62	-2	37.5	56.02	17.67	
70	0	38	56.73	17.90	
78	2	37.5	56.02	17.67	
90	3	36.75	54.95	17.33	
98	3.5	34.5	51.75	16.33	
107	4	30	45.36	14.31	
118	4.25	28.25	42.87	13.52	
126	4	27	41.10	12.96	
135	4	27	41.10	12.96	
143	4	26.75	40.74	12.85	
152	4.5	26.5	40.38	12.74	

Table C-26. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	11.57	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-1	10	16.94	5.34	
5	-1.25	14.25	22.98	7.25	
11	-2	17.75	27.95	8.82	
14	-2.25	22	33.99	10.72	
23	-2.25	25.5	38.96	12.29	
29	-2	29	43.94	13.86	
39	-1	32.5	48.91	15.43	
47	1	35.75	53.53	16.89	
56	4	37.5	56.02	17.67	
64	5	38.25	57.08	18.01	
75	6.5	38.5	57.44	18.12	
75	6.5	37.75	56.37	17.78	
63	8	36	53.89	17.00	
94	8	31.25	47.14	14.87	
104	8.25	28.75	43.58	13.75	
112	8.5	27.75	42.16	13.30	
121	8.5	27	41.10	12.96	
130	8	27	41.10	12.96	
140	7.75	26.5	40.38	12.74	
150	6	25.75	39.32	12.40	

Table C-27. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% C1 Added 2 11-Apr-97				
Test A (4 kg)				
			Sample Dimensions	
Soil Moisture	11.53	%	Diameter	6.35 cm
Soil Weight	174	gm	Depth	2.794 cm
Depth in Cell	0.7	in	Area	31.7 cm^2
Normal Force	4	kg	Volume	88.4 cm^3
	39.24	N		
Proving Ring Constant =	0.001421163*Y+0.0027238958			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
2	-1.25	12	19.78	6.24
6	-2	17.75	27.95	8.82
9	-2.75	24	36.83	11.62
15	-3.25	27	41.10	12.96
21	-3.75	32	48.20	15.21
30	-3.75	38	56.73	17.90
38	-3	41.25	61.35	19.35
46	-2	44.75	66.32	20.92
54	-0.5	47.5	70.23	22.15
63	1	49.5	73.07	23.05
73	3	50	73.78	23.28
84	4.25	47.75	70.58	22.27
93	4.5	41.25	61.35	19.35
103	4.5	38.25	57.08	18.01
111	4	37.25	55.66	17.56
120	4	36.75	54.95	17.33
128	4	36.25	54.24	17.11
137	4	36.25	54.24	17.11
145	3.75	36	53.89	17.00

Table C-28. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.43	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	-1.25	13.5	21.91	6.91	
7	-2.25	21.5	33.28	10.50	
14	-2.75	27	41.10	12.96	
22	-3	34	51.04	16.10	
30	-2.75	39	58.15	18.34	
40	-2	42.5	63.12	19.91	
47	-1	46	68.10	21.48	
57.5	0.75	48.75	72.01	22.71	
66	3	50	73.78	23.28	
75	3.75	50.5	74.49	23.50	
75	3.75	50	73.78	23.28	
84	4.5	47.5	70.23	22.15	
94	5.25	44.5	65.97	20.81	
104	5.75	41.75	62.06	19.58	
113	6.25	39.25	58.50	18.46	
122	6	37.5	56.02	17.67	
131	6.5	36.25	54.24	17.11	
139	7	36.5	54.60	17.22	
147	7.25	36	53.89	17.00	

Table C-29. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 4 kg Loading – Test C.

Test C (4kg)					
			Sample Dimensions		
Soil Moisture	11.19	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-0.5	15	24.04	7.58	
4	-1	21.5	33.28	10.50	
7	-1	27	41.10	12.96	
11	-1	31	46.78	14.76	
19	0	37.5	56.02	17.67	
28	1	42.25	62.77	19.80	
35	3	46.25	68.45	21.59	
45	4.75	49.5	73.07	23.05	
53	7	51.75	76.27	24.06	
63	9	52	76.62	24.17	
63	9	51.25	75.56	23.84	
72	10	48	70.94	22.38	
81	10.5	44	65.26	20.59	
90	10.5	41.5	61.70	19.46	
103	10.25	38.25	57.08	18.01	
109	10.5	37.75	56.37	17.78	
118	10.5	37.5	56.02	17.67	
128	10.75	37	55.31	17.45	
137	10.75	36.75	54.95	17.33	
145	10.5	36.25	54.24	17.11	

Table C-30. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% C1 Added 3 11-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	11.01	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
1	-1	15	24.04	7.58
4	-2	27	41.10	12.96
7.5	-3.25	36	53.89	17.00
11.5	-4.25	43	63.83	20.14
20	-5.75	55	80.89	25.52
36	-6.75	65	95.10	30.00
35	-7	72	105.05	33.14
44	-7	78.25	113.93	35.94
53	-6.25	82.75	120.33	37.96
63	-5.75	85.75	124.59	39.30
71	-5	87	126.37	39.86
80	-4.5	83.75	121.75	38.41
91	-4.25	77.75	113.22	35.72
100	-4.25	74.75	108.96	34.37
110	-4.25	72.5	105.76	33.36
117	-4	70.5	102.92	32.47
127	-4	69.5	101.49	32.02
136	-4	69	100.78	31.79
144	-4	68.5	100.07	31.57

Table C-31. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	11.24	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	-1	17.5	27.59	8.70	
5	-1.75	30	45.36	14.31	
7.5	-2.25	39	58.15	18.34	
12	-3	46	68.10	21.48	
20	-3.5	58	85.15	26.86	
27	-3.75	62	90.84	28.65	
37	-3.25	73	106.47	33.59	
45	-3	79.25	115.35	36.39	
52	-2	83.75	121.75	38.41	
62	-1.5	86	124.94	39.41	
70	-0.75	86.5	125.65	39.64	
80	1	85.75	124.59	39.30	
91	1.75	76.25	111.09	35.04	
103	1.5	70.5	102.92	32.47	
110	1.25	68.5	100.07	31.57	
120	1.75	67.5	98.65	31.12	
128	1.5	66.75	97.59	30.78	
138	1	66.25	96.88	30.56	
146	1	66.25	96.88	30.56	

Table C-32. Slaughterville Sandy Loam with 0.5% C1 Direct Shear Data for 10 kg Loading – Test C.

Test C (10kg)					
			Sample Dimensions		
Soil Moisture	11.01	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1.5	-0.75	20	31.15	9.83	
4	-1.5	34	51.04	16.10	
7	-2	44	65.26	20.59	
11	-2.5	51.5	75.91	23.95	
19	-3	62	90.84	28.65	
26	-3	70	102.21	32.24	
35	-2.25	76	110.73	34.93	
42	-1	83	120.68	38.07	
51	0.5	86	124.94	39.41	
62	2.25	86.25	125.30	39.53	
62	2.25	85.5	124.23	39.19	
72	3.25	81.5	118.55	37.40	
81	4	76	110.73	34.93	
91	3.75	65.25	95.45	30.11	
101	3	63.5	92.97	29.33	
110	2.75	62.75	91.90	28.99	
117	2.75	61.5	90.13	28.43	
126	2.5	61.25	89.77	28.32	
134	2	61	89.41	28.21	
143	2	60.75	89.06	28.09	

Table C-33. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Slaughterville - 1% C1 Added 1 15-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	11.74	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3.5	-1	10	16.94	5.34	
6.5	-1.1	13	21.20	6.69	
10	-1.5	15.1	24.18	7.63	
15	-1.5	17.5	27.59	8.70	
23	-1.25	21	32.57	10.27	
31	-1	24	36.83	11.62	
42	-0.25	27.75	42.16	13.30	
51	0.5	29	43.94	13.86	
58	2	31	46.78	14.76	
68	3.25	32.25	48.56	15.32	
76	4.75	33.25	49.98	15.77	
86	6	33.5	50.33	15.88	
86	6	33.25	49.98	15.77	
95	7	32.5	48.91	15.43	
107	7.75	31.25	47.14	14.87	
115	7.75	29.75	45.00	14.20	
123	8	28	42.52	13.41	
132	8	27.5	41.81	13.19	
141	8	27	41.10	12.96	
150	8.1	26.5	40.38	12.74	

Table C-34. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.73	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
4	-1.5	10	16.94	5.34	
7	-2	12.5	20.49	6.46	
11	-3	15.1	24.18	7.63	
16	-3.25	18	28.30	8.93	
24	-3	21.75	33.63	10.61	
32	-2.25	26	39.67	12.52	
40	-1	29	43.94	13.86	
49	0.75	31	46.78	14.76	
58	2.5	33	49.62	15.65	
67	4.1	34.25	51.40	16.21	
77	6	34.75	52.11	16.44	
85	7	33.75	50.69	15.99	
96	7	31.25	47.14	14.87	
104	7.1	29.75	45.00	14.20	
112.5	7.25	28	42.52	13.41	
123	7.5	27.5	41.81	13.19	
132	7.25	27	41.10	12.96	
142	7.1	27	41.10	12.96	
150	7.25	26.75	40.74	12.85	

Table C-35. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	11.54	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-2	9	15.51	4.89	
5.5	-2.5	13	21.20	6.69	
8.5	-2.75	15.5	24.75	7.81	
14	-2.5	18	28.30	8.93	
21	-2.5	22.5	34.70	10.95	
29	-2	26.5	40.38	12.74	
37.5	-1	29.5	44.65	14.08	
45	0.5	32	48.20	15.21	
53.5	2.5	34.5	51.75	16.33	
63	4.25	36	53.89	17.00	
71	6	36.75	54.95	17.33	
80	7.1	36.5	54.60	17.22	
90	8	35	52.46	16.55	
100	8.5	32	48.20	15.21	
109	8.75	30.5	46.07	14.53	
118	9.25	29.25	44.29	13.97	
128	9.25	28.25	42.87	13.52	
136	9.25	27.5	41.81	13.19	
145	9.25	27.25	41.45	13.08	

Table C-36. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Slaughterville - 1% C1 Added 2 15-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	11.7	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-1	10	16.94	5.34	
4	-1.25	15	24.04	7.58	
8.5	-1.5	19	29.73	9.38	
12	-1.5	21	32.57	10.27	
21	-1.5	25.25	38.61	12.18	
30	-2	32.5	48.91	15.43	
38	-1.75	36.1	54.03	17.04	
45	-1	38.75	57.79	18.23	
54	0	41	60.99	19.24	
63	1	43	63.83	20.14	
72	2.75	44.25	65.61	20.70	
80	3.75	45	66.68	21.03	
91	5	45.25	67.03	21.15	
91	5	45	66.68	21.03	
102	5.5	44	65.26	20.59	
108	6	43	63.83	20.14	
117	7	41.25	61.35	19.35	
126	7.25	39	58.15	18.34	
135	7.5	37.25	55.66	17.56	
145	7.75	36.5	54.60	17.22	

Table C-37. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.55	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	-1.5	12	19.78	6.24	
4.5	-2	16.5	26.17	8.26	
8.5	-2.75	21.25	32.92	10.39	
12	-3.25	25.25	38.61	12.18	
21	-3.5	31.25	47.14	14.87	
29	-3.5	36	53.89	17.00	
39	-2.75	39.5	58.86	18.57	
47	-2	42.25	62.77	19.80	
55	-1	44.5	65.97	20.81	
64	-0.25	45.5	67.39	21.26	
74	0.75	46.75	69.16	21.82	
82	1	47.1	69.66	21.97	
91	2	46	68.10	21.48	
101	2.5	44.75	66.32	20.92	
110	3	43	63.83	20.14	
118	3.25	41	60.99	19.24	
128	3.5	38.75	57.79	18.23	
137	3.5	37.25	55.66	17.56	
146	3.25	36.75	54.95	17.33	

Table C-37. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 4 kg Loading – Test C.

Test C (4kg)					
			Sample Dimensions		
Soil Moisture	11.39	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-0.75	11	18.36	5.79	
6	-1.75	17	26.88	8.48	
10	-2.5	21.5	33.28	10.50	
14	-3	24	36.83	11.62	
23	-3.3	30.5	46.07	14.53	
31	-3.25	36.75	54.95	17.33	
40	-3	40.25	59.93	18.90	
47.5	-2	43.75	64.90	20.47	
57	-0.75	45.75	67.74	21.37	
75	1.5	48	70.94	22.38	
84	2.25	47.25	69.87	22.04	
92	3	45.5	67.39	21.26	
101	3.5	43	63.83	20.14	
111	3.75	40	59.57	18.79	
122	3.25	38.5	57.44	18.12	
129	3	37.5	56.02	17.67	
138	3	37	55.31	17.45	
148	2.9	36.25	54.24	17.11	

Table C-39. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Slaughterville - 1% C1 Added 3 15-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	11.51	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-0.5	15	24.04	7.58	
4.5	-1.5	26.5	40.38	12.74	
8	-2.5	36	53.89	17.00	
11.5	-3.5	42	62.41	19.69	
19	-5	52	76.62	24.17	
29	-5.25	59.5	87.28	27.53	
36	-5.5	66	96.52	30.45	
45	-5.5	71.5	104.34	32.91	
54	-5	76.25	111.09	35.04	
63	-4.5	79.3	115.42	36.41	
72	-3.25	82.75	120.33	37.96	
81	-2.5	83	120.68	38.07	
90	-2	81	117.84	37.17	
101	-2	78.25	113.93	35.94	
110	-1.5	75.5	110.02	34.71	
119	-1.5	73.5	107.18	33.81	
128	-1.5	71.8	104.76	33.05	
137.5	-1.25	71.5	104.34	32.91	
147.5	-0.9	71.25	103.98	32.80	

Table C-40. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	11.51	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.5	-0.25	13	21.20	6.69	
2.5	-1	25	38.25	12.07	
6.5	-2	35.5	53.18	16.77	
9	-2.5	43	63.83	20.14	
18	-3.5	54	79.47	25.07	
27	-3.5	62	90.84	28.65	
35	-3.25	68.5	100.07	31.57	
42	-2.25	76.25	111.09	35.04	
52	-1	79.75	116.06	36.61	
60	0	82.9	120.54	38.02	
68	1.5	84.5	122.81	38.74	
79	3	85.25	123.88	39.08	
79	3	84.75	123.17	38.85	
88	4	81.25	118.19	37.28	
98.5	4.5	72.25	105.40	33.25	
108	4.75	69.5	101.49	32.02	
118	5	66.5	97.23	30.67	
127	5	63.75	93.32	29.44	
135	5	62	90.84	28.65	
144	5	62	90.84	28.65	

Table C-41. Slaughterville Sandy Loam with 1% C1 Direct Shear Data for 10 kg Loading – Test C.

Test C (10kg)					
			Sample Dimensions		
Soil Moisture	11.43	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-0.5	14	22.62	7.14	
4	-1.25	25	38.25	12.07	
7.5	-2	36	53.89	17.00	
11	-2.75	42	62.41	19.69	
19	-4	53	78.05	24.62	
27	-4.25	61.5	90.13	28.43	
35	-4	68	99.36	31.34	
44	-3.5	73.75	107.53	33.92	
54	-2.75	78	113.57	35.83	
62	-1.75	82	119.26	37.62	
69	0	84.5	122.81	38.74	
78	1	85.5	124.23	39.19	
91	1.5	82.5	119.97	37.85	
97	1.75	80.25	116.77	36.84	
110	2.5	73.5	107.18	33.81	
117	2.25	69.25	101.14	31.91	
125	2.25	67	97.94	30.90	
134	2.5	65.75	96.17	30.34	
142.5	2.5	65	95.10	30.00	

Table C-42. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% C2 Added 1 16-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	11.44	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
1	-2.5	10	16.94	5.34
3	-3.25	16	25.46	8.03
6	-3.5	20.5	31.86	10.05
9	-4	23.5	36.12	11.39
19	-4.5	29.5	44.65	14.08
27	-4	33.5	50.33	15.88
35	-3	36.5	54.60	17.22
45	-1.25	38	56.73	17.90
51	-0.5	38.25	57.08	18.01
55	1	37	55.31	17.45
63	3	33	49.62	15.65
70	4.25	31	46.78	14.76
80	5	29	43.94	13.86
91	5.25	27.25	41.45	13.08
100	5.25	26.33	40.14	12.66
110	5.25	25.75	39.32	12.40
119	5	25.25	38.61	12.18
128	5	24.75	37.90	11.96
136	4.75	24.75	37.90	11.96
148	5	25.25	38.61	12.18

Table C-43. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	11.44	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-4	12	19.78	6.24	
6	-5	17	26.88	8.48	
10	-6.25	19.5	30.44	9.60	
14	-7.25	22	33.99	10.72	
25	-8.25	26.9	40.95	12.92	
32	-8.25	31.25	47.14	14.87	
41	-8.25	35	52.46	16.55	
52	-7.75	37	55.31	17.45	
59	-7	37.75	56.37	17.78	
69	-6	35.75	53.53	16.89	
78	-4.5	31.5	47.49	14.98	
88	-3.5	28.5	43.23	13.64	
97	-3	26.75	40.74	12.85	
106	-3	25.75	39.32	12.40	
116	-2	25.5	38.96	12.29	
125	-1.5	25	38.25	12.07	
134	-1	24.5	37.54	11.84	
143	-0.5	24	36.83	11.62	
154	-0.25	24.75	37.90	11.96	

Table C-44. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	11.48	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	-2.75	10	16.94	5.34	
2.5	-3.5	13.5	21.91	6.91	
5	-3.75	17.5	27.59	8.70	
8	-4	20.5	31.86	10.05	
16	-4.5	27	41.10	12.96	
25	-4	31.25	47.14	14.87	
32	-3	35.5	53.18	16.77	
40.5	-1	38.5	57.44	18.12	
51	1.75	39.25	58.50	18.46	
60	4	37.75	56.37	17.78	
70	6	36	53.89	17.00	
78	7.5	32.25	48.56	15.32	
89	8.5	27.75	42.16	13.30	
96	9	25.25	38.61	12.18	
105	9	24.25	37.19	11.73	
115	9	23.75	36.48	11.51	
124	9	23.75	36.48	11.51	
132	9	23.25	35.77	11.28	
141	9	23	35.41	11.17	

Table C-45. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% C2 Added 2 9-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	11.42	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-1.25	14.5	23.33	7.36	
4.5	-2.25	22.25	34.34	10.83	
9	-2.75	29	43.94	13.86	
12	-3	33.5	50.33	15.88	
22	-2.75	41	60.99	19.24	
28	-1.25	46	68.10	21.48	
36	0.25	49.25	72.72	22.94	
44	2.5	51	75.20	23.72	
53	5.25	50	73.78	23.28	
64	7.75	48.25	71.30	22.49	
72	9.5	45.25	67.03	21.15	
81	10.5	41.75	62.06	19.58	
91	10.5	38.5	57.44	18.12	
101	10.75	36.5	54.60	17.22	
110	11	35.5	53.18	16.77	
119	10.5	33.75	50.69	15.99	
128	10.25	33.5	50.33	15.88	
136	10	33.5	50.33	15.88	
145.5	10	33.25	49.98	15.77	

Table C-46. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	11.42	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-1.5	15	24.04	7.58	
4	-2	23	35.41	11.17	
8	-2.5	30	45.36	14.31	
12	-2.75	34	51.04	16.10	
20	-2.25	41.25	61.35	19.35	
28	-1	46.5	68.81	21.71	
37	1	50	73.78	23.28	
45	3	51.1	75.35	23.77	
55	5.5	50	73.78	23.28	
65	7.75	47.75	70.58	22.27	
75	9.25	44.75	66.32	20.92	
85	10	38.25	57.08	18.01	
94	10	35	52.46	16.55	
104	9.75	33.75	50.69	15.99	
114	9	33	49.62	15.65	
122	9	32.25	48.56	15.32	
128	9.75	31.75	47.85	15.09	
139	9.5	31.8	47.92	15.12	
148	9.5	31.6	47.63	15.03	

Table C-47. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 4 kg Loading – Test C.

Test C (4kg)					
			Sample Dimensions		
Soil Moisture	11.37	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-0.75	16	25.46	8.03	
5	-1	25	38.25	12.07	
9	-1.75	31.5	47.49	14.98	
13	-1.75	35	52.46	16.55	
21	-1.25	41.75	62.06	19.58	
29	-1	45	66.68	21.03	
38	0.5	49	72.36	22.83	
46.5	3.5	51.1	75.35	23.77	
56	6.25	50.5	74.49	23.50	
66	8.3	47.75	70.58	22.27	
74	9	43.25	64.19	20.25	
85	9.5	38.5	57.44	18.12	
94	9.6	35.5	53.18	16.77	
104	9.6	34.25	51.40	16.21	
113	9.6	34	51.04	16.10	
122	9.5	33.25	49.98	15.77	
131	9.5	3	6.99	2.20	
140	9.5	33.3	50.05	15.79	
148	9.6	33.1	49.76	15.70	

Table C-48. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Slaughterville - 0.5% C2 Added 3 16-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	11.34	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0.5	-1	11.5	19.07	6.01
2	-1.5	17	26.88	8.48
5.25	-2.5	40	59.57	18.79
8	-3.25	51.5	75.91	23.95
16	-3.5	65	95.10	30.00
24	-3.5	74	107.89	34.03
31	-3	80.75	117.48	37.06
40	-2.25	85	123.52	38.97
52	-0.75	87.25	126.72	39.97
61	0.25	85	123.52	38.97
72	0.75	77.75	113.22	35.72
80	0.75	70	102.21	32.24
90	1	66.75	97.59	30.78
99	1	65	95.10	30.00
108	0.75	63.25	92.61	29.22
117	0.75	62.25	91.19	28.77
126	1	62	90.84	28.65
134	1	62	90.84	28.65
144	1.1	61.75	90.48	28.54

Table C-49. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	11.29	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-1	15	24.04	7.58	
3	-1.75	32	48.20	15.21	
7	-3	44.5	65.97	20.81	
12	-4.5	55	80.89	25.52	
18	-5	66.5	97.23	30.67	
27	-5.25	74.75	108.96	34.37	
35	-5.25	81.25	118.19	37.28	
42	-4.75	85.25	123.88	39.08	
52	-4.5	86.25	125.30	39.53	
62	-3.75	84.75	123.17	38.85	
71	-4	79.5	115.71	36.50	
81	-4	72.25	105.40	33.25	
91	-4.25	67	97.94	30.90	
101	-4.25	64.25	94.03	29.66	
110	-4.6	63	92.26	29.10	
120	-4.8	62	90.84	28.65	
128	-5	61.75	90.48	28.54	
138	-5.25	61.6	90.27	28.48	
146	-5.3	61.3	89.84	28.34	

Table C-50. Slaughterville Sandy Loam with 0.5% C2 Direct Shear Data for 10 kg Loading – Test C.

Test C (10kg)					
			Sample Dimensions		
Soil Moisture	11.29	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	-0.75	11.5	19.07	6.01	
3	-1.75	29	43.94	13.86	
7	-2.75	41	60.99	19.24	
9	-4	46	68.10	21.48	
19	-6	59	86.57	27.31	
26	-7	68.5	100.07	31.57	
33	-7	76.5	111.44	35.16	
38	-6.5	79.75	116.06	36.61	
49	-5	83	120.68	38.07	
58	-5	84.25	122.46	38.63	
68	-4.75	83.5	121.39	38.29	
77.5	-4.25	82.8	120.40	37.98	
86	-3.5	81	117.84	37.17	
96	-2.75	77.5	112.86	35.60	
107	-2	70.25	102.56	32.35	
115	-2	64	93.68	29.55	
125	-2.25	61	89.41	28.21	
134	-2.25	59.5	87.28	27.53	
143	-2.5	58.75	86.22	27.20	

Table C-51. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 2 kg Loading – Test A.

Shear Test Data Slaughterville -1%C2 Added 1 17-Apr-97					
Test A (2 kg)					
			Sample Dimensions		
Soil Moisture	12.53	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
3	-1.75	17	26.88	8.48	
6.5	-2	22	33.99	10.72	
12	-2	26.5	40.38	12.74	
16	-1.75	30	45.36	14.31	
24	-0.5	36	53.89	17.00	
31	1	41	60.99	19.24	
41	3.1	45.5	67.39	21.26	
49	6	47	69.52	21.93	
58	9	47.5	70.23	22.15	
68	9.9	45.25	67.03	21.15	
78	14	41	60.99	19.24	
88	15.75	35.5	53.18	16.77	
97	16.75	31.5	47.49	14.98	
106	17.75	29.25	44.29	13.97	
113	18.5	28.25	42.87	13.52	
122	19.5	27.5	41.81	13.19	
129	20	27	41.10	12.96	
138	20.5	27	41.10	12.96	
147	21	26.5	40.38	12.74	

Table C-52. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 2 kg Loading – Test B.

Test B (2 kg)					
			Sample Dimensions		
Soil Moisture	12.65	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
2	-2.25	6.5	11.96	3.77	
5	-3	19	29.73	9.38	
9	-3	23.5	36.12	11.39	
13	-2.5	27	41.10	12.96	
21	-1.25	31.25	47.14	14.87	
29	1	36.75	54.95	17.33	
36	3	40	59.57	18.79	
45	5	42.75	63.48	20.02	
53	7.25	44.75	66.32	20.92	
60	10	46	68.10	21.48	
66	12.5	46	68.10	21.48	
73	14	44.75	66.32	20.92	
81	15.75	41	60.99	19.24	
91	17.75	35.5	53.18	16.77	
101	18.75	31.5	47.49	14.98	
110	19.25	29.25	44.29	13.97	
118	20	28	42.52	13.41	
128	20.75	27.25	41.45	13.08	
135	21.75	21.75	33.63	10.61	
145	22	21.75	33.63	10.61	

Table C-53. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 2 kg Loading – Test C.

Test C (2 kg)					
			Sample Dimensions		
Soil Moisture	12.32	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	2	kg	Volume	88.4	cm^3
	19.62	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1.5	-1	14	22.62	7.14	
4	-1.25	20.5	31.86	10.05	
9	-1.75	26.5	40.38	12.74	
14	-1.75	31	46.78	14.76	
20	-1.25	37	55.31	17.45	
29	1	41.5	61.70	19.46	
38	3.75	45.5	67.39	21.26	
47	6.25	47	69.52	21.93	
57	9	44	65.26	20.59	
66	9.75	37.5	56.02	17.67	
75	12.5	33.75	50.69	15.99	
83	12.5	30	45.36	14.31	
94	14.5	27.5	41.81	13.19	
104	15.5	27	41.10	12.96	
114	16.25	26.25	40.03	12.63	
122	16.75	26	39.67	12.52	
131	17.25	25.5	38.96	12.29	
139	18	25.25	38.61	12.18	
147	18.5	25.25	38.61	12.18	

Table C-54. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 4 kg Loading – Test A.

Shear Test Data Slaughterville - 1% C2 Added 2 17-Apr-97					
Test A (4 kg)					
			Sample Dimensions		
Soil Moisture	12.4	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0.5	-1	11	18.36	5.79
2.5	-1.25	20	31.15	9.83
8	-2	28.5	43.23	13.64
19	-2.25	42	62.41	19.69
26	-1	49	72.36	22.83
35	0.75	55	80.89	25.52
44	3	59.5	87.28	27.53
53	5	62	90.84	28.65
62	7.25	62.25	91.19	28.77
62	7.25	61	89.41	28.21
71	9.5	58	85.15	26.86
80	10.5	55	80.89	25.52
90	11	48.25	71.30	22.49
100	10.75	44	65.26	20.59
109	12.25	41	60.99	19.24
119	12.5	39.5	58.86	18.57
127	13	38.25	57.08	18.01
138	13.75	38	56.73	17.90
148	14	37.8	56.44	17.81

Table C-55. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 4 kg Loading – Test B.

Test B (4 kg)					
			Sample Dimensions		
Soil Moisture	12.37	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0.75	-0.25	13.5	21.91	6.91	
4	-0.3	23	35.41	11.17	
7	-0.25	30	45.36	14.31	
11	0.25	35	52.46	16.55	
18	1.5	42	62.41	19.69	
25	2.75	48.25	71.30	22.49	
31.5	4.75	53	78.05	24.62	
40	7.75	57	83.73	26.41	
49	11	58.75	86.22	27.20	
57	13	60	87.99	27.76	
68	15	55.75	81.95	25.85	
78	17.5	44.75	66.32	20.92	
88	17.5	38	56.73	17.90	
97.5	17.75	36	53.89	17.00	
106	18	35	52.46	16.55	
115	18	34.25	51.40	16.21	
124	18.25	34	51.04	16.10	
133	18.5	33.5	50.33	15.88	
142	18.5	33.25	49.98	15.77	

Table C-56. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 4 kg Loading – Test C.

Test C (4kg)					
			Sample Dimensions		
Soil Moisture	12.3	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	4	kg	Volume	88.4	cm^3
	39.24	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
5	-2.5	26	39.67	12.52	
9	-3.5	31.5	47.49	14.98	
12	-4.25	36.5	54.60	17.22	
17	-4.75	40	59.57	18.79	
24.5	-4.5	46	68.10	21.48	
31	-3.5	51	75.20	23.72	
39	-2	54.5	80.18	25.29	
47	0	56.25	82.66	26.08	
57	2.25	57.25	84.09	26.53	
66	4.25	55.25	81.24	25.63	
76	5.75	51	75.20	23.72	
85	7	48.25	71.30	22.49	
94.5	8.25	47	69.52	21.93	
103	9.75	44	65.26	20.59	
113	10.25	39.25	58.50	18.46	
122	10.25	36.75	54.95	17.33	
131	10.25	35.75	53.53	16.89	
139	10.5	35.25	52.82	16.66	
149	10.5	34.8	52.18	16.46	

Table C-57. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 10 kg Loading – Test A.

Shear Test Data Slaughterville - 1% C2 Added 3 17-Apr-97					
Test A (10 kg)					
			Sample Dimensions		
Soil Moisture	12.37	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Proving Ring Constant =	0.001421163*Y+0.0027238958				

Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)
0.5	-1	15	24.04	7.58
2.5	-1.25	32	48.20	15.21
6	-1.75	46	68.10	21.48
10	-2	57	83.73	26.41
17	-1.75	70	102.21	32.24
25	-1	80.5	117.13	36.95
33	0.25	88	127.79	40.31
43	2.5	95	137.73	43.45
50	3.75	96.5	139.87	44.12
60	5.5	94.5	137.02	43.23
69	6.25	90.5	131.34	41.43
80	6.75	84.5	122.81	38.74
90	6.75	75.5	110.02	34.71
100	6.5	69.75	101.85	32.13
110	6.5	67.25	98.30	31.01
119	6.25	66	96.52	30.45
128	6.1	64.75	94.74	29.89
137	6	64.5	94.39	29.78
145	6	64	93.68	29.55

Table C-58. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 10 kg Loading – Test B.

Test B (10 kg)					
			Sample Dimensions		
Soil Moisture	21.37	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
1	-0.25	19	29.73	9.38	
3	-1	34.5	51.75	16.33	
6.5	-1.5	48	70.94	22.38	
10	-1.75	57.5	84.44	26.64	
18	-1.5	72.5	105.76	33.36	
25	-0.5	83	120.68	38.07	
32	1.25	91	132.05	41.66	
41	3	96	139.16	43.90	
50	5	97.75	141.64	44.68	
60	6.75	95.3	138.16	43.58	
69	7.5	87	126.37	39.86	
80	7.5	79.25	115.35	36.39	
90	7.5	76	110.73	34.93	
99	7.25	71	103.63	32.69	
109	7.25	69.5	101.49	32.02	
117	7	68	99.36	31.34	
126	7	67.2	98.23	30.99	
136	7	66.1	96.66	30.49	
145	7	65	95.10	30.00	

Table C-59. Slaughterville Sandy Loam with 1% C2 Direct Shear Data for 10 kg Loading – Test C.

Test C (10kg)					
			Sample Dimensions		
Soil Moisture	12.64	%	Diameter	6.35	cm
Soil Weight	174	gm	Depth	2.794	cm
Depth in Cell	0.7	in	Area	31.7	cm^2
Normal Force	10	kg	Volume	88.4	cm^3
	98.1	N			
Horizontal Displacement (mm)	Vertical Displacement (mm)	Proving Ring Reading	Horizontal Shear Force (N)	Shear Stress (kPa)	
0	-0.25	11.5	19.07	6.01	
2	-0.75	28	42.52	13.41	
6	-1.25	42	62.41	19.69	
9	-1.75	53	78.05	24.62	
16	-1.5	67	97.94	30.90	
23	-1.25	77	112.15	35.38	
31	-0.75	86	124.94	39.41	
40	0	92.5	134.18	42.33	
50	1	97.25	140.93	44.46	
59	1.75	96.5	139.87	44.12	
69	2.5	92.25	133.83	42.22	
79	3	83.5	121.39	38.29	
89	3	70	102.21	32.24	
99	2.9	66	96.52	30.45	
109	2.5	64.75	94.74	29.89	
117	2	64	93.68	29.55	
127	1.75	63.75	93.32	29.44	
135	1.75	63.5	92.97	29.33	
145	1.5	63.4	92.83	29.28	

VITA

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