FINAL REPORT
For the Florida Department of Transportation

Influence of Soil Suction and Environmental Condition on the Drying Rate for Some Problematic Soils
Phase II Study

Research Report No. FL/DOT/RMC/0702 (2)-9192
State Job No.: 99700-7606-119
WPI No.: 0510702
FSU Project No.: 6120-518-39

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December 1998
Influence of Soil Suction and Environmental Condition on the Drying Rate for Some Problematic Soils

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There have been problems on pavement construction claimed by contractors in the State of Florida that the pavement soils hold excessive water and are difficult to dry and compact. This study presents recent research on the effects of the soil suction and the environmental conditions on the soil drying rate. A series of soil suction tests using thermocouple psychrometer method and the drying rate tests using the environmental chamber were conducted in this study. A review of soil suction theory was also conducted. The results of the experimental program show that both suction and relative humidity have direct effect on the soil drying rate. Drying rate decreases with an increase in soil suction for each soil. As compared to the suction, relative humidity has more significant influence on the soil drying rate. For the A-2-4 soil, which contains percent of fines greater than 20%, the drying rate is low due to the higher suction.

Pavement, Suction, Drying rate, Humidity, Environmental condition

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METRIC CONVERSIONS

inches = 25.4 millimeters
feet = 0.305 meters
square inches = 645.1 millimeters squared
square feet = 0.093 meters squared
cubic feet = 0.028 meters cubed
pounds = 0.454 kilograms
poundforce = 4.45 newtons
poundforce per square inch = 6.89 kilopascals
pound per cubic inch = 16.02 kilograms per meters cubed
DISCLAIMER

"The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the U.S. Department of Transportation. This publication is prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation."
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CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Highway contractors in the State of Florida occasionally encounter soils, which are troublesome or problematic during construction. Common problems include excessive expansion, difficulty in compaction, and slowness in drying. The Florida Department of Transportation (FDOT) has attempted to avoid such problems by limiting the type of soils, which can be used in highway embankment.

According to the FDOT Design Standards (FDOT, 1992), three types of soils, based on the AASHTO Classification System, are selected for embankment use, namely, A-1, A-3, and A-2-4. A-1 soils consist of stone fragment, gravel and sand. A-3 soils are mostly fine sand. Both of these soils are generally rated as excellent to good for roadbed use. However, A-2-4 soils have a maximum of 35% passing No. 200 sieve and a maximum Plasticity Index (PI) of 10. Some types of A-2-4 soils may contain a certain percentage of clay. The clay soils retain excess moisture easily and can
cause problems of expansion and slow drying. Therefore, FDOT tries to establish identification methods for screening out those problematic soils before construction.

The FDOT had chosen six potentially problematic soils around the State of Florida to examine their properties. A series of laboratory tests were performed to evaluate the engineering properties of six soils during Phase I study (McDonald, 1995). The laboratory tests consisted of Atterberg limits, grain-size analysis, compaction test, bearing ratio, expansion index, permeability, x-ray diffraction and scanning electron microscope (SEM). The results of the tests showed no significant indication of expansion or swelling and all soils were classified as "Very Low" and "Inactive" in regards to expansion potential. It was found that without the presence of Montmorillonite clay, the soils can also experience the same problem and therefore should not be used as an indicator.

Apparently the previous study could not identify the causes of these problematic soils. It was recommended to study the problem through the approach of environmental effect (i.e., temperature and humidity) and the influence of soil suction on the drying rate.
1.2 Scope of Study

The objective of this study was to find the effects of the soil suction and the environmental condition on the soil drying rate. The goal was to establish a guideline or specification to limit the A-2-4 soils for embankment use through the findings of the test results. Two types of laboratory tests were conducted to correlate the suction and the drying rate of a soil. First, a series of soil suction tests were conducted by using the thermocouple psychrometer method. Second, the soils were subjected to a range of temperature and humidity levels in an environmental chamber to investigate the effect on the drying rate. The soils used in this study were the same as those for the previous (Phase I) study, which were selected by the FDOT in conjunction with the researchers. The test results would allow further correlation of drying rate with suction.

1.3 Report Organization

This report summarizes the laboratory experimental program of suction and drying rate measurements to evaluate the effects of the soil suction and the environmental condition on the drying rate of the soil. This report is the second phase sequential to the previous (Phase I) study (McDonald, 1995).
The problem statement, background, and the objective of this study are presented in Chapter 1. A literature review of soil suction is presented in detail in Chapter 2. The previous (Phase I) work, which evaluated the engineering properties of six troublesome soils, is reviewed in Chapter 3. Two types of experimental program for evaluating the effects of the soil suction and the environmental condition on the soil drying rate are described in Chapter 4. The soil suction test results are presented and analyzed in Chapter 5. The drying rate test results are presented and analyzed in Chapter 6. Correlation and analysis of suction and drying rate experimental results are presented in Chapter 7. The conclusions along with the recommendations are stated in Chapter 8. Some test results from Phase I are included in Appendix A. The raw data and individual test results are summarized in the sequence of the calibration, suction, and drying rate tests in Appendices B, C, and D, respectively.
CHAPTER 2

LITERATURE REVIEW

2.1 Soil Suction Concept

2.1.1 Water in Soil

Two forms of moisture can occur in soil. One is the adsorbed water surrounding the grains in the form of a viscous film. Moisture attracted by a soil particle and accumulated either at its surface or even in its interior is termed "adsorbed moisture", though in the latter case the term "disrobed" would be more correct. The other form of moisture is free water, filling partially or completely, the voids between the grains. Ground water is termed "free" or "gravitational" because the action of gravity is prevailing in this case, whereas in other kinds of moisture the action of gravity is negligible in comparison with that of molecular forces and surface tension. They can be further classified into four catalogues as described in the following:

Combined water is the water held in chemical
combination. It will not evaporate and can only be driven off by heating the soil.

**Hygroscopic water** is the water attracted from the air by soil particles, as common salt attracts water. It is held as a thin film around grains of soil and the finer the texture, the more the surface area to hold hygroscopic water. However, on exposure to variations of temperature and pressure, some evaporates, and may condense on another part of the soil.

**Capillary water** is the water attracted by particles from the level of a liquid and held by internal attraction against gravity. This water moves from areas of higher tension to lower tension, which may be upward, downward, or sideward. The water discussed in this study falls into this category.

**Gravitational water** is the water that drains away from a soil through large pores and cracks. Gravitational water is termed "free" or "gravitational" because the action of gravity is prevailing in this case, whereas in other kinds of moisture the action of gravity is negligible in comparison with that of molecular forces and surface tension.

Figures 2.1 and 2.2 systematically illustrate the water classification.
2.1.2 Establishment of Soil Suction Theory

Two approaches of analysis of soil water have been developed:

(1) The static equilibrium method, also known as the capillary rise method, based on the principles of static equilibrium in capillary tubes.

(2) The energy method, also known as the fluid potential method, based on the water potential of the soil.

**Surface tension.** In a mass of water, forces of attraction exist between the molecules. Below the surface forces tend to balance out resulting in a constant free molecular movement. The molecular attraction between molecules at the surface of the liquid differs from those in the interior of the mass of the liquid. At the surface, the reduced attraction between the liquid and air resulting in increased attractions along the surface of the liquid. These molecular forces pull and hold the water molecules together in a permanent state of tension so that the surface of the water permanently attempts to contract into a minimum area; hence, a drop of water is spherical. The effects of the surface tension can be easily understood by imagining that the surface of water is covered by a thin molecular membrane that is capable of carrying tensile stress. Such a surface cannot possibly exist but the idea is a useful
concept to explain surface tension phenomena. Surface tension increases as temperature decreases.

**Capillary rise.** The earliest approach to the analysis of water retained between soil particles is based on the model representing the soil pores as a system of capillary tubes. A capillary tube is a glass tube of fine diameter. When such a tube is placed into a basin of water, the water inside the tube will be lifted up to a maximum height, \( h_s \), above the surface of the water in the basin and come to equilibrium. In capillary water consideration it is customary to take the free water surface as a datum of zero pressure. So as in soils, we consider pressure above and below atmospheric pressure and simplify readings by taking the value of the atmospheric pressure, \( P_a \), as equal to 0. As shown in Figure 2.3, the forces acting at the top of the water column can be derived from their vertical equilibrium as in equation 2.1:

\[
2\pi r T \cos(\alpha) + \pi r^2 u = 0
\]

(2.1)

Where

- \( T \) = surface tension
- \( \alpha \) = contact angle
- \( u \) = suction caused by surface tension
- \( r \) = Radius of glass tube
From which
\[ u = \frac{-2T\cos(\alpha)}{r} \]  \hspace{1cm} (2.2)

The height of rise can be obtained by substituting \(-\gamma_wh_c\) for \(u\),
\[ h_c = \frac{2T\cos(\alpha)}{\gamma_w r} \]  \hspace{1cm} (2.3)

Both \(u\) and \(h_c\) depend on the value of \(r\). They increase as \(r\) decreases. For water in a glass tube, \(\alpha = 0\), \(\gamma_w = 1\) g/cm\(^2\) and \(T = 0.074\) g/cm at 20°C.

\[ h_{\text{max}} = \frac{0.296}{r} \]  \hspace{1cm} (2.4)

In soils, there are no regular capillary tubes as such. The channels connecting the voids between soil particles are irregular in shape, size, and distribution. Therefore using the capillary tube model to simulate water in soils is unrealistic.

**Energy concept.** Due to the limitations of the static equilibrium method, previous researchers tried to explain the soil-water problem by using the potential energy concept. The introduction of the energy concept in soil
mechanics dates back to 1907 when E. Buckingham formulated the capillary potential as the work per unit volume of water required pulling water away from soil. In classical studies, the soil water was described in terms of the "forms" of water, such as "gravitational water", "capillary water" and "hygroscopic water". Hillel [1971] argued that soil-water potential should replace the arbitrary categorization of these "forms" of water. Water differs from time to time and place to place not in form, but in its potential energy condition. In unsaturated soil, water is constrained by the capillary and absorptive forces. The water within the soil will exhibit suction of tension, which is at a pressure of less than one atmosphere. This kind of energy condition is generally called the soil tension or soil suction.

The theoretical relationship between water potential and relative humidity is given by Kelvin's equation, as follows:

\[ \Psi' = \left(\frac{RT}{N_b}\right) \log \frac{e}{e_0} \quad (2.5) \]

Where:

\[ \Psi' = \text{water potential [Pa]} \]

\[ R = \text{universal gas constant [8.3143 J mol}^{-1} \text{K}^{-1}] \]

\[ e/e_0 = \text{relative humidity expressed as a fraction} \]
\[ T = \text{absolute Temperature [K]} \]

\[ V_w = \text{molar volume of water [1.8*10^5 m}^3 \text{ mol}^{-1}] \]

Soil suction is a measure of the affinity of the soil for water, and is determined from the relative humidity at which there is no movement of water into or out of the soil. Soil suction can vary with season and depth. It is important to have knowledge of the soil suction both at the time of construction and long-term equilibrium has been achieved.

### 2.1.3 Historical Review of Energy Concept

In 1907, Buckingham first introduced the energy concept to describe the stress state of the soil water. He considered that the soil exerts an attraction sufficient to hold water against the action of gravity, and that this attraction decreases as the amount of water held by the soil increases. He proposed the term "capillary potential," \( \psi \), to describe this attraction. \( \psi(\theta) \) has been defined as the work required to pull a unit mass of water away from the large mass of soil whose water content is \( \theta \). He introduced the equation as follows:

\[ \psi = f(x) \quad (2.6) \]
Where $x$ is the height above water surface in a column of soil standing in water at equilibrium.

Before that time, only "water content" had been used to express the state of water in soil. But if the water contents of two soils are equal, the state of water in soil need not be the same. The concept of capillary potential enabled scientists to compare, with the same scale, the state of water in various moist soils quantitatively.

The concept of capillary potential proposed by Buckingham is in the basis of assuming that the water in soil is in contact with a free water surface. But in most cases, water in soil is subjected to certain pressure. It is not always realistic to measure the value of capillary potential of such water with Buckingham's concept.

Gardner et al [1922] solved the problem by proposing an equation that shows the relationship between the pressure of water in soil and its capillary potential as follows:

$$
\psi = \int \frac{dp}{\rho} \quad (2.7)
$$

Where

$\rho = \text{density of water in soil}$

$P = \text{pressure of water in soil relative to}$
atmospheric pressure

In the general case, \( \rho \) is a function of pressure; however, assuming that water is incompressible, \( \psi \) becomes equal to \( P/\rho \). The introduction of this relationship between \( \psi \) and \( \rho \) led to the development of apparatus for measuring capillary potential of water in soil which was not in contact with a free water surface. Tensiometer and suction plate methods were developed on the basis of the above equation. Gardner also pointed out the sign of the \( f(x) \) in equation 2.6 should be negative.

The existence of solutes in soil solution can not be ignored in the studies of soil water potential. Various concepts were proposed in the decade after 1935 in an attempt to satisfy this demand. They included pH by Schofield [1935], water potential by Veihmeyer & Edlefsen [1937], osmotic potential and pressure potential by Day [1947], and soil moisture stress, the sum of water suction and osmotic pressure, by Wadleigh & Ayers [1945]. They are all expressions of total potential of water in soil relative to free water at the same temperature.

The concept of pH was introduced by Schofield [1935]. It is defined as the logarithm of the tension (expressed in cm. of water) under which the water is held in the soil.
Schofield has shown that this tension is equal to the
decrease in the free energy of the water in the soil
relative to a free water surface at the same temperature.
It is therefore equal to the work that must be done to
remove one gram of water from the soil.

In 1943, Edlefsen and Anderson published a highly
valuable report entitled "Thermodynamics of Soil Moisture". It was the first systematic study of thermodynamics of water in soil, and it emphasized the importance of the use of
chemical potential which is the water potential in soil.

2.1.4 Definition of Soil Suction

Precise definitions of total potential and its various
component potentials were provided by a committee of The
International Soil Science Society (ISSS) in 1963 and
slightly modified in 1976. The total potential ($\psi_t$) of a
soil can be divided into three components:

$$\psi_t = \psi_p + \psi_g + \psi_o \quad (2.8)$$

Where:

$\psi_t$ = total potential

$\psi_p$ = pressure potential

$\psi_g$ = gravitational potential
\[ \psi_0 = \text{osmotic potential} \]

The pressure potential, \( \psi_p \), is defined as "the amount of useful work that must be done per unit quantity of pure water to transfer reversibly and isothermally to the soil water an infinitesimal quantity of water from a pool at standard atmospheric pressure that contains a solution identical in composition to the soil water and is at the elevation of the point under consideration" [Marshall, 1996]. Similar definitions have been given for gravitational potential, \( \psi_g \), and osmotic potential, \( \psi_0 \), which refer to the effect of elevation and the effect of solutes on the energy status of soil water. The sum of gravitational and pressure potential is called hydraulic potential, \( \psi_h \). For pressure potential, ISSS has further defined it as follows:

1. The positive hydraulic pressure that exists below a water table.

2. The potential difference experienced by soil that is under a gas pressure different from that of water in the reference state.

3. The negative pressure or suction experienced by soil water as a result of its affinity for the soil matrix.
Most researchers agree on the third equivalent definition for matric potential which is a subcomponent of pressure potential and is defined as the value of $\psi_p$ when there is no difference between the pressure of air or gas in the soil and the gas pressure on the water in the reference state.

Matric potential can have only a zero or negative value, the magnitude of which increases as water is held more and tightly in the soil. Matric or soil water suction or tension refers the same property but takes the opposite sign (to matric potential).

The sum of matric and osmotic potential is referred to as the water potential $\psi_w$ and is directly related to the relative humidity of vapor in equilibrium with the liquid phase in soils and in plants. $\psi_w$ is an important measure of plant water status and is also important in saline soils, where the osmotic potential of the soil solution is of sufficient magnitude to influence plant water uptake.

The definition for water potential in terms of suction is summarized as follows and illustrated in Figure 2.4.

**Total suction ($\tau$).** The negative gage pressure, relative to the external gas pressure on the soil water, to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable (permeable to water
molecule only) membrane with the soil water. It is the sum of the matric suction and osmotic suction.

**Osmotic (solute) suction (t_o).** The negative gage pressure to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable membrane with a pool containing a solution identical in composition with the soil water. The value of osmotic suction depends on the concentration of soluble salts in the soil water. It is also termed solute suction or solute potential and is independent of water content and surcharge pressure.

**Matric (soil water) suction (t_m).** The negative gage pressure, relative to the external gas pressure on the soil water, to which a solution identical in composition with the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water. It is also termed matric potential or capillary potential and is both water content and surcharge pressure dependent.

Matric potential refers to the tenacity with which water is held by the soil matrix and, in the absence of high concentrations of solutes, is the major factor that determines the availability of water to plants in soil science.

Krahn and Fredlund [1972] carried out tests to find the relationship between total, matric and osmotic suction. The
results showed that the difference between total suction and matric suction decreases with increasing water content as anticipated since the concentration of salts in the pore water increases with decreasing water content.

2.1.5 Units of Soil Suction

Potentials can be defined as energy per unit mass and therefore they have units of joules per kilogram (J/Kg) in the SI system. It is also possible to define potentials as energy per unit volume or per unit weight. Thus, since the dimensions of energy per unit volume are identical to those of pressure, the appropriate SI unit of pressure is the pascal. Similarly, the dimensions of energy per unit weight are identical to those of length, so the appropriate SI unit is the meter. The terminology that is often used to describe potential energy per unit weight is "pressure head". The parameters, $\gamma$ and $g$, are used to convert potentials from one system of dimensions to another as in the following equation:

$$\psi \ [J \ kg^{-1}] = \gamma \psi \ [Pa] = \frac{\psi \ [m]}{g} \quad (2.9)$$

Where

$\gamma$ = density of water

$g$ = acceleration due to gravity
A logarithmic pF scale for expressing matric potential proposed by Schofield is also in use, where

\[ pF = \log_{10} (\text{negative pressure head, in cm}) \] (2.10)

The complete conversion relationship is shown in Table 2.1.

2.1.6 Soil-Water Characteristic Curve

Mathematical models. The soil-water characteristic curve for a soil is defined as the relationship between water content and suction of the soil. It can be used to estimate various parameters used to describe unsaturated soil behavior such as volume change, shear strength, and flow. Several mathematical models have been studied to characterize the soil-water characteristic curve. Each equation has its own limitation and only applies to some particular soils. The latest model proposed by Fredlund and Xing in 1994 provides not only a theoretical basis for most of the empirical equations but also proposes a new, more general description of the soil-water characteristic curve. The water-characteristic model proposed by Fredlund and Xing [1993] is shown in Equation 2.11.
\[ \theta = \theta_s \left[ \frac{1}{\ln \left( e + \left( \frac{\psi}{a} \right)^n \right)} \right]^m \] 

(2.11)

Where

\[ \theta_s = \text{saturation moisture content} \]
\[ e = \text{constant 2.718} \]
\[ a = \text{parameter related to air entry value of suction head, } \psi_{sea}, \text{ and dimensional consistent} \]
\[ n, m = \text{independent model parameters} \]
\[ \psi = \text{Matric suction} \]

For loam, \( a = 0.834m, \theta_s = 0.43, n = 9.9, \text{ and } m = 0.44. \)

For Yolo light clay, \( a = 2.7m, \theta_s = 0.375, n = 2.05, \text{ and } m = 0.36. \)

Hysteresis is introduced into the soil moisture due to the geometric effects and variations in the wetting contact angle, which is referred to as the ink bottle and raindrop effect. Two types of water-characteristic curves formed due to the hysteresis effect. A typical desorption and adsorption characteristic curve for a silty soil is shown in Figure 2.5 [Fredlund, 1993]. The relationship between desorption and adsorption is highly hysteretic. The curve covers the entire suction range from 0 to 10^6 kPa. Most
soil-water characteristic curves apply in soil science in which volumetric water content, $\theta$, is most commonly used. In geotechnical engineering gravimetric water content, $w$, is most commonly used. The degree of saturation $S$ is another common measure to be used in the mathematical model.

2.1.7 Factors Affecting Soil Suction

Many factors affect the soil suction value. From a view of the entire environmental circumstance, rainfall, vegetation and ground water play big roles in the variation of soil suction. Nevertheless, the micro mechanism behaviors of the soil-water interaction are the major factors affecting the soil suction value.

Climate. It has been recognized that, in the absence of a shallow water table, soil suction at depth in a profile is generally controlled by the regional climate. Nearer to the exposed ground surface, moisture can be lost and gained rapidly enough to be affected by seasonal weather and other transient influences. At extreme climatic conditions, soil suction could fall to equal only the solute suction during sustained wet weather, or rise beyond the wilting point of trees during a hot dry period. The depth over which these variations persist depends on the severity and duration of the particular influence, and on the nature of the soil
itself.

Research into the relationship between soil suction and climate has predominantly used the Thornthwaite Index to quantify the latter. Russam & Coleman (1961), Aitchison & Richards (1965) studied the correlation between equilibrium suction and climate.

**Ground water table.** A shallow water table may present low soil suction due to the short clearance. The clearance of high water in the State of Florida has been studied [Davidson, 1986]. A minimum height, the clearance, between a groundwater level and a particular elevation within the pavement system has been specified for different types of pavement in Florida.

**Vegetation.** Vegetation on the ground surface has the ability to apply a tension to the pore-water of up to 1-2 Mpa through the evapotranspiration process.

**Temperature.** Campbell & Gardner (1971) indicated that change in soil water potential with temperature becomes greater as soils become drier. When water potential falls below about -20 bars, temperature effects may become significant, especially in fine textured soils. Also, a decrease in temperature increase the surface tension and thus increases the soil suction (decreases soil water potential). In fall and winter, cooling of soil tends to
draw more moisture into soil subgrades under pavement, whereas summer heating reduces soil affinity of water, the decrease in surface tension T being about 1% per 5°C.

**Bulk density.** The studies from Campbell & Gardner [1971] also showed, in most cases, that negligible differences will arise from the use of disturbed field samples with altered bulk density rather than undisturbed field soil. Little change was noted except on a clay subsoil sample. Most test results indicate that the variation of matric suction with dry density appears to be of a secondary interest.

**Dissolved salts.** An increase in the amount of dissolved salts in the soil water slightly increases its surface tension and lowers the capillary potential of the soil. Theoretically, coastal areas or the regions where the soil has high alkaline content should attract more capillary water than similar subgrades do in fresh water areas. In fact, the effect of dissolved salts is relatively minor because of the insignificant evidence.

**Moisture content.** A decrease in moisture content results in an increase in surface tension and therefore increases soil suction. This is due to the influence on the radii of curvature of the water-wedge surfaces.

**Grain size.** With the same water content, the fine-
grained soils, which have more contact areas, will have less water collected at each of the contact points, and thereby increase the curvature on the air-water interface. The increases of curvature on the air-water interface results in an increase in soil suction.

**State of packing of soil.** During the process of compressing the soil, the curvature of the air-water interface gradually decreases and the matric potential increases from a negative value to zero. That is why "undisturbed" soil is preferred when the soil suction test is undertaken.

**Angle of contact.** An increase in the angle of contact will tend to decrease the curvature of the air-water interface and thereby increase the capillary potential of the soil at given water content. A soil treated with oil has less attraction to water than the one in which the particles are completely wetted.

**Clay Mineralogy.** This is the strongest factor that influences the matric potential. Clay particles adsorb and are surrounded by a diffuse double layer of ions and water molecules. In the last drying stage, the adsorbed water is held by a potential of thousands of bars. Therefore, the higher the active clay content, the lower (the more negative) the matric potential.
Permeability. When a soil is not saturated, the pore size effect contributes little to the permeability. The suction gradient results in the flow of water along particle surfaces and through the finer pores. An increase in soil suction decreases the hydraulic permeability and will increase the time required to obtain static equilibrium.

2.1.8 Values of in-situ soil suction

Henderson [1991] summarized measurements of maximum (dry) and minimum (wet) near-surface suction, and depth to the limit of seasonal influence, extracted from the data collected from a literature review. Apparently, there were no consistent patterns. The extreme dry values may have been affected by unreported or unobserved vegetation, and the wet limit may include values reflecting a shallow water table or a local water surplus. The range of values for each parameter argues in favor of obtaining site-specific suction data. Also it is not wise to rely on one measurement for a particular area.

2.2 Methods for Soil Suction Measurement

There are several ways to classify the methods of measuring soil suction. According to Smith [1991], with different measurement principles involved, the measuring
methods can be categorized into five groups. They are High air entry disk method, Porous material method, Psychrometer method, Filter paper method, and squeezing technique. Some methods can only measure matric suction if the measurements are made through the liquid phase. Field and laboratory methods for measuring matric suction are based on the same principles, only the apparatus and procedure are designed for different test environmental conditions. Many of these instruments are available in versions that may be attached to a data logger or some kind of continuous recording device.

There are several problems with many of the techniques due to lack of range, length of time required to reach equilibrium, and their ability to measure only matric suction. Usually, no single method can be used to cover the entire range of moisture tension. Thus, researchers may use more than one measurement method to cover the suction range according to their test purpose and test results. However, evaluating soil suction using the thermocouple psychrometer is one of the most simple and accurate methods, which provides a valuable tool in determining the water potential of solutions, tissues and soils. Table 2.2 modified from Smith [1991] compares the above methods in detail.
2.2.1 High Air Entry Disk

Direct measurement of soil matric suction is operated based on the use of high air entry disk. A high air entry disk has small pores of relatively uniform size. The disk acts as a membrane between air and water. The difference between the air pressure above the contractile skin and the water below the contractile skin is defined as matric suction. The maximum matric suction that can be maintained across the surface of the disk is called its air entry value, \((u_a - u_w)_d\). It is the function of surface tension, \(T_s\), and radius of curvature, \(R_s\), as illustrated in Kelvin’s equation:

\[
(u_a - u_w)_d = \frac{2T_s}{R_s}
\]

(2.12)

Where

\((u_a - u_w)_d\) = air entry value of the high air entry disk

\(T_s\) = surface tension of the contractile skin or the air-water interface

\(R_s\) = radius of the curvature of the contractile skin or the radius of the maximum pore size

The ability of the high air entry disk to withstand a difference between air and water pressures makes the disk
suitable for the direct measurement of negative pore-water pressures in an unsaturated soil. More details were described by Fredlund [1995]. Two common devices are used for the direct measurement of matric suction: tensiometer and axis-translation apparatus.

**Tensiometer method.** For measuring matric and hydraulic potential under wet conditions, there is no substitute for the accuracy of tensiometer, especially as they function equally well below the water table. Two limitations are presented here: trapped-air and response time. Several measuring systems for a tensiometer are available to overcome the problems as pressure transducers and hydraulic selector switches are employed.

**Axis-translation technique.** Hilf [1956] proposed a technique to measure the negative pore-water pressures that can be performed on either undisturbed or compacted specimens. The major device included a soil chamber with a measuring probe, which was made of a needle with a saturated high air entry ceramic tip. The difference between the air pressure in the chamber and the measured negative water pressure at equilibrium was taken to be the matric suction of the soil, \((u_a - u_w)\). Several types of pressure plate apparatus utilizing the axis-translation technique were studied by Olson and Langfelder [1965].
2.2.2 Porous Material Method

The indirect measurement of soil matric suction can be made using a standard porous block as a measuring sensor. Sensors of this type consist of a porous material whose water content varies with matric potential in a reproducible manner. A physical property of the material that varies with water content is measured and related to the matric potential using a calibration curve. Wide range of porous materials has been examined for their soil-water characteristic relationship in order to select the most appropriate material for making the sensor. These materials include nylon, fiberglass, gypsum plaster, clay ceramics, sintered glass, and metal. The porous block sensors must be brought into equilibrium. At equilibrium, the matric suction in the porous block and the soil are equal. The measurement is made utilizing the electrical or thermal properties of the porous block.

Electrical conductivity sensors. A standard matrix is equilibrated with the soil solution. The measurement is made when the matric potential of the standard matrix in the sensor equals the potential of the soil solution. The matric potential of the sensor is inferred from a measurement of electrical resistance of the sensor and a previously determined relationship between the electrical
resistance and the water potential of the matrix. The standard matrix can be any material that desaturated over the water potential range of interest to the investigator. Materials in common use are gypsum, nylon, and fiberglass. The electrical resistance of the sensor will be determined primarily by the water content of the sensor.

**Thermal conductivity sensors.** A standard matrix is equilibrated with the soil solution. The measurement is made when the matric potential of the standard matrix in the sensor equals the potential of the soil solution. At equilibrium, the water content of the standard matrix is determined by measuring the heat dissipation characteristics of the matrix. The standard matrix is typically a porous ceramic but other porous materials have been used. Heat dissipation is determined by applying a heat pulse to a heater within the ceramic and monitoring the temperature at the center of the ceramic before and after heating. The temperature difference is a function of the thermal diffusivity, and therefore of the water content of the ceramic. Because the thermal conductivity of the surrounding soil may differ substantially from that of the reference matrix, it is important that the reference matrix should be large enough to contain the entire heat pulse over the period of measurement.
2.2.3 Psychrometer Method

In 1951, Spanner began the development of an instrument to measure relative humidity in equilibrium with a plant or soil sample within the narrow range between 0.99 and 1.00. Afterward the major developments were focused on improving the accuracy and reliability of measurements, as well as simplifying psychrometer construction and measurement techniques. This method can measure soil total suction because the processing is made through the vapor phase.

Thermocouple psychrometer method. Thermocouple psychrometers sense the relative humidity of vapor in equilibrium with the liquid phase in the soil. The method is best suited to measurements in the range of potentials covered by the thermocouple psychrometer, which is generally -0.1 to -7.0 MPa. Because psychrometers cover an important range of potentials, for which there is a lack of accurate measurement techniques and they are capable of high accuracy, in theory. They have sometimes been used as a standard method against which to compare other methods. This is still too low for testing soils sampled at the end of a drying cycle in the semi-arid and arid areas. The response time depends on the cover of the psychrometer and the magnitude of total suction being measured. It varies from a few hours at several thousand kilopascals suction to
about two weeks at 100 kPa suction [Richards, 1974]. The operating principle is explained thoroughly in chapter 4.

**Transistor psychrometer method.** Improvements in performance have been made and the latest instrument can measure a much wider range of soil suctions in a shorter time. With good laboratory temperature control and the current operating procedures, the transistor psychrometer is capable of measuring the total suction of a soil in the range of pF3.0 to pF5.0 with an accuracy of about ±0.02pF above pF3.5 and only 1 hour needed to reach equilibrium. It has now been established that the transistor psychrometer is an accurate device for the measurement of the total water potential of soils. Work on the instrument is continuing with tests now being carried out on a more portable 8-channel model. It is believed that this will be suitable for field laboratory applications where high accuracy below about pF3.75 is not required.

### 2.2.4 Filter Paper Method

The Filter Paper Method was adopted by Mcqueen and Miller in 1968 from a technique proposed by Gardner in 1937 and the range is from less than 0.1 tsf to more than 1000 tsf. It is less complicated and more economical than the thermocouple psychrometer method. Small changes in weight
may create large errors. The material of the filter paper and calibration solution has big effect on the measurement. A gravimetric scale accurate to 0.001g is required. It is also a time consuming test. Monitoring of the filter paper weight over a period of at least a week may be required to ensure that the equilibrium has been reached and great care must be taken to ensure no moisture loss occurs prior to weighing. This method can measure both matric and total suction and has been widely adopted in the past few years.

In this method, filter paper is used as a sensor and will be at equilibrium with soil water, either through the vapor phase or through liquid and vapor combined phase flow. The soil water potential is determined by measuring the water content of the filter paper and using a moisture release curve to determine the water potential of the paper. When the paper is placed in contact with the water in the soil and the exchange is through the liquid phase flow, then the equilibrium water content of the filter paper corresponds to the matric suction of the soil. On the other hand, the equilibrium water content of the filter paper corresponds to the total suction of the soil if the paper is not in contact with the soil and the exchange is entirely in the vapor phase. Therefore, the same calibration curve is used for both the matric and total suction measurement.
2.2.5 Squeezing Technique

The osmotic suction can be indirectly estimated by measuring the electrical conductivity of the soil. Pure water has low electrical conductivity in comparison to pore water, which contains dissolved salts. The electrical conductivity of the pore-water from the soil can be used to indicate the total concentration of dissolved salts, which is related to the osmotic suction of the soil.

2.3 Application of Soil Suction

2.3.1 Estimation of Volume Change

Clay soil exhibits high strength and low compressibility in most natural conditions. When the moisture content of the soil increases, the volume of the soil mass increases. The driving force behind this volume change is the soil moisture retention force or soil suction. Because of its greater sensitivity to volume change in comparison to moisture content, soil suction has been shown to be a more sensitive and accurate indicator of potential swell, as well as a more reliable parameter for estimating volume change. As the moisture content increases, the soil suction decreases and the soil swell. Various researchers involved in characterization of expansive soils have
developed heave prediction methods that involve different interpretations or uses of the soil suction data [Snethen, 1970; Johnson, 1974; Thompson, 1995].

2.3.2 Determination of Coefficient of Permeability

For an unsaturated soil, the coefficient of permeability is primarily determined by the pore-size distribution of the soil and can be predicted from the soil-water characteristic curve. Knowledge of the pore-water pressure or hydraulic head is the major interest in solving the problems involving unsaturated soils. The coefficient of permeability, $k$, of an unsaturated soil is not constant and depends on the volumetric water content, $\theta$, which, in turn, depends on the soil suction, $\psi$. There are two approaches in obtaining the permeability function of an unsaturated soil, namely empirical equations and statistical models. Several mathematical models governing the relationship between the coefficient of permeability and matric suction have been proposed and are summarized in Table 2.3.

2.3.3 Influence on Shear Strength

In engineering studies, soil tension is acting as a negative pore pressure, which is very important in affecting
problems such as bearing capacity, lateral earth pressures, and the slope stability are related to the shear strength of a soil. The strength state variables generally used for an unsaturated soil are the net normal stress \((\sigma - u_a)\), and the matric suction \((u_a - u_w)\). In this case, the in situ matric suction can increase or decrease in response to the change in the climate conditions such as evaporation and precipitation. As a result, the undrained shear strength will also change. The change can be expressed as follows:

\[
\Delta C_u = \Delta (u_a - u_w) \tan \psi^b \tag{2.13}
\]

Where

\(\Delta C_u\) = change in undrained shear strength due to matric suction change

\(\Delta (u_a-u_w)\) = change in matric suction due to drying and wetting

\(\psi^b\) = friction angle respect to change of suction

The application of the shear strength equation to different types of geotechnical problems is well presented in Soil Mechanics for Unsaturated Soils by Fredlund [1993].

2.3.4 Relation with Evaporation of Soil Moisture

Previous works describing evaporation most apply to
hydrology and soil science. In response to the need to develop a clear rational for geotechnical applications, predictive techniques have been studied to evaluate evaporation from soil surface. The analysis showed that increased evaporative fluxes during the summer months decreased the thickness of the tension-saturated zone above the water table resulting in the increased potential for desaturation of the tailing surface. Figure 2.6 [Holmes, 1961] shows that the actual evaporation rate (AE) from soil surfaces relative to the potential evaporation rate (PE) is a function of water availability, soil texture, and drying rate. No single variable or soil property appears to control the evaporation rate from the soils.

A simple approach for prediction of evaporation from soil surface was presented by Fredlund [1997] and the actual evaporation rates for different types of soils were measured and compared. It was found that a relationship between the actual evaporation rate and total suction does exist when the soil sample is thin. When the observation applies to a thick soil sample, a theoretical approach that includes the influence of flow processes below the soil surface would be required.

Many variables contribute to the variation of soil drying rate, such as water content, temperature, humidity, and soil texture.
An equation shown in Equation 2.14 governs the evaporation from a water surface.

\[ E = f(u) (e_s - e_a) \]  

(2.14)

Where

\( E = \) rate of evaporation (mm/day)

\( f(u) = \) transmission function

\( e_s = \) saturation vapor pressure at the temperature of the water surface

\( e_a = \) vapor pressure of the air in the atmosphere above the water surface
## Table 2.1: Soil Suction Conversion Table

<table>
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<tr>
<th>pF</th>
<th>cm (H₂O)</th>
<th>mm (Hg)</th>
<th>kPa (tN/m²)</th>
<th>bar</th>
<th>erg/cm³</th>
<th>tcn/ft²</th>
<th>lb/in²</th>
<th>atm</th>
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<tbody>
<tr>
<td>0</td>
<td>1*10⁰</td>
<td>(7.35)10⁰</td>
<td>(9.8)10⁻²</td>
<td>(9.8)10⁻⁴</td>
<td>(9.8)10²</td>
<td>(1.0245)10³</td>
<td>(1.42)10⁻²</td>
<td>(9.676)10⁻⁴</td>
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<tr>
<td>1</td>
<td>1*10¹</td>
<td>(7.35)10¹</td>
<td>(9.8)10⁻¹</td>
<td>(9.8)10⁻³</td>
<td>(9.8)10³</td>
<td>(1.0245)10²</td>
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<tr>
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<td>(9.8)10⁰</td>
<td>(9.8)10⁻²</td>
<td>(9.8)10⁴</td>
<td>(1.0245)10¹</td>
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<tr>
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<td>(9.8)10⁵</td>
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<td>(9.676)10⁻¹</td>
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<td>4</td>
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<td>(1.42)10⁴</td>
<td>(9.676)10²</td>
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Table 2.2: Summary of methods for measuring soil suction

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<tr>
<th>Method</th>
<th>Place</th>
<th>Type</th>
<th>Range</th>
<th>Accuracy</th>
<th>Commercial equipment</th>
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<tr>
<td>Tensiometers</td>
<td>Lab. &amp; Field</td>
<td>$\psi_m$</td>
<td>0 to -65 kPa</td>
<td>0.25 kPa</td>
<td>Bourdon gauge, Portable Bourdon gauge, Mercury manometer, Funicure tensiometer, Portable electric readout</td>
</tr>
<tr>
<td>Axis-Translation</td>
<td>Lab. &amp; Field</td>
<td>$\psi_n$</td>
<td>0 to 1500 kPa</td>
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<tr>
<td>Electrical resistance sensors</td>
<td>Field</td>
<td>$\psi_n$</td>
<td>-0.1 to -100 kPa</td>
<td>Low, depends on calibration, salinity, and temperature correction</td>
<td>Fiberglass sensor, Gypsum sensor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-50 to -1.5 Mpa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat dissipation sensors</td>
<td>Field</td>
<td>$\psi_n$</td>
<td>0 to -1 Mpa</td>
<td>0 to -100 to -10 kPa, 0 to -300 to -20 kPa, 0 to -600 to -100 kPa</td>
<td></td>
</tr>
<tr>
<td>Psychrometers</td>
<td>Lab &amp; Field</td>
<td>$\psi_w$</td>
<td>0 to -300 Mpa</td>
<td>Laboratory, 4 kPa</td>
<td>Laboratory sample changer, Psychrometer, Soil psychrometer, nanovoltmeter, thermometer, Dew-point microvoltmeter</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0 to -7 Mpa</td>
<td>Field, 50 kPa</td>
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<tr>
<td>Filter Paper</td>
<td>Lab</td>
<td>$\psi_m/\psi_w$</td>
<td>-1 kPa to -100 Mpa</td>
<td>~+50% at -10 kPa</td>
<td>Paper</td>
</tr>
<tr>
<td>Pore Fluid Squeezer</td>
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<td>$\psi_s$</td>
<td>entire range</td>
<td></td>
<td></td>
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<td>Equations</td>
<td>Symbols</td>
<td>Source</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>------------------------------------------</td>
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<td>( k_w = k_s ) for ((u_a - u_w) \leq (u_a - u_w)_b) ( k_w = k_s \left( \frac{(u_a - u_w)}{(u_a - u_w)_b} \right)^{\eta} ) for ((u_a - u_w) &gt; (u_a - u_w)_b)</td>
<td>( \eta = \text{empirical constant} ) ( \eta = 2+3l )</td>
<td>Brooks &amp; Corey (1964)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( k_w = \frac{k_s}{1 + \left( \frac{(u_a - u_w)}{(u_a - u_w)_b} \right)^{n'}} )</td>
<td>( n' = \text{constant} )</td>
<td>Arbhabhirama &amp; Kridakorn (1968)</td>
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<tr>
<td>( k_w = \frac{k_s}{1 + \alpha \left( \frac{(u_a - u_w)}{\rho_w \alpha} \right)^n} )</td>
<td>( a, n = \text{constant} )</td>
<td>Gardner (1956)</td>
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</table>
Figure 2.2: Conventional illustration of soil-water distribution
Figure 2.3(a) : Pressure versus depth in a capillary tube

Figure 2.3(b) : Cross section of capillary meniscus
Figure 2.4: Illustration of the definition of suction

* No passage of water through membranes at equilibrium
Figure 2.5: A typical desorption and adsorption characteristic curve for a silty soil
Figure 2.6: Typical drying curve for sand and clay
CHAPTER 3

REVIEW OF PHASE I STUDY

3.1 Phase I Experimental Program

The problem that soils are difficult to dry and compact was revealed during highway construction in the State of Florida. For this reason, a Phase I evaluation of engineering properties of problematic soils in highway construction was performed (McDonald, 1995). Prior to accepting soils from districts 2, 3, and 5, two soils from each of 6 districts were first examined to determine if they were suitable for the evaluation project. A site location map is shown in Figure 3.1. Table 3.1 lists the basic properties of the selected soils. In order to provide a method to identify the problematic soils, McDonald conducted tests concerning the properties of the problematic soils selected by FDOT. Those tests included Moisture Content, Atterberg Limits, Grain-Size Analysis, Compaction Test, Bearing Ratio, Expansion Index, Permeability, X-Ray Diffraction, and Scanning Electron Microscope (SEM). A detailed description of each test was illustrated [McDonald,
1995] and is briefly reviewed in the following. The test results of soil properties for six troublesome soils are summarized in Table 3.2.

3.1.1 Natural Moisture Content

To ensure that a constant moisture content level was maintained during the storage time, a moisture content check was performed. The procedure and calculation followed the Standard Method ASTM D 2216. The soils were put in metal tins and dried in a drying oven at 110°C (230°F) for 24 hours. Three samples from different depths within the container were obtained for the test. Test results showed that the moisture was well controlled inside the storage container. The results of the test could also be used as an indication of the in-situ moisture content of the soil. The values from the district 5 soils were probably less than the in-situ values because they were shipped in soil bags during a dry period in the summer. The moisture content of each soil is presented in Table 3.3.

3.1.2 Atterberg Limits

The Atterberg limits refer to the Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), and Plasticity Index (PI). These properties were used in the
classification of the soil and gave an indication of their engineering properties. The LL, PL, and PI were determined for the soils in the test program. The procedure followed the Standard ASTM D 423 for determining the LL, and the Standard ASTM D 424 for PL and PI. The LL, PL, and PI for each soil are listed in Table 3.4

3.1.3 Grain size Analysis

A combination of ASTM D 421 Standard Method (Sieve Analysis) for particle sizes larger than 0.075 mm (.003 in) and ASTM D 1140 Standard Method (Hydrometer Analysis) for particles smaller than 0.075mm were used to analyze soil grain size. The hydrometer analysis is useful in identifying the percentage of clay in each soil in this study. The percentage of passing versus the grain size for each soil was plotted in Figures A.1 through A.6. From the graphs, the corresponding percentage of gravel, sand, and clay for each soil was determined and is shown in Table 3.5. The soil classification using the AASHTO and Unified systems is presented in Table 3.6.

3.1.4 Compaction Test

A modified compaction test was performed on all soils. In this test, determination of the dry unit weight of the
soil was done for each compacted sample and then plotted against the water content as included in Appendix from Figures A.7 to A.12. Figure 3.2 compares the dry density-water content for six soils. Maximum dry density for each soil was determined at optimum moisture content from the peak of the regression curve. The results from the compaction test for the maximum dry density are consistent with normal values obtained for clayey sand and silty sand soils. The procedures followed Standard ASTM D 1557. Table 3.7 lists the values for each of the soils at optimum conditions.

3.1.5 Bearing Ratio

In this test, the Limerock Bearing Ratio (LBR) method is used to measure the bearing capacity of a soil. The LBR test is a modification of the California Bearing Ratio (CBR) test. Three main modifications were employed to best present the soils encountered in Florida. They were eliminating the swell test, using a two-day soaking period instead of four-day, and changing the strength standard to that of typical crushed Florida limerock, which is 5.5 Mpa (800 psi). Minimum LBR values of soils have been set by the FDOT for use in pavement construction. The LBR value can be obtained from the following equation. The results of
limerock bearing ratio values for 2-day soaking and 4-day soaking are shown in Table 3.8(a) and Table 3.8(b) respectively.

\[
LBR (\%) = \frac{\text{Corrected - Unit - Load}(\text{lb/in}^2)}{800(\text{lb/in}^2)} \times 100 \tag{3.1}
\]

### 3.1.6 Expansion Index

The expansion index is used to classify soils according to their potential for expansion, which is considered to be a basic property of the soil. The soil was first compacted to a degree of saturation \(S_{\text{meas}}\) of 50%±1 and then allowed to swell against a surcharge pressure. An empirical equation recommended in the Standard Test Method was used to eliminate the difficulty of achieving the degree of saturation of 50%±1. Equation 3.2 shows the recommended relationship. A value of 50 or higher of the soil indicates that the potential problems in pavement design would become significant. Test results were presented in Table 3.9 and showed that the potential expansion of each soil is "very low".

\[
EI_{50} = EI_{\text{meas}} - (50 - S_{\text{meas}}) \times \left(\frac{65 + EI_{\text{meas}}}{220 - S_{\text{meas}}}\right) \tag{3.2}
\]
3.1.7 X-ray Diffraction and Scanning Electron Microscope

For identifying the fine-grained soil minerals and the study of their crystal structure, X-ray diffraction is the most widely used method. The principle of this method is based on Bragg's law as shown in the following equation:

\[ n\lambda = 2d \sin \theta \]  

A Phillips Automatic Powder Diffractometer Model APD 35-20 was used to produce the X-ray diffractometer charts for the samples. The results of the analysis are shown in Table 3.10.

Another method, scanning electron microscope, can directly reveal particles and particle arrangements since it can resolve distances to less than 100 Å. An Environmental Scanning Electron Microscope (ESEM) Model E-3 by ElectroScan Corporation was used to take the pictures. Some pictures show that a normal sieve analysis may not give an accurate size distribution due to the attractive forces, which hold the particles together. Either a mechanical breaking of the soil or a wet sieve is required when using this test program to separate the clay and the silt particles from the sands.
3.1.8 Permeability

Permeability is the property of a porous material, which permits the passage, or seepage of fluids through its interconnecting voids. Two methods were available to tackle the difficulty of the saturation. The Florida Method FM 5-513 was used when possible. If the soil was difficult to saturate completely, then ASTM Standard D 5084 was adopted and the coefficient of permeability was found using a flexible wall permeameter (FWP). The FWP is best used when the coefficient of permeability is less than $1 \times 10^{-3}$ cm/sec ($3.28 \times 10^{-3}$ ft/sec). Permeability results are listed in Table 3.11.

3.2 Summary of Test Results

The primary complaint about the soils from the contractors was that they were hard to compact and slow in drying. From the moisture content test, it was found that the in-situ water content was greater than the optimum water content for most soils. All soils have a good distribution of particle sizes for the sand range. This allows for the tight packing of the particles during compaction. A low value of permeability conformed to the tight packing. Also the presence of montmorillonite or similar type clay in the soil could be a factor in the low permeability values. From
the expansion index test results, all of the soils were classified as very low for expansion potential and were inactive. The summary of the test results is presented in Table 3.2. The low permeability and high in-situ moisture content may contribute to the slow drying and compacting problems during construction.

The motivation for evaluating the effect of soil suction and environmental conditions for the six problematic soils is based on the results of a previous evaluation (Ping & McDonald, 1996). Since no significant evidence directly related to those properties for the drying problem existed, a further study of the effect of soil suction and the environmental conditions was recommended to evaluate the problematic soils.
<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>AASHTO Class</th>
<th>Description</th>
<th>Color</th>
</tr>
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<td>A-2-6</td>
<td>Clayey Sand</td>
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<td>SR 100 and C-21B</td>
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<td>Brown</td>
</tr>
<tr>
<td></td>
<td>SR 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>A-2-4</td>
<td>Silty Sand</td>
<td>Brown</td>
</tr>
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<td></td>
<td>US 231, Alford City</td>
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<td></td>
<td></td>
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<td>Reddish</td>
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<tr>
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<td>US 231, Jacobs Road</td>
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<td>24</td>
<td>12</td>
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<td>Maximum Dry Density, KN/m</td>
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<td>20.4</td>
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<td>LER (2 Day Soaking)</td>
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<td>LER (4 Day Soaking)</td>
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Table 3.5: Percentage of major soil constituents

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<th>Sand, %</th>
<th>Silt, %</th>
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<td>Jacobs Roads</td>
<td>1.8</td>
<td>78.2</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>2.4</td>
<td>80.8</td>
<td>6.8</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>1.3</td>
<td>78.8</td>
<td>7.9</td>
<td>12</td>
</tr>
</tbody>
</table>
Table 3.6: Soil classification by AASHTO and Unified system

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Passing No.40</th>
<th>Passing No.200</th>
<th>LL, %</th>
<th>PI, %</th>
<th>AASHTO</th>
<th>Unified</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Clay County</td>
<td>89.50</td>
<td>27.50</td>
<td>27</td>
<td>13</td>
<td>A-2-0</td>
<td>SC</td>
</tr>
<tr>
<td>2</td>
<td>Madison County</td>
<td>91.00</td>
<td>25.10</td>
<td>18</td>
<td>NP</td>
<td>A-2-4</td>
<td>SM</td>
</tr>
<tr>
<td>3</td>
<td>Alford City</td>
<td>71.90</td>
<td>17.60</td>
<td>NP</td>
<td>NP</td>
<td>A-2-4</td>
<td>SM</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Road</td>
<td>78.30</td>
<td>20.00</td>
<td>15</td>
<td>NP</td>
<td>A-2-4</td>
<td>SM</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>89.30</td>
<td>16.80</td>
<td>19</td>
<td>NP</td>
<td>A-2-4</td>
<td>SM</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>78.20</td>
<td>16.90</td>
<td>23</td>
<td>9</td>
<td>A-2-4</td>
<td>SC</td>
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</tbody>
</table>
Table 3.7: Results from the modified proctor compaction test

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Max Dry r. kN/m³</th>
<th>Optimum $W_o$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Clay County</td>
<td>20.5</td>
<td>9.1</td>
</tr>
<tr>
<td>2</td>
<td>Madison County</td>
<td>20.6</td>
<td>8.5</td>
</tr>
<tr>
<td>3</td>
<td>Altord City</td>
<td>20.4</td>
<td>7.6</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Road</td>
<td>20.5</td>
<td>7.9</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>19.8</td>
<td>9.25</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>20.4</td>
<td>9.3</td>
</tr>
</tbody>
</table>
### TABLE 3.8(a): Limerock bearing ratio values for 2-day soaking

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Wc,(%)</th>
<th>$\rho_{dry},\text{kN/m}^3$</th>
<th>LBR</th>
<th>Swell,%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Clay</td>
<td>9.06</td>
<td>19.4</td>
<td>30</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>County</td>
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<td>19.3</td>
<td>31</td>
<td>0.13</td>
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<tr>
<td>2</td>
<td>Madison</td>
<td>8.50</td>
<td>20.1</td>
<td>85</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>County</td>
<td>8.50</td>
<td>20.4</td>
<td>89</td>
<td>0.02</td>
</tr>
<tr>
<td>3</td>
<td>Alford</td>
<td>7.75</td>
<td>20.0</td>
<td>88</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>City</td>
<td>7.75</td>
<td>20.3</td>
<td>100</td>
<td>0.02</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs</td>
<td>7.93</td>
<td>20.2</td>
<td>63</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Road</td>
<td>7.93</td>
<td>20.2</td>
<td>78</td>
<td>0.13</td>
</tr>
<tr>
<td>5</td>
<td>Brevard</td>
<td>9.25</td>
<td>19.5</td>
<td>91</td>
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<tr>
<td></td>
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<td>19.4</td>
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<td>20.1</td>
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<td>0.02</td>
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### TABLE 3.8(b): Limerock bearing ratio values for 4-day soaking

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Wc,(%)</th>
<th>$\rho_{dry},\text{kN/m}^3$</th>
<th>LBR</th>
<th>Swell,%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
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<td>19.9</td>
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<tr>
<td></td>
<td>County</td>
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<td>44</td>
<td>0.41</td>
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<tr>
<td>2</td>
<td>Madison</td>
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<td>20.0</td>
<td>88</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>County</td>
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<td>20.1</td>
<td>89</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>Alford</td>
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<td>96</td>
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</tr>
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<td>City</td>
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<td>County</td>
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<tr>
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<td>Marion</td>
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<td>County</td>
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<td>20.2</td>
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<tr>
<td>District</td>
<td>Location</td>
<td>Test 1</td>
<td>Test 2</td>
<td>Test 3</td>
<td>Average</td>
</tr>
<tr>
<td>----------</td>
<td>------------------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>2</td>
<td>Clay County</td>
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<tr>
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<tr>
<td>3</td>
<td>Alford City</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Roads</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>5</td>
<td>Marion County</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

0-20: Very Low; 21-50: Low; 51-90: Medium; 91-130: High; >130: Very High
TABLE 3.10: X-ray diffraction results

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Minerals Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Clay County</td>
<td>Kaolinite</td>
</tr>
<tr>
<td>2</td>
<td>Madison County</td>
<td>Kaolinite, minor quartz, trace chlorite</td>
</tr>
<tr>
<td>3</td>
<td>Alford City</td>
<td>Kaolinite, minor quartz, trace chlorite</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Road</td>
<td>Kaolinite, trace quartz</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>Kaolinite, Smectite, Illite, minor quartz</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>Kaolinite</td>
</tr>
<tr>
<td>District</td>
<td>Location</td>
<td>Dry Density ( \text{kN/m}^3 )</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>2</td>
<td>Clay County</td>
<td>19.3</td>
</tr>
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<td></td>
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<td>18.5</td>
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</tr>
<tr>
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<td></td>
<td>19.6</td>
</tr>
<tr>
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<td>Alford City</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.7</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Road</td>
<td>19.6</td>
</tr>
<tr>
<td></td>
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<td>19.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.3</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>18.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.7</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.1</td>
</tr>
</tbody>
</table>
### Table 3.12: Activity values for soils in experimental study

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Activity</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Clay County</td>
<td>0.54</td>
<td>Inactive</td>
</tr>
<tr>
<td>2</td>
<td>Madison County</td>
<td>0</td>
<td>Inactive</td>
</tr>
<tr>
<td>3</td>
<td>Alford City</td>
<td>0</td>
<td>Inactive</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Road</td>
<td>0</td>
<td>Inactive</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>0</td>
<td>Inactive</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>0.67</td>
<td>Inactive</td>
</tr>
</tbody>
</table>
Figure 3.1: Site Location Map
Dry Density vs Water Content for Six Soils

Figure 3.2: Dry density at different water contents for six soils
CHAPTER 4

LABORATORY EXPERIMENTAL PROGRAM

4.1 General

The purposes of the experimental program were to correlate drying rate with soil suction as well as environmental effects such as temperature and humidity, and to further investigate the relationship between the drying rate and the percent of fines. The laboratory testing program involved two types of test: the soil suction test and the drying rate test. The soil suction test was chosen from AASHTO Designation T273-86 to determine the soil suction values at different water content for six troublesome soils. The soil drying rate test was generated by using an environmental chamber (incubator) in which a variety of temperature and humidity were used to simulate the environmental condition in Florida.

The soils selected for this study were the same as those used for Phase I tests [McDonald, 1996]. The basic soil properties were summarized in Chapter 3 in detail.
4.2 Soil Suction Test

Basically, the soil suction test procedure followed AASHTO DESIGNATION T 273-86 [1993], which is the standard method of testing for measuring soil suction, except that the soil samples were remolded. This test method covers the procedure for determining total suction force using thermocouple psychrometers of the Spanner [1951] type.

Two series of suction tests were performed. Series A was done in normal laboratory room temperature and humidity, and series B was performed inside an incubator, which provides desired constant temperature and relative humidity. The soil suction test program is summarized in Table 4.1.

4.2.1 Suction Measurement Devices

The test devices consisted of three major parts: monitor system, sensor system, and sample chamber system. Each system has its own designation for this test.

Monitor system. A WESCOR HR-33T Dew Point Microvoltmeter shown in Figure 4.1 was used to monitor and record the output data. The HR-33T Dew Point Microvoltmeter is a self-contained electronic system that has been specifically designed for measuring water
potential with thermocouple transducers. It contains sophisticated sensing and control circuitry that automatically maintains the temperature of the thermocouple junction at the dew point temperature when operating in the dew point mode. The HR-33T permits water potential to be determined with a variety of sensors in either the dew point (hygrometric) or the wet bulb (psychrometric) mode. The same sensors are used for both modes but the electronic control and measuring apparatus operate differently. The operation principle for both modes is illustrated in Figure 4.2. According to the work by Brisco [1984], one advantage of the dew point mode is that it provides a continuous output rather than a falling plateau. Since the time of reading is not critical, the dew point mode was chosen to obtain accurate measurement in this program.

Sensor system. Thermocouple psychrometer was used as a sensor for this test. Klute [1986] thoroughly illustrated the use of the psychrometer for both laboratory and in-situ. Two major types of thermocouple psychrometers were most often used. One was developed by Richards and Ogata in 1958 and the other was developed by Spanner in 1951. Nine thermocouple psychrometers of the Spanner type with a known cooling coefficient (\(\Pi_v\)) produced by Wescor, Inc.
(Model PST-55-15-SF) were used for the tests. A typical psychrometer consists of a sensing thermocouple junction, a chromel-constantan thermocouple, and two reference junctions of copper-constantan and copper-chromel. A construction schematic view of the psychrometer is shown in Figure 4.3.

Wescor peltier cooled psychrometers are available with either stainless steel screen shields or porous ceramic shields. A PST-55-15-SF psychrometer is specified as a psychrometer that is covered with a Dutch weave stainless thermocouple shield and has 1.5 meters lead length. SF is the SUREFAST connector with which the connection process can be accomplished by pushing the cable connector into the receptacle until it is firmly in place.

Two important principles underlie the usefulness of thermocouple psychrometers: The Seebeck Effect and the Peltier Effect. The electrical principles of these two effects are briefly described in the following. More details about the electrical behavior of the psychrometer may be found elsewhere [Brisco, 1984].

1. The Seebeck Effect is the phenomenon that permits a thermocouple to be used for temperature measurement. A thermocouple is formed when two different metals
are joined together. If both ends of the wire are joined to form a closed loop, electrical current will flow through the wires whenever the junctions are at different temperatures. The magnitude of the produced voltage is dependent upon the temperature difference between the junctions.

2. The Peltier Effect is the phenomenon, which allows a thermocouple junction to be cooled by passing an electrical current through the junction. When current flows across the junction of two dissimilar metals, heat will be either absorbed or liberated at the junction. If the current flows in the same direction as the current produced by the Seebeck Effect at the hot junction, heat is absorbed. If the current flows in the opposite direction, heat is liberated.

In order to have accurate measurement, protecting psychrometers from contamination is most important. If contaminations are presented at the junction, the rate of evaporation will be changed, thereby the output is reduced, and satisfactory precision cannot be obtained.

Sample chamber system. The sample chamber assembled with metal cans and polystyrene box is shown in Figure 4.4
4.2.2 Calibration of Psychrometers

Nine PST-55-15-SF thermocouple psychrometers were calibrated with the assistance of salt solution which causes a vapor pressure lowering of relative humidity in the atmosphere that can be converted to suction using Kelvin's equation (Equation 3.5). Sodium chloride (NaCl) was chosen as the salt in the calibration solutions because the relative humidity of these solutions is independent of temperature in the normal range of operating temperature. Four calibration standard concentrations were used to adequately define the calibration lines. They were 290, 500, 1000, and 1800 osmolality, respectively. Table 4.2 specifies the gram formula weight of NaCl per 1000 grams of distilled water (the molality M) for some levels of
relative humidity in equilibrium with the solutions. The
time to reach equilibrium depends on the concentration of
salt solution. According to Snethen [1970], the
equilibrium voltage outputs from the psychrometers can be
obtained within the metal pint container in 48 hours or
less with 0.05M solutions and 12 hours or less with 2.0M
solutions.

The calibration of psychrometers was accomplished
using the device illustrated in Section 4.1 except that the
soil specimen was substituted by filter paper with 3ml
known water potential of sodium chloride solutions in it.
Sufficient time was allowed for the vapor equilibrium to
occur within each container. The calibration of
psychrometers followed the procedure illustrated in AASHTO
DESIGNATION T 273-86 [1993]. Eight(8) amps of cooling
current was applied for 30 seconds. The output of the
psychrometer was approximately 0.75 microvolts per bar in
the dewpoint mode. After the temperature and the microvolt
output were obtained, a straight line representing the best
fit of the data points was determined for each
psychrometer. The calibration line of each psychrometer
can be expressed by the following equation:
\[ \tau^o = a E_{25} - b \]  \hspace{1cm} (4.1)

Where

\[ \tau^o = \text{total soil suction, Kpa} \]
\[ a, b = \text{calibration constants} \]
\[ E_{25} = \text{psychrometric microvoltmeter reading corrected to 25°C, \mu V} \]

The slope of the calibration line will always be positive and the \( y \)-intercept should be equal to or less than zero. The calibration line is valid for the useful life of the thermocouple psychrometer. However, under normal use, an annual check of the calibration at least one point will assure that the equipment is operating properly. For this study, the psychrometers were calibrated twice within one year to adjust the soil suction test results.

4.2.3 Sample Preparation

The soils used in this study were from different locations around the State of Florida, i.e., Clay County, Madison County, Jackson County, Brevard County, and Marion County. Classification indices for these soils are shown in Table 3.6. Five soils were classified as A-2-4 soil,
according to the AASHTO Classification System, except one soil from Clay County, which was classified as A-2-6 soil.

The soils were compacted in a mold, which has a diameter of 4-inch and a height of 8-inch, at optimum water content for Series A tests and at optimum water content plus 4% for Series B tests. The compaction energy was achieved by using a 10-lb hammer dropped from a height of 457 mm (18 in) with eight equal layers for 25 blows per layer. The compacted soils were cut into nine 1.5in. x 1.5in. x 1.5in cubes immediately after removal from the mold. The maximum dry density and optimum water content were recorded.

4.2.4 Test Procedure

According to the suggested data record form from the AASHTO Standard Test, the procedure can be divided into three parts. They are Suction test, Weight-Volume Relation test, and Water Content test. Each test is described in the following:

Soil suction. The nine 1.5-in. x 1.5-in x 1.5-in-cube soil samples described in Section 4.2.3 were placed in individual metal containers (one-pint paint cans with interiors coated with wax to prevent corrosion). Of nine
specimens, two were tested at their optimum water content and sealed with rubber stoppers right after cutting. These two specimens represented the optimum water content of the soils. The remainder were either wetted with varying amounts of distilled water or dried at room temperature for varying lengths of time. Three of the remaining specimens were dried at room temperature for 1, 2, and 4 hours. The dried specimens were sealed after their drying times. The remaining four specimens were wetted with 0.5, 1, 2, and 4 ml distilled water respectively, and sealed in the sample containers immediately after adding water. The purpose of the wetting and drying process is to establish a range of water contents over which the soil suction can be measured. All of the nine specimens were weighed before the containers were sealed.

Nine thermocouple psychrometers were first fed through the center of the polystyrene box together and then each of them was fed through the hole in the center of rubber stopper. Both the holes on the cover of the polystyrene box and the rubber stopper were sealed with sealant to ensure that the system was airtight and the thermocouple psychrometers were extended approximately one inch beyond the bottom of the stoppers.
The specimens were allowed to come to equilibrium in the sealed containers. The temperature equilibrium was obtained in a few hours after placing the cover on the thermal container. Equilibrium of the relative humidity of the air measured by the psychrometers is usually obtained within 48 to 72 hours, according to the AASHTO Standard Method. It was found that the time to reach the relative humidity equilibrium varied widely for different samples. It was ranged from three days to ten days depending on the suction values of the soils.

Each psychrometer was connected to the HR-33T microvoltmeter (Figure 4.6) and the output electromotive forces (emfs) for each psychrometer were recorded. The cooling coefficient, $\Pi_v$, of each psychrometer at $25^\circ C$ was measured at manufacture preliminarily. And the cooling coefficient at the temperatures other than $25^\circ C$ was calibrated using the following equation:

$$\Pi_v(\text{at } T^\circ C) - \Pi_v(25^\circ C) = (25 - T) \times 0.7$$  \hspace{1cm} (4.2)

Where

$T =$ measured temperature before applying cooling current
The operation of the HR-33T dew point microvoltmeter followed the manual provided by Wescor Inc [1988]. The magnitude of the peak output emf is directly related to the relative humidity of the medium. The temperature output of the thermocouple psychrometer was recorded in °C and the output of emf in microvolts. 30 seconds of cooling current was applied for the test which was identical to that used to determine the calibration line.

**Weight-volume relations.** Since the soil specimens might experience volume change during the soil suction test, determining the specific volume of each specimen after the soil suction test becomes more complicated. Most of the researchers use the volume displacement method to measure the volume of the specimen, which has an irregular shape, by submerging it into water.

The wet weight of the specimens was measured immediately after removal from the metal containers. Before putting the soil into water, the soil was wrapped with pure wax to prevent water coming into contact with the soil and then the weight of the soil with wax on it was determined. The temperature of the water was recorded. The temperature of the melted wax needed to be well controlled to make the wrapping work easier. The weight of
the soil with the wax in water was measured by submerging
the object, which was hung under the scale, into water to
determine the bulk densitics.

Figure 4.7 illustrates the schematic view of the
measuring system for the weight-volume relation test.

Water content. Following the soil suction and weight-
volume relation measurements, the actual moisture content
was then determined. The wax was taken off from the soil
sample carefully so that no water was allowed to flow into
the soil specimen. The wet specimens were weighed
immediately after the wax was taken off and dried in a
microwave for 12 minutes until the water inside the soil
was completely gone.

4.2.5 Data Reduction and Interpretation

Soil suction. The recorded psychrometer voltage
outputs, $E_t$, can be converted to the equivalent outputs at
the calibration temperature, $E_{25}$, using the following
equation:

\[
E_{25} = \frac{E_t}{0.325 + 0.027T} \quad (4.3)
\]
The soil suction, \( \tau \), of each individual specimen was determined using the psychrometer calibration equation obtained from the calibration test. Nine calculated suction values (ordinate, log scale) versus the corresponding water contents (abscissa) were plotted on a semi-log plot to establish the relationship of log soil suction and water content, which is linear and can be expressed using the following equation:

\[
\log \tau = A - Bw \tag{1.4}
\]

Where

- \( \tau \) = Soil suction, kPa
- \( A \) = y-intercept
- \( B \) = slope
- \( W \) = water content, percent

The data points between soil suction values of 200 kPa (2 tsf) and 2000 kPa (20 tsf) were recommended by AASHTO Standard to establish the \( \tau \)-\( W \) relationship if some variation occurred at the upper or lower end of the curve because the limits of the measurement range were approached. The recommendation was too conservative according to the
literature, which stated that the measurement of a psychrometer could range from 100 kPa to 8000 kPa.

**Weight-volume relations.** The volume of wet soil plus wax can be found by determining the apparent loss of weight when the body is wholly immersed in the water of known specific gravity, which is the weight of wet soil plus wax minus the weight of wet soil plus wax in water over the density of water at the recorded temperature. The volume of the wax can be obtained by the weight of wax over its specific gravity, which is 0.55. The equations for specific volume test are as follows:

\[
V_{\text{wet soil + wax}} = \frac{(W_{\text{wet soil + wax}}) - (W_{\text{wet soil + wax}})_{\text{in water}}}{d_{\text{water}}} \quad (4.5)
\]

\[
V_{\text{wax}} = \frac{W_{\text{wax}}}{0.55} \quad (4.6)
\]

\[
V_{\text{wet soil}} = V_{\text{wet soil + wax}} - V_{\text{wax}} \quad (4.7)
\]

\[
\gamma_{\text{dry}} = \frac{W_{\text{dry soil}}}{V_{\text{wet soil}}} \quad (4.8)
\]

\[
\text{Specific Volume} = \frac{1}{\gamma_{\text{dry}}} \quad (4.9)
\]

The specific volume can be used to determine the compressibility of a soil (α).
Water content. The actual water content in percentage is the difference in weight between the wet soil and the dry soil over the dry soil weight. The water contents determined in the final stage were compared to those prepared in the beginning of the test.

4.3 Soil Drying Rate Test

The purpose of this experiment was to investigate the environmental influence on the soil drying rate. The drying rate of a soil is defined as the amount of water loss (gram) within one unit of time (hour) in this study. An environmental chamber (incubator) was used to simulate the temperature and humidity conditions in Florida. Two groups of experiments were conducted. In the Group I tests, the samples were compacted at their optimum water content and the drying path was starting from the optimum water content. Four levels of temperature were selected from 0° to 40° (0°C, 10°C, 25°C, and 40°C) to cover the variation in temperature, to which the soil surface was subjected. Three levels of relative humidity (55%, 75%, and 95%) were chosen to represent the dry, normal, and wet weather through a year in the State of Florida. In the Group II tests, the soils were compacted at their optimum
water content plus 4.0 percent. Two levels of temperature (10°C and 25°C) and two levels of relative humidity (75% and 95%) were used. The soil drying rate test program is tabulated in Table 4.3.

4.3.1 Equipment

In order to simulate the variations of temperature and humidity in the State of Florida, a Reach-In Incubator, Model 3911, manufactured by Forma Scientific, Inc. was used as an environmental chamber in the drying rate test. The incubator has 11 cubic feet capacity and wide temperature ranges, heated or refrigerated. Its temperature range is from 0°C to 60°C (±0.3°C at temperature range from 25°C to 35°C) and the humidity range is above ambient to 95% ±5%. A controller of Watlow 982 Dual LED PID type microprocessor allows researchers to program the machine. A schematic view of the machine is shown in Figure 4.8.

4.3.2 Sample Preparation

The soils used for the drying rate test were the same as those used in the soil suction test. They were compacted using the modified Proctor compaction method at optimum water content for Group I tests. The maximum dry
density and the optimum water content were recorded. For Group II tests, soils were compacted at the water content of optimum plus 4.0 percent. The corresponding dry density for each soil was also recorded. The specimen size was 4-inch in diameter and 5-inch in height. The specimens were weighed before being placed in the environmental chamber.

4.3.3 Test Procedure

Six troublesome soils were compacted using the 4-in mold modified Proctor method with optimum conditions. As mentioned above, for the Group I tests, the samples were dried at their optimum water content until the drying rate (water loss per hour) was less than 0.05. For the Group II tests, soils were dried from optimum water content plus 4.0 percent to optimum water content minus 4.0 percent. The drying time depends on the range of the water content, and the temperature and humidity selected for each test. Usually it took about 7 to 10 days for the Group I tests and 4 to 7 days for the Group II tests. The drying rate versus time as well as water content was compared among the six problematic soils.

Initially, the proposed tests consisted of 12 sets (the combination of 4 levels of temperature and 3 levels of
humidity). Due to the limitation of the incubator, only seven sets out of the twelve combinations were achieved for the Group I test and 4 sets for the Group II test. For each test, the temperature and humidity were set at the desired level and allowed to reach equilibrium. The soil samples were then placed into the incubator immediately after removal from the compaction molds. The initial weight of each sample was recorded along with the time when sample was weighed. The measuring interval was increased as the water content decreased. Temperature and humidity at each measurement were also recorded to control the designated environmental condition.

Once the measurements of a set of temperature and humidity were done, the above steps were repeated for the remaining sets of temperature and humidity.

4.3.4 Data Reduction and Interpretation

The drying rate of each soil at different time can be obtained by dividing the difference in the weight by the elapsed time between two consecutive measurements and the sample surface area. The drying rate decreases as the elapsed time increases. The relation between the drying
rate and the elapsed time is shown in the following equation:

\[
\text{drying rate [gram/hr/ft}^2\text{]} = \frac{W_n - W_{n-1}}{(t_n - t_{n-1})A} \quad (4.10)
\]

where,

\(W_n\) = the weight of the \(n^{th}\) measurement, gram

\(W_{n-1}\) = the weight of the \((n-1)^{th}\) measurement, gram

\(t_n\) = the elapsed time of the \(n^{th}\) measurement, hour

\(t_{n-1}\) = the elapsed time of the \((n-1)^{th}\) measurement, hour

\(A\) = sample surface area exposed to air, \(ft^2\)

The average drying rate is the total water loss divided by the total elapsed time and the surface area. The equation can be written as the following:

\[
\text{average drying rate (gram/hr/ft}^2\text{)} = \frac{W_n - W_i}{(t_n - t_i)A} \quad (4.11)
\]

where,

\(W_n\) = the weight of the \(n^{th}\) measurement, gram

\(W_i\) = the weight of the initial measurements, gram
\( t_n = \) the elapsed time of the \( n^{th} \) measurement, hour

\( t_i = \) the elapsed time of the initial measurement, hour

\( A = \) sample surface area exposed to air, \( \text{ft}^2 \)

The effect of temperature and humidity on the drying rate was analyzed. The relation between water content and drying rate was also determined to correlate the soil suction with the drying rate of the soil.
<table>
<thead>
<tr>
<th>Soil Location</th>
<th>Series A</th>
<th></th>
<th>Series B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture content</td>
<td>Dry density</td>
<td>Moisture content</td>
<td>Dry density</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>kN/m$^3$</td>
<td>%</td>
<td>kN/m$^3$</td>
</tr>
<tr>
<td>Clay County</td>
<td>18.7</td>
<td>9.27</td>
<td>19.5</td>
<td>9.1</td>
</tr>
<tr>
<td>Madison County</td>
<td>19.1</td>
<td>9</td>
<td>19.1</td>
<td>8.6</td>
</tr>
<tr>
<td>Alford City</td>
<td>19.4</td>
<td>7.6</td>
<td>19.4</td>
<td>7.6</td>
</tr>
<tr>
<td>Jacobs Road</td>
<td>19.08</td>
<td>7.8</td>
<td>19.9</td>
<td>7.8</td>
</tr>
<tr>
<td>Brevard County</td>
<td>18.9</td>
<td>9.3</td>
<td>18.9</td>
<td>9.3</td>
</tr>
<tr>
<td>Marion County</td>
<td>19.4</td>
<td>9.3</td>
<td>19.4</td>
<td>9.3</td>
</tr>
<tr>
<td>Environmental condition</td>
<td></td>
<td>Lab temperature and humidity</td>
<td>Temperature : 25°C</td>
<td>Humidity : 75%</td>
</tr>
<tr>
<td>Calibration</td>
<td>Series A</td>
<td></td>
<td>Series B</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.2: Concentration of Sodium Chloride for Certain Levels of Relative Humidity

<table>
<thead>
<tr>
<th>Osmolality (mM/kg)</th>
<th>NaCl / 100 grams solution (gram)</th>
<th>Molality (M)</th>
<th>Relative Humidity (%)</th>
<th>Suction at 25 °C (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>290</td>
<td>0.9094</td>
<td>0.15704</td>
<td>99.47</td>
<td>725</td>
</tr>
<tr>
<td>500</td>
<td>1.571</td>
<td>0.55014</td>
<td>99.09</td>
<td>1250</td>
</tr>
<tr>
<td>1000</td>
<td>3.115</td>
<td>0.27283</td>
<td>98.19</td>
<td>2500</td>
</tr>
<tr>
<td>1800</td>
<td>5.463</td>
<td>0.88878</td>
<td>96.77</td>
<td>4500</td>
</tr>
</tbody>
</table>
Table 4.3 Summary of drying rate tests at different temperature and humidity

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Group I</th>
<th></th>
<th>Group II</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Humidity</td>
<td></td>
<td>Humidity</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>55%</td>
<td>75%</td>
<td>95%</td>
<td>75%</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>40</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Compaction</td>
<td></td>
<td>Optimum water content</td>
<td></td>
<td>Optimum water content plus 4 percent</td>
</tr>
<tr>
<td>condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


WESCOR Model C-52 Sample Chamber
0.5514 molal NaCl
25°C
(Water Potential = 25.2 bars)

Figure 4.2: Operational principle for both modes of Psychrometers
Figure 4.5: Sample chamber system for soil suction test

Figure 4.6: Soil suction test apparatus assembly
Figure 4.7: Schematic view of measuring system for Weight-Volume relation test
Figure 4.8: Schematic view of Reach-in Incubator, Model 3911
CHAPTER 5

PRESENTATION AND ANALYSIS OF SOIL SUCTION TEST

RESULTS

5.1 General

This chapter presents the soil suction test results from the experimental program described in Chapter 4. Calibration results of nine psychrometers are also presented. The soil suction test results are analyzed to investigate the suction values at different water content and to further correlate with other parameters such as the percent of fines, degree of saturation, and permeability. Factors affecting the suction test results are also discussed in this chapter.

5.2 Results of Psychrometer Calibration

Four different concentrations of sodium chloride were used to establish the calibration lines of nine psychrometers, i.e., 290, 500, 1000, and 1800 Osmolality, respectively. Each psychrometer was calibrated using two
pieces of filter papers (5.5 cm in diameter) saturated with 3 ml NaCl solution. Microvolt outputs, which are related to the humidity conditions inside the cans, were recorded at least 3 times a day after temperature equilibrium (deviations within ±0.5 microvolts).

Many factors contribute to the variation of the equilibrium time. The more concentrated the solution, the less time it takes to reach equilibrium. A change in psychrometer reading can occur as a result of changes in psychrometer sensitivity with temperature [Rawlins, 1966]. Thus, psychrometer calibrations are necessary for each temperature at which soil-water potential is measured if greater accuracy is required.

Since the soil suction test program had been conducted for longer than one year, the psychrometers were calibrated twice in order to meet the required measurement conditions for suction tests. Calibration A, which was performed in normal laboratory room temperature, was synchronized with the series A suction tests. Calibration B was performed inside an incubator where the series B suction tests were also performed. It was found that the time needed to reach equilibrium for Calibration B (4 to 7 days) was shorter than that for Calibration A, which was about 10 to 15 days.
There exists a relationship between water potential and the concentration of a solution as shown in Equation 5.1. For a 100 Osmolality Sodium Chloride, its water potential is 2.5 bar. The water potentials for 290, 500, 1000, and 1800 Osmolality can be calculated using the following equation:

\[
\text{WaterPotential[bar]} = -2.5 \times \frac{\text{concentration[osmolality]}}{100}
\]  

(5.1)

From the test results, it is apparent that the #7 psychrometer has the highest \( E_{25} \) value among the nine psychrometers. Microvolt outputs at measured temperatures were adjusted to the equivalent microvolts at 25°C (\( E_{25} \)). The average \( E_{25} \) values from the last three \( E_{25}s \) of each psychrometer for four different concentrations are shown in Tables B.1(a) through B.1(b). The data were used to build the calibration lines of nine psychrometers. The calibration lines of each psychrometer for Calibration A and B are shown in Figures B.1 through B.9. The equations obtained from the calibration lines are listed in Tables B.2(a) and B.2(b). All of the equations have the y-intercept less than zero, and a positive slope of the calibration line.
5.3 Presentation of Soil Suction Test Results

The final three microvolts readings for each test at temperature 25°C ($E_{25}$) were averaged and utilized to obtain the suction values at different water content. Two different suction units, kilopascal (kPa) and tons per square foot (tsf) were used in analysis. The test results, which include soil suction, water content, and specific volume, are illustrated in Tables 5.1(a) and 5.1(b) for the soil from Clay County. The relationship between soil suction and water content is illustrated in Figure 5.1 for the soil from Clay County. The complete detailed test results of each soil are presented in Appendix C. The soil suction test results for six soils (Scric A and Series B) are summarized in Tables 5.2(a) and 5.2(b). Only the results from Series B test are utilized for further analysis.

5.4 Analysis of Soil Suction Test Results

The primary objective of the soil suction test program in this study was to investigate the suction value at different water content and further correlate it with other soil parameters such as the percent of fines, degree of
saturation, permeability, and drying rate. As shown in Table 5.2, the suction values ranged from 0 kPa to 4000 kPa, which are relatively small as compared to the entire range of suction from 0 kPa to $10^6$ kPa [Fredlund, 1995]. For silty sands, the magnitudes of suction values from this study are reasonable.

5.4.1 Effect of Moisture Content

The suction test results shown in Table 5.2(b) indicate that while most of the soils possess low suction values (less than 665 kPa) when the soils are air-dried up to four hours from optimum water content, the soils from Clay County and Madison County have relatively high suction values (2262.95 kPa for Clay County soil and 3697.94 kPa for Madison County soil). Most of the data fell into the range of 100 kPa to 1000 kPa. The data from Series B tests were analyzed using exponential regression model and plotted in Figure 5.2 for all six soils. Figure 5.3 is a modification from Figure 5.2 by changing Y-axis from linear to logarithm scale so that the change of soil suction at lower values can be observed more clearly. The difference in soil suction among six soils at the wet side of optimum is relatively small as compared to those at the dry side.
It is shown in Figure 5.2 that the soil suction increases with a decrease in water content, and it increases sharply for dry soils with very little decrease in water content. The slope of the regression line for Clay County soil is the highest among the six soils while the one for Alford City has the lowest slope. This indicates that the suction value of Clay County soil is highly sensitive to the change of moisture. The suction–water content ($\tau$–$\omega$) relationships for the wet side of optimum behave differently from those for the dry side.

The suction values at optimum moisture content (OMC) are compared as shown in Figure 5.4. It shows that Madison County soil has the highest suction value at OMC. The suction values for the moisture range from optimum minus 4 to optimum plus 4 percent for the six soils are summarized in Table 5.3. The suction values at different water content for the six soils are presented in Table 5.4. The results show that Alford City soil has the lowest suction value among the six soils (168kPa to 405kPa). As shown in Figure 5.3, the regression lines for Clay County and Madison County soils have much higher slopes than those for the other soils. This may be a good indicator to explain the difference in behavior for these two soils.
5.4.2 Effect of Percent Fines

For soils with substantial clay fraction (greater than 15%), the interactions of the clay minerals with the pore fluid are expected to dominate the measured soil suction. The study by Acar (1992) demonstrated that the total suction in soil specimens compacted at their optimum water content may be estimated by a knowledge of the plasticity index of the soil. It can vary up to 20 times the atmospheric pressure only by the changes in the composition of the clay fraction. Similar to the swelling potential of fine-grained soils, the fine fraction and activity of the soil mixture define the total suction at optimum water content. Swelling potential is directly related to the total suction in soil by a factor dependent upon the activity of the soil mixture.

The suction values are plotted versus the percent of clay content as well as the percent of passing #200 sieve fines for the six soils at different water content in Figures 5.5 and 5.6, respectively. It is shown that the suction values vary significantly with water content when the percent of clay content is greater than 10, and the percent of passing #200 sieve fines is greater than 20. The
suction values can be limited within 100 to 3000 kPa with the percent of fines (\#200 sieve) less than 20.

5.4.3 Effect of Permeability

The suction value and the permeability at specific water content (at which the permeability was measured) for the six soils are summarized in Table 5.5. Figure 5.7 shows no significant evidence of any correlation between the soil suction and permeability for these soils. It may be due to the narrow range of suction values (from 100kPa to 500kPa). A wide range of suction values and the permeability values at unsaturated condition should be obtained in order to correlate suction and permeability of unsaturated soils.

5.4.4 Effect of Degree of Saturation

The effect of saturation on soil suction has often been of fundamental concern in groundwater flow. Soil suction has been demonstrated to increase from 100 kPa to 10 MPa by a decrease in the degree of saturation from 100% to 20% [Olson and Daniel, 1981]. Figures 5.8 and 5.9 illustrate the effect of degree of saturation on the soil suction value. There is basically no significant change in suction values when the degree of saturation falls into the
range of 95% to 70%. However, the suction values of Clay County and Madison County soils increase significantly by a decrease in the degree of saturation below 70%.

5.5 Presentation of Specific volume test results

Most clay soils increase in volume as the soil moisture content increases. Another way to state the generalization of clay soils is that soil volume decreases as soil suction increases and vise versa. Volume change for sand soils is not as significant as for clay soils. The results from the weight-volume tests are presented in Table 5.2 as with the suction test results. The values of the specific volume for each soil remain at the same level (within the range of 0.04 to 0.07) regardless of the water content. These values are extremely low as compared with those from high volume change soils.

5.6 Discussion on Factors Affecting Test Results

Many factors contributed to the deviation of the test results. The most significant one was the temperature fluctuation. The laboratory room temperature was not well controlled, and varied with the ambient temperature when the Series A was conducted. The fluctuation of temperature
resulted in unstable microvolts outputs and a longer equilibrium time. Therefore, the lower $R^2$ values for the Series A tests were obtained as a result. the situation was improved for the series B by using the environmental chamber for a better control of the temperature. Rawlings and Dalton [1967] pointed out that as air is heated, its water-holding capacity increases. This causes a decrease in relative humidity unless sufficient water enters the air during heating to compensate. In a sealed chamber where water vapor can neither enter nor leave, the error in water potential resulting from changes in temperature of the chamber would be very small. The error will be also less as the sample area increases relative to the chamber wall area, and will be the least for the ideal psychrometer where the junction is completely surrounded by the sample and heat flow to and from the junction is restricted to conduction through air.

The concentration of the calibration solution for psychrometers is very important and it needs to be made accurately. The more concentrated the solution, the more accurate the calibration will result. When measuring extremely low soil suction, a more soluble calibrating solute than NaCl or KCl is needed.
The water distribution of each specimen is also a factor of test error. A wider range of water content is needed to cover the wet and dry conditions when high accuracy is required. The regression model needs more data points to achieve a higher confidence level. As shown in Tables 5.2(a) and 5.2(b), most regression curves have $R^2$ values between 0.7 and 0.9.
Table 5.1(a): Summary of soil suction, water content, and specific volume test results for Clay County Soil

<table>
<thead>
<tr>
<th>Series A</th>
<th>Dry density: 18.7 kN/m³</th>
<th>Water content: 9.27%</th>
</tr>
</thead>
</table>

A. Soil Suction Test

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>9B</th>
<th>8</th>
<th>7</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample container No.</td>
<td>63</td>
<td>63</td>
<td>52</td>
<td>50</td>
<td>61</td>
<td>61</td>
<td>58</td>
<td>55</td>
<td>54</td>
</tr>
<tr>
<td>Water content Increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>0.5ml</td>
<td>N</td>
<td>N</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>$E_{2s}$. Microvolts*</td>
<td>23.85</td>
<td>13.87</td>
<td>5.39</td>
<td>3.10</td>
<td>2.90</td>
<td>2.83</td>
<td>2.83</td>
<td>3.40</td>
<td>3.66</td>
</tr>
<tr>
<td>Soil Suction, Tons/ft² (ps)</td>
<td>37.83</td>
<td>15.21</td>
<td>4.55</td>
<td>2.75</td>
<td>2.65</td>
<td>2.69</td>
<td>2.71</td>
<td>2.57</td>
<td>3.35</td>
</tr>
<tr>
<td>Soil Suction, kPa (σ)</td>
<td>3619.63</td>
<td>1551.21</td>
<td>435.20</td>
<td>263.09</td>
<td>254.03</td>
<td>252.25</td>
<td>258.90</td>
<td>245.53</td>
<td>320.58</td>
</tr>
</tbody>
</table>

B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>332.5</th>
<th>350.45</th>
<th>368.3</th>
<th>376.5</th>
<th>378.8</th>
<th>372.3</th>
<th>371.5</th>
<th>361.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tare Plus Dry Soil Water (Wₐ)</td>
<td>326.2</td>
<td>342</td>
<td>357.8</td>
<td>364.59</td>
<td>364.7</td>
<td>363.29</td>
<td>359.2</td>
<td>358</td>
<td>369.9</td>
</tr>
<tr>
<td>Water (Wₐ)</td>
<td>3.3</td>
<td>6.45</td>
<td>10.5</td>
<td>11.91</td>
<td>11.92</td>
<td>12.01</td>
<td>12.3</td>
<td>13.7</td>
<td>16</td>
</tr>
<tr>
<td>Tare</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
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<td></td>
</tr>
<tr>
<td>Dry Soil (Wₐ)</td>
<td>89.1</td>
<td>104.9</td>
<td>120.7</td>
<td>127.49</td>
<td>127.6</td>
<td>123.2</td>
<td>122.1</td>
<td>130.9</td>
<td>132.8</td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>7.07%</td>
<td>8.36%</td>
<td>8.70%</td>
<td>9.34%</td>
<td>9.34%</td>
<td>9.75%</td>
<td>10.37%</td>
<td>10.47%</td>
<td>12.05%</td>
</tr>
</tbody>
</table>

C. Specific Volume

<table>
<thead>
<tr>
<th>Test Temperature of Water (°C)</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>135.6</td>
<td>148.2</td>
<td>160.5</td>
<td>166.7</td>
<td>164</td>
<td>168.7</td>
<td>151.5</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
<td>132.1</td>
<td>142.5</td>
<td>143.4</td>
<td>147.6</td>
<td>148.3</td>
<td>155.1</td>
<td>147.4</td>
<td>148</td>
</tr>
<tr>
<td>Wax</td>
<td>3.5</td>
<td>5.7</td>
<td>17.1</td>
<td>13.1</td>
<td>17.1</td>
<td>17.7</td>
<td>13.6</td>
<td>17.1</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
<td>34.4</td>
<td>39.5</td>
<td>38.5</td>
<td>42</td>
<td>38</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Dry Soil (Wₐ)</td>
<td>123.38</td>
<td>131.88</td>
<td>131.92</td>
<td>134.99</td>
<td>133.8</td>
<td>141.32</td>
<td>133.91</td>
<td>133.98</td>
</tr>
<tr>
<td>Volume in CC</td>
<td>Wet soil and Wax</td>
<td>101.2</td>
<td>108.7</td>
<td>122</td>
<td>124.7</td>
<td>126</td>
<td>129.7</td>
<td>112.5</td>
</tr>
<tr>
<td>Wet Soil (V)</td>
<td>6.36</td>
<td>10.36</td>
<td>31.09</td>
<td>34.73</td>
<td>32.18</td>
<td>24.73</td>
<td>7.45</td>
<td>31.09</td>
</tr>
<tr>
<td>Wax</td>
<td>94.84</td>
<td>98.34</td>
<td>90.91</td>
<td>86.97</td>
<td>93.82</td>
<td>104.97</td>
<td>105.05</td>
<td>95.01</td>
</tr>
<tr>
<td>Density KN/m³</td>
<td>Wet Density ($\gamma_m$) = (W/V)*9.3</td>
<td>16.55</td>
<td>14.20</td>
<td>15.46</td>
<td>16.08</td>
<td>15.28</td>
<td>14.48</td>
<td>13.75</td>
</tr>
<tr>
<td>Specific Volume ($\gamma_d$)</td>
<td>0.076</td>
<td>0.076</td>
<td>0.070</td>
<td>0.068</td>
<td>0.072</td>
<td>0.076</td>
<td>0.080</td>
<td>0.072</td>
</tr>
</tbody>
</table>

* $E_{2s}$ was calculated by averaging the last three readings from soil suction test results.
### Table 5.1(b): Summary of soil suction, water content, and specific volume test results for Clay County soil

#### A. Soil Suction Test

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample container No.</td>
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<td>55</td>
<td>55</td>
<td>63</td>
<td>61</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Water content increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E25 Microwatts*</td>
<td>18.87</td>
<td>16.62</td>
<td>11.03</td>
<td>8.03</td>
<td>6.81</td>
<td>3.70</td>
<td>2.79</td>
<td>2.75</td>
<td>2.77</td>
</tr>
<tr>
<td>Soil Suction, Tons/ft2 (s)</td>
<td>23.65</td>
<td>19.39</td>
<td>13.61</td>
<td>9.30</td>
<td>7.57</td>
<td>3.78</td>
<td>1.19</td>
<td>1.14</td>
<td>1.13</td>
</tr>
<tr>
<td>Soil Suction, kPa (s)</td>
<td>2262.95</td>
<td>1855.44</td>
<td>1302.47</td>
<td>890.26</td>
<td>724.32</td>
<td>362.07</td>
<td>114.06</td>
<td>106.95</td>
<td>106.17</td>
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#### B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>27.9</th>
<th>268</th>
<th>258.8</th>
<th>248.4</th>
<th>246.1</th>
<th>257.7</th>
<th>271.7</th>
<th>246.5</th>
<th>253.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tare Plus Dry Soil</td>
<td>262.2</td>
<td>257.9</td>
<td>249.1</td>
<td>240.3</td>
<td>236.9</td>
<td>247.7</td>
<td>259.8</td>
<td>235.8</td>
<td>240.6</td>
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</tr>
<tr>
<td>Water (Ww)</td>
<td>9.7</td>
<td>10.1</td>
<td>9.7</td>
<td>9.1</td>
<td>9.2</td>
<td>10</td>
<td>11.9</td>
<td>10.7</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>Tare</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.1</td>
<td></td>
</tr>
<tr>
<td>Dry Soil (Wt)</td>
<td>128</td>
<td>123.7</td>
<td>114.9</td>
<td>106.1</td>
<td>104.7</td>
<td>112.5</td>
<td>125.6</td>
<td>101.7</td>
<td>106.5</td>
<td></td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>7.58%</td>
<td>8.16%</td>
<td>8.44%</td>
<td>8.58%</td>
<td>8.79%</td>
<td>8.81%</td>
<td>9.47%</td>
<td>10.52%</td>
<td>11.92%</td>
<td></td>
</tr>
</tbody>
</table>

#### C. Specific Volume

<table>
<thead>
<tr>
<th>Test Temperature of Water (°C)</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>162.4</td>
<td>152.4</td>
<td>142.57</td>
<td>132.65</td>
<td>131.4</td>
<td>137.53</td>
<td>154.35</td>
<td>126.65</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
<td>139.97</td>
<td>142.88</td>
<td>125.5</td>
<td>115.89</td>
<td>114.5</td>
<td>124.5</td>
<td>138.19</td>
<td>112.9</td>
<td>119.25</td>
</tr>
<tr>
<td>Wax</td>
<td>23.43</td>
<td>10.52</td>
<td>17.87</td>
<td>16.76</td>
<td>16.9</td>
<td>13.03</td>
<td>16.16</td>
<td>13.75</td>
<td>16.35</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
<td>45.1</td>
<td>55.4</td>
<td>44.29</td>
<td>39.31</td>
<td>39.78</td>
<td>44.5</td>
<td>51.77</td>
<td>36.7</td>
<td>40.12</td>
</tr>
<tr>
<td>Dry Soil (Wht)</td>
<td>129.18</td>
<td>132.09</td>
<td>115.73</td>
<td>106.74</td>
<td>105.25</td>
<td>114.42</td>
<td>126.23</td>
<td>102.15</td>
<td>106.54</td>
</tr>
<tr>
<td>Volume in C2</td>
<td>Wet soil and Wax</td>
<td>117.3</td>
<td>96</td>
<td>98.28</td>
<td>93.34</td>
<td>91.62</td>
<td>93.03</td>
<td>102.58</td>
<td>87.95</td>
</tr>
<tr>
<td>Wax</td>
<td>42.6</td>
<td>19.13</td>
<td>31.64</td>
<td>30.47</td>
<td>30.73</td>
<td>23.69</td>
<td>29.38</td>
<td>25.00</td>
<td>29.73</td>
</tr>
<tr>
<td>Wet Soil (V)</td>
<td>74.7</td>
<td>78.87</td>
<td>67.24</td>
<td>62.87</td>
<td>60.69</td>
<td>69.34</td>
<td>73.30</td>
<td>62.95</td>
<td>65.75</td>
</tr>
<tr>
<td>Wet Density (W/V) = (W/V)*9.8</td>
<td>18.23</td>
<td>17.75</td>
<td>18.29</td>
<td>18.07</td>
<td>18.43</td>
<td>17.60</td>
<td>18.50</td>
<td>17.58</td>
<td>17.77</td>
</tr>
<tr>
<td>Dry Density (ρd) = (W/V)*9.6</td>
<td>16.95</td>
<td>16.41</td>
<td>16.87</td>
<td>16.64</td>
<td>16.64</td>
<td>16.17</td>
<td>16.90</td>
<td>15.90</td>
<td>15.88</td>
</tr>
<tr>
<td>Specific Volume (V) = 1/ρd</td>
<td>0.059</td>
<td>0.061</td>
<td>0.059</td>
<td>0.060</td>
<td>0.059</td>
<td>0.062</td>
<td>0.059</td>
<td>0.063</td>
<td>0.063</td>
</tr>
</tbody>
</table>

* E25 was calculated by averaging the last three readings from soil suction test results.
Table 5.2(a): Summary of soil suction test results for six soils (Series A)

<table>
<thead>
<tr>
<th>Psychrometer Number Cooling Coefficient</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water status</td>
<td>4hr*</td>
<td>2hr</td>
<td>1hr</td>
<td>N**</td>
<td>N</td>
<td>2.5ml***</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
<td></td>
</tr>
<tr>
<td>Clay County</td>
<td>12.05%</td>
<td>10.47%</td>
<td>10.07%</td>
<td>9.34%</td>
<td>9.34%</td>
<td>9.75%</td>
<td>8.70%</td>
<td>8.06%</td>
<td>7.07%</td>
<td>0.5849</td>
</tr>
<tr>
<td>suction (kPa)</td>
<td>320.58</td>
<td>245.53</td>
<td>258.00</td>
<td>263.09</td>
<td>254.03</td>
<td>257.25</td>
<td>435.20</td>
<td>151.21</td>
<td>3619.63</td>
<td></td>
</tr>
<tr>
<td>specific volume</td>
<td>0.070</td>
<td>0.072</td>
<td>0.080</td>
<td>0.088</td>
<td>0.072</td>
<td>0.076</td>
<td>0.070</td>
<td>0.076</td>
<td>0.078</td>
<td></td>
</tr>
<tr>
<td>Madison County</td>
<td>11.54%</td>
<td>10.28%</td>
<td>9.66%</td>
<td>9.27%</td>
<td>8.89%</td>
<td>8.95%</td>
<td>8.18%</td>
<td>7.67%</td>
<td>6.49%</td>
<td>0.7418</td>
</tr>
<tr>
<td>suction (kPa)</td>
<td>229.94</td>
<td>273.54</td>
<td>306.50</td>
<td>325.94</td>
<td>329.21</td>
<td>326.21</td>
<td>572.21</td>
<td>599.21</td>
<td>3211.14</td>
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<tr>
<td>specific volume</td>
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<td>0.069</td>
<td>0.038</td>
<td>0.069</td>
<td>0.066</td>
<td>0.068</td>
<td>0.067</td>
<td>0.069</td>
<td>0.066</td>
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</tr>
<tr>
<td>Aford City</td>
<td>4.41%</td>
<td>5.57%</td>
<td>6.74%</td>
<td>7.46%</td>
<td>7.41%</td>
<td>7.50%</td>
<td>7.91%</td>
<td>8.55%</td>
<td>10.20%</td>
<td>0.7535</td>
</tr>
<tr>
<td>suction (kPa)</td>
<td>360.59</td>
<td>314.94</td>
<td>280.52</td>
<td>306.32</td>
<td>315.36</td>
<td>315.10</td>
<td>258.10</td>
<td>286.9</td>
<td>237.57</td>
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</tr>
<tr>
<td>specific volume</td>
<td>0.056</td>
<td>0.057</td>
<td>0.056</td>
<td>0.053</td>
<td>0.054</td>
<td>0.058</td>
<td>0.057</td>
<td>0.055</td>
<td>0.056</td>
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</tr>
<tr>
<td>Jacobs Road</td>
<td>4.30%</td>
<td>5.41%</td>
<td>6.11%</td>
<td>7.07%</td>
<td>7.10%</td>
<td>7.73%</td>
<td>7.94%</td>
<td>9.60%</td>
<td>11.30%</td>
<td>0.6172</td>
</tr>
<tr>
<td>suction (kPa)</td>
<td>460.15</td>
<td>191.62</td>
<td>354.78</td>
<td>110.69</td>
<td>258.70</td>
<td>229.53</td>
<td>196.66</td>
<td>148.38</td>
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<tr>
<td>specific volume</td>
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<td>0.064</td>
<td>0.065</td>
<td>0.062</td>
<td>0.064</td>
<td>0.064</td>
<td>0.066</td>
<td>0.067</td>
<td>0.065</td>
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</tr>
<tr>
<td>Brevard County</td>
<td>6.17%</td>
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<td>7.75%</td>
<td>9.05%</td>
<td>9.03%</td>
<td>9.55%</td>
<td>10.13%</td>
<td>10.57%</td>
<td>12.00%</td>
<td>0.7028</td>
</tr>
<tr>
<td>suction (kPa)</td>
<td>586.14</td>
<td>401.17</td>
<td>444.61</td>
<td>259.27</td>
<td>213.13</td>
<td>251.22</td>
<td>241.26</td>
<td>46.69</td>
<td>102.71</td>
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<tr>
<td>specific volume</td>
<td>0.058</td>
<td>0.058</td>
<td>0.060</td>
<td>0.055</td>
<td>0.057</td>
<td>0.059</td>
<td>0.057</td>
<td>0.057</td>
<td>0.056</td>
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</tr>
<tr>
<td>Marion County</td>
<td>5.76%</td>
<td>7.57%</td>
<td>8.33%</td>
<td>8.92%</td>
<td>9.06%</td>
<td>9.25%</td>
<td>9.43%</td>
<td>11.18%</td>
<td>12.15%</td>
<td>0.8653</td>
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<td>suction (kPa)</td>
<td>647.73</td>
<td>425.33</td>
<td>435.30</td>
<td>424.86</td>
<td>343.47</td>
<td>325.94</td>
<td>205.79</td>
<td>141.37</td>
<td>14.48</td>
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</tr>
<tr>
<td>specific volume</td>
<td>0.054</td>
<td>0.057</td>
<td>0.055</td>
<td>0.054</td>
<td>0.057</td>
<td>0.058</td>
<td>0.056</td>
<td>0.058</td>
<td>0.056</td>
<td></td>
</tr>
</tbody>
</table>

* 4hr indicates that soil had been air-dried for 4 hours after removal from compaction mold.
** N represents natural condition which is at its optimum water content.
*** 0.5 ml means that the soil was wetted by adding 0.5 ml distilled water after removal from compaction mold.
Table 5.2(b): Summary of soil suction test results for six soils (Series B)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>8B</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrometer Number</td>
<td>54</td>
<td>55</td>
<td>58</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Cooling Coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water status</td>
<td>4hr*</td>
<td>2hr</td>
<td>1hr</td>
<td>N**</td>
<td>N</td>
<td>0.5ml***</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
<td></td>
</tr>
<tr>
<td>Clay County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water content</td>
<td>7.58%</td>
<td>8.16%</td>
<td>8.44%</td>
<td>8.58%</td>
<td>8.79%</td>
<td>8.81%</td>
<td>9.47%</td>
<td>10.52%</td>
<td>11.92%</td>
<td>0.7569</td>
</tr>
<tr>
<td>Suction (kPa)</td>
<td>2262.95</td>
<td>1955.44</td>
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<td>890.26</td>
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<td>0.069</td>
<td>0.061</td>
<td>0.059</td>
<td>0.060</td>
<td>0.059</td>
<td>0.062</td>
<td>0.062</td>
<td>0.063</td>
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<tr>
<td>Madison County</td>
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<td></td>
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<tr>
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<td>5.60%</td>
<td>7.13%</td>
<td>7.69%</td>
<td>8.12%</td>
<td>8.40%</td>
<td>8.77%</td>
<td>9.14%</td>
<td>9.78%</td>
<td>11.27%</td>
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<td>420.70</td>
<td>556.84</td>
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<tr>
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<td>Water content</td>
<td>4.32%</td>
<td>5.82%</td>
<td>7.06%</td>
<td>7.52%</td>
<td>7.40%</td>
<td>7.75%</td>
<td>8.08%</td>
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<td>10.40%</td>
<td>0.8339</td>
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<td>223.26</td>
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<td>261.03</td>
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<td>0.061</td>
<td>0.061</td>
<td>0.061</td>
<td>0.063</td>
<td>0.061</td>
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<td></td>
<td></td>
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<tr>
<td>Water content</td>
<td>6.53%</td>
<td>7.71%</td>
<td>8.29%</td>
<td>8.93%</td>
<td>8.81%</td>
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<td>429.18</td>
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<td>0.057</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Water content</td>
<td>6.31%</td>
<td>7.60%</td>
<td>8.36%</td>
<td>9.20%</td>
<td>9.20%</td>
<td>9.34%</td>
<td>9.78%</td>
<td>10.59%</td>
<td>11.99%</td>
<td>0.9023</td>
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<td>Suction (kPa)</td>
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<td>0.055</td>
<td>0.057</td>
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</tbody>
</table>

* 4hr indicates that soil had been air-dried for 4 hours after removal from compaction mold.
** N represents natural condition which is at its optimum water content.
*** 0.5 ml means that the soil was wetted by adding 0.5 ml distilled water after removal from compaction mold.
Table 5.3: Soil suction values at different water content for six soils (Series B)

<table>
<thead>
<tr>
<th>Soils</th>
<th>Calibration Equations</th>
<th>Water content, ( \omega ) [%]</th>
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<tr>
<td></td>
<td></td>
<td>OMC-4%</td>
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<tr>
<td>Clay County</td>
<td>( \tau = 8.228E5 \times \exp(-0.8117 \omega) )</td>
<td>13106</td>
</tr>
<tr>
<td>Madison County</td>
<td>( \tau = 3.181E4 \times \exp(-0.5039 \omega) )</td>
<td>3294</td>
</tr>
<tr>
<td>Alford City</td>
<td>( \tau = 600.9 \times \exp(-0.1097 \omega) )</td>
<td>405</td>
</tr>
<tr>
<td>Jacobs Road</td>
<td>( \tau = 1250 \times \exp(-0.1668 \omega) )</td>
<td>652</td>
</tr>
<tr>
<td>Brevard County</td>
<td>( \tau = 1149 \times \exp(-0.1026 \omega) )</td>
<td>670</td>
</tr>
<tr>
<td>Marion County</td>
<td>( \tau = 2622 \times \exp(-0.2287 \omega) )</td>
<td>780</td>
</tr>
</tbody>
</table>

Notes: \( \tau \) = soil suction in kPa  
\( \omega \) = water content
Table 5.4: Soil suction values at different water content for six soils (Series B)

<table>
<thead>
<tr>
<th>Soils</th>
<th>Calibration Equations</th>
<th>Soil suction value at different water content, $\tau$ [kPa]</th>
<th>Water content, $\omega$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>Clay County</td>
<td>$\tau = 8.228E5*\text{EXP}(-0.8117\omega)$</td>
<td>822800</td>
<td>108144</td>
</tr>
<tr>
<td>Madison County</td>
<td>$\tau = 3.181E4*\text{EXP}(-0.5039\omega)$</td>
<td>31810</td>
<td>9025</td>
</tr>
<tr>
<td>Alford City</td>
<td>$\tau = 600.9*\text{EXP}(-0.1097\omega)$</td>
<td>601</td>
<td>457</td>
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<tr>
<td>Jacobs Road</td>
<td>$\tau = 1250*\text{EXP}(-0.1668\omega)$</td>
<td>1250</td>
<td>824</td>
</tr>
<tr>
<td>Brevard County</td>
<td>$\tau = 1149*\text{EXP}(-0.1026\omega)$</td>
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<td>889</td>
</tr>
<tr>
<td>Marion County</td>
<td>$\tau = 2622*\text{EXP}(-0.2287\omega)$</td>
<td>2622</td>
<td>1480</td>
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</tbody>
</table>

Note: $\tau$ = soil suction in kPa
$\omega$ = water content
$+^*$ the value represents the actual water content @ OMC
Table 5.5: Summary of permeability and suction values for six soils

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Water content [%]</th>
<th>Average permeability [$10^{-6}$ cm/sec]</th>
<th>Suction [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Clay County</td>
<td>9.40</td>
<td>29.3</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>Madison County</td>
<td>9.73</td>
<td>1.3</td>
<td>236</td>
</tr>
<tr>
<td>3</td>
<td>Alford City</td>
<td>7.20</td>
<td>3.8</td>
<td>273</td>
</tr>
<tr>
<td>3</td>
<td>Jacobs Road</td>
<td>7.83</td>
<td>58.4</td>
<td>339</td>
</tr>
<tr>
<td>5</td>
<td>Brevard County</td>
<td>10.15</td>
<td>50.8</td>
<td>406</td>
</tr>
<tr>
<td>5</td>
<td>Marion County</td>
<td>9.60</td>
<td>12.9</td>
<td>292</td>
</tr>
</tbody>
</table>
Soil Suction vs Water Content
(Clay County)

Passing #200 fines = 27.5%, Clay content = 24%

OMC = 9.1%

Figure 5.1: Comparison of suction values from Series A and Series B for Clay County soil
Figure 5.2: Soil suction values at different water content for six soils (Series B)
Soil Suction vs Water Content

(Series B)

Figure 5.3: Soil suction values at different water content for six soils (Series B, Semi-log scale)
Figure 5.4: Comparison of suction values at optimum water content from Series A and Series B for six soils.
Figure 5.5: Relationship between soil suction and percent of clay content for different water content (Series B)
Figure 5.6: Relationship between soil suction and percent of passing #200 fines for different water content (Series B).
Figure 5.7: Relationship between soil suction and permeability for six soils (Series B)
Figure 5.8: Soil suction values at different degree of saturation for six soils (Series B)
Figure 5.9: Soil suction values at different degree of saturation for six soils (Series B, Semi-log scale)
CHAPTER 6

PRESENTATION AND ANALYSIS OF DRYING RATE TEST

RESULTS

6.1 General

The soils were tested to investigate the drying rate under different environmental conditions. During the drying rate test, soil weight was measured approximately every 4 hours in the first 24 hours, and then the measuring interval was gradually increased to avoid the measurement error due to the smaller amount of water loss and the accuracy of the measuring scale. The temperature and humidity inside the incubator were recorded at the time when the weight of the soil was measured. The measured soil weight data were further converted to the loss in water for each time interval. The accumulated water loss was calculated as well as the water content for each measurement. Finally the soil drying rates were determined from the measurements. The drying rate test results are presented and analyzed in this chapter.
6.2 Presentation of Soil Drying Rate Test Results

Two groups of test results from the drying rate experiment are presented in this section. The soil drying rate basically follows the logarithmic trend of decreasing drying rate versus the elapsed time.

6.2.1 Group I test results

For Group I tests, the soil samples were dried from optimum water content to the desired water content. The measured soil weight data are summarized in Table 6.1. The recorded weight and time interval are further developed in terms of water loss, water content, and drying rate as shown in Tables 6.2(a) through 6.2(f) for the six soils, respectively. The drying characteristics of the six soils under the condition of 25°C temperature and 75% relative humidity are presented in Table 6.3 for further analysis. Table 6.4 summarizes the accumulated water loss within 200 hours for the six soils under different conditions. Detailed data concerning the Group I test results are presented in Appendix D.

The accumulated water loss versus elapsed time for the six soils are illustrated in Figure 6.1. The changes of water content with the elapsed time are shown in Figure
6.2. The changes of drying rate with the corresponding water content are shown in Figure 6.3. Tables and figures for the complete group I test results are presented in Appendix D in detail.

6.2.2 Group II test results

For Group II tests, the soil samples were dried from a wet condition in which the water content was at optimum water content plus 4 percent. The water evaporation characteristics of the Group II tests were different from the optimum water content to the dry side. The soil drying data (Group II) are summarized in Table 6.5. The recorded weight and time interval are further developed in terms of water loss, water content, and drying rate as shown in Tables 6.6(a) through 6.6(f) for the six soils, respectively. The drying characteristics of the six soils under the condition of 25°C temperature and 75% relative humidity are presented in Table 6.7 for further analysis. The accumulated water loss within the first 24, 48, 72, 90, and 200 hours for the six soils under various conditions are summarized in Table 6.8(a), (b), (c), (d), and (e), respectively. The Group II test results are presented in Appendix E in detail.
The accumulated water loss versus elapsed time for the six soils is shown in Figure 6.4. The changes of water content with the elapsed time are shown in Figure 6.5. The changes of drying rate with the corresponding water content are illustrated in Figure 6.6. Tables and figures for the complete Group II test results at various levels of temperature and relative humidity are presented in Appendix E in detail.

6.3 Analysis of Soil Drying Rate Test Results

The factors affecting the soil drying rate, such as drying time, water content, temperature and relative humidity, percent of clay content and percent of passing #200 sieve, are discussed in this section. The water content for the Group I test covers the range from optimum water content down to almost dry condition, while the range of water content is from optimum water content plus 4 percent to optimum water content minus 4 percent for the Group II test.

6.3.1 Effect of water content

As shown in Figure 6.1, for Group I tests, the water evaporates quickly at the beginning for all six soils, and
then the rate of water loss levels off after drying for several days. It is also shown that the drying rate for the Clay County soil continues to dry even at the end of the drying period. As shown in Figure 6.2, the water content of the soils decreases rapidly at the beginning and the Marion County soil ceases to dry at a relatively higher water content (slightly over 3 percent) after a few days of drying. The water content of the soils other than the Marion County retains within the range of 2 percent to 1 percent. The drying rate versus water content is shown in Figure 6.3 and the Alford City soil has the highest drying rate whereas the Marion County soil has the lowest drying rate for the range of water content less than 8 percent.

As shown in Figures 6.4 and 6.5, the rate of water loss and the corresponding water content level for Group II tests have similar trend as found in Figures 6.1 and 6.2. However, as shown in Figure 6.6, the relationship between the drying rate and water content is different from that in Figure 6.3 when the soil water content is higher than the optimum water content (8-9 percent). The Clay County soil has the lowest drying rate at a water content higher than 8 percent, and the Marion County soil has the lowest drying rate at a water content lower than 7 percent. Similarly as
for the Group I test, the Alford City soil has the highest drying rate overall for the Group II test.

The evaporation rate data are summarized in Table 6.4 for the Group I test results at different environmental conditions. It is shown in Table 6.4 that the Clay County soil lost the highest amount of water while the Marion County soil evaporated the least amount of water within a certain period of time. Apparently, the Marion County soil has the lowest average drying rate while the Clay County soil appears to have the highest average drying rate. Figure 6.7 shows the comparison of the average drying rate within first 200 hours for the Group I test at temperature 25°C and 75% relative humidity. The drying rate for both Group I and Group II tests in a 90-hour period of elapsed time are compared in Figure 6.8.

The drying rates for Group I and Group II tests for each soil type are different at the identical water content under either the dry or wet condition. The drying rates at optimum water content for the two groups are compared in Figure 6.9 at temperature 25°C and 75% relative humidity. As shown in Figure 6.9, the average drying rate from the Group II test is lower than that from the Group I test for the same moisture condition. This is probably due to the
difference in moisture distribution at the surface of the tested specimen. For instance, at optimum water content, the surface of the cylindrical soil from the Group II test was drier than that from the Group I test, which was still saturated with water immediately after compaction.

6.3.2 Effect of temperature and relative humidity

The influence of temperature and relative humidity on the drying rate are demonstrated in Figures 6.10, 6.11, and 6.12 for the Clay County soil from the Group I tests. It is shown that the drying curves at 95% relative humidity are very different from those at 55% and 75% relative humidities. When the relative humidity is either 55% or 75%, the accumulated water loss increases rapidly with time at the early stage, and it increases with an increase in temperature. Thus, large differences in water evaporation are found at the early drying stage in a couple of days. When the relative humidity is up to 95%, the accumulated water loss is not much influenced by the temperature, and it increases slowly with time. The drying curves for the Group II tests are shown in Figures 6.13, 6.14, and 6.15 for the Clay County soil, and the trend is similar with the Group I test results.
Considering the effect of the relative humidity as illustrated in Figures 6.16 and 6.17 for the Group I and Group II tests, respectively, it is apparent that the relative humidity has much stronger effect on the soil drying rate than the temperature. It also indicates that extremely humid weather condition reduces the evaporation of soil water significantly regardless of the temperature. Another observation is that the difference in the accumulated water loss due to the effect of relative humidity becomes more significant when the temperature is higher. It indicates that, in the severe humid environment, higher temperature tends to prevent water from evaporating.

The objective of the Group II drying rate tests is to compare the drying time from the wet side of optimum water content to optimum water content for the six soils. The drying time data are summarized in Table 6.9(a), (b), (c), and (d) at different environmental conditions. The comparison of the drying time needed to dry from optimum water content plus 4, 3, 2, and 1 percent to optimum water content for the six soils at different environmental conditions are illustrated in Figures 6.18, 6.19, 6.20, and 6.21, respectively. It is shown that at 75% relative
humidity, the Marion County soil is taken the shortest time to reach the optimum water content, while the Clay County soil is taken the longest time. When the relative humidity is up to 95%, the Alford City soil is taken the shortest time to reach the optimum water content. The difference in drying time between 10°C and 25°C at 75% relative humidity is greater than that at 95% relative humidity. The effect of temperature becomes insignificant when the relative humidity is greater than about 90%.

6.3.3 Effect of percent of clay content and passing #200 fines

The effect of the percent of clay content on the drying time is presented in Figure 6.22. Basically, the drying time increases gradually with an increase in the percent of clay content. At temperature 25°C, the drying time at 95% relative humidity is about 4 times higher than that at 75% relative humidity for the same percent of clay content. The trend for the soils to dry from optimum water content plus 4 percent to optimum water content versus the percent of fines is shown in Figures 6.23. Although the data are scattered, the drying time increases with an increase in the percent of passing #200 fines.
6.4 Discussion on Factors Affecting Drying Rate Test Result

There were two minor problems observed when the drying rate tests were performed. The relative locations of the soil samples inside the environmental chamber were different when the six samples were placed and tested simultaneously. This resulted in different airflow impact inside the chamber to which the six soil samples were subjected. The other problem was that the digital weighing scale was only significant to one decimal point. This could cause an error in reading when the weight loss was less than 0.1 gram. The data points at the drier conditions (water content less than 2%) should be taken with caution for possible measurement errors.

There is also a practical limitation in using the Reach-In Incubator (Model 3911). The chamber cannot be operated with extremely high relative humidity and high temperature or with low relative humidity and low temperature. Therefore, the drying rates of the soils at the extreme environmental conditions (e.g., very humid with high temperature) are not included in this study.
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<td>1.13</td>
<td>0.06</td>
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<th></th>
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<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
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<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>19.9</td>
<td>19.9</td>
<td>20.2</td>
<td>19.9</td>
<td>19.9</td>
<td>18.8</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>9.15</td>
<td>8.50</td>
<td>7.90</td>
<td>7.60</td>
<td>9.30</td>
<td>9.25</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>172.30</td>
<td>163.15</td>
<td>153.53</td>
<td>145.21</td>
<td>178.23</td>
<td>167.03</td>
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<tr>
<td>Total elapsed time [hour]</td>
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<td>230.33</td>
<td>253.82</td>
<td>250.48</td>
<td>340.10</td>
<td>236.45</td>
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<tr>
<td>Total water loss [gram]</td>
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<td>125.20</td>
<td>119.30</td>
<td>129.30</td>
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**Average drying rate, [gram per hour per ft²]**

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<th>Within first 90 hours</th>
<th>Within first 200 hours</th>
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<td>3.08</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>1.54</td>
<td>1.26</td>
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</table>

**Drying rate, [gram per hour per ft²]**

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<th>0.27</th>
<th>0.67</th>
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<th>-</th>
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<td>-</td>
<td>-</td>
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<td>9.20</td>
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<tr>
<td>@ optimum water content</td>
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<td>10.27</td>
<td>10.27</td>
<td>12.32</td>
<td>9.04</td>
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Table 5.4(a): Water evaporation within 90 hours for six soils (Group I)

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<th>% Clay</th>
<th>% - #200</th>
<th>Weight of evaporated water within 90 hour at different conditions, [gram]</th>
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<tr>
<td></td>
<td>(%)</td>
<td>(%)</td>
<td>0°C</td>
</tr>
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<td></td>
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<td>95% R.H.</td>
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<td>24</td>
<td>27.5</td>
<td>90.7</td>
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<td>20</td>
<td>69.7</td>
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<td>Alford City</td>
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<tr>
<td>Maron County</td>
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<td>Brevard County</td>
<td>10</td>
<td>16.8</td>
<td>58.6</td>
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Table 6.4(b): Water evaporation within 200 hours for six soils (Group I)

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<tr>
<td></td>
<td>(%)</td>
<td>(%)</td>
<td>0°C</td>
</tr>
<tr>
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<td>95% R.H.</td>
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Table 6.5: Measured soil weight (Group II) at temperature 25°C & humidity 75%

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<th>Humidity %</th>
<th>Soil Weight [gram]</th>
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<td>Clay (18.5,13.3%)</td>
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<td></td>
<td>Madison (19,11.7%)</td>
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<td></td>
<td>Jacobs (19,12%)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Alford (19,11.7%)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Marion (18.3,13.2%)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Brevard (18.1,12.9%)</td>
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<td>75</td>
<td>1818.3</td>
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</table>

| Total elapsed time [hr] | 93.59 | 95.17 | 94.15 | 93.01 | 93.37 | 90.34 |
| Dry Soil weight [gram]  | 1777.2 | 1828.3 | 1825.7 | 1832.3 | 1766.9 | 1742.6 |
| Initial Water Content   | 13.28% | 11.85% | 12.00% | 11.71% | 13.16% | 12.93% |
| Dry Unit Weight [KN/m³] | 18.45 | 18.08 | 18.06 | 19.02 | 10.34 | 10.09 |
Table 6.6(a) : Drying rate test results for Clay County soil (Group II)

Dry density : 18.45 KJ/m$^3$
Water content : 13.28%

<table>
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<th>Time</th>
<th>Weight (gram)</th>
<th>Temperature (°C)</th>
<th>Humidity (%)</th>
<th>Time (hour)</th>
<th>Cum. Time (hour)</th>
<th>Water loss (gram)</th>
<th>Cum. Water loss (gram)</th>
<th>Water Con. (%)</th>
<th>Avg. Drying Rate (gram/hr/ft$^2$)</th>
<th>Dying Rate (gram/hr/ft$^2$)</th>
</tr>
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Table 6.6(c): Drying rate test results for Jacobs Road soil (Group II)
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<th>Cum. Water Loss (gram)</th>
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Table 6.6(e) : Drying rate test results for Marion County soil (Group II)

Dry density : 18.34 kN/m³  Water content : 13.16%

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<th>Time (hour)</th>
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<th>Water loss (gram)</th>
<th>Cum. Water loss (gram)</th>
<th>Water Conc. (%)</th>
<th>Avg. Drying Rate (gram/hr/ft²)</th>
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Table 6.6(f): Drying rate test results for Brevard County soil (Group II)

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<th>Cum. Water loss (gram)</th>
<th>Water Conc. (%)</th>
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Table 6.7: Summary of soil drying rate Group II test results
(Temperature: 25°C, Relative Humidity: 75%)

Sample Surface Area = 0.487 ft²

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<th>Jacobs</th>
<th>Aford</th>
<th>Marion</th>
<th>Brevard</th>
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<td>13.20</td>
<td>12.90</td>
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<td>186.0</td>
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<td>Average drying rate, [gram per hour per ft²]</td>
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<td>Within first 30 hours</td>
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<td>Within first 200 hours</td>
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Table 6.8 (a): Water evaporation within 24 hours for six soils (Group II)

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<th>% - #200 (%)</th>
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Table 6.8 (b): Water evaporation within 48 hours for six soils (Group II)

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<th>% - #200 (%)</th>
<th>Weight of evaporated water within 48 hours at different conditions, [gram]</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>75% RH</td>
</tr>
<tr>
<td>Clay County</td>
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<td>131.0</td>
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</tr>
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<td>19.9</td>
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<tr>
<td>Brevard County</td>
<td>10</td>
<td>16.8</td>
<td>125.0</td>
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</table>
Table 6.8 (c) : Water evaporation within 72 hours for six soils (Group II)

<table>
<thead>
<tr>
<th>Soil</th>
<th>% Clay (%)</th>
<th>% - #200 (%)</th>
<th>Weight of evaporated water within 72 hours at different conditions, [gram]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>75% RH</td>
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Table 6.8 (d) : Water evaporation within 90 hours for six soils (Group II)

<table>
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<th>% Clay (%)</th>
<th>% - #200 (%)</th>
<th>Weight of evaporated water within 90 hours at different conditions, [gram]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10°C</td>
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<td></td>
<td>75% RH</td>
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<td>25.1</td>
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<td>171.8</td>
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<td>Brevard County</td>
<td>10</td>
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Table 6.8 (e) : Water evaporation within 200 hours for six soils (Group II)

<table>
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<th>Weight of evaporated water within 200 hours at different conditions, [gram]</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>Alford City</td>
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<td>17.6</td>
<td>-</td>
</tr>
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<td>Marion County</td>
<td>12</td>
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<tr>
<td>Brevard County</td>
<td>10</td>
<td>16.8</td>
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Table 6.9(a) : Time needed for soils to dry from OMC+4% to OMC

<table>
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<th>Percentage of Clay</th>
<th>Percentage of passing #200</th>
<th>Time to reach OMC, [hour]</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
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<td>@ Environmental Condition</td>
</tr>
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<td>10°C,75%</td>
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<td>22.24</td>
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<tr>
<td>Marion County</td>
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<td>Brevard County</td>
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<td>16.8</td>
<td>19.14</td>
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Table 6.9(b) : Time needed for soils to dry from OMC+3% to OMC

<table>
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<th>Soil</th>
<th>Percentage of Clay</th>
<th>Percentage of passing #200</th>
<th>Time to reach OMC, [hour]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>@ Environmental Condition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10°C,75%</td>
</tr>
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Table 6.9(c): Time needed for soils to dry from OMC+2% to OMC

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<th>Percentage of passing #200</th>
<th>Time to reach OMC, [hour]</th>
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</thead>
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<tr>
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<td></td>
<td>@ Environmental Condition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10°C,75%</td>
</tr>
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Table 6.9(d): Time needed for soils to dry from OMC+1% to OMC

<table>
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<th>Percentage of Clay</th>
<th>Percentage of passing #200</th>
<th>Time to reach OMC, [hour]</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
<td>@ Environmental Condition</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>10°C,75%</td>
</tr>
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<td>25.1</td>
<td>6.73</td>
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<td>5.02</td>
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<td>Brevard County</td>
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<td>16.8</td>
<td>5.93</td>
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Figure 6.1: Water loss versus elapsed time at temperature 25°C and 75% relative humidity for six soils (Group I).
Water Content vs Elapsed Time
(Temperature 25°C, Humidity 75%)

Figure 6.2: Water content versus elapsed time at temperature 25°C and relative humidity 75% for six soils (Group I)
Figure 5.3: Drying rate vs elapsed time for six soils at temperature 25°C and 75% relative humidity (Group I)
Figure 6.4: Water loss vs elapsed time at temperature 25°C and 75% relative humidity for six soils (Group II).
Figure 6.6: Drying rate vs water content for six soils at temperature 25°C and 75% relative humidity (Group II)
Comparison of Average Drying Rate Within 200 Hours
(Temperature: 25°C, Relative humidity: 75%)

Figure 6.7: Comparison of average drying rate for six soils within 200 hours (Group I)
Comparison of Average Drying Rate Within First 90 Hours
(Temperature : 25°C, Relative humidity : 75%)

Figure 6.8: Comparison of average drying rate for Group I and Group II tests within first 90 hours
Comparison of Drying Rate at Optimum Water Content

(Temperature: 25°C, Relative Humidity: 75%)

Figure 6.9: Comparison of drying rate at optimum water content for Group I and Group II tests
Figure 6.10: Comparison of water loss at different temperature and relative humidity for Clay County soil (Group I)
Figure 6.11: Comparison of the change of water content at different temperature and relative humidity for Clay County soil (Group I)
Figure 6.12: Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group 1)
Figure 6.13: Comparison of water loss at different temperature and relative humidity for Clay County soil (Group II)
Figure 6.14: Comparison of the change of water content at different temperature and relative humidity for Clay County soil (Group II)
Figure 6.15: Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group II)
Figure 6.16(a): Comparison of water loss within 90 hours at different environmental conditions for six soils (Group I)
Comparison of Water Loss within 200 Hours

Figure 6.16(b): Comparison of water loss within 200 hours at different environmental conditions for six soils (Group I)
Figure 6.17(a): Comparison of water loss within 24 hours at different environmental conditions for six soils (Group II)
Comparison of Water Loss within 48 Hours

Figure 6.17(b): Comparison of water loss within 48 hours at different environmental conditions for six soils (Group II)
Figure 6.17(c): Comparison of water loss within 72 hours at different environmental conditions for six soils (Group II)
Comparison of Water Loss within 90 Hours

Figure 6.17(d): Comparison of water loss within 90 hours at different environmental conditions for six soils (Group II)
Figure 6.17(e): Comparison of water loss within 200 hours at different environmental conditions for six soils (Group II)
Figure 6.18: Comparison of drying time from OMC+4% to OMC at different environmental conditions for six soils (Group II)
Figure 6.19: Comparison of drying time from OMC+3% to OMC at different environmental conditions for six soils (Group II)
Comparison of Drying Time from OMC+2% to OMC

Figure 6.20: Comparison of drying time from OMC+2% to OMC at different environmental conditions for six soils (Group II)
Comparison of Drying Time from OMC+1% to OMC

Figure 6.21: Comparison of drying time from OMC+1% to OMC at different environmental conditions for six soils (Group II)
Figure 6.22: Comparison of drying time for different percent of clay content from OMC+4% to OMC (Group II)
Figure 6.23: Comparison of drying time for different percent of passing #200 sieve from OMC+4% to OMC (Group II)
CHAPTER 7

CORRELATION AND ANALYSIS OF SUCTION AND DRYING RATE

EXPERIMENTAL RESULTS

7.1 Correlation of Suction and Drying Rate Test Results

Soil suction is a basic soil property that represents the ability of a soil to retain water. Correlation relationship exists between drying rate and soil suction. The suction and drying rate test results are further analyzed in this chapter. Detailed plots concerning the correlation of soil suction and drying rate results are presented in Appendix F.

7.1.1 Soil suction versus drying time

Since the test results from the soil suction Series B are more reliable than those from Series A, the data from the drying rate test are used to correlate with the data from the Series B suction test. Figures 7.1 through 7.5 provide the changes of soil suction value with time for the
six soils at temperature 25°C with various relative humidity during the drying period. It is shown in the figures that the soils from Clay County and Madison County have higher suction values compared to the other four soils. The drying curves shown in Figures 7.1 and 7.2 indicate that there is no significant influence on the soil suction values when the environmental relative humidity changes from 55% to 75%. As shown in Figure 7.3, the drying curves under 95% relative humidity increase very slowly with time, which is in contrast to the sharp increase on soil suction in the beginning of the drying period under lower relative humidity (55% and 75%). With the same amount of elapsed time, the suction values for Clay County and Madison County soils under 95% relative humidity condition are much lower than those under 55% and 75% relative humidity conditions. Similar trends apply to the drying rate Group II tests, which are illustrated in Figures 7.4 and 7.5.

7.1.2 Drying rate versus drying time

Figures 7.6 through 7.10 demonstrate the drying rate versus elapsed drying time. The drying rate is the highest under 55% relative humidity condition and is the lowest under 95% relative humidity condition at the beginning of
the drying cycles. It is shown in Figure 7.9 that, when the soil water condition of the drying cycle is below the optimum water content, the difference in the drying rate is not significant for the six soils. However, when the soil water condition is above the optimum water content, the soils from Clay County and Madison County have lower drying rates than the other soils.

7.1.3 Drying rate versus soil suction

Summaries of drying rate and soil suction at temperature 25°C are presented in Tables 7.1 and 7.2. The drying rates are plotted as a function of soil suction as shown in Figures 7.11 through 7.15. Each type of soil has its own drying rate-suction characteristics. It is shown that the drying rate decreases with an increase in soil suction. It appears that the soils from Alford City, Jacobs Road, Brevard County, and Marion County have drying rates higher than those from Clay County and Madison County. In terms of percent of fines, it appears that a soil, which has percent of fines higher than 20%, may have a lower drying rate under high humidity and would be more difficult to handle during construction.
7.2 Discussion on Theoretical Relationship Between Suction and Relative Humidity

A theoretical relationship between the relative humidity (actual vapor pressure divided by saturation vapor pressure in the unsaturated soil voids) and total suction based on the Kelvin's equation (Equation 2.5) is shown in Figure 7.16. It indicates that relative humidity is an exponential function of total suction. The decline in relative humidity with increasing suction is initially small and a substantial decrease in the relative humidity occurs only after the suction value 1000 kPa. Theoretically, the relationship occurs independent of water content when all the variables are well controlled.

As shown in Figure 7.16, a suction value at 7000 kPa has a corresponding relative humidity 95% (in unsaturated soil voids). A soil with the suction value higher than 7000 kPa will result in a relative humidity lower than 95% and this means no more water will evaporate from the soil when a soil is subjected to an environmental condition at 95% relative humidity. For instance, the soils from Clay and Madison County, which contain percent of fines greater than 20%, possess suction value higher than 7000 kPa will cause the soil to stop drying.
It is difficult to compare all the controlling variables since each soil type has a different initial water content and the volume of water available for evaporation. The analysis for a soil sample other than a thin layer requires a theoretical approach that includes the influence of the flow process below the soil surface.
Table 7.1(a): Summary of soil suction and drying rate at OMC

<table>
<thead>
<tr>
<th>Soils</th>
<th>Percent of Clay</th>
<th>Percent of Passing #200</th>
<th>Water content</th>
<th>Suction kPa</th>
<th>Drying rate (Group II) @75% R.H.</th>
<th>@95% R.H.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>24%</td>
<td>27.5%</td>
<td>9.1%</td>
<td>510</td>
<td>7.5 gram/hour/ft²</td>
<td>1.8</td>
</tr>
<tr>
<td>Madison</td>
<td>12%</td>
<td>25.1%</td>
<td>8.5%</td>
<td>439</td>
<td>8.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Jacobs</td>
<td>8%</td>
<td>20%</td>
<td>7.9%</td>
<td>335</td>
<td>8.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Alford</td>
<td>4%</td>
<td>17.6%</td>
<td>7.6%</td>
<td>281</td>
<td>10.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Marion</td>
<td>12%</td>
<td>19.9%</td>
<td>9.3%</td>
<td>313</td>
<td>11.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Brevard</td>
<td>10%</td>
<td>16.8%</td>
<td>9.25%</td>
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Table 7.1(b): Summary of soil suction and drying rate at OMC plus 1%

<table>
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<th>Soils</th>
<th>Percent of Clay</th>
<th>Percent of Passing #200</th>
<th>Water content</th>
<th>Suction kPa</th>
<th>Drying rate (Group II) @75% R.H.</th>
<th>@95% R.H.</th>
</tr>
</thead>
<tbody>
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<td>Clay</td>
<td>24%</td>
<td>27.5%</td>
<td>10.1%</td>
<td>226</td>
<td>7.5 gram/hour/ft²</td>
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</tr>
<tr>
<td>Madison</td>
<td>12%</td>
<td>25.1%</td>
<td>9.5%</td>
<td>265</td>
<td>8.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Jacobs</td>
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<td>20%</td>
<td>8.9%</td>
<td>283</td>
<td>9.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Alford</td>
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<td>17.6%</td>
<td>8.6%</td>
<td>234</td>
<td>11.3</td>
<td>2.5</td>
</tr>
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<td>Marion</td>
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<td>10.3%</td>
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<td>1.8</td>
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<td>Brevard</td>
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<td>10.25%</td>
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### Table 7.1(c): Summary of soil suction and drying rate at OMC plus 2%

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<th>Percent of Passing #200</th>
<th>Water content</th>
<th>Suction</th>
<th>Drying rate (Group II)</th>
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<td></td>
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<td>%</td>
<td>%</td>
<td>kPa</td>
<td>gram/hour/ft²</td>
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### Table 7.1(d): Summary of soil suction and drying rate at OMC plus 3%

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<th>Percent of Passing #200</th>
<th>Water content</th>
<th>Suction</th>
<th>Drying rate (Group II)</th>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>kPa</td>
<td>@75% R.H.</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>kPa</td>
<td>gram/hour/ft²</td>
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Table 7.1(e): Summary of soil suction and drying rate at OMC plus 4%

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<th>Water content</th>
<th>Suction</th>
<th>Drying rate (Group II)</th>
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<tbody>
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<td>%</td>
<td>%</td>
<td>kPa</td>
<td>@75%R.H.</td>
</tr>
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<td>Brevard</td>
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Table 7.2(a): Summary of soil suction and drying rate at 25°C  
(Water content = 8%)

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<th>Drying rate (Group II)</th>
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<td>%</td>
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Table 7.2(b): Summary of soil suction and drying rate at 25°C  
(Water content = 9%)

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<th>Suction</th>
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<td>kPa</td>
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Table 7.2(c) : Summary of soil suction and drying rate at 26°C
(Water content = 10%)

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<td></td>
<td>@85% R.H.</td>
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Table 7.2(d) : Summary of soil suction and drying rate at 25°C
(Water content = 11%)

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<th>Percent of Passing #200</th>
<th>Suction</th>
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<tr>
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<td>%</td>
<td>kPa</td>
<td>@75% R.H.</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>@85% R.H.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>gram/hour/ft²</td>
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</tr>
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### Table 7.2(e) : Summary of soil suction and drying rate at 25°C (Water content = 12%)

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### Table 7.2(f) : Summary of soil suction and drying rate at 25°C (Water content = 13%)

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<th>Drying rate (Group II)</th>
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<td>Jacobs</td>
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Soil Suction vs Drying Time
(Temperature: 25°C, Humidity: 55%)

Figure 7.1: Soil suction versus drying time for six soils at temperature 25°C and 55% relative humidity (Group I)
Soil Suction vs Drying Time
(Temperature: 25°C, Humidity: 75%)

Figure 7.2: Soil suction versus drying time for six soils at temperature 25°C and 75% relative humidity (Group I)
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Soil Suction vs Drying Time

(Temperature: 25°C, Humidity: 95%)

Figure 7.5: Soil suction versus drying time for six soils at temperature 25°C and 95% relative humidity (Group II)
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Drying Rate vs Drying Time
(Temperature: 25°C, Humidity: 95%)

Figure 7.8: Drying rate vs drying time for six soils at temperature 25°C and 95% relative humidity (Group I)
Figure 7.9: Drying rate vs drying time for six soils at temperature 25°C and 75% relative humidity (Group II)
Figure 7.10: Drying rate vs drying time for six soils at temperature 25°C and 95% relative humidity (Group II)
Drying Rate vs Suction
(Temperature: 25°C, Humidity: 55%)

Figure 7.11: Drying rate versus soil suction for six soils at temperature 25°C and 55% relative humidity (Group I)
Figure 7.12: Drying rate versus soil suction for six soils at temperature 25°C and 75% relative humidity (Group I)
Drying Rate vs Soil Suction
(Temperature: 25°C, Humidity: 95%)

Figure 7.13: Drying rate versus soil suction for six soils at temperature 25°C and 95% relative humidity (Group I)
Drying Rate vs Soil Suction

(Temperature: 25°C, Humidity: 75%)

Figure 7.14: Drying rate versus soil suction for six soils at temperature 25°C and 75% relative humidity (Group II)
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CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The soils used for this study were classified as low in plasticity and permeability, non-swelling and non-active and were tested with a range of water content below and above the optimum water content. The conclusions are drawn based on the analysis and findings of the soil suction and drying rate test results.

8.1.1 Suction Test Program

Based on the test results, the conclusions may be drawn as the following:

1. Most of the soils possess low suction values in the range of 100 kPa to 1000 kPa except that the soils from Clay County and Madison County have relatively higher suction values at drier condition (more than 3000 kPa). These suction values are relatively low as compared to the full range of suction values from 0 kPa to 1000000 kPa for the moisture condition from
full saturation to air-dry condition.

2. The soil suction increases with a decrease in water content and it increases rapidly for some soils with very little decrease in water content. The suction-water content (t-ω) relationships for the wet side of the optimum water content behave differently from those for the dry side of the optimum. This trend is very significant for the soils from Clay County and Madison County.

3. The suction values vary significantly with water content when the percent of clay content is greater than 10% and the percent of fines passing the #200 sieve is greater than 20%. The suction values are generally limited to within 100 to 3000 kPa with the percent of fines (~#200 sieve) less than 20%.

4. No significant evidence of correlation exists between the soil suction and permeability values for the six soils.

5. No significant changes in suction value occur when the degree of saturation is within 95% to 70%. However, the suction values of Clay County and Madison County soils increase significantly with a decrease in the degree of saturation below 70%.

6. The values of the specific volume for the six soils
are within the range of 0.04 to 0.07 regardless of the water content. Those values are very low as compared with those from high volume change soils.

8.1.2 Soil drying rate test program

1. The Clay County soil evaporated the largest amount of water among the six soils within a certain period of time while the Marion County soil evaporated the least amount of water.

2. In general, the drying rate decreases with a decrease in water content. When the soil is dried from the wet side of optimum water content, the rate of decrease in drying is more significant.

3. Overall, the Alford City soil had the highest drying rate for the entire range of drying period. The Clay County soil had the lowest drying rate at the water content higher than 8 percent. The Marion County soil ceased to dry at relatively higher water content, which resulted in the lowest drying rate at the water content lower than 7 percent.

4. The influence of the relative humidity on the soil drying rate is much more significant than that of the temperature. When the relative humidity is at 95%, the rate of water evaporation reduces significantly as compared to the rate at either 55%
or 75% relative humidity.

5. The time needed to dry from the wet side of optimum water content to optimum water content for the six soils varied at different levels of relative humidity. Generally, the Clay County soil needs the longest time to reach optimum water content whereas the Marion County soil needs the shortest time at 75% relative humidity. When the relative humidity is high (95%), the Jacobs Road soil takes the longest time to reach optimum water content while the Alford City soil takes the shortest time to reach optimum water content.

6. The drying rate increases with an increase in the percent of -"200 fines or clay content.

8.1.3 Correlation and analysis of suction and drying rate

experimental results

1. The difference in the drying rate for the six soils is not significant when the soil water condition is below the optimum water content. When the soil water condition is above the optimum water content, the Clay and Madison County soils have lower drying rates.

2. The drying rate decreases with an increase in soil
suction. The drying rate values for both Group I and Group II tests in terms of soil suction are quite similar when the soil suction value is higher than 400 kPa. When the soil suction is lower than 400 kPa, it appears that the Clay County soil has the lowest drying rate on the basis of the same amount of suction.

3. The soils from Alford City, Jacobs Road, Brevard County, and Marion County have higher drying rates than those from Clay County and Madison County.

4. The A-2-4 soils with high percent of 
   (>20%) may have lower drying rates or higher suction values, which would be more difficult to handle for highway construction in a region with high relative humidity.

8.2 Recommendations

The following recommendations are made based on the observations and discussions in this study

1. Both suction and drying rate tests should be done in a well temperature-controlled laboratory to eliminate the effect of temperature fluctuation and gradient so that a high accuracy may be achieved.

2. For the suction test, alternative test methods should be used to double check the test results.
The filter paper method is recommended for its economical sake.

3. When the suction value is low, the accuracy of the data recording becomes important. A data logger connected to a PC is recommended to allow the automated storage, reduction, and manipulation of the data.

4. In order to fully investigate the relationship between the drying rate and the percent of clay fraction or percent of fines passing #200 sieve, the soils selected for the test program should have an entire range of distribution of the percent of fines up to 35% for A-2-4 soils.
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U.S. Standard Sieve Size

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Grain Size Distribution plot
(Brevard County)

U.S. Standard Sieve Size

Figure A.6: Grain size distribution plot for Brevard County soil
Dry Density vs Water Content

(Clay County)

Figure A.7: Plot of Compaction Test for Clay County
Dry Density vs Water Content
(Madison County)

Figure A.8: Plot of Compaction Test for Madison County
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Figure A.10: Plot of Compaction Test for Alford City
Dry Density vs Water Content
(Marion County)

Figure A.11: Plot of Compaction Test for Marion County
Dry Density vs Water Content

(Brevard County)

Regression

Dry Density, KN/M³

Water Content, %

20.0 19.5 19.0 18.5 18.0

Figure A.12: Plot of Compaction Test for Brevard County
APPENDIX B: CALIBRATION RESULTS
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<td>7.15</td>
<td>9.14</td>
<td>8.39</td>
<td>9.17</td>
<td>7.60</td>
</tr>
<tr>
<td>1800</td>
<td>36.54</td>
<td>38.47</td>
<td>36.43</td>
<td>36.77</td>
<td>38.24</td>
<td>38.11</td>
<td>38.47</td>
<td>36.77</td>
<td>36.86</td>
<td>47.16</td>
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<th>4</th>
<th>5</th>
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<th>8</th>
<th>9</th>
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<tbody>
<tr>
<td>290</td>
<td>8.10</td>
<td>7.04</td>
<td>6.81</td>
<td>5.70</td>
<td>5.64</td>
<td>7.63</td>
<td>7.61</td>
<td>6.15</td>
<td>5.52</td>
<td>7.60</td>
</tr>
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<td>500</td>
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<td>12.44</td>
<td>12.87</td>
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<td>15.01</td>
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<td>21.62</td>
<td>24.66</td>
<td>22.52</td>
<td>22.73</td>
<td>26.20</td>
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<tr>
<td>1800</td>
<td>35.60</td>
<td>39.62</td>
<td>36.13</td>
<td>38.08</td>
<td>37.75</td>
<td>36.64</td>
<td>40.14</td>
<td>36.02</td>
<td>37.65</td>
<td>47.16</td>
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</table>
Table B.2(a) : Equations of Calibration Lines for Nine Psychrometers
(Calibration A)

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>Cooling Coefficient</th>
<th>Equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54</td>
<td>( \tau = 127.67 \text{ E}_{25} - 146.69 )</td>
<td>0.9916</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>( \tau = 121.76 \text{ E}_{26} - 168.45 )</td>
<td>0.9946</td>
</tr>
<tr>
<td>3</td>
<td>58</td>
<td>( \tau = 127.2 \text{ E}_{25} - 101.08 )</td>
<td>0.9977</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>( \tau = 127.16 \text{ E}_{25} - 131.11 )</td>
<td>0.9917</td>
</tr>
<tr>
<td>5</td>
<td>61</td>
<td>( \tau = 120.29 \text{ E}_{25} - 94.81 )</td>
<td>0.9969</td>
</tr>
<tr>
<td>6</td>
<td>61</td>
<td>( \tau = 120.52 \text{ E}_{25} - 83.824 )</td>
<td>0.9969</td>
</tr>
<tr>
<td>7</td>
<td>62</td>
<td>( \tau = 123.43 \text{ E}_{25} - 230.09 )</td>
<td>0.9924</td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>( \tau = 129.7 \text{ E}_{25} - 247.73 )</td>
<td>0.9965</td>
</tr>
<tr>
<td>9</td>
<td>63</td>
<td>( \tau = 129.68 \text{ E}_{25} - 251.32 )</td>
<td>0.9898</td>
</tr>
</tbody>
</table>

Table B.2(b) : Equations of Calibration Lines for Nine Psychrometers
(Calibration B)

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>Cooling Coefficient</th>
<th>Equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54</td>
<td>( \tau = 132.05 \text{ E}_{25} - 231.4 )</td>
<td>0.9926</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>( \tau = 122.08 \text{ E}_{25} - 208.73 )</td>
<td>0.9979</td>
</tr>
<tr>
<td>3</td>
<td>58</td>
<td>( \tau = 131.23 \text{ E}_{25} - 279.38 )</td>
<td>0.9965</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>( \tau = 119.8 \text{ E}_{25} - 119.44 )</td>
<td>0.9923</td>
</tr>
<tr>
<td>5</td>
<td>61</td>
<td>( \tau = 120.8 \text{ E}_{25} - 127.46 )</td>
<td>0.9913</td>
</tr>
<tr>
<td>6</td>
<td>61</td>
<td>( \tau = 130.54 \text{ E}_{25} - 327.71 )</td>
<td>0.9991</td>
</tr>
<tr>
<td>7</td>
<td>62</td>
<td>( \tau = 119.36 \text{ E}_{25} - 356.83 )</td>
<td>0.991</td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>( \tau = 129.21 \text{ E}_{25} - 253.61 )</td>
<td>0.989</td>
</tr>
<tr>
<td>9</td>
<td>63</td>
<td>( \tau = 121.38 \text{ E}_{26} - 160.44 )</td>
<td>0.9856</td>
</tr>
</tbody>
</table>
Figure B.1: Regression lines of psychrometer #1 for Calibration A and B
Calibration Line of Psychrometer #2

Figure B.2: Regression lines of psychrometer #2 for Calibration A and B
Figure B.4: Regression lines of psychrometer #4 for Calibration A and B
Figure B.5: Regression lines of psychrometer #5 for Calibration A and B
Figure B.6: Regression lines of psychrometer #6 for Calibration A and B.
Figure B.7: Regression lines of psychrometer #7 for Calibration A and B
Figure B.8: Regression lines of psychrometer #8 for Calibration A and B

\[ y = 129.7x - 247.73 \]
\[ R^2 = 0.9965 \]

\[ y = 129.21x - 253.61 \]
\[ R^2 = 0.989 \]
Figure B.9: Regression lines of psychrometer #9 for Calibration A and B.
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<table>
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<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
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<td>Summary of soil suction, water content, and specific volume test results for Clay County soil (Series A)</td>
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</tr>
<tr>
<td>Table C.1(b)</td>
<td>Summary of soil suction, water content, and specific volume test results for Clay County soil (Series B)</td>
<td>256</td>
</tr>
<tr>
<td>Table C.2(a)</td>
<td>Summary of soil suction, water content, and specific volume test results for Madison County soil (Series A)</td>
<td>257</td>
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<td>Table C.2(b)</td>
<td>Summary of soil suction, water content, and specific volume test results for Madison County soil (Series B)</td>
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<td>Table C.3(a)</td>
<td>Summary of soil suction, water content, and specific volume test results for Alford City soil (Series A)</td>
<td>259</td>
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<td>Table C.3(b)</td>
<td>Summary of soil suction, water content, and specific volume test results for Alford City soil (Series B)</td>
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<td>Summary of soil suction, water content, and specific volume test results for Jacobs Road soil (Series A)</td>
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</tr>
<tr>
<td>Table C.4(b)</td>
<td>Summary of soil suction, water content, and specific volume test results for Jacobs Road soil (Series B)</td>
<td>262</td>
</tr>
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<td>Table C.5(a)</td>
<td>Summary of soil suction, water content, and specific volume test results for Brevard County soil (Series A)</td>
<td>263</td>
</tr>
<tr>
<td>Table C.5(b)</td>
<td>Summary of soil suction, water content, and specific volume test results for Brevard County soil (Series B)</td>
<td>264</td>
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</table>
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Table C.1(a): Summary of soil suction, water content, and specific volume test results for Clay County soil

<table>
<thead>
<tr>
<th>Series A</th>
<th>Dry density: 18.7 KN/m³</th>
<th>Water content: 9.27%</th>
</tr>
</thead>
</table>

### A. Soil Suction Test

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>9B</th>
<th>6</th>
<th>7</th>
<th>4</th>
<th>9B</th>
<th>6</th>
<th>58</th>
<th>55</th>
<th>54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample container No.</td>
<td>63</td>
<td>63</td>
<td>62</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>58</td>
<td>55</td>
<td>54</td>
</tr>
<tr>
<td>Water content Increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>0.5ml</td>
<td>N</td>
<td>N</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E&lt;sub&gt;25&lt;/sub&gt;, Microvotels*</td>
<td>29.85</td>
<td>13.87</td>
<td>5.39</td>
<td>3.10</td>
<td>2.90</td>
<td>2.33</td>
<td>2.83</td>
<td>3.40</td>
<td>3.66</td>
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<tr>
<td>Soil Suction, Tons/#2 (t)</td>
<td>37.83</td>
<td>16.21</td>
<td>4.55</td>
<td>2.75</td>
<td>2.65</td>
<td>2.59</td>
<td>2.71</td>
<td>2.57</td>
<td>3.35</td>
</tr>
<tr>
<td>Soil Suction, kPa (t)</td>
<td>3619.63</td>
<td>1551.21</td>
<td>435.20</td>
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<td>254.03</td>
<td>257.25</td>
<td>254.90</td>
<td>245.53</td>
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</table>

### B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>332.5</th>
<th>350.45</th>
<th>368.3</th>
<th>376.5</th>
<th>376.8</th>
<th>372.3</th>
<th>371.5</th>
<th>381.7</th>
<th>385.9</th>
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<tbody>
<tr>
<td>Tare Plus Dry Soil</td>
<td>326.2</td>
<td>342</td>
<td>357.8</td>
<td>364.59</td>
<td>364.7</td>
<td>360.29</td>
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<td>358</td>
<td>369.9</td>
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<tr>
<td>Water (Wₚ)</td>
<td>6.3</td>
<td>8.45</td>
<td>10.5</td>
<td>11.91</td>
<td>11.92</td>
<td>12.01</td>
<td>12.3</td>
<td>13.7</td>
<td>16</td>
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<tr>
<td>Tare</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td></td>
</tr>
<tr>
<td>Dry Soil (Wₜₚ)</td>
<td>89.1</td>
<td>104.9</td>
<td>120.7</td>
<td>127.49</td>
<td>127.6</td>
<td>123.2</td>
<td>122.1</td>
<td>130.9</td>
<td>132.6</td>
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<tr>
<td>Water Content (%)</td>
<td>7.07%</td>
<td>8.06%</td>
<td>8.79%</td>
<td>9.34%</td>
<td>9.34%</td>
<td>9.75%</td>
<td>10.07%</td>
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### C. Specific Volume

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<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
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</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>135.6</td>
<td>146.2</td>
<td>165.5</td>
<td>166.7</td>
<td>164</td>
<td>168.7</td>
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<td>Wet Soil (Wₚ)</td>
<td>132.1</td>
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<td>147.6</td>
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<td>147.4</td>
<td>148</td>
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<td>Wax</td>
<td>3.5</td>
<td>5.7</td>
<td>17.1</td>
<td>19.1</td>
<td>17.7</td>
<td>13.6</td>
<td>4.1</td>
<td>17.1</td>
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<td>Wet Soil and Wax in Water</td>
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<td>39.5</td>
<td>38.5</td>
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<td>Dry Soil (Wₜₚ)</td>
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<td>131.92</td>
<td>134.99</td>
<td>133.8</td>
<td>141.32</td>
<td>135.91</td>
<td>133.98</td>
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<tr>
<td>Volume in CC</td>
<td>Wet soil and Wax</td>
<td>101.2</td>
<td>106.7</td>
<td>122</td>
<td>124.7</td>
<td>126</td>
<td>129.7</td>
<td>112.5</td>
</tr>
<tr>
<td>Wax</td>
<td>6.35</td>
<td>10.36</td>
<td>31.09</td>
<td>34.73</td>
<td>32.18</td>
<td>24.73</td>
<td>7.45</td>
<td>31.09</td>
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<tr>
<td>Wet Soil (Vₚ)</td>
<td>94.84</td>
<td>98.34</td>
<td>90.91</td>
<td>89.97</td>
<td>93.32</td>
<td>104.97</td>
<td>105.05</td>
<td>95.01</td>
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<td>Density KN/m³</td>
<td>Wet Density (¥ₚ) = (W/V) * 9.8</td>
<td>13.65</td>
<td>14.20</td>
<td>15.46</td>
<td>16.08</td>
<td>15.28</td>
<td>14.48</td>
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<tr>
<td>Specific Volume (Vₚ) = 1/¥ₚ</td>
<td>0.078</td>
<td>0.076</td>
<td>0.070</td>
<td>0.068</td>
<td>0.072</td>
<td>0.076</td>
<td>0.080</td>
<td>0.072</td>
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* E<sub>25</sub> was calculated by averaging the last three readings from soil suction test results
Table C.1(b): Summary of soil suction, water content, and specific volume test results for Clay County soil

### A. Soil Suction Test

<table>
<thead>
<tr>
<th>Sample container No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (cm)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>18.87</td>
<td>16.62</td>
<td>1.03</td>
<td>8.03</td>
<td>6.81</td>
<td>3.70</td>
<td>2.79</td>
<td>2.75</td>
<td>2.77</td>
</tr>
<tr>
<td>Soil Suction, kPa (°)</td>
<td>2282.95</td>
<td>1855.44</td>
<td>1302.47</td>
<td>850.26</td>
<td>724.32</td>
<td>362.07</td>
<td>114.06</td>
<td>103.95</td>
<td>100.17</td>
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</table>

### B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>Tare Plus Dry Soil</th>
<th>Water (W&lt;sub&gt;d&lt;/sub&gt;)</th>
<th>Tare</th>
<th>Dry Soil (W&lt;sub&gt;s&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>271.9</td>
<td>268</td>
<td>258.8</td>
<td>249.4</td>
<td>248.1</td>
<td>257.7</td>
</tr>
<tr>
<td>262.2</td>
<td>257.9</td>
<td>249.1</td>
<td>240.3</td>
<td>238.9</td>
<td>247.7</td>
</tr>
<tr>
<td>9.7</td>
<td>13.1</td>
<td>9.7</td>
<td>9.1</td>
<td>9.2</td>
<td>10</td>
</tr>
<tr>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
<td>134.2</td>
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<tr>
<td>128</td>
<td>123.7</td>
<td>114.9</td>
<td>106.1</td>
<td>104.7</td>
<td>113.5</td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>7.58%</td>
<td>8.6%</td>
<td>8.44%</td>
<td>8.58%</td>
<td>8.79%</td>
</tr>
</tbody>
</table>

### C. Specific Volume

<table>
<thead>
<tr>
<th>Test: Temperature of Water (°C)</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
<th>33°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Soil and Wax</td>
<td>162.4</td>
<td>153.4</td>
<td>142.57</td>
<td>132.65</td>
<td>131.4</td>
<td>137.53</td>
<td>154.35</td>
<td>126.65</td>
<td>135.6</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
<td>138.97</td>
<td>142.88</td>
<td>125.5</td>
<td>115.89</td>
<td>114.5</td>
<td>124.5</td>
<td>138.19</td>
<td>112.9</td>
<td>119.25</td>
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<tr>
<td>Wax</td>
<td>23.43</td>
<td>16.52</td>
<td>17.07</td>
<td>16.76</td>
<td>16.9</td>
<td>13.03</td>
<td>16.16</td>
<td>13.75</td>
<td>16.35</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
<td>45.1</td>
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<tr>
<td>Dry Soil (W&lt;sub&gt;s&lt;/sub&gt;)</td>
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<td>106.74</td>
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<td>114.42</td>
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<td>106.54</td>
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<td>Volume in Wax</td>
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<td>93.03</td>
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<td>69.34</td>
<td>73.20</td>
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<tr>
<td>Density KN/m³</td>
<td>18.23</td>
<td>17.75</td>
<td>18.29</td>
<td>18.07</td>
<td>18.43</td>
<td>17.60</td>
<td>18.50</td>
<td>17.58</td>
<td>17.77</td>
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<tr>
<td>Wet Density (ρ&lt;sub&gt;W&lt;/sub&gt;)</td>
<td>16.95</td>
<td>16.41</td>
<td>16.87</td>
<td>16.64</td>
<td>16.94</td>
<td>16.17</td>
<td>16.90</td>
<td>15.90</td>
<td>15.68</td>
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<td>Dry Density (ρ&lt;sub&gt;S&lt;/sub&gt;)</td>
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<td>0.061</td>
<td>0.059</td>
<td>0.060</td>
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* E₂₅; was calculated by averaging the last three readings from soil suction test results
### Table C.2(a): Summary of soil suction, water content, and specific volume test result for Madison County soil

<table>
<thead>
<tr>
<th>A. Soil Suction Test</th>
<th></th>
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<td>Water content (ml)</td>
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<td>0.5ml</td>
<td>N</td>
<td>N</td>
<td>1hr</td>
<td>2hr</td>
<td>4hr</td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>2.95</td>
<td>3.63</td>
<td>3.22</td>
<td>3.40</td>
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<td>5.50</td>
<td>6.53</td>
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<td>273.54</td>
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<td>329.21</td>
<td>326.21</td>
<td>572.21</td>
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<th>B. Water Content</th>
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<tr>
<td>Weight in Grams</td>
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<tr>
<td>Tare Plus Dry Soil</td>
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<tr>
<td>Water (W&lt;sub&gt;D&lt;/sub&gt;)</td>
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<tr>
<td>Tare Dry Soil (W&lt;sub&gt;T&lt;/sub&gt;)</td>
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<tr>
<td>Dry Sol (W&lt;sub&gt;D&lt;/sub&gt;)</td>
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<th>C. Specific Volume</th>
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<td>Test Temperature of Water (°C)</td>
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<tr>
<td>Weight in Grams</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
</tr>
<tr>
<td>Wax</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
</tr>
<tr>
<td>Dry Sol (W&lt;sub&gt;D&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Volume in CC</td>
</tr>
<tr>
<td>Wet Sol (V)</td>
</tr>
<tr>
<td>Density KN/m³</td>
</tr>
<tr>
<td>Specific Volume (V) =1/ρ&lt;sub&gt;d&lt;/sub&gt;</td>
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* E<sub>25</sub> was calculated by averaging the last three readings from soil suction test results.
### Table C.2(b): Summary of soil suction, water content, and specific volume test result for Madison County soil

**Series B**

Dry density: 19.1 KN/m³  
Water content: 8.6%

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<thead>
<tr>
<th>A. Soil Suction Test</th>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water content increment (0, 0, 0)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>29.76</td>
<td>7.89</td>
<td>5.26</td>
<td>4.51</td>
<td>5.66</td>
<td>5.17</td>
<td>4.56</td>
<td>3.84</td>
<td>2.91</td>
</tr>
<tr>
<td>Soil Suction, Tons/ft²</td>
<td>38.64</td>
<td>7.89</td>
<td>4.29</td>
<td>4.40</td>
<td>5.82</td>
<td>3.63</td>
<td>1.96</td>
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<td>2.01</td>
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<td>3697.94</td>
<td>755.02</td>
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<td>420.70</td>
<td>556.84</td>
<td>347.18</td>
<td>187.45</td>
<td>242.43</td>
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<th>275.16</th>
<th>274.14</th>
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<th>282.21</th>
<th>284.2</th>
<th>283.53</th>
<th>285.62</th>
<th>234.19</th>
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<td>Weight in Grams</td>
<td>Tare Plus Dry Soil</td>
<td>261.33</td>
<td>267.07</td>
<td>264.55</td>
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<td>271.16</td>
<td>272.54</td>
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<td>272.61</td>
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<td>10.61</td>
<td>11.05</td>
<td>11.66</td>
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<td>139.56</td>
<td>139.56</td>
<td>139.56</td>
<td>139.56</td>
<td>139.56</td>
<td>139.56</td>
<td>139.56</td>
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<tr>
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<td>121.6</td>
<td>127.5</td>
<td>124.97</td>
<td>130.63</td>
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<td>132.98</td>
<td>131.91</td>
<td>133.05</td>
<td>129.98</td>
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<tr>
<td>Water Content (%)</td>
<td>5.60%</td>
<td>7.13%</td>
<td>7.69%</td>
<td>8.12%</td>
<td>8.40%</td>
<td>8.77%</td>
<td>9.14%</td>
<td>9.78%</td>
<td>11.27%</td>
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</table>

<table>
<thead>
<tr>
<th>C. Specific Volume</th>
<th>Test Temperature of Water (°C)</th>
<th>35°C</th>
<th>34°C</th>
<th>33°C</th>
<th>32°C</th>
<th>31°C</th>
<th>30°C</th>
<th>29°C</th>
<th>28°C</th>
<th>27°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>144.3</td>
<td>148.2</td>
<td>150</td>
<td>152.3</td>
<td>167.58</td>
<td>158.74</td>
<td>155.58</td>
<td>188.49</td>
<td>160.57</td>
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<td></td>
<td>Wet Soil (W)</td>
<td>132</td>
<td>138.4</td>
<td>139</td>
<td>142</td>
<td>143.51</td>
<td>144.65</td>
<td>145.98</td>
<td>117.65</td>
<td>145.17</td>
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<tr>
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<td>Wax</td>
<td>12.31</td>
<td>9.8</td>
<td>11</td>
<td>10.3</td>
<td>24.07</td>
<td>14.09</td>
<td>9.6</td>
<td>20.84</td>
<td>15.4</td>
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<tr>
<td></td>
<td>Wet Soil and Wax in Water</td>
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<td>41</td>
<td>44</td>
<td>43</td>
<td>44</td>
<td>43</td>
<td>42</td>
<td>42.5</td>
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<tr>
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<td>Dry Soil (Wd)</td>
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<td>129.07</td>
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<td>132.39</td>
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<td>133.75</td>
<td>134.50</td>
<td>130.47</td>
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<tr>
<td>Volume in CC</td>
<td>Wet soil and Wax</td>
<td>102.31</td>
<td>107.2</td>
<td>106</td>
<td>109.3</td>
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<td>113.58</td>
<td>125.99</td>
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<td>Wax</td>
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<td>18.73</td>
<td>43.76</td>
<td>25.62</td>
<td>17.45</td>
<td>37.89</td>
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<td>79.82</td>
<td>90.12</td>
<td>96.13</td>
<td>88.10</td>
<td>88.57</td>
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<tr>
<td>Density (Kn/m³)</td>
<td>Wet Density (fW) = (W/W)*9.8</td>
<td>16.18</td>
<td>15.17</td>
<td>15.84</td>
<td>15.36</td>
<td>17.62</td>
<td>15.73</td>
<td>14.88</td>
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<td>0.069</td>
<td>0.073</td>
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* E25 was calculated by averaging the last three readings from soil suction test results
Table C.3(a): Summary of soil suction, water content, and specific volume test result for Jacobs Road soil

### A. Soil Suction Test

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<thead>
<tr>
<th>Psychrometer No.</th>
<th>1</th>
<th>2</th>
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<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
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<tbody>
<tr>
<td>Sample container No.</td>
<td>54</td>
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<td>61</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Water content increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E25. Microvolts</td>
<td>4.75</td>
<td>2.96</td>
<td>3.58</td>
<td>1.90</td>
<td>2.94</td>
<td>2.60</td>
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<td>229.53</td>
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### B. Water Content

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<th>Tare Pus We. Soil</th>
<th>Tare Pus Dry Soil</th>
<th>Water (W&lt;sub&gt;0&lt;/sub&gt;)</th>
<th>Tare</th>
<th>Dry Soil (W&lt;sub&gt;d&lt;/sub&gt;)</th>
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<tr>
<td></td>
<td>7.73%</td>
<td>7.94%</td>
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### C. Specific Volume

<table>
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<th>24°C</th>
<th>22°C</th>
<th>20°C</th>
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</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>Wet Soil (W)</td>
<td>Wax</td>
<td>Wet Soil and Wax in Water</td>
<td>Dry Soil (W&lt;sub&gt;d&lt;/sub&gt;)</td>
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<td>Wet Soil and Wax in Water</td>
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<td>102.7</td>
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<td>103.5</td>
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<td>103.7</td>
<td>99.9</td>
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<td>29.64</td>
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<tr>
<td></td>
<td>78.70</td>
<td>75.79</td>
<td>75.43</td>
<td>68.36</td>
<td>74.05</td>
<td>74.99</td>
<td>75.52</td>
<td>76.08</td>
<td>74.03</td>
</tr>
<tr>
<td>Density (t) KNm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Wet Density (t&lt;sub&gt;0&lt;/sub&gt;) = (W/V)&lt;sup&gt;°&lt;/sup&gt;9.8</td>
<td>5.65</td>
<td>16.38</td>
<td>16.33</td>
<td>17.30</td>
<td>15.85</td>
<td>16.74</td>
<td>18.44</td>
<td>16.46</td>
</tr>
<tr>
<td></td>
<td>Dry Density (t&lt;sub&gt;d&lt;/sub&gt;) = (W&lt;sub&gt;d&lt;/sub&gt;/V)&lt;sup&gt;°&lt;/sup&gt;9.8</td>
<td>5.05</td>
<td>15.54</td>
<td>15.39</td>
<td>15.16</td>
<td>15.73</td>
<td>15.54</td>
<td>15.23</td>
<td>15.02</td>
</tr>
<tr>
<td>Specific Volume (V&lt;sub&gt;d&lt;/sub&gt;) =1/ρ&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.066</td>
<td>0.064</td>
<td>0.065</td>
<td>0.062</td>
<td>0.064</td>
<td>0.064</td>
<td>0.066</td>
<td>0.067</td>
<td>0.065</td>
</tr>
</tbody>
</table>

* E<sub>25</sub> was calculated by averaging the last three readings from soil suction test results.
Table C.3(b): Summary of soil suction, water content, and specific volume test result for Jacobs Road

<table>
<thead>
<tr>
<th>A. Soil Suction Test</th>
<th>Dry density: 19.9 KN/m³</th>
<th>Water content: 7.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Chamber No.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sample container No.</td>
<td>54</td>
<td>55</td>
</tr>
<tr>
<td>Water content increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
</tr>
<tr>
<td>E25, Microwatts*</td>
<td>6.77</td>
<td>5.17</td>
</tr>
<tr>
<td>Soil Suction, Tons/ft² (v)</td>
<td>6.93</td>
<td>4.41</td>
</tr>
<tr>
<td>Soil Suction, kPa (v)</td>
<td>663.14</td>
<td>422.42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Water Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
</tr>
<tr>
<td>Tare Plus Dry Soil</td>
</tr>
<tr>
<td>Water (W_d)</td>
</tr>
<tr>
<td>Tare</td>
</tr>
<tr>
<td>Dry Soil (W_d)</td>
</tr>
<tr>
<td>Water Content (%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Specific Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Temperature of Water (°C)</td>
</tr>
<tr>
<td>Weight in Grams</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
</tr>
<tr>
<td>Wax</td>
</tr>
<tr>
<td>Dry Soil (W_d)</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
</tr>
<tr>
<td>Volume in CC</td>
</tr>
<tr>
<td>Wet Soil (V)</td>
</tr>
<tr>
<td>Wax</td>
</tr>
<tr>
<td>Density (KN/m³)</td>
</tr>
<tr>
<td>Dry Density (ρo) = (W_d/V)^9.8</td>
</tr>
<tr>
<td>Specific Volume (V_f) = 1/ρ</td>
</tr>
</tbody>
</table>

* E_5 was calculated by averaging the last three readings from soil suction test results
### Table C.4(a): Summary of soil suction, water content, and specific volume test result for Alford City soil

<table>
<thead>
<tr>
<th></th>
<th>Series A</th>
<th>Dry density 19.4 kN/m³</th>
<th>Water content: 7.6%</th>
</tr>
</thead>
</table>

#### A. Soil Suction Test

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample container No.</td>
<td>54</td>
<td>55</td>
<td>58</td>
<td>60</td>
<td>51</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Water content (g/hr)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E25, Microvolts</td>
<td>4.13</td>
<td>3.97</td>
<td>3.00</td>
<td>3.44</td>
<td>3.41</td>
<td>3.31</td>
<td>3.96</td>
<td>4.12</td>
<td>3.77</td>
</tr>
<tr>
<td>Soil Suction, Tons/ft² (g)</td>
<td>3.98</td>
<td>3.29</td>
<td>2.93</td>
<td>3.20</td>
<td>3.30</td>
<td>3.29</td>
<td>2.70</td>
<td>3.00</td>
<td>2.48</td>
</tr>
<tr>
<td>Soil Suction, kPa (g)</td>
<td>330.59</td>
<td>314.94</td>
<td>280.52</td>
<td>306.32</td>
<td>315.38</td>
<td>315.10</td>
<td>259.69</td>
<td>285.63</td>
<td>237.57</td>
</tr>
</tbody>
</table>

#### B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>267.9</th>
<th>332.9</th>
<th>283</th>
<th>329.3</th>
<th>298</th>
<th>301.2</th>
<th>334</th>
<th>306.9</th>
<th>377.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tare Plus Dry Soil</td>
<td>266.6</td>
<td>227.5</td>
<td>250.1</td>
<td>322.9</td>
<td>293.8</td>
<td>266.8</td>
<td>326.9</td>
<td>301.4</td>
<td>364.6</td>
<td></td>
</tr>
<tr>
<td>Water (Wₜ)</td>
<td>1.3</td>
<td>5.4</td>
<td>2.9</td>
<td>5.4</td>
<td>4.2</td>
<td>4.4</td>
<td>7.1</td>
<td>5.5</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Tare</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>238.1</td>
<td>257.1</td>
<td>227.1</td>
<td>227.1</td>
<td></td>
</tr>
<tr>
<td>Dry Soil (Wₜ)</td>
<td>29.5</td>
<td>90.4</td>
<td>43</td>
<td>65.8</td>
<td>55.7</td>
<td>53.7</td>
<td>69.8</td>
<td>64.3</td>
<td>127.5</td>
<td></td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>4.41%</td>
<td>5.97%</td>
<td>6.74%</td>
<td>7.46%</td>
<td>7.41%</td>
<td>7.50%</td>
<td>7.91%</td>
<td>8.55%</td>
<td>10.20%</td>
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</tr>
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</table>

#### C. Specific Volume

<table>
<thead>
<tr>
<th>Test Temperature of Water (°C)</th>
<th>45°C</th>
<th>40°C</th>
<th>35°C</th>
<th>30°C</th>
<th>25°C</th>
<th>20°C</th>
<th>15°C</th>
<th>10°C</th>
<th>31°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>132.3</td>
<td>134.5</td>
<td>141.9</td>
<td>113.2</td>
<td>136.5</td>
<td>141.1</td>
<td>74.2</td>
<td>144.3</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
<td>117.8</td>
<td>123.3</td>
<td>122.3</td>
<td>102.6</td>
<td>115</td>
<td>127.1</td>
<td>65.2</td>
<td>127.3</td>
<td></td>
</tr>
<tr>
<td>Wax</td>
<td>14.5</td>
<td>11.2</td>
<td>10.5</td>
<td>19.6</td>
<td>13.6</td>
<td>11.5</td>
<td>14</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
<td>44.5</td>
<td>49.5</td>
<td>27.8</td>
<td>45.6</td>
<td>43.8</td>
<td>44.8</td>
<td>49.5</td>
<td>25.4</td>
<td>50.1</td>
</tr>
<tr>
<td>Dry Soil (Wₜ)</td>
<td>112.83</td>
<td>116.35</td>
<td>69.61</td>
<td>113.81</td>
<td>95.52</td>
<td>106.88</td>
<td>117.79</td>
<td>60.06</td>
<td>115.52</td>
</tr>
<tr>
<td>Volume in CC</td>
<td>Wet soil and Wax</td>
<td>87.8</td>
<td>85</td>
<td>57</td>
<td>95.2</td>
<td>69.4</td>
<td>81.7</td>
<td>91.6</td>
<td>48.8</td>
</tr>
<tr>
<td>Wet Soil (V)</td>
<td>26.36</td>
<td>20.36</td>
<td>19.09</td>
<td>35.64</td>
<td>15.27</td>
<td>20.91</td>
<td>25.45</td>
<td>16.36</td>
<td>30.91</td>
</tr>
<tr>
<td>Wax</td>
<td>61.44</td>
<td>64.64</td>
<td>37.91</td>
<td>59.56</td>
<td>55.13</td>
<td>60.79</td>
<td>66.15</td>
<td>32.44</td>
<td>63.29</td>
</tr>
<tr>
<td>Dry Density (µₗ) = (Wₜ/VT) * 9.8</td>
<td>18.00</td>
<td>17.64</td>
<td>17.99</td>
<td>18.73</td>
<td>16.88</td>
<td>17.25</td>
<td>17.45</td>
<td>18.15</td>
<td>17.89</td>
</tr>
<tr>
<td>Specific Volume (VV)</td>
<td>0.056</td>
<td>0.057</td>
<td>0.056</td>
<td>0.053</td>
<td>0.054</td>
<td>0.058</td>
<td>0.057</td>
<td>0.055</td>
<td>0.056</td>
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* E25 was calculated by averaging the last three readings from soil suction test results
Table C.4(b): Summary of soil suction, water content, and specific volume test result for Alford City soil

Series B

<table>
<thead>
<tr>
<th>A. Soil Suction Test</th>
<th></th>
<th></th>
<th></th>
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<th></th>
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<tbody>
<tr>
<td>Psychrometer No.</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>5B</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9B</td>
</tr>
<tr>
<td>Sample container No.</td>
<td>54</td>
<td>55</td>
<td>58</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Water content Inclrement (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>Soil Suction, Tons/ft2 (s)</td>
<td>4.32</td>
<td>3.30</td>
<td>2.70</td>
<td>2.82</td>
<td>2.68</td>
<td>2.43</td>
<td>2.33</td>
<td>2.52</td>
<td>2.28</td>
</tr>
<tr>
<td>Soil Suction, kPa (s)</td>
<td>413.00</td>
<td>316.21</td>
<td>258.66</td>
<td>269.91</td>
<td>276.01</td>
<td>232.31</td>
<td>223.26</td>
<td>241.26</td>
<td>218.27</td>
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</table>

<table>
<thead>
<tr>
<th>B. Water Content</th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Tare Plus Wet Soil</td>
<td>268.5</td>
<td>333.4</td>
<td>284.1</td>
<td>330</td>
<td>299.51</td>
<td>301.9</td>
<td>334.94</td>
<td>337.34</td>
</tr>
<tr>
<td>Tare Plus Dry Soil</td>
<td>267.2</td>
<td>328.1</td>
<td>281</td>
<td>323.5</td>
<td>295.21</td>
<td>297.31</td>
<td>327.64</td>
<td>331.99</td>
<td>365.13</td>
</tr>
<tr>
<td>Water (W_d)</td>
<td>1.3</td>
<td>5.3</td>
<td>3.1</td>
<td>6.5</td>
<td>4.3</td>
<td>4.59</td>
<td>7.3</td>
<td>5.35</td>
<td>13.31</td>
</tr>
<tr>
<td>Tare &amp; Dry Soil</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td>237.1</td>
<td></td>
</tr>
<tr>
<td>Dry Soil (W_d)</td>
<td>30.1</td>
<td>91</td>
<td>43.9</td>
<td>86.4</td>
<td>58.11</td>
<td>59.21</td>
<td>90.54</td>
<td>64.69</td>
<td>128.03</td>
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</table>

<table>
<thead>
<tr>
<th>C. Specific Volume</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Temperature of Water (°C)</td>
<td>45°C</td>
<td>40°C</td>
<td>39°C</td>
<td>37°C</td>
<td>35°C</td>
<td>34°C</td>
<td>33°C</td>
<td>31°C</td>
<td>30°C</td>
</tr>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>133.13</td>
<td>133.64</td>
<td>86.2</td>
<td>142.33</td>
<td>113.66</td>
<td>127.77</td>
<td>146.19</td>
<td>80.81</td>
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<td>Wet Soil (W_d)</td>
<td>118.56</td>
<td>123.98</td>
<td>76.3</td>
<td>122.54</td>
<td>102.64</td>
<td>115.88</td>
<td>129.26</td>
<td>71.67</td>
<td>143.59</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
<td>44.37</td>
<td>49.61</td>
<td>27.64</td>
<td>44.31</td>
<td>43.11</td>
<td>44.67</td>
<td>48.54</td>
<td>25.97</td>
<td>52.6</td>
</tr>
<tr>
<td>Dry Soil (W_d)</td>
<td>113.16</td>
<td>117.16</td>
<td>71.27</td>
<td>113.97</td>
<td>95.57</td>
<td>107.54</td>
<td>119.62</td>
<td>63.21</td>
<td>130.07</td>
</tr>
<tr>
<td>Volume in CC</td>
<td>Wet soil and Wax</td>
<td>88.76</td>
<td>84.03</td>
<td>58.56</td>
<td>98.02</td>
<td>70.55</td>
<td>53.1</td>
<td>97.65</td>
<td>54.84</td>
</tr>
<tr>
<td>Wax</td>
<td>26.49</td>
<td>17.56</td>
<td>18.00</td>
<td>35.96</td>
<td>20.04</td>
<td>21.62</td>
<td>30.78</td>
<td>15.62</td>
<td>44.27</td>
</tr>
<tr>
<td>Wet Soil (V)</td>
<td>62.27</td>
<td>66.47</td>
<td>40.56</td>
<td>62.04</td>
<td>50.51</td>
<td>61.48</td>
<td>66.87</td>
<td>33.22</td>
<td>7.07</td>
</tr>
<tr>
<td>Density KN/m³</td>
<td>Wet Density (ρ) = (V/ρ)*g</td>
<td>18.68</td>
<td>18.28</td>
<td>18.44</td>
<td>19.36</td>
<td>19.91</td>
<td>18.47</td>
<td>18.94</td>
<td>18.38</td>
</tr>
<tr>
<td>Dry Density (ρ_d) = (W_d/ρ)*g</td>
<td>17.89</td>
<td>17.27</td>
<td>17.22</td>
<td>18.00</td>
<td>18.54</td>
<td>17.14</td>
<td>17.53</td>
<td>18.98</td>
<td>17.94</td>
</tr>
<tr>
<td>Specific Volume (V_s) = 1/ρ_d</td>
<td>0.056</td>
<td>0.058</td>
<td>0.058</td>
<td>0.058</td>
<td>0.058</td>
<td>0.057</td>
<td>0.057</td>
<td>0.059</td>
<td>0.056</td>
</tr>
</tbody>
</table>

* E25 was calculated by averaging the last three readings from soil suction test results.
Table C.5(a): Summary of soil suction, water content, and specific volume test result for Marion County soil

### A. Soil Suction Test

<table>
<thead>
<tr>
<th>Psychrometer No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample container No.</td>
<td>54</td>
<td>55</td>
<td>58</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Water content increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>6.22</td>
<td>4.68</td>
<td>4.22</td>
<td>4.37</td>
<td>3.64</td>
<td>3.40</td>
<td>3.53</td>
<td>3.00</td>
<td>3.08</td>
</tr>
<tr>
<td>Soil Suction, Tons/t2 (s)</td>
<td>6.77</td>
<td>4.44</td>
<td>4.55</td>
<td>4.44</td>
<td>3.59</td>
<td>3.41</td>
<td>2.15</td>
<td>1.48</td>
<td>1.55</td>
</tr>
<tr>
<td>Soil Suction, kPa (s)</td>
<td>547.73</td>
<td>425.33</td>
<td>435.30</td>
<td>424.86</td>
<td>343.47</td>
<td>325.94</td>
<td>205.79</td>
<td>141.37</td>
<td>148.48</td>
</tr>
</tbody>
</table>

### B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>271.3</th>
<th>268.3</th>
<th>278.5</th>
<th>277</th>
<th>271.3</th>
<th>-273.5</th>
<th>274.5</th>
<th>260.4</th>
<th>279.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tare Plus Dry Soil</td>
<td>263.8</td>
<td>257</td>
<td>267.4</td>
<td>265.3</td>
<td>259.9</td>
<td>261.7</td>
<td>262.4</td>
<td>247.7</td>
<td>264.1</td>
<td></td>
</tr>
<tr>
<td>Water (Ww)</td>
<td>7.5</td>
<td>9.3</td>
<td>11.1</td>
<td>11.7</td>
<td>11.4</td>
<td>11.8</td>
<td>12.1</td>
<td>12.7</td>
<td>15.8</td>
<td></td>
</tr>
<tr>
<td>Tare</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td>134.1</td>
<td></td>
</tr>
<tr>
<td>Dry Soil (Ww)</td>
<td>129.7</td>
<td>122.9</td>
<td>133.3</td>
<td>131.2</td>
<td>125.8</td>
<td>127.6</td>
<td>128.3</td>
<td>113.6</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>5.78%</td>
<td>7.57%</td>
<td>8.33%</td>
<td>8.92%</td>
<td>9.06%</td>
<td>9.25%</td>
<td>9.43%</td>
<td>11.18%</td>
<td>12.15%</td>
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</tbody>
</table>

### C. Specific Volume

<table>
<thead>
<tr>
<th>Test Temperature of Water (°C)</th>
<th>44</th>
<th>39</th>
<th>36</th>
<th>33</th>
<th>32</th>
<th>31</th>
<th>30</th>
<th>29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>161.3</td>
<td>152.7</td>
<td>167</td>
<td>166.3</td>
<td>156.3</td>
<td>153.2</td>
<td>161.8</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
<td>141.3</td>
<td>133.1</td>
<td>144.8</td>
<td>143.8</td>
<td>138.2</td>
<td>136</td>
<td>141.1</td>
<td>125.8</td>
</tr>
<tr>
<td>Wax</td>
<td>20</td>
<td>19.8</td>
<td>22.2</td>
<td>22.5</td>
<td>18.1</td>
<td>17.2</td>
<td>20.7</td>
<td>15.4</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water Dry Soil (Ww)</td>
<td>53.7</td>
<td>49.1</td>
<td>55.1</td>
<td>54.93</td>
<td>52.2</td>
<td>51.6</td>
<td>53.05</td>
<td>49</td>
</tr>
<tr>
<td>Wet soil and Wax</td>
<td>133.58</td>
<td>123.74</td>
<td>133.67</td>
<td>132.03</td>
<td>126.72</td>
<td>124.49</td>
<td>128.94</td>
<td>131.15</td>
</tr>
<tr>
<td>Wax</td>
<td>107.16</td>
<td>104.6</td>
<td>111.9</td>
<td>111.37</td>
<td>104.1</td>
<td>101.6</td>
<td>108.75</td>
<td>92.2</td>
</tr>
<tr>
<td>CC</td>
<td>36.36</td>
<td>35.64</td>
<td>40.36</td>
<td>40.91</td>
<td>32.91</td>
<td>31.27</td>
<td>37.64</td>
<td>28.00</td>
</tr>
<tr>
<td>Wet Soil (Vw)</td>
<td>71.24</td>
<td>68.98</td>
<td>71.54</td>
<td>70.46</td>
<td>71.19</td>
<td>73.33</td>
<td>71.11</td>
<td>64.20</td>
</tr>
<tr>
<td>Density Kt/m³</td>
<td>Wet Density (ρw) = (W/w)*9.8</td>
<td>19.44</td>
<td>18.91</td>
<td>19.64</td>
<td>20.00</td>
<td>19.02</td>
<td>19.95</td>
<td>19.44</td>
</tr>
<tr>
<td>Dry Density (ρd) = (W/w)*9.8</td>
<td>18.38</td>
<td>17.58</td>
<td>18.31</td>
<td>18.36</td>
<td>17.44</td>
<td>17.35</td>
<td>17.77</td>
<td>17.27</td>
</tr>
<tr>
<td>Specific Volume (Vw) = 1/ρw</td>
<td>3.054</td>
<td>0.057</td>
<td>0.055</td>
<td>0.054</td>
<td>0.057</td>
<td>0.058</td>
<td>0.056</td>
<td>0.058</td>
</tr>
</tbody>
</table>

* E25 was calculated by averaging the last three readings from soil suction test results
Table C.5(b) : Summary of soil suction, water content, and specific volume test result for Marion County soil

<table>
<thead>
<tr>
<th>A. Soil Suction Test</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5B</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrometer No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>6.54</td>
<td>5.36</td>
<td>5.31</td>
<td>4.01</td>
<td>4.11</td>
<td>4.50</td>
<td>4.97</td>
<td>3.61</td>
<td>2.68</td>
</tr>
<tr>
<td>Sample container No.</td>
<td>54</td>
<td>55</td>
<td>58</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Water content (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
<td>1hr</td>
<td>N</td>
<td>N</td>
<td>0.5ml</td>
<td>1ml</td>
<td>2ml</td>
<td>4ml</td>
</tr>
<tr>
<td>Soil Suction, Tors/ft2 (y)</td>
<td>6.61</td>
<td>4.66</td>
<td>4.36</td>
<td>3.77</td>
<td>3.86</td>
<td>2.71</td>
<td>2.47</td>
<td>2.22</td>
<td>1.98</td>
</tr>
<tr>
<td>Soil Suction, kPa (s)</td>
<td>632.21</td>
<td>445.62</td>
<td>417.45</td>
<td>360.96</td>
<td>369.03</td>
<td>258.72</td>
<td>236.39</td>
<td>212.84</td>
<td>169.13</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Water Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
</tr>
<tr>
<td>Tare Plus Wet Soil</td>
</tr>
<tr>
<td>Tare Plus Dry Soil</td>
</tr>
<tr>
<td>Water (Ww)</td>
</tr>
<tr>
<td>Tare</td>
</tr>
<tr>
<td>Dry Soil (Wd)</td>
</tr>
<tr>
<td>Water Content (%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Specific Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Temperature of Water (°C)</td>
</tr>
<tr>
<td>Weight in Grams</td>
</tr>
<tr>
<td>Wet Soil and Wax</td>
</tr>
<tr>
<td>Wet Soil (W)</td>
</tr>
<tr>
<td>Wax</td>
</tr>
<tr>
<td>Wet Soil and Wax in Water</td>
</tr>
<tr>
<td>Dry Soil (Wd)</td>
</tr>
<tr>
<td>Volume in CC</td>
</tr>
<tr>
<td>Wet soil and Wax</td>
</tr>
<tr>
<td>Wet Soil (V)</td>
</tr>
<tr>
<td>Density kN/m³</td>
</tr>
<tr>
<td>Wet Density (fW) = (W/W)*9.8</td>
</tr>
<tr>
<td>Dry Density (fD) = (Wd/V)*9.8</td>
</tr>
<tr>
<td>Specific Volume (Vd)</td>
</tr>
</tbody>
</table>

* E25 was calculated by averaging the last three readings from soil suction test results.
### Table C.6(a) : Summary of soil suction, water content, and specific volume test result for Brevard County soil

#### Series A
- **Dry density**: 18.9 KN/m³
- **Water content**: 9.3%

<table>
<thead>
<tr>
<th>A. Soil Suction Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Psychrometer No.</strong></td>
<td><strong>1</strong></td>
</tr>
<tr>
<td>Sample container no.</td>
<td>54</td>
</tr>
<tr>
<td>Water content increment (0, +, -)</td>
<td>4hr</td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>5.74</td>
</tr>
<tr>
<td><strong>Soil Suction, Tons/ft² (+)</strong></td>
<td>6.13</td>
</tr>
<tr>
<td><strong>Soil Suction, kPa (1)</strong></td>
<td>586.14</td>
</tr>
</tbody>
</table>

#### B. Water Content

<table>
<thead>
<tr>
<th>Weight</th>
<th>Weight (Water)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tare Plus Wet Soil</strong></td>
<td>264.42</td>
</tr>
<tr>
<td><strong>Tare Plus Dry Soil</strong></td>
<td>256.85</td>
</tr>
<tr>
<td><strong>Water (W)</strong></td>
<td>7.57</td>
</tr>
<tr>
<td><strong>Grams</strong></td>
<td>134.25</td>
</tr>
<tr>
<td><strong>Dry Soil (Wd)</strong></td>
<td>122.6</td>
</tr>
<tr>
<td><strong>Water Content (%)</strong></td>
<td>6.17%</td>
</tr>
</tbody>
</table>

#### C. Specific Volume

<table>
<thead>
<tr>
<th>Test Temperature of Water (°C)</th>
<th>36</th>
<th>34.2</th>
<th>32.4</th>
<th>31.2</th>
<th>33</th>
<th>30.7</th>
<th>33.5</th>
<th>32.6</th>
<th>31.3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
<td><strong>Weight and Wax</strong></td>
<td>149.61</td>
<td>146.94</td>
<td>136.29</td>
<td>163.9</td>
<td>159.2</td>
<td>156.7</td>
<td>149.1</td>
<td>135.6</td>
</tr>
<tr>
<td><strong>Weight (W)</strong></td>
<td>130.42</td>
<td>125.38</td>
<td>116.24</td>
<td>137.02</td>
<td>136.9</td>
<td>136.2</td>
<td>126.2</td>
<td>135.3</td>
<td>136.4</td>
</tr>
<tr>
<td><strong>Wax</strong></td>
<td>19.19</td>
<td>21.56</td>
<td>20.05</td>
<td>26.88</td>
<td>22.3</td>
<td>20.5</td>
<td>22.9</td>
<td>21.3</td>
<td>24.3</td>
</tr>
<tr>
<td><strong>Grams</strong></td>
<td><strong>Weight and Wax in Water</strong></td>
<td>45.46</td>
<td>40.84</td>
<td>36.65</td>
<td>47.4</td>
<td>48.52</td>
<td>47.56</td>
<td>43.6</td>
<td>49.4</td>
</tr>
<tr>
<td><strong>Dry Soil (Wd)</strong></td>
<td>122.84</td>
<td>117.21</td>
<td>137.88</td>
<td>125.65</td>
<td>125.56</td>
<td>124.32</td>
<td>114.59</td>
<td>122.37</td>
<td>121.79</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td><strong>Water and Wax</strong></td>
<td>104.15</td>
<td>106.1</td>
<td>99.64</td>
<td>116.5</td>
<td>110.68</td>
<td>105.14</td>
<td>105.5</td>
<td>107.2</td>
</tr>
<tr>
<td><strong>Volume (V)</strong></td>
<td>34.89</td>
<td>39.20</td>
<td>36.45</td>
<td>46.87</td>
<td>43.55</td>
<td>37.27</td>
<td>41.64</td>
<td>38.73</td>
<td>44.18</td>
</tr>
<tr>
<td><strong>CC</strong></td>
<td><strong>Water and Soil (V)</strong></td>
<td>69.26</td>
<td>66.90</td>
<td>63.19</td>
<td>67.63</td>
<td>73.13</td>
<td>71.87</td>
<td>63.66</td>
<td>68.47</td>
</tr>
<tr>
<td><strong>Specific Volume (Vd) = 1/(ρd)</strong></td>
<td>0.058</td>
<td>0.058</td>
<td>0.058</td>
<td>0.058</td>
<td>0.057</td>
<td>0.059</td>
<td>0.057</td>
<td>0.057</td>
<td>0.056</td>
</tr>
</tbody>
</table>

* E25 was calculated by averaging the last three readings from soil suction test results
Table C.6(b): Summary of soil suction, water content, and specific volume test result for Brevard County soil

Series B

<table>
<thead>
<tr>
<th>A. Soil Suction Test</th>
<th>Dry density: 18.9 KN/m³</th>
<th>Water content: 9.3%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrometer No.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sample container No.</td>
<td>54</td>
<td>55</td>
</tr>
<tr>
<td>Water content increment (0, +, -)</td>
<td>4hr</td>
<td>2hr</td>
</tr>
<tr>
<td>E25, Microvolts*</td>
<td>6.55</td>
<td>5.87</td>
</tr>
<tr>
<td>Soil Suction, Tors/t2 (τ)</td>
<td>6.62</td>
<td>5.31</td>
</tr>
<tr>
<td>Soil Suction, kPa (τ)</td>
<td>633.82</td>
<td>507.88</td>
</tr>
</tbody>
</table>

B. Water Content

<table>
<thead>
<tr>
<th>Weight in Grams</th>
<th>Tare Plus Wet Soil</th>
<th>Tare Plus Dry Soil</th>
<th>Water (W₁)</th>
<th>Tare</th>
<th>Dry Soil (W₂)</th>
<th>Water Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>274.85</td>
<td>278.97</td>
<td>279.72</td>
<td>281.41</td>
<td>272.15</td>
<td>281.29</td>
</tr>
<tr>
<td></td>
<td>266.49</td>
<td>268.99</td>
<td>269.78</td>
<td>261.41</td>
<td>269.24</td>
<td>270.42</td>
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<td></td>
<td>8.37</td>
<td>9.98</td>
<td>10.73</td>
<td>11.63</td>
<td>10.74</td>
<td>12.05</td>
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<td></td>
<td>139.55</td>
<td>139.55</td>
<td>139.55</td>
<td>139.55</td>
<td>139.57</td>
<td>139.55</td>
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<td></td>
<td>126.94</td>
<td>129.44</td>
<td>129.44</td>
<td>130.23</td>
<td>121.86</td>
<td>29.69</td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>6.59%</td>
<td>7.71%</td>
<td>8.29%</td>
<td>8.93%</td>
<td>5.81%</td>
<td>9.29%</td>
</tr>
</tbody>
</table>

C. Specific Volume

<table>
<thead>
<tr>
<th>Test Temperature of Water (°C)</th>
<th>36</th>
<th>34.2</th>
<th>32.4</th>
<th>31.2</th>
<th>33</th>
<th>30.7</th>
<th>33.5</th>
<th>32.6</th>
<th>31.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Grams</td>
<td>Wet Soil and Wax</td>
<td>Wet Soil (W₁)</td>
<td>Wax</td>
<td>Wet Soil and Wax in Water</td>
<td>Dry Soil (W₂)</td>
<td>Wet Soil (V)</td>
<td>Wax</td>
<td>CC</td>
<td>Wet Soil (V)</td>
</tr>
<tr>
<td>148.61</td>
<td>146.94</td>
<td>136.26</td>
<td>163.9</td>
<td>159.2</td>
<td>156.7</td>
<td>149.1</td>
<td>156.6</td>
<td>160.7</td>
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<tr>
<td>130.42</td>
<td>125.38</td>
<td>116.24</td>
<td>137.02</td>
<td>136.9</td>
<td>136.2</td>
<td>126.2</td>
<td>135.3</td>
<td>136.4</td>
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<tr>
<td>19.15</td>
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<td>26.88</td>
<td>22.3</td>
<td>20.5</td>
<td>22.9</td>
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<td>24.3</td>
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</tr>
<tr>
<td>45.46</td>
<td>40.84</td>
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<td>47.4</td>
<td>48.52</td>
<td>47.56</td>
<td>43.6</td>
<td>49.4</td>
<td>49.63</td>
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<tr>
<td>122.35</td>
<td>116.41</td>
<td>107.34</td>
<td>125.79</td>
<td>125.81</td>
<td>124.62</td>
<td>114.90</td>
<td>122.20</td>
<td>122.10</td>
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</tr>
<tr>
<td>Volume in Wax</td>
<td>Wet soil and Wax</td>
<td>Wet soil (W₁)</td>
<td>Wax</td>
<td>Wet soil and Wax in Water</td>
<td>Dry soil (W₂)</td>
<td>Wet soil (V)</td>
<td>Wax</td>
<td>CC</td>
<td>Wet soil (V)</td>
</tr>
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<td>104.15</td>
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<td>110.9</td>
<td>109.14</td>
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<td>111.07</td>
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<td>34.69</td>
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<td>40.55</td>
<td>37.27</td>
<td>41.64</td>
<td>38.73</td>
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<tr>
<td>69.26</td>
<td>66.90</td>
<td>63.19</td>
<td>67.53</td>
<td>70.13</td>
<td>71.87</td>
<td>63.86</td>
<td>68.47</td>
<td>65.69</td>
<td></td>
</tr>
<tr>
<td>Density kN/m³</td>
<td>Wet Density (ρₘ) = (W/V)*9.8</td>
<td>18.45</td>
<td>18.37</td>
<td>18.03</td>
<td>18.86</td>
<td>18.13</td>
<td>18.57</td>
<td>19.37</td>
<td>19.36</td>
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<tr>
<td>17.31</td>
<td>17.05</td>
<td>16.65</td>
<td>18.23</td>
<td>17.58</td>
<td>16.99</td>
<td>17.63</td>
<td>17.49</td>
<td>17.89</td>
<td></td>
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<tr>
<td>Specific Volume (V₂) = 1/ρₘ</td>
<td>0.059</td>
<td>0.059</td>
<td>0.060</td>
<td>0.055</td>
<td>0.057</td>
<td>0.059</td>
<td>0.057</td>
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<td>0.056</td>
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</tbody>
</table>

* E₂₅ was calculated by averaging the last three readings from soil suction test results.
Figure C.1: Comparison of suction values from Series A and Series B for Clay County soil.
Figure C.2: Comparison of suction values from Series A and Series B for Marion County soil

Soil Suction vs Water Content

(Marion County)

#200 fines = 25.1%, Clay content = 12%

OMC = 8.5%
Figure C.3: Comparison of suction values from Series A and Series B for Alford City soil
Figure C.4: Comparison of suction values from Series A and Series B for Jacobs Road soil.
Soil Suction vs Water Content

(Marion County)

-#200 fines = 19.9%, Clay content = 12%

OMC = 9.3%

Figure C.6: Comparison of suction values from Series A and Series B for Marion County soil
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Table D.1: Summary of soil drying rate (Group I) test results

(Temperature: 30°C, Relative Humidity: 95%)

Sample Surface Area = 0.487 ft²

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>19.4</td>
<td>20.1</td>
<td>20.1</td>
<td>20.0</td>
<td>20.0</td>
<td>18.8</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>9.10</td>
<td>8.50</td>
<td>7.90</td>
<td>9.20</td>
<td>9.20</td>
<td>9.25</td>
</tr>
<tr>
<td>Initial water weight (gram)</td>
<td>169.92</td>
<td>164.49</td>
<td>152.68</td>
<td>177.37</td>
<td>177.37</td>
<td>166.90</td>
</tr>
<tr>
<td>Total elapsed time [hour]</td>
<td>282.60</td>
<td>280.60</td>
<td>254.78</td>
<td>255.45</td>
<td>254.30</td>
<td>253.62</td>
</tr>
<tr>
<td>Total water loss [gram]</td>
<td>127.60</td>
<td>96.80</td>
<td>100.00</td>
<td>114.00</td>
<td>33.90</td>
<td>99.70</td>
</tr>
<tr>
<td>Average drying rate, [gram per hour per ft²]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within first 90 hours</td>
<td>2.07</td>
<td>1.74</td>
<td>1.60</td>
<td>1.66</td>
<td>1.47</td>
<td>1.34</td>
</tr>
<tr>
<td>Within first 200 hours</td>
<td>1.23</td>
<td>0.94</td>
<td>0.99</td>
<td>1.13</td>
<td>0.84</td>
<td>0.94</td>
</tr>
<tr>
<td>Drying rate, [gram per hour per ft²]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ water content = 2%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.29</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>1.06</td>
<td>0.29</td>
<td>0.92</td>
<td>1.63</td>
<td>-</td>
<td>0.53</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>1.93</td>
<td>1.53</td>
<td>1.54</td>
<td>2.50</td>
<td>0.77</td>
<td>0.77</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>8.08</td>
<td>6.35</td>
<td>3.65</td>
<td>-</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>@ optimum water content</td>
<td>14.78</td>
<td>6.98</td>
<td>3.70</td>
<td>3.70</td>
<td>3.49</td>
<td>3.59</td>
</tr>
</tbody>
</table>
Table D.2: Summary of soil drying rate (Group I) test results
(Temperature: 10°C, Relative Humidity: 75%)

Sample Surface Area = 0.487 ft²

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Allord</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>19.3</td>
<td>20.1</td>
<td>19.7</td>
<td>19.5</td>
<td>19.8</td>
<td>18.6</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>9.10</td>
<td>8.50</td>
<td>7.90</td>
<td>7.60</td>
<td>9.30</td>
<td>9.20</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>169.00</td>
<td>164.36</td>
<td>150.11</td>
<td>143.02</td>
<td>177.01</td>
<td>164.72</td>
</tr>
<tr>
<td>Total elapsed time [hour]</td>
<td>240.15</td>
<td>239.55</td>
<td>238.52</td>
<td>238.98</td>
<td>238.07</td>
<td>237.30</td>
</tr>
<tr>
<td>Total water loss [gram]</td>
<td>141.00</td>
<td>129.10</td>
<td>119.60</td>
<td>118.10</td>
<td>105.60</td>
<td>123.00</td>
</tr>
</tbody>
</table>

Average drying rate , [gram per hour per ft²]

<p>| | | | | | | |</p>
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<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Within first 90 hours</td>
<td>2.74</td>
<td>2.60</td>
<td>2.42</td>
<td>2.43</td>
<td>2.14</td>
<td>2.33</td>
</tr>
<tr>
<td>Within first 200 hours</td>
<td>1.43</td>
<td>1.31</td>
<td>1.21</td>
<td>1.19</td>
<td>1.09</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Drying rate, [gram per hour per ft²]

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>@ water content = 2%</td>
<td>0.32</td>
<td>0.18</td>
<td>0.25</td>
<td>0.42</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>2.40</td>
<td>2.83</td>
<td>2.80</td>
<td>4.71</td>
<td>0.19</td>
<td>1.12</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>5.25</td>
<td>5.39</td>
<td>5.42</td>
<td>5.45</td>
<td>3.05</td>
<td>3.65</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>8.64</td>
<td>12.82</td>
<td>-</td>
<td>-</td>
<td>6.42</td>
<td>7.74</td>
</tr>
<tr>
<td>@ optimum water content</td>
<td>12.94</td>
<td>14.37</td>
<td>17.04</td>
<td>13.04</td>
<td>27.72</td>
<td>11.09</td>
</tr>
</tbody>
</table>
Table D.3: Summary of soil drying rate (Group I) test results

(Temperature: 10°C, Relative Humidity: 95%)

Sample Surface Area = 0.487 ft$^2$

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m3]</td>
<td>19.1</td>
<td>20.2</td>
<td>20.2</td>
<td>19.6</td>
<td>20.1</td>
<td>18.7</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>9.10</td>
<td>8.50</td>
<td>7.90</td>
<td>7.60</td>
<td>9.30</td>
<td>9.20</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>167.18</td>
<td>165.15</td>
<td>153.39</td>
<td>143.44</td>
<td>180.04</td>
<td>165.57</td>
</tr>
<tr>
<td>Total elapsed time [hour]</td>
<td>236.37</td>
<td>236.09</td>
<td>235.22</td>
<td>235.82</td>
<td>234.44</td>
<td>233.59</td>
</tr>
<tr>
<td>Total water loss [gram]</td>
<td>118.10</td>
<td>105.40</td>
<td>112.00</td>
<td>108.20</td>
<td>78.50</td>
<td>96.60</td>
</tr>
<tr>
<td>Average drying rate, [gram per hour per ft$^2$]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within first 90 hours</td>
<td>1.89</td>
<td>2.02</td>
<td>2.02</td>
<td>2.09</td>
<td>1.96</td>
<td>1.65</td>
</tr>
<tr>
<td>Within first 200 hours</td>
<td>1.17</td>
<td>1.07</td>
<td>1.13</td>
<td>1.09</td>
<td>0.80</td>
<td>0.97</td>
</tr>
<tr>
<td>Drying rate, [gram per hour per ft$^2$]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ water content = 2%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.14</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>0.95</td>
<td>1.00</td>
<td>1.66</td>
<td>2.19</td>
<td>-</td>
<td>0.22</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>1.79</td>
<td>2.40</td>
<td>2.25</td>
<td>2.42</td>
<td>0.80</td>
<td>1.30</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>2.43</td>
<td>5.67</td>
<td>-</td>
<td>-</td>
<td>2.00</td>
<td>2.11</td>
</tr>
<tr>
<td>@ optimum water content</td>
<td>7.60</td>
<td>7.80</td>
<td>9.86</td>
<td>7.91</td>
<td>15.91</td>
<td>5.54</td>
</tr>
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</table>
Table D.4: Summary of soil drying rate (Group I) test results
(Temperature: 25°C, Relative Humidity: 55%)

Sample Surface Area = 0.487 ft²

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Allord</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>19.5</td>
<td>19.9</td>
<td>19.8</td>
<td>19.7</td>
<td>20.0</td>
<td>18.9</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>9.10</td>
<td>8.50</td>
<td>7.90</td>
<td>7.50</td>
<td>9.30</td>
<td>9.20</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>171.00</td>
<td>162.70</td>
<td>150.40</td>
<td>155.35</td>
<td>*78.9c</td>
<td>167.80</td>
</tr>
<tr>
<td>Total elapsed time [hour]</td>
<td>237.13</td>
<td>236.73</td>
<td>234.70</td>
<td>235.57</td>
<td>239.58</td>
<td>233.68</td>
</tr>
<tr>
<td>Total water loss [gram]</td>
<td>154.90</td>
<td>132.50</td>
<td>119.90</td>
<td>132.60</td>
<td>130.00</td>
<td>139.50</td>
</tr>
</tbody>
</table>

Average drying rate, [gram per hour per ft²]

<table>
<thead>
<tr>
<th></th>
<th>Within first 90 hours</th>
<th>Within first 200 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.22</td>
<td>3.29</td>
</tr>
<tr>
<td></td>
<td>2.52</td>
<td>2.84</td>
</tr>
<tr>
<td></td>
<td>2.70</td>
<td>2.70</td>
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<td>2.88</td>
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<td>1.21</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>1.31</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Drying rate, [gram per hour per ft²]

<table>
<thead>
<tr>
<th></th>
<th>@ water content = 2%</th>
<th>@ water content = 4%</th>
<th>@ water content = 6%</th>
<th>@ water content = 8%</th>
<th>@ optimum water content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.84</td>
<td>7.02</td>
<td>11.01</td>
<td>17.00</td>
<td>17.45</td>
</tr>
<tr>
<td></td>
<td>0.26</td>
<td>6.12</td>
<td>11.78</td>
<td>17.30</td>
<td>17.45</td>
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<tr>
<td></td>
<td>0.25</td>
<td>7.39</td>
<td>14.20</td>
<td>-</td>
<td>16.22</td>
</tr>
<tr>
<td></td>
<td>1.50</td>
<td>10.44</td>
<td>13.42</td>
<td>-</td>
<td>14.37</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>1.34</td>
<td>7.06</td>
<td>-</td>
<td>20.53</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>2.28</td>
<td>9.11</td>
<td>-</td>
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</table>
Table D.5: Summary of soil drying rate (Group I) test results
(Temperature: 25°C, Relative Humidity: 75%)

Sample Surface Area = 0.487 ft²

<table>
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<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>19.9</td>
<td>16.9</td>
<td>20.2</td>
<td>19.9</td>
<td>19.9</td>
<td>18.8</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>9.15</td>
<td>8.50</td>
<td>7.90</td>
<td>7.60</td>
<td>9.30</td>
<td>9.25</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>172.30</td>
<td>163.15</td>
<td>153.53</td>
<td>145.21</td>
<td>178.23</td>
<td>167.03</td>
</tr>
<tr>
<td>Total elapsed time [hcur]</td>
<td>257.95</td>
<td>230.33</td>
<td>253.82</td>
<td>250.48</td>
<td>340.10</td>
<td>236.45</td>
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<tr>
<td>Total water loss [garr]</td>
<td>153.90</td>
<td>125.70</td>
<td>124.10</td>
<td>125.20</td>
<td>119.30</td>
<td>129.90</td>
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</table>

Average drying rate, [g/m² per hour per ft²]

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<tr>
<th></th>
<th>Within first 90 hours</th>
<th>Within first 200 hours</th>
</tr>
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<tr>
<td></td>
<td>3.08</td>
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</tr>
<tr>
<td></td>
<td>2.51</td>
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<tr>
<td></td>
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<td>1.25</td>
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<tr>
<td></td>
<td>2.62</td>
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<tr>
<td></td>
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<tr>
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<td>2.65</td>
<td>1.31</td>
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Drying rate, [g/m² per hour per ft²]

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<th>@ water content = 2%</th>
<th>@ water content = 4%</th>
<th>@ water content = 6%</th>
<th>@ water content = 8%</th>
<th>Optimum water content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.58</td>
<td>3.75</td>
<td>7.65</td>
<td>9.20</td>
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<td>2.08</td>
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<tr>
<td></td>
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<td>9.14</td>
<td>-</td>
<td>10.27</td>
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<tr>
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<td>0.67</td>
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<td>-</td>
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<td>4.99</td>
<td>-</td>
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<td>7.21</td>
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<td>10.27</td>
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Table D.5: Summary of soil drying rate (Group I) test results

(Temperature: 25°C, Relative Humidity: 95%)

Sample Surface Area = 0.487 ft²

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<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
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<td>20.0</td>
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<td>20.1</td>
<td>19.0</td>
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<tr>
<td>Initial water content [%]</td>
<td>9.10</td>
<td>8.50</td>
<td>7.90</td>
<td>7.30</td>
<td>9.20</td>
<td>9.25</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>172.10</td>
<td>164.30</td>
<td>152.50</td>
<td>145.30</td>
<td>178.20</td>
<td>169.60</td>
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<td>Total elapsed time [hour]</td>
<td>214.25</td>
<td>214.70</td>
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<td>112.40</td>
<td>79.60</td>
<td>121.00</td>
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Average drying rate, [gram per hour per ft²]

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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Within first 90 hours</td>
<td>1.84</td>
<td>1.65</td>
<td>2.09</td>
<td>2.22</td>
<td>1.65</td>
<td>2.17</td>
</tr>
<tr>
<td>Within first 200 hours</td>
<td>1.15</td>
<td>0.80</td>
<td>1.09</td>
<td>1.13</td>
<td>0.82</td>
<td>1.31</td>
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</table>

Drying rate, [gram per hour per ft²]

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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>@ water content = 2%</td>
<td></td>
<td></td>
<td></td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>0.75</td>
<td>-</td>
<td>1.84</td>
<td>2.22</td>
<td>-</td>
<td>1.16</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>1.49</td>
<td>1.96</td>
<td>0.55</td>
<td>3.21</td>
<td>1.27</td>
<td>2.30</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>3.51</td>
<td>4.96</td>
<td>-</td>
<td></td>
<td>2.58</td>
<td>3.00</td>
</tr>
<tr>
<td>@ optimum water content</td>
<td>6.16</td>
<td>5.54</td>
<td>4.72</td>
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<td>0.88</td>
<td>3.08</td>
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</table>
### Table D.7: Summary of soil drying rate (Group I) test results
(Temperature: 43°C, Relative Humidity: 55%)

Sample Surface Area = 0.487 ft²

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<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>19.7</td>
<td>20.3</td>
<td>20.1</td>
<td>19.9</td>
<td>20.0</td>
<td>19.1</td>
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<tr>
<td>Initial water content [%]</td>
<td>9.10</td>
<td>8.50</td>
<td>7.90</td>
<td>7.60</td>
<td>9.30</td>
<td>9.20</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>172.51</td>
<td>165.89</td>
<td>152.68</td>
<td>145.41</td>
<td>179.59</td>
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<td>Total elapsed time [hour]</td>
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<td>247.75</td>
<td>248.62</td>
<td>248.95</td>
<td>248.43</td>
<td>248.88</td>
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<tr>
<td>Total water loss [gram]</td>
<td>160.50</td>
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<td>134.50</td>
<td>147.40</td>
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**Average drying rate, [gram per hour per ft²]**

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<tr>
<td>Within first 90 hours</td>
<td>3.45</td>
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<td>2.90</td>
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<tr>
<td>Within first 200 hours</td>
<td>1.64</td>
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<td>1.36</td>
<td>1.36</td>
<td>1.38</td>
<td>1.52</td>
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**Drying rate, [gram per hour per ft²]**

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<th></th>
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<th></th>
</tr>
</thead>
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<td>-</td>
<td>1.04</td>
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<td>@ water content = 4%</td>
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<td>13.72</td>
<td>15.10</td>
<td>13.52</td>
</tr>
<tr>
<td>@ water content = 8%</td>
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<td>-</td>
<td>-</td>
<td>14.31</td>
<td>15.79</td>
</tr>
<tr>
<td>@ optimum water content</td>
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<td>19.51</td>
<td>19.51</td>
<td>20.64</td>
<td>22.59</td>
<td>16.84</td>
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Table D.8: Measured soil weight at temperature 0°C & humidity 95% (Group I)

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<th>Humidity (%)</th>
<th>Weight (g)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
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<td></td>
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<td></td>
<td>Clay</td>
<td>Madison</td>
<td>Alford</td>
<td>Jacobs</td>
<td>Brevard</td>
<td>Marion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(19.4,9.1%)</td>
<td>(20.1,8.5%)</td>
<td>(20.7,6%)</td>
<td>(20.1,7.9%)</td>
<td>(18.8,9.25%)</td>
<td>(20.9,2%)</td>
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### Table D.9: Measured soil weight at temperature 10°C & humidity 75% (Group I)

<table>
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<tr>
<th>Date</th>
<th>Time</th>
<th>Temp. °C</th>
<th>Humidity (%)</th>
<th>Clay (19.3,9.1%)</th>
<th>Madison (20.1,8.5%)</th>
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<th>Jacobs (19.7,7.9%)</th>
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Table D.10: Measured soil weight at temperature 10°C & humidity 95% (Group I)

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Table D.11 : Measured soil weight at temperature 25°C & humidity 55% (Group I)

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Table D.12: Measured soil weight (Group I) at temperature 25°C & humidity 75% (Cont’d)

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Table D.14: Measured soil weight (Group I) at temperature 40°C & humidity 55%

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Figure D.1(a): Water loss versus elapsed time at temperature 0°C and 95% relative humidity for six soils (Group I)
Water Content vs Elapsed Time

(Temperature 0°C, Relative Humidity 95%)

Figure D.1(b): Water content versus elapsed time at temperature 0°C and relative humidity 95% for six soils (Group I)
Drying Rate vs Water Content

(Temperature: 0°C, Humidity: 95%)

Figure D.1(c): Drying rate versus water content for six soils at temperature 0°C and 95% relative humidity (Group I)
Figure D.2(a): Water loss versus elapsed time at temperature 10°C and 75% relative humidity for six soils (Group 1)
Figure D.2(b) : Water content versus elapsed time at temperature 10°C and relative humidity 75% for six soils (Group I)
Figure D.2(c): Drying rate versus water content for six soils at temperature 10°C and 75% relative humidity (Group I)
Figure D.3(a): Water loss versus elapsed time at temperature 10°C and 95% relative humidity for six soils (Group I)
Figure D.3(b): Water content versus elapsed time at temperature 10°C and relative humidity 95% for six soils (Group I)
Figure D.3(c): Drying rate versus water content for six soils at temperature 10°C and 95% relative humidity (Group I)
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(Temperature 25°C, Relative Humidity 95%)

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(Temperature 25°C, Relative Humidity 95%)

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(Temperature: 25°C, Humidity: 95%)

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(Madison County)

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<tr>
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<th>Marion</th>
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<td>11.29</td>
<td>12.97</td>
<td>12.70</td>
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<tr>
<td>Initial water weight [gram]</td>
<td>252.12</td>
<td>246.69</td>
<td>239.74</td>
<td>231.61</td>
<td>259.37</td>
<td>251.10</td>
</tr>
<tr>
<td>Total elapsed time [hr]</td>
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<td>119.5</td>
<td>116.9</td>
<td>118.3</td>
<td>117.6</td>
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<tr>
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<td>178.1</td>
<td>177.2</td>
<td>171.1</td>
<td>172.3</td>
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Average drying rate, [gram per hour per ft^2]

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Within first 90 hours</td>
<td>4.03</td>
<td>3.79</td>
<td>3.95</td>
<td>3.97</td>
<td>3.80</td>
<td>3.72</td>
</tr>
<tr>
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Drying rate, [gram per hour per ft^2]

<table>
<thead>
<tr>
<th>Water content</th>
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<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>@ water content = 2%</td>
<td>-</td>
<td>-</td>
<td>0.52</td>
<td>3.65</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>2.99</td>
<td>3.05</td>
<td>3.82</td>
<td>5.71</td>
<td>1.36</td>
<td>1.78</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>4.94</td>
<td>4.89</td>
<td>5.21</td>
<td>7.57</td>
<td>4.42</td>
<td>4.07</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>5.28</td>
<td>5.39</td>
<td>5.74</td>
<td>7.11</td>
<td>6.37</td>
<td>5.50</td>
</tr>
<tr>
<td>@ water content = 10%</td>
<td>5.60</td>
<td>5.76</td>
<td>6.28</td>
<td>7.33</td>
<td>7.57</td>
<td>6.26</td>
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<tr>
<td>@ water content = 12%</td>
<td>7.11</td>
<td>21.55</td>
<td>-</td>
<td>-</td>
<td>13.46</td>
<td>13.64</td>
</tr>
<tr>
<td>@ water content = optimum water content</td>
<td>5.50</td>
<td>5.49</td>
<td>5.74</td>
<td>7.04</td>
<td>8.24</td>
<td>6.09</td>
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Table E.2: Summary of soil drying rate Group II test results
(Temperature: 10°C, Relative Humidity: 95%)

Sample Surface Area = 0.487 ft²

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<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>18.6</td>
<td>19.1</td>
<td>19.1</td>
<td>19.1</td>
<td>18.5</td>
<td>18.3</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>13.02</td>
<td>11.83</td>
<td>11.64</td>
<td>11.11</td>
<td>12.81</td>
<td>12.60</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>262.00</td>
<td>241.90</td>
<td>238.68</td>
<td>227.29</td>
<td>257.25</td>
<td>250.24</td>
</tr>
<tr>
<td>Total elapsed time [hr]</td>
<td>87.0</td>
<td>231.6</td>
<td>232.5</td>
<td>232.7</td>
<td>235.2</td>
<td>231.2</td>
</tr>
<tr>
<td>Total water loss [gram]</td>
<td>174.1</td>
<td>147.4</td>
<td>160.4</td>
<td>167.9</td>
<td>145.3</td>
<td>161.3</td>
</tr>
<tr>
<td>Average drying rate, [gram per hour per ft²]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within first 90 hours</td>
<td>2.23</td>
<td>2.34</td>
<td>2.20</td>
<td>2.73</td>
<td>2.32</td>
<td>2.15</td>
</tr>
<tr>
<td>Within first 200 hours</td>
<td>1.68</td>
<td>1.60</td>
<td>1.61</td>
<td>1.70</td>
<td>1.47</td>
<td>1.53</td>
</tr>
<tr>
<td>Drying rate, [gram per hour per ft²]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ water content = 2%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>0.86</td>
<td>0.33</td>
<td>1.03</td>
<td>2.30</td>
<td>-</td>
<td>0.67</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>1.44</td>
<td>1.98</td>
<td>1.97</td>
<td>2.51</td>
<td>1.23</td>
<td>1.55</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>1.88</td>
<td>2.15</td>
<td>1.99</td>
<td>2.62</td>
<td>2.04</td>
<td>1.94</td>
</tr>
<tr>
<td>@ water content = 10%</td>
<td>2.15</td>
<td>2.29</td>
<td>2.15</td>
<td>2.77</td>
<td>2.25</td>
<td>2.04</td>
</tr>
<tr>
<td>@ water content = 12%</td>
<td>2.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.51</td>
<td>5.25</td>
</tr>
<tr>
<td>@ water content = optimum water content</td>
<td>1.96</td>
<td>2.15</td>
<td>1.99</td>
<td>2.56</td>
<td>2.10</td>
<td>1.94</td>
</tr>
</tbody>
</table>
Table E.3: Summary of soil drying rate Group II test results

(Temperature: 25°C, Relative Humidity: 75%)

Sample Surface Area = 0.487 ft²

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacoos</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>18.5</td>
<td>19.0</td>
<td>19.0</td>
<td>19.0</td>
<td>18.3</td>
<td>18.1</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>13.30</td>
<td>11.70</td>
<td>12.00</td>
<td>11.70</td>
<td>13.20</td>
<td>12.90</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>236.10</td>
<td>213.00</td>
<td>219.10</td>
<td>214.50</td>
<td>232.50</td>
<td>225.30</td>
</tr>
<tr>
<td>Total elapsed time [hr]</td>
<td>95.6</td>
<td>95.2</td>
<td>94.2</td>
<td>93.0</td>
<td>93.4</td>
<td>90.3</td>
</tr>
<tr>
<td>Total water loss [gram]</td>
<td>195.0</td>
<td>168.0</td>
<td>185.3</td>
<td>186.0</td>
<td>177.0</td>
<td>180.6</td>
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</tbody>
</table>

Average drying rate, [gram per hour per ft²]

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Within first 90 hours</td>
<td>4.43</td>
<td>3.74</td>
<td>4.18</td>
<td>4.18</td>
<td>3.99</td>
<td>3.99</td>
</tr>
<tr>
<td>Within first 200 hours</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

Drying rate, [gram per hour per ft²]

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>@ water content = 2%</td>
<td>-</td>
<td>-</td>
<td>0.75</td>
<td>1.02</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>@ water content = 4%</td>
<td>4.00</td>
<td>4.30</td>
<td>5.36</td>
<td>7.44</td>
<td>1.99</td>
<td>2.82</td>
</tr>
<tr>
<td>@ water content = 6%</td>
<td>6.50</td>
<td>7.30</td>
<td>7.60</td>
<td>9.53</td>
<td>6.20</td>
<td>5.94</td>
</tr>
<tr>
<td>@ water content = 8%</td>
<td>7.30</td>
<td>8.40</td>
<td>8.96</td>
<td>10.74</td>
<td>9.30</td>
<td>7.93</td>
</tr>
<tr>
<td>@ water content = 10%</td>
<td>7.52</td>
<td>8.00</td>
<td>8.86</td>
<td>10.67</td>
<td>11.20</td>
<td>9.98</td>
</tr>
<tr>
<td>@ water content = 12%</td>
<td>7.80</td>
<td>-</td>
<td>14.37</td>
<td>10.52</td>
<td>11.60</td>
<td>10.83</td>
</tr>
<tr>
<td>@ water content = optimum water content</td>
<td>7.53</td>
<td>8.30</td>
<td>8.67</td>
<td>10.60</td>
<td>11.20</td>
<td>9.13</td>
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</table>
### Table E.4: Summary of soil drying rate Group II test results

(Temperature: 25°C, Relative Humidity: 95%)

Sample Surface Area = 0.487 ft²

<table>
<thead>
<tr>
<th></th>
<th>Clay</th>
<th>Madison</th>
<th>Jacobs</th>
<th>Alford</th>
<th>Marion</th>
<th>Brevard</th>
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<tbody>
<tr>
<td>Dry density [KN/m³]</td>
<td>18.2</td>
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<td>18.7</td>
<td>18.6</td>
<td>18.5</td>
<td>18.0</td>
</tr>
<tr>
<td>Initial water content [%]</td>
<td>13.87</td>
<td>12.56</td>
<td>12.14</td>
<td>12.66</td>
<td>13.05</td>
<td>13.47</td>
</tr>
<tr>
<td>Initial water weight [gram]</td>
<td>372.30</td>
<td>251.95</td>
<td>245.11</td>
<td>255.20</td>
<td>263.22</td>
<td>264.65</td>
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<tr>
<td>Total elapsed time [hr]</td>
<td>287.5</td>
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<td>286.2</td>
<td>286.5</td>
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<td>287.0</td>
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<tr>
<td>Total water loss [gram]</td>
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<td>144.0</td>
<td>159.4</td>
<td>186.5</td>
<td>142.0</td>
<td>179.0</td>
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Average drying rate, [gram per hour per ft²]

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<tr>
<th></th>
<th>Within first 90 hours</th>
<th>Within first 200 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.03</td>
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<td></td>
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<tr>
<td></td>
<td>2.00</td>
<td>1.67</td>
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</table>

Drying rate, [gram per hour per ft²]

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<thead>
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<th>Water content</th>
<th>2%</th>
<th>4%</th>
<th>6%</th>
<th>8%</th>
<th>10%</th>
<th>12%</th>
<th>Optimum water content</th>
</tr>
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<tbody>
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<td>-</td>
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<td>-</td>
<td>-</td>
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</tr>
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Table E.5: Measured soil weight at temperature 10°C & humidity 75% (Group II)

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<th>Alford (19.1.11.3%)</th>
<th>Jacobs (19.1.11.7%)</th>
<th>Brevard (18.2.12.7%)</th>
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Total elapsed time: 118.84
Dry Soil: 1790.5
Initial Water Content: 12.96%
Dry Unit Weight: 18.99
Table E.6: Measured soil weight at temperature 10°C & humidity 95% (Group II)

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<th>Madison (19.11.8%)</th>
<th>Alford (19.11.1%)</th>
<th>Jacobs (19.11.16%)</th>
<th>Brevard (18.3, 12.6%)</th>
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Total elapsed time: 235.2h
Dry Soil: 1785.4
Initial Water Content: 13.02%
Dry Unit Weight: 18.85
Table E.7 : Measured soil weight at temperature 25°C & humidity 75% (Group II)

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<td>(19.12%)</td>
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Total elapsed time [hr] 95.59          95.17          94.16          93.01          93.37          90.34
Dry Soil weight [gram]  1777.2        1828.3        1825.7        1832.3        1766.9        1742.6
Initial Water Content  13.28%        11.65%        12.00%        11.71%        13.16%        12.93%
Dry Unit Weight [KN/m³] 16.45          16.99          18.96          19.02          18.34          18.09
Table E.8: Measured soil weight at temperature 25°C & humidity 95% (Group II)

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<th>Time</th>
<th>Temp. °C</th>
<th>Humidity</th>
<th>Clay (18.2,13.9%)</th>
<th>Madison (18.5,12.6%)</th>
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Total elapsed time: 287.47
Dry Soil: 1748.4
Initial Water Content: 13.87%
Dry Unit Weight: 18.15
Figure E.1(a): Water loss versus elapsed time at temperature 10°C and 75% relative humidity for six soils (Group II).

Accumulated Water Loss vs Elapsed Time
(Temperature 10°C, Humidity 75%)

Accumulated Water Loss (grams)

Elapsed time, [hour]

Clay County
Madison County
Alford City
Jacobs Road
Brevard County
Malion County
Figure E.1(b): Water content versus elapsed time at temperature 10°C and relative humidity 75% for six soils (Group II)
Figure E.1(c) : Drying rate versus water content for six soils at temperature 10°C and 75% relative humidity (Group II)
Figure E.2(a): Water loss versus elapsed time at temperature 10°C and 95% relative humidity for six soils (Group II)
Figure E.2(b) : Water content versus elapsed time at temperature 10°C and relative humidity 95% for six soils (Group II)
Figure E.2(c): Drying rate versus water content for six soils at temperature 10°C and 55% relative humidity (Group II)
Figure E.3(a): Water loss versus elapsed time at temperature 25°C and 75% relative humidity for six soils (Group II)
Water Content vs Elapsed Time
(Temperature 25°C, Humidity 75%)

Figure E.3(b): Water content versus elapsed time at temperature 25°C and relative humidity 75% for six soils (Group II)
Drying Rate vs Water Content
(Temperature: 25°C, Humidity: 75%)

Figure E.3(c): Drying rate versus water content for six soils at temperature 25°C and 75% relative humidity (Group II)
Figure E.4(a): Water loss versus elapsed time at temperature 25°C and 95% relative humidity for six soils (Group II)
Figure E.4(i): Water content versus elapsed time at temperature 25°C and relative humidity 95% for six soils (Group II)
Figure E.4(c): Drying rate versus water content for six soils at temperature 25°C and 95% relative humidity (Group II)
Figure E.5(a): Comparison of water loss at different temperature and relative humidity for Clay County soil (Group II)
Figure E.5(b): Comparison of water loss at different temperature and relative humidity for Madison County soil (Group II)
Figure E.5(c): Comparison of water loss at different temperature and relative humidity for Jacobs Road soil (Group II)
Figure E.5(d): Comparison of change of water content at different temperature and relative humidity for Alford City soil (Group II)
Figure E.5(e): Comparison of water loss at different temperature and relative humidity for Marion County soil (Group II)
Figure E.5(f): Comparison of water loss at different temperature and relative humidity for Brevard County soil (Group II)
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Figure E.6(b): Comparison of change of water content at different temperature and relative humidity for Madison County soil (Group II)
Figure E.6(c) : Comparison of change of water content at different temperature and relative humidity for Jacobs Road soil (Group II)
Figure E.6(d): Comparison of the change of water content at different temperature and relative humidity for Alford City soil (Group II)
Figure E.6(e) : Comparison of change of water content at different temperature and relative humidity for Marion County soil (Group II)
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Figure E.7(a): Comparison of drying rate at different temperature and relative humidity for Clay County soil (Group II)
Drying Rate vs Water Content
(Madison County)

Figure E.7(b): Comparison of drying rate at different temperature and relative humidity for Madison County soil (Group II)
Figure E.7(c): Comparison of drying rate at different temperature and relative humidity for Jacobs Road soil (Group II)
Drying Rate vs Water Content
(Alford City)

Figure E.7(d) : Comparison of drying rate at different temperature and relative humidity for Alford City soil (Group II)
Drying Rate vs Water Content

(Marion County)

Figure E.7(e): Comparison of drying rate at different temperature and relative humidity for Marion County soil (Group II)
Drying Rate vs Water Content
(Brevard County)

Figure E.7(f) : Comparison of drying rate at different temperature and relative humidity for Brevard County soil (Group II)
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(Temperature: 10°C, Humidity: 75%)

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(Temperature: 10°C, Humidity: 95%)

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Soil Suction vs Drying Time

(Temperature: 10°C, Humidity: 75%)

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Soil Suction vs Drying Time

(Temperature: 10°C, Humidity: 95%)

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Drying Rate vs Drying Time

(Temperature: 0°C, Humidity: 95%)

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(Temperature: 10°C, Humidity: 75%)

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(Temperature: 40°C, Humidity: 55%)

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Drying rate, [gram/hour/ft²]

Drying time, [hour]

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(Temperature: 40°C, Relative Humidity: 55%)

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(Temperature: 10°C, Relative Humidity: 95%)

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