# DETERMINATION OF DIFFUSION COEFFICIENT THROUGH LABORATORY TESTS AND ANALYTICALLY VALIDATING IT USING EMPIRICAL RELATIONS FOR UNSATURATED SOILS

A Thesis

by

ANSHUMAN B. THAKUR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2005

Major Subject: Civil Engineering

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Approved by:
Co-Chairs of Committee, Charles Aubeny
Robert L Lytton
Committee Member, Kevin McInnes.
Head of Department, David V. Rosowsky

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# ABSTRACT

Determination of Diffusion Coefficient through Laboratory Tests and Analytically Validating It Using Empirical Relations for Unsaturated Soils. (August 2005)

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Dr. Robert L. Lytton

Soil suction is one of the most important physical variables affecting the soil engineering behavior, moisture content. Suction has a major controlling influence on soil shear strength. The moisture diffusivity properties of unsaturated properties of soils exert a critical influence on the depth to which seasonal variations of moisture and suction at the ground surface extend into the soil mass. Hence, a study of moisture diffusion coefficient is pivotal.

In this research the drying test originally proposed by Mitchell (1979) has been validated by back calculating the moisture diffusion values using the empirical relation established by Lytton (2003).

The non-linear flow through unsaturated soils has been simplified to a linear problem for simplicity in this study. Owing to this simplification, certain refinements have therefore been applied in the determination of diffusion coefficient. Thermocouple psychrometer was used to measure the soil suction along the length of the sample and at different times in the laboratory. Initial suction measurements were done using the filter paper test. Curve fitting procedure established by (Aubeny and Lytton, 2003), has been used for the determination of the diffusion coefficient.

Analytical validation of the moisture diffusion coefficient, required coefficient of permeability, ‘k’, slope of suction water characteristic curve ‘S’ and air entry value ‘$h_o$’ as the major input parameters.

Mitchell (1979) assumed the value of ‘$h_o$’ to be 100 cm. In this research air entry value, ‘$h_o$’ has been re-evaluated and it comes out to be higher than the pre estimated value. The value of slope of suction water characteristic curve, ‘S’ obtained from pressure plate tests, compares well to the empirical equation of Lytton (2003).

The results of moisture diffusion coefficient obtained from the empirical equation come out in the same range as obtained from the refined Mitchell’s (1979) drying test. The refinements includes introduction of constant temperature environment. Owing to the least variation in temperature, more reliable and reproducible data was obtained.

The range of moisture diffusion coefficient, $\alpha$-values obtained from empirical equation, comes out to be coherent with the laboratory data. Hence, it can be concluded that the research was successful.

*To my parents*

*and*

*elder brother*

# ACKNOWLEDGMENTS

I would like to take this opportunity to thank my advisors Dr. Charles Aubeny and Dr. Robert Lytton. They guided me towards the right direction through out my research. Dr. Charles Aubeny helped me in cracking the problems whenever they cropped up, and, hence guided me in completing the research. At the same time, Dr. Robert Lytton, with his immense knowledge in this field, taught me the basics and constantly encouraged me to strive for better results. His proficiency in this field made this research a success.

I would like to express my profound gratitude to Dr. Kevin Mcinnes for being there whenever I needed him. He provided me the tools with which I could perform the experiments. Without his immense help, I could not have reached so far.

Dr.Rifat Bulut has been a great mentor in the laboratory. I owe him all the skills, I have learned during the course of my study. I would like to especially thank him for being a guide as well as friend at all the times.

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Finally, I can never thank my parents, Mrs. Vijaya Thakur, and, Mr. Bramhanand Thakur, enough for their unconditional love and prayers, without which I could never have come so far.

# TABLE OF CONTENTS

Page

# TABLE OF CONTENTS (Continued)

Page

## TABLE OF CONTENTS (Continued)

# LIST OF FIGURES

## LIST OF FIGURES (Continued)

Page

# LIST OF FIGURES (Continued)

# LIST OF TABLES

Page

# LIST OF TABLES (Continued)

Page

# CHAPTER I

# INTRODUCTION

Soil suction is one of the most important physical variables affecting the soil engineering behavior, moisture content. Suction has a major controlling influence on soil shear strength, particularly in shallow soils where mechanical stress is relatively small, seasonal cycles of moisture and suction lead to cycle of heave and shrinkage in the soil lead to deformations that can potentially damage overlying structures and pavements. The moisture diffusivity properties of unsaturated properties of soils exert a critical influence on the depth to which seasonal variations of moisture and suction at the ground surface extend into the soil mass. The key properties relevant to moisture diffusion are soil hydraulic conductivity and the moisture storage characteristics of the soil. In unsaturated soils, both involve non-linear behavior. However, following a procedure by Mitchell (1979), a linear analysis is possible when a transformed measure of suction (e.g. the logarithm of suction) is used in the moisture diffusion analysis. The analysis may be further simplified by combining the hydraulic conductivity and the moisture storage properties if the soil into a single moisture diffusion coefficient $\alpha$, analogous to the coefficient of consolidation, $c_v$ widely used in the consolidation analyses of saturated soils. Infiltration through unsaturated soils is non-linear in contrast to the one in saturated soil. This research is based on the approach originally proposed by Mitchell (1979) for estimating $\alpha$-coefficient from suction measurements.

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This thesis follows the style of the *Journal of Geotechnical and Geoenvironmental Engineering.*

The main objective of this research is to evaluate the validity of Michell's (1979) framework. The following procedure is used:

1. Measure '$\alpha$' directly in a drying test. This step will include refinements to the test procedure to achieve better temperature control to obtain better suction measurements, and refinements to the test interpretation, particularly with regard to characterizing the evaporation process. Chapter III of this report deals with the details regarding procedure and results obtained from direct measurement of '$\alpha$' in the laboratory.
2. Independently evaluate the moisture diffusivity coefficient through measurement of hydraulic conductivity (Chapter V) and the soil moisture characteristic curve (Chapter IV).
3. Compare diffusivity '$\alpha$' determined for direct measurement (step 1) and from theoretical determination. Chapter VI of this report deals with the evaluation and comparison of diffusion coefficient obtained through laboratory testing and empirical relationship.

Pertinent details are described briefly below:

## 1.1 Direct measurement of moisture diffusion coefficient

### 1.1.1 Background

In saturated soil mechanics, Darcy's law defines permeability by equation 1 below:

$$v = -k * \frac{d\phi}{dx} \tag{1}$$

Here,

$v$ = velocity

$k$ = permeability

$\phi$ = total head

$x$ = distance

Total head $\varphi$ has both total suction $h$ and elevation $z$ components (Equation 2). In shallow foundation and slope problems, variations in elevations are small relative to typical variations in total suction; hence, $z$ will be neglected in equation 2 in this thesis.

$$\varphi \approx h \tag{2}$$

Here,

$h$ = total suction

Permeability of partially saturated soil as described earlier varies as a function of suction. Hence, the problem is non-linear. Laliberte and Corey (1967) proposed the permeability and suction relationship, shown in equation 3.

$$k = k_0 \left(h_0 / h\right)^n \tag{3}$$

Here,

$k_0$ = saturated permeability

$h_0$ = total suction corresponding to $k_0$

$h$ = total suction

$n$ = material constant

Invoking Darcy's law and assuming n=1 with equation 3 yield the following,

$$v = -k_o * \frac{h_o}{h} * \frac{dh}{dx} \tag{4}$$

Since, $\frac{dh}{h} = \frac{d \log_{10} h}{0.434}$, so equation 4, can be re-written as

$$v = -\left(k_o * \frac{h_o}{0.434}\right) * d * \left(\log_{10} h\right) / dx \tag{5}$$

Equation 4 can also be written as given in equation 5 below

$$v = -p * \frac{du}{dx} \tag{6}$$

Here,

$p$ (permeability parameter) = $-k_o * \dfrac{h_o}{0.434}$

$u$ (total suction on a pF scale) = $\log_{10} h$ (cm of water)

### 1.1.2 Mitchell's diffusion equation for unsteady flow

Mitchell (1979) considered an incremental section of soil of dimensions ΔxΔyΔz (Figure 1) for the evaluation of diffusion coefficient. The section has a source of moisture at a rate per unit volume defined as f(x, t). The moisture flow was assumed to be in x direction.

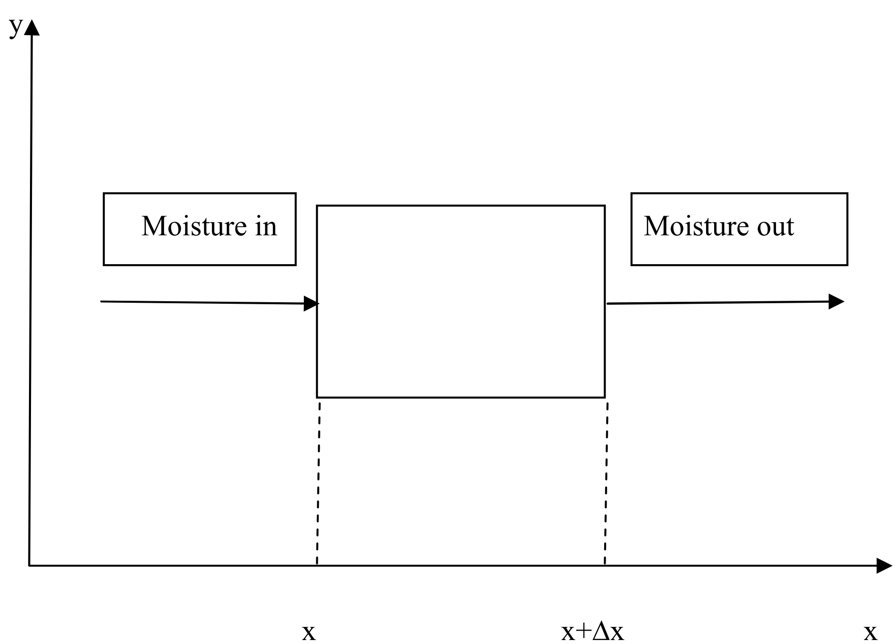



**Figure 1:Flow of moisture in soil sample** ( Mitchell, 1979)

The net moisture flow in the soil invoking the conservation of mass is given as:

$$\Delta Q = v_x \Delta y \Delta z \Delta t\big|_x - v_x \Delta y \Delta z \Delta t\big|_{x+\Delta x} + f(x,t)\Delta x \Delta y \Delta z \Delta t \quad \text{[Dimension-L}^3\text{]} \tag{7}$$

Substituting equation 6 in 7 we get:

$$\Delta Q = -p\Delta y \Delta z\left(\frac{\partial u}{\partial x}\right)_x \Delta t - \left(-p\Delta y \Delta z\left(\frac{\partial u}{\partial x}\right)_{x+\Delta x} \Delta t\right) + f(x,t)\Delta x \Delta y \Delta z \Delta t \tag{8}$$

Equation 8 becomes:

$$\Delta Q = p\Delta x \Delta y \frac{\left\{\left(\frac{\partial u}{\partial x}\right)_{x+\Delta x} - \left(\frac{\partial u}{\partial x}\right)_x\right\}}{\Delta x}\Delta t + f(x,t)\Delta x \Delta y \Delta z \Delta t \tag{9}$$

As $\Delta x \to 0$, equation 9 becomes:

$$\Delta Q_{\Delta x \to 0} = p\Delta x \Delta y \Delta z \Delta t \frac{\partial^2 u}{\partial x^2} + f(x,t)\Delta x \Delta y \Delta z \Delta t \tag{10}$$

The amount of moisture, $\Delta Q'$ stored can be defined as:

$$\Delta Q' = \Delta\theta \Delta x \Delta y \Delta z \tag{11}$$

Here,

$\theta$ = Volumetric water content $= \frac{\gamma_d}{\gamma_w} w$

$w$ = Gravimetric water content

Hence, moisture stored (Equation 11) becomes:

$$\Delta Q' = \left(\frac{\gamma_d}{\gamma_w}\right)\Delta w \Delta x \Delta y \Delta z \quad \text{[Dimension- L}^3\text{]} \tag{12}$$

Here,

| | | |
|---|---|---|
| $\Delta\theta$ | = | Change in volumetric moisture content. |
| $\gamma_d$ | = | Unit weight of solid particles. |
| $\gamma_w$ | = | Unit weight of water. |

The net flow in the soil sample is the moisture stored inside. Hence, equating equations 10 and 12 we get:

$$p\frac{\partial^2 u}{\partial x^2} + f(x,t)\Big|_{\Delta x,\Delta y,\Delta z,\Delta t \to 0} = \frac{\gamma_d}{\gamma_w} c \frac{\partial u}{\partial t}\Big|_{\Delta x,\Delta y,\Delta z,\Delta t \to 0} \tag{13}$$

Where,

$$c = \frac{dw}{du},$$

Here,

| | | |
|---|---|---|
| $dw$ | = | Volumetric water content |
| $du$ | = | Suction in pF. |

$$\Rightarrow \frac{\partial^2 u}{\partial x^2} + \frac{f(x,t)}{p} = \frac{\gamma_d c}{\gamma_w p}\frac{\partial u}{\partial t} \tag{14}$$

Therefore, the diffusion equation is given as:

$$\frac{\partial^2 u}{\partial x^2} + \frac{f(x,t)}{p} = \frac{1}{\alpha}\frac{\partial u}{\partial t} \tag{15}$$

Here,

$\alpha$ , diffusion coefficient = $\dfrac{p\gamma_w}{\gamma_d c}$

The dimension of $\alpha$ in the equation above is $L^2/T$.

When the flow in y and z directions is also taken in to consideration, the general form of diffusion coefficient becomes as shown in equation 16.

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} + \frac{f(x,y,z,t)}{p} = \frac{1}{\alpha}\frac{\partial u}{\partial t} \tag{16}$$

Assuming n=1 and invoking the conservation of mass requirement, Mitchell (1979) showed

$$\nabla^2 u = \frac{1}{\alpha}\frac{\partial u}{\partial t} \tag{17}$$

Here,

$u$ = Total suction on a pF scale.

$t$ = time

$\alpha$ = Diffusion coefficient

### 1.1.3 Experimental determination of $\alpha$

Originally two laboratory tests were proposed by Mitchell (1979) for the determination of diffusion coefficient in unsaturated soils, wetting and drying tests. The names were given according whether moisture flow into or out of the sample. An undisturbed Shelby tube sample is utilized in both the tests. All boundaries of the specimen are sealed except one end that is exposed to drying or wetting (Figure 2) Moisture flow was allowed on the open end. Measurement of total suction as a function of distance and time allows back – calculation of a moisture diffusion coefficient. The two tests have been discussed below:

Drying test

To start with the initial suction ($u_0$) of the soil sample was measured. Keeping one cross-sectional end open, all the other sides of the cylindrical sample was enclosed with an impermeable membrane to avoid any loss or gain of moisture from the sealed boundaries. A sling psychrometer was used to measure the atmospheric suction ($u_a$). Moisture was allowed to flow out from the open end. At different time intervals and different distances on the soil sample, the suction was measured. The experimental setup has been shown in Figure 2.

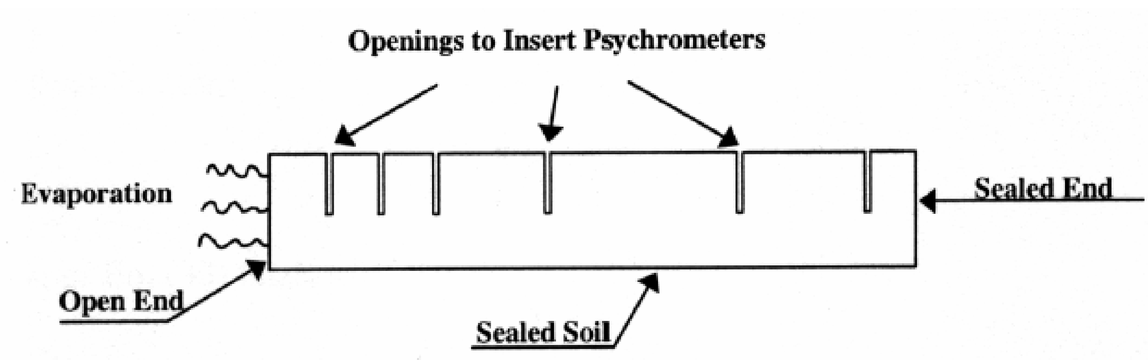



**Figure 2: Drying test** ( Tang 2003)

### 1.1.4 Calculation of $\alpha$ for drying test (Mitchell, 1979)

Setting f(x,y,z,t)=0 in equation 17 , it becomes:

$$\alpha \frac{\partial^2 u}{\partial x^2} = \frac{\partial u}{\partial t} \quad (18)$$

Using the following boundary condition, equation 18 was utilized to calculate the $\alpha$ coefficient:

Sealed boundary: $\frac{\partial u(0,t)}{\partial x} = 0$ (19)

Open boundary: $\frac{\partial u(l,t)}{\partial x} = -h_e\left[u(l,t) - u_a\right]$ (20)

Initial suction: $u(x, 0) = u_0$ (21)

Solution of equation 18 under the imposed boundary condition leads to the following equation:

$$u = u_a + \sum_{n=1}^{\infty} A_n \exp\left(-\frac{z_n^2 t\alpha}{l^2}\right)\cos\left(z_n \frac{x}{l}\right) \quad (22)$$

Here,

$$A_n = \frac{2(u_0 - u_a)\sin z_n}{z_n + \sin z_n \cos z_n} \; and \; \cot z_n - \frac{z_n}{h_e l} = 0$$

Here,

| | | |
|---|---|---|
| $u$ | = | Suction as a function of distance and time |
| $t$ | = | time |
| $x$ | = | Distance from closed end |
| $l$ | = | Total length of the soil sample |
| $u_o$ | = | Initial suction of soil sample |
| $u_a$ | = | Atmospheric suction |
| $h_e$ | = | Evaporation coefficient= 0.54 $cm^{-1}$ |

Tang (2003) used this drying test. The tests had achieved limited success, but some erratic suction measurements occurred due to temperature variations. Using thermocouple psychrometer to measure the suction, good temperature control was found to be essential for reliable measurements.

Wetting test (Mitchell 1979)

To start with the initial suction value of the soil sample was measured ($u_0$).Keeping one cross-sectional end open, all the sides of the cylindrical sample were enclosed with an impermeable membrane to avoid any loss or gain of moisture. Change in moisture was allowed from the open end. The open end of the soil sample was exposed to a liquid of known suction ($u_1$) for 4 days. At different time intervals and different distances along the length of the soil sample, the suction was measured. The experimental setup has been shown in Figure 3.

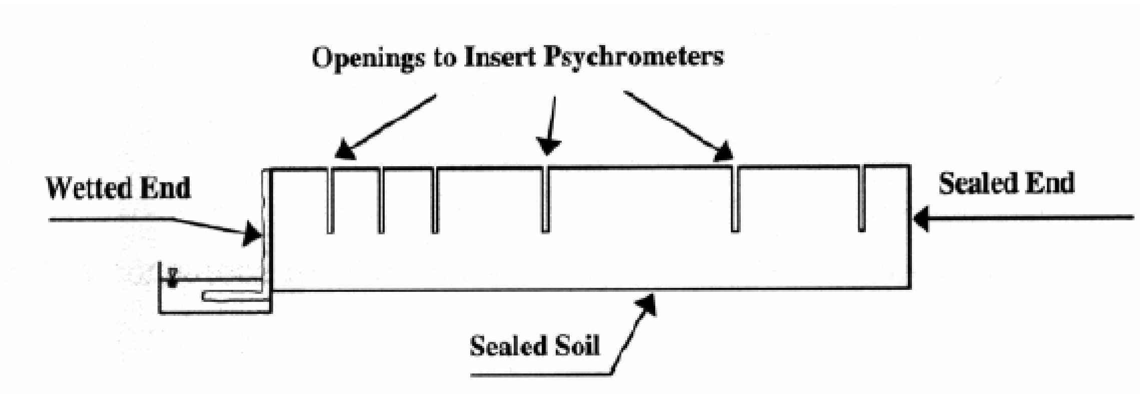



**Figure 3: Wetting test** ( Tang 2003)

Using the following boundary condition, equation 20 was utilized to calculate the $\alpha$ coefficient:

Sealed boundary: $\frac{\partial u(0,t)}{\partial x} = 0$ (23)

Open boundary: $u(l,t) = u_1$ (24)

Initial suction: $u(x, 0) = u_0$ (25)

Solution of equation 20 under the imposed boundary condition leads to the following equation:

$$u = u_1 + \frac{4(u_1 - u_0)}{\Pi} \sum_{n=1}^{\infty} \frac{(-1)^n}{2n-1} \exp\left( -\frac{(2n-1)^2 \Pi^2 t \alpha}{4l^2} \right) \cos \frac{(2n-1)-x}{2l} \quad (26)$$

Here,

$u$ = Suction as a function of distance and time

$t$ = time

$x$ = Distance from closed end

$l$ = Total length of the soil sample

$u_o$ = Initial suction of soil sample

$u_1$ = Suction of the liquid

### 1.1.5 Mitchell's results

Mitchell followed his postulated method and performed the diffusion test. The results from his study have been summarized:

Drying test

A soil sample of length 68 mm and initial suction at 3.97 pF was taken. Above mentioned drying test procedure was followed. Soil sample was exposed to an atmospheric suction of 6.34 pF and, the evaporation coefficient was taken to be 0.54 $cm^{-1}$. The apparatus used for the conventional sorption limit test (C.S.I.R.O., 1971) was used to maintain the constant atmosphere during the test. The sample was exposed for 335 min and 1745 min and then the suction measurements were made. A constant value parameter $T = \frac{t\alpha}{l^2}$ was used to show the suction value

The diffusion coefficient calculated was:

1) For t= 335 min, T=0.015 and l=68mm,

$\alpha = 3.5 * 10^{-5}$ $cm^2$/sec.

2) For t = 1745 min, T = 0.1 and l = 68 mm,

$\alpha = 4.4 \times 10^{-5}$ cm$^2$/sec.

So, the range of diffusion coefficient is 3.5 to 4.4 x $10^{-5}$ cm$^2$/sec. The graph obtained from this study is given in Figure 4.

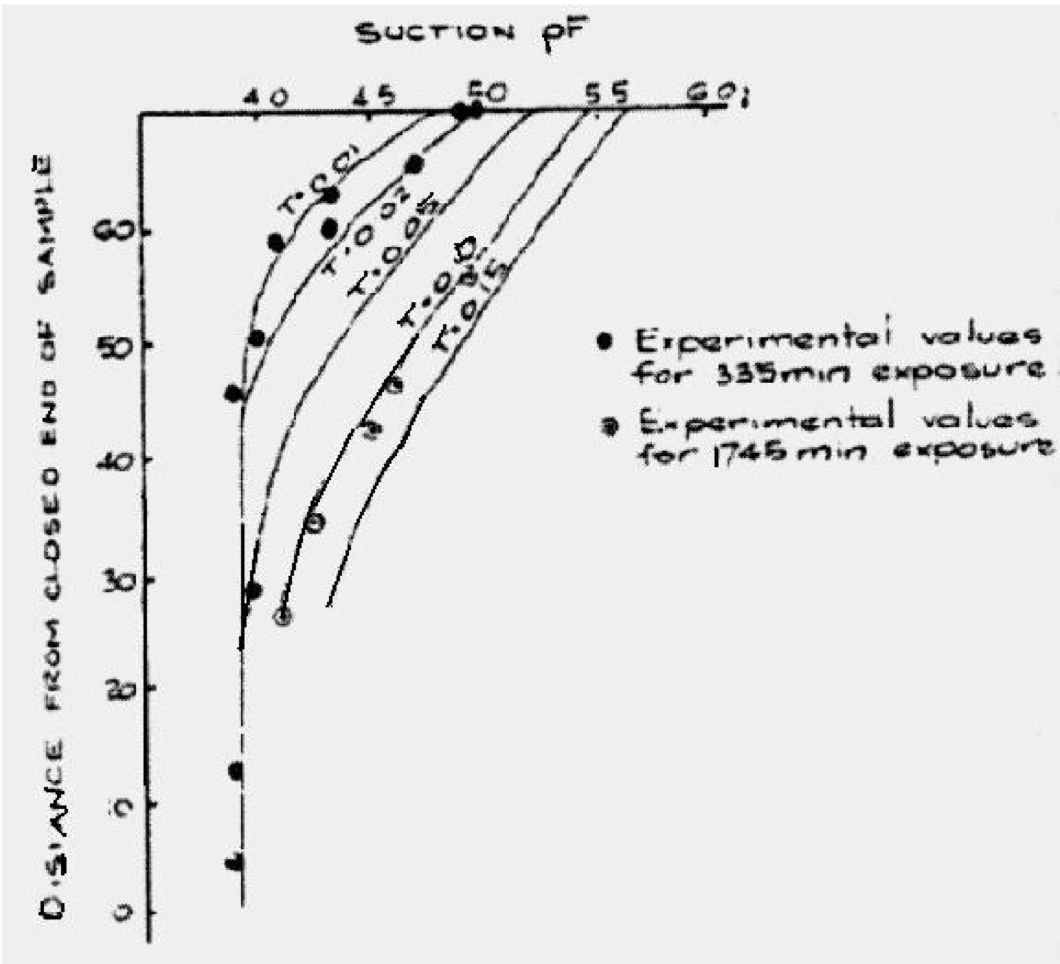



**Figure 4: Curve fitting for drying test** ( Mitchell 1979)

Wetting test

A soil sample of length 110 mm and initial suction at 4.60 pF was taken. Above mentioned wetting test procedure was followed. Soil sample was exposed to liquid of known suction of 2.75 pF and, the evaporation coefficient was taken to be 0.54 $cm^{-1}$. The moisture diffusion coefficient was calculated using curve fitting. The result has been presented in Figure 5.

For t = 5760 min, T = 0.1 and l = 110 mm,

$\alpha = 3.5 \times 10^{-5}$ $cm^2$/sec

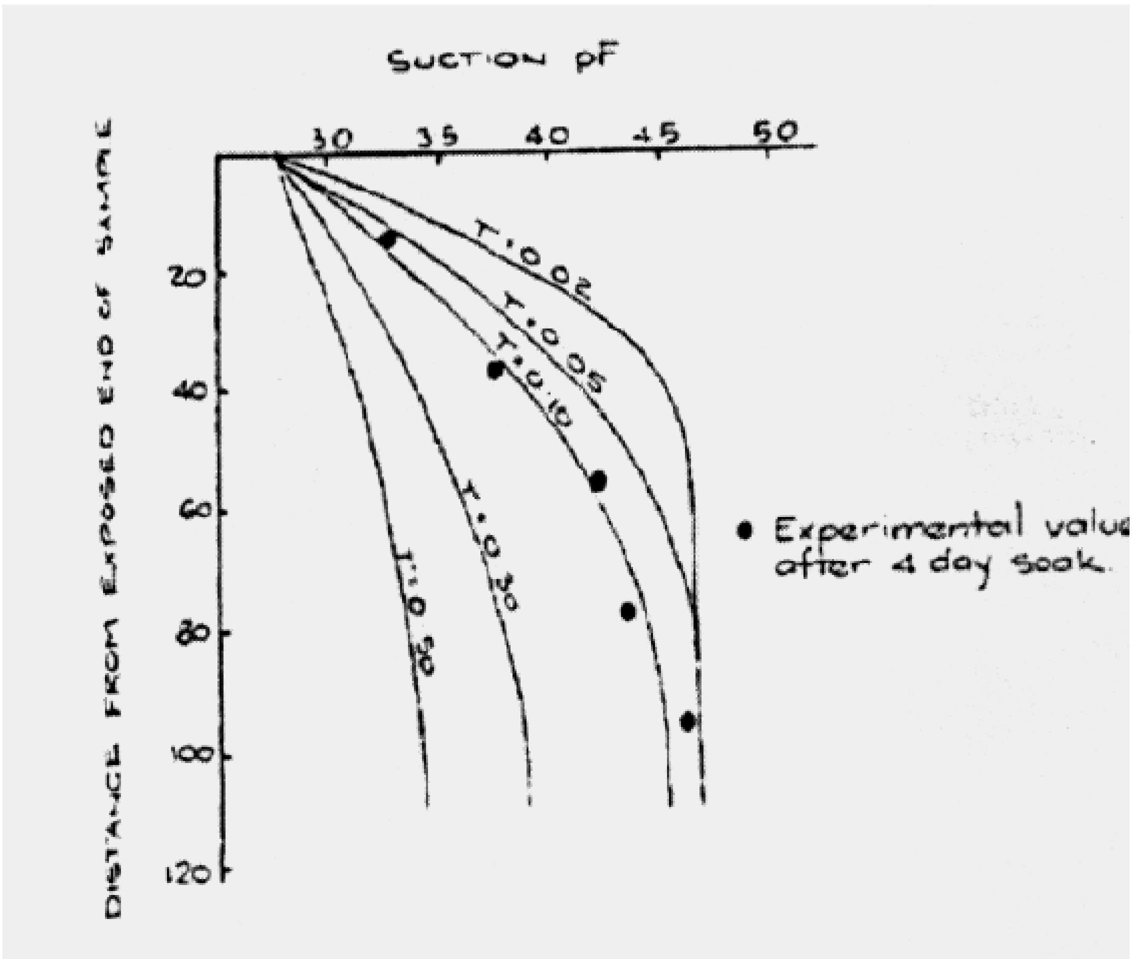



**Figure 5: Curve fitting for wetting test** ( Mitchell 1979)

Looking at the result, it can be concluded that both the drying as well as wetting test proposed by Mitchell provide a simple and fast means to calculate diffusion coefficient in laboratory. But the problem arises as to how to validate these results. Hence, another method of calculating moisture diffusion coefficient through empirical relations was employed in this research to analytically validate the test procedure. Only the drying procedure has been verified within the scope of this research.

### 1.2 Validation of the proposed procedure using empirical relationships

The empirical relation used to calculate he moisture diffusion coefficient α uses several soil parameters. The equation can be given below:

$$\alpha = -S * k_0 * h_0^{\ n} * \frac{\gamma_w}{\gamma_d} \tag{27}$$

Here,

| | | |
|---|---|---|
| $k_o$ | = | the saturated permeability of the soil |
| $h_o$ | = | Air-entry value. |
| $S$ | = | slope of the moisture characteristic curve |
| $\gamma_d$ | = | dry unit weight of soil |
| $\gamma_w$ | = | unit weight of water |
| $u$ | = | log h |
| $n$ | = | 1 |

The value of soil permeability, 'k' was obtained using one-dimensional consolidation test and empirical relations. This is presented in chapter IV.

Chapter II of this report deals with the test-sites and, the soil samples on which the study was made. The soil samples used were provided by Texas Department .of. Transportation

In this research, direct calculation of '$\alpha$' will be done under a temperature controlled environment for getting more accurate and reproducible results. And at the same time, empirical relations would be utilized to evaluate the validation of the whole process.

# CHAPTER II

# BACKGROUND OF CASE STUDY SITES

This chapter deals with the soil sample and the case study sites. An over all picture of the location and topography of the sites undertaken for study has been given. Along with these details, index properties of the soil samples have also been provided.

All the samples used for testing, were received from Texas Department of Transportation. Each boring was up to a depth of approximately 20 ft. The samples were wrapped in one layer of aluminium foil and sealed in plastic bags. The average length of sample was 1 ft. The samples were kept in a moisture-controlled room before the testing.

Laboratory tests such as Atterberg limits, sieve analysis, and hydrometer analysis were conducted to obtain the index properties. Other tests carried along were diffusion test, filter paper test, gas pressure extractor's, and one-dimensional consolidation tests. The diffusion test, filter paper test, gas pressure extractor's, and one-dimensional consolidation tests are discussed in the later chapters.

The index properties were used to determine diffusion coefficient and slope of moisture characteristic curve and these results have been compared with the data obtained from the experiments conducted in the laboratory. Diffusion coefficients and slope of moisture characteristic curve are dealt in detail in later chapters.

Some of the tests carried out to obtain the index properties are given below:

1) Atterberg Limits.

2) Determination of water content.

3) Sieve analysis.

4) Hydrometer analysis.

These tests have been covered in detail in Appendix E. The soil samples used for the study were obtained from three locations:

1) Fort Worth North Loop IH 820.

2) Atlanta US 271and

3) Austin Loop1 at SH 360.

## 2.1 Fort Worth North Loop IH 820

### 2.1.1 Location

This site is located in Tarrant County, north of Fort Worth on Loop IH 820. Figure 6 shows the precise location of the site. The site is located on expansive clay. The problem associated with this site was the expansion of fill. The roadway was being planned to be expanded.

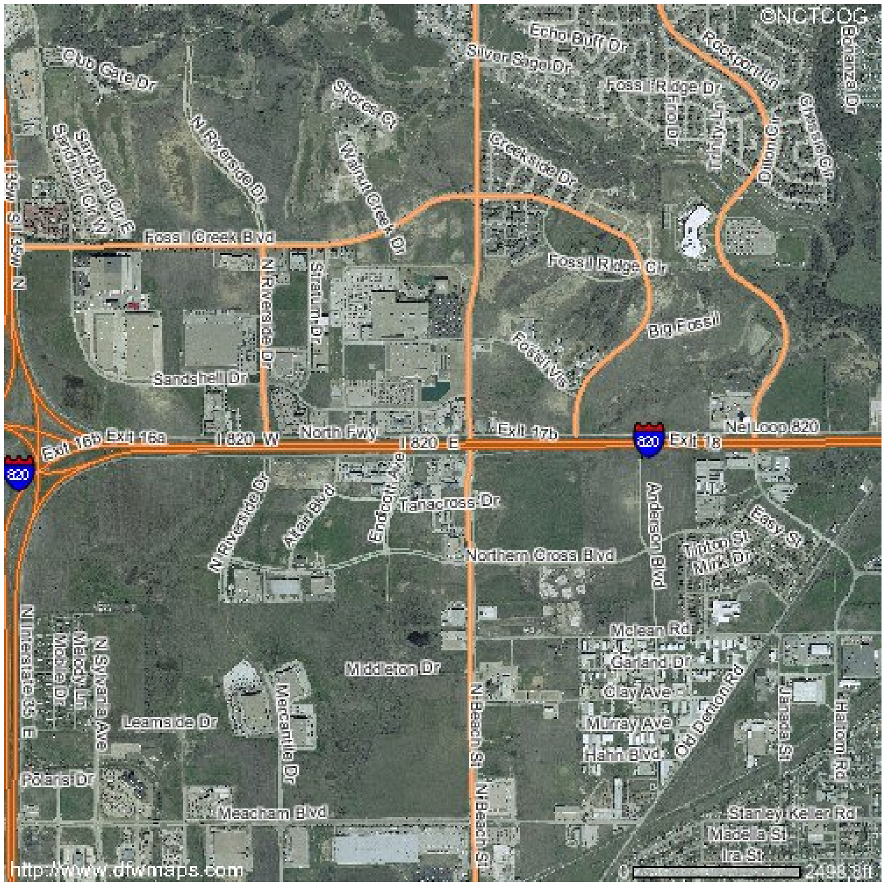



**Figure 6: Map of location of site in Fort Worth District** (www.dfwmaps.com)

### 2.1.2 Site Description

All the borings were oriented perpendicular to the highway alignment. Borings were made along three alignments designated as areas A, B, and C. Each area contained five borings.

Area A

The five boreholes in area A were assigned the name A1, A2, A3, A4, and A5. These were located on a line oriented perpendicular to the highway alignment. Boreholes A1 and A5 were located near the frontage road, A3 was in the median ditch, and A2 and A4 were at the outside shoulders of the pavement. The boreholes were taken in the soil past the pavement edges.

Area B

The five boreholes in area B were assigned the name B1, B2, B3, B4, and B5. These were located on a line oriented perpendicular to the highway alignment. Boreholes B1 and B5 were located near the frontage road, B3 was in the median ditch, and B2 and B4 were at the outside shoulders of the pavement. The boreholes were taken in the soil past the pavement edges.

Area C

The five boreholes in area C were assigned the name C1, C2, C3, C4, and C5. These were located on a line oriented perpendicular to the highway alignment. Boreholes C1 and C5 were located near the frontage road, C3 was in the median ditch, and C2 and C4 were at the outside shoulders of the pavement. The boreholes were taken in the soil past the pavement edges.

### 2.1.3 Geologic sections

Area A

A cross-sectional view of Fort Worth North Loop IH 820, area A (sections A1, A2, A3, A4, A5) has been shown in Figure 7. The detailed description of the boreholes, A1, A3, and A5 and A2, A3, and A4, respectively are given in Figures 8 and 9. The data presented are on the basis of borehole logs provided by Texas Department of Transportation and the laboratory tests. Figures 8 and 9 contain only the vertical scale. Horizontal distance can be located approximately from Figure 7.

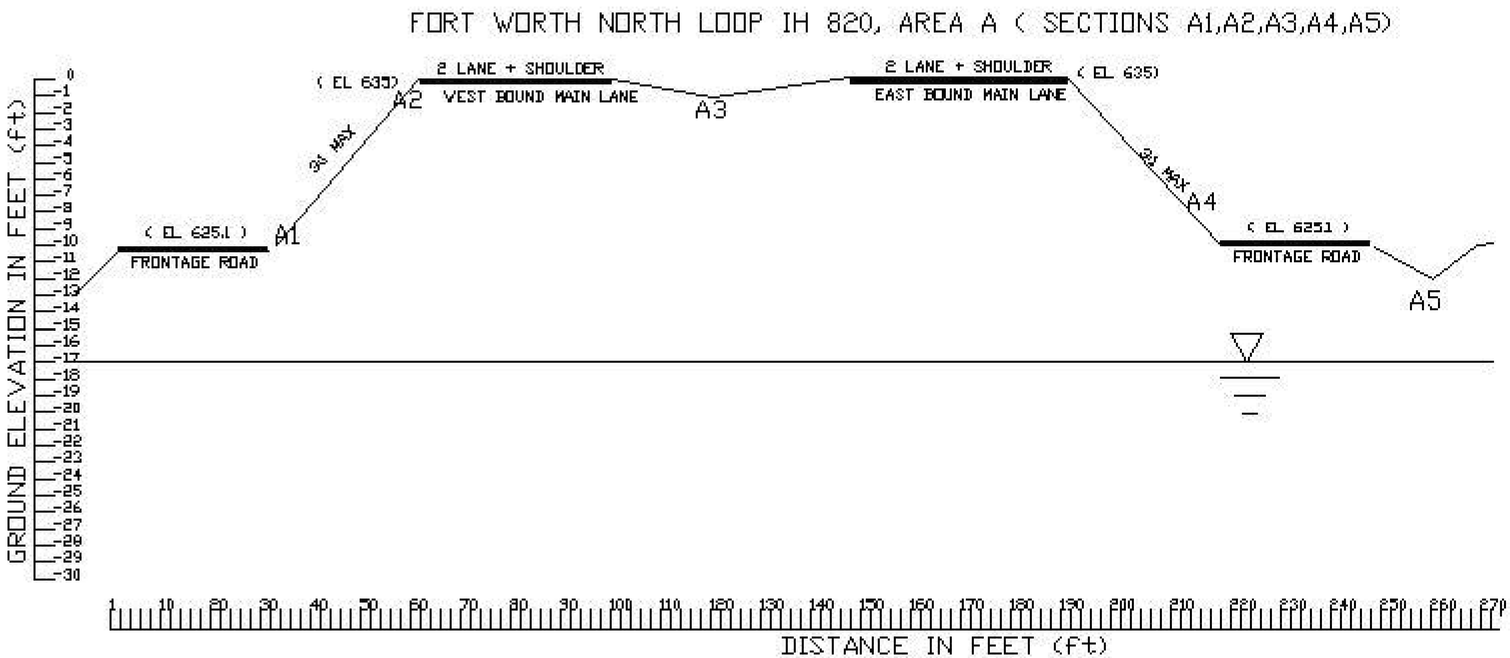



**Figure 7: Cross-sectional view of area A (Fort Worth site)**

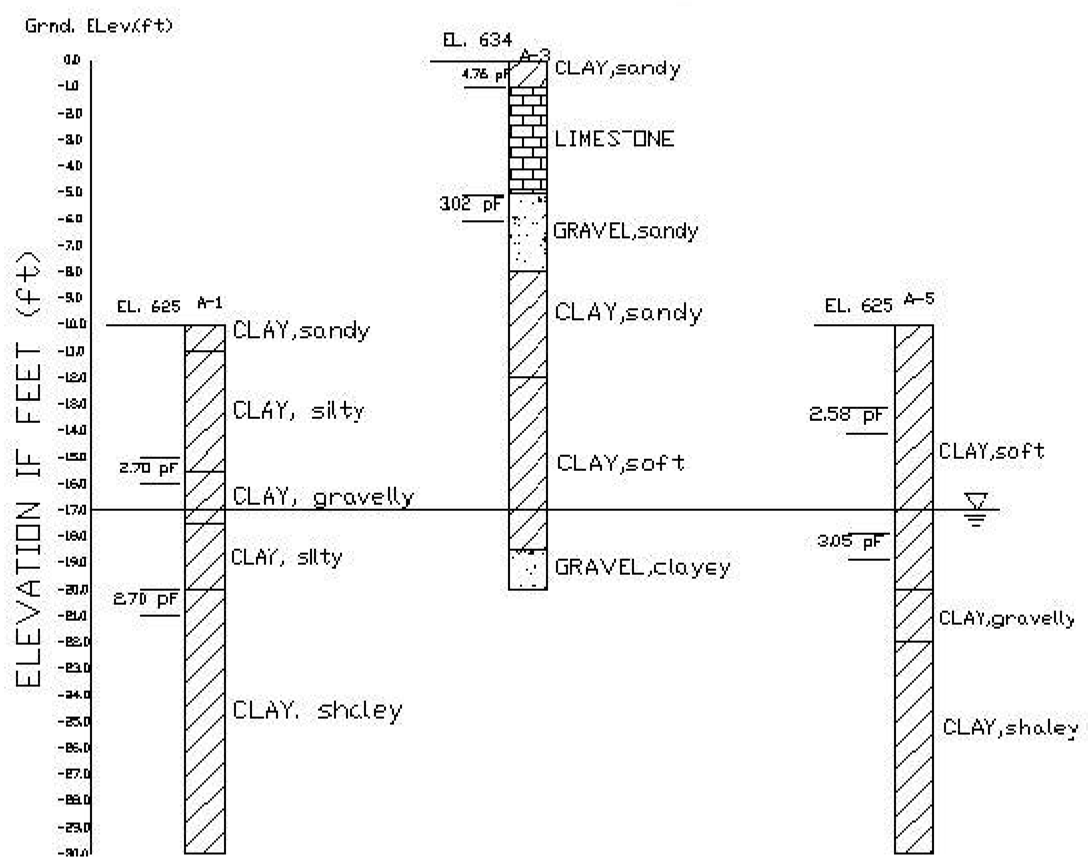



**Figure 8: Cross-sectional view at boreholes A1, A3, and A5 (Fort Worth site)**

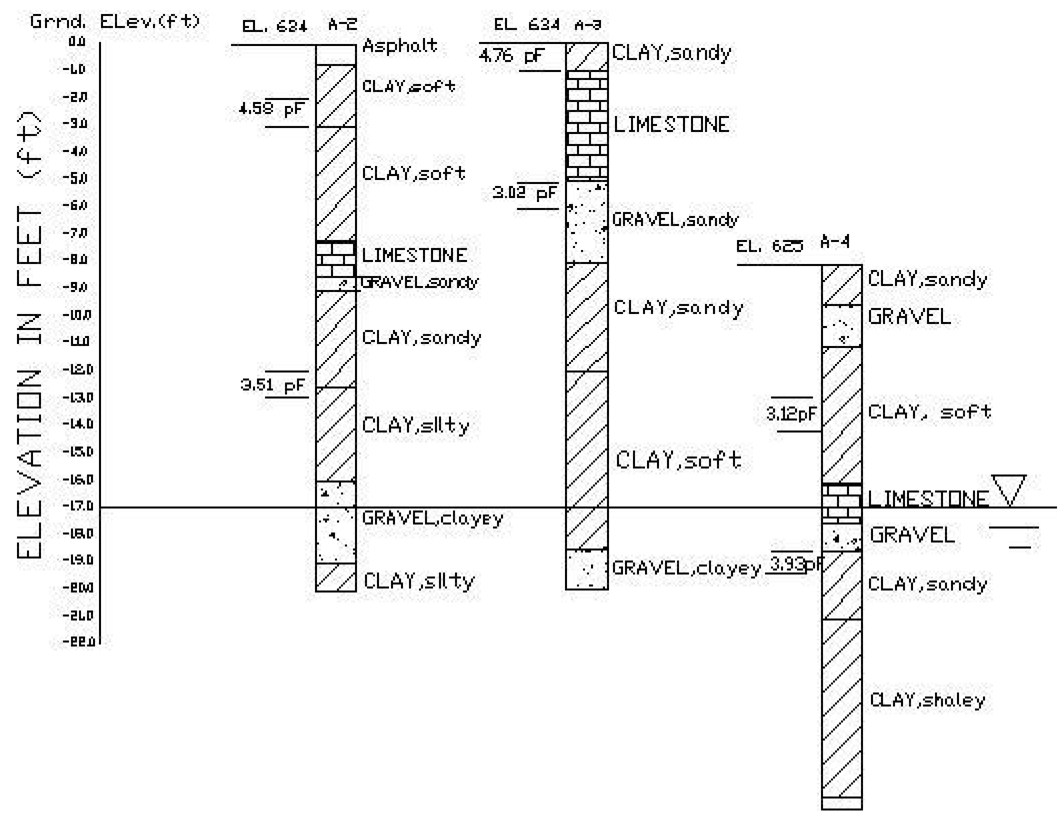



**Figure 9: Cross-sectional view at boreholes A2, A3, and A4 (Fort Worth site)**

Area B

A cross-sectional view of Fort Worth North Loop IH 820, area B (sections B1, B2, B3, B4, and B5) has been shown in Figure 10. The detailed description of the boreholes, B1, B2, B3, B4 and B5 are given in Figure 11. The data presented are on the basis of borehole logs provided by Texas Department of Transportation and the laboratory tests. Figure 11 contain only the vertical scale. Horizontal distance can be located approximately from Figure 10. Horizontal distance between boreholes B1 through B5 shown in Figure 11 can be obtained from Figure 10.

Area C

A cross-sectional view of Fort Worth North Loop IH 820, area C (sections C1, C2, C3, C4, and C5) has been shown in Figure 12. The detailed description of the boreholes, C1, C2, C3, C4 and C5 is given in Figure 13. The data presented are on the basis of borehole logs provided by Texas Department of Transportation and the laboratory tests. Figure 13 contain only the vertical scale. Horizontal distance can be located approximately from Figure 12.

The details of the Atterberg limits and other index properties of this district are tabulated in Tables 1 and 2

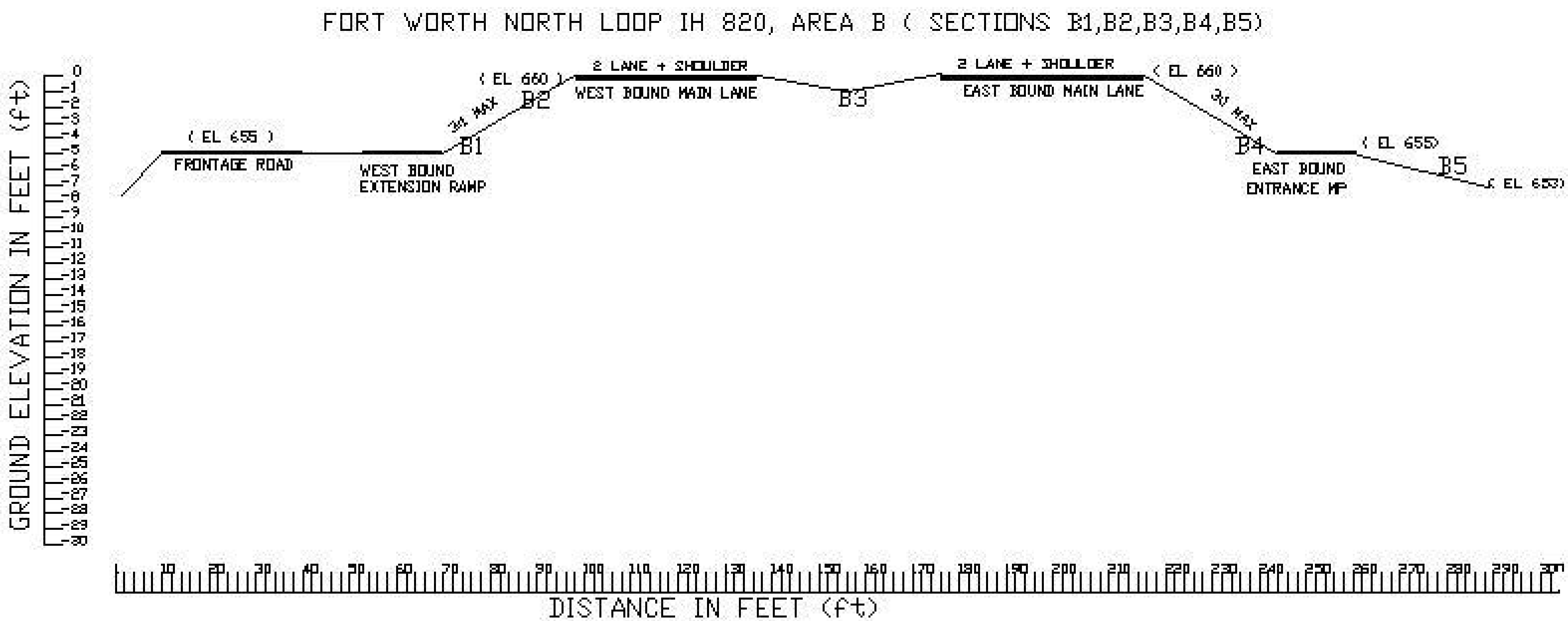



**Figure 10: Cross-sectional view of area B (Fort Worth site)**

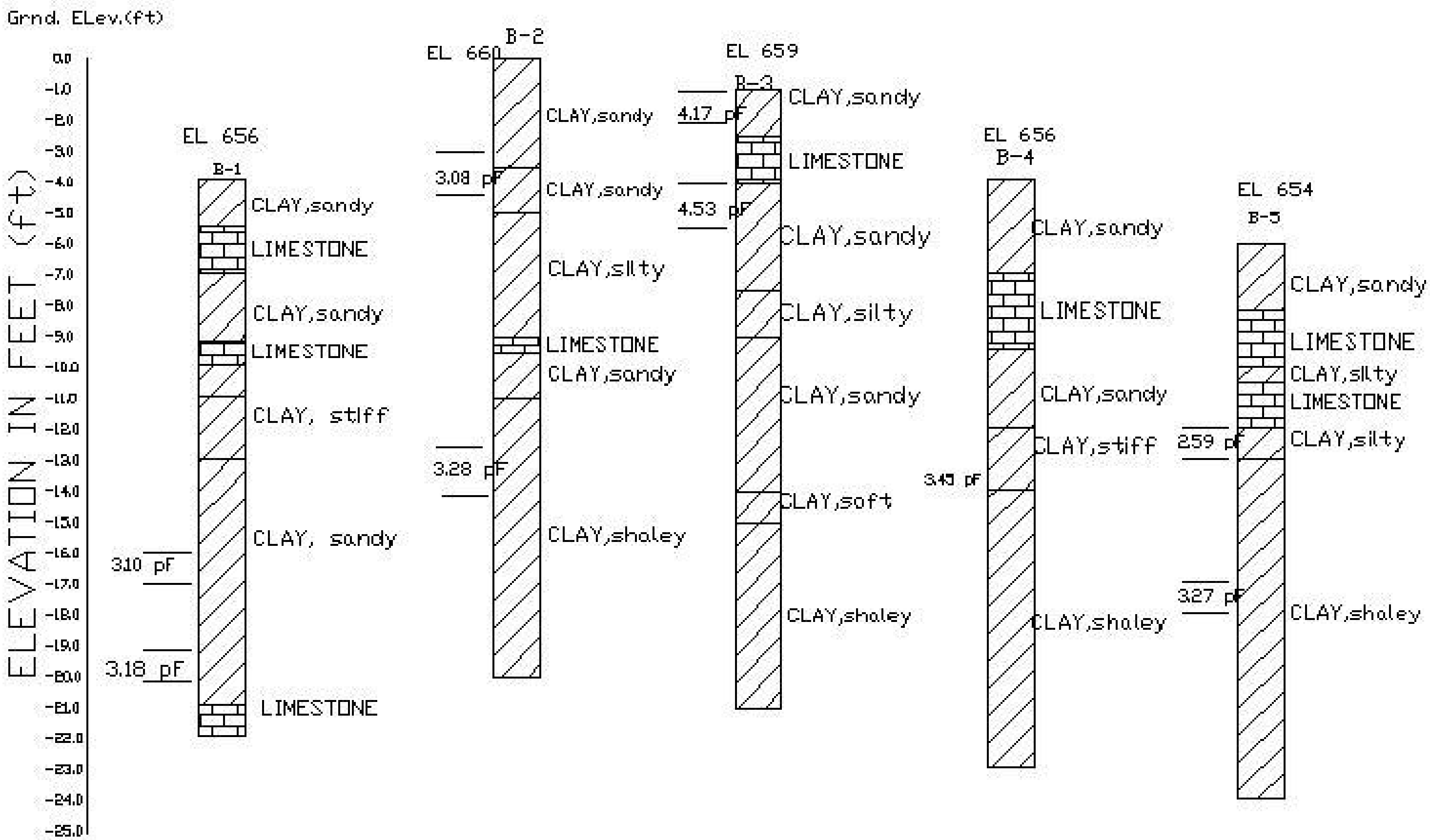



**Figure 11: Cross-sectional view at boreholes B1, B2, B3, B4, and B5 (Fort Worth site)**

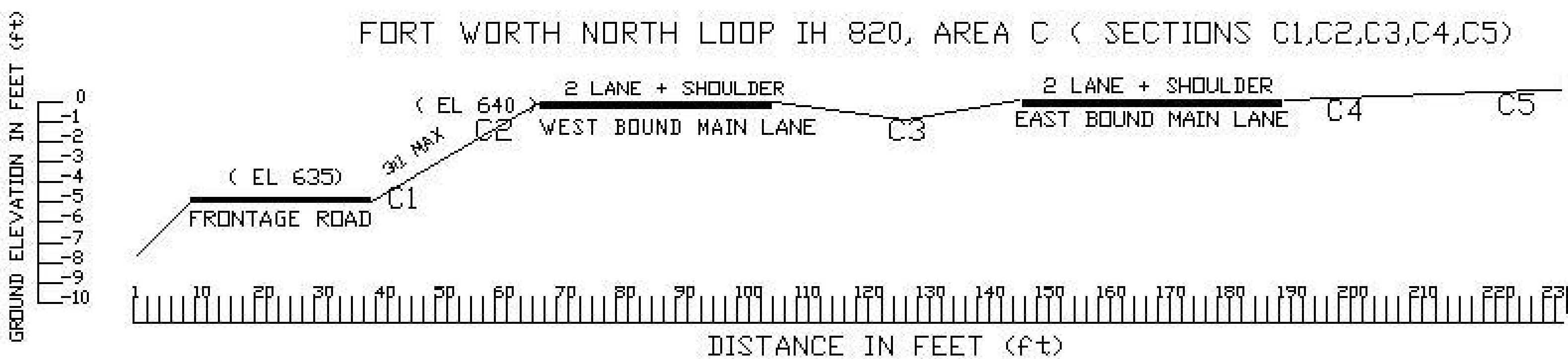



**Figure 12: Cross-sectional view of area C (Fort Worth site)**

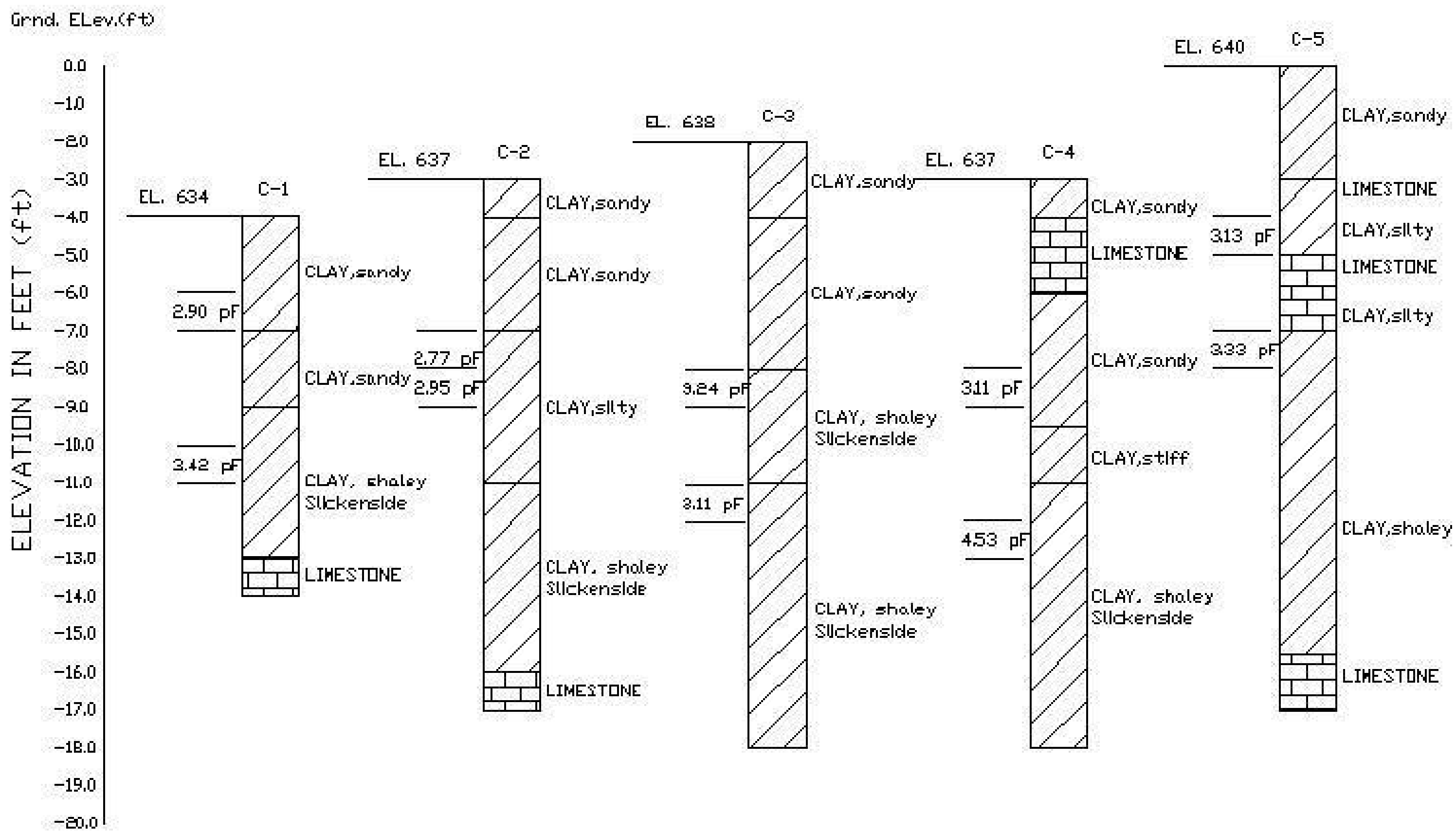



**Figure 13: Cross-sectional view at boreholes C1, C2, C3, C4, and C5 (Fort Worth site)**

**Table 1. Summary of Atterberg limits and hydrometer test for Fort Worth District.**

| No. | Sample No. | Depth (ft) | LL | PL | PI | % clay (<0.002mm) | Fines Content (% passing #200) | Soil Description | Water Content (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A1 | 5-6 | - | - | - | - | - | Tan color clay, small stones, roots, calcareous. | 25.9 |
| 2 | A1 | 11-12 | 45 | 23 | 22 | 21 | 84 | Light brown, silty, natural clay with gravels, shaley. | 18.0 |
| 3 | A2 | 2-3 | 60 | 20* | 40** | - | - | Soft, dark brown clay. | 10.8 |
| 4 | A2 | 12-13 | - | - | - | - | - | Soft, dark brown silty clay. | 24.8 |
| 5 | A3 | 0-1 | - | - | - | - | - | Dark brown clay with roots and sandy. | 15.3 |
| 6 | A3 | 9-10 | 63 | 20* | 43** | 30 | 94 | Red brown color clay with limestone fragments, small cracks. | 23.8 |
| 7 | A4 | 5-6 | - | - | - | - | - | Tan color clay, with calcareous nodules, small roots. | 27.0 |
| 8 | A4 | 10-11 | 49 | 21 | 28 | - | - | Clay with limestones, sandy and cracks present, dry and hard. | 8.8 |
| 9 | A5 | 3-4 | 49 | 19 | 30 | - | - | Tan color clay, with calcareous nodules. | 29.4 |
| 10 | A5 | 8-9 | - | - | - | - | - | Tan color clay with gravels. | 19.3 |
| 11 | B1 | 6-7 | - | - | - | - | - | Light brown clay, calcareous, sandy on side and clayey on the other. | 11.0 |
| 12 | B1 | 9-10 | 58 | 20* | 38** | - | - | Light brown clay, soft clay, silt present in small amount. | 19.1 |
| 13 | B2 | 3-4 | - | - | - | - | - | Dark brown color clay, calcareous, roots, large cracks. | 25.0 |
| 14 | B2 | 11-12 | 53 | 21 | 32 | - | - | Tan color clay, shaley. | 18.4 |
| 15 | B3 | 0-1 | - | - | - | - | - | Light brown clay, with calcareous nodules, sandy. | 12.8 |

**Table 1. (Continued)**

| No. | Sample No. | Depth (ft) | LL | PL | PI | % clay (<0.002mm) | Fines Content (% passing #200) | Soil Description | Water Content (%) |
|---|---|---|---|---|---|---|---|---|---|
| 16 | B3 | 3-4 | 60 | 24 | 36 | 1 | 96 | Light brown clay, with limestone fragments and sandy. | 11.8 |
| 17 | B4 | 1-2 | - | - | - | - | - | Dark brown clay, roots present, calcareous and cracks all around. | 11.4 |
| 18 | B4 | 13-14 | 45 | 24 | 21 | 37 | 99 | Tan color, shaley clay. | 24.9 |
| 19 | B5 | 6-7 | 36 | 21 | 15 | - | - | Tan color clay, silty, with calcareous nodules. | 11.3 |
| 20 | B5 | 11-12 | - | - | - | - | - | Light brown soft clay. | 18.7 |
| 21 | C1 | 2-3 | 62 | 26 | 36 | 25 | 100 | Brown color clay, gravels present, small cracks. | 22.8 |
| 22 | C1 | 6-7 | - | - | - | - | - | Dark brown soft clay. | 24.8 |
| 23 | C2 | 4-5 | 49 | 19 | 30 | - | - | Tan color clay, silty. | 25.0 |
| 24 | C2 | 5-6 | - | - | - | - | - | Tan color clay, silty. | 26.9 |
| 25 | C3 | 6-7 | - | - | - | - | - | Light brown clay, calcareous and cracks present. | 18.0 |
| 26 | C3 | 9-10 | 52 | 24 | 28 | - | - | Tan to light gray clay, shaley with calcareous nodules. | 25.2 |
| 27 | C4 | 5-6 | 50 | 19 | 31 | - | - | Light brown clay, sandy with limestone, cracked and soft. | 15.5 |
| 28 | C4 | 9-9.5 | - | - | - | - | - | Light brown clay, soft, yellowish core & silty. | 22.1 |
| 29 | C5 | 4-5 | - | - | - | - | - | Tan color clay, sandy with limestones. | 17.8 |
| 30 | C5 | 7-8 | 42 | 23 | 19 | 32 | 98 | Light brown clay, shaley, hard. | 22.9 |

* Inferred PL values from the other soils with similar texture.

** PI values calculated from the inferred PL values.

**Table 2. Summary of the Atterberg limits and hydrometer analysis for samples of Fort Worth District on which pressure plate test was carried out.**

| S.No | Sample | Depth | LL | PL | PI | %clay <0.02 mm | % fines passing #200 | Water Content |
|---|---|---|---|---|---|---|---|---|
| 1 | A1 | 11-12 | 45 | 23 | 22 | 21 | 84 | 18.9 |
| 2 | A2 | 12-13 | 50 | 18 | 32 | 25 | 89 | 24.5 |
| 3 | A2 | 6-7 | 48 | 20 | 28 | 22 | 87 | 16.1 |
| 4 | A3 | 11-13 | 65 | 20 | 45 | 30 | 94 | 24.5 |
| 5 | B2 | 10-11 | 50 | 20 | 30 | 26 | 84 | 25.2 |
| 6 | B5 | 6-7 | 36 | 21 | 15 | 20 | 85 | 19.9 |
| 7 | C2 | 4-5 | 49 | 19 | 30 | 25 | 87 | 21.9 |
| 8 | C2 | 5-6 | 48 | 20 | 28 | 27 | 87 | 20.9 |
| 9 | C3 | 6-7 | 60 | 30 | 30 | 24 | 95 | 18.1 |
| 10 | C1 | 2-3 | 62 | 26 | 36 | 25 | 100 | 24.3 |
| 11 | C4 | 5-6 | 38 | 18 | 20 | 22 | 80 | 19.9 |
| 12 | C5 | 10-11 | 42 | 23 | 19 | 20 | 92 | 22.4 |
| 13 | C5 | 7-8 | 42 | 23 | 19 | 32 | 98 | 22.3 |

## 2.2 Atlanta US 271

### 2.2.1 Location

This site is located in Titus County, in the northeast part of Texas near Talco. Figure 14 shows the site location. The site consisted of expansive clay. The problem associated with this site was the drying/shrinkage cracking due to trees. Highway US 271 has been shown by arrow in the Figure 14.

Soil samples from three boreholes, designated A, B, and C, located on a line oriented perpendicular to the roadway were used for the research.

### 2.2.2 Site description

A plan view of the US 271 site has been shown in the Figure 15. This Figure is followed by Figure 16 which shows the cross-section view at X-X with the locations of boreholes A, B, and C relative to a post oak tree trunk and the tree drip line.

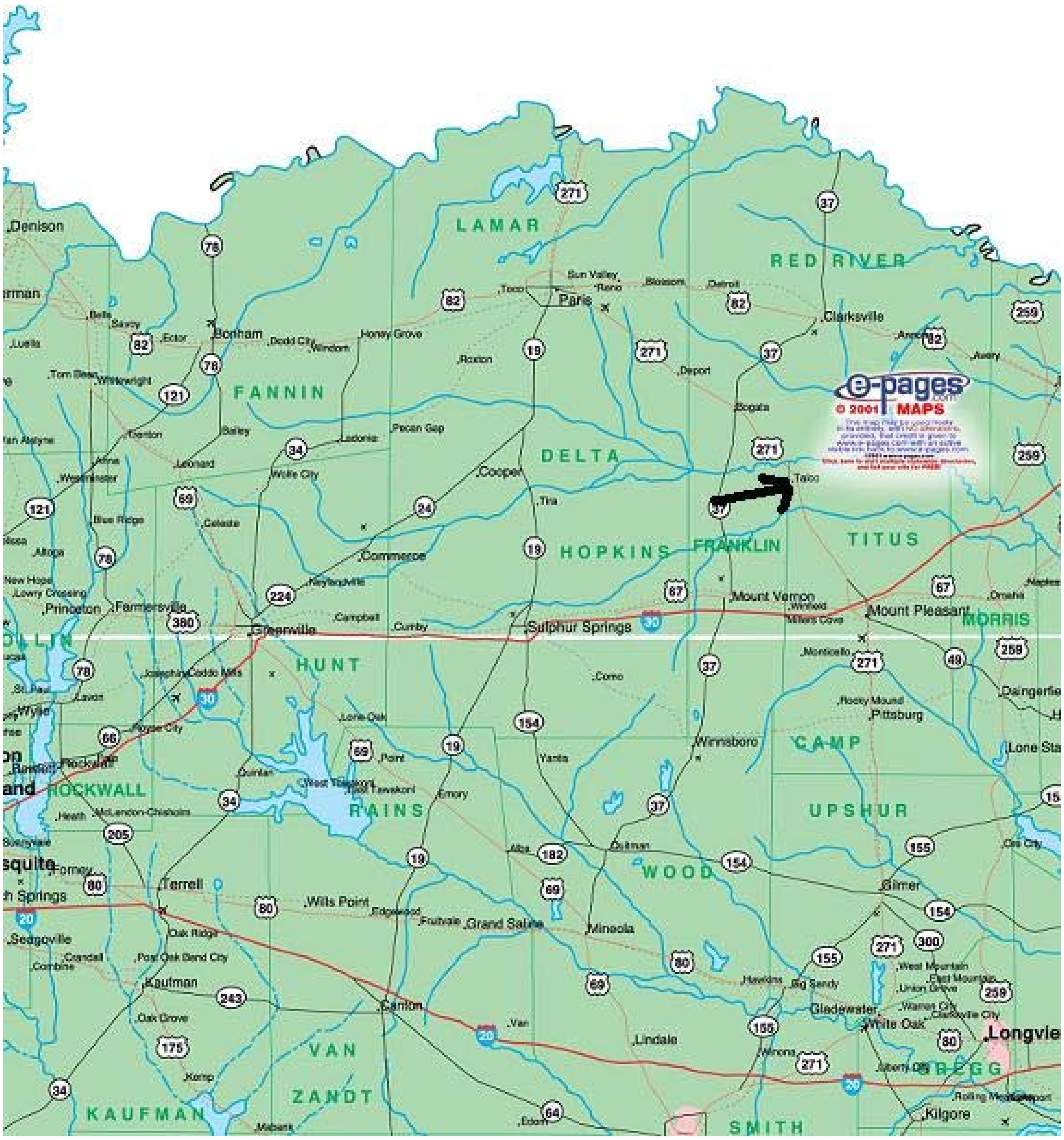



**Figure 14: Map of location of site in Atlanta District showing US 271** ( http://maps.e-pages.com/texas/tx_j.html) (www.e-pages.com. ©2001 www.e-pages.com)

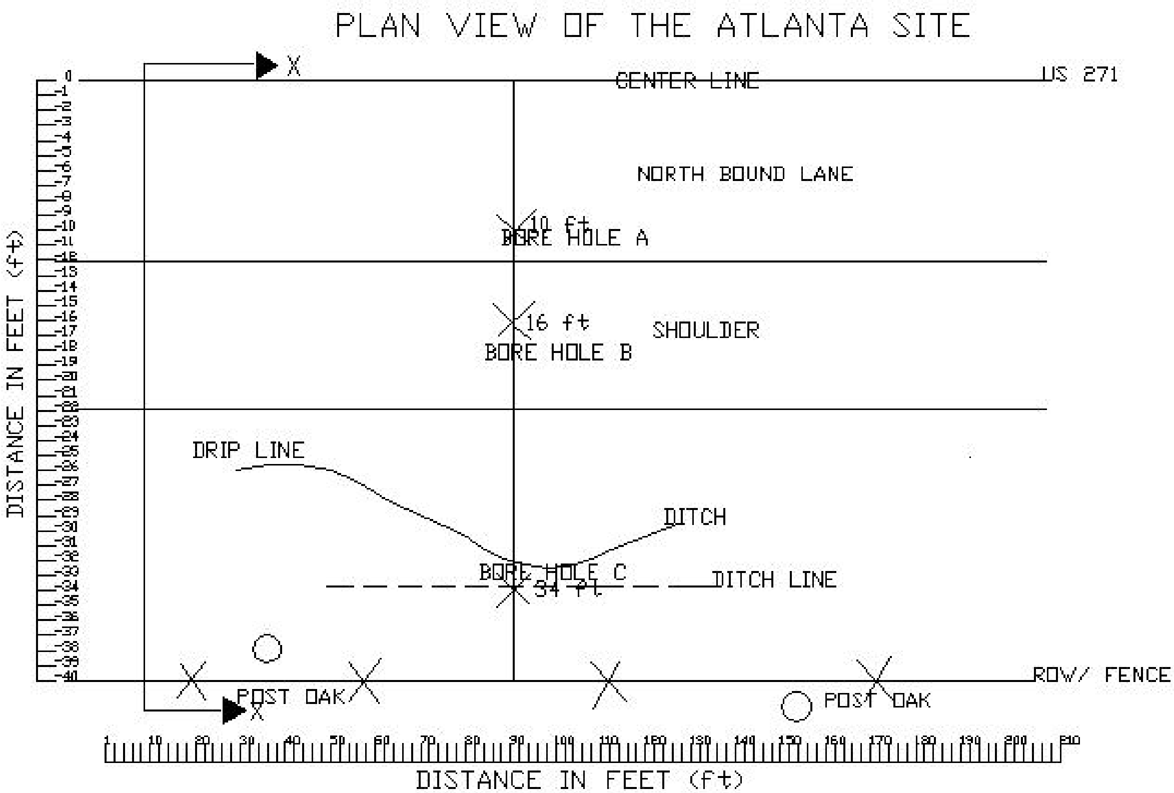



**Figure 15: Plan view of the Atlanta Site**

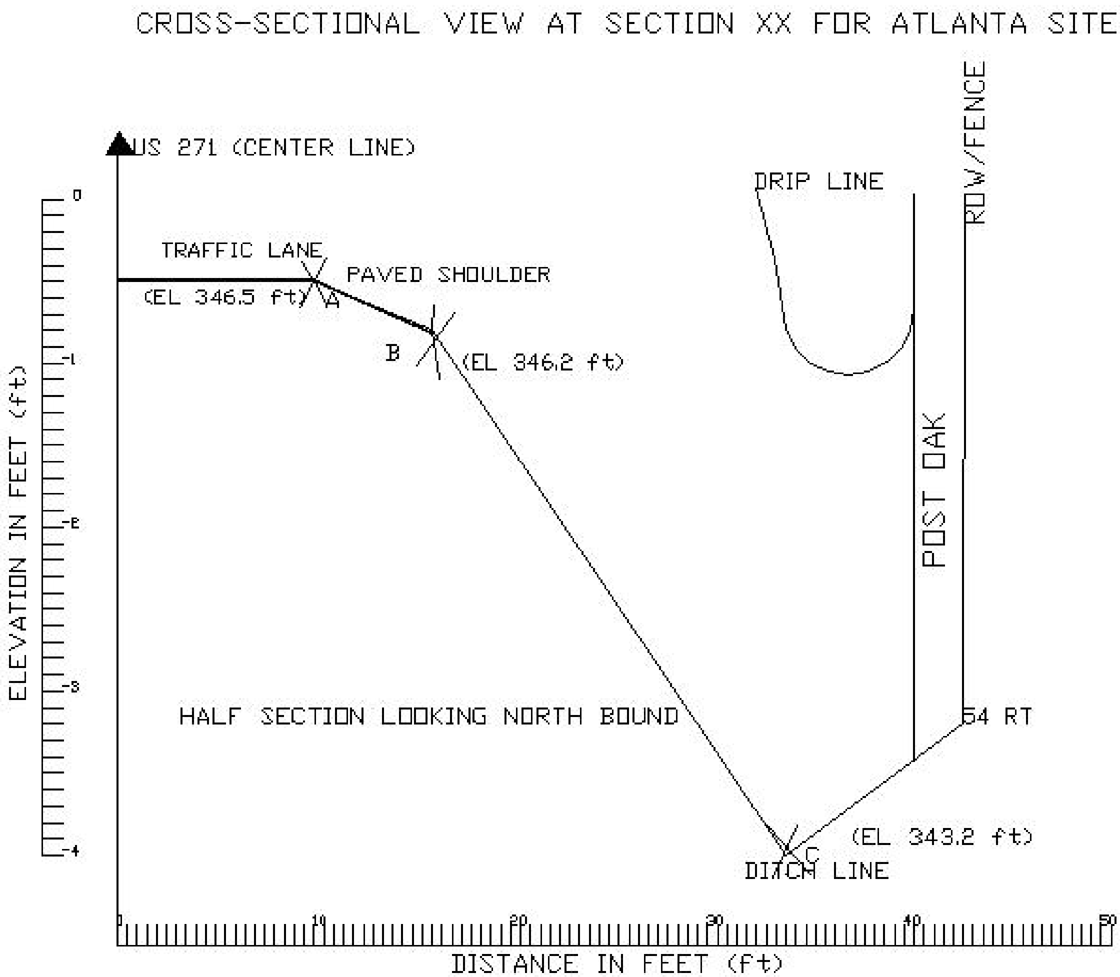



**Figure 16: Borehole location at the site in Atlanta District**

### 2.2.3 Geologic sections

The cross-sectional view of the soil at the Atlanta District site is shown in Figure 17. In borehole C soil samples, roots were present up to 13 ft. The details of the Atterberg limits and other index properties of this district are tabulated in Tables 3 and 4.

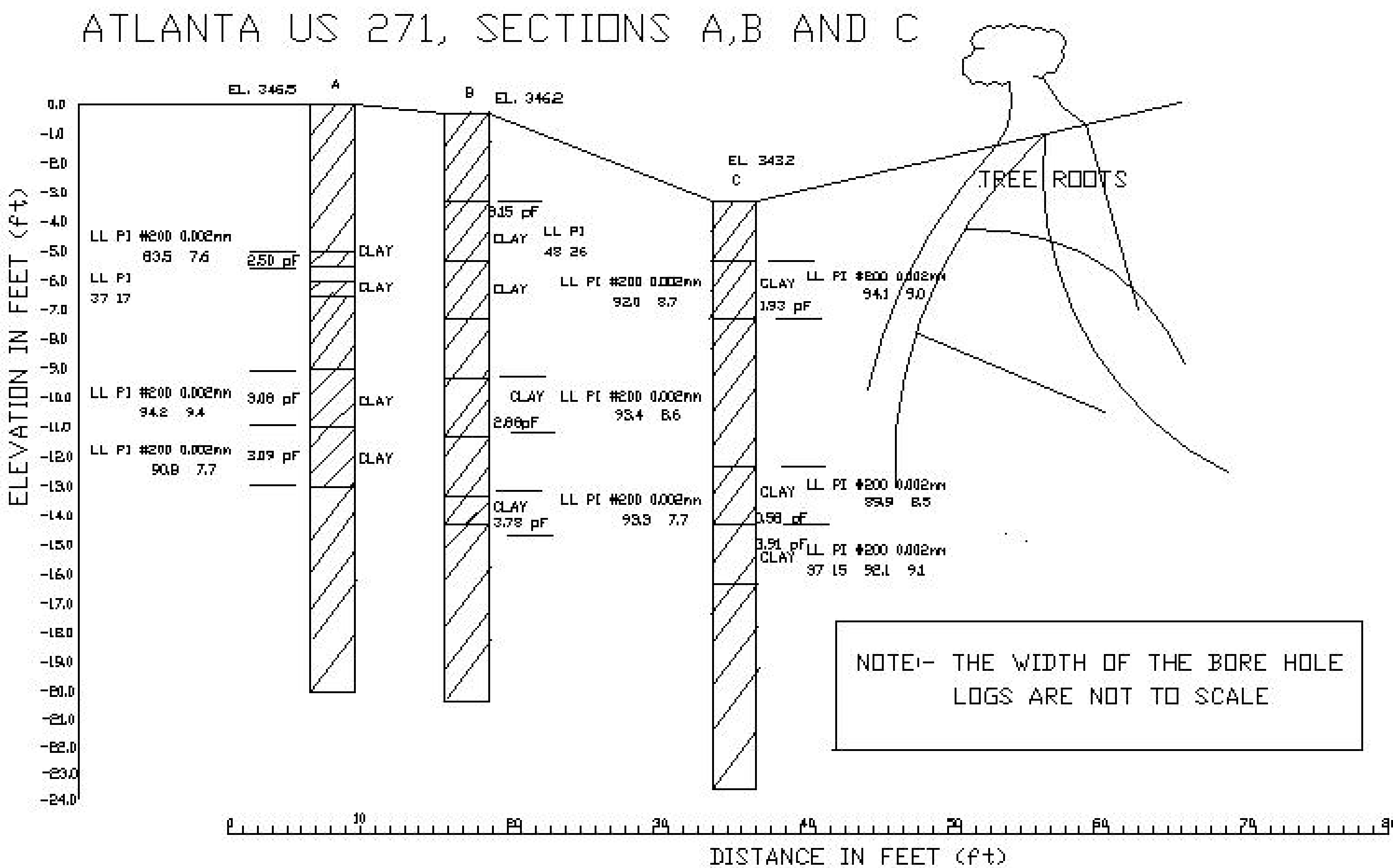



**Figure 17: Cross-sectional view at boreholes A, B, and C**

**Table 3. Summary of Atterberg limits and hydrometer test for Atlanta District.**

| No. | Sample No. | Depth (ft) | Depth of Sample for Atterberg Limits (ft) | LL | PL | PI | % Clay <0.002mm | Fines Content (% passing #200) | In-situ Water Content (%) | Soil Description |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A1 | 5-5.5 | 6-6.5 | 37 | 20 | 17 | 7.6 | 84 | 20.5 | Dark brown clay with stones. |
| 2 | A2 | 9-11 | | | | | 9.4 | 94 | 27.4 | Tan color clay. |
| 3 | A3 | 11-13 | | | | | 7.7 | 91 | 23.3 | Tan color clay. |
| 4 | B1 | 5-7 | 3-5 | 48 | 22 | 26 | 8.7 | 92 | 17.0 | Light brown, natural clay. |
| 5 | B2 | 9-11 | | | | | 8.6 | 93 | 26.8 | Light brown, natural clay. |
| 6 | B3 | 13-14 | | | | | 7.7 | 93 | 12.5 | Tan color clay, sandy, dark brown tinge in some places, cracks on the surface. |
| 7 | C1 | 2-4 | 11-13 | 37 | 22 | 15 | 9.0 | 94 | 16.1 | Dark brown clay, sandy. |
| 8 | C2 | 9-11 | | | | | 8.5 | 90 | 16.7 | Light brown clay, sandy with roots. |
| 9 | C3 | 11-13 | | | | | 9.1 | 92 | 15.8 | Light brown clay, sandy with roots. |

**Table 4. Summary of the Atterberg limits and hydrometer analysis for samples of Atlanta District on which pressure plate test was carried out.**

| S.No | Sample | Depth | LL | PL | PI | %clay <0.02 mm | % fines passing #200 | Water Content |
|---|---|---|---|---|---|---|---|---|
| 1 | A3 | 11-13 | 37 | 20 | 17 | 7.7 | 91 | 20.7 |
| 2 | B2 | 7-9 | 52 | 28 | 24 | 8.7 | 92 | 18.5 |
| 3 | B2 | 11-13 | 50 | 26 | 24 | 8.6 | 93 | 19.6 |
| 4 | C1 | 2-4 | 37 | 22 | 15 | 9.0 | 94 | 17.8 |
| 5 | C2 | 9-11 | 37 | 22 | 15 | 8.5 | 90 | 17.7 |

## 2.3 Austin Loop 1

### 2.3.1 Location

This site is located on Loop 1 at SH 360 in Austin. Severe damage to existing frontage road was observed at the site due to shrink swell soils. Figure 18 shows the site location. The site has been shown by arrow in the Figure 18.

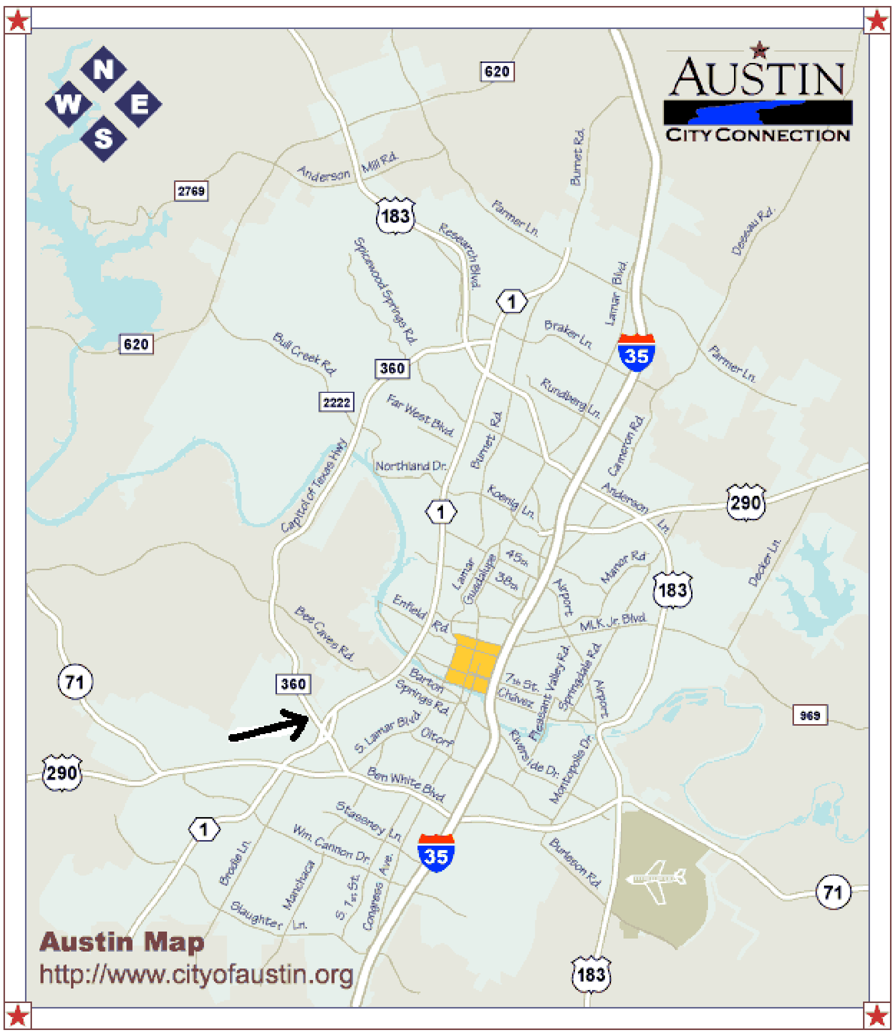



**Figure 18: Map of location of site in Austin District** (http://www.ci.austin.tx.us/help/austinmap.htm.)

### 2.3.2 Site description

This site consisted of a shallow clay layer over a sloping limestone bed as shown in Figure 19. The Borings B1, B2, and B3 were drilled about 2 ft from the frontage road curb as shown in Figure 20. The location and cross section along the boring can be seen in Figure 20.

### 2.3.3 Geologic sections

The soil profile shown in Figure 20 has been constructed on the basis of the borehole logs provided by Texas Department of Transportation. The distance between boreholes B1, B2, and B3 are estimated, as surveys were not performed.

The details of the Atterberg limits and other index properties of this district have been tabulated in Tables 5 and 6.

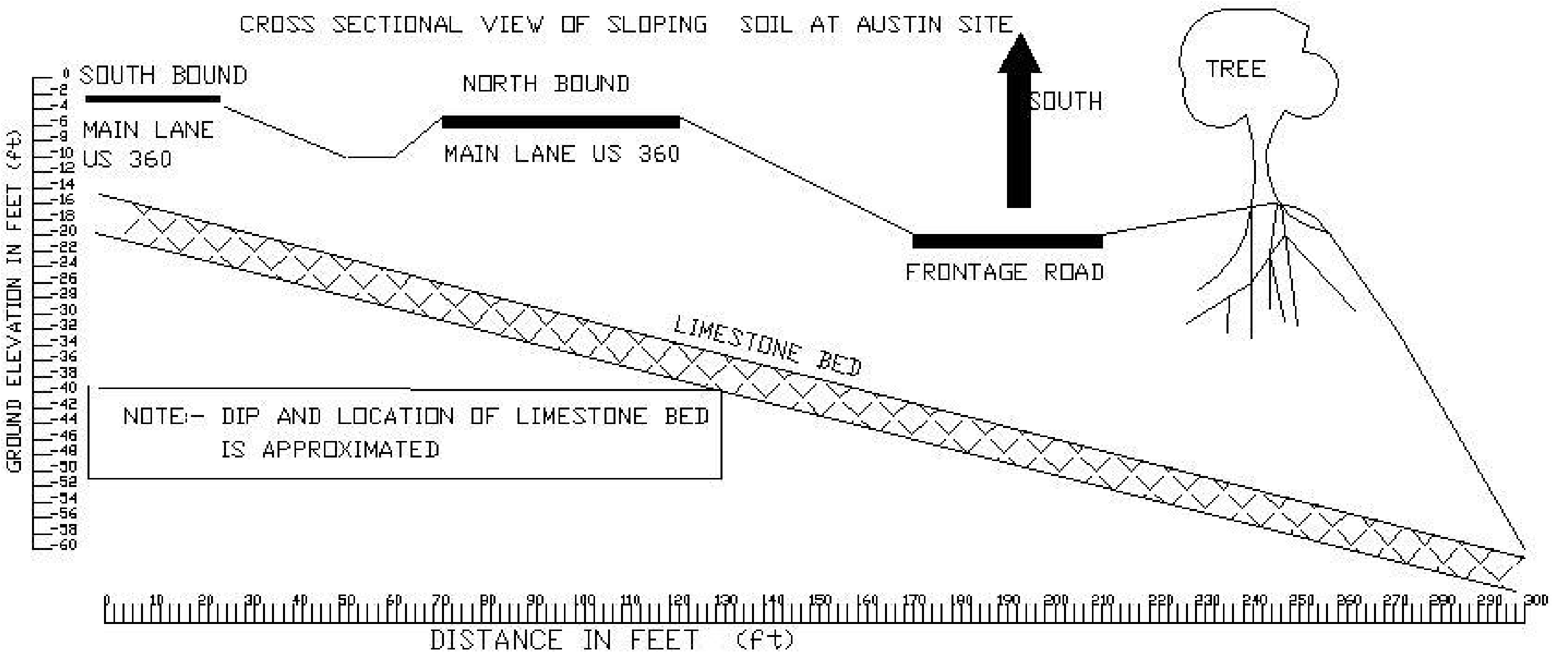



**Figure 19: Cross-sectional view of sloping soil at Austin District**

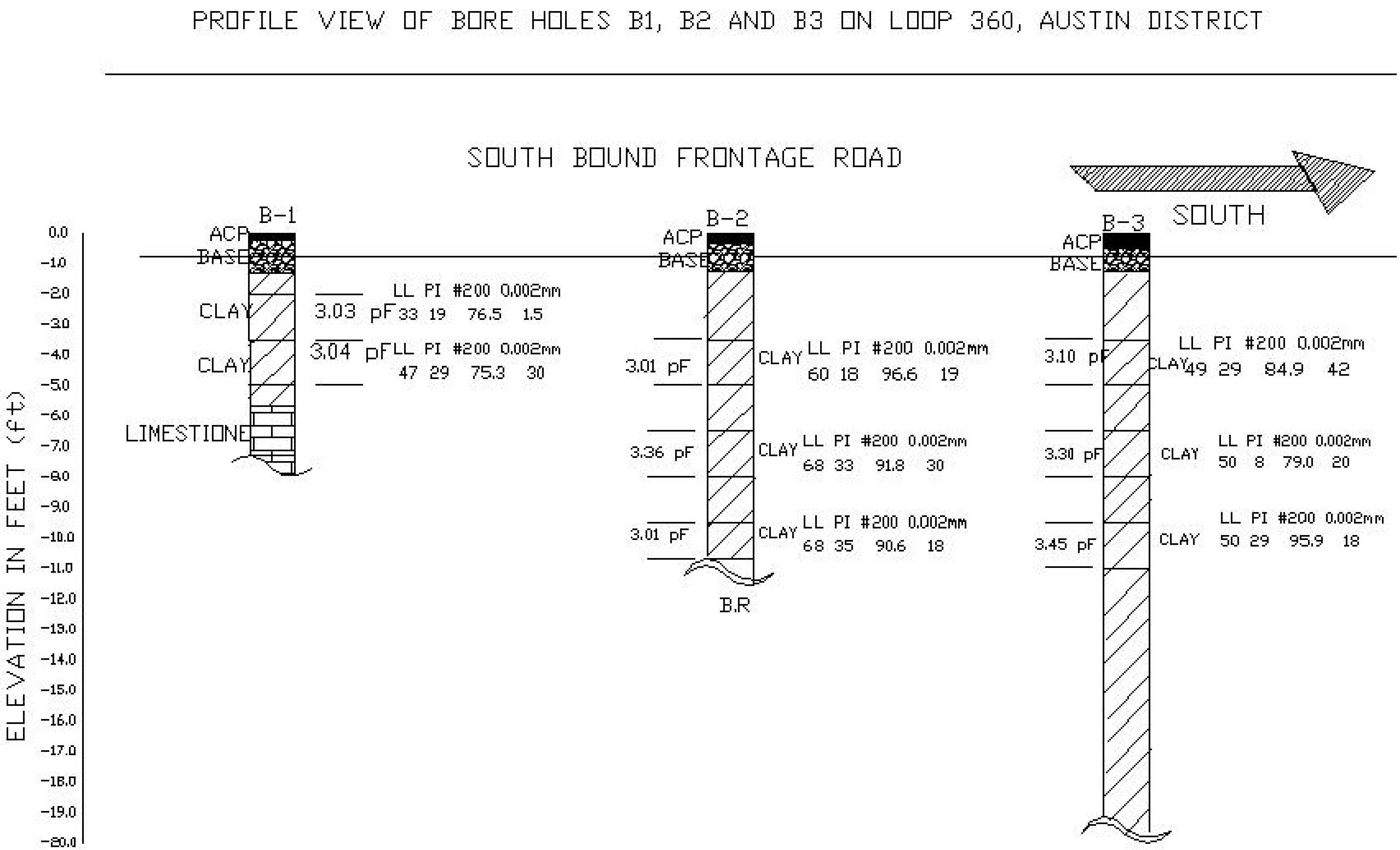



**Figure 20: Cross-sectional view at bore holes B1, B2, and B3 ( Austin site)**

**Table 5. Summary of Atterberg limits and hydrometer test for Austin District.**

| No. | Sample No. | Depth (ft) | LL | PL | PI | % Clay <0.002mm | Fines Content (% passing #200) | Water Content (%) | Soil Description |
|---|---|---|---|---|---|---|---|---|---|
| 1 | B1 | 2-3.5 | 33 | 14 | 19 | 1.5 | 77 | 19.0 | Tan color sandy clay, calcareous, soft, roots present and crack on face. |
| 2 | B1 | 3.5-5 | 47 | 18 | 29 | 30.0 | 75 | 19.4 | Tan color sandy clay. |
| 3 | B2 | 3.5-5 | 60 | 20* | 40** | 19.0 | 97 | 23.1 | Silty clay, gypsum, small stones present. |
| 4 | B2 | 6.5-8 | 68 | 20* | 48** | 30.0 | 92 | 23.0 | Sandy clay, small stones, gypsum in small amount |
| 5 | B2 | 9.5-10.7 | 68 | 20* | 48** | 18.0 | 91 | 13.7 | Soft silty clay, gravel, roots, no cracks |
| 6 | B3 | 3.5-5 | 49 | 20 | 29 | 42.0 | 85 | 21.2 | Calcareous, gravelly clay, soft, stones present and tan color. |
| 7 | B3 | 6.5-8 | 50 | 20* | 30** | 20.0 | 79 | 20.3 | Calcareous, gravelly clay, soft, stones present and tan color. |
| 8 | B3 | 9.5-11 | 50 | 21 | 29 | 18.0 | 96 | 24.1 | Soft tan color clay, gravels present and no cracks. |

* Inferred PL values from the other soils with similar texture.

** PI values calculated from the inferred PL values.

**Table 6. Summary of the Atterberg limits and hydrometer analysis for samples of Austin District on which pressure plate test was carried out.**

| S.No | Sample | Depth | LL | PL | PI | Matric suction | %clay <0.02 mm | % fines passing #200 | Water Content |
|---|---|---|---|---|---|---|---|---|---|
| 1 | B1 | 3.5-5 | 47 | 18 | 29 | 3.04 | 30 | 75 | 19.6 |
| 2 | B3 | 9.5-11 | 50 | 21 | 29 | 3.45 | 18 | 96 | 24.0 |

# CHAPTER III

# SUCTION AND DIFFUSION PROPERTIES

## 3.1 Introduction

The rate at which moisture diffuses through soil is critical to a number of problems in unsaturated soil mechanics. The rate of diffusion in water or fluid through unsaturated soil is basically governed by soil permeability and the moisture-suction characteristic curve. The Diffusion coefficient (α) controls the rate of infiltration of surface moisture into the soil mass. It can be measured in the laboratory. The diffusion coefficient can also be estimated using empirical correlations to index properties.

## 3.2 Sample selection

The samples used for the study were provided by the Texas Department of Transportation. In order to maintain the natural water content of the soil, these samples were stored in a moisture and temperature-controlled environment prior to testing.

As explained in chapter II, there were three test sites studied under this research viz., Fort Worth District, Atlanta District and Austin District. In the Fort Worth District site, moisture diffusion tests were performed on two samples from each borehole. In the Atlanta and Austin District sites, three soil samples from each borehole were tested for moisture diffusivity. The samples were taken from the top, middle, and bottom depths of each borehole.

## 3.3 Test procedure

### 3.3.1 Overview

This procedure determines the measurement of soil diffusion coefficient in the laboratory. Transient moisture flow due to suctions imposed at the boundaries of the soil mass is controlled by the unsaturated soil moisture diffusion coefficient.

The soil sample is sealed in such a way that evaporation is allowed only from one open end of the soil specimen. This is done by sealing all the sides as well as one end of the soil specimen. The total suction of a soil specimen is measured using thermocouple psychrometers. The measurements for total suction with time are made at different locations along the length of the soil specimen. The filter paper method was employed to obtain the initial total suction and as a means of validating psychrometer measurements.

The diffusion coefficient of soil was back calculated from the measured data using the Matlab program in Appendix D. Successive values of $\alpha$ are tried to find the best fit between the theoretical and measured suction as a function of time at a given location in the specimen. The value of the soil moisture diffusion coefficient that best fit all the laboratory data was taken as the diffusion coefficient for that particular soil specimen.

Out of the three psychrometers installed inside the soil specimen, the first psychrometer closest to the open end of the specimen gave the most reliable data for the $\alpha$ coefficient determination. The data from the second psychrometer was used to obtain the $\alpha$ coefficient where the first psychrometer gave insufficient data.

### 3.3.2 Apparatus

The following apparatus is required:

1. Constant temperature environment, with stability in temperature less than $\pm 1^o C$, preferably in the order of $\pm 0.1^o C$.
2. Stainless steel shield type thermocouple psychrometers from Wescor, Inc.
3. A sling psychrometer to measure the atmospheric suction.
4. Data logger: micro voltmeter; (a) CR 7 or (b) HR 33T from Wescor, Inc.
5. A drill-bit to drill a hole into the soil specimen.
6. Cutting and trimming tools such as knife, spatula and an ice chest,
7. Sealing material such as silicon sealant, electrical tape, aluminum foil, plastic wrap.

The major apparatus that was used to measure the suction is thermocouple psychrometer. This is discussed below.

### 3.3.3 Thermocouple psychrometer

A thermocouple psychrometer measures the relative humidity in the air phase of the soil pores. This in turn is used to measure the total suction of soil. The basic principle that underlies the operation of a thermocouple psychrometer is the temperature difference measurements between a non-evaporating surface (i.e., dry bulb) and an evaporating surface (i.e., wet bulb, Fredlund and Rahardjo, 1993). Relative humidity is related to the difference between these surfaces. Under a controlled temperature environment of ±0.001 ºC, the lowest suction that can be measured using a thermocouple psychrometer is approximately 3 pF. A thermocouple psychrometer is shown in Figure 21.

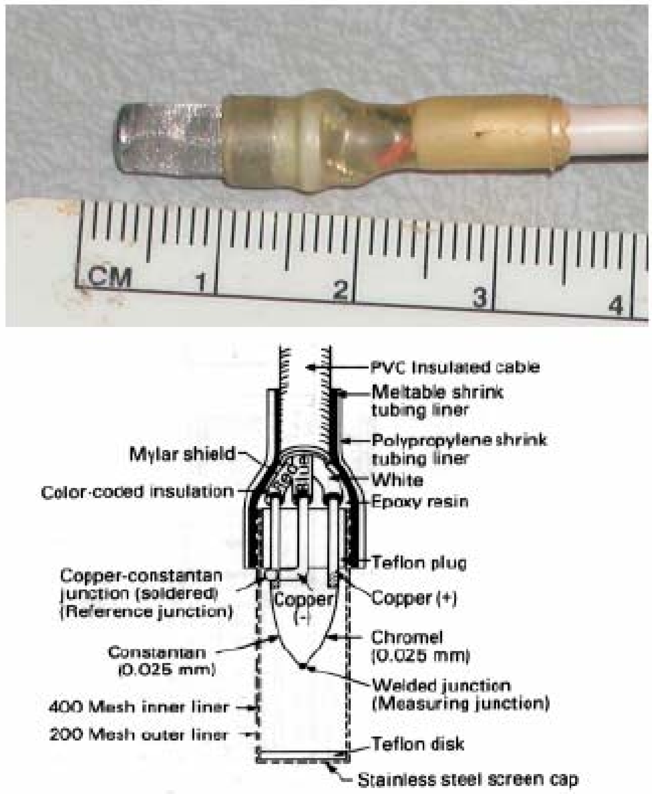



**Figure 21: Screen caged single-junction Peltier thermocouple psychrometer** ( Fredlund and Rahardjo, 1993)

The psychrometers were calibrated before using them for total suction measurement in soil. The calibrations of thermocouple psychrometers are performed using salt solution of different molalities and for a suction range of 3 to 5 pF of osmotic suction.

### 3.3.4 Preparation of salt solution

1. The amount of NaCl to be used is determined depending upon the required suction value. The amount of NaCl to be used in the salt solution decides the quantity of water to be used for the preparation of the solution. Table 7 gives the amount of NaCl required to the amount of distilled water in g/liter.

**Table 7. NaCl osmotic suctions for psychrometer calibration** ( Bulut et al., 2001).

| Molality | NaCl Amount (grams/liter) | Osmotic Suction (bar) | Osmotic Suction (pF) | Osmotic Suction (kPa) |
|---|---|---|---|---|
| 0.02 | 1.1688 | 0.95 | 2.99 | 95.02 |
| 0.05 | 2.9221 | 2.34 | 3.38 | 233.90 |
| 0.10 | 5.8442 | 4.62 | 3.67 | 462.32 |
| 0.20 | 11.6885 | 9.16 | 3.97 | 916.08 |
| 0.50 | 29.2212 | 22.86 | 4.37 | 2286.15 |
| 0.70 | 40.9097 | 32.17 | 4.52 | 3216.82 |
| 1.20 | 70.1310 | 56.26 | 4.76 | 5626.15 |
| 2.20 | 128.5734 | 108.87 | 5.05 | 10887.35 |
| 1 Mole NaCl = 58.442468 grams<br>1 bar = 100 kPa | | | | |

2. The electronic sensitive balance is used to weigh salt to the nearest 0.0001 g. It must be ensured that the salt is not exposed for long periods to the atmosphere; therefore the bottle containing the salt is sealed after use.
3. Salt solution is prepared by dissolving the measured salt in the required amount of distilled water in a flask.
4. The salt solutions are stored in plastic bottles and sealed with electrical tape.

### 3.3.5 Calibration of psychrometer

The psychrometers are calibrated before they are used for the purpose of testing. Each psychrometer has a calibration curve which is unique. These curves are used to obtain the equation relating microvolt outputs from the thermocouple and corresponding suction value in bars. The thermocouple psychrometers are calibrated as given:

1. Holes of diameter 1.5 to 2 cm are made on the lid of the glass jar (Figure 22).

   (The diameter of the hole is dependent on the size of the rubber stopper being used)
2. The rubber stopper is cut, lengthwise, to its middle.
3. The psychrometer wire is plugged in the middle of the rubber stopper.. Sufficient length of wire is provided so that the tip of the psychrometer is within the solution in the glass jar.
4. The psychrometers are passed along with the rubber stoppers through the lid holes. Silicon sealant is put on the rubber stopper, psychrometer contact area, and lid contact area to prevent entry of air. The sealant is allowed to dry for half an hour before proceeding with the testing.
5. The psychrometer is immersed in salt solution (prepared above) in a glass jar. The jar is made water and air tight using electrical tape.
6. The whole set up is kept in a water bath having a constant temperature of 25 $^{o}$C and controlled within ±0.1 $^{o}$C accuracy for maintaining isothermal conditions. The setup is left for an hour for the psychrometer to attain equilibrium.
7. HR 33T micro voltmeter is used for measuring the total suction value in micro volts. A set of three readings is taken for each psychrometer in case of HR 33T.
8. The process is repeated for different salt solutions having varying suction values.
9. The readings are plotted for different salt solutions, in micro volts, against the suction value of the corresponding salt solution and the required calibration curve is obtained. This curve is used to convert the microvolt output into total suction. Figure 23 shows a typical calibration curve obtained from the above procedure.

10. The psychrometers are washed with distilled water and air dried after each set of calibration process to remove the salt from the fine screen of the psychrometers.

**Figure 22: Calibration of thermocouple psychrometer**

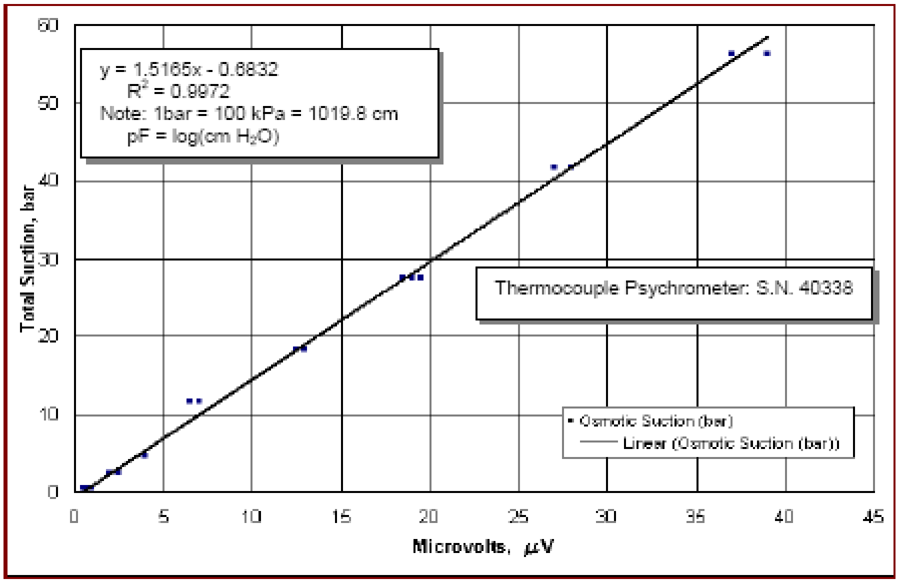



**Figure 23: A typical calibration curve**

This whole procedure of determination of diffusivity coefficient in laboratory can be divided into following three steps:

1. Total suction of the soil sample was determined as a function of distance and time.
2. Initial suction, matric and total suction was determined using filter paper method.
3. Atmospheric suction was measured during the testing using sling psychrometer.

Before starting the test the thermocouple psychrometers were calibrated.

All the tests mentioned above have been discussed below:

### 3.3.6 Measurement of total suction as a function of distance and time

1. A soil specimen of about 200 mm long is selected from the boring log samples, or specimen of approximately this size 200 mm is cut from a longer sample and the ends of the specimen are trimmed. The soil specimen is recorded as length L.

2. The locations of the thermocouple psychrometers on the specimen are marked after deciding which end of the specimen will be exposed to the atmospheric suction (figure on page 54). Relative to the closed end of the specimen (Figure 24), the location and spacing of the psychrometers. Small holes are drilled on the lateral side of the soil sample as shown in Figure 24. The first hole was drilled approximately 1.5 cm from the open end and the second hole was drilled approximately 1.3 to 4 cm from the first hole. The third hole was drilled approximately at the center of the soil sample and the fourth at about 2 to 3 cm from the third hole. Depending on the soil type, the current moisture state of the soil specimen, and the method of making a hole into the specimen for the installation of the psychrometer, distance from the open end to the first psychrometer might change.

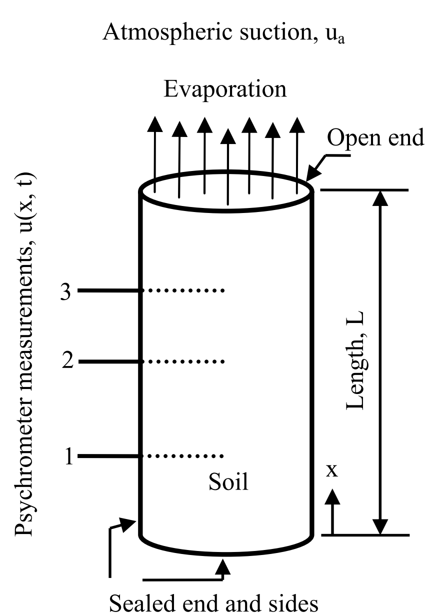



**Figure 24: Typical soil specimen used for test**

3. A drill-bit of around 0.6 to 0.7cm is used to make the holes for the psychrometer. The depth of the hole is kept approximately half the diameter of the soil sample (figure on page 54).
4. Calibrated thermocouple psychrometers are inserted inside the holes in the soil specimen. Number is assigned to each psychrometer corresponding to its hole number in the specimen. The coordinates of the psychrometers are measured and recorded.
5. In order to keep the psychrometer in place and to avoid any moisture loss or gain from the inside of the hole, the hole is tightly sealed on the surface of the specimen (figure on page 54). Small chunks of soil extruded during drilling were used to seal the holes. This process is repeated for each psychrometer.
6. The whole specimen is sealed with aluminum foil and plastic wrap to prevent any moisture loss or gain, except the selected end that is exposed to the atmosphere.
7. The whole set up is put inside a constant temperature environment (Figure 25) for the suction measurements and the corresponding time is recorded. The temperature is maintained at 25 $^{o}$C and controlled within ±0.1 $^{o}$C accuracy using a water bath as depicted in Figure 22.

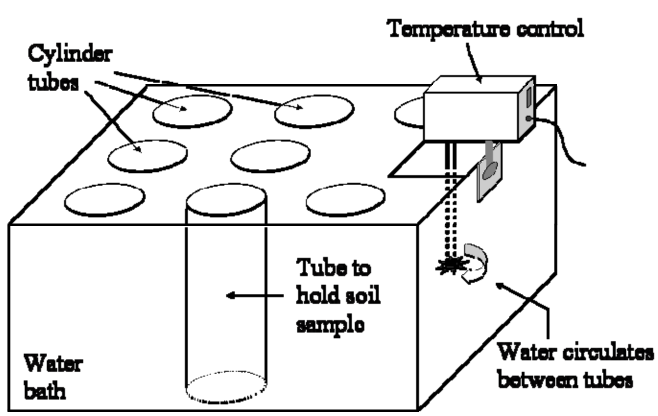
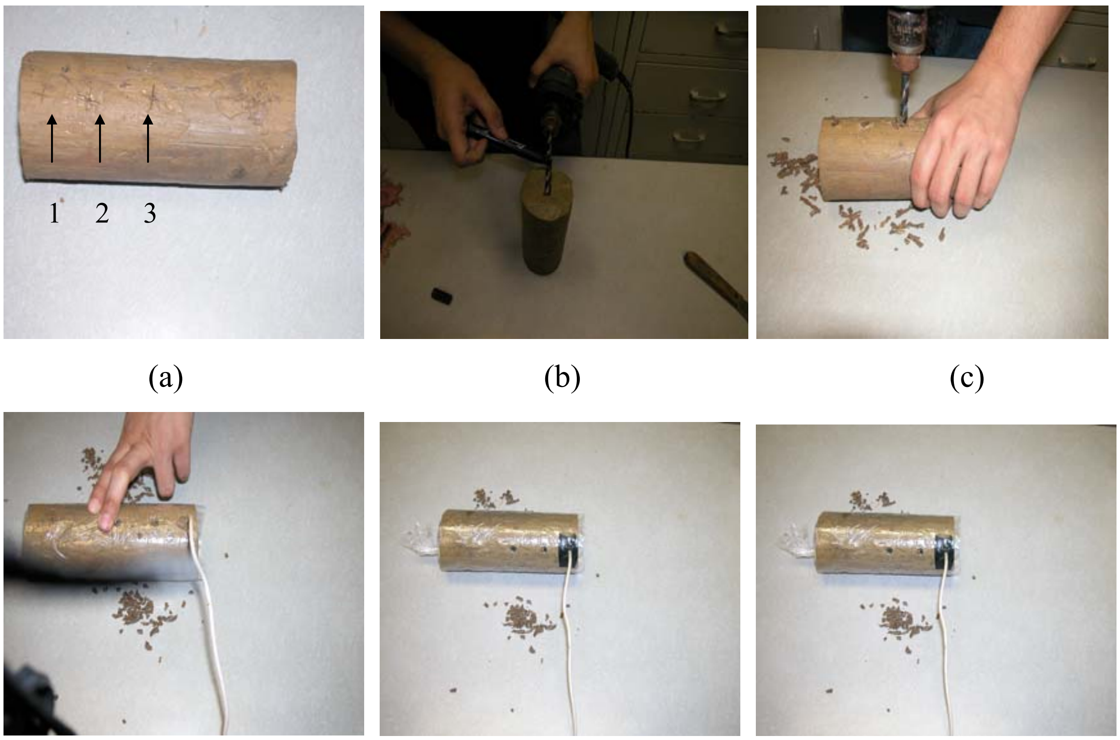



**Figure 25: Water bath used to maintain constant temperature**

8. Steps 1 through 7 are repeated for each soil specimen.

Figure 26 shown below gives in short the various stages of how the soil sample is prepared in the laboratory.




(a) (b) (c)

(d) (e) (f)

**Figure 26: Various stages of sample preparation before setting it up for testing**

The data is collected using HR- 33 T voltmeter and this is shown in Figure 27.

**Figure 27: Samples kept in water bath (black box) and measurements being taken by HR-33T (Voltmeter)**

### 3.3.7 Measurement of initial suction

Filter Paper Test was carried out to measure the initial, total and matric suction of the soil sample. The wetting filter paper calibration curve developed by Bulut et al. (2001) paper was used for both total and matric suction components. The filter paper used for the construction of calibration curve was Schleicher & Schuell No. 589-White Hard (WH) 5.5 cm in diameter. The same brand of filter paper was used in this study for both total and matric soil suction measurements.

The main principle on which this test is based is that at equilibrium, suction value of the filter paper and the soil is equal. Filter paper comes in equilibrium with the soil either through the vapor or liquid. When the filter paper comes in equilibrium by interaction with vapor, it gives a total suction measurement and when the filter paper comes to equilibrium by interaction with liquid, it gives the matric suction value. Using the wetting filter paper calibration curve and the water content of the filter paper disc the corresponding suction value is found from the curve

(Figure 28). Figure 29 shows the procedure of measuring total and matric suction using filter paper method.

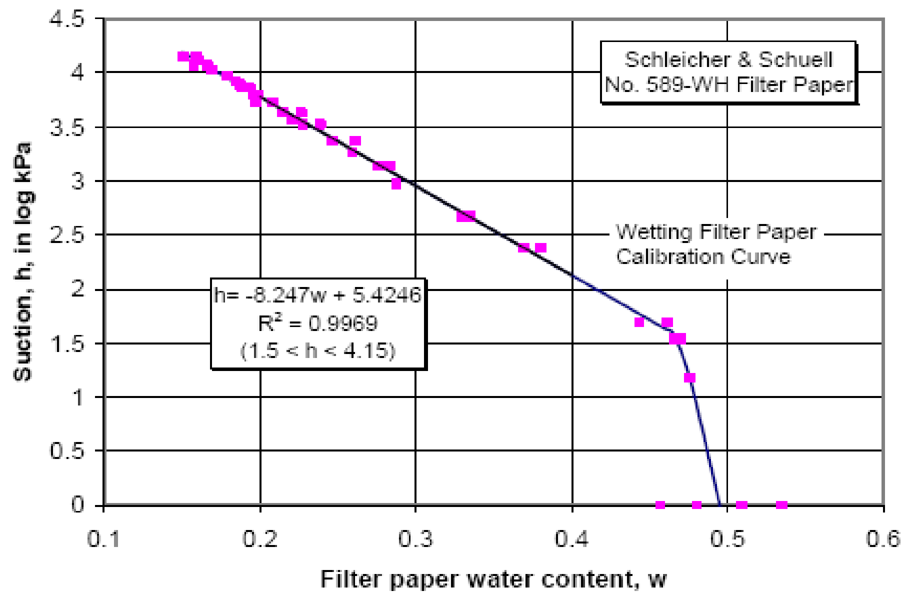



**Figure 28: Filter paper calibration curve** (Bulut et al., 2001)

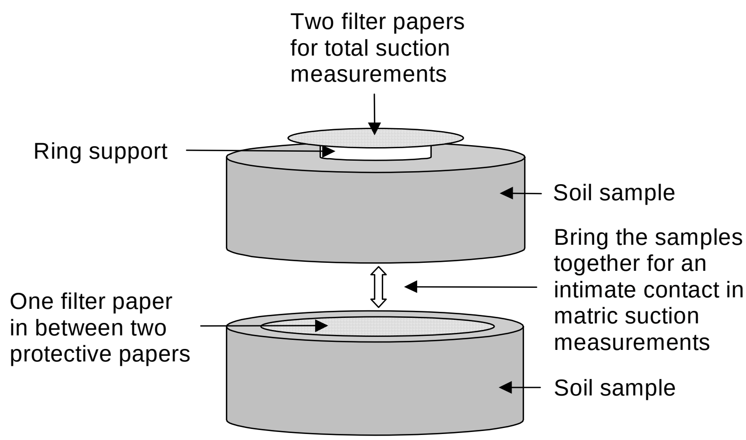



**Figure 29: Procedure of measuring total suction and matric suction by filter paper method** (Bulut et al. (2001)

The procedure can be summarized as follows:

1. Soil specimen is cut into two halves and trimmed.
2. A 5.5 cm in diameter filter paper [Schleicher & Schuell No. 589-White Hard (WH)] is taken and sandwiched between two larger size diameter filter papers. The outer filter paper helps in avoiding direct contact of the filter paper with the soil sample, and hence, acts as the protective filter paper.
3. The filter papers are placed between the two halves of the soil sample and sealed with an electrical tape.
4. The sample is put in a glass jar and some supporting material is inserted on the sides of the glass jar ensuring that the sample does not move in the glass jar.
5. A ring-type support is put on top of the soil in order to provide a non-contact system between the filter paper and the soil.
6. Two Schleicher & Schuell No. 589-WH filter papers one on top of the other are placed on the ring using tweezers as shown in Figure 26. It is essential that the filter papers should not touch the soil, the bottom of the lid in any way, or the inside surface of wall of the jar.
7. The glass jar lid is sealed very tightly with electrical tape.
8. An ice chest is used to store the glass jars containing the soil samples during the equilibration period to maintain a temperature controlled environment. A period of one week is allowed for equilibration.
9. After one week, the filter papers are shifted to pre-weighed aluminum cans. A temperature of 110 $\pm 5^{o}$C is maintained inside the oven. The filter papers are kept in oven for at least 10 hrs. The wet filter paper and the aluminum can are weighed to the nearest 0.001 gm and then put in oven.

10. The cans are closed with their lids and allowed to equilibrate for about 5 minutes inside the oven before weighing the dried filter papers to the nearest 0.001gm.
11. The aluminum cans are weighed, with and without the filter paper and the moisture content of each of the filter paper is determined using the following formula.

$$MC\% = \frac{W_2 - W_1}{W_3 - W_1} * 100 \tag{28}$$

Here,

$W_1$ = Weight of tin (gm)

$W_2$ = Weight of moist filter paper + tin (gm)

$W_3$ = Weight of dried filter paper + tin (gm)

Matric suction values of the soil samples is obtained using the equation for the wetting filter paper calibration curve (Figure 28).The water content obtained for the various filter papers is utilized in the equations 29 and 30.

$$h_1 = -8.247W_f + 5.4246 \ (h_1 > 1.5 \log kPa) \tag{29}$$

Where,

$h_1$ = matric suction (in log kPa)

$W_f$ = filter paper water content (gm/gm, in decimals)

$$h_2 = -8.247W_f + 6.4246 \ (h_2 > 2.5 \text{ pF}) \tag{30}$$

Here,

$h_2$ = matric suction (in pF)

### 3.3.8 Measurement of atmospheric suction

A sling psychrometer was used to measure the relative humidity and the calculations were done using the following Kelvin's equation (Fredlund and Rahardjo 1993) (equation 31). Figure 30 shows the sling psychrometer used for the testing

$$h = (RT/V)\ln(RH) \tag{31}$$

Here,

| | | |
|---|---|---|
| $h$ | = | total suction |
| $T$ | = | absolute temperature |
| $R$ | = | universal gas constant |
| $V$ | = | molecular volume of water |
| $RH$ | = | relative humidity |


**Figure 30: Sling psychrometer**

A sling psychrometer comprises of two thermometers (a) a wet bulb thermometer which is used to measure the saturation temperature, $T_{wb}$, and (b) a dry bulb thermometer that is used to measure the air temperature, $T_{db}$. These two thermometers are mounted on a common swivel. It is ensured that sufficient air flow is available around these thermometers. A small ventilator is used to blow the air on the stationary wet bulb. Relative humidity, RH is determined using psychrometric charts (Table 8).The measured temperatures $T_{wb}$ and $T_{db}$ obtained from the sling psychrometer is used in the Table 8.

### 3.3.9 Determination of α coefficient using laboratory data of drying test

Two Matlab programs “dry test” and “alpha dry test” (Appendix D) are used for fitting the actual laboratory data in the theoretical curve and eventually used to calculate the α-value. The best fitting value of the soil diffusion coefficient with the laboratory data is taken as the diffusion coefficient for the soil specimen.

The data required for the determination of α coefficient are as follows:

- Initial total suction in soil (calculated using the filter paper test).
- Atmospheric suction (measured using a sling psychrometer).
- Length of the soil specimen.
- Distance of each psychrometer from the closed end.
- Evaporation coefficient, he = 0.54 $cm^{-1}$.
- Total suction measurements with time along the length of the soil specimen.

**Table 8. Psychrometric chart** (Reynolds and Perkins, 1970).

| Air (dry Bulb Temperature) (°F) | Wet Bulb Depression (Dry Bulb Temperature minus Wet Bulb Temperature ) (°F) | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 25 | 30 | 35 | 40 |
| 0 | 67 | 31 | 1 | | | | | | | | | | | | | | | | | | | | | |
| 5 | 73 | 46 | 20 | | | | | | | | | | | | | | | | | | | | | |
| 10 | 78 | 56 | 34 | 13 | | | | | | | | | | | | | | | | | | | | |
| 15 | 82 | 64 | 46 | 29 | 11 | | | | | | | | | | | | | | | | | | | |
| 20 | 85 | 70 | 55 | 40 | 26 | 12 | | | | | | | | | | | | | | | | | | |
| 25 | 87 | 74 | 62 | 49 | 37 | 25 | 13 | 1 | | | | | | | | | | | | | | | | |
| 30 | 89 | 78 | 67 | 56 | 46 | 36 | 26 | 16 | 6 | | | | | | | | | | | | | | | |
| 35 | 91 | 81 | 72 | 63 | 54 | 45 | 36 | 27 | 19 | 10 | 2 | | | | | | | | | | | | | |
| 40 | 92 | 83 | 75 | 68 | 60 | 52 | 45 | 37 | 29 | 22 | 15 | 7 | | | | | | | | | | | | |
| 45 | 93 | 86 | 78 | 71 | 64 | 57 | 51 | 44 | 38 | 31 | 25 | 18 | 12 | 6 | | | | | | | | | | |
| 50 | 93 | 87 | 80 | 71 | 67 | 61 | 55 | 49 | 43 | 38 | 32 | 27 | 21 | 16 | 10 | 5 | | | | | | | | |
| 55 | 94 | 88 | 82 | 76 | 70 | 65 | 59 | 54 | 49 | 43 | 38 | 33 | 28 | 23 | 19 | 14 | 9 | 5 | | | | | | |
| 60 | 94 | 89 | 83 | 78 | 73 | 68 | 63 | 58 | 53 | 48 | 43 | 39 | 34 | 30 | 26 | 21 | 17 | 13 | 9 | 5 | | | | |
| 65 | 95 | 90 | 85 | 80 | 75 | 70 | 66 | 61 | 56 | 52 | 48 | 44 | 39 | 35 | 31 | 27 | 24 | 20 | 16 | 12 | | | | |
| 70 | 95 | 90 | 86 | 81 | 77 | 72 | 68 | 64 | 59 | 55 | 51 | 48 | 44 | 40 | 36 | 33 | 29 | 25 | 22 | 19 | 3 | | | |
| 75 | 96 | 91 | 86 | 82 | 78 | 74 | 70 | 66 | 62 | 58 | 54 | 51 | 47 | 44 | 40 | 37 | 34 | 30 | 57 | 24 | 9 | | | |
| 80 | 96 | 91 | 87 | 83 | 79 | 75 | 72 | 68 | 64 | 61 | 57 | 54 | 50 | 47 | 44 | 41 | 38 | 35 | 32 | 29 | 15 | 3 | | |
| 85 | 96 | 92 | 88 | 84 | 80 | 76 | 73 | 69 | 66 | 62 | 59 | 56 | 52 | 49 | 46 | 43 | 41 | 38 | 35 | 32 | 20 | 8 | | |
| 90 | 96 | 92 | 89 | 85 | 81 | 78 | 74 | 71 | 68 | 65 | 61 | 58 | 55 | 52 | 49 | 47 | 44 | 41 | 39 | 36 | 24 | 13 | 3 | |
| 95 | 96 | 93 | 89 | 85 | 82 | 79 | 75 | 72 | 69 | 66 | 63 | 60 | 57 | 54 | 51 | 49 | 46 | 43 | 41 | 38 | 27 | 17 | 7 | 1 |
| 100 | 96 | 93 | 89 | 86 | 83 | 80 | 77 | 73 | 70 | 68 | 65 | 62 | 59 | 56 | 54 | 51 | 49 | 46 | 44 | 41 | 30 | 21 | 12 | 4 |
| 105 | 97 | 93 | 90 | 87 | 83 | 80 | 77 | 74 | 71 | 69 | 66 | 63 | 60 | 58 | 55 | 53 | 50 | 48 | 46 | 43 | 33 | 23 | 15 | 7 |
| 110 | 97 | 93 | 90 | 87 | 84 | 81 | 78 | 75 | 73 | 70 | 67 | 65 | 62 | 60 | 57 | 55 | 52 | 50 | 48 | 46 | 36 | 26 | 18 | 11 |
| 115 | 97 | 94 | 91 | 88 | 85 | 82 | 79 | 76 | 74 | 71 | 68 | 66 | 63 | 61 | 58 | 56 | 54 | 52 | 49 | 47 | 37 | 28 | 21 | 13 |
| 120 | 97 | 94 | 91 | 88 | 85 | 82 | 80 | 77 | 74 | 72 | 69 | 67 | 65 | 62 | 60 | 58 | 55 | 53 | 51 | 49 | 40 | 31 | 23 | 17 |

### 3.3.10 Interpretation of measured data

The measured data is interpreted using a procedure outlined by Aubeny and Lytton (2003). To compute the theoretical value of suction corresponding to each measurement location $x$ and measurement time $t$ an initial estimate of α is made. Mitchell (1979) (equation 32 and 33) expression is used.

$$u = u_a + \sum_{n=1}^{\infty} \frac{2(u_0 - u_a)\sin z_n}{z_n + \sin z_n \cos z_n} \exp\left[\frac{z_n{}^2 \alpha t}{l^2}\right] \cos\left[\frac{z_n x}{l}\right] \quad (32)$$

$$\cot z_n = z_n / h_e L \quad (33)$$

Here,

| | | |
|---|---|---|
| $u_a$ | = | atmospheric suction |
| $u_0$ | = | initial suction in soil |
| $\alpha$ | = | diffusion coefficient |
| $t$ | = | time |
| $L$ | = | sample length |
| $x$ | = | psychrometer coordinate |
| $h_e$ | = | evaporation coefficient |

- Equation 31 is used to calculate the theoretical values of suction, i.e. $u_{theory}$. The suction measured by the thermocouple psychrometer is called $u_{measured}$ $E$ (error) is the difference between the values of $u_{theory}$ and $u_{measured}$ and numerically it is expressed as equation 34 below:

$$E = u_{theory} - u_{measured} \quad (34)$$

$E_{sum}$ is the summation of square of the errors ($E$) for all measurements as given by equation 35.

$$E_{sum} = \Sigma\left(u_{theory} - u_{meausred}\right)^2 \tag{35}$$

- A trial and error approach is used to minimize the value of $E_{sum}$ by optimizing the value of α in the previous step.

The soil diffusion coefficient values are reported to the nearest two significant digits in $cm^2/sec$. A typical best fit curve for the diffusion-coefficient has been given in Figure 31. The data used for obtaining the curve shown in Figure 31.

| | | |
|---|---|---|
| Total Length of the sample, $L$ | = | 15.9 cm |
| Distance of psychrometer 1 from closed end, $x$ | = | 14.2cm |
| Initial Suction, $u_0$ | = | 3.51 pF |
| Relative Humidity | = | 56% |
| Atmospheric Suction, $u_a$ | = | 5.91 pF |
| Diffusion Coefficient, α | = | 2.00E-5 $cm^2/sec$ |

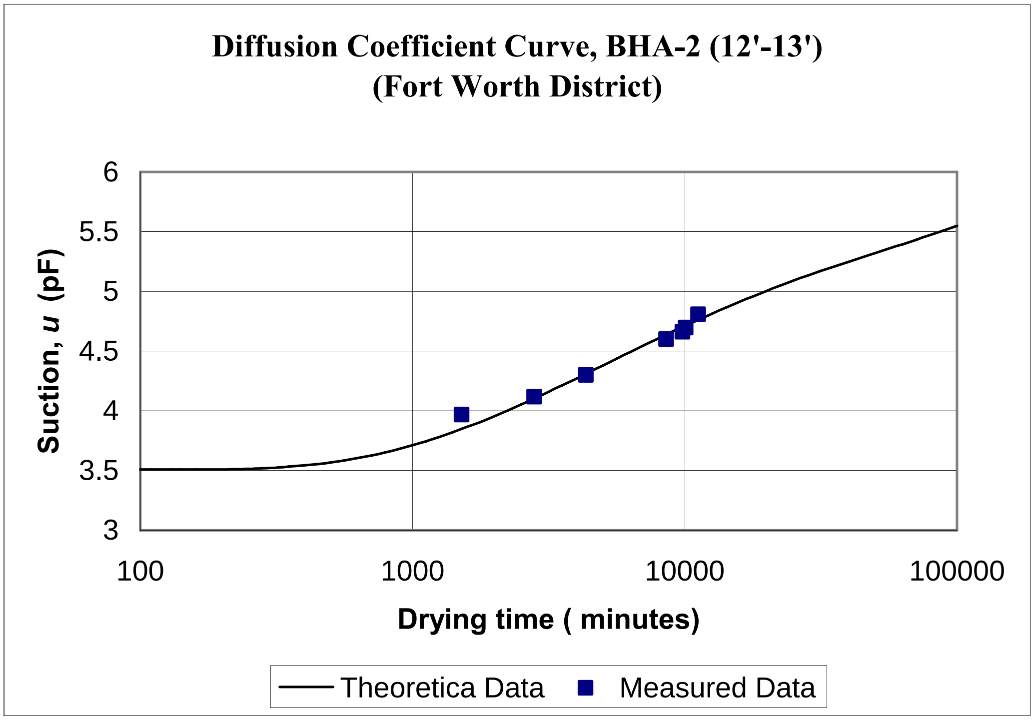



**Figure 31: Best fit curve of diffusion coefficient obtained from laboratory data and theoretical curve**

Tables 9, 10 and 11 shows the diffusion coefficient values and the matric suction values of the test sites, Fort Worth North Loop IH820, Atlanta US 271, and, Austin Loop 1 respectively. The comparison of diffusion coefficient using the empirical correlations and laboratory tests is given in table on page 117..

### 3.4 Determination of moisture diffusion coefficient using empirical relations

The moisture diffusion coefficient can be evaluated by using Equation 36 given by Lytton (2003).

$$\alpha = |\mathrm{S}|\, p\gamma_w / \gamma_d \qquad (36)$$

Here,

$|S|$ = Slope of the suction water characteristic curve.

$\gamma_d$ = Dry unit weight of soil

$\gamma_w$ = Unit weight of water

$p$ = Measure of unsaturated permeability $= |h_o|\ k / 0.434$

$h_o$ = Air entry value.

$k$ = Coefficient of permeability.

In the later chapters each parameter of equation 36 has been individually evaluated and then a comparison has been made between the theoretical moisture diffusivity and empirical moisture diffusivity in chapter VI.

**Table 9. Summary of diffusion and filter paper test for Fort Worth District.**

| No. | Sample No. | Depth (ft) | α coefficient ($cm^2/sec$) | Atomospheric Suction pF | Filter Paper Test (Initial Suction) pF | Filter Paper Test (Matric Suction) pF | Soil Description | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | A1 | 5-6 | 8.9x10-5 | 6.21 | 3.28 | 2.70 | Tan color clay, small stones, roots, calcareous. | |
| 2 | A1 | 11-12 | 5.9x10-5 | 6.06 | 3.38 | 2.71 | Light brown, silty, natural clay with gravels, shaley. | |
| 3 | A2 | 2-3 | *3.1x10-5 | 6.21 | 4.59 | 4.58 | Soft, dark brown clay. | α coefficient found from 2nd psychrometer. Results taken out by assuming intial suction. |
| 4 | A2 | 12-13 | 2.0x10-5 | 5.91 | 3.51 | - | Soft, dark brown silty clay. | |
| 5 | A3 | 0-1 | **8.7x10-5 | 6.22 | 4.92 | 4.76 | Dark brown clay with roots and sandy. | Results taken out by assuming intial suction. |
| 6 | A3 | 9-10 | 5.1x10-5 | 6.21 | 3.25 | 3.02 | Red brown color clay with limestone fragments, small cracks. | |
| 7 | A4 | 5-6 | 9.9x10-5 | 6.21 | 3.22 | 3.12 | Tan color clay, with calcareous nodules, small roots. | |
| 8 | A4 | 10-11 | 0.3x10-5 | 6.22 | 4.26 | 3.93 | Clay with limestones, sandy and cracks present, dry and hard. | |
| 9 | A5 | 3-4 | 7.9x10-5 | 6.21 | 3.02 | 2.58 | Tan color clay, with calcareous nodules. | |
| 10 | A5 | 8-9 | 10.3x10-5 | 6.21 | 3.09 | 3.05 | Tan color clay with gravels. | |
| 11 | B1 | 6-7 | 8.3x10-5 | 6.11 | 3.38 | 3.09 | Light brown clay, calcareous, sandy on one side and clayey on the other. | |
| 12 | B1 | 9-10 | 8.6x10-5 | 5.93 | 3.20 | 3.18 | Light brown clay, soft clay, silt present in small amount. | |
| 13 | B2 | 3-4 | 0.1x10-5 | 6.11 | 3.24 | 3.08 | Dark brown color clay, calcareous, roots, large cracks. | Cracks on the cross section of open end. |
| 14 | B2 | 11-12 | 9.7x10-5 | 5.93 | 3.30 | 3.25 | Tan color clay, shaley. | |
| 15 | B3 | 0-1 | 6.2x10-5 | 6.06 | 4.20 | 4.17 | Light brown clay, with calcareous nodules, sandy. | α coefficient found from 2nd psychrometer. |

Table 9. (Continued)

| No. | Sample No. | Depth (ft) | α coefficient (cm$^2$/sec) | Atomospheric Suction pF | Filter Paper Test (Initial Suction) pF | Filter Paper Test (Matric Suction) pF | Soil Description |
|---|---|---|---|---|---|---|---|
| 16 | B3 | 3-4 | - | 6.06 | 4.50 | ***4.53 | Light brown clay, with limestone fragments and sandy. |
| 17 | B4 | 1-2 | 8.4x10-5 | 6.11 | 3.59 | 3.49 | Dark brown clay, roots present, calcareous and cracks all around. |
| 18 | B4 | 13-14 | 1.1x10-5 | 5.92 | 3.56 | 3.45 | Tan color, shaley clay. |
| 19 | B5 | 6-7 | 13.7x10-5 | 6.06 | 2.67 | 2.59 | Tan color clay, silty, with calcareous nodules. |
| 20 | B5 | 11-12 | 7.6x10-5 | 6.06 | 3.49 | 3.27 | Light brown soft clay. |
| 21 | C1 | 2-3 | $3.7x10^{-5}$ | 6.22 | 3.28 | 2.89 | Brown color clay, gravels present, small cracks. |
| 22 | C1 | 6-7 | $3.1x10^{-5}$ | 6.22 | 3.76 | 3.42 | Dark brown soft clay. |
| 23 | C2 | 4-5 | $1.5x10^{-5}$ | 5.91 | 3.74 | 2.77 | Tan color clay, silty. |
| 24 | C2 | 5-6 | $6.1x10^{-5}$ | 6.06 | 3.57 | 2.95 | Tan color clay, silty. |
| 25 | C3 | 6-7 | $9.2x10^{-5}$ | 6.11 | 4.03 | 3.24 | Light brown clay, calcareous and cracks present. |
| 26 | C3 | 9-10 | $0.9x10^{-5}$ | 6.75 | 3.38 | 3.11 | Tan to light gray clay, shaley with calcareous nodules. |
| 27 | C4 | 5-6 | $1.9x10^{-5}$ | 5.93 | 3.38 | 3.11 | Light brown clay, sandy with limestone, cracked and soft. |
| 28 | C4 | 9-9.5 | $**1.9x10^{-5}$ | 6.22 | 4.57 | 4.53 | Light brown clay, soft, yellowish core & silty. |
| 29 | C5 | 4-5 | $2.9x10^{-5}$ | 6.22 | 3.61 | 3.13 | Tan color clay, sandy with limestones. |
| 30 | C5 | 7-8 | $1.7x10^{-5}$ | 5.93 | 3.81 | 3.33 | Light brown clay, shaley, hard. |

* Diffusion coefficient for second psychrometer

** Initial suction assumed for calculation of diffusion coefficient

*** One week equilibrium time not enough to obtain matric suction values

**Table 10. Summary of diffusion and filter paper test for Atlanta District.**

| No. | Sample No. | Depth (ft) | α coefficient ($cm^2$/sec) | Atomospheric Suction pF | Filter Paper Test (Initial Suction) pF | Filter Paper Test (Matric Suction) pF | Soil Description |
|---|---|---|---|---|---|---|---|
| 1 | A1 | 5-5.5 | $4.8x10^{-5}$ | 6.06 | 2.84 | 2.50 | Dark brown clay with stones. |
| 2 | A2 | 9-11 | $3.9x10^{-5}$ | 6.06 | 3.13 | 3.08 | Tan color clay. |
| 3 | A3 | 11-13 | $1.2x10^{-5}$ | 6.06 | 3.21 | 3.09 | Tan color clay. |
| 4 | B1 | 5-7 | $5.7x10^{-5}$ | 5.79 | 3.38 | 3.15 | Light brown, natural clay. |
| 5 | B2 | 9-11 | $3.1x10^{-5}$ | 5.79 | 3.22 | 2.88 | Light brown, natural clay. |
| 6 | B3 | 13-14 | $8.3x10^{-5}$ | 5.79 | 3.96 | 3.78 | Tan color clay, sandy, dark brown tinge in some places, cracks on the surface. |
| 7 | C1 | 2-4 | $9.2x10^{-5}$ | 5.76 | 3.07 | <2.50 | Dark brown clay, sandy. |
| 8 | C2 | 9-11 | $13.1x10^{-5}$ | 5.76 | 3.43 | <2.50 | Light brown clay, sandy with roots. |
| 9 | C3 | 11-13 | $4.3x10^{-5}$ | 5.76 | 3.99 | 3.91 | Light brown clay, sandy with roots. |

**Table 11. Summary of diffusion and filter paper test for Austin District.**

| No. | Sample No. | Depth (ft) | $\alpha$ coefficient ($cm^2$/sec) | Atomospheric Suction pF | Filter Paper Test (Initial Suction) pF | Filter Paper Test (Matric Suction) pF | Soil Description |
|---|---|---|---|---|---|---|---|
| 1 | B1 | 2-3.5 | 10.6x10$^{-5}$ | 5.84 | 3.45 | 3.03 | Tan color sandy clay, calcareous, soft, roots present and crack on face. |
| 2 | B1 | 3.5-5 | 5.7x10$^{-5}$ | 5.84 | 3.53 | 3.04 | Tan color sandy clay. |
| 3 | B2 | 3.5-5 | 7.7x10$^{-5}$ | 5.76 | 3.21 | 3.01 | Silty clay, gypsum, small stones present. |
| 4 | B2 | 6.5-8 | 6.3x10$^{-5}$ | 5.76 | 3.39 | 3.03 | Sandy clay, small stones, gypsum in small amount |
| 5 | B2 | 9.5-10.7 | 10.7x10$^{-5}$ | 5.76 | 3.21 | 3.01 | Soft silty clay, gravel, roots, no cracks |
| 6 | B3 | 3.5-5 | 3.2x10$^{-5}$ | 5.9 | 3.46 | 3.10 | Calcareous, gravelly clay, soft, stones present and tan color. |
| 7 | B3 | 6.5-8 | 1.8x10$^{-5}$ | 5.9 | 3.64 | 3.30 | Calcareous, gravelly clay, soft, stones present and tan color. |
| 8 | B3 | 9.5-11 | 4.7x10$^{-5}$ | 5.76 | 3.77 | 3.45 | Soft tan color clay, gravels present and no cracks. |

# CHAPTER IV

# PRESSURE PLATE APPARATUS

## 4.1 Introduction

One of the most important physical characteristics of soils for engineering purposes is the relationship between matric suction and moisture content. Owing to its ease in handling and usage, pressure plate extractors and the pressure membranes have become indispensable tool in the laboratory study and a major research tool. These tools are used for characterizing the physical properties of soil as well as the extraction of soil solution for chemical analysis.

In contrast to the various cumbersome physical and chemical methods of soil investigations such as compaction, centrifugation, displacement, molecular absorption, and, suction, the pressure plate extractor, and, the pressure membrane extractor provides a convenient, reliable means of removing soil moisture, under controlled conditions without disturbing the soil structure.

In the study undertaken the pressure plate extractor and pressure membrane extractor were carried on high PI clays to develop the characteristic moisture retention curve for the different type of soils. The relationship is known as soil-water characteristic curve (Croney and Coleman 1954).The soils used for the study were obtained from the Atlanta district, Austin district, and Fort Worth district in Texas, USA. The two major point of consideration in the soil-moisture characteristic curve was
(i) slope of the curve, S and, (ii) the air entry value, $h_o$.

Mitchell (1979) assumed the value of '$h_o$' to be 100 cm approximately in his analysis. When an increasing air pressure is applied, a certain critical value is exceeded at which no outflow may occur. This critical value of soil pressure head is called the air-entry value, $h_o$. In Figure 32, the procedure used to obtain the air entry value has been shown. A typical SWCC curve has been shown in Figure 33.

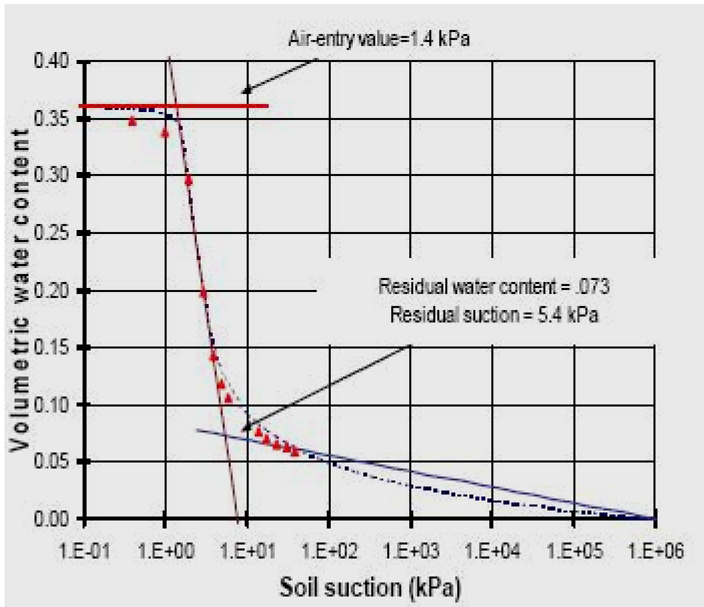



**Figure 32: Construction procedure to estimate the residual state and the air-entry value of sand.**

(Dane et al. 1983)

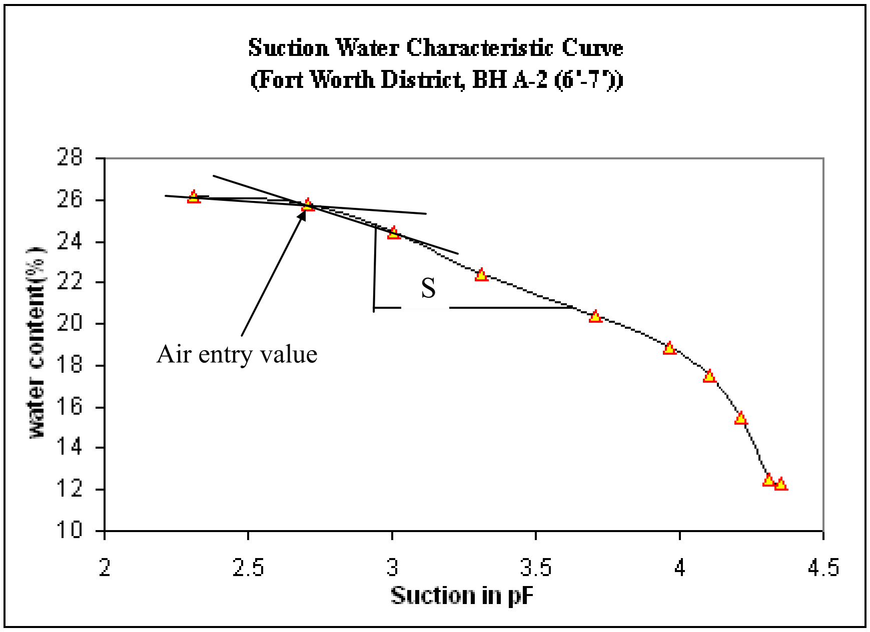



**Figure 33: Typical SWCC obtained from laboratory pressure plate and pressure membrane tests**

The parameter 'S' is obtained from the slope of the soil-moisture characteristic curve. In the Transportation Institute (TTI) Project Report 197-28, another empirical relationship has been given for obtaining the value of S (equation 37). A typical soil moisture characteristic curve can be seen in the Figure 32.

$$S = -20.29 + 0.155 * (LL\%) - 0.117(PI\%) + 0.0684(F) \qquad (37)$$

Here,

LL = Liquid limit

PL = Plasticity index

F = Percentage of particle sizes passing the #200 sieve on a dry weight basis.

The pressure membrane and pressure plate extractor has important application in determining the permeability and moisture storage characteristics of undisturbed soil. In addition, these instruments are used in calibrating moisture-measuring equipment and in filtration works. Pressure plate extractors are used in the laboratory to determine the relationship between water content and matric suction of soils (ASTM D 2325 (2001 d)and ASTM D3152-72 (2001 e)).

## 4.2 Principle

The Figure 34 below illustrates the procedure involved in the pressure membrane extractor. Saturated soil sample is placed over the porous cellulose membrane underneath which lies a support screen. This fine mesh screen provides a passage for the extracted solution. Saturated soil samples are kept over the cellulose membrane and air pressure is applied which pushes out water present in the voids of the soil sample.

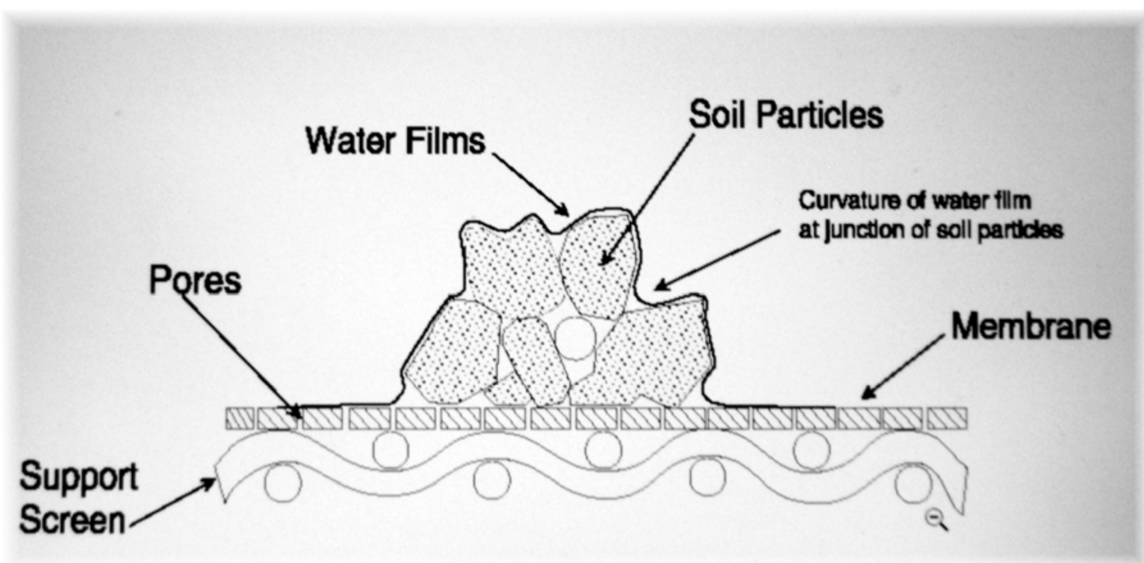



**Figure 34: Figure illustrates process of extraction in a pressure membrane extractor** ("0899-103 Using the Gas Pressure Extractor", Soil Moisture Equipment Corporation, Santa Barbara, California, USA-9310. http://www.soilmoisture.com/PDF%20Files/9103.pdf.)

The pressure inside the gas chamber is raised above the atmospheric pressure and this forces the excess water present in the soil sample through the microscopic pores in the cellulose membrane. Due to the surface tension of water at the liquid-gas interface, the high pressure air is not allowed to flow through the pores since they are filled with water. As the air-pressure is increased, the radius of the liquid-gas interface decreases. This is illustrated in the Figure 35. The decrease in radius does not cause the water film to break and allows the air to pass through the whole pressure range of the extractor.

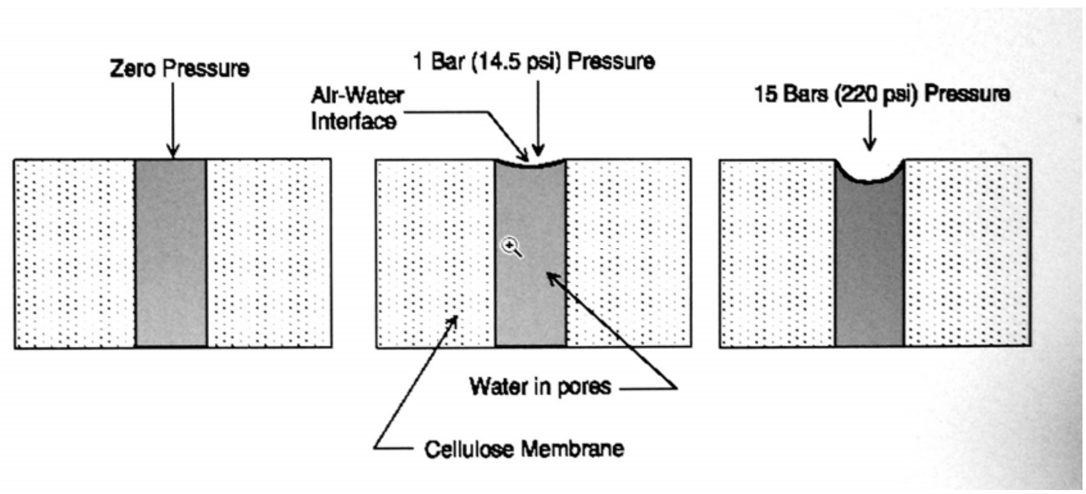



**Figure 35: Figure shows the change in the radius of curvature of air water interface with change in pressure** ("0899-103 Using the Gas Pressure Extractor", Soil Moisture Equipment Corporation, Santa Barbara, California, USA-9310, http://www.soilmoisture.com/PDF%20Files/9103.pdf.)

The flow of moisture ceases when equilibrium is attained, i.e., when there is an exact balance between the air pressure in the gas pressure extractor and matric suction in the sample. The water present in the soil will continue moving out of the cellulose membrane, at any given pressure until the effective curvature of the water film throughout the soil is same as that at the pores in the membrane present inside the gas pressure extractor. Such a condition of no flow at any given pressure is termed as equilibrium for that given pressure. When the air pressure inside the gas pressure extractor is increased then the flow of water starts again until a new equilibrium is reached. For example, at an air pressure of 15 atmospheres, the soil suction is 15 bars. In the pressure plate extractors the cellulose membrane is replaced by porous ceramic plate. Since, the ceramic plates have pores that are much larger in comparison to the pores present in the cellulose membrane; the pressure they can withstand without leaking air is less. Hence, in the study conducted pressure plates were used to cover a range of pressure from 0 bars to 15 bars and at higher pressures, pressure membrane extractors were used.

## 4.3 Description of instrument

### 4.3.1 Pressure plate apparatus

The pressure plate apparatus used for the study was manufactured by Soil Moisture Equipment Corporation, Santa Barbara, California, USA-9310.The test performed was called as “pressure plate test”(ASTM D2325) (2001 d).The extractor was basically used to apply various matric suctions on the soil specimen.

The main component of the pressure plate apparatus is high air entry porous ceramic disk. These disks are used to separate the air and water phases. These plates are made up of a mixture of ball clays and are manufactured by a sintering process. Porous ceramic plates are covered on one side by a thin neoprene diaphragm and are sealed to the edges of the ceramic plate. A screen is provided between the plate and the diaphragm. This screen provides a route for flow of water. An outlet stem is provided which connects this route to an outflow tube fitting. This outlet tube fitting connects to the atmosphere outside of the extractor. Figure 36 shows the description of a pressure plate apparatus along with the details of the ceramic porous plate. Plates are designated on the basis of the magnitude of the air entry value that the ceramic plate can withstand when the ceramic plate is fully saturated. The air entry value depends on the pore size. Smaller size pore correspond to larger air entry values. Currently, there are four types of commercially available pressure plates which are used for the different matric suction ranges. The details of those four pressure plates are given in Table 12. For this study only 15 bar pressure plates were used. The 5 bar and 15 bar ceramic plates are larger in size and several soil specimen can be tested at one time.

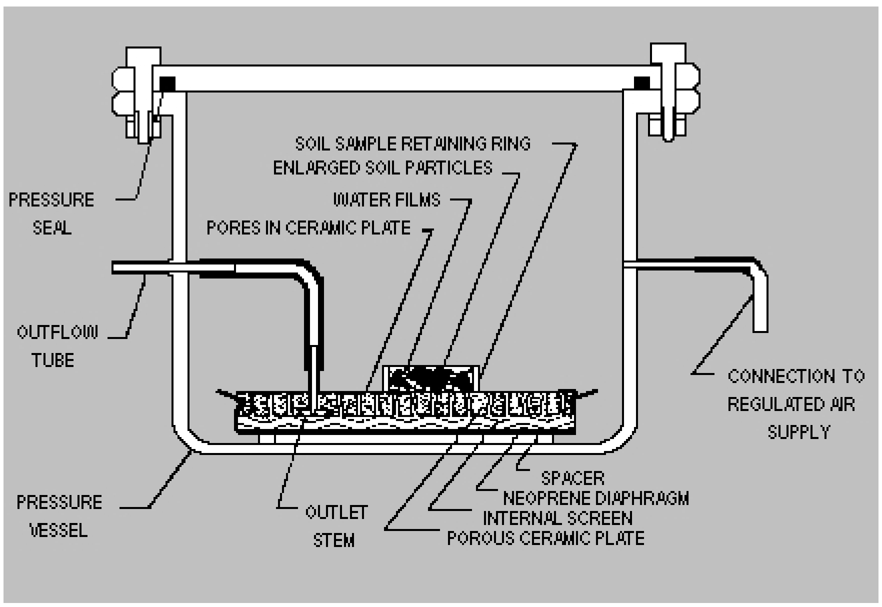



**Figure 36: Description of a pressure plate apparatus**

(http://weathermirror.nmsu.edu/Teaching_Material/soil698/Student_Material/pressureplate/Performance.htm.)

The ceramic plate is saturated, and is always in contact with the water in a compartment below the plate. Saturated soil samples are enclosed in the rings and placed in contact with the ceramic plate on the topside. The overall setup inside the compartment is maintained at zero water pressure. The chamber is then pressurized, which squeezes water out of the soil pores. Figure 37 shows the conventional 5 bar pressure plate and Figure 38 shows the conventional 15 bar pressure plate. In the study conducted by the author, only 15 bar pressure plates were used and at one time three soil samples were tested with two specimen of each inside the compartment on the ceramic plate.

Maximum applied matric suction in 5 bar pressure plate apparatus is 500kPa, and, 1500kPa in the 15 bar pressure plate apparatus.

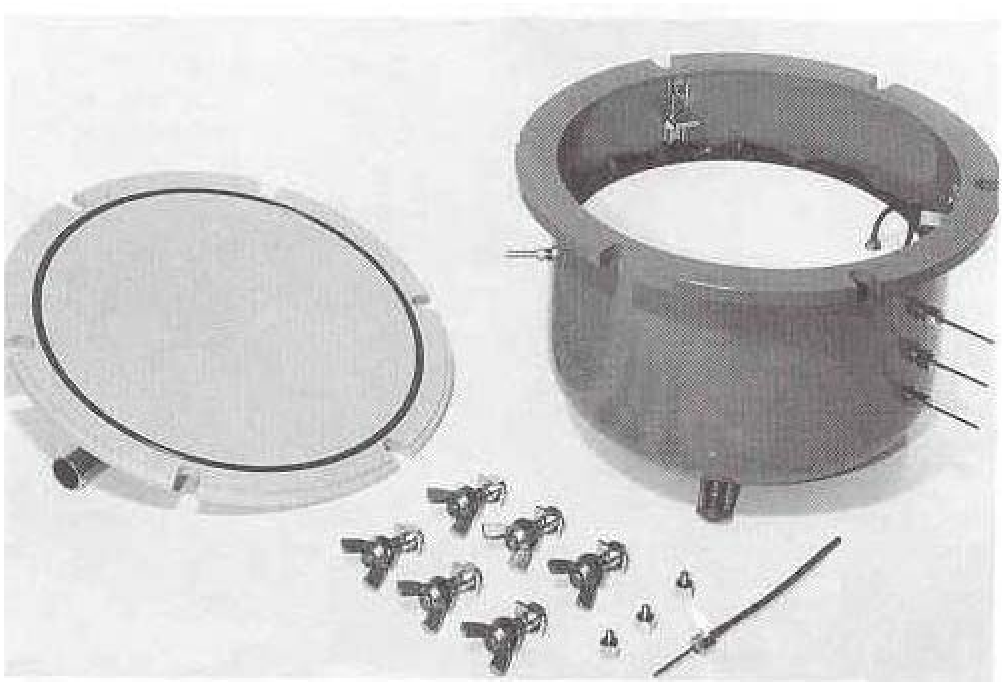


**Figure 37: Conventional 5-bar pressure plate apparatus** (Soil moisture Equipment Corporation, USA)

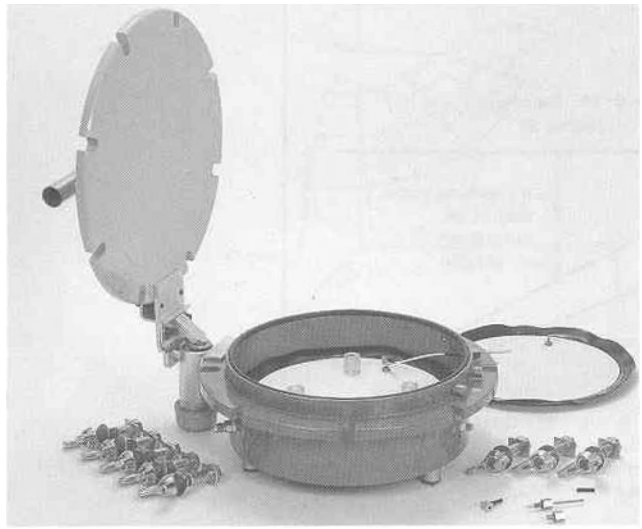


**Figure 38: Conventional 15-bar pressure plate apparatus..**

(Soil Moisture Equipment Corporation, USA)

**Table 12. Characteristics of pressure plate from Soil Moisture Equipment Corporation.** (Leong et al 2004 )

| Type of Pressure Plate (1) | Type of Ceramic Plate (2) | Method of Ceramic Plate Fabrication (3) | Color of Ceramic Plate (4) | Approximate Porosity (% vol.) (5) | Maximum Pore Size, µm (6) | Designated Air Entry Value, kPa (7) | Diameter,[1] mm (9) | Thickness,[1] mm (10) | Thickness/Diameter (11) | Approx. Failure Stress,[2] kPa (12) SS | FS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tempe cell | 1 bar, high flow | Moderately fired largely talc body | Ivory white | 45 | 2.5 | 100 | 92 | 5.75 | 1/16.0 | 192 | 313 |
| Volumetric pressure plate | 2 bar, standard flow | Variety of ball clays into a moderately fired ceramic body | Creamy white | 32 | 1.1 | 200 | 110 | 5.7 | 1/19.3 | 132 | 215 |
| 5 bar pressure plate | 5 bar, standard flow | Complex mixture of ball clays fired to a ceramic body | Brownish-white | 31 | 0.5 | 500 | 270 | 7.5 | 1/36.0 | 38 | 62 |
| 15 bar pressure plate | 15 bar, standard flow | Proprietary mixture of ball clays fired to a ceramic body | Pinkish-tan | 32 | 0.16 | 1500 | 262 | 6.2 | 1/42.3 | 28 | 45 |

*Note*: [1] Average of measurements from five ceramic plates of each type.
[2] Computed using Eqs 1 and 2 for simply supported (SS) and fixed (FS) edge conditions using tensile strength, $\sigma_t = 15$ MPa and Poisson's ratio, $\nu = 0.25$.

### 4.3.2 Pressure membrane apparatus

The pressure membrane apparatus (ASTM D3152-72) (2001 e) is used when the pressure inside the compartment is higher then 1500kPa. In this type of extractor the cellulose membrane replaces the high air entry ceramic disk. As explained earlier, since the ceramic plates have pores that are much larger in comparison to the pores present in the cellulose membrane, the pressure they can withstand without leaking air is less.

Apart from the cellulose membrane, other thing that is different in the pressure membrane extractor is the presence of compression diaphragm. This is provided on the lid of the pressure membrane extractor. The pressure regulator helps in maintaining higher pressure behind the diaphragm than inside the extractor. This difference in pressure keeps the soil specimen in contact with the cellulose membrane during the test.

When matric suction is applied to the soil sample, pore water drains out from the soil sample to the water compartment through the cellulose membrane. In the study conducted by the author, three different soil samples were tested at the same time and for better precision on results two specimen of the same sample were used. Figure 39 shows a conventional pressure membrane extractor.

**Figure 39: Conventional pressure membrane apparatus** ( Soil Moisture Equipment Corporation, USA)

## 4.4 Operation

### 4.4.1 Operation of pressure plate apparatus

Summary of test method

- A saturated porous ceramic plate is installed in the pressure chamber.
- Saturated soil samples are placed inside a ring and kept in contact over the ceramic plate.
- The bottom of ceramic plate is covered by rubber membrane and is maintained at atmospheric pressure. A small tube is provided on the side of the pressure chamber to help in maintaining the pressure.
- The desired air pressure is applied to the pressure chamber and hence to the top of the porous plate.

- Water held at a lower tension than the pressure drop existing across the porous plate, moves out through the soil sample, plate and eventually drains out through the drain tube. This soil water is collected outside the pressure chamber.
- When water ceases to flow through the drain tube, i.e. water stops to come out through the soil sample, moisture content of each soil sample is determined.
- A series of these tests is carried out at higher pressure level in order to get a complete SWCC curve.

Apparatus

Figure 37 and Figure 38 the pressure plate extractors. In general both the 5 bar and 15 bar pressure plate consist of following:

- Pressure container- It is the main component of the pressure plate apparatus. It usually has a capacity of 15-L (approximately 16-qt) capacity.
- Porous ceramic plates- Table 12 shows detail of 4 types of commercially available ceramic plates from Soil Moisture Equipment Corporation.
- Brass spout- The brass spout consists of brass tube and associated washers, gaskets, and brass nuts. It is provided at a distance of 1.5 inch from the edge of the plate and serves the purpose of providing an air tight joint when inserted through the porous plate. The dimensions are according to the ASTM D2325-68 (2001 d).
- Tubing- A flexible tube of 3mm diameter is used to carry the outflow water from the brass spout on the porous plate to a short length of rigid tubing that passes through the rubber stopper installed in the wall of the pressure container.
- Sample Retainer Rings- rigid plastic rings, approximately, 6.8 cm in diameter and 5 cm high.
- Pressure source- Compressed air or nitrogen gas cylinders
- Pressure regulator- A pressure regulator for fine pressure control.

- Ice chest- An ice chest big enough to adjust porous ceramic disks to keep it saturated.
- Test specimen cutter- A cylindrical ring with a sharp cutting edge on end. In the tests conducted by author, rings (inner diameter 6.2 cm and height 1.9 cm), used for 1-D consolidation was used.
- Spatula- A short, wide-blade for removing samples from the pressure plate.
- Moisture tin or aluminum cans- Containers that are made of material which is resistant to corrosion and not subjected to change in weight on repeated heating or cooling. Containers with lid are preferable to avoid the loss of moisture from soil samples.
- Saturation tray- A water proof tray about 30mm in depth, large enough to hold at least 2 porous plates at a time. It is used for keeping the samples saturated.
- Balance-A balance with a capacity of 200gm (at least) and sensitive to 0.01gm.
- Desiccator- A desiccator of suitable size to hold the samples after removal from the oven.
- Oven- A thermostatically controlled drying oven capable of maintaining temperatures at 110±5 ºC.
- Trimmers-Small tools for trimming the specimen.
- Grease- used in seating and sealing the gasket of the pressure chamber and it does not allow air from inside to leak.
- Container-Required for collecting the soil water coming out of the pressure chamber.
- Wrench-Required for tightening and loosening of the screws in the pressure plate.

Preparation of test specimen

The test was carried out on undisturbed sample. Following procedure was carried out for the preparation of the test specimen:

- Soil sample (extracted out from Shelby tube), approximately of 10 cm or greater in length was taken out from the moisture controlled room.

- The sample was wrapped up with wet cloth and kept in the saturation tray. Water was sprayed over it at intervals so as to keep the sample wet but care was taken in preventing the soil from getting wet enough to form slurry. Soil sample was kept wet for approximately 24 hours.
- Ice chest was filled with water up to the level so that porous ceramic plate could be submerged in it.
- Porous ceramic plate was submerged inside the ice chest for around 24 hours before the test was started. Ceramic plate was properly checked for cracks and leaks.
- Soil sample was unwrapped.
- Cylindrical blocks of soil sample were cut out using the trimmer. The thickness of the block cut out was approximately 1.6 cm or greater. Five blocks of sample was cut out. Two of the samples were used for pressure plate test and two of the samples were used in the pressure membrane test and one of the samples was used to get the dry density of that particular soil sample.
- A cylindrical ring used for one –dimensional consolidation test was used for cutting out the soil block and extruding the sample out of it for carrying out the test. The diameter of the sample was 6.2 cm which was as per the ASTM D 2345 (2001 f), inner diameter of the consolidation ring. The cutter was placed over the specimen with the cutting edge downward, on top of one of the plane faces and the cutter was forced down lightly and gradually and excess material was trimmed from the outside. Minimum pressure was applied on the cutter. The trimming motion followed was from the cutter outward and downwards, and it was made sure that a column of soil slightly larger than the outside diameter of the cutting edge was left out. When the cutter was more than half full of soil, excess soil was removed at the bottom with the wire saw. The cutter was inverted again and a straightedge was used to

make the soil flush. The cutter was inverted again, and placed on the smooth face of the metal blank, and carefully forced downward until the blank was flushed.

- The sample was flattened out on either side of the ring by using the trimmer and eventually five cylindrical blocks of 6.2 cm diameter and 1.6 cm thickness with both the cross-section flattened out was prepared. It was made sure, that at least one side of the sample was completely flat with all the gravels and pebbles removed from the surface, and the hole created filled with the remaining soil carved out while preparing the sample.
- Two samples for each pressure plate and pressure membrane were prepared in order to verify the consistency in data and to have more data points.
- Samples were kept in closed container until the time for testing.

Procedure

1. The porous plate to be used for testing was submerged in the ice chest filled with water for about 24 hours before the test.
2. The pressure chamber was cleaned from inside.
3. The gas supply was checked for any leaks and the also for the pressure till which it was available, was verified. If a higher pressure supply was required then nitrogen gas cylinder was used.
4. Keeping the gas supply closed using the pressure regulator, the pressure chamber and the gas supply was connected.
5. The porous ceramic disk was placed inside the pressure chamber. The flexible tube attached to the brass spout at one, end was put in side the rigid tubing, which passed through a rubber stopper installed in the wall of the pressure container.
6. Five sample retainer plastic rings of the dimensions mentioned above were placed on the top of the pressure plate. In order to make the rings identifiable markings were made for

example- A-1, A-2, etc. The positioning of the rings was such that the centre of each of the rings formed the edges of a pentagon.

7. Two samples of three different soil samples were placed inside the rings. The purpose of ring was basically to prevent the soil sample from intermixing. One sample which was kept in the centre of the pressure chamber was not inside the ring due to lack of space. All the samples were properly labeled as per their location inside the pressure chamber.
8. Water was poured inside the pressure chamber so as to submerge the soil samples completely. Care was taken to prevent the water, flow through the vent, which was meant for the gas supply inside the pressure chamber. So, keeping the bottom of that vent as the bench mark, water was poured inside the chamber.
9. The gasket was placed inside the groove present on the top of the pressure chamber and it was made sure that all the space between the gasket and the groove was completely sealed with grease.
10. Lid was put over the pressure chamber, with due care being taken that the gasket does not loose its position and a gap was created.
11. The lid was closed properly using the screws. The screws diagonally opposite to each other were tightened first so as to distribute equal pressure on either side. Two wrenches were used to grab the screw and tighten it. In case if this pattern of tightening the screws was not followed, then either side of the lid was displaced, this in turn displaced the gasket from the groove and hence left a gap for leakage of gas.
12. The outflow tube was inserted in side the container and was used for collecting the soil water.

13. The valve of the pressure regulator was opened and a pressure of 0.3 bars was applied initially for 2-3 hours and the whole assembly was kept under observation to check for any pressure leaks.
14. After making sure that there was not any leak in pressure, the pressure was increased to 0.5 bar or more to the desired pressure level but never below 0.3 bars or whatever the initial pressure was. This started the first run of the test.
15. Pressure was monitored regularly and the test was run till the flow of water from the pressure chamber stopped or as explained above, equilibrium was reached inside. Usually it took approximately 7 to 10 days to reach the equilibrium at low air pressure or matric suction.
16. After the equilibrium was achieved, the first priority was to release the pressure inside the chamber before opening the lid. So, the knob below the pressure regulator was switched off and the gas supply was stopped, then the pipe connecting the pressure chamber and gas supply was opened at the end of pressure regulator and the pressure inside the chamber was released. If the pressure inside the chamber is not released before opening the pressure plate apparatus, the gasket may be damaged and personnel injury can occur.
17. Before opening the lid, six moisture tins or aluminium cans well measured and cleaned.
18. During unscrewing the lid, proper sequence was followed taking care that screws diagonally opposite to each other were opened first.
19. Proper care was taken while removing the lid to ensure that the gasket does not slip and fall on the soil samples. This point is worth mentioning. The gasket was all greased, and if it touched the wet soil, it would have stuck to it and might hamper the results.

20. Once the lid was removed spatula was used to take out a small piece of sample and was used for measurement of moisture content. These samples were collected in the moisture tins.
21. The weight of these moisture tins with moist samples in it was measured and recorded and then these tins were placed inside the oven at temperature 110±5 ºC.
22. Water was again poured inside the pressure chamber, and the soil samples over the pressure plate were submerged in it.
23. Grease was applied over the gasket and care was taken to ensure that the gasket was placed properly inside the groove with no chance of leakage present.
24. The lid of the pressure plate was closed and the screws were tightened up in the similar fashion as explained earlier in point number 11.
25. The pipe connecting the pressure chamber and gas supply was again connected at the pressure regulator end.
26. Procedure starting from point number 12 was repeated, but the matric suction value was increased from 0.5 bars to a higher level. This procedure of pressure plate was carried out to a pressure level of 11 bars over the 15 bars ceramic plate. For higher pressures then 15 bars, pressure membrane was used.

### 4.4.2 Operation of pressure membrane apparatus

Summary of test method

- Saturated porous membrane was placed on a screen disk installed within a high- pressure chamber.
- Saturated soil samples were placed inside a ring and kept in contact over the saturated porous membrane.

- The bottom of the membrane was maintained at atmospheric pressure. A small opening was provided at the bottom of the pressure chamber to help in maintaining the atmospheric pressure.
- The desired air pressure was allowed inside the pressure chamber and hence on the top of the pressure membrane.
- Water held at a lower tension than the pressure drop existing across the membrane, moved out through the soil sample, membrane and eventually drained out through the opening. This soil water was collected outside the pressure chamber.
- When water ceased to flow through the drain tube, the moisture content of each soil sample was determined.
- A series of these tests was carried out at higher pressure level in order to get a complete SWCC curve for the particular soil sample.

Apparatus

Figure 38 shows the conventional pressure membrane apparatus. This equipment is available from several commercial firms, but in the study conducted by the author the equipment manufactured by Soil moisture Equipment Corporation, USA was used.

- Pressure-membrane chamber-The dimensions are as per the ASTM D3152-72 (2001 e) standards. The pressure chamber consists of a space ring of about 305mm (12 inch) in diameter about 13mm (1/2 inch), 51mm (2 inch), or 102 mm (4 inch) high, with heavy top and bottom steel plates 482 MPa (70 000 psi) tensile strength; the top and bottom plates are held tightly against the O-ring gaskets on the spacer ring by heavy-duty 5/8-inch bolts. A rubber diaphragm 1.6mm (1/16 inch) thick was cemented to the top plate.
- Pressure source- Compressed air or nitrogen gas in cylinders, or high-pressure compressor. If the soil water has to chemically analyzed nitrogen gas should be used.

- Pressure regulator- A pressure regulator for fine pressure control.
- Cellulose membrane- The dimensions are as per the ASTM D3152-72 (2001 e) standards. The membrane is like a cellulose sausage case, usually seamless tubing about 6m (20ft) long and about 152 mm (6 inch) wide.
- Sample Retainer Rings- rigid plastic rings, approximately, 6.8 cm in diameter and 5 cm high.
- Ice chest- An ice chest big enough to adjust porous ceramic disks to keep it saturated.
- Test specimen cutter- A cylindrical ring with a sharp cutting edge on one end. In the tests conducted by author, rings used for one-dimensional consolidation (inner diameter 6.2 cm and height 1.9 cm) were used.
- Spatula- A short, wide-blade for removing samples from the pressure plate.
- Moisture tin or aluminum cans- Containers that are made of material which is resistant to corrosion and not subjected to change in weight on repeated heating or cooling. Containers with lid are preferable to avoid the loss of moisture from soil samples.
- Torque wrench- It is used to tighten up the nut bolts of the apparatus. It should be capable of exerting a torque of atleast 6.8 N-m (5 lbf-ft) on apparatus bolts.
- Saturation tray- A water proof tray about 25mm in depth, large enough to hold the circular membrane while it is being saturated. Another water proof tray about 30mm in depth, is used for keeping the samples saturated
- Balance-A balance with a capacity of 200gm (at least) and sensitive to 0.01gm.
- Desiccator- A desiccator of suitable size to hold the samples after removal from the oven.
- Oven- A thermostatically controlled drying oven capable of maintaining temperatures at 110±5 ºC.
- Trimmers-Small tools for trimming the specimen.

- Grease- It is used in seating and sealing the gasket of the pressure chamber and it does not allow air from inside to leak.
- Container-It was used for collecting the soil water coming out of the pressure chamber.

Preparation of test specimen

The test was carried out on undisturbed sample. Following procedure was carried out for the preparation of the test specimen:

- Soil sample (extracted out from Shelby tube), approximately of 10 cm or greater in length was taken out from the moisture controlled room.
- The sample was wrapped up with wet cloth and kept in the saturation tray. Water was sprayed over it at intervals so as to keep the sample wet but care was taken in preventing the soil from getting wet enough to form slurry. Soil sample was kept wet for approximately 24 hours.
- Ice chest was filled with water up to the level so that porous ceramic plate gets submerged in it.
- Porous ceramic plate was submerged inside the ice chest for around 24 hours before the test was started. Ceramic plate is properly checked for cracks and leaks.
- Soil sample was unwrapped.
- Cylindrical blocks of soil sample are cut out using the trimmer. The thickness of the block cut out was approximately 1.6 cm or greater. Five blocks of sample was cut out. Two of the samples were used for pressure plate test and two of the samples were used in the pressure membrane test and one of the samples was used to get the fry density of that particular soil sample.
- A cylindrical ring used for one–dimensional consolidation test was used for cutting out the soil block and extruding the sample out of it for carrying out the test. The diameter of the

sample was 6.2 cm which was as per the ASTM D 2345-96 (2001 f), inner diameter of the consolidation ring. The cutter was placed over the specimen with the cutting edge downward, on top of one of the plane faces and the cutter was forced down lightly and gradually and excess material was trimmed from the outside. Minimum pressure was applied on the cutter. The trimming motion followed was from the cutter outward and downwards, and it was made sure that a column of soil slightly larger than the outside diameter of the cutting edge was left out. When the cutter was more than half full of soil, excess soil at the bottom was removed with the wire saw. The cutter was inverted again and a straightedge was used to make the soil flush. The cutter was inverted again, and placed on the smooth face of the metal blank, and carefully forced downward until the blank was flushed.

- Sample was flattened out on either side of the ring by using the trimmer and eventually five cylindrical blocks of 6.2 cm diameter and 1.6 cm thickness with both the cross-section flattened out is prepared. It was made sure, that at least one side of the sample was completely flat with all the gravels and boulders removed from the surface, and the hole created filled with the remaining soil carved out while preparing the sample. Two samples for each pressure plate and pressure membrane were prepared in order to verify the consistency in data and to have more data points.
- Samples were kept in closed container until the time for testing.

Procedure

1. A piece of cellulose membrane was cut as long as outside diameter of the pressure chamber.
2. The membrane was split open on one side and was soaked in thoroughly in the saturation tray for approximately 24 hrs. The soaking of the cellulose membrane helped

in eliminating the possibility of leaks caused from small cracks formed by the handling of the membrane while it was stiff and brittle

3. The membrane was cut to the size and shape of the outside of the apparatus spacer ring.
4. The gasket was placed over the screen in the pressure chamber and membrane was placed on it.
5. The spacer ring with the gasket in position was placed over the membrane. Care was taken in keeping the soil particle away from the O-ring (lower gasket) of the pressure chamber. The presence of soil particles could have punctured the cellulose membrane, when the top was clamped down.
6. Five sample retainer plastic rings of the dimensions mentioned above were placed on the top of the cellulose membrane. In order to make the rings identifiable markings were made for example- A-1, A-2, etc. The positioning of the rings was such that the centre of each the rings formed the edges of a pentagon. It was made sure that the bottom surface of the ring was smooth because even a small protrusion could have punctured the soft porous membrane and made the test set-up invalid.
7. Two samples of three different soil samples were placed inside the rings. The purpose of ring was basically to prevent the soil sample from intermixing. One sample which was kept in the centre of the pressure chamber was not inside the ring. This was because of the lack of space. A ring can also be placed around this sample. It was made sure that all the samples were properly notified as per their location inside the pressure chamber.
8. The samples were thoroughly saturated by poring water on the membrane. Initially around 3.2 mm (as per ASTM D3152) (2001 e) of water was poured and then the depth

of water was gradually increased. It was observed carefully and was taken care off that water does not leak out through the connection between the O-ring and the screen.

9. Water was poured until it reached the top edge of the sample.
10. The top of the chamber was centered carefully on the spacing ring with the O- ring gasket in place.
11. All the bolts were uniformly tightened to a tightness of 5.4-6.8 Nm. A torque wrench was used to obtain the desired results.
12. A small cloth was connected from the drain opening at the bottom of the pressure chamber to container for collecting soil water.
13. The nitrogen gas pressure regulator was connected to the set up.
14. A small pressure of 4-5 bars was applied and was kept under observation for a period of approximately 4 hours and the whole assembly was kept under observation to check for any pressure leaks.
15. After making sure that there wasn't any leak in pressure, the pressure was increased to 11-12 bars or more to the desired pressure level but never below 10 bars or whatever the initial pressure was. This started the first run of the test.
16. Pressure was monitored regularly and the test was run till the flow of water from the pressure chamber stopped or as explained above, equilibrium was reached inside. Usually, it took approximately 3 to 4 days to reach the equilibrium at high air pressure or matric suction. Thicker samples took longer time.
17. After the equilibrium was achieved, the first priority was to release the pressure inside the chamber before opening the lid. So, the knob below the pressure regulator was switched off and the gas supply was stopped, then the pipe connecting the pressure chamber and gas supply was opened at the end of pressure regulator and the pressure

inside the chamber was released. The samples can be removed anytime after the outflow into the container has ceased.

18. Before opening the lid, it was made sure that there were six moisture tins or aluminum cans well measured and cleaned.
19. During unscrewing the bolts, proper sequence was followed taking care that bolts diagonally opposite to each other are opened first.
20. Once the lid was removed spatula was used to take out a small piece of sample and was used for measurement of moisture content. These samples were collected in the moisture tins. Proper care was taken while chopping out the soil samples out of the main
21. Weight of these moisture tins with moist samples in it was measured and recorded and then these tins were placed inside the oven at temperature 110±5 ºC.
22. Water was again poured inside the pressure chamber and the soil samples over the pressure plate were submerged in it.
23. Lid of the pressure plate was closed and the bolts were tightened up in the similar fashion as explained earlier in point number 11.
24. The pipe connecting the pressure chamber and gas supply was again connected at the pressure regulator end.
25. Procedure starting from point number 15 was repeated, but the matric suction value was increased from 11-12 bars to a higher level.

## 4.5 Test results

Appendix B presents plots of all soil water characteristic curves measured in the pressure plate and pressure membrane tests. Table 13 shows comparison between experimental measurements and empirical estimates (equation 38) of  the slope of the Suction-Water Characteristic Curve 'S', obtained from equation 38. The values obtained from the empirical relationship typically compares favorably with measured values. The other relevant point is the air entry value, 'ho'. Air entry values for the 20 tests ranged from 316.23 to 794.33 cm (average 558.03 cm). This value is well above the value ho=100 cm assumed by Mitchell (1979).

**Table 13. Table showing the values of '$h_o$' and 'S' for all the three sites with Atterberg limits and hydrometer analysis values.**

| S.No | Sample | Depth | District | LL | PL | PI | %clay <0.02 mm | % fines passing #200 | Water Content | S (SWCC) | S (SWCC) (Empirical) | $h_O$(pF) | $h_O$(cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BHA-3 | 11-13 | Atlanta | 37 | 20 | 17 | 7.7 | 90.8 | 20.74 | -8.12 | -10.33 | 2.5 | 316.23 |
| 2 | BHB-2 | 7-9 | Atlanta | 52 | 28 | 24 | 8.7 | 92 | 18.52 | -12.50 | -8.75 | 2.82 | 660.69 |
| 3 | BHB-2 | 11-13 | Atlanta | 50 | 26 | 24 | 8.6 | 93.4 | 19.55 | -6.36 | -8.96 | 2.8 | 630.96 |
| 4 | BHC-1 | 2-4 | Atlanta | 37 | 22 | 15 | 9.0 | 94.1 | 17.79 | -8.41 | -9.87 | 2.7 | 501.19 |
| 5 | BHC-2 | 9-11 | Atlanta | 37 | 22 | 15 | 8.5 | 89.9 | 17.68 | -8.11 | -10.16 | 2.87 | 741.31 |
| 6 | BHA-1 | 11-12 | Fort worth | 45 | 23 | 22 | 21 | 84.15 | 18.88 | -8.60 | -10.13 | 2.71 | 512.86 |
| 7 | BHA-2 | 12-13 | Fort worth | 50 | 18 | 32 | 25 | 89.3 | 24.51 | -8.57 | -10.18 | 2.7 | 501.19 |
| 8 | BHA-2 | 6-7 | Fort worth | 48 | 20 | 28 | 22 | 87 | 16.08 | -6.55 | -10.18 | 2.85 | 707.95 |
| 9 | BHA-3 | 11-13 | Fort worth | 65 | 20 | 45 | 30 | 93.57 | 24.46 | -6.80 | -9.08 | 2.75 | 562.34 |
| 10 | BHB-2 | 10-11 | Fort worth | 50 | 20 | 30 | 26 | 84 | 25.24 | -7.38 | -10.3 | 2.7 | 501.19 |
| 11 | BHB-5 | 6-7 | Fort worth | 36 | 21 | 15 | 20 | 85 | 19.96 | -6.43 | -10.65 | 2.72 | 524.81 |
| 12 | BHC-2 | 4-5 | Fort worth | 49 | 19 | 30 | 25 | 87 | 21.91 | -8.23 | -10.25 | 2.72 | 524.81 |
| 13 | BHC-2 | 5-6 | Fort worth | 48 | 20 | 28 | 27 | 86.9 | 20.96 | -11.19 | -10.18 | 2.58 | 380.19 |
| 14 | BHC-3 | 6-7 | Fort worth | 60 | 30 | 30 | 24 | 94.56 | 18.11 | -6.60 | -8.03 | 2.65 | 446.68 |
| 15 | BHC-1 | 2-3 | Fort worth | 62 | 26 | 36 | 25 | 99.68 | 24.26 | -8.80 | -8.07 | 2.89 | 776.25 |
| 16 | BHC-4 | 5-6 | Fort worth | 38 | 18 | 20 | 22 | 80 | 19.91 | -8.30 | -11.27 | 2.75 | 562.34 |
| 17 | BHC-5 | 10-11 | Fort worth | 42 | 23 | 19 | 20 | 91.6 | 22.36 | -7.16 | -9.74 | 2.9 | 794.33 |
| 18 | BHC-5 | 7-8 | Fort worth | 42 | 23 | 19 | 32 | 98.16 | 22.3 | -7.08 | -9.29 | 2.7 | 501.19 |
| 19 | BHB-1 | 3.5-5 | Austin | 47 | 18 | 29 | 30 | 75.3 | 19.59 | -8.20 | -11.25 | 2.71 | 512.86 |
| 20 | BHB-3 | 9.5-11 | Austin | 50 | 21 | 29 | 18 | 95.9 | 24.02 | -7.30 | -9.37 | 2.7 | 501.19 |
| **Average values** | | | | | | | | | | -8.03 | -9.80 | | 558.03 |

# CHAPTER V

# SATURATED HYDRAULIC CONDUCTIVITY FROM ONE-DIMENSIONAL CONSOLIDATION TEST

## 5.1 Introduction

One of the major parameter to be studied within the scope of the study is coefficient of permeability, 'k'. Permeability can be defined as the rate of flow of fluid through the soil sample. The objective of the test was to independently determine the compressibility characteristics of a soil by one dimensional consolidation test. This test method covers procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading.

## 5.2 Principle

Terzaghi's consolidation equation to compute the coefficient of consolidation, $c_v$ forms the basis of conventional consolidation theory. Equation 38 given below is the basic differential equation of Terzaghi's one-dimensional consolidation theory.

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2} \tag{38}$$

Here,

$u$ = excess pore water pressure

$t$ = time

$c_v$ = coefficient of consolidation

$z$ = depth

Following assumptions were made in order to carry out this analysis.

1. Soil is saturated and has homogenous soil properties.
2. The flow of pore water is in the vertical direction.
3. The compressibility of soil particles and pore water is neglected.
4. The stress-strain relationship is considered linear over the load increment.
5. Darcy's law for flow through porous media is valid,
6. The ratio of soil permeability over soil compressibility is constant over the load increment.
7. The change in volume of the soil is equal to the volume of the excess pore water expelled.

The coefficient of permeability 'k' can be calculated using the equation 39.

$$c_v = \frac{k}{\gamma_w * m_v} \tag{39}$$

Here,

$c_v$ = coefficient of consolidation

$k$ = Coefficient of permeability

$m_v$ = coefficient of volume compressibility

$\gamma_w$ = unit of weight of water

Coefficient of volume compressibility, '$m_v$' can be calculated using the equations 40 and 41.

$$C_c = \frac{\Delta e}{\Delta \log \overline{\sigma_v}} \tag{40}$$

$$m_v = \frac{0.434 * C_c}{(1 + e_o) * \sigma_v} \tag{41}$$

Here,

$C_c$ = Compression index.

$\Delta e$ = Change in void ratio corresponding to the increment of $\Delta\sigma$

$\sigma_v$ = Effective vertical stress.

The value of 'k' is obtained in this research using:

1. From 1-D consolidation test.
2. Knowing the values of LL, fines content and void ratio, the permeability can also be estimated using Figure 40.

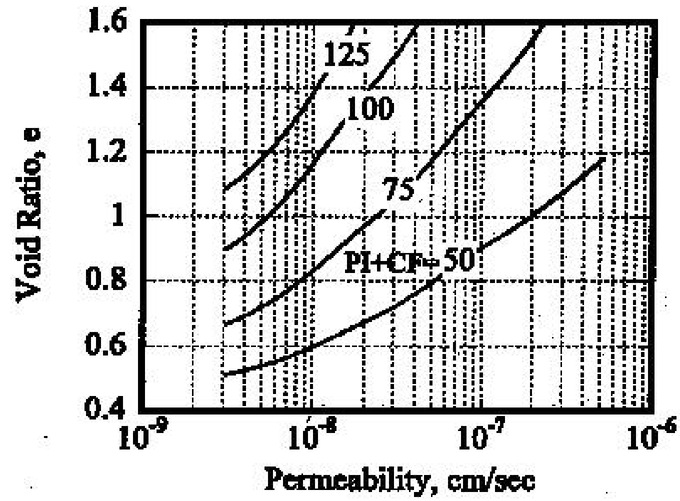



**Figure 40: Empirical correlations of index properties to clay permeability** (Tavenas et al 1983)

### 5.3 Soil tested

The soil samples used for consolidation tests were provided by Texas Department of Transportation. These samples were obtained from three districts in Texas namely, Fort Worth North Loop IH 820, Atlanta FM 271, and Austin Loop1. Overall four different soil samples were tested for one- dimensional consolidation test. These were all remolded soil specimens.

## 5.4 Test procedure

The test was performed on the ASTM D 2435-96 (2001 f), 'test method A', standard procedure. In this test the soil specimen was loaded axially and restrained laterally. The load is doubled in each increment, resulting in a load-increment ratio to be 1. Each stress is maintained over the soil sample until the total excess pore pressure is dissipated completely. Measurement of change in height of the sample during the testing is made and these data are used to determine the relationship between the effective stress and void ratio. The coefficient of consolidation is calculated based on the rate of deformation. The amount of vertical displacement 'ΔH' that a homogenous layer of thickness 'H' will undergo if subjected to a vertical stress increase at the surface is given by equation 42.

$$\Delta H = \frac{\Delta e}{(1 + e_o)} * H \tag{42}$$

Here,

$\Delta e$ = Change in void ratio corresponding to the increment of $\Delta\sigma$

$H$ = Specimen thickness at any initial pressure $\sigma$

$\Delta H$ = Change in specimen thickness corresponding to the increment of $\Delta\sigma$

A typical arrangement of consolidation test in the laboratory can be seen in Figures 41 and 42. Steps in the procedure are as follows:

1. Swell test performed: Soil sample is restrained laterally and wetted while it is subjected to no external loading except for the cap of the Consolidometer ring. A typical swell test curve can be seen in Figure 43. Rest of the plots for swell of all the samples tested can be seen in the Appendix C.
2. Soil sample is restrained laterally and compressed and drained axially while it is subjected to incrementally applied, controlled stress loading.

3. The sample is loaded by doubling the load in 24 hour increments and the deformation response is recorded.
4. The initial and final water contents of the sample before and after the test are calculated along with the initial height of the soil (ht. of the ring) and the intermediate heights of the sample.
5. A series of graphs displaying displacement as a function of log time is obtained. From these graphs $c_c$, e, and $c_v$ are calculated for each increment of load.
6. An e vs. log $\sigma_v$ curve is plotted. The e vs. log $\sigma_v$ curve for the samples tested can be seen in Figure 44.

**Figure 41: Sample being set inside the consolidometer**

**Figure 42: Consolidometer being loaded using the loading frame**

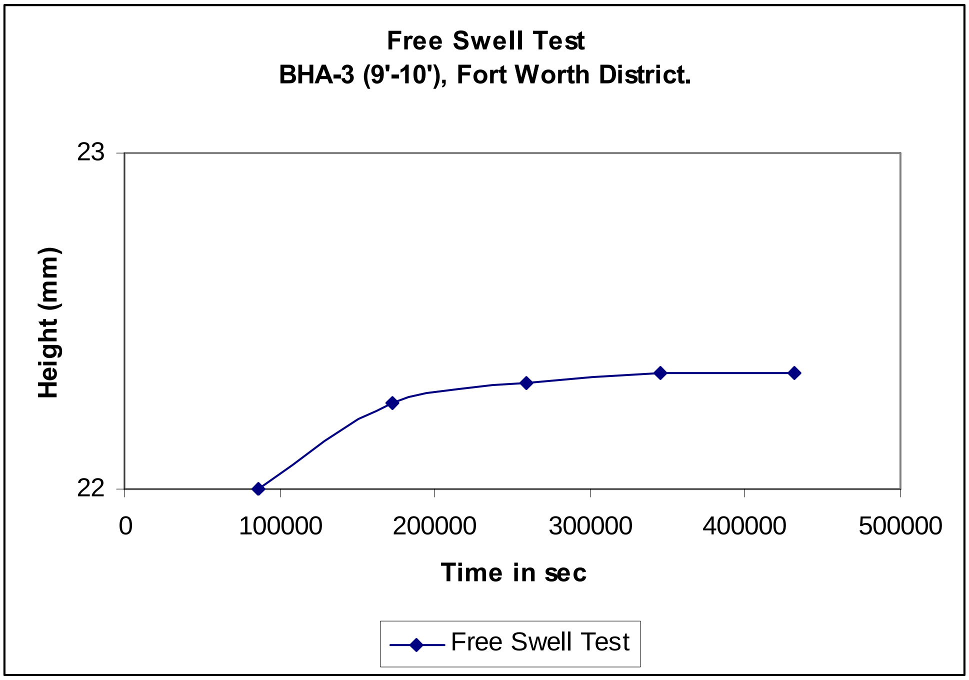



**Figure 43: Typical free swell test curve**

### 5.5 Test measurement

The main measurement that is made in this test is the deformation with respect to time. The void ratio 'e' is calculated by the equations 43, 44, 45 and, 46.

1. Calculation of volume of solids, $V_s = \dfrac{M_d}{G * \gamma_w}$ (43)

2. Calculation of Equivalent height of solids, $H_s$

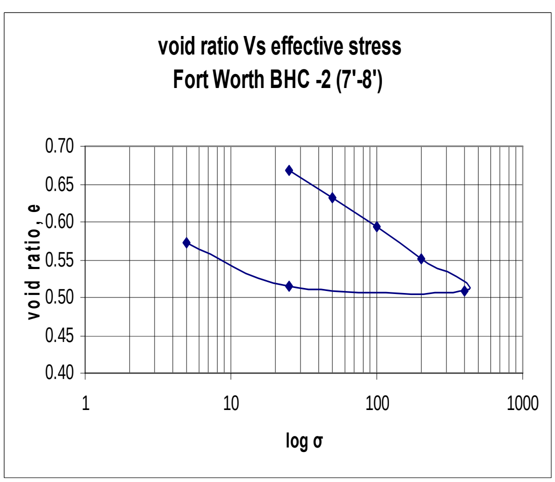
$$H_s = \frac{V_s}{A} \quad (44)$$

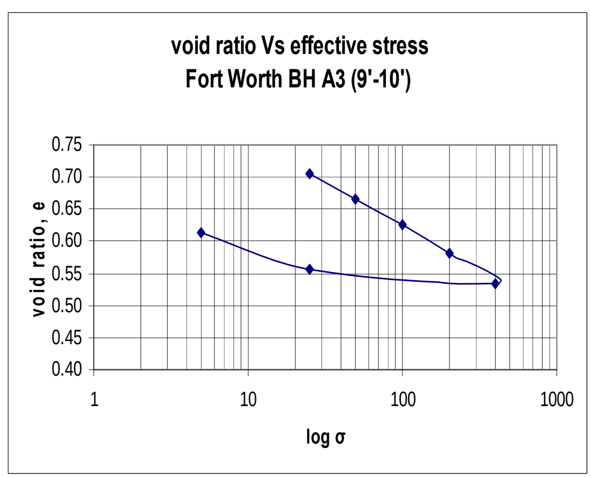
3. Void ratio before test, $e_o = \dfrac{H_o - H_s}{H_s}$ (45)

4. Void ratio after the test, $e_f = \dfrac{H_f - H_s}{H_s}$ (46)

Here,

| | | |
|---|---|---|
| G | = | Specific gravity of the solids, |
| $\gamma_w$ | = | Density of water, 1.0 gm/cm$^3$ or Mg/m$^3$ |
| $A$ | = | Specimen of area, cm$^2$ or mm$^2$. |
| $H_o$ | = | Initial specimen height, cm or mm; and |
| $H_f$ | = | Final specimen height, cm or mm. |



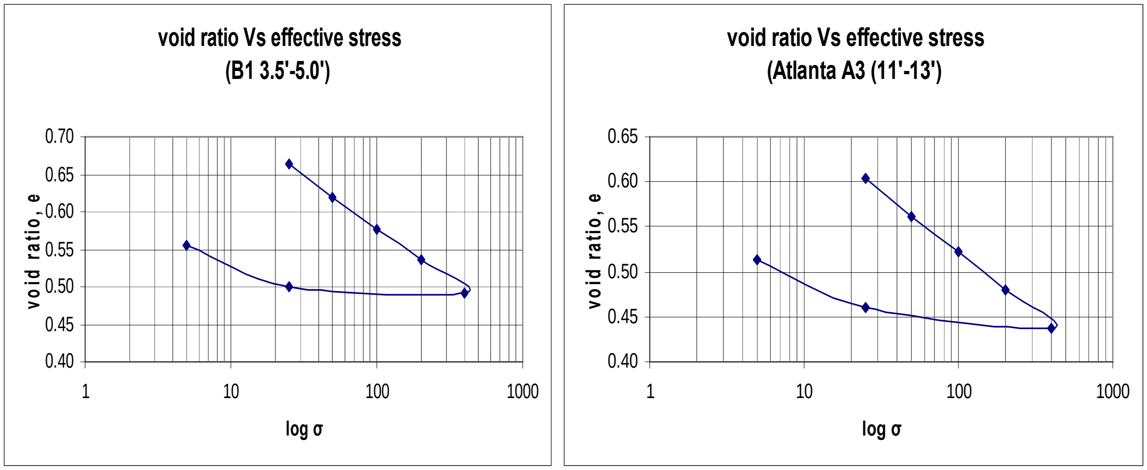



**Figure 44: e vs. log $\sigma_v$ curve for the samples tested**

The deformation Vs log time curve of each day for all the samples tested has been given in the Appendix C.

## 5.6 Test interpretation

The 'coefficient of consolidation, $c_v$' is calculated using the equations 47, 48, and 49.

$$c_v = \frac{T_{50} H_{dr}^{\ 2}}{t_{50}} \tag{47}$$

The parameters used to calculate, $c_v$ are given in equations 48 and 49.

$$T_{50} = 0.197 \tag{48}$$

$$H_{dr} = \frac{1}{2} d_{50} \quad \text{(double drainage)} \tag{49}$$

The parameter '$t_{50}$' is calculated using the 'Log-of- Time Method', ASTM D 2435-96 (2001 f). This can be explained using the Figure 45.

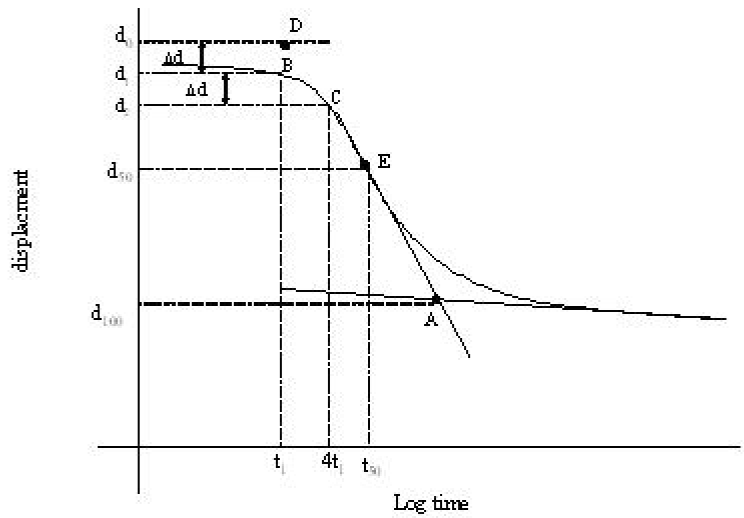



**Figure 45: Calculation of '$t_{50}$' using Log-of- Time Method**

The straight portions of the primary consolidation and secondary compression are projected to intersect at A. The ordinate of A, $d_{100}$, is the displacement gauge reading for 100% primary consolidation.

A time $t_1$, point B, is selected near the head of the initial portion of the curve (U<60%) and then another time $t_2$, point C, such that $t_2 = 4t_1$.

The distance 'Δd' is calculated between $t_1$ and $t_2$. A point D is plotted at a vertical distance 'Δd' from B. The ordinate of point D is the corrected initial displacement gauge reading, $d_0$ at the beginning of primary consolidation.

The ordinate for 50% consolidation $d_{50} = (d_{100} + d_0)/2$ is calculated. A horizontal line is drawn through this point to intersect the curve at E. The abscissa of point E is the time for 50% consolidation, $t_{50}$.

The values of '$c_v$' vary not only with the loading but also with the type of soil being tested. This can be seen from the Figure 46. All the soil samples used for the testing remolded soil samples. A comparison between the expected '$c_v$' and obtained '$c_v$' has been made in the Table 18.

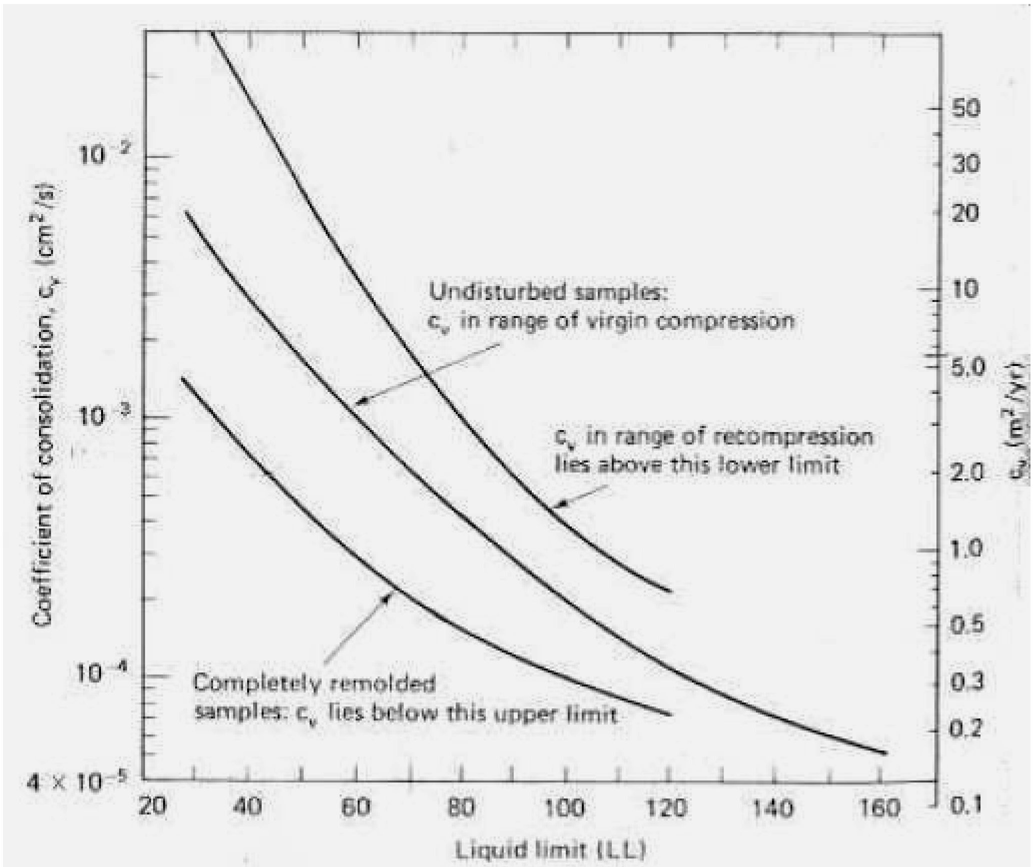



**Figure 46: Correlation of coefficient of consolidation, $c_v$ with the liquid limit** ( After US Navy, 1971)

Tables 14, 15, 16 and 17 show the detailed data obtained from laboratory test. It can be seen in the Table 18 that the values almost match except for some discrepancies which can be attributed to the experimental errors. Table 19 shows the '$c_v$' values calculated using the values of LL, fines content, and void ratio and using the Figure 40.

**Table 14.Test data obtained for Fort Worth District, sample BHC-2 (Depth= 7'-8').**

| Day | Cv ($cm^2$/sec) | Cv ($m^2$/yr) | $\sigma_v$ (kPa) | Log $\sigma_v$ (kPa) | avg e* | $m_v$ ($kPa^{-1}$) | $m_v$ ($cm^2$/kg) | k (m/sec) | k (cm/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 8.50E-03 | 26.81 | 25 | 1.40 | 0.67 | 1.02E-03 | 1.00E-01 | 8.32E-09 | 8.32E-07 |
| 2 | 5.95E-03 | 18.76 | 50 | 1.70 | 0.63 | 9.19E-04 | 9.01E-02 | 5.24E-09 | 5.24E-07 |
| 3 | 3.90E-03 | 12.30 | 100 | 2.00 | 0.59 | 5.36E-04 | 5.26E-02 | 2.00E-09 | 2.00E-07 |
| 4 | 3.60E-03 | 11.35 | 200 | 2.30 | 0.55 | 2.81E-04 | 2.75E-02 | 9.69E-10 | 9.69E-08 |
| 5 | 3.40E-03 | 10.72 | 400 | 2.60 | 0.51 | 1.47E-04 | 1.44E-02 | 4.78E-10 | 4.78E-08 |
| 6 | 1.98E-03 | 6.24 | 25 | 1.40 | 0.51 | 9.19E-05 | 9.01E-03 | 1.74E-10 | 1.74E-08 |
| 7 | 1.32E-03 | 4.16 | 5 | 0.70 | 0.57 | 1.92E-03 | 1.88E-01 | 2.42E-09 | 2.42E-07 |
| Average | 4.09E-03 | | | | | | 6.88E-02 | | 2.80E-07 |

**Table 15.Test data obtained for Fort Worth District, sample BHA-3 (Depth= 9'-10').**

| Day | Cv ($cm^2$/sec) | Cv ($m^2$/yr) | $\sigma_v$ (kPa) | Log $\sigma_v$ (kPa) | avg e* | $m_v$ ($kPa^{-1}$) | $m_v$ ($cm^2$/kg) | k (m/sec) | k (cm/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.90E-03 | 1.86E+01 | 25 | 1.40 | 0.71 | 1.00E-03 | 9.85E-02 | 5.68E-09 | 5.68E-07 |
| 2 | 4.70E-03 | 1.48E+01 | 50 | 1.70 | 0.67 | 8.61E-04 | 8.44E-02 | 3.88E-09 | 3.88E-07 |
| 3 | 7.90E-03 | 2.49E+01 | 100 | 2.00 | 0.63 | 5.26E-04 | 5.16E-02 | 3.98E-09 | 3.98E-07 |
| 4 | 1.19E-02 | 3.75E+01 | 200 | 2.30 | 0.58 | 2.75E-04 | 2.70E-02 | 3.14E-09 | 3.14E-07 |
| 5 | 5.30E-03 | 1.67E+01 | 400 | 2.60 | 0.53 | 1.50E-04 | 1.47E-02 | 7.59E-10 | 7.59E-08 |
| 6 | 1.58E-03 | 4.98E+00 | 25 | 1.40 | 0.56 | 1.15E-04 | 1.13E-02 | 1.74E-10 | 1.74E-08 |
| 7 | 7.94E-05 | 2.50E-01 | 5 | 0.70 | 0.61 | 1.61E-03 | 1.58E-01 | 1.23E-10 | 1.23E-08 |
| Average | 5.34E-03 | | | | | | 6.37E-02 | | 2.53E-07 |

**Table 16.Test data obtained for Austin District, sample BHB-1 (Depth= 3.5’-5’).**

| Day | Cv ($cm^2$/sec) | Cv ($m^2$/yr) | $\sigma_v$ (kPa) | Log $\sigma_v$ (kPa) | avg e* | $m_v$ ($kPa^{-1}$) | $m_v$ ($cm^2$/kg) | k (m/sec) | k (cm/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.90E-03 | 2.49E+01 | 25 | 1.40 | 0.66 | 1.22E-03 | 1.20E-01 | 9.23E-09 | 9.23E-07 |
| 2 | 7.70E-03 | 2.43E+01 | 50 | 1.70 | 0.62 | 1.12E-03 | 1.10E-01 | 8.25E-09 | 8.25E-07 |
| 3 | 6.80E-03 | 2.14E+01 | 100 | 2.00 | 0.58 | 5.33E-04 | 5.23E-02 | 3.48E-09 | 3.48E-07 |
| 4 | 3.66E-03 | 1.15E+01 | 200 | 2.30 | 0.54 | 2.92E-04 | 2.86E-02 | 1.02E-09 | 1.02E-07 |
| 5 | 1.58E-03 | 4.98E+00 | 400 | 2.60 | 0.49 | 1.40E-04 | 1.37E-02 | 2.12E-10 | 2.12E-08 |
| 6 | 1.49E-03 | 4.70E+00 | 25 | 1.40 | 0.50 | 9.14E-05 | 8.96E-03 | 1.31E-10 | 1.31E-08 |
| 7 | 1.13E-03 | 3.56E+00 | 5 | 0.70 | 0.56 | 1.84E-03 | 1.81E-01 | 1.99E-09 | 1.99E-07 |
| Average | 4.32E-03 | | | | | | 7.33E-02 | | 3.47E-07 |

**Table 17.Test data obtained for Atlanta District, sample BHA-3 (Depth= 11’-13’)**

| Day | Cv ($cm^2$/sec) | Cv ($m^2$/yr) | $\sigma_v$ (kPa) | Log $\sigma_v$ (kPa) | avg e* | $m_v$ ($kPa^{-1}$) | $m_v$ ($cm^2$/kg) | k (m/sec) | k (cm/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 8.51E-03 | 26.84 | 25 | 1.40 | 0.59 | 1.16E-03 | 1.13E-01 | 9.43E-09 | 9.43E-07 |
| 2 | 5.96E-03 | 18.80 | 50 | 1.70 | 0.55 | 1.08E-03 | 1.06E-01 | 6.18E-09 | 6.18E-07 |
| 3 | 3.67E-03 | 11.56 | 100 | 2.00 | 0.51 | 5.41E-04 | 5.30E-02 | 1.90E-09 | 1.90E-07 |
| 4 | 2.64E-03 | 8.33 | 200 | 2.30 | 0.47 | 2.83E-04 | 2.77E-02 | 7.16E-10 | 7.16E-08 |
| 5 | 2.39E-03 | 7.53 | 400 | 2.60 | 0.43 | 1.35E-04 | 1.33E-02 | 3.10E-10 | 3.10E-08 |
| 6 | 6.80E-03 | 21.44 | 25 | 1.40 | 0.45 | 1.15E-04 | 1.13E-02 | 7.48E-10 | 7.48E-08 |
| 7 | 2.97E-03 | 9.37 | 5 | 0.70 | 0.50 | 1.78E-03 | 1.75E-01 | 5.07E-09 | 5.07E-07 |
| Average | 4.71E-03 | | | | | | 7.13E-02 | | 3.48E-07 |

* The ‘e’ value has been averaged over the data given in Appendix C for specific loading condition for each of the sample

**Table 18.Comparison between $c_v$ (calculated) and $c_v$ (Figure 46) from curve for remolded specimen.**

| S.No | Sample | Depth | District | $m_v$ ($cm^2/kg$) | $c_v$ ($cm^2/sec$) (calculated) | $c_v$ ($cm^2/sec$) (Fig 5.7 ) | k (cm/sec) | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | BHC- 2 | 7-8 | Fort Worth | 0.009 | 2.0E-03 | $3*10^{-3}$ | 1.74E-08 | *considering e=0.51 |
| 2 | BHA- 3 | 9-10 | Fort Worth | 0.052 | 7.9E-03 | $1.2*10^{-3}$ | 7.9E-07 | *considering e=0.63 |
| 3 | BHB-1 | 3.5-5 | Austin | 0.014 | 1.6E-03 | $4*10^{-3}$ | 2.12E-08 | *considering e=0.49 |
| 4 | BHA-3 | 11-13 | Atlanta | 0.013 | 2.4E-03 | $7*10^{-3}$ | 3.10E-08 | *considering e=0.43 |

- Void ratio at which diffusion test was conducted on these samples.

**Table 19. Empirical estimate of coefficient of permeability, k using Figure 40.**

| S.No | Sample | Depth | District | LL | PL | PI | e | PI+CF | k(cm/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | BHA-3 | 11-13 | Atlanta | 37 | 20 | 17 | 0.55 | 24.7 | * |
| 2 | BHB-2 | 7-9 | Atlanta | 52 | 28 | 24 | 0.49 | 32.7 | * |
| 3 | BHB-2 | 11-13 | Atlanta | 50 | 26 | 24 | 0.52 | 32.6 | * |
| 4 | BHC-1 | 2-4 | Atlanta | 37 | 22 | 15 | 0.47 | 24 | * |
| 5 | BHC-2 | 9-11 | Atlanta | 37 | 22 | 15 | 0.47 | 23.5 | * |
| 6 | BHA-1 | 11-12 | Fort worth | 45 | 23 | 22 | 0.50 | 43 | * |
| 7 | BHA-2 | 12-13 | Fort worth | 50 | 18 | 32 | 0.65 | 57 | 1.20E-08 |
| 8 | BHA-2 | 6-7 | Fort worth | 48 | 20 | 28 | 0.43 | 50 | * |
| 9 | BHA-3 | 11-13 | Fort worth | 65 | 20 | 45 | 0.65 | 75 | 2.00E-08 |
| 10 | BHB-2 | 10-11 | Fort worth | 50 | 20 | 30 | 0.67 | 56 | 1.24E-08 |
| 11 | BHB-5 | 6-7 | Fort worth | 36 | 21 | 15 | 0.53 | 35 | * |
| 12 | BHC-2 | 4-5 | Fort worth | 49 | 19 | 30 | 0.58 | 55 | 1.10E-08 |
| 13 | BHC-2 | 5-6 | Fort worth | 48 | 20 | 28 | 0.56 | 55 | 1.10E-08 |
| 14 | BHC-3 | 6-7 | Fort worth | 60 | 30 | 30 | 0.48 | 54 | 5.00E-08 |
| 15 | BHC-1 | 2-3 | Fort worth | 62 | 26 | 36 | 0.64 | 61 | 1.25E-08 |
| 16 | BHC-4 | 5-6 | Fort worth | 38 | 18 | 20 | 0.53 | 42 | * |
| 17 | BHC-5 | 10-11 | Fort worth | 42 | 23 | 19 | 0.59 | 39 | * |
| 18 | BHC-5 | 7-8 | Fort worth | 42 | 23 | 19 | 0.59 | 51 | 1.02E-08 |
| 19 | BHB-1 | 3.5-5 | Austin | 47 | 18 | 29 | 0.52 | 59 | 2.36E-08 |
| 20 | BHB-3 | 9.5-11 | Austin | 50 | 21 | 29 | 0.64 | 47 | * |

* PI+ CF value was not sufficient enough to fall within the range of curve as per Figure 40.

## 5.7 Comparison of values of coefficient of permeability, 'k' from the two methods

Table 20 shows the comparison between the coefficients of permeability value obtained from the two different methods. It can be observed that the values come out to be approximately same. Due to the limited amount of sample available, Atterberg limits and One-Dimensional Consolidation Test could not be run at the same depth for all the samples.

**Table 20. Comparison of values of coefficient of permeability, 'k' from the two methods.**

| S.No | Sample | Depth (ft) | District | k (empirical) (Fig 5-1) (cm/sec) | k ( One-dimensional Consolidation test) (cm/sec) |
|---|---|---|---|---|---|
| 1 | BHB-1 | 3.5-5 | Austin | 2.36E-08 | 2.12E-08 |

Using the Table 14, 15, 16 and 17, a relationship between coefficient of permeability 'k', and, void ratio 'e' can be observed. Figure 47 shows a plot between log k and e. It can be observed that there is almost a linear relationship between 'k' and 'e'.

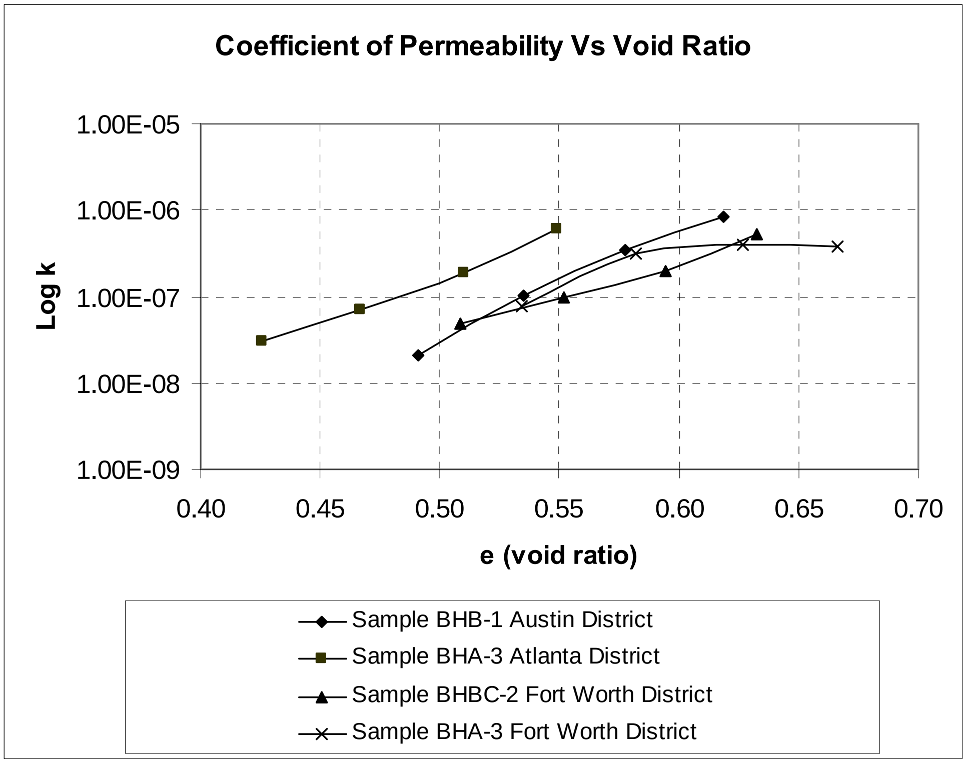



**Figure 47: Figure showing relationship between coefficient of permeability 'k' and void ratio 'e'**

# CHAPTER VI

# EVALUATION OF LINEARIZED MOISTURE DIFFUSION FRAMEWORK

## 6.1 Theoretical versus direct measurements of alpha

This chapter deals with the final aim of this research, which is to obtain and compare the moisture diffusion coefficient through the laboratory test (established by Mitchell (1979)) and the empirical relationship given by Lytton 2003, equation 36 (chapter III).

### 6.1.1 Theoretical measurement of $\alpha$ through moisture diffusion test in laboratory

As mentioned in chapter II, there were three test sites Fort worth North Loop IH 820, Atlanta US 271, and Austin Loop 1. Overall 47 moisture diffusion tests were run successfully. Along with this, filter paper tests were also conducted on these samples. The diffusion coefficient curves for each site have been included in Appendix A. Tables 9, 10, and 11, shows the diffusion coefficient values and the matric suction values of the test sites, Fort Worth North Loop IH 820, Atlanta US 271, and, Austin Loop 1 respectively.

The values of diffusivity coefficient (theoretical value) of the soil samples tested for diffusion test in the laboratory, was done using the Matlab programs given in appendix D. The values of n=1 and $h_e$= 0.54 $cm^{-1}$ was used. The range of the results is provided in Table 23.

### 6.1.2 Analytical evaluation and validation of diffusion coefficient using empirical relations

Equation 36 (chapter III) shows a relationship given by Lytton 2003.

$$\alpha = -S * k * h_0^{\,n} * \frac{\gamma_w}{\gamma_d}$$

Here,

| | | |
|---|---|---|
| $k$ | = | the saturated permeability of the soil |
| $h_o$ | = | Air-entry value. |

$S$ = slope of the moisture characteristic curve

$\gamma_d$ = dry unit weight of soil

$\gamma_w$ = unit weight of water

The parameter 'n' is assumed to be 1. 'S' and '$h_o$' values are obtained from the Table 13. The coefficients of permeability, 'k' value are obtained from Tables 18 and 19. The value of '$\gamma_d$' for all the samples was obtained using the equation 50:

$$\gamma_d = \frac{1 - \frac{V_a}{100}}{\frac{1}{\gamma_s} + \frac{w}{100 * \gamma_w}} \tag{50}$$

Here,

$\gamma_d$ = Dry density in $g/cm^3$

$V_a$ = Volume of air voids, assumed to be 10 %.

$\gamma_w$ = Density of water , assumed ti be equal to 1 $g/cm^3$

$\gamma_s$ = Particle density, assumed to be 2.67 $g/cm^3$

$w$ = Moisture water content in %

The value of '$\gamma_w$' is taken as 1 $gm/cm^3$. Putting all the values from the above mentioned source values of parameters on the right hand side of the equation, 'α', moisture diffusion coefficient is obtained and is tabulated in the Tables 21 and 22. The range of diffusivity coefficients obtained from theoretical value (diffusion test ) and empirical relations have been tabulated in Tables 23 and 24 respectively.

**Table 21.Table showing the comparison between moisture diffusion coefficient calculated by empirical relations and diffusion test.**

**('k' obtained by empirical relations).**

| S.No | Sample | Depth | District | S (SWCC) | $h_O$(cm) | $\gamma_d$ (gm/cm$^3$) | k (cm/sec) | alfa (empirical) (cm$^2$/sec) | alfa (theoretical) (cm$^2$/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | BHA-3 | 11-13 | Atlanta | -8.12 | 316.23 | 1.539 | * | ** | 1.23E-05 |
| 2 | BHB-2 | 7-9 | Atlanta | -12.50 | 660.69 | 1.6 | * | ** | *** |
| 3 | BHB-2 | 11-13 | Atlanta | -6.36 | 630.96 | 1.571 | * | ** | *** |
| 4 | BHC-1 | 2-4 | Atlanta | -8.41 | 501.19 | 1.621 | * | ** | 9.16E-05 |
| 5 | BHC-2 | 9-11 | Atlanta | -8.11 | 741.31 | 1.624 | * | ** | 1.31E-04 |
| 6 | BHA-1 | 11-12 | Fort Worth | -8.60 | 512.86 | 1.590 | * | ** | 5.09E-05 |
| 7 | BHA-2 | 12-13 | Fort Worth | -8.57 | 501.19 | 1.446 | 1.20E-08 | 3.56E-05 | 2.00E-05 |
| 8 | BHA-2 | 6-7 | Fort Worth | -6.55 | 707.95 | 1.672 | * | ** | *** |
| 9 | BHA-3 | 11-13 | Fort Worth | -6.80 | 562.34 | 1.447 | 2.00E-08 | 5.28E-05 | *** |
| 10 | BHB-2 | 10-11 | Fort Worth | -7.38 | 501.19 | 1.429 | 1.24E-08 | 3.21E-05 | *** |
| 11 | BHB-5 | 6-7 | Fort Worth | -6.43 | 524.81 | 1.560 | * | ** | 1.37E-04 |
| 12 | BHC-2 | 4-5 | Fort Worth | -8.23 | 524.81 | 1.509 | 1.10E-08 | 3.10E-05 | 1.53E-05 |
| 13 | BHC-2 | 5-6 | Fort Worth | -11.19 | 380.19 | 1.533 | 1.10E-08 | 3.05E-05 | 6.10E-05 |
| 14 | BHC-3 | 6-7 | Fort Worth | -6.60 | 446.68 | 1.612 | 5.00E-08 | 9.15E-05 | 9.20E-05 |
| 15 | BHC-1 | 2-3 | Fort Worth | -8.80 | 776.25 | 1.452 | 1.25E-08 | 5.88E-05 | 3.73E-05 |
| 16 | BHC-4 | 5-6 | Fort Worth | -8.30 | 562.34 | 1.561 | * | ** | *** |
| 17 | BHC-5 | 10-11 | Fort Worth | -7.16 | 794.33 | 1.498 | * | ** | *** |
| 18 | BHC-5 | 7-8 | Fort Worth | -7.08 | 501.19 | 1.499 | 1.02E-08 | 2.41E-05 | 1.73E-05 |
| 19 | BHB-1 | 3.5-5 | Austin | -8.05 | 512.86 | 1.570 | 2.36E-08 | 6.32E-05 | 5.65E-05 |
| 20 | BHB-3 | 9.5-11 | Austin | -7.30 | 501.19 | 1.457 | * | ** | *** |

* PI+ CF value was not sufficient enough to fall within the range of curve as per Figure 40.

** Moisture diffusion coefficient could not be calculated due to lack of 'k' value.

*** Diffusion test was not carried out on these soil specimens.

**Table 22.Table showing the comparison between moisture diffusion coefficient calculated by empirical relations and diffusion test.**

**('k' Obtained by One-Dimensional Consolidation Test).**

| S.No | Sample | Depth | District | S (SWCC) | $h_O$(cm) | $\gamma_d$ (gm/cm$^3$) | k (cm/sec) | alfa (empirical) (cm$^2$/sec) | alfa (theoretical) (cm$^2$/sec) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BHC 2 | 4-5 | Fort Worth | -8.03 | 398 | 1.509 | 1.74E-08 | 3.70E-05 | *** | considering e=0.51 |
| 2 | BHA 3 | 9-10 | Fort Worth | -6.50 | 501 | 1.4 | 7.9E-07 | 9.27E-04 | *** | considering e=0.63 |
| 3 | BHB-1 | 3.5-5 | Austin | -8.05 | 513 | 1.570 | 2.12E-08 | 5.56E-05 | 5.6E-05 | considering e=0.49 |
| 4 | BHA-3 | 11-13 | Atlanta | -8.12 | 316 | 1.539 | 3.10E-08 | 5.16E-05 | 1.23E-05 | considering e=0.43 |

*** Diffusion test was not carried out on these soil specimens.

**Table 23.Table showing the obtained diffusion coefficient from diffusion test (theoretical value).**

| **Range of Diffusivity Coefficient, cm$^2$/sec** | | | | | |
|---|---|---|---|---|---|
| Fort worth District | | Atlanta District | | Austin District | |
| Bore Hole | $\alpha$ (cm$^2$/sec) | Bore Hole | $\alpha$ (cm$^2$/sec) | Bore Hole | $\alpha$ (cm$^2$/sec) |
| A | 0.33 to 10.3x10$^{-5}$ | A | 1.23 to 4.83x10$^{-5}$ | B1 | 5.65 to 10.6x10$^{-5}$ |
| B | 0.106 to 13.7x10$^{-5}$ | B | 3.07 to 8.33x10$^{-5}$ | B2 | 6.3 to 10.7x10$^{-5}$ |
| C | 0.93 to 6.10x10$^{-5}$ | C | 4.26 to 13.1x10$^{-5}$ | B3 | 1.82 to 4.66x10$^{-5}$ |

**Table 24.Table showing the obtained diffusion coefficient from empirical relations.**

| Range of Diffusivity Coefficient, $cm^2/sec$ | | | | | |
|---|---|---|---|---|---|
| Fort worth District | | Atlanta District | | Austin District | |
| Bore Hole | $\alpha$ ($cm^2/sec$) | Bore Hole | $\alpha$ ($cm^2/sec$) | Bore Hole | $\alpha$ ($cm^2/sec$) |
| A | $3.56$ to $4.66x\ 10^{-5}$ | A | $5.16x\ 10^{-5**}$ | B1 | $6.17x\ 10^{-5}$ |
| | $9.27x\ 10^{-4**}$ | | | | $5.56x\ 10^{-5**}$ |
| B | $3.04\ x\ 10^{-5}$ | B | | B2 | |
| C | $2.39$ to $8.32x\ 10^{-5}$ | C | | B3 | |
| | $3.7x\ 10^{-5**}$ | | | | |

** Values are calculated using the coefficient of permeability obtained from One- dimensional consolidation test.

## 6.2 Sources of differences between the moisture diffusion coefficients obtained by two different methods

There are various reasons that can be ascertained as the cause for the discrepancy. Some of these are as follow:

1. Difference in the timing of conduct of each test: All the tests were conducted for different durations. This might have caused change in moisture content and eventually void ratio 'e' gets affected. We have seen in the previous chapter that, coefficient of permeability; 'k' varies linearly with 'e'. Hence, any change in 'e' changes 'k' which in turn would lead to a changed moisture diffusivity coefficient.
2. Degree of sample disturbance: Each soil sample was used for the various tests conducted during the study. Hence, the samples were heavily disturbed. Disturbance in sample leads to change in void ratio, 'e' which again would change 'k' and eventually moisture diffusivity coefficient changes.
3. Experimental errors: Pressure plates and pressure membrane results are sensitive to the experimental setup. At times, due to human error there can be slight variation in reading. Any change in reading of moisture content causes variation in values of slope of suction-water characteristic curve, 'S' and, air-entry value, '$h_o$'. These two are very important in the empirical evaluation of moisture diffusion coefficient.
4. Accuracy and alertness of the experimentalist: A lot of tests have to be conducted to empirically determine $\alpha$. Hence, each test has to be conducted with equal accuracy and diligence. Any negligence could lead to a difference in value.

5. Instrumental errors: Temperature sensitive instruments such as psychrometer are used to measure the moisture diffusion coefficient directly. Any variation in the testing environmental conditions could lead to an erroneous value.

# CHAPTER VII

# CONCLUSIONS AND RECOMMENDATIONS

On the grounds of the evaluations done in chapter VI, the conclusions of this research and analysis can be summarized as below:

## 7.1 Pressure plate and pressure membrane apparatus

1. Mitchell (1979), assumed the air- entry value of ‘$h_o$’ to be 100 cm approximately in his analysis. From the results given in Table 13, it can be seen that the value obtained through the tests range from 316.23 cm to 794.33 cm (average 558.03 cm) which is well above the initial value assumed.
2. Another significant observation regards the slope of suction water characteristic curve. As shown in Table 13, estimates of ‘S’ obtained from the empirical relationship (Equation 38) are in reasonable agreement with those obtained from the laboratory curves.
3. During the preparation of the specimen, care should be taken that the surface is flat and smooth so that it makes perfect contact with the porous ceramic plate or cellulose membrane. Any undulation or lack of contact between the surfaces might lead to erroneous moisture content determination.
4. Any leak in pressure during the test leads to faulty results. Hence, before and during the test extreme care should be given to ensure that leaks do not develop.
5. One of the sources of error in pressure plate test results is the air entrapment in the outflow tube and the bottom water reservoir. This air needs to be removed before the test is started. The soil specimen might not reach a total equilibrium condition under the applied matric

suction value unless the entrapped air is removed. The air can percolate inside in case of a micro-fracture in the plate or a micro-puncture in the neoprene membrane.

### 7.2 One-dimensional consolidation

1. The test results are greatly influenced by the method of sample preparation and sample disturbance. Hence, proper care has to be taken while selecting and preparing the specimen.
2. The soils specimen tested were remolded high PI clays; hence the $c_v$ values are not entirely representative of intact soil conditions in the field.
3. In chapter V, Table 20, a comparison between the coefficients of permeability, k, obtained from the one-dimensional consolidation test and empirical relations have been tabulated. It can be observed that the values come out to be approximately same. There was limited amount of sample available at the exact depth in the same bore hole after carrying out diffusion test, pressure plate tests, and Atterberg limits to conduct the one-dimensional consolidation test. Hence, very few data is available for comparison of coefficient of consolidation, 'k'.

### 7.3 Diffusion test

1. A major point is to test the samples as soon as possible. The time lag between the sample extrusion from Shelby tube and set up for testing should be kept to a minimum, to avoid moisture loss or gain from atmosphere. Change in moisture content affects the void ratio and suction and therefore the permeability and moisture diffusion coefficient.
2. Maintenance of boundary conditions is a critical concern at all the time during the testing. During the diffusion test, there is constant loss of moisture from soil sample, which in turn causes the sample to shrink, potentially creating a gap between sample and aluminum foil.

Plastic cling wrap helps in maintain an effective seal as it can deform with the shrinking specimen.

3. Thermocouple psychrometers are very sensitive to the temperature variations and hence any deviation in temperature during the testing leads to scatter in the testing results. Hence, in the measurements conducted using thermocouple psychrometers, proper temperature control should stringently maintained to obtain the best data.
4. Changes in relative humidity or atmospheric suction affect the evaporation process and hence affect the diffusion coefficient. Therefore, it should be measured daily during when test is in progress, and on an average value should be used for test interpretation.
5. The samples to be tested for diffusion test should be prepared with minimum sample disturbance. Trimming the ends and drilling should be done slowly so as to avoid creation of cracks. Any crack on the soil sample accelerates the drying process which in turn gives an erroneously high moisture diffusion coefficient value.
6. As mentioned earlier a constant temperature controlled environment is required for the proper working of the thermocouple psychrometers. Hence, any laboratory condition that could create temperature difference should be avoided such as, fan, vents or open doorways.
7. Soil particles stick on the sides of the thermocouple psychrometer and hence block the mesh which hinders in the proper flow of moisture. Hence, it is recommended to properly wash the psychrometers with distilled water and air dry it after every test. These psychrometers should also be re-calibrated after one to two months of continuous usage.

## 7.4 Filter paper test

1. For the determination of matric suction, the contact between filter paper and soil sample should be excellent. Hence, the surface of the soil sample has to be trimmed smooth and

leveled. Accurate measurements of matric suction can be difficult in dry, crumbly soils, where smooth trimming is not possible.

2. In this study, filter paper method was used to measure the initial suction. In the previous study conducted by Tang (2003), one of the problems encountered was the calculation of initial suction value. Thermocouple psychrometer was employed for the purpose but owing to the difficulties met, filter paper was given the priority.
3. On some occasions, suction values lower then 2.5 pF were encountered which cannot be measured with great reliability using filter paper test. Thus, it was concluded that one week equilibrium time was not sufficient enough. Hence, future studies should be preferred to establish the best duration.

### 7.5 Theoretical versus measured values of diffusion coefficient, $\alpha$

Table 23 provides the range of diffusivity coefficient obtained from the direct $\alpha$ measurement and Table 24 gives the range of diffusivity coefficient obtained from the empirical relationship. It can be observed from these tables, that, the values of moisture diffusion coefficient come out to be pretty much in the same range. So, it can be concluded that the drying diffusion test suggested by Mitchell (1979) is valid. This point can be more efficiently validated by Table 25.

**Table 25.Table showing the comparison between moisture diffusion coefficient calculated by empirical relations and diffusion test.**

| S.No | Sample | Depth | District | alfa (empirical) ($cm^2$/sec) | alfa (theoretical) ($cm^2$/sec) | Mode of evaluating k |
|---|---|---|---|---|---|---|
| 1 | BHB-1 | 3.5-5 | Austin | 5.56E-05 | 5.6E-05 | One-Dimensional Consolidation Test |
| 2 | BHC-3 | 6-7 | Fort Worth | 9.15E-05 | 9.20E-05 | Empirically using Figure 40 |

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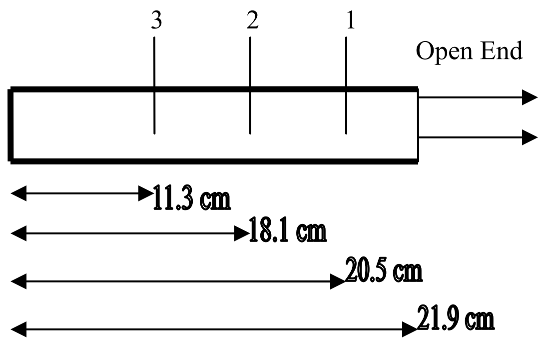
# APPENDIX A

This appendix includes the diffusion coefficient values and curves of different soil samples obtained from the diffusion tests carried out in laboratory. There are three subparts: APPENDIX A-1, APPENDIX A-2, and APPENDIX A-3, that show the data of Fort Worth, Atlanta, and Austin Districts respectively.

# APPENDIX A-1




**Project: Fort Worth District**
**Bore Hole: A1**
**Sample Depth: 5'-6'**

Total Length of the sample, L = 21.9 cm

Distance of psychrometer 1 from closed end, x = 20.5cm

Initial Suction, $u_0$ = 3.28 pF

Relative Humidity = 31%

Atmospheric Suction, $u_a$ = 6.21 pF

Diffusion Coefficient, $\alpha = 8.93E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 43447, $\pi_{v0}$ = 58 @ 25ºC

Setup Time & Date: 5:23 PM, 12/20/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 55.20 | 12.5 | 15.7 | 4.20 | 416 | 12:19 AM | 12/21/2003 |
| 2 | 22.5 | 56.25 | 26.0 | 36.0 | 4.57 | 1560 | 7:23 PM | 12/21/2003 |
| 3 | 22.5 | 56.25 | 42.0 | 60.2 | 4.79 | 2975 | 6:58 PM | 12/22/2003 |

Psychrometer 2:

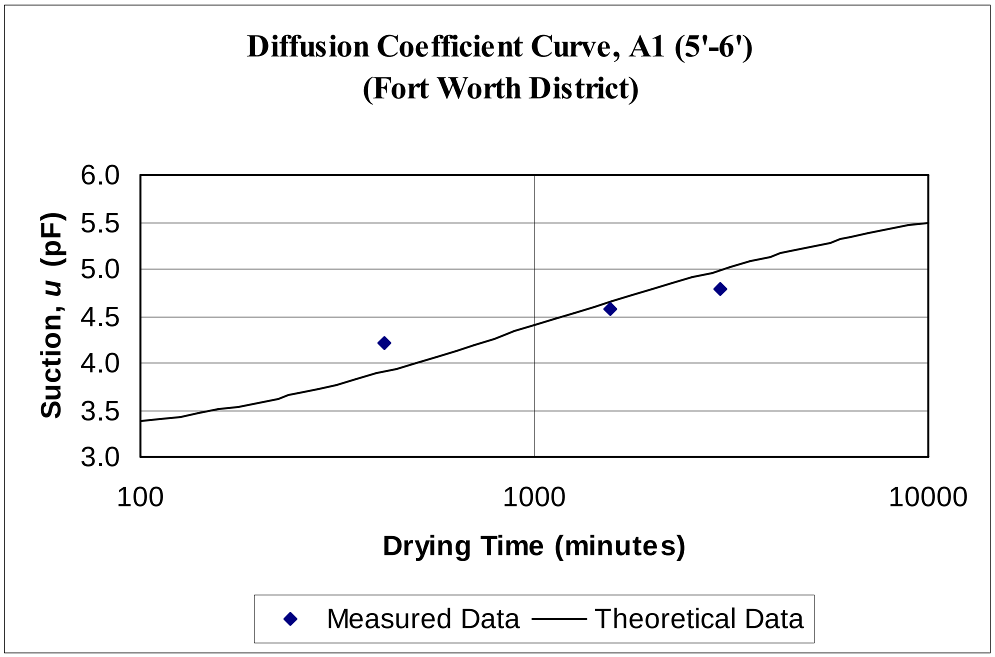
No.: 40305, $\pi_{v0} = 60$ @ 25ºC

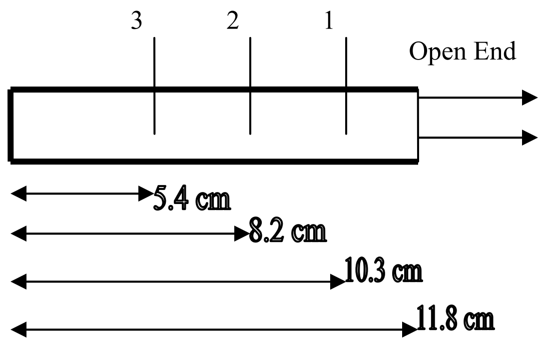
Setup Time & Date: 5:23 PM, 12/20/03

**Project: Fort Worth District**
**Bore Hole: A1**
**Sample Depth: 5'-6'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 57.90 | 3.0 | 3.3 | 3.52 | 419 | 12:22 AM | 12/21/2003 |
| 2 | 23.0 | 58.60 | 9.5 | 12.4 | 4.10 | 1561 | 7:24 PM | 12/21/2003 |
| 3 | 23.0 | 58.60 | 11.0 | 14.5 | 4.17 | 2977 | 7:00 PM | 12/22/2003 |
| 4 | 23.0 | 58.60 | 16.0 | 21.6 | 4.34 | 4448 | 7:31 PM | 12/232003 |
| 5 | 23.5 | 58.95 | 23.0 | 31.5 | 4.51 | 5838 | 6:21 PM | 12/24/2003 |
| 6 | 24.0 | 59.30 | 35.0 | 48.4 | 4.69 | 7298 | 6:41 PM | 12/26/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: A1**
**Sample Depth: 11'-12'**

Total Length of the sample, L = 11.8 cm

Distance of psychrometer 1 from closed end, x = 10.3cm

Initial Suction, $u_0$ = 3.38 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 5.90E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40332, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 4:00 PM, 11/19/03

| **No.** | **T** | $\pi_v$ | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 48.25 | 15.5 | 22.8 | 4.37 | 1419 | 3:39 PM | 11/20/2003 |
| 2 | 22.5 | 48.25 | 31.0 | 46.2 | 4.67 | 2890 | 4:10 PM | 11/22/2003 |

Psychrometer 2:

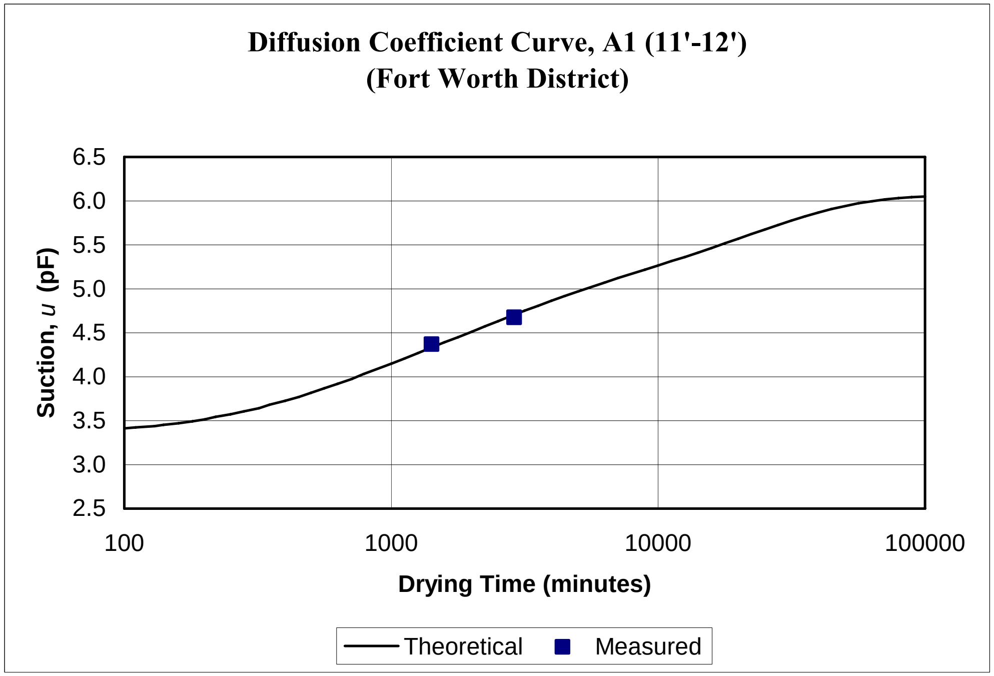
No.: 40336, $\pi_{v0}$ = 50 @ 25ºC

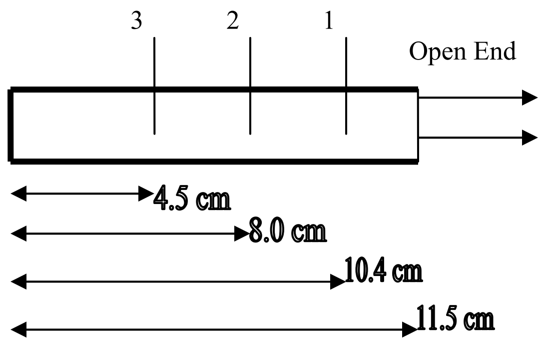
Setup Time & Date: 4:00 PM, 11/19/03

**Project: Fort Worth District**
**Bore Hole: A1**
**Sample Depth: 11'-12'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 48.60 | 9.0 | 12.8 | 4.12 | 1422 | 3:42 PM | 11/20/2003 |
| 2 | 23.0 | 48.60 | 18.0 | 26.3 | 4.43 | 2894 | 4:14 PM | 11/22/2003 |
| 3 | 23.5 | 48.95 | 22.5 | 33.0 | 4.53 | 5730 | 3:30 PM | 11/24/2003 |
| 4 | 23.5 | 48.95 | 38.0 | 56.2 | 4.76 | 8638 | 3:58 PM | 11/27/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: A2**
**Sample Depth: 2’-3’**

Total Length of the sample, L = 11.5 cm

Distance of psychrometer 2 from closed end, x = 8cm

Initial Suction, $u_0$ = 4.56 pF

Relative Humidity = 31%

Atmospheric Suction, $u_a$ = 6.21 pF

Diffusion Coefficient, $\alpha = 3.06E^{-5}\ cm^2/sec$

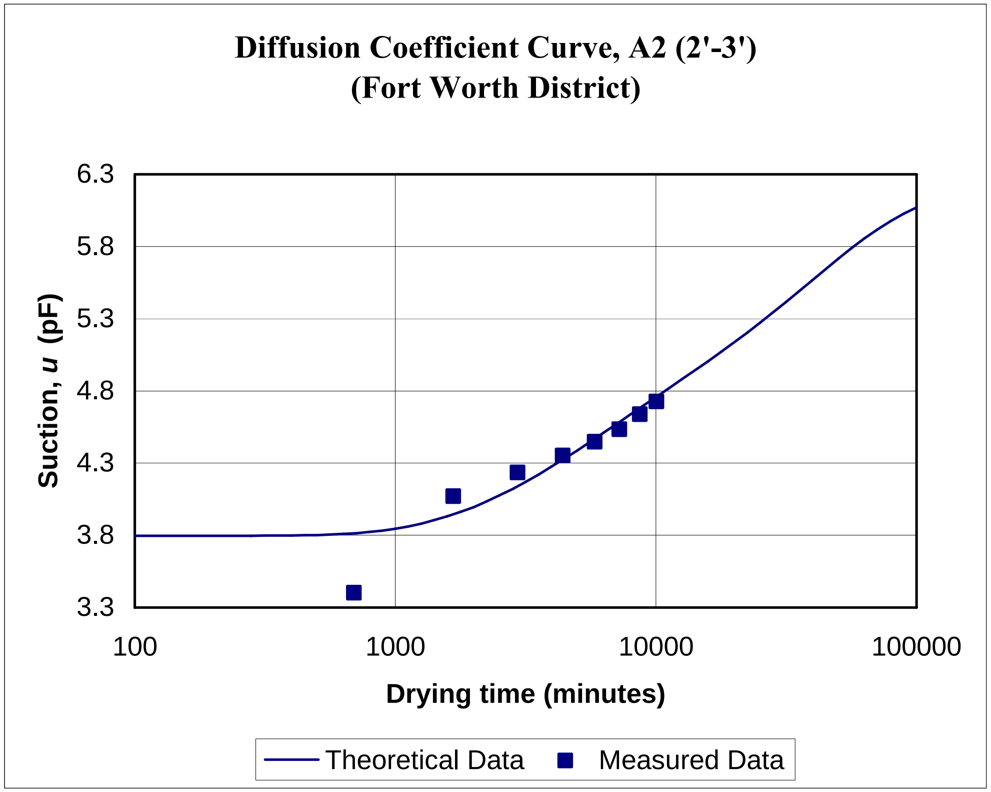
Psychrometer 2:

No.: 40322, $\pi_{v0}$ = 50 @ 25ºC

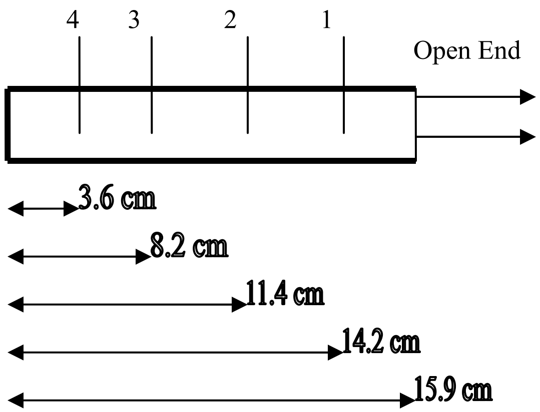
Setup Time & Date: 2:52 PM, 12/18/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.5 | 46.85 | 2.0 | 2.5 | 3.40 | 695 | 1:17 AM | 12/19/2003 |
| 2 | 22.0 | 47.90 | 8.0 | 11.5 | 4.07 | 1670 | 5:02 PM | 12/19/2003 |
| 3 | 22.0 | 47.90 | 11.5 | 16.8 | 4.23 | 2948 | 2:20 PM | 12/20/2003 |
| 4 | 22.5 | 48.25 | 15.0 | 22.1 | 4.35 | 4395 | 7:27 PM | 12/21/2003 |
| 5 | 23.0 | 48.60 | 18.5 | 27.4 | 4.45 | 5818 | 7:10 PM | 12/22/2003 |
| 6 | 22.5 | 48.25 | 22.5 | 33.4 | 4.53 | 7251 | 7:03 PM | 12/23/2003 |
| 7 | 23.5 | 48.95 | 28.5 | 42.5 | 4.64 | 8676 | 6:48 PM | 12/24/2003 |
| 8 | 23.5 | 48.95 | 35.0 | 52.3 | 4.73 | 10049 | 5:41 PM | 12/26/2003 |

Diffusion Coefficient Curve for Psychrometer 2:




**Project: Fort Worth District**
**Bore Hole: A2**
**Sample Depth: 2'-3'**




**Project: Fort Worth District**
**Bore Hole: A2**
**Sample Depth: 12’-13’**

Total Length of the sample, L = 15.9 cm

Distance of psychrometer 1 from closed end, x = 14.2cm

Initial Suction, $u_0$ = 3.51 pF

Relative Humidity = 56%

Atmospheric Suction, $u_a$ = 5.91 pF

Diffusion Coefficient, $\alpha = 2.00E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40307, $\pi_{v0}$ = 56 @ 25ºC

Setup Time & Date: 3:30 PM, 10/07/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 54.25 | 9.0 | 9.1 | 3.97 | 1515 | 4:45 PM | 10/8/03 |
| 2 | 22.0 | 53.90 | 11.5 | 12.9 | 4.12 | 2800 | 2:10 PM | 10/9/03 |
| 3 | 21.5 | 53.55 | 16.0 | 19.6 | 4.30 | 4335 | 3:45 PM | 10/10/03 |
| 4 | 21.5 | 53.55 | 29.0 | 39.0 | 4.60 | 8540 | 1:50 PM | 10/13/03 |
| 5 | 21.5 | 53.55 | 33.0 | 45.0 | 4.66 | 9812 | 11:02 AM | 10/14/03 |
| 6 | 22.0 | 53.90 | 35.5 | 48.7 | 4.70 | 10094 | 3:44 PM | 10/14/03 |
| 5 | 21.5 | 53.55 | 45.0 | 62.9 | 4.81 | 11217 | 10:27 AM | 10/15/03 |

Psychrometer 2:

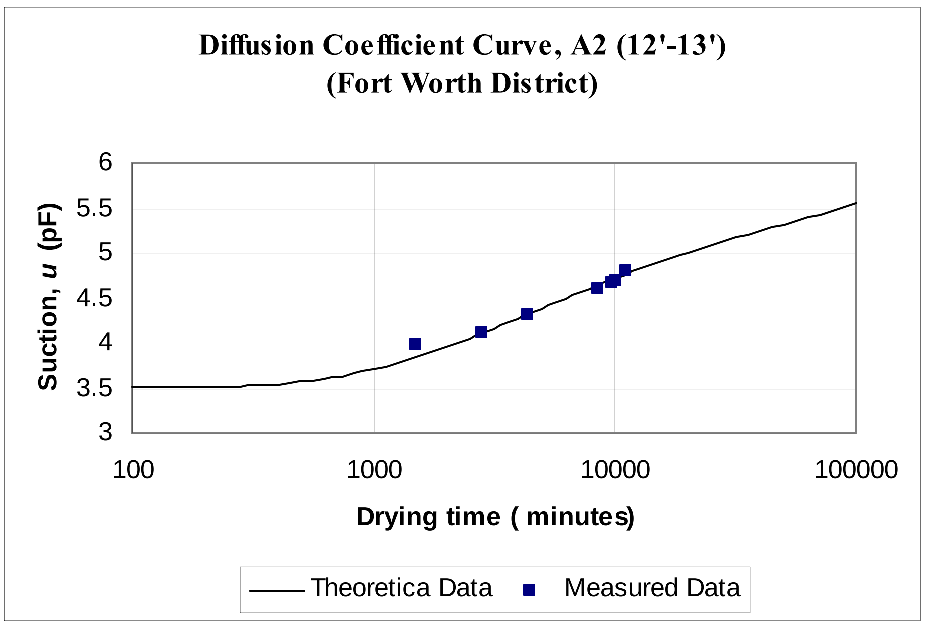
No.: 40326, $\pi_{v0}$ = 49 @ 25ºC

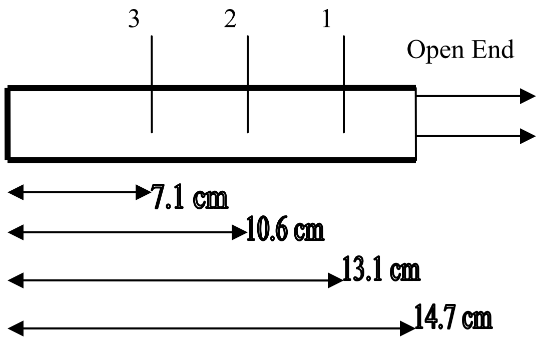
Setup Time & Date: 3:30 PM, 10/07/03

**Project: Fort Worth District**
**Bore Hole: A2**
**Sample Depth: 12'-13'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 47.25 | 5.5 | 3.8 | 3.58 | 1520 | 4:50 PM | 10/8/03 |
| 2 | 22.0 | 46.90 | 6.5 | 5.2 | 3.73 | 2805 | 2:15 PM | 10/9/03 |
| 3 | 21.5 | 46.55 | 8.0 | 7.4 | 3.88 | 4338 | 3:48 PM | 10/10/03 |
| 4 | 21.5 | 46.55 | 14.0 | 16.3 | 4.22 | 8558 | 2:08 PM | 10/13/03 |
| 5 | 22.0 | 46.90 | 15.5 | 18.5 | 4.28 | 9815 | 11:05 AM | 10/14/03 |
| 6 | 22.0 | 46.90 | 17.0 | 20.7 | 4.32 | 10095 | 3:45 PM | 10/14/03 |
| 7 | 21.5 | 46.55 | 19.5 | 24.4 | 4.40 | 11223 | 10:30 AM | 10/15/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: A3**
**Sample Depth: 0'-1'**

Total Length of the sample, L = 14.7 cm

Distance of psychrometer 2 from closed end, x = 10.6 cm

Initial Suction, $u_0$ = 4.10 pF

Relative Humidity = 30%

Atmospheric Suction, $u_a$ = 6.22 pF

Diffusion Coefficient, $\alpha = 8.66E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 5:30 PM, 12/20/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 49.90 | 20.5 | 28.1 | 4.46 | 395 | 12:05 AM | 12/21/2003 |

Psychrometer 2:

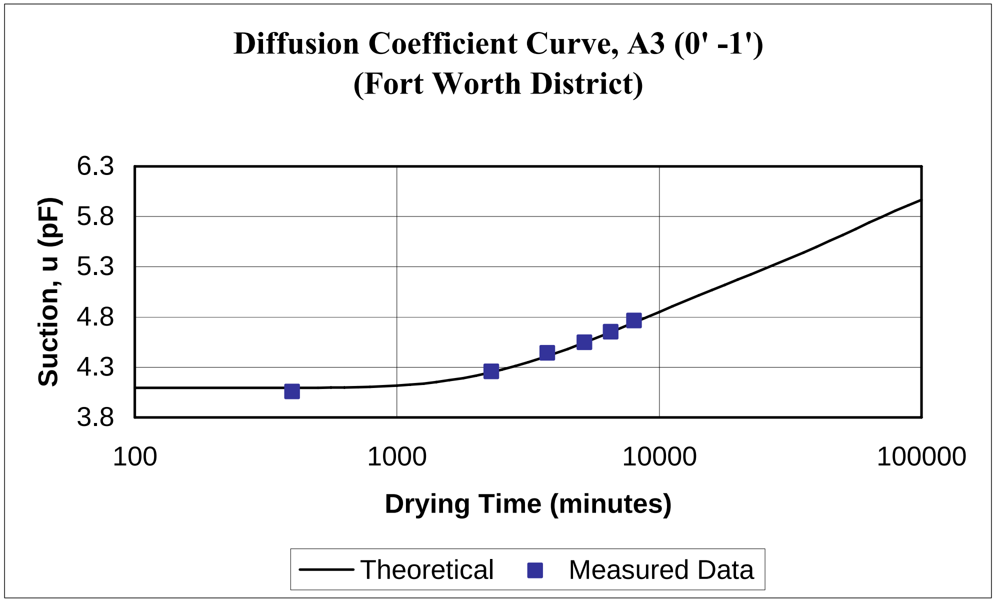
No.: 40325, $\pi_{v0}$ = 49 @ 25ºC

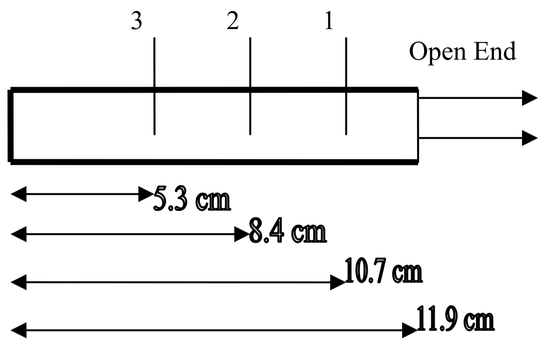
Setup Time & Date: 5:30 PM, 12/20/03

**Project: Fort Worth District**
**Bore Hole: A3**
**Sample Depth: 0'-1'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 47.60 | 8.5 | 11.2 | 4.06 | 398 | 12:08 AM | 12/21/2003 |
| 2 | 24.5 | 48.65 | 13.0 | 17.8 | 4.26 | 2288 | 7:38 PM | 12/21/2003 |
| 3 | 24.5 | 48.65 | 19.5 | 27.3 | 4.44 | 3738 | 7:28 PM | 12/22/2003 |
| 4 | 24.0 | 48.30 | 24.5 | 34.5 | 4.55 | 5184 | 7:34 PM | 12/23/2003 |
| 5 | 24.0 | 48.30 | 31.0 | 44.0 | 4.65 | 6536 | 6:10 PM | 12/24/2003 |
| 6 | 24.5 | 48.65 | 40.0 | 57.1 | 4.77 | 8010 | 6:44 PM | 12/26/2003 |

Diffusion Coefficient Curve for Psychrometer 2:






**Project: Fort Worth District**
**Bore Hole: A3**
**Sample Depth: 9'-10'**

Total Length of the sample, L = 11.9 cm

Distance of psychrometer 2 from closed end, x = 10.7 cm

Initial Suction, $u_0$ = 3.25 pF

Relative Humidity = 31%

Atmospheric Suction, $u_a$ = 6.21 pF

Diffusion Coefficient, $\alpha = 5.05E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40333, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 6:35 PM, 12/19/03

| **No.** | **T** | $\pi_v$ | **μV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.5 | 50.55 | 18.5 | 26.7 | 4.44 | 1195 | 2:30 PM | 12/20/2003 |
| 2 | 21.0 | 50.20 | 26.0 | 37.9 | 4.59 | 2455 | 11:40 PM | 12/20/2003 |
| 3 | 23.0 | 51.60 | 35.0 | 51.4 | 4.72 | 3671 | 7:56 PM | 12/21/2003 |

Psychrometer 2:

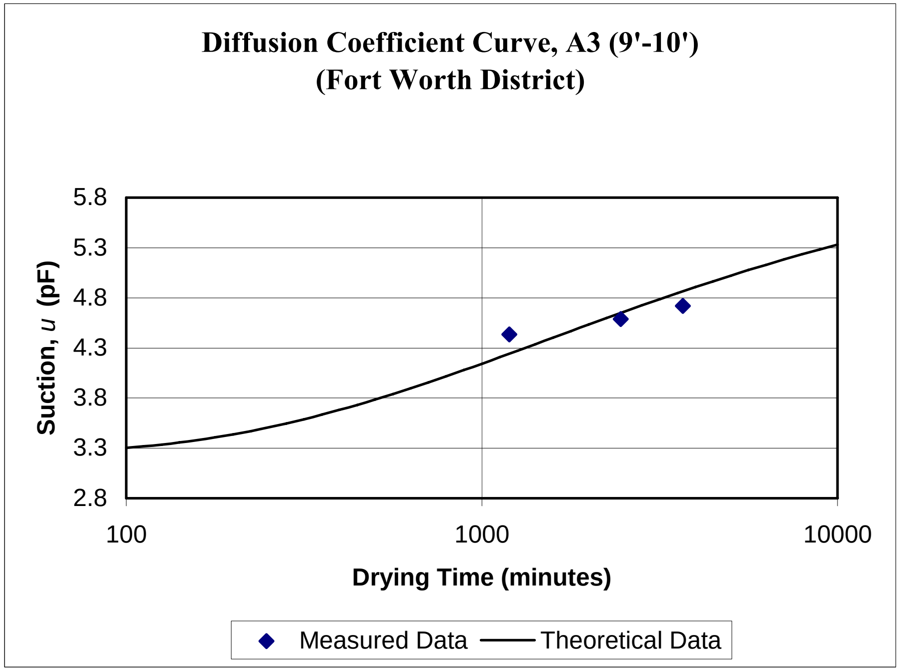
No.: 40312, $\pi_{v0}$ = 56 @ 25ºC

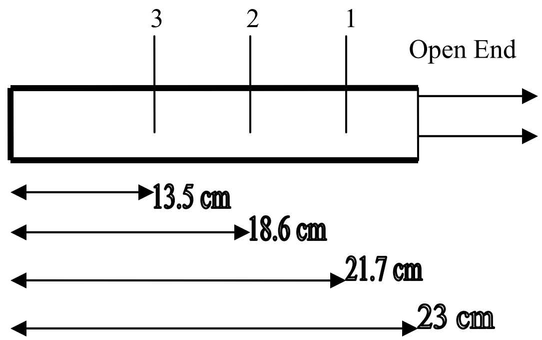
Setup Time & Date: 6:35 PM, 12/19/03

**Project: Fort Worth District**
**Bore Hole: A3**
**Sample Depth: 9'-10'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 53.90 | 9.5 | 10.4 | 4.03 | 1196 | 2:31 PM | 12/20/2003 |
| 2 | 22.0 | 53.90 | 12.5 | 14.9 | 4.18 | 2456 | 11:41 PM | 12/20/2003 |
| 3 | 23.5 | 54.95 | 12.5 | 14.9 | 4.18 | 3675 | 8:00 PM | 12/21/2003 |
| 4 | 23.5 | 54.95 | 21.5 | 28.4 | 4.46 | 5108 | 7:53 PM | 12/22/2003 |
| 5 | 22.5 | 54.25 | 30.0 | 41.1 | 4.62 | 6592 | 7:09 PM | 12/23/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: A4**
**Sample Depth: 5'-6'**

Total Length of the sample, L = 23 cm

Distance of psychrometer 2 from closed end, x = 21.7 cm

Initial Suction, $u_0$ = 3.22 pF

Relative Humidity = 31%

Atmospheric Suction, $u_a$ = 6.21 pF

Diffusion Coefficient, $\alpha = 9.88E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40320, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 7:20 PM, 12/19/03

| **No.** | **T** | **$\pi_v$** | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 50.90 | 25.5 | 35.0 | 4.55 | 1194 | 3:26 PM | 12/20/2003 |
| 2 | 22.0 | 50.90 | 39.0 | 55.1 | 4.75 | 1733 | 12:25 AM | 12/21/2003 |

Psychrometer 2:

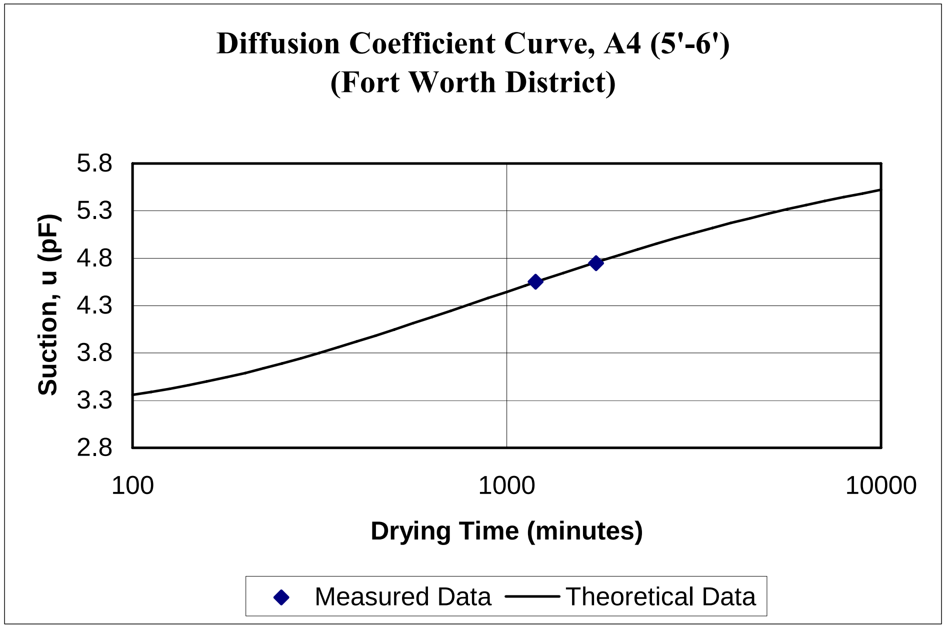
No.: 43311, $\pi_{v0}$ = 52 @ 25ºC

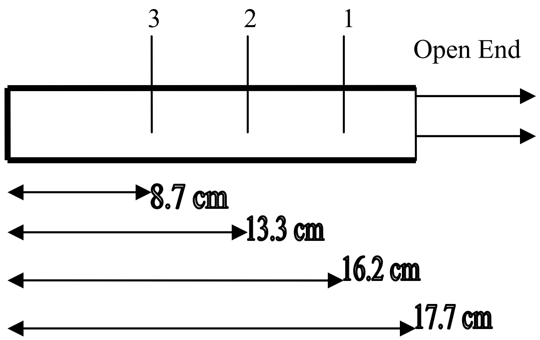
Setup Time & Date: 7:20 PM, 12/19/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 50.25 | 4.0 | 3.8 | 3.59 | 1220 | 3:40 PM | 12/20/2003 |
| 2 | 23.0 | 50.60 | 4.0 | 3.8 | 3.59 | 2492 | 12:28 AM | 12/21/2003 |
| 3 | 23.5 | 50.95 | 4.0 | 3.8 | 3.59 | 3647 | 7:13 PM | 12/21/2003 |
| 4 | 23.0 | 50.60 | 5.5 | 6.0 | 3.79 | 5078 | 7:04 PM | 12/22/2003 |
| 5 | 23.5 | 50.95 | 8.0 | 9.6 | 3.99 | 6534 | 7:20 PM | 12/23/2003 |
| 6 | 23.5 | 50.95 | 14.0 | 18.1 | 4.27 | 7923 | 6:29 PM | 12/24/2003 |
| 7 | 23.5 | 50.95 | 15.0 | 19.6 | 4.30 | 9362 | 6:28 PM | 12/26/2003 |
| 8 | 24.0 | 51.30 | 25.0 | 33.9 | 4.54 | 10778 | 7:04 PM | 12/27/2003 |
| 9 | 24.0 | 51.30 | 32.0 | 43.9 | 4.65 | 12124 | 5:30 PM | 12/29/2003 |

**Project: Fort Worth District**
**Bore Hole: A4**
**Sample Depth: 5’-6’**

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: A4**
**Sample Depth: 10'-11'**

Total Length of the sample, L = 17.7 cm

Distance of psychrometer 2 from closed end, x = 16.2 cm

Initial Suction, $u_0$ = 4.26 pF

Relative Humidity = 30%

Atmospheric Suction, $u_a$ = 6.22 pF

Diffusion Coefficient, $\alpha = 0.33E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40331, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 2:20 PM, 12/20/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.5 | 46.85 | 5.5 | 7.3 | 3.87 | 569 | 11:49 AM | 12/20/2003 |
| 2 | 22.0 | 47.90 | 7.5 | 10.2 | 4.02 | 1771 | 7:47 PM | 12/21/2003 |
| 3 | 23.0 | 48.60 | 9.0 | 12.4 | 4.10 | 3199 | 7:35 PM | 12/22/2003 |
| 4 | 23.0 | 48.60 | 14.5 | 20.5 | 4.32 | 4661 | 7:13 PM | 12/23/2003 |
| 5 | 23.0 | 48.60 | 21.5 | 30.7 | 4.50 | 6063 | 6:35 PM | 12/24/2003 |
| 6 | 23.5 | 48.95 | 27.5 | 39.4 | 4.60 | 7459 | 5:51 PM | 12/26/2003 |
| 7 | 24.0 | 49.30 | 31.0 | 44.5 | 4.66 | 8857 | 7:09 PM | 12/27/2003 |

Psychrometer 2:

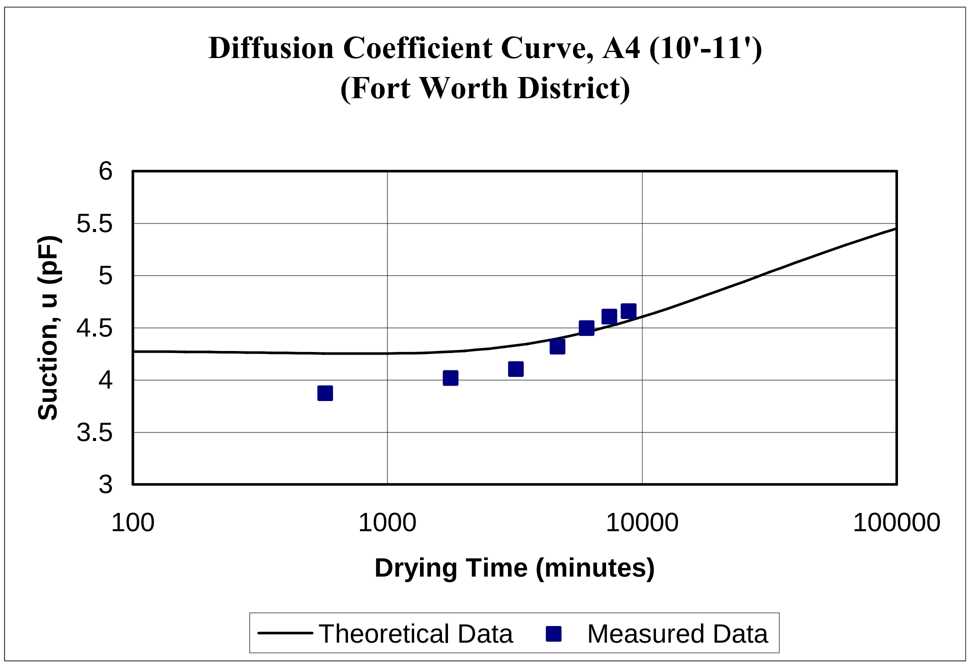
No.: 40321, $\pi_{v0}$ = 51 @ 25ºC

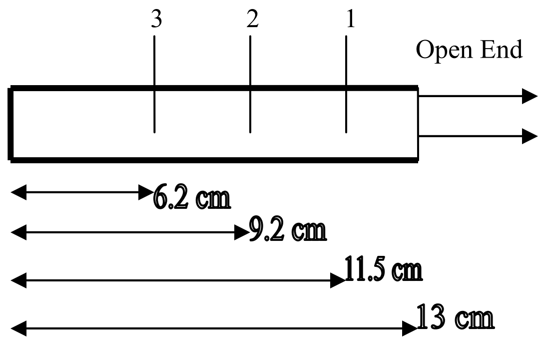
Setup Time & Date: 2:20 PM, 12/20/03

**Project: Fort Worth District**
**Bore Hole: A4**
**Sample Depth: 10'-11'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 48.90 | 4.0 | 5.0 | 3.71 | 572 | 11:52 AM | 12/20/2003 |
| 2 | 23.0 | 49.60 | 4.0 | 5.0 | 3.71 | 1778 | 7:51 PM | 12/21/2003 |
| 3 | 23.5 | 49.95 | 4.0 | 5.0 | 3.71 | 3211 | 7:40 PM | 12/22/2003 |
| 4 | 23.0 | 49.60 | 5.5 | 7.2 | 3.87 | 4676 | 7:16 PM | 12/23/2003 |
| 5 | 23.5 | 49.95 | 7.0 | 9.4 | 3.98 | 6080 | 6:37 PM | 12/24/2003 |
| 6 | 23.5 | 49.95 | 9.0 | 12.4 | 4.10 | 7479 | 5:54 PM | 12/26/2003 |
| 7 | 23.5 | 49.95 | 11.5 | 16.0 | 4.21 | 8880 | 7:12 PM | 12/27/2003 |
| 8 | 23.5 | 49.95 | 16.0 | 22.6 | 4.36 | 10215 | 5:24 PM | 12/29/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: A5**
**Sample Depth: 3'-4'**

Total Length of the sample, L = 13.0 cm

Distance of psychrometer 2 from closed end, x = 11.5 cm

Initial Suction, $u_0$ = 3.02 pF

Relative Humidity = 31%

Atmospheric Suction, $u_a$ = 6.21 pF

Diffusion Coefficient, $\alpha = 7.86E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40316, $\pi_{v0}$ = 58 @ 25ºC

Setup Time & Date: 2:30 PM, 12/18/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 55.20 | 16.0 | 19.0 | 4.29 | 618 | 1:00 AM | 12/19/2003 |
| 2 | 22.5 | 56.25 | 27.0 | 35.1 | 4.55 | 1587 | 5:09 PM | 12/19/2003 |
| 3 | 22.5 | 56.25 | 30.0 | 39.4 | 4.60 | 3174 | 7:36 PM | 12/19/2003 |
| 4 | 22.5 | 56.25 | 48.0 | 65.7 | 4.83 | 4298 | 2:10 PM | 12/20/2003 |

Psychrometer 2:

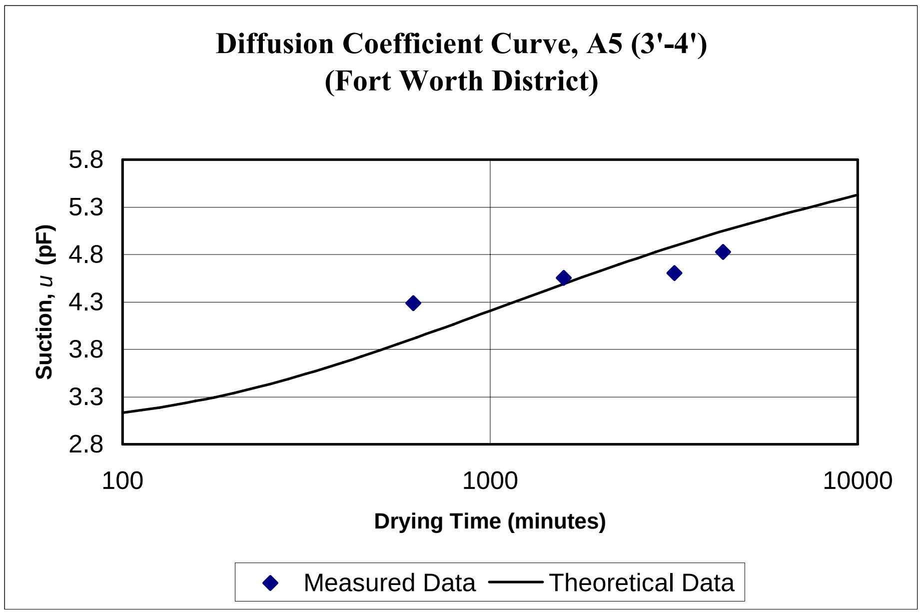
No.: 40363, $\pi_{v0}$ = 49 @ 25ºC

Setup Time & Date: 2:30 PM, 12/18/03

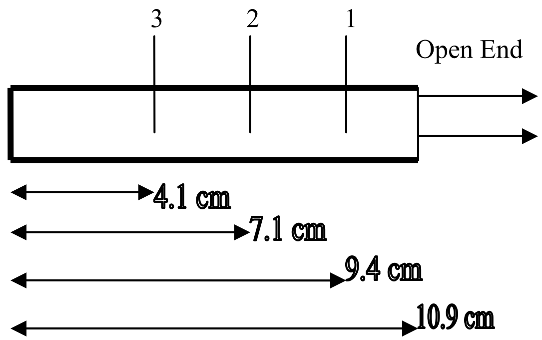
**Project: Fort Worth District**
**Bore Hole: A5**
**Sample Depth: 3'-4'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 46.90 | 6.0 | 4.7 | 3.68 | 635 | 1:05 AM | 12/19/2003 |
| 2 | 23.0 | 47.60 | 5.5 | 3.9 | 3.60 | 1600 | 5:10 PM | 12/19/2003 |
| 3 | 23.0 | 47.60 | 6.0 | 4.7 | 3.68 | 2861 | 2:11 PM | 12/20/2003 |
| 4 | 23.5 | 47.95 | 10.5 | 11.9 | 4.08 | 4658 | 8:08 PM | 12/21/2003 |
| 5 | 24.0 | 48.30 | 12.0 | 14.3 | 4.16 | 6046 | 7:59 PM | 12/22/2003 |
| 6 | 23.5 | 47.95 | 15.0 | 19.1 | 4.29 | 7519 | 7:26 PM | 12/23/2003 |
| 7 | 23.5 | 47.95 | 18.0 | 23.9 | 4.39 | 8898 | 6:25 PM | 12/24/2003 |
| 8 | 24.0 | 48.30 | 25.0 | 35.0 | 4.55 | 10348 | 6:35 PM | 12/26/2003 |
| 9 | 23.5 | 47.95 | 28.0 | 39.8 | 4.61 | 11813 | 7:00 PM | 12/27/2003 |
| 10 | 23.5 | 47.95 | 37.0 | 54.2 | 4.74 | 13168 | 5:35 PM | 12/29/2003 |

Diffusion Coefficient Curve for Psychrometer 1:



**Project: Fort Worth District**
**Bore Hole: A5**
**Sample Depth: 8'-9'**




Total Length of the sample, L = 10.9 cm

Distance of psychrometer 2 from closed end, x = 9.4 cm

Initial Suction, $u_0$ = 3.09 pF

Relative Humidity = 31%

Atmospheric Suction, $u_a$ = 6.21 pF

Diffusion Coefficient, $\alpha = 10.3E^{-5}\ cm^2/sec$

Psychrometer 1:

No.: 40338, $\pi_{v0}$ = 49 @ 25ºC

Setup Time & Date: 3:00 PM, 12/18/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 46.20 | 12.5 | 18.1 | 4.27 | 630 | 12:30 AM | 12/19/2003 |
| 2 | 22.5 | 47.25 | 23.0 | 33.7 | 4.54 | 1645 | 4:55 PM | 12/19/2003 |
| 3 | 22.0 | 46.90 | 24.8 | 36.4 | 4.57 | 1875 | 7:32 PM | 12/19/2003 |

Psychrometer 2:

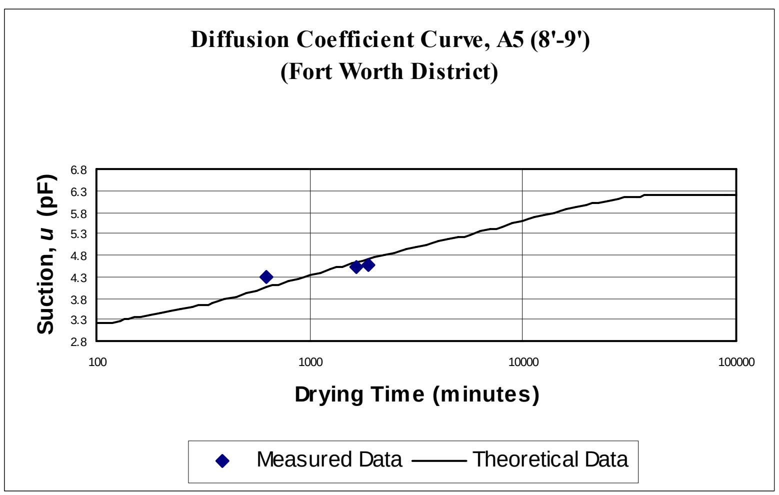
No.: 40321, $\pi_{v0}$ = 51 @ 25ºC

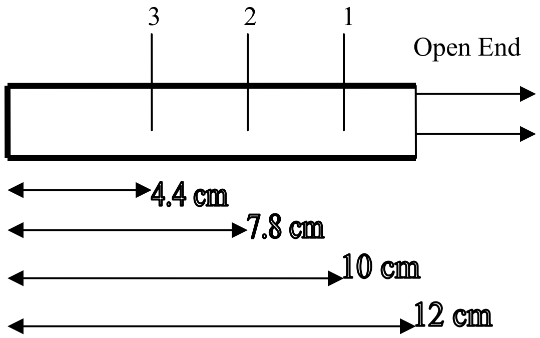
Setup Time & Date: 3:00 PM, 12/18/03

**Project: Fort Worth District**
**Bore Hole: A5**
**Sample Depth: 8'-9'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 48.90 | 5.5 | 7.2 | 3.87 | 655 | 12:55 AM | 12/19/2003 |
| 2 | 22.5 | 49.25 | 5.0 | 6.5 | 3.82 | 1648 | 4:58 PM | 12/19/2003 |
| 3 | 23.0 | 49.60 | 6.0 | 8.0 | 3.91 | 2939 | 1:59 PM | 12/20/2003 |
| 4 | 24.5 | 50.65 | 7.5 | 10.2 | 4.02 | 3055 | 11:33 PM | 12/20/2003 |
| 5 | 24.5 | 50.65 | 9.5 | 13.1 | 4.13 | 4323 | 8:11 PM | 12/21/2003 |
| 6 | 24.5 | 50.65 | 11.5 | 16.0 | 4.21 | 5785 | 8:03 PM | 12/22/2003 |
| 7 | 23.0 | 49.60 | 13.0 | 18.2 | 4.27 | 7190 | 6:58 PM | 12/23/2003 |
| 8 | 24.0 | 50.30 | 17.5 | 24.8 | 4.40 | 8654 | 6:52 PM | 12/24/2003 |
| 9 | 24 | 50.30 | 22 | 31.4 | 4.51 | 10082 | 5:34 PM | 12/26/2003 |
| 10 | 24.5 | 50.65 | 25.0 | 35.8 | 4.56 | 11655 | 7:17 PM | 12/27/2003 |
| 11 | 23.5 | 49.95 | 32.0 | 46.1 | 4.67 | 13003 | 5:15 PM | 12/29/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B1**
**Sample Depth: 6'-7'**

Total Length of the sample, L = 12.0 cm

Distance of psychrometer 2 from closed end, x = 10.0 cm

Initial Suction, $u_0$ = 3.38 pF

Relative Humidity = 39.2%

Atmospheric Suction, $u_a$ = 6.11 pF

Diffusion Coefficient, $\alpha = 8.26E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40307, $\pi_{v0}$ = 56 @ 25ºC

Setup Time & Date: 6:10 PM, 01/21/04

| **No.** | **T** | **$\pi_v$** | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 53.20 | 8.5 | 8.4 | 3.93 | 220 | 9:50 PM | 1/21/2004 |
| 2 | 21.5 | 53.55 | 18.0 | 22.6 | 4.36 | 1309 | 3:59 PM | 1/22/2004 |
| 3 | 21.5 | 53.55 | 19.5 | 24.8 | 4.40 | 1429 | 5:59 PM | 1/22/2004 |
| 4 | 21.5 | 53.55 | 22.0 | 28.5 | 4.46 | 1740 | 11:10 PM | 1/22/2004 |
| 5 | 22.0 | 53.90 | 35.0 | 47.9 | 4.69 | 2749 | 3:59 PM | 1/23/2004 |
| 6 | 23.0 | 54.60 | 41.0 | 56.9 | 4.76 | 4145 | 3:15 PM | 1/24/2004 |
| 7 | 23.0 | 54.60 | 50.0 | 70.3 | 4.86 | 5787 | 6:27 PM | 1/25/2004 |

Psychrometer 2:

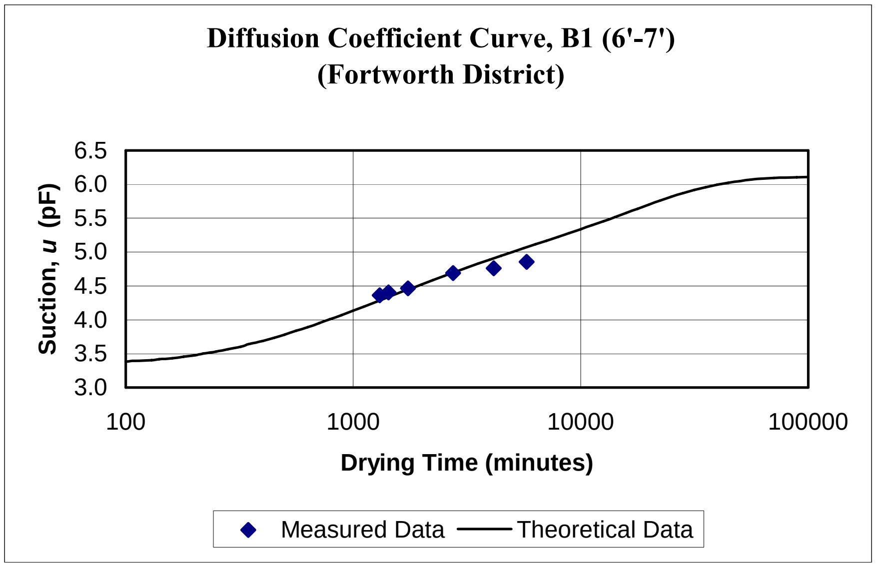
No.: 40336, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 6:10 PM, 01/21/04

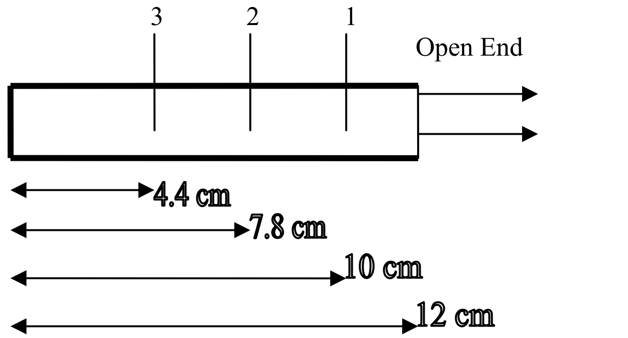
**Project: Fort Worth District**
**Bore Hole: B1**
**Sample Depth: 6’-7’**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 48.25 | 4.0 | 5.4 | 3.74 | 1310 | 4:00 PM | 1/22/2004 |
| 2 | 22.5 | 48.25 | 5.0 | 6.9 | 3.84 | 1430 | 6:00 PM | 1/22/2004 |
| 3 | 22.5 | 48.25 | 15.0 | 21.8 | 4.35 | 2752 | 4:02 PM | 1/23/2004 |
| 4 | 22.5 | 48.25 | 20.0 | 29.3 | 4.47 | 4147 | 3:17 PM | 1/24/2004 |
| 5 | 23.5 | 48.95 | 21.5 | 31.5 | 4.51 | 4420 | 7:50 PM | 1/24/2004 |
| 6 | 23.5 | 48.95 | 25.0 | 36.7 | 4.57 | 5790 | 6:30 PM | 1/25/2004 |
| 7 | 23.5 | 48.95 | 26.0 | 38.2 | 4.59 | 5920 | 8:40 PM | 1/25/2004 |
| 8 | 23.5 | 48.95 | 28.0 | 41.2 | 4.62 | 7030 | 3:10 PM | 1/26/2004 |
| 9 | 23.5 | 48.95 | 30.0 | 44.2 | 4.65 | 8515 | 3:55 PM | 1/27/2004 |

Diffusion Coefficient Curve for Psychrometer 1:



**Project: Fort Worth District**
**Bore Hole: B1**
**Sample Depth: 9'-10'**




Total Length of the sample, L = 12.0 cm

Distance of psychrometer 2 from closed end, x = 10.0 cm

Initial Suction, $u_0$ = 3.38 pF

Relative Humidity = 39.2%

Atmospheric Suction, $u_a$ = 6.11 pF

Diffusion Coefficient, $\alpha = 8.26E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40307, $\pi_{v0}$ = 56 @ 25ºC

Setup Time & Date: 6:10 PM, 01/21/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 53.20 | 8.5 | 8.4 | 3.93 | 220 | 9:50 PM | 1/21/2004 |
| 2 | 21.5 | 53.55 | 18.0 | 22.6 | 4.36 | 1309 | 3:59 PM | 1/22/2004 |
| 3 | 21.5 | 53.55 | 19.5 | 24.8 | 4.40 | 1429 | 5:59 PM | 1/22/2004 |
| 4 | 21.5 | 53.55 | 22.0 | 28.5 | 4.46 | 1740 | 11:10 PM | 1/22/2004 |
| 5 | 22.0 | 53.90 | 35.0 | 47.9 | 4.69 | 2749 | 3:59 PM | 1/23/2004 |
| 6 | 23.0 | 54.60 | 41.0 | 56.9 | 4.76 | 4145 | 3:15 PM | 1/24/2004 |
| 7 | 23.0 | 54.60 | 50.0 | 70.3 | 4.86 | 5787 | 6:27 PM | 1/25/2004 |

Psychrometer 2:

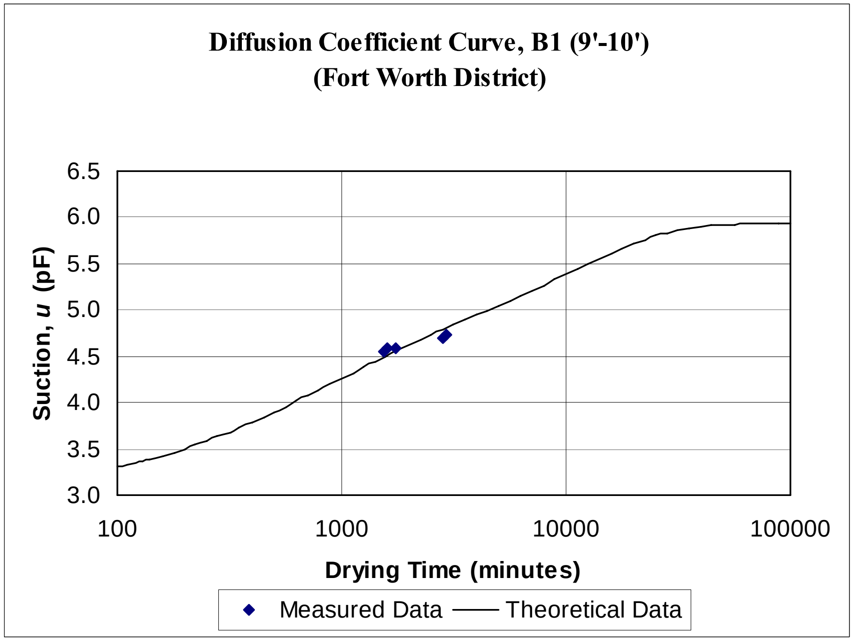
No.: 40336, πv0 = 50 @ 25ºC

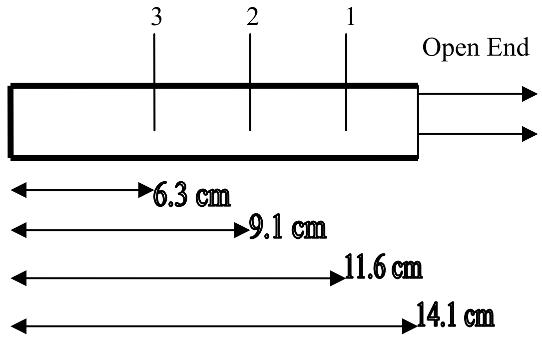
Setup Time & Date: 6:10 PM, 01/21/04

**Project: Fort Worth District**
**Bore Hole: B1**
**Sample Depth: 9'-10'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 48.25 | 4.0 | 5.4 | 3.74 | 1310 | 4:00 PM | 1/22/2004 |
| 2 | 22.5 | 48.25 | 5.0 | 6.9 | 3.84 | 1430 | 6:00 PM | 1/22/2004 |
| 3 | 22.5 | 48.25 | 15.0 | 21.8 | 4.35 | 2752 | 4:02 PM | 1/23/2004 |
| 4 | 22.5 | 48.25 | 20.0 | 29.3 | 4.47 | 4147 | 3:17 PM | 1/24/2004 |
| 5 | 23.5 | 48.95 | 21.5 | 31.5 | 4.51 | 4420 | 7:50 PM | 1/24/2004 |
| 6 | 23.5 | 48.95 | 25.0 | 36.7 | 4.57 | 5790 | 6:30 PM | 1/25/2004 |
| 7 | 23.5 | 48.95 | 26.0 | 38.2 | 4.59 | 5920 | 8:40 PM | 1/25/2004 |
| 8 | 23.5 | 48.95 | 28.0 | 41.2 | 4.62 | 7030 | 3:10 PM | 1/26/2004 |
| 9 | 23.5 | 48.95 | 30.0 | 44.2 | 4.65 | 8515 | 3:55 PM | 1/27/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B2**
**Sample Depth: 3'- 4'**

Total Length of the sample, L = 14.1 cm

Distance of psychrometer 2 from closed end, x = 11.6 cm

Initial Suction, $u_0$ = 3.24 pF

Relative Humidity = 39.2%

Atmospheric Suction, $u_a$ = 6.11 pF

Diffusion Coefficient, $\alpha = 0.106E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40363, $\pi_{v0}$ = 49 @ 25ºC

Setup Time & Date: 5:32 PM, 01/22/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.5 | 46.55 | 8.0 | 11.9 | 4.08 | 378 | 11:14:00 PM | 1/22/2004 |
| 2 | 23.0 | 47.60 | 9.5 | 14.2 | 4.16 | 1406 | 4:22:00 PM | 1/23/2004 |
| 3 | 23.5 | 47.95 | 21.0 | 32.2 | 4.52 | 2804 | 3:04:00 PM | 1/24/2004 |
| 4 | 23.0 | 47.60 | 24.0 | 36.9 | 4.58 | 3104 | 8:00:00 PM | 1/24/2004 |
| 5 | 23.0 | 47.60 | 36.0 | 55.6 | 4.75 | 4409 | 6:15:00 PM | 1/25/2004 |
| 6 | 24.0 | 48.30 | 42.0 | 65.0 | 4.82 | 4544 | 8:30:00 PM | 1/25/2004 |

Psychrometer 2:

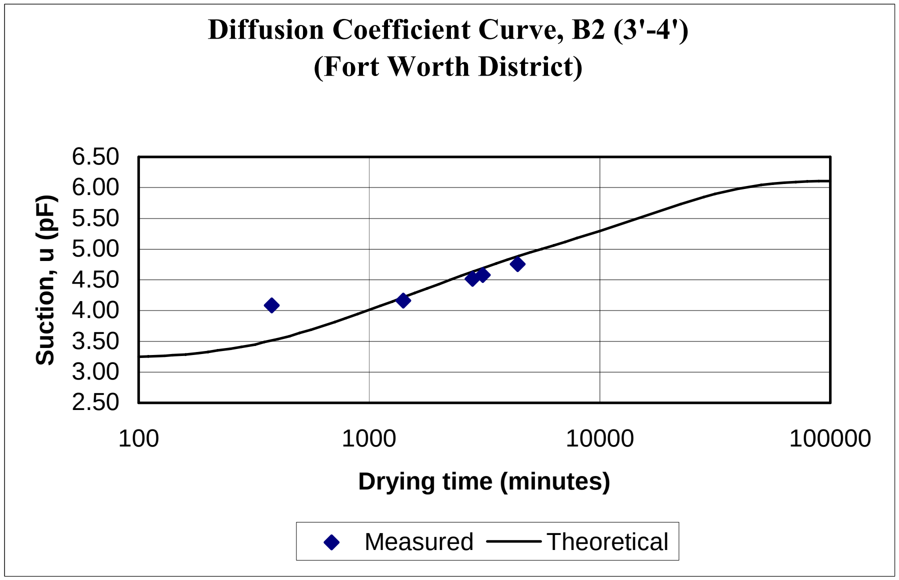
No.: 40333, $\pi_{v0}$ = 53 @ 25ºC

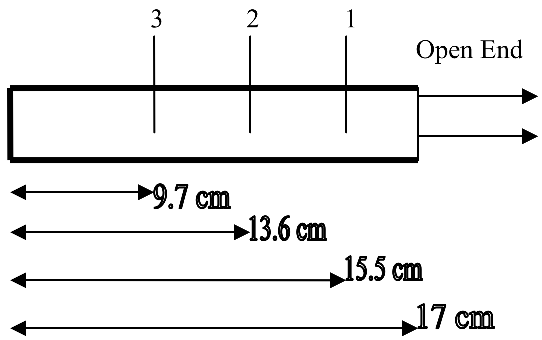
Setup Time & Date: 5:32 PM, 01/22/04

**Project: Fort Worth District**
**Bore Hole: B2**
**Sample Depth: 3'- 4'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 24.0 | 52.30 | 3.0 | 3.3 | 3.53 | 1409 | 4:25:00 PM | 1/23/2004 |
| 2 | 24.0 | 52.30 | 3.5 | 4.1 | 3.62 | 2806 | 3:06:00 PM | 1/24/2004 |
| 3 | 24.0 | 52.30 | 3.5 | 4.1 | 3.62 | 3108 | 8:04:00 PM | 1/24/2004 |
| 4 | 24.0 | 52.30 | 4.5 | 5.5 | 3.75 | 4431 | 6:17:00 PM | 1/25/2004 |
| 5 | 24.5 | 52.65 | 4.5 | 5.5 | 3.75 | 4548 | 8:34:00 PM | 1/25/2004 |
| 6 | 24.5 | 52.65 | 4.5 | 5.5 | 3.75 | 5704 | 3:50:00 PM | 1/26/2004 |
| 7 | 24.0 | 52.30 | 8.0 | 10.5 | 4.03 | 7205 | 4:51:00 PM | 1/27/2004 |
| 8 | 24.5 | 52.65 | 11.5 | 15.5 | 4.20 | 8636 | 4:40:00 PM | 1/28/2004 |
| 9 | 24 | 52.30 | 13.5 | 18.4 | 4.27 | 10496 | 11:40:00 PM | 1/29/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B2**
**Sample Depth: 11'-12'**

Total Length of the sample, L = 17.0 cm

Distance of psychrometer 2 from closed end, x = 15.5 cm

Initial Suction, $u_0$ = 3.18 pF

Relative Humidity = 54.2%

Atmospheric Suction, $u_a$ = 5.93 pF

Diffusion Coefficient, $\alpha = 9.66E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40325, $\pi_{v0}$ = 49 @ 25ºC

Setup Time & Date: 3:05 PM, 01/11/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 47.60 | 24.5 | 34.5 | 4.55 | 1503 | 4:08 PM | 1/12/2004 |
| 2 | 22.5 | 47.25 | 25.5 | 36.0 | 4.56 | 1567 | 5:12 PM | 1/12/2004 |
| 3 | 22.0 | 46.90 | 27.0 | 38.2 | 4.59 | 1700 | 7:25 PM | 1/12/2004 |
| 4 | 23.0 | 47.60 | 31.0 | 44.0 | 4.65 | 2789 | 1:34 PM | 1/13/2004 |
| 5 | 22.5 | 47.25 | 40.0 | 57.1 | 4.77 | 4255 | 2:00 PM | 1/14/2004 |

Psychrometer 2:

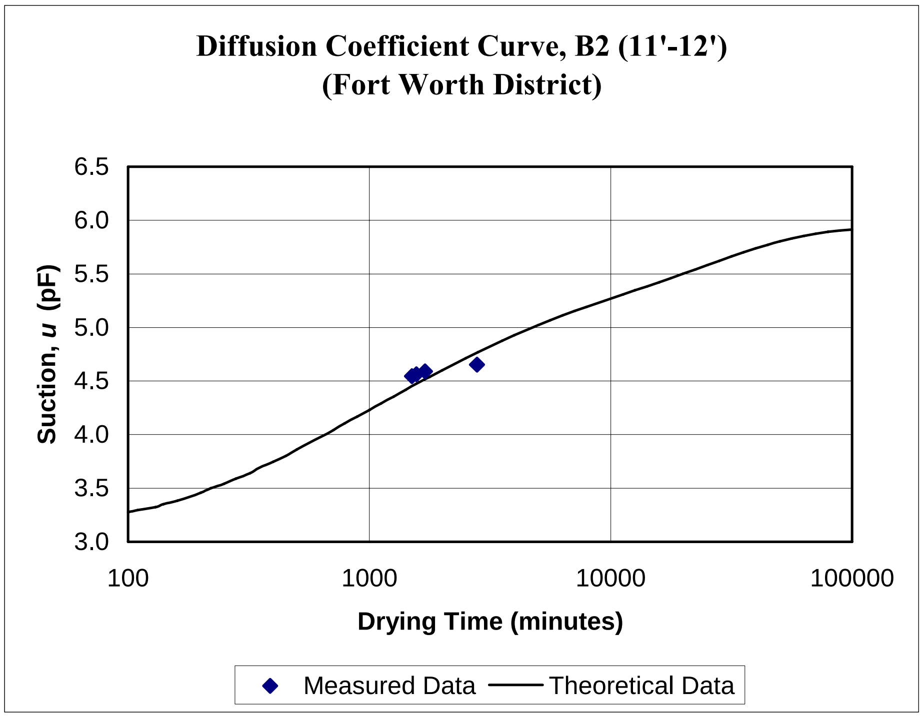
No.: 40362, $\pi_{v0}$ = 50 @ 25ºC

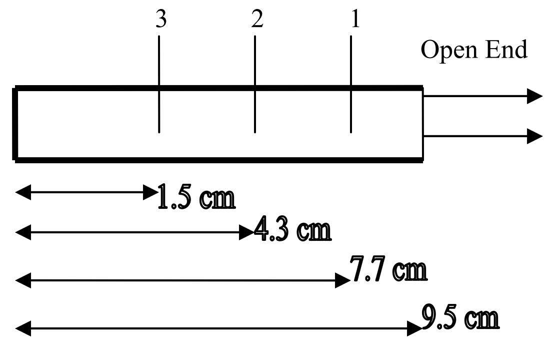
Setup Time & Date: 3:05 PM, 01/11/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 47.90 | 7.0 | 10.3 | 4.02 | 1509 | 4:14 PM | 1/12/2004 |
| 2 | 23.0 | 48.60 | 11.0 | 16.6 | 4.23 | 2900 | 3:25 PM | 1/13/2004 |
| 3 | 24.5 | 49.65 | 14.5 | 22.1 | 4.35 | 4260 | 2:05 PM | 1/14/2004 |
| 4 | 24.0 | 49.30 | 27.0 | 41.6 | 4.63 | 8666 | 3:31 PM | 1/17/2004 |
| 5 | 24.0 | 49.30 | 33.0 | 50.9 | 4.72 | 10275 | 6:20 PM | 1/18/2004 |
| 6 | 23.5 | 48.95 | 34.0 | 52.5 | 4.73 | 11589 | 4:14 PM | 1/19/2004 |

**Project: Fort Worth District**
**Bore Hole: B2**
**Sample Depth: 11'-12'**

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B3**
**Sample Depth: 0'-1'**

Total Length of the sample, L = 9.5 cm

Distance of psychrometer 2 from closed end, x = 7.7 cm

Initial Suction, $u_0$ = 4.2 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 6.20E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40324, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 4:30 PM, 11/17/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 24.5 | 52.65 | 13.5 | 17.1 | 4.24 | 1472 | 5:02:00 PM | 11/18/2003 |
| 2 | 23.5 | 51.95 | 0.0 | | | | 4:38:00 AM | 11/19/2003 |

Psychrometer 2:

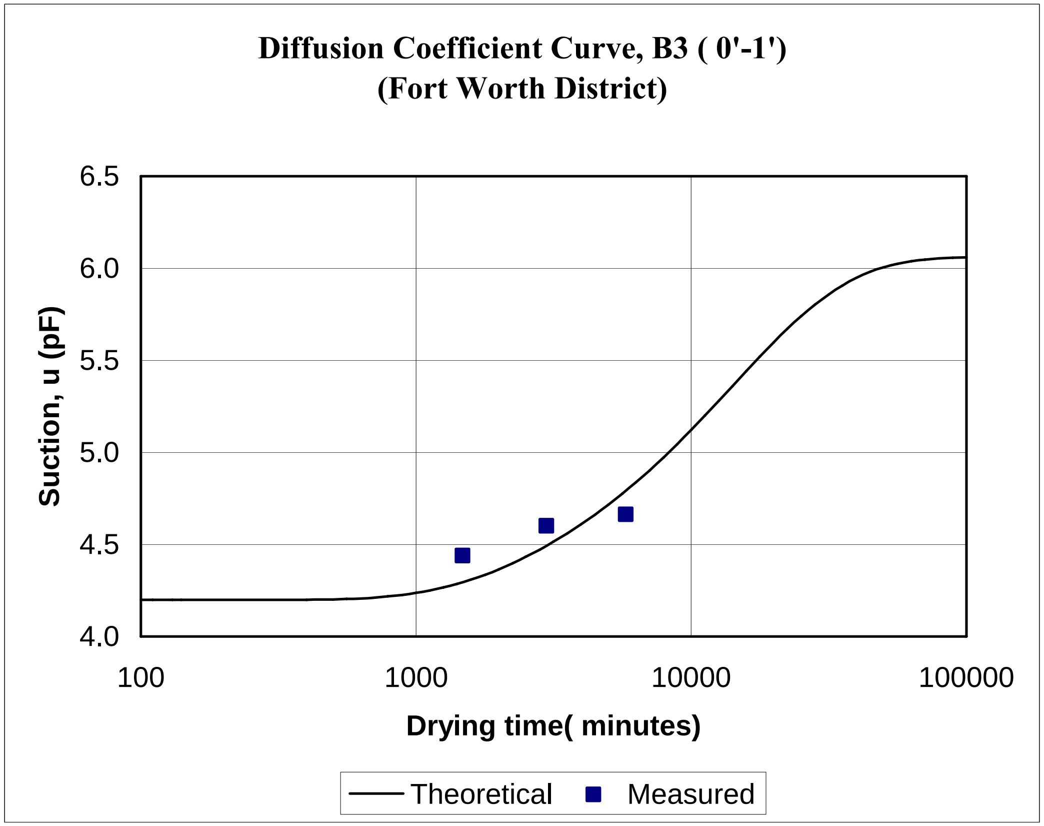
No.: 40316, $\pi_{v0}$ = 58 @ 25ºC

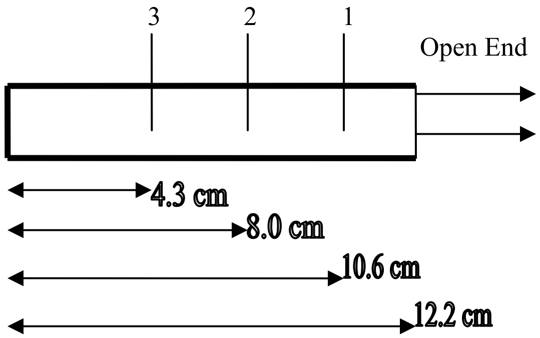
Setup Time & Date: 4:30 PM, 11/17/03

**Project: Fort Worth District**
**Bore Hole: B3**
**Sample Depth: 0'-1'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 24.5 | 57.65 | 20.5 | 27.0 | 4.44 | 1474 | 5:04 PM | 11/20/2003 |
| 2 | 24.5 | 57.65 | 28.5 | 39.2 | 4.60 | 2974 | 4:40 PM | 11/22/2003 |
| 3 | 24.5 | 57.65 | 32.5 | 45.2 | 4.66 | 5783 | 3:29 PM | 11/24/2003 |

Diffusion Coefficient Curve for Psychrometer 2:






**Project: Fort Worth District**
**Bore Hole: B4**
**Sample Depth: 1'-2'**

Total Length of the sample, L = 12.2 cm

Distance of psychrometer 2 from closed end, x = 10.6 cm

Initial Suction, $u_0$ = 3.59 pF

Relative Humidity = 39.2%

Atmospheric Suction, $u_a$ = 6.11 pF

Diffusion Coefficient, α = 8.40E$^{-5}$ cm$^2$/sec

Psychrometer 1:

No.: 40322, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 5:35 PM, 01/21/04

| **No.** | **T** | **$\pi_v$** | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 47.20 | 6.0 | 8.5 | 3.94 | 265 | 10:00 PM | 1/21/2004 |
| 2 | 22.0 | 47.90 | 24.5 | 36.4 | 4.57 | 1331 | 3:46 PM | 1/22/2004 |
| 3 | 22.0 | 47.90 | 27.0 | 40.2 | 4.61 | 1455 | 5:50 PM | 1/22/2004 |
| 4 | 23.0 | 48.60 | 32.0 | 47.7 | 4.69 | 1768 | 11:03 PM | 1/22/2004 |

Psychrometer 2:

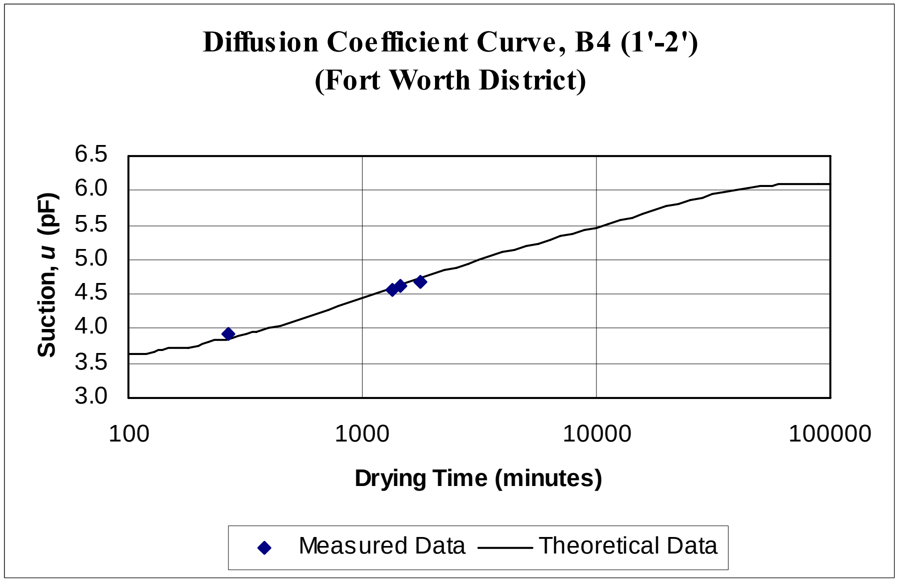
No.: 43447, $\pi_{v0}$ = 58 @ 25ºC

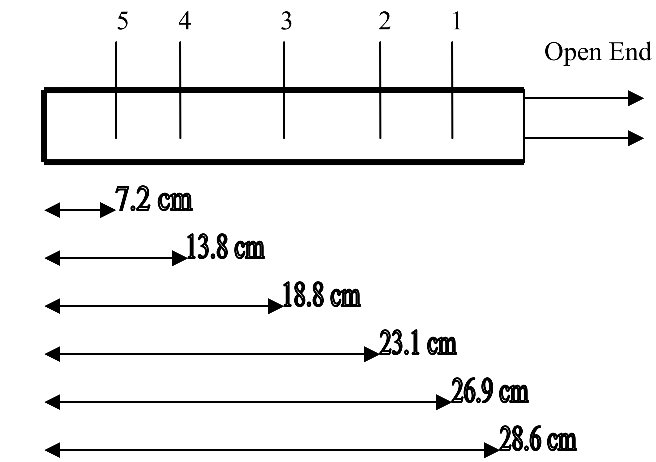
Setup Time & Date: 5:35 PM, 01/21/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 56.25 | 5.0 | 4.4 | 3.65 | 1335 | 3:50 PM | 1/22/2004 |
| 2 | 22.5 | 56.25 | 6.5 | 6.6 | 3.83 | 1456 | 5:51 PM | 1/22/2004 |
| 3 | 23.0 | 56.60 | 9.5 | 11.2 | 4.06 | 2802 | 4:17 PM | 1/23/2004 |
| 4 | 24.0 | 57.30 | 13.0 | 16.4 | 4.22 | 4175 | 3:10 PM | 1/24/2004 |
| 5 | 23.5 | 56.95 | 14.0 | 17.9 | 4.26 | 5180 | 7:55 PM | 1/24/2004 |
| 6 | 23.5 | 56.95 | 18.5 | 24.7 | 4.40 | 6529 | 6:24 PM | 1/25/2004 |
| 7 | 24.0 | 57.30 | 19.0 | 25.5 | 4.41 | 6661 | 8:36 PM | 1/25/2004 |
| 8 | 24.0 | 57.30 | 23.5 | 32.3 | 4.52 | 7790 | 3:25 PM | 1/26/2004 |
| 9 | 23.5 | 56.95 | 30.0 | 42.1 | 4.63 | 9327 | 5:02 PM | 1/27/2004 |
| 10 | 23.5 | 56.95 | 38.0 | 54.1 | 4.74 | 10733 | 4:28 PM | 1/28/2004 |

**Project: Fort Worth District**
**Bore Hole: B4**
**Sample Depth: 1'-2'**

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B4**
**Sample Depth: 13'-14'**

Total Length of the sample, L = 28.6 cm

Distance of psychrometer 2 from closed end, x = 26.9 cm

Initial Suction, $u_0$ = 3.56 pF

Relative Humidity = 54.6%

Atmospheric Suction, $u_a$ = 5.92 pF

Diffusion Coefficient, $\alpha = 1.08E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 43311, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 4:25 PM, 09/10/03

**Project: Fort Worth District**
**Bore Hole: B4**
**Sample Depth: 13'-14'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 50.25 | 5.5 | 6.0 | 3.79 | 1010 | 9:35 AM | 9/11/03 |
| 2 | 23.0 | 50.60 | 6.0 | 6.7 | 3.83 | 1490 | 5:35 PM | 9/11/03 |
| 3 | 22.5 | 50.25 | 6.5 | 7.4 | 3.88 | 2465 | 9:50 AM | 9/12/03 |
| 4 | 22.5 | 50.25 | 7.5 | 8.8 | 3.96 | 2895 | 5:00 PM | 9/12/03 |
| 5 | 22.5 | 50.25 | 8.0 | 9.6 | 3.99 | 4270 | 3:55 PM | 9/13/03 |
| 6 | 22.0 | 49.90 | 10.5 | 13.1 | 4.13 | 5515 | 12:40 PM | 9/14/03 |
| 7 | 22.0 | 49.90 | 12.0 | 15.3 | 4.19 | 6766 | 9:31 AM | 9/15/03 |
| 8 | 22.0 | 49.90 | 13.0 | 16.7 | 4.23 | 7238 | 5:23 PM | 9/15/03 |
| 9 | 22.5 | 50.25 | 15.5 | 20.3 | 4.32 | 8539 | 3:04 PM | 9/16/03 |
| 10 | 23.0 | 50.60 | 15.0 | 19.6 | 4.30 | 8713 | 5:58 PM | 9/16/03 |
| 11 | 22.3 | 50.08 | 18.0 | 23.9 | 4.39 | 9625 | 9:10 AM | 9/17/03 |
| 12 | 22.5 | 50.25 | 21.0 | 28.2 | 4.46 | 11195 | 11:20 AM | 9/18/03 |
| 13 | 23.0 | 50.60 | 21.0 | 28.2 | 4.46 | 11430 | 3:15 PM | 9/18/03 |

Psychrometer 2:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

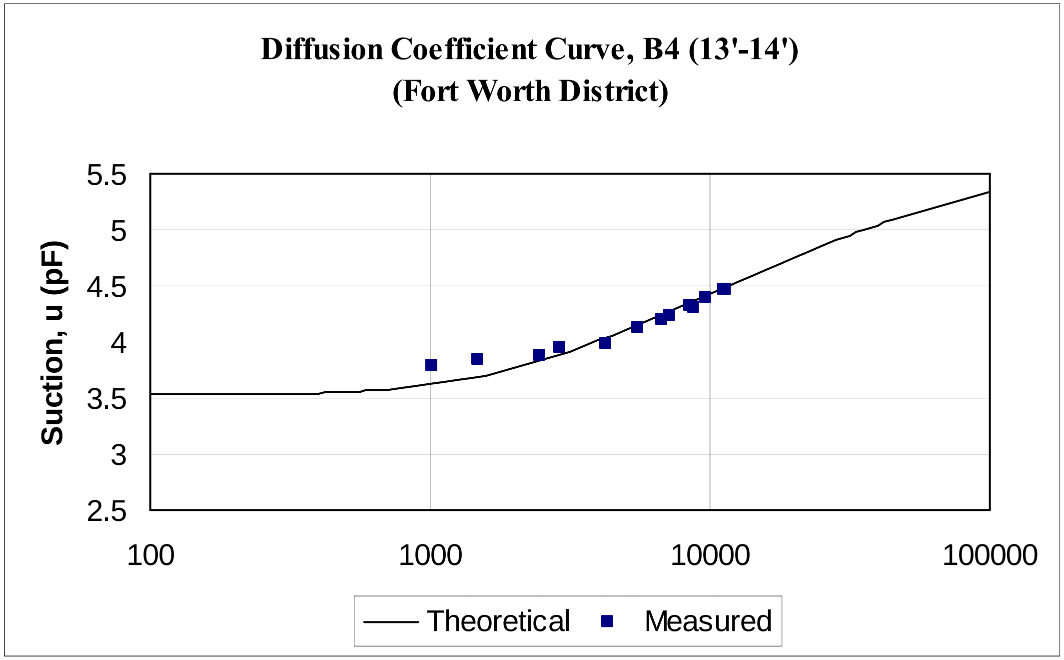
Setup Time & Date: 4:25 PM, 09/10/03

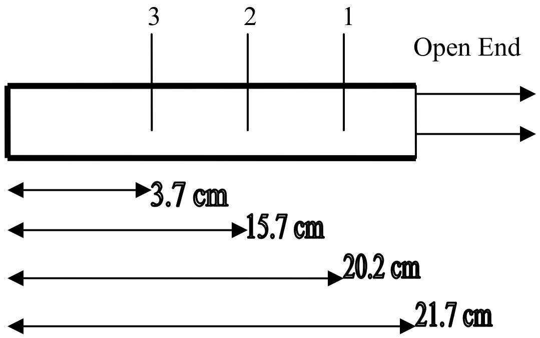
**Project: Fort Worth District**
**Bore Hole: B4**
**Sample Depth: 13'-14'**

| **No.** | **T** | **$\pi_v$** | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 50.25 | 5.0 | 4.9 | 3.7 | 1015 | 9:40 AM | 9/11/03 |
| 2 | 23.0 | 50.60 | 5.0 | 4.9 | 3.7 | 1495 | 5:40 PM | 9/11/03 |
| 3 | 22.5 | 50.25 | 5.5 | 5.7 | 3.8 | 2468 | 9:53 AM | 9/12/03 |
| 4 | 22.5 | 50.25 | 5.5 | 5.7 | 3.8 | 2895 | 5:00 PM | 9/12/03 |
| 5 | 23.0 | 50.60 | 7.0 | 7.9 | 3.9 | 4273 | 3:58 PM | 9/13/03 |
| 6 | 22.5 | 50.25 | 7.0 | 7.9 | 3.9 | 5517 | 12:42 PM | 9/14/03 |
| 7 | 22.0 | 49.90 | 8.0 | 9.4 | 4.0 | 6770 | 9:35 AM | 9/15/03 |
| 8 | 22.0 | 49.90 | 8.5 | 10.2 | 4.0 | 7251 | 5:36 PM | 9/15/03 |
| 9 | 22.5 | 50.25 | 9.5 | 11.7 | 4.1 | 8542 | 3:07 PM | 9/16/03 |
| 10 | 23.0 | 50.60 | 10.0 | 12.4 | 4.1 | 8715 | 6:00 PM | 9/16/03 |
| 11 | 22.5 | 50.25 | 10.0 | 12.4 | 4.1 | 9629 | 9:14 AM | 9/17/03 |
| 12 | 22.5 | 50.25 | 11.0 | 13.9 | 4.2 | 11199 | 11:24 AM | 9/18/03 |
| 13 | 23.0 | 50.60 | 11.0 | 13.9 | 4.2 | 11436 | 3:21 AM | 9/18/03 |

**Project: Fort Worth District**
**Bore Hole: B4**
**Sample Depth: 13'-14'**

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B5**
**Sample Depth: 6'-7'**

Total Length of the sample, L = 21.7 cm

Distance of psychrometer 2 from closed end, x = 20.2 cm

Initial Suction, $u_0$ = 2.67 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 13.7E^{-5}\ cm^2/sec$

Psychrometer 1:

No.: 40305, $\pi_{v0}$ = 60 @ 25ºC

Setup Time & Date: 4:10 PM, 11/18/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 58.60 | 20.0 | 27.2 | 4.44 | 1475 | 4:45 PM | 11/19/03 |
| 2 | 22.5 | 58.25 | 44.0 | 61.0 | 4.79 | 2770 | 2:20 PM | 11/20/03 |

Psychrometer 2:

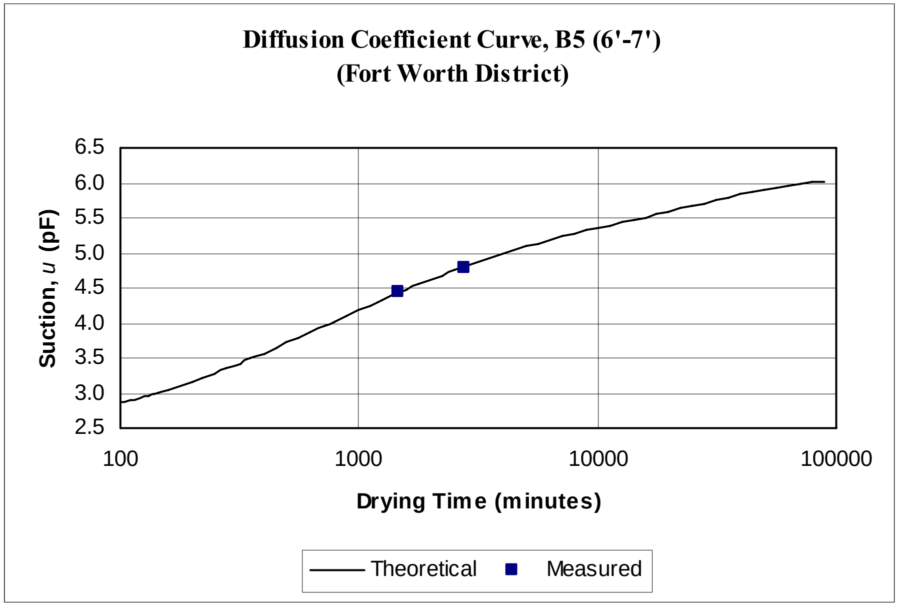
No.: 40330, $\pi_{v0}$ = 51 @ 25ºC

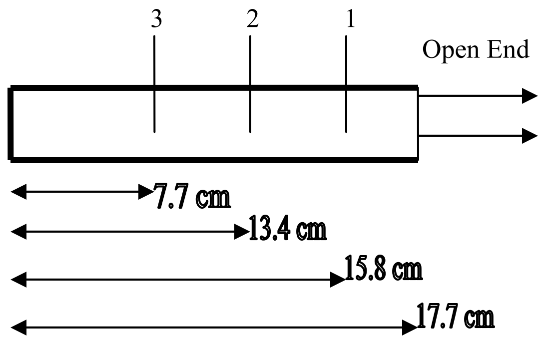
Setup Time & Date: 4:10 PM, 11/18/03

**Project: Fort Worth District**
**Bore Hole: B5**
**Sample Depth: 6'-7'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 49.25 | 7.5 | 10.0 | 4.01 | 1480 | 4:50 PM | 11/19/03 |
| 2 | 23.0 | 49.60 | 12.0 | 16.7 | 4.23 | 2772 | 2:22 PM | 11/20/03 |
| 3 | 24.0 | 50.30 | 17.5 | 24.9 | 4.40 | 5775 | 4:25 PM | 11/22/03 |
| 4 | 24.0 | 50.30 | 23.5 | 33.8 | 4.54 | 8575 | 3:05 PM | 11/24/03 |
| 5 | 24.0 | 50.30 | 26.0 | 37.6 | 4.58 | 12955 | 4:05 PM | 11/27/03 |
| 6 | 24.0 | 50.30 | 30.0 | 43.5 | 4.65 | 14390 | 4:10 PM | 11/28/03 |
| 7 | 24.0 | 50.30 | 34.0 | 49.5 | 4.70 | 15955 | 6:15 PM | 11/29/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: B5**
**Sample Depth: 11'-12'**

Total Length of the sample, L = 17.7 cm

Distance of psychrometer 2 from closed end, x = 15.8 cm

Initial Suction, $u_0$ = 3.49 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 7.61E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40362, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 3:00 PM, 11/19/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 48.25 | 26.5 | 40.8 | 4.62 | 1409 | 2:29:00 PM | 11/20/2003 |

Psychrometer 2:

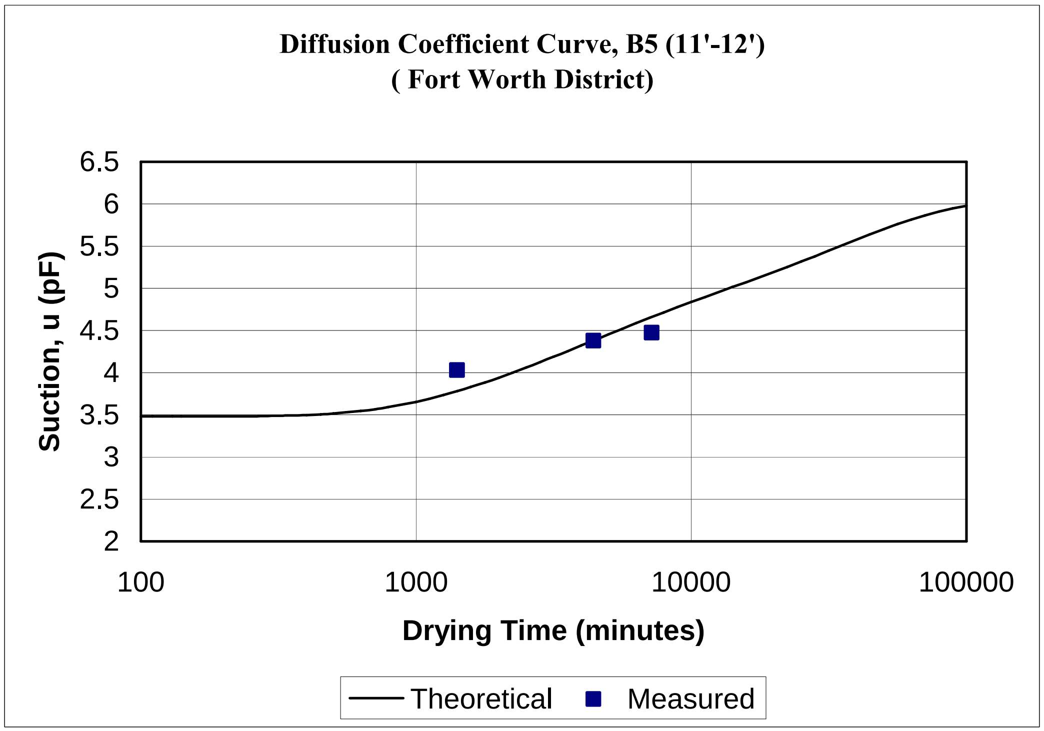
No.: 40348, $\pi_{v0} = 51$ @ 25ºC

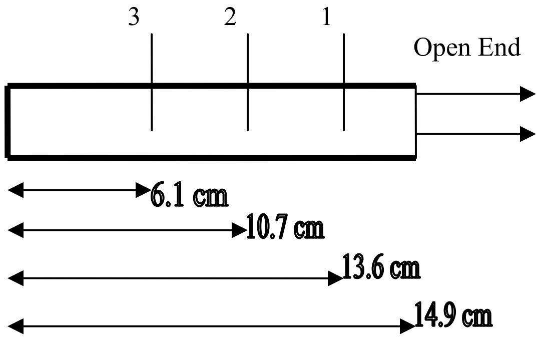
Setup Time & Date: 3:00 PM, 11/19/03

**Project: Fort Worth District**
**Bore Hole: B5**
**Sample Depth: 11'-12'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 49.60 | 8.0 | 10.5 | 4.03 | 1412 | 2:32 PM | 11/20/2003 |
| 2 | 24.0 | 50.30 | 17.0 | 23.4 | 4.38 | 4412 | 4:31 PM | 11/22/2003 |
| 3 | 23.5 | 49.95 | 21.0 | 29.1 | 4.47 | 7196 | 2:55 PM | 11/24/2003 |

Diffusion Coefficient Curve for Psychrometer 2:






**Project: Fort Worth District**
**Bore Hole: C1**
**Sample Depth: 2'-3'**

Total Length of the sample, L = 14.9 cm

Distance of psychrometer 2 from closed end, x = 13.6 cm

Initial Suction, $u_0$ = 3.28 pF

Relative Humidity = 30%

Atmospheric Suction, $u_a$ = 6.22 pF

Diffusion Coefficient, $\alpha = 3.73E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40324, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 8:05 PM, 12/30/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 47.90 | 22.0 | 29.7 | 4.48 | 1305 | 5:50 PM | 12/31/03 |
| 2 | 23.0 | 48.60 | 28.0 | 38.6 | 4.60 | 2733 | 5:38 PM | 01/01/04 |
| 3 | 23.5 | 48.95 | 35.0 | 49.0 | 4.70 | 4213 | 6:08 PM | 01/02/04 |
| 4 | 23.5 | 48.95 | 38.0 | 53.5 | 4.74 | 5665 | 6:20 PM | 01/03/04 |
| 5 | 23.5 | 48.95 | 41.0 | 57.9 | 4.77 | 7122 | 6:37 PM | 01/04/04 |

Psychrometer 2:

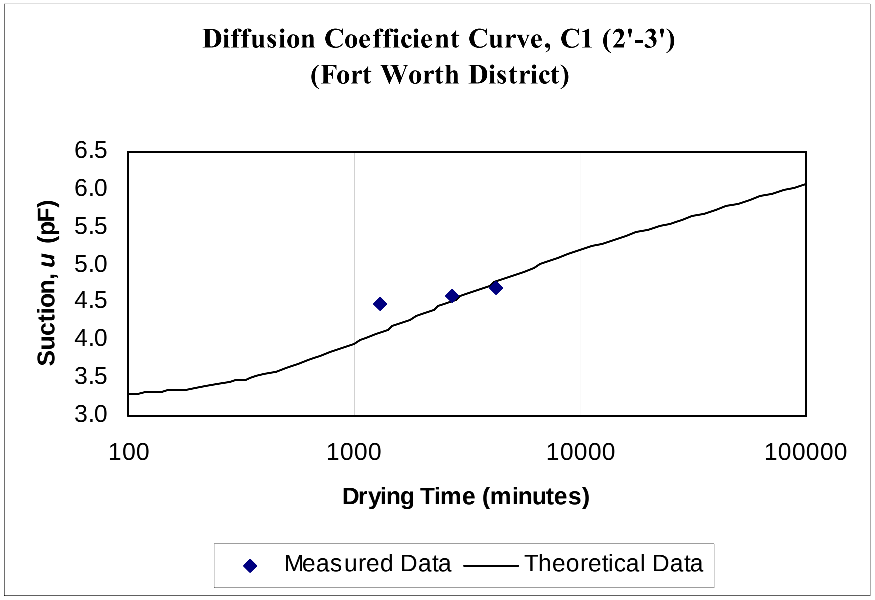
No.: 40312, $\pi_{v0}$ = 56 @ 25ºC

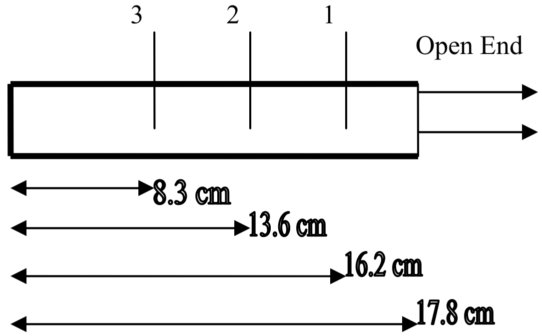
Setup Time & Date: 8:05 PM, 12/30/03

**Project: Fort Worth District**
**Bore Hole: C1**
**Sample Depth: 2'-3'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 54.60 | 11.5 | 13.4 | 4.14 | 1306 | 5:51 PM | 12/31/03 |
| 2 | 24.0 | 55.30 | 14.5 | 17.9 | 4.26 | 2735 | 5:40 PM | 01/01/04 |
| 3 | 24.0 | 55.30 | 17.5 | 22.4 | 4.36 | 4215 | 6:10 PM | 01/02/04 |
| 4 | 24.0 | 55.30 | 20.0 | 26.2 | 4.43 | 5669 | 6:24 PM | 01/03/04 |
| 5 | 24.0 | 55.30 | 23.5 | 31.4 | 4.51 | 7125 | 6:40 PM | 01/04/04 |
| 6 | 23.5 | 54.95 | 27.0 | 36.6 | 4.57 | 8543 | 6:18 PM | 01/05/04 |
| 7 | 23.0 | 54.60 | 34.0 | 47.1 | 4.68 | 9987 | 6:22 PM | 01/06/04 |
| 8 | 24.0 | 55.30 | 35.0 | 48.6 | 4.70 | 11267 | 3:42 PM | 01/07/04 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C1**
**Sample Depth: 6'-7'**

Total Length of the sample, L = 17.8 cm

Distance of psychrometer 2 from closed end, x = 16.2 cm

Initial Suction, $u_0$ = 3.76 pF

Relative Humidity = 30%

Atmospheric Suction, $u_a$ = 6.22 pF

Diffusion Coefficient, $\alpha = 3.06E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 7:00 PM, 12/30/03

| **No.** | **T** | $\pi_v$ | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 49.90 | 23.5 | 32.6 | 4.52 | 1380 | 6:00 PM | 12/31/2003 |
| 2 | 22.0 | 49.90 | 30.0 | 42.3 | 4.64 | 2790 | 5:30 PM | 1/1/2004 |
| 3 | 23.0 | 50.60 | 32.0 | 45.3 | 4.66 | 4275 | 6:15 PM | 1/2/2004 |
| 4 | 22.5 | 50.25 | 43.0 | 61.8 | 4.80 | 5715 | 6:15 PM | 1/3/2004 |

Psychrometer 2:

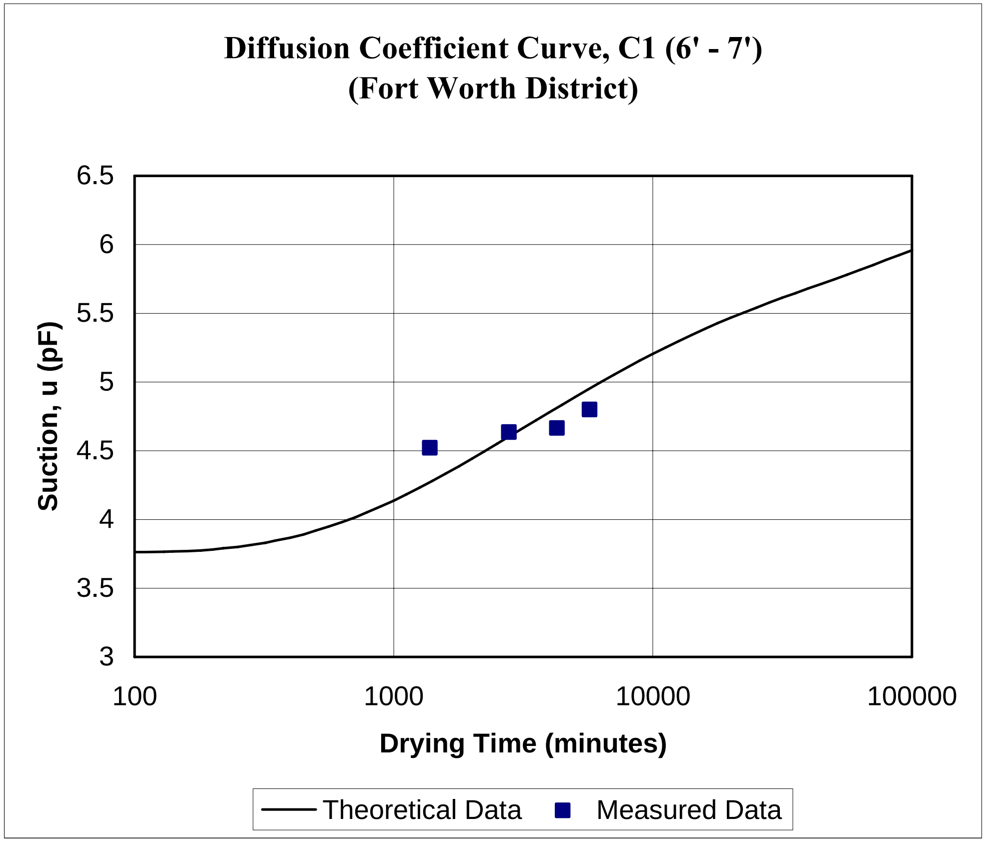
No.: 43448, $\pi_{v0}$ = 54 @ 25ºC

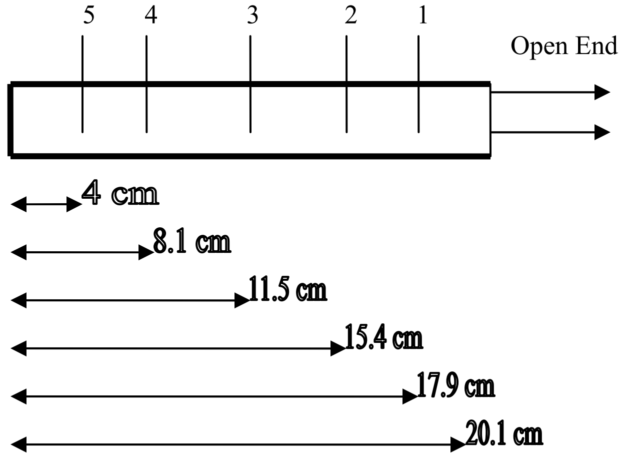
Setup Time & Date: 7:00 PM, 12/30/03

**Project: Fort Worth District**
**Bore Hole: C1**
**Sample Depth: 6'-7'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 52.25 | 7.5 | 8.2 | 3.92 | 1383 | 6:03 PM | 12/31/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C2**
**Sample Depth: 4'-5'**

Total Length of the sample, L = 20.1 cm

Distance of psychrometer 2 from closed end, x = 17.9 cm

Initial Suction, $u_0$ = 3.74 pF

Relative Humidity = 56%

Atmospheric Suction, $u_a$ = 5.91 pF

Diffusion Coefficient, $\alpha = 1.53E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 2:30 PM, 10/08/03

| **No.** | **T** | $\pi_v$ | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 49.90 | 7.0 | 7.9 | 3.91 | 1435 | 2:25 PM | 10/9/03 |
| 2 | 22.0 | 49.90 | 8.5 | 10.2 | 4.02 | 2965 | 3:55 PM | 10/10/03 |
| 3 | 22.0 | 49.90 | 19.0 | 25.9 | 4.42 | 7192 | 2:22 PM | 10/13/03 |
| 4 | 22.0 | 49.90 | 21.5 | 29.6 | 4.48 | 8443 | 11:13 AM | 10/14/03 |
| 5 | 22.0 | 49.90 | 23.0 | 31.9 | 4.51 | 8724 | 3:54 PM | 10/14/03 |
| 6 | 21.5 | 49.55 | 28.0 | 39.3 | 4.60 | 9823 | 10:15 AM | 10/15/03 |
| 7 | 22.0 | 49.90 | 33.0 | 46.8 | 4.68 | 10868 | 3:40 PM | 10/16/03 |
| 8 | 22.5 | 50.25 | 37.0 | 52.8 | 4.73 | 11952 | 9:44 AM | 10/17/03 |

Psychrometer 2:

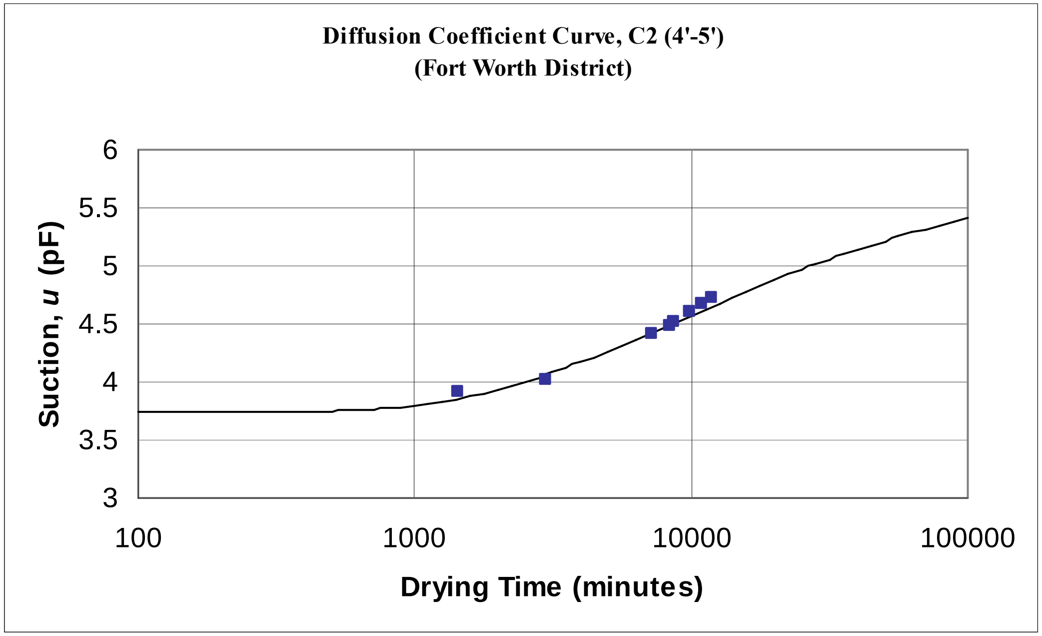
No.: 43447, $\pi_{v0}$ = 58 @ 25ºC

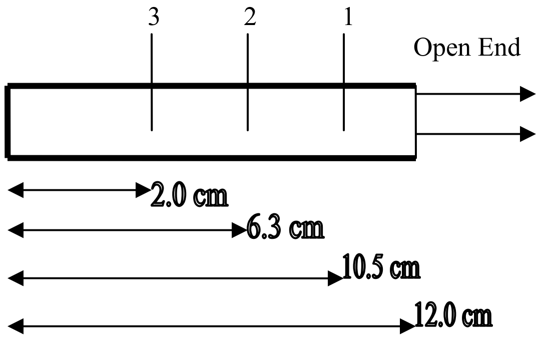
Setup Time & Date: 2:30 PM, 10/08/03

**Project: Fort Worth District**
**Bore Hole: C2**
**Sample Depth: 4'-5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 56.25 | 6.0 | 5.9 | 3.78 | 1439 | 2:29 PM | 10/9/03 |
| 2 | 22.0 | 55.90 | 7.0 | 7.4 | 3.88 | 2966 | 3:56 PM | 10/10/03 |
| 3 | 22.5 | 56.25 | 9.5 | 11.2 | 4.06 | 7195 | 2:25 PM | 10/13/03 |
| 4 | 22.0 | 55.90 | 10.8 | 13.0 | 4.12 | 8445 | 11:15 AM | 10/14/03 |
| 5 | 22.0 | 55.90 | 11.5 | 14.2 | 4.16 | 8725 | 3:55 PM | 10/14/03 |
| 6 | 21.5 | 55.55 | 12.5 | 15.7 | 4.20 | 9825 | 10:17 AM | 10/15/03 |
| 7 | 22.0 | 55.90 | 14.5 | 18.7 | 4.28 | 10874 | 3:46 PM | 10/16/03 |
| 8 | 22.5 | 56.25 | 16.0 | 21.0 | 4.33 | 11954 | 9:46 AM | 10/17/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C2**
**Sample Depth: 5’-6’**

Total Length of the sample, L = 12.0 cm

Distance of psychrometer 2 from closed end, x = 10.5 cm

Initial Suction, $u_0$ = 3.57 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 6.10E^{-5}\ cm^2/sec$

Psychrometer 1:

No.: 40307, $\pi_{v0}$ = 56 @ 25ºC

Setup Time & Date: 4:00 PM, 12/02/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 53.90 | 20.5 | 26.3 | 4.43 | 1397 | 3:17 PM | 12/3/03 |
| 2 | 22.0 | 53.90 | 44.0 | 61.4 | 4.80 | 2809 | 2:49 PM | 12/4/03 |

Psychrometer 2:

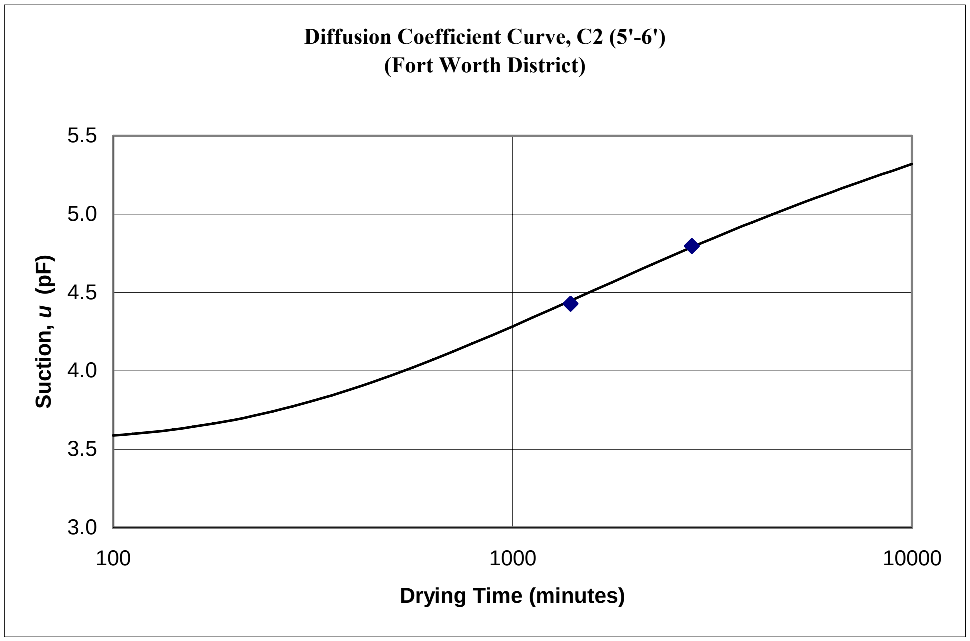
No.: 40293, $\pi_{v0}$ = 57 @ 25ºC

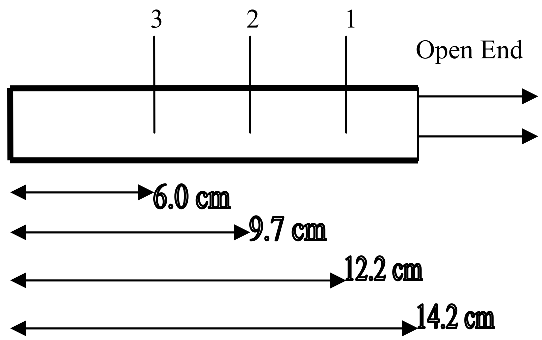
Setup Time & Date: 4:00 PM, 12/02/03

**Project: Fort Worth District**
**Bore Hole: C2**
**Sample Depth: 5’-6’**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 55.60 | 7.0 | 7.9 | 3.91 | 1405 | 3:25 PM | 12/3/03 |
| 2 | 22.0 | 54.90 | 10.5 | 12.9 | 4.12 | 2806 | 2:46 PM | 12/4/03 |
| 3 | 22.0 | 54.90 | 13.5 | 17.1 | 4.24 | 4300 | 3:40 PM | 12/5/03 |
| 4 | 22.0 | 54.90 | 20.0 | 26.3 | 4.43 | 5950 | 7:10 PM | 12/6/03 |
| 5 | 23.0 | 55.60 | 23.5 | 31.3 | 4.50 | 7380 | 7:00 PM | 12/7/03 |
| 6 | 23.0 | 55.60 | 27.0 | 36.2 | 4.57 | 8385 | 11:45 AM | 12/8/03 |
| 7 | 23.0 | 55.60 | 29.5 | 39.8 | 4.61 | 10220 | 6:20 PM | 12/9/03 |
| 8 | 23.0 | 55.60 | 35.0 | 47.6 | 4.69 | 11350 | 1:10 PM | 12/10/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C3**
**Sample Depth: 6'-7'**

Total Length of the sample, L = 14.2 cm

Distance of psychrometer 2 from closed end, x = 12.2 cm

Initial Suction, $u_0$ = 4.03 pF

Relative Humidity = 39.2%

Atmospheric Suction, $u_a$ = 6.11 pF

Diffusion Coefficient, $\alpha = 9.20E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40321, $\pi_{v0}$ = 51 @ 25ºC

Setup Time & Date: 6:02 PM, 01/22/04

| **No.** | **T** | $\pi_v$ | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 48.90 | 15.0 | 21.1 | 4.33 | 298 | 11:00 PM | 1/22/04 |
| 2 | 23.0 | 49.60 | 33.0 | 47.5 | 4.69 | 1308 | 3:50 PM | 1/23/04 |

Psychrometer 2:

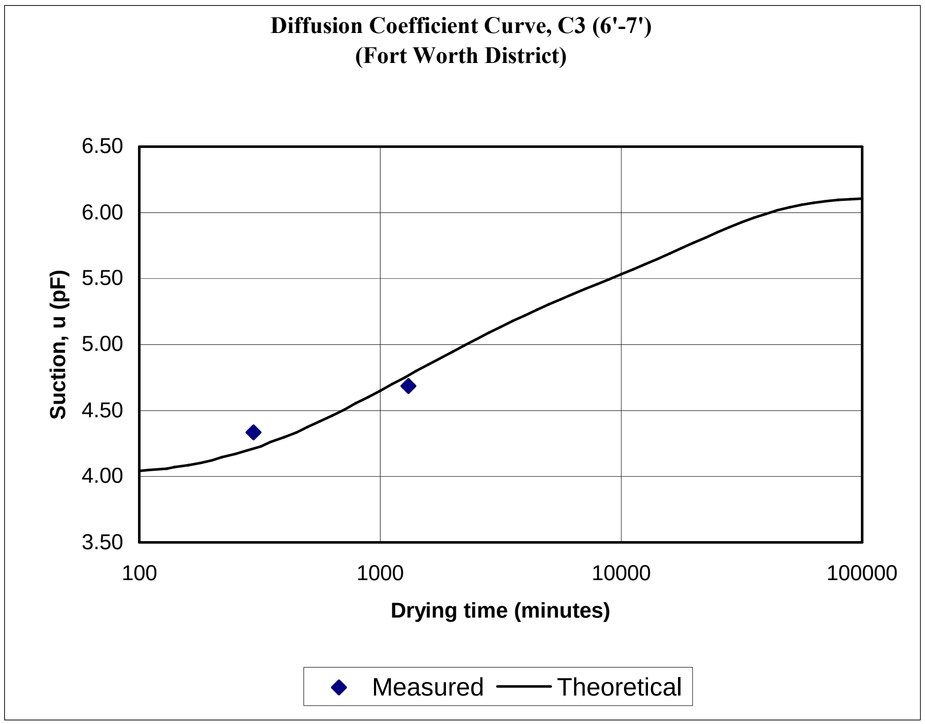
No.: 40320, $\pi_{v0}$ = 48 @ 25ºC

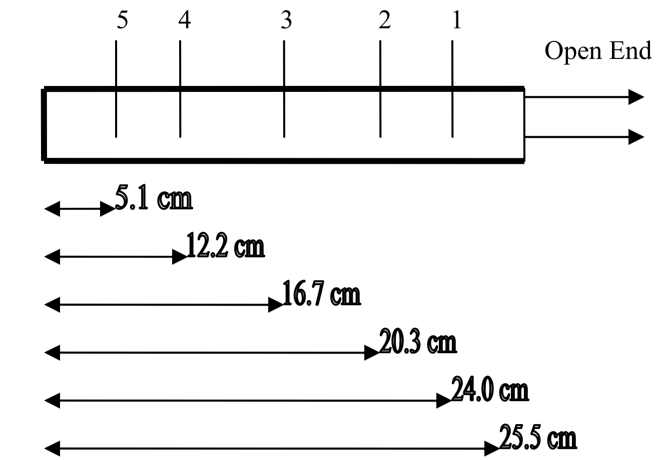
Setup Time & Date: 6:02 PM, 01/22/04

**Project: Fort Worth District**
**Bore Hole: C3**
**Sample Depth: 6'-7'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 46.60 | 9.0 | 10.4 | 4.03 | 1371 | 3:53 PM | 1/23/04 |
| 2 | 24.0 | 47.30 | 18.0 | 23.8 | 4.39 | 2756 | 2:58 PM | 1/24/04 |
| 3 | 24.0 | 47.30 | 20.0 | 26.8 | 4.44 | 3066 | 8:08 PM | 1/24/04 |
| 4 | 23.5 | 46.95 | 24.5 | 33.5 | 4.53 | 4394 | 6:41 PM | 1/25/04 |
| 5 | 24.5 | 47.65 | 25.0 | 34.3 | 4.54 | 4518 | 8:45 PM | 1/25/04 |
| 6 | 24.5 | 47.65 | 29.0 | 40.2 | 4.61 | 5671 | 3:58 PM | 1/26/04 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C3**
**Sample Depth: 9’-10’**

Total Length of the sample, L = 25.5 cm

Distance of psychrometer 2 from closed end, x = 24.0 cm

Initial Suction, $u_0$ = 3.38 pF

Relative Humidity = 54.3%

Atmospheric Suction, $u_a$ = 6.75 pF

Diffusion Coefficient, $\alpha = 0.93E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 43311, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 1:00 PM, 09/19/03

**Project: Fort Worth District**
**Bore Hole: C3**
**Sample Depth: 9'-10'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.5 | 49.55 | 6.5 | 7.4 | 3.88 | 1539 | 2:39 PM | 9/20/03 |
| 2 | 21.5 | 49.55 | 9.0 | 11.0 | 4.05 | 4125 | 9:45 AM | 9/22/03 |
| 3 | 22.0 | 49.90 | 10.0 | 12.4 | 4.10 | 4360 | 3:30 PM | 9/22/03 |
| 4 | 21.5 | 49.55 | 12.0 | 15.3 | 4.19 | 5690 | 1:40 PM | 9/23/03 |
| 5 | 22.0 | 49.90 | 16.0 | 21.0 | 4.33 | 6875 | 10:25 AM | 9/24/03 |
| 6 | 22.0 | 49.90 | 16.5 | 21.7 | 4.35 | 7235 | 4:25 PM | 9/24/03 |
| 7 | 22.0 | 49.90 | 20.5 | 27.5 | 4.45 | 8302 | 10:12 AM | 9/25/03 |
| 8 | 22.0 | 49.90 | 22.0 | 29.6 | 4.48 | 8715 | 5:05 PM | 9/25/03 |
| 9 | 21.5 | 49.55 | 26.5 | 36.0 | 4.57 | 9815 | 11:25 AM | 9/26/03 |
| 10 | 21.0 | 49.20 | 33.5 | 46.1 | 4.67 | 10690 | 2:00 PM | 9/27/03 |
| 11 | 21.0 | 49.20 | 40.0 | 55.4 | 4.75 | 12080 | 2:10 PM | 9/28/03 |

Psychrometer 2:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

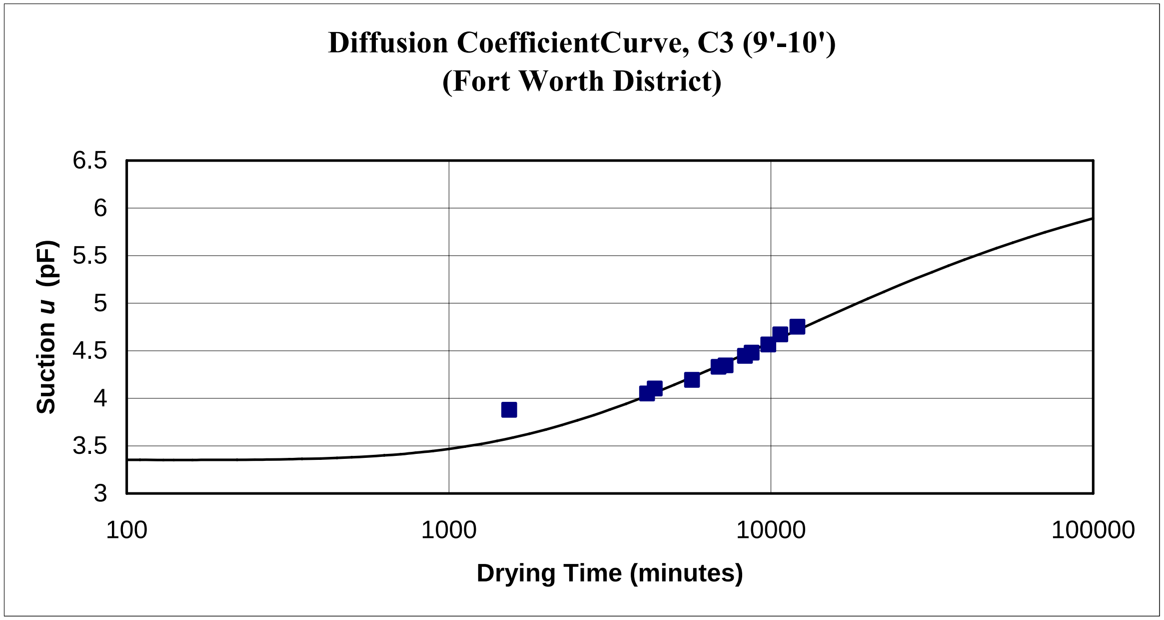
Setup Time & Date: 1:00 PM, 09/19/03

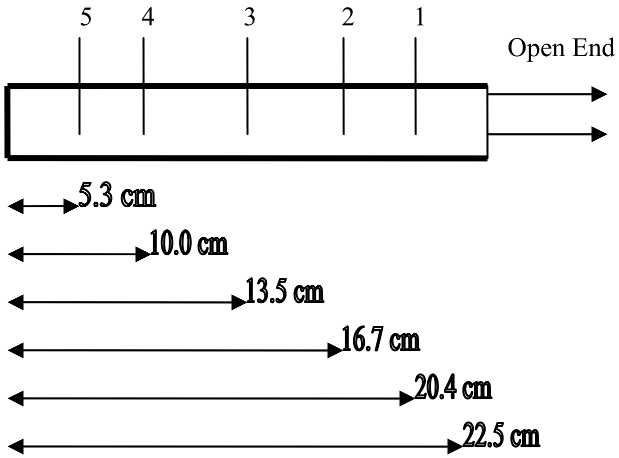
**Project: Fort Worth District**
**Bore Hole: C3**
**Sample Depth: 9'-10'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 50.25 | 4.5 | 4.2 | 3.63 | 1541 | 2:41 PM | 9/20/03 |
| 2 | 21.5 | 49.55 | 4.5 | 4.2 | 3.63 | 4128 | 9:48 AM | 9/22/03 |
| 3 | 22.0 | 49.90 | 4.5 | 4.2 | 3.63 | 4363 | 3:33 PM | 9/22/03 |
| 4 | 21.5 | 49.55 | 5.0 | 4.9 | 3.70 | 5694 | 1:44 PM | 9/23/03 |
| 5 | 22.5 | 50.25 | 6.3 | 6.8 | 3.84 | 6878 | 10:28 AM | 9/24/03 |
| 6 | 22.5 | 50.25 | 6.0 | 6.4 | 3.82 | 7236 | 4:26 PM | 9/24/03 |
| 7 | 22.5 | 50.25 | 7.0 | 7.9 | 3.91 | 8304 | 10:14 AM | 9/25/03 |
| 8 | 22.5 | 50.25 | 7.5 | 8.7 | 3.95 | 8717 | 5:07 PM | 9/25/03 |
| 9 | 21.5 | 49.55 | 8.0 | 9.4 | 3.98 | 9816 | 11:26 AM | 9/26/03 |
| 10 | 21.5 | 49.55 | 9.0 | 10.9 | 4.05 | 10691 | 2:01 PM | 9/27/03 |
| 11 | 21.5 | 49.55 | 10.0 | 12.4 | 4.10 | 10705 | 2:15 PM | 9/28/03 |
| 12 | 22.0 | 49.90 | 12.0 | 15.4 | 4.20 | 12167 | 2:37 PM | 9/29/03 |

Diffusion Coefficient Curve for Psychrometer 1:

**Project: Fort Worth District**
**Bore Hole: C3**
**Sample Depth: 9'-10'**






**Project: Fort Worth District**
**Bore Hole: C4**
**Sample Depth: 5'-6'**

Total Length of the sample, L = 22.5 cm

Distance of psychrometer 2 from closed end, x = 20.4 cm

Initial Suction, $u_0$ = 3.38 pF

Relative Humidity = 54.3%

Atmospheric Suction, $u_a$ = 5.93 pF

Diffusion Coefficient, $\alpha = 1.93E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40293, $\pi_{v0}$ = 57 @ 25ºC

Setup Time & Date: 1:00 PM, 09/19/03

**Project: Fort Worth District**
**Bore Hole: C4**
**Sample Depth: 5'-6'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 55.25 | 7.5 | 8.6 | 3.94 | 1555 | 2:55 PM | 09/20/03 |
| 2 | 22.0 | 54.90 | 8.5 | 10.1 | 4.01 | 2700 | 10:00 AM | 09/22/03 |
| 3 | 22.0 | 54.90 | 10.0 | 12.2 | 4.09 | 2986 | 3:46 PM | 09/22/03 |
| 4 | 21.5 | 54.55 | 10.5 | 12.9 | 4.12 | 4407 | 1:55 PM | 09/23/03 |
| 5 | 22.0 | 54.90 | 12.0 | 15.0 | 4.18 | 5645 | 10:38 AM | 09/24/03 |
| 6 | 22.5 | 55.25 | 13.0 | 16.4 | 4.22 | 5944 | 4:39 PM | 09/24/03 |
| 7 | 22.5 | 55.25 | 14.0 | 17.8 | 4.26 | 7006 | 10:21 AM | 09/25/03 |
| 8 | 22.5 | 55.25 | 15.0 | 19.3 | 4.29 | 7425 | 5:20 PM | 09/25/03 |
| 9 | 21.5 | 54.55 | 17.5 | 22.8 | 4.36 | 8523 | 11:38 AM | 09/26/03 |
| 10 | 21.5 | 54.55 | 21.0 | 27.8 | 4.45 | 10115 | 2:10 PM | 09/27/03 |
| 11 | 21.5 | 54.55 | 25.0 | 33.4 | 4.53 | 11567 | 2:22 PM | 09/28/03 |
| 12 | 22.0 | 54.90 | 29.0 | 39.1 | 4.60 | 13043 | 2:58 PM | 09/29/03 |

Psychrometer 2:

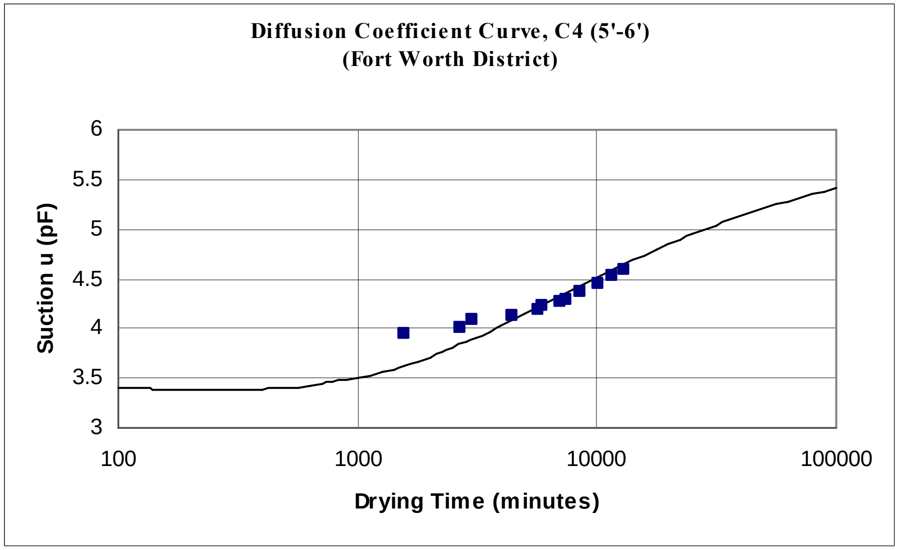
No.: 40320, $\pi_{v0}$ = 48 @ 25ºC

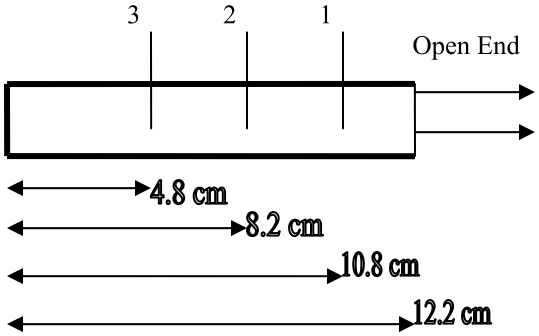
Setup Time & Date: 1:00 PM, 09/19/03

**Project: Fort Worth District**
**Bore Hole: C4**
**Sample Depth: 5'-6'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 46.60 | 5.5 | 5.2 | 3.72 | 1565 | 3:05 PM | 09/20/03 |
| 2 | 22.0 | 45.90 | 6.5 | 6.7 | 3.83 | 2705 | 10:05 AM | 09/22/03 |
| 3 | 22.5 | 46.25 | 7.0 | 7.5 | 3.88 | 2990 | 3:50 PM | 09/22/03 |
| 4 | 21.5 | 45.55 | 8.0 | 8.9 | 3.96 | 4412 | 2:00 PM | 09/23/03 |
| 5 | 22.5 | 46.25 | 9.0 | 10.4 | 4.03 | 5649 | 10:42 AM | 09/24/03 |
| 6 | 22.5 | 46.25 | 9.0 | 10.4 | 4.03 | 5945 | 4:40 PM | 09/24/03 |
| 7 | 22.5 | 46.25 | 10.0 | 11.9 | 4.08 | 7008 | 10:23 AM | 09/25/03 |
| 8 | 22.5 | 46.25 | 10.0 | 11.9 | 4.08 | 7428 | 5:23 AM | 09/25/03 |
| 9 | 21.5 | 45.55 | 12.0 | 14.9 | 4.18 | 8526 | 11:41 AM | 09/26/03 |
| 10 | 21.5 | 45.55 | 13.5 | 17.1 | 4.24 | 10119 | 2:14 PM | 09/27/03 |
| 11 | 21.5 | 45.55 | 15.0 | 19.4 | 4.30 | 11568 | 2:23 PM | 09/28/03 |
| 12 | 22.0 | 45.90 | 17.0 | 22.4 | 4.36 | 13045 | 3:00 PM | 09/29/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C4**
**Sample Depth: 9'-9.5'**

Total Length of the sample, L = 12.2 cm

Distance of psychrometer 2 from closed end, x = 10.8 cm

Initial Suction, $u_0$ = 4.57 pF

Relative Humidity = 30%

Atmospheric Suction, $u_a$ = 6.22 pF

Diffusion Coefficient, $\alpha = 1.93E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40336, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 7:20 PM, 01/06/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.0 | 46.50 | 9.5 | 13.6 | 4.14 | 1614 | 10:14 PM | 1/6/2004 |
| 2 | 21.0 | 47.90 | 26.5 | 39.0 | 4.60 | 2645 | 3:25 PM | 1/7/2004 |

Psychrometer 2:

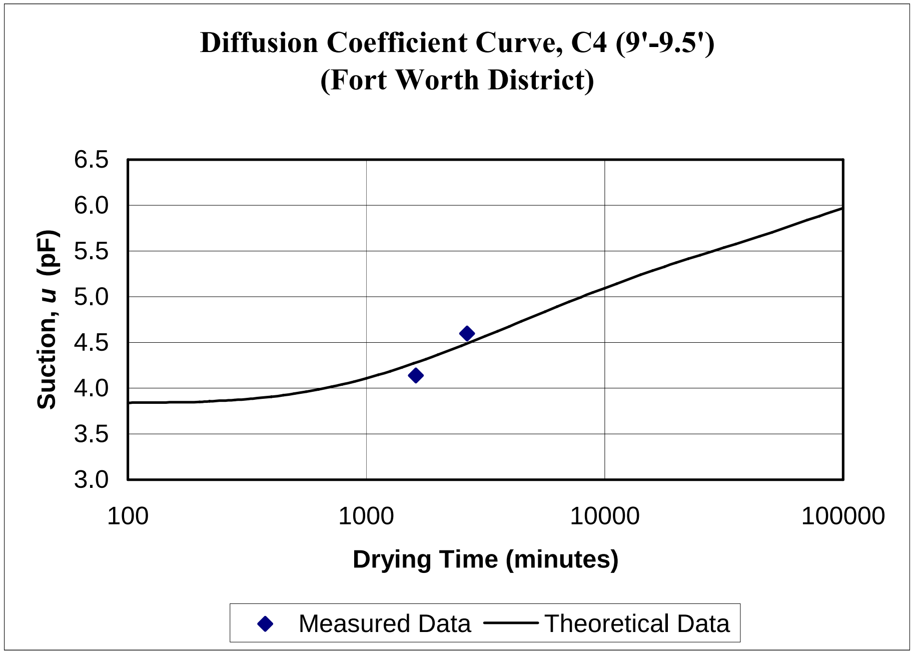
No.: 40338, $\pi_{v0} = 49$ @ 25ºC

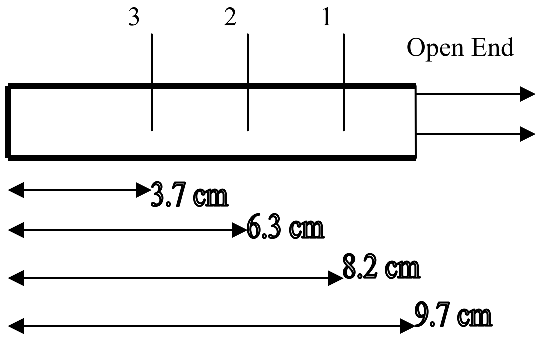
Setup Time & Date: 7:20 PM, 01/06/04

**Project: Fort Worth District**
**Bore Hole: C4**
**Sample Depth: 9'-9.5'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 46.20 | 6.0 | 8.4 | 3.93 | 1615 | 10:15 PM | 1/6/2004 |
| 2 | 21.5 | 46.55 | 8.0 | 11.4 | 4.07 | 2650 | 3:30 PM | 1/7/2004 |
| 3 | 22.5 | 47.25 | 9.0 | 13.0 | 4.12 | 3915 | 12:35 PM | 1/8/2004 |
| 4 | 22.5 | 47.25 | 19.0 | 28.1 | 4.46 | 5588 | 4:28 PM | 1/9/2004 |
| 5 | 22.5 | 47.25 | 24.0 | 35.7 | 4.56 | 6995 | 3:55 PM | 1/10/2004 |
| 6 | 23.0 | 47.60 | 30.0 | 44.8 | 4.66 | 8302 | 1:42 PM | 1/11/2004 |
| 7 | 24.0 | 48.30 | 35.0 | 52.4 | 4.73 | 9868 | 3:48 PM | 1/12/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C5**
**Sample Depth: 4’-5’**

Total Length of the sample, L = 9.7 cm

Distance of psychrometer 2 from closed end, x = 8.2 cm

Initial Suction, $u_0$ = 3.61 pF

Relative Humidity = 30%

Atmospheric Suction, $u_a$ = 6.22 pF

Diffusion Coefficient, $\alpha = 2.93E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40348, $\pi_{v0}$ = 51 @ 25ºC

Setup Time & Date: 8:35 PM, 01/03/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.5 | 48.55 | 8.0 | 10.5 | 4.03 | 1313 | 6:28 PM | 01/04/04 |
| 2 | 21.0 | 48.20 | 25.5 | 35.6 | 4.56 | 2735 | 6:10 PM | 01/05/04 |
| 3 | 21.5 | 48.55 | 41.0 | 57.8 | 4.77 | 4196 | 6:31 PM | 01/06/04 |

Psychrometer 2:

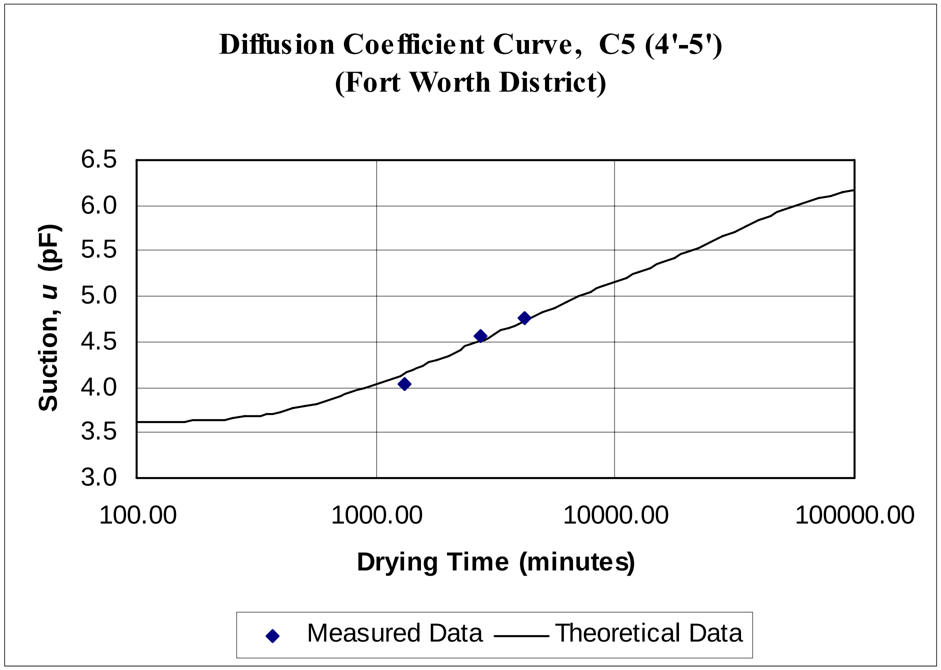
No.: 40331, $\pi_{v0}$ = 50 @ 25ºC

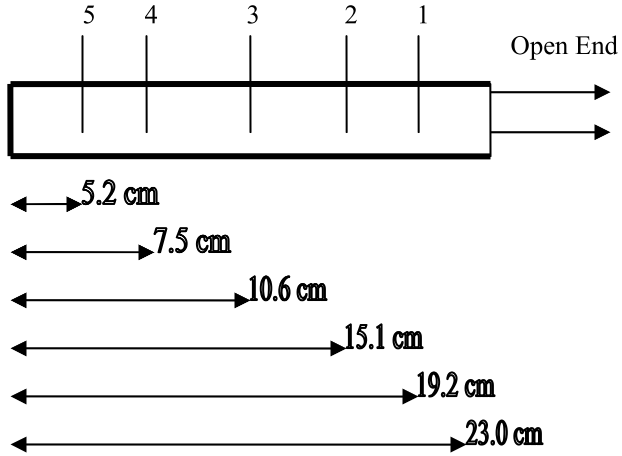
Setup Time & Date: 8:35 PM, 01/03/04

**Project: Fort Worth District**
**Bore Hole: C5**
**Sample Depth: 4'-5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 48.25 | 5.0 | 6.6 | 3.83 | 1315 | 6:30 PM | 01/04/04 |
| 2 | 22.0 | 47.90 | 11.0 | 15.3 | 4.19 | 2740 | 6:15 PM | 01/05/04 |
| 3 | 22.0 | 47.90 | 20.5 | 29.2 | 4.47 | 4200 | 6:35 PM | 01/06/04 |
| 4 | 22.5 | 48.25 | 26.0 | 37.2 | 4.58 | 5460 | 3:35 PM | 01/07/04 |
| 5 | 23.0 | 48.60 | 31.0 | 44.5 | 4.66 | 6727 | 12:42 PM | 01/08/04 |
| 6 | 23.0 | 48.60 | 36.0 | 51.8 | 4.72 | 8405 | 4:40 PM | 01/09/04 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Fort Worth District**
**Bore Hole: C5**
**Sample Depth: 7'-8'**

Total Length of the sample, L = 23.0 cm

Distance of psychrometer 2 from closed end, x = 19.2 cm

Initial Suction, $u_0$ = 3.81 pF

Relative Humidity = 54.3%

Atmospheric Suction, $u_a$ = 5.93 pF

Diffusion Coefficient, $\alpha = 1.73E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40334, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 2:35 PM, 09/20/03

**Project: Fort Worth District**
**Bore Hole: C5**
**Sample Depth: 7’-8’**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 50.90 | 6.0 | 6.7 | 3.83 | 1185 | 10:30 AM | 9/22/2003 |
| 2 | 22.5 | 51.25 | 6.5 | 7.4 | 3.88 | 1526 | 4:01 PM | 9/22/2003 |
| 3 | 22.0 | 50.90 | 7.0 | 8.1 | 3.92 | 2860 | 2:15 PM | 9/23/2003 |
| 4 | 23.0 | 51.60 | 8.0 | 9.6 | 3.99 | 4098 | 10:53 AM | 9/24/2003 |
| 5 | 23.0 | 51.60 | 8.5 | 10.3 | 4.02 | 4577 | 4:52 PM | 9/24/2003 |
| 6 | 22.5 | 51.25 | 9.5 | 11.7 | 4.08 | 5637 | 10:32 AM | 9/25/2003 |
| 7 | 22.5 | 51.25 | 10.5 | 13.1 | 4.13 | 6055 | 5:30 PM | 9/25/2003 |
| 8 | 22.0 | 50.90 | 12.0 | 15.3 | 4.19 | 7159 | 11:54 AM | 9/26/2003 |
| 9 | 22 | 50.90 | 14 | 18.1 | 4.27 | 8811 | 2:22 PM | 9/27/2003 |
| 10 | 21.5 | 50.55 | 17.0 | 22.4 | 4.36 | 10463 | 2:28 PM | 9/28/2003 |
| 11 | 22.0 | 50.90 | 23.0 | 31.0 | 4.50 | 11945 | 3:10 PM | 9/29/2003 |
| 12 | 22 | 50.90 | 27.0 | 36.8 | 4.57 | 13406 | 3:31 PM | 9/30/2003 |

Psychrometer 2:

No.: 40316, $\pi_{v0}$ = 58 @ 25ºC

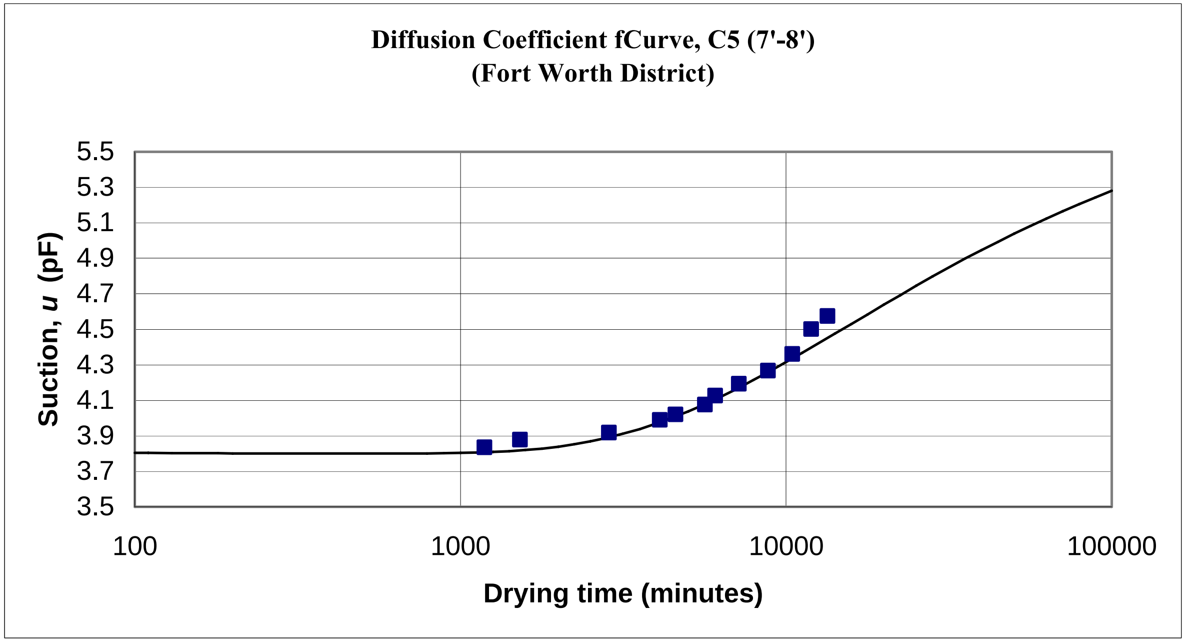
Setup Time & Date: 2:35 PM, 09/20/03

**Project: Fort Worth District**
**Bore Hole: C5**
**Sample Depth: 7'-8'**

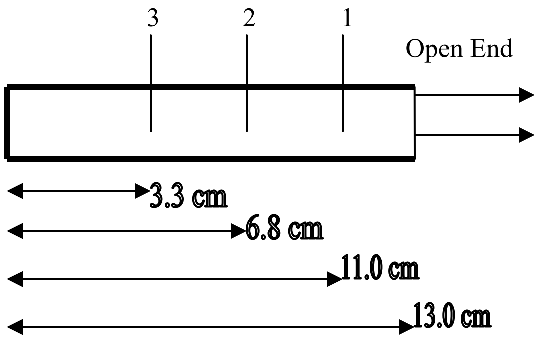
| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 56.25 | 5.0 | 5.3 | 3.73 | 1195 | 10:20 AM | 9/22/2003 |
| 2 | 22.5 | 56.25 | 5.5 | 6.0 | 3.79 | 1528 | 4:03 PM | 9/22/2003 |
| 3 | 22.0 | 55.90 | 6.5 | 7.4 | 3.88 | 2905 | 3:00 PM | 9/23/2003 |
| 4 | 23.0 | 56.60 | 6.0 | 6.7 | 3.83 | 4100 | 10:55 AM | 9/24/2003 |
| 5 | 23.0 | 56.60 | 8.5 | 10.3 | 4.02 | 4580 | 4:55 PM | 9/24/2003 |
| 6 | 22.5 | 56.25 | 7.0 | 8.1 | 3.92 | 5639 | 10:34 AM | 9/25/2003 |
| 7 | 23.0 | 56.60 | 7.8 | 9.3 | 3.98 | 6056 | 5:31 PM | 9/25/2003 |
| 8 | 22.5 | 56.25 | 8.0 | 9.6 | 3.99 | 7163 | 11:58 AM | 9/26/2003 |
| 9 | 22 | 55.90 | 9.5 | 11.7 | 4.08 | 8814 | 2:25 PM | 9/27/2003 |
| 10 | 21.5 | 55.55 | 11.0 | 13.9 | 4.15 | 10464 | 2:29 PM | 9/28/2003 |
| 11 | 22.0 | 55.90 | 14.0 | 18.1 | 4.27 | 11949 | 3:14 PM | 9/29/2003 |
| 12 | 22 | 55.90 | 16.0 | 21.0 | 4.33 | 13409 | 3:34 PM | 9/30/2003 |

**Project: Fort Worth District**
**Bore Hole: C5**
**Sample Depth: 7'-8'**

Diffusion Coefficient Curve for Psychrometer 1:



# APPENDIX A-2




**Project: Atlanta District**
**Bore Hole: A1**
**Sample Depth: 5'-5.5'**

Total Length of the sample, L = 13.0 cm

Distance of psychrometer 2 from closed end, x = 11.0 cm

Initial Suction, $u_0$ = 2.84 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 4.83E^{-5}\ cm^2/sec$

Psychrometer 1:

No.: 40293, $\pi_{v0}$ = 57 @ 25ºC

Setup Time & Date: 12:45 PM, 11/14/03

**Project: Atlanta District**
**Bore Hole: A1**
**Sample Depth: 5'-5.5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 55.60 | 5.0 | 5.1 | 3.72 | 1834 | 6:11:00 PM | 11/15/2003 |
| 2 | 23.5 | 55.95 | 10.5 | 12.9 | 4.12 | 3278 | 6:15:00 AM | 11/16/2003 |
| 3 | 23.0 | 55.60 | 15.0 | 19.3 | 4.29 | 4486 | 2:33:00 PM | 11/17/2003 |
| 4 | 23.0 | 55.60 | 24.0 | 32.0 | 4.51 | 5113 | 4:30:00 PM | 11/18/2003 |
| 5 | 24.0 | 56.30 | 36.5 | 49.7 | 4.70 | 6533 | 4:10:00 PM | 11/19/2003 |
| 6 | 24.0 | 56.30 | 45.0 | 61.7 | 4.80 | 7828 | 2:45:00 PM | 11/20/2003 |

Psychrometer 2:

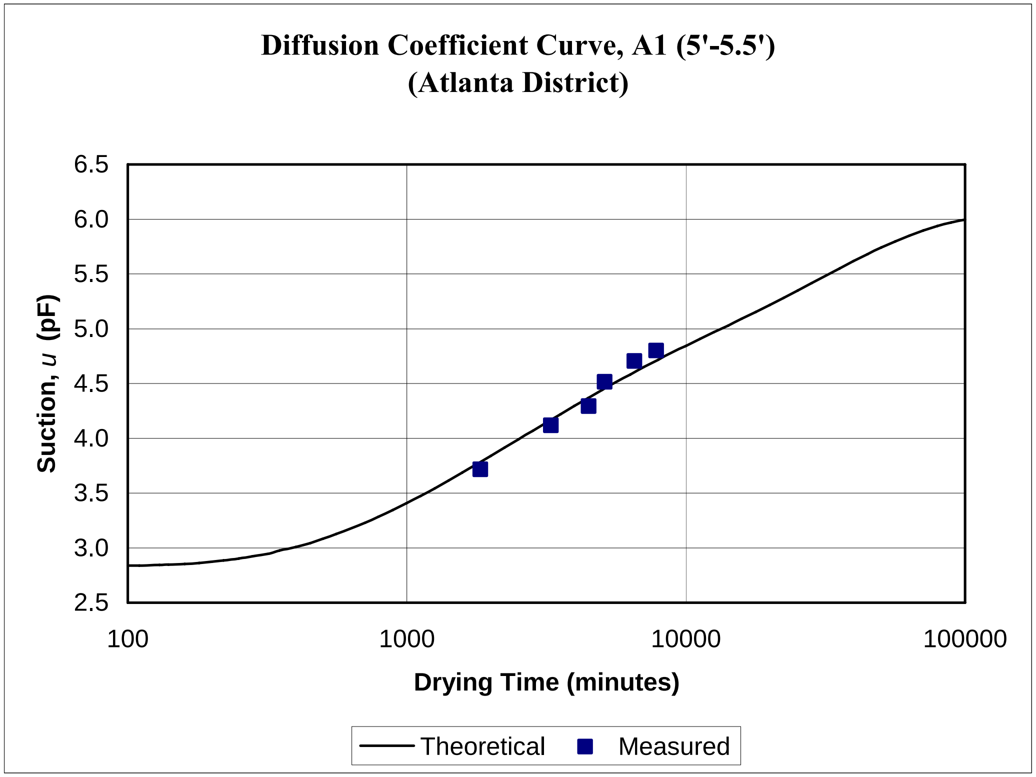
No.: 40334, $\pi_{v0}$ = 53 @ 25ºC

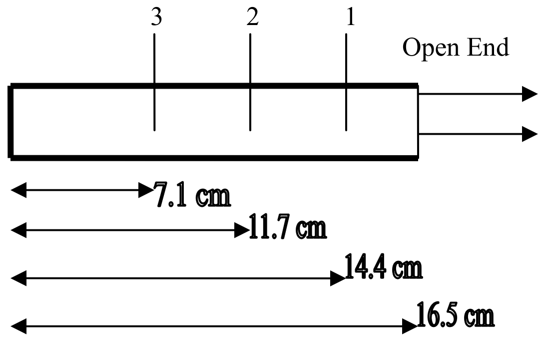
Setup Time & Date: 12:45 PM, 11/14/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 51.60 | 3.0 | 0.1 | 1.79 | 1837 | 6:14 PM | 11/15/2003 |
| 2 | 23.5 | 51.95 | 3.0 | 0.1 | 1.79 | 3280 | 6:17 AM | 11/16/2003 |
| 3 | 23.0 | 51.60 | 3.0 | 0.1 | 1.79 | 4488 | 2:35 PM | 11/17/2003 |
| 4 | 23.0 | 51.60 | 3.5 | 0.8 | 2.92 | 5114 | 4:31 PM | 11/18/2003 |
| 5 | 24.0 | 52.30 | 5.0 | 3.1 | 3.50 | 6536 | 4:13 AM | 11/19/2003 |
| 6 | 24.0 | 52.30 | 6.5 | 5.4 | 3.74 | 7830 | 2:47 PM | 11/20/2003 |

**Project: Atlanta District**
**Bore Hole: A1**
**Sample Depth: 5'-5.5'**

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: A2**
**Sample Depth: 9'-11'**

Total Length of the sample, L = 16.5 cm

Distance of psychrometer 2 from closed end, x = 14.4 cm

Initial Suction, $u_0$ = 3.13 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 3.93E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 12:05 PM, 11/14/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 50.25 | 6.0 | 6.4 | 3.82 | 1797 | 6:02 PM | 11/15/2003 |
| 2 | 22.5 | 50.25 | 10.5 | 13.2 | 4.13 | 3235 | 6:00 PM | 11/16/2003 |
| 3 | 23.0 | 50.60 | 15.0 | 19.9 | 4.31 | 4460 | 2:25 PM | 11/17/2003 |
| 4 | 23.0 | 50.60 | 23.5 | 32.6 | 4.52 | 6030 | 4:35 PM | 11/18/2003 |
| 5 | 24.0 | 51.30 | 34.0 | 48.3 | 4.69 | 7451 | 4:16 PM | 11/19/2003 |

Psychrometer 2:

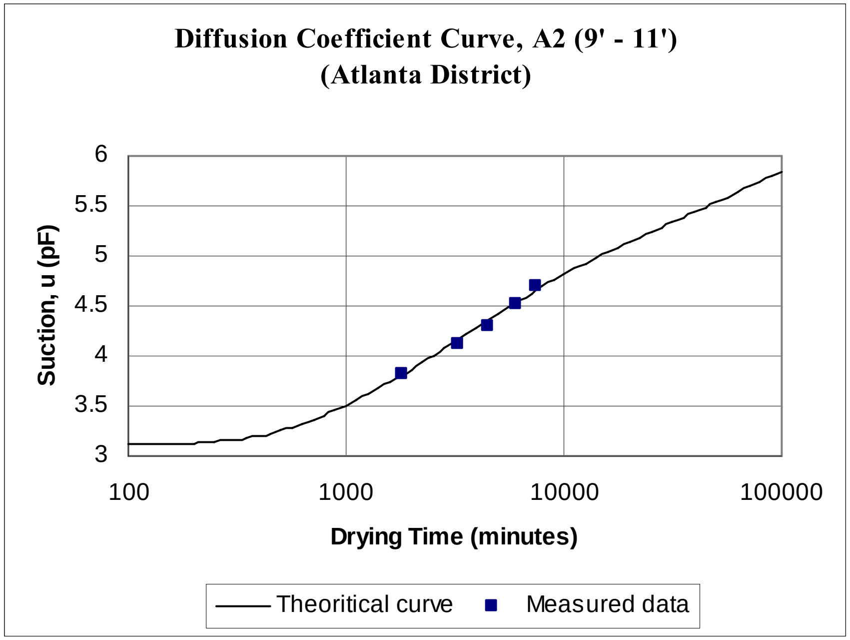
No.: 43447, $\pi_{v0}$ = 58 @ 25ºC

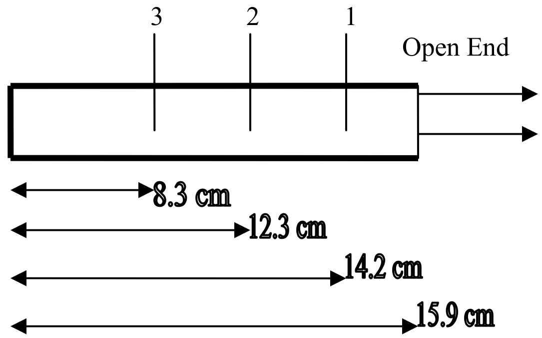
Setup Time & Date: 12:05 PM, 11/14/03

**Project: Atlanta District**
**Bore Hole: A2**
**Sample Depth: 9'-11'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 56.60 | 3.8 | 2.5 | 3.40 | 1800 | 6:05 PM | 11/15/2003 |
| 2 | 23.5 | 56.95 | 3.5 | 2.1 | 3.33 | 3238 | 6:03 PM | 11/16/2003 |
| 3 | 23.5 | 56.95 | 4.0 | 2.9 | 3.46 | 4462 | 2:27 PM | 11/17/2003 |
| 4 | 23.5 | 56.95 | 6.0 | 5.9 | 3.78 | 6035 | 4:40 PM | 11/18/2003 |
| 5 | 24.5 | 57.65 | 11.0 | 13.4 | 4.14 | 7452 | 4:17 AM | 11/19/2003 |
| 6 | 24.5 | 57.65 | 13.0 | 16.4 | 4.22 | 8810 | 2:55 PM | 11/20/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: A3**
**Sample Depth: 11'-13'**

Total Length of the sample, L = 15.9 cm

Distance of psychrometer 2 from closed end, x = 14.2 cm

Initial Suction, $u_0$ = 3.21 pF

Relative Humidity = 44%

Atmospheric Suction, $u_a$ = 6.06 pF

Diffusion Coefficient, $\alpha = 1.23E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 42448, $\pi_{v0}$ = 54 @ 25ºC

Setup Time & Date: 12:00 PM, 11/14/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 51.90 | 4.0 | 3.15 | 3.51 | 1798 | 5:59 PM | 11/15/2003 |
| 2 | 23.0 | 52.60 | 5.5 | 5.32 | 3.73 | 3250 | 6:12 PM | 11/16/2003 |
| 3 | 23.0 | 52.60 | 6.5 | 6.77 | 3.84 | 4455 | 2:16 PM | 11/17/2003 |
| 4 | 23.5 | 52.95 | 10.0 | 11.83 | 4.08 | 6044 | 4:46 PM | 11/18/2003 |
| 5 | 24.0 | 53.30 | 14.5 | 18.35 | 4.27 | 7505 | 4:25 PM | 11/19/2003 |
| 6 | 24.0 | 53.30 | 18.5 | 24.13 | 4.39 | 8892 | 3:18 PM | 11/20/2003 |
| 7 | 24.0 | 53.30 | 24 | 32.09 | 4.51 | 11714 | 4:20 PM | 11/22/2003 |
| 8 | 23.0 | 52.60 | 36 | 49.46 | 4.70 | 14537 | 3:20 PM | 11/24/2003 |

Psychrometer 2:

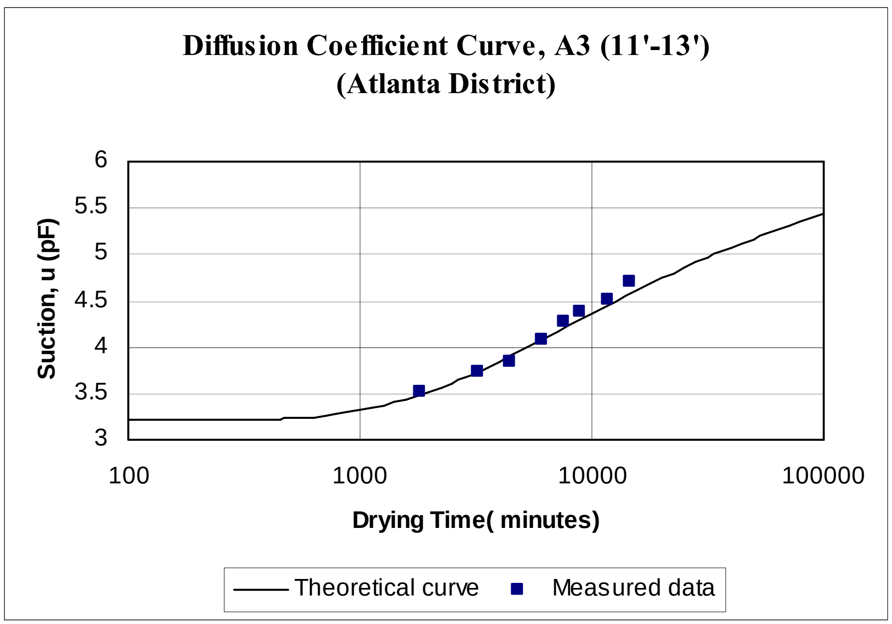
No.: 43316, $\pi_{v0}$ = 53 @ 25ºC

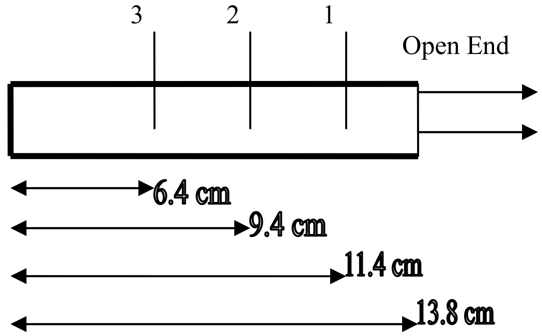
Setup Time & Date: 12:00 PM, 11/14/03

**Project: Atlanta District**
**Bore Hole: A3**
**Sample Depth: 11'-13'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 51.60 | 3.5 | 1.13 | 3.06 | 1799 | 5:58 PM | 11/15/2003 |
| 2 | 23.5 | 51.95 | 4.0 | 1.89 | 3.28 | 3252 | 6:10 PM | 11/16/2003 |
| 3 | 23.0 | 51.60 | 4.0 | 1.89 | 3.28 | 4456 | 2:15 PM | 11/17/2003 |
| 4 | 24.0 | 52.30 | 5.5 | 4.17 | 3.63 | 6046 | 4:44 PM | 11/18/2003 |
| 5 | 24.0 | 52.30 | 5.5 | 4.17 | 3.63 | 7507 | 4:23 PM | 11/19/2003 |
| 6 | 24.0 | 52.30 | 5.5 | 4.17 | 3.63 | 8894 | 3:16 PM | 11/20/2003 |
| 7 | 24.0 | 52.30 | 7.5 | 7.21 | 3.87 | 11716 | 4:18 PM | 11/22/2003 |
| 8 | 23.5 | 51.95 | 9.5 | 10.26 | 4.02 | 14542 | 3:15 PM | 11/24/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: B1**
**Sample Depth: 5'-7'**

Total Length of the sample, L = 13.8 cm

Distance of psychrometer 2 from closed end, x = 11.4 cm

Initial Suction, $u_0$ = 3.38 pF

Relative Humidity = 64.2%

Atmospheric Suction, $u_a$ = 5.79 pF

Diffusion Coefficient, $\alpha = 5.66E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40312, $\pi_{v0}$ = 56 @ 25ºC

Setup Time & Date: 12:35 PM, 10/31/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 53.90 | 3.5 | 1.4 | 3.16 | 302 | 5:37 PM | 10/31/03 |
| 2 | 21.0 | 53.20 | 6.8 | 6.3 | 3.81 | 1556 | 2:31 PM | 11/1/03 |
| 3 | 21.5 | 53.55 | 13.0 | 15.7 | 4.20 | 3121 | 4:36 PM | 11/2/03 |
| 4 | 21.5 | 53.55 | 28.5 | 38.9 | 4.60 | 4247 | 11:22 AM | 11/4/03 |
| 5 | 22.0 | 53.90 | 37.0 | 51.6 | 4.72 | 5880 | 2:35 PM | 11/5/03 |
| 6 | 21.0 | 53.20 | 46.0 | 65.1 | 4.82 | 7315 | 2:30 PM | 11/6/03 |

Psychrometer 2:

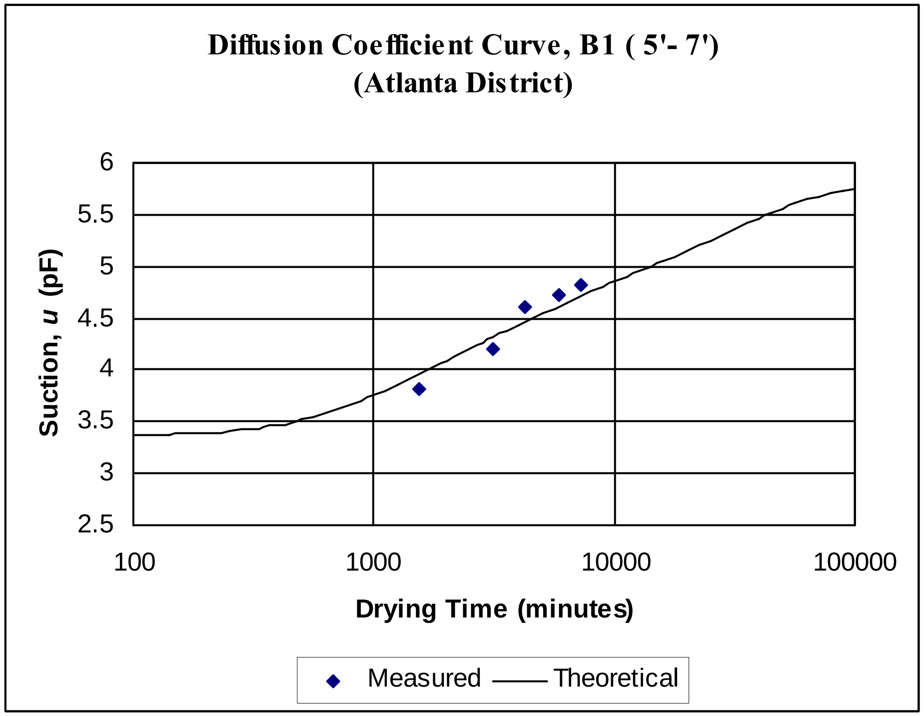
No.: 40334, $\pi_{v0}$ = 53 @ 25ºC

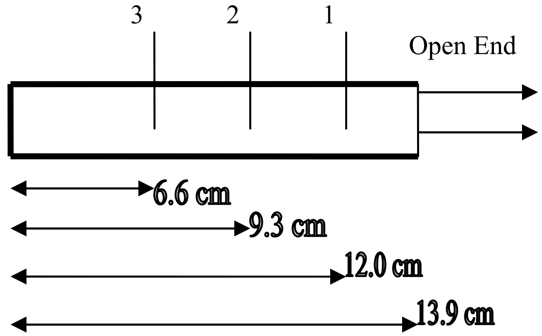
Setup Time & Date: 12:35 PM, 10/31/03

**Project: Atlanta District**
**Bore Hole: B1**
**Sample Depth: 5'-7'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 55.20 | 4.0 | 2.9 | 3.46 | 1558 | 2:33 PM | 10/31/03 |
| 2 | 21.5 | 55.55 | 4.5 | 3.6 | 3.57 | 3123 | 4:38 PM | 11/1/03 |
| 3 | 21.5 | 55.55 | 8.0 | 8.9 | 3.96 | 4250 | 11:25 AM | 11/2/03 |
| 4 | 22.0 | 55.90 | 10.5 | 12.7 | 4.11 | 5885 | 2:40 PM | 11/4/03 |
| 5 | 21.0 | 55.20 | 13.0 | 16.4 | 4.22 | 7318 | 2:33 PM | 11/5/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: B2**
**Sample Depth: 9'-11'**

Total Length of the sample, L = 13.9 cm

Distance of psychrometer 2 from closed end, x = 12.0 cm

Initial Suction, $u_0$ = 3.22 pF

Relative Humidity = 64.2%

Atmospheric Suction, $u_a$ = 5.79 pF

Diffusion Coefficient, $\alpha = 3.07E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 43316, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 12:00 PM, 10/31/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 50.20 | 5.0 | 3.4 | 3.54 | 1524 | 2:24 PM | 11/1/03 |
| 2 | 21.5 | 50.55 | 8.0 | 8.0 | 3.91 | 3105 | 4:45 PM | 11/2/03 |
| 3 | 21.5 | 50.55 | 15.0 | 18.6 | 4.28 | 4215 | 11:15 AM | 11/4/03 |
| 4 | 22.0 | 50.90 | 20.0 | 26.2 | 4.43 | 5875 | 2:55 PM | 11/5/03 |
| 5 | 21.5 | 50.55 | 24.0 | 32.3 | 4.52 | 7300 | 2:40 PM | 11/6/03 |
| 6 | 21.0 | 50.20 | 29.0 | 39.9 | 4.61 | 8625 | 12:45 PM | 11/7/03 |
| 7 | 21.0 | 50.20 | 33.0 | 46.0 | 4.67 | 10270 | 4:10 PM | 11/8/03 |
| 8 | 21.5 | 50.55 | 38.0 | 53.6 | 4.74 | 11655 | 3:15 PM | 11/9/03 |

Psychrometer 2:

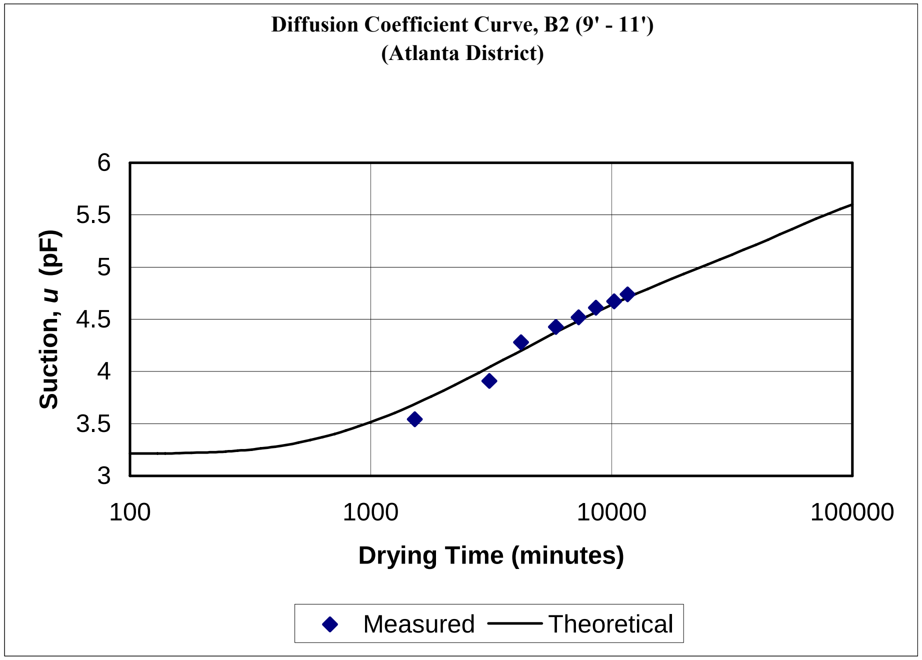
No.: 40334, $\pi_{v0}$ = 53 @ 25ºC

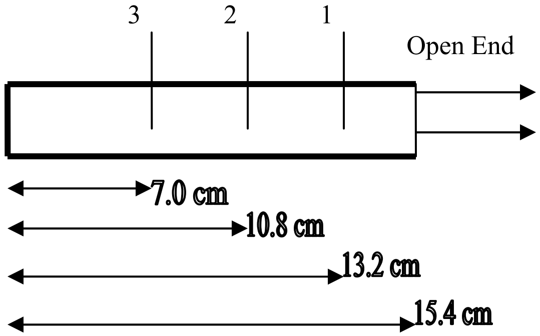
Setup Time & Date: 12:00 PM, 10/31/03

**Project: Atlanta District**
**Bore Hole: B2**
**Sample Depth: 9'-11'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.0 | 51.20 | 2.5 | 1.0 | 3.00 | 1526 | 2:26 PM | 11/1/03 |
| 2 | 21.5 | 51.55 | 3.0 | 1.7 | 3.24 | 3107 | 4:47 PM | 11/2/03 |
| 3 | 21.5 | 51.55 | 3.5 | 2.4 | 3.39 | 4216 | 11:16 AM | 11/4/03 |
| 4 | 22.0 | 51.90 | 5.0 | 4.6 | 3.67 | 5878 | 2:58 PM | 11/5/03 |
| 5 | 21.5 | 51.55 | 6.0 | 6.0 | 3.79 | 7304 | 2:44 PM | 11/6/03 |
| 6 | 21.0 | 51.20 | 7.0 | 7.5 | 3.88 | 8626 | 12:46 PM | 11/7/03 |
| 7 | 21.0 | 51.20 | 7.5 | 8.2 | 3.92 | 10272 | 4:12 PM | 11/8/03 |
| 8 | 21.5 | 51.55 | 8.0 | 8.9 | 3.96 | 11657 | 3:17 PM | 11/9/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: B3**
**Sample Depth: 13’-14’**

Total Length of the sample, L = 15.4 cm

Distance of psychrometer 2 from closed end, x = 13.2 cm

Initial Suction, $u_0$ = 3.96 pF

Relative Humidity = 64.2%

Atmospheric Suction, $u_a$ = 5.79 pF

Diffusion Coefficient, $\alpha = 8.33E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40293, $\pi_{v0}$ = 57 @ 25ºC

Setup Time & Date: 3:35 PM, 10/30/03

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 55.25 | 12.0 | 15.0 | 4.18 | 344 | 9:19 PM | 10/30/03 |
| 2 | 22.0 | 54.90 | 23.0 | 30.6 | 4.49 | 1153 | 10:50 AM | 10/31/03 |
| 3 | 22.0 | 54.90 | 42.0 | 57.5 | 4.77 | 2823 | 2:40 PM | 11/1/03 |

Psychrometer 2:

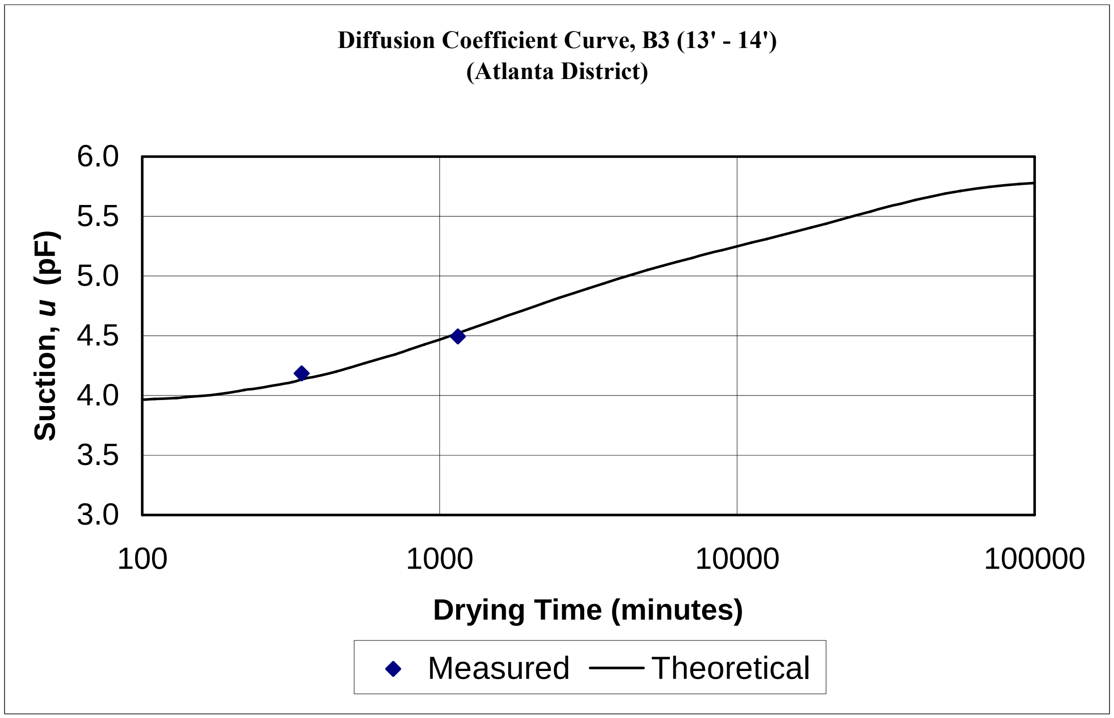
No.: 40334, $\pi_{v0}$ = 53 @ 25ºC

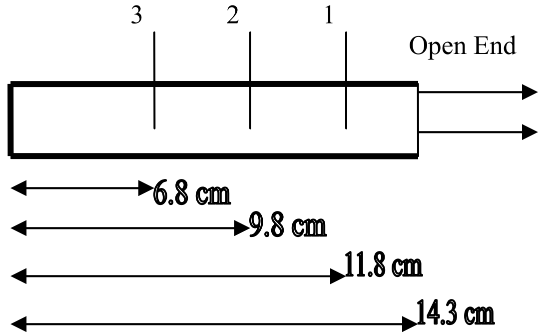
Setup Time & Date: 3:35 PM, 10/30/03

**Project: Atlanta District**
**Bore Hole: B3**
**Sample Depth: 13'-14'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 46.25 | 7.5 | 8.2 | 3.92 | 346 | 9:21 PM | 10/30/03 |
| 2 | 22.0 | 45.90 | 9.0 | 10.4 | 4.03 | 1158 | 10:55 AM | 10/31/03 |
| 3 | 22.5 | 46.25 | 12.5 | 15.6 | 4.20 | 2828 | 2:45 PM | 11/1/03 |
| 4 | 22.5 | 46.25 | 17.0 | 22.3 | 4.36 | 4388 | 4:35 PM | 11/2/03 |
| 5 | 22.0 | 45.90 | 23.0 | 31.3 | 4.50 | 5500 | 11:07 AM | 11/3/03 |
| 6 | 22.5 | 46.25 | 29.0 | 40.2 | 4.61 | 7163 | 2:50 PM | 11/4/03 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: C1**
**Sample Depth: 2'-4'**

Total Length of the sample, L = 14.3 cm

Distance of psychrometer 2 from closed end, x = 11.8 cm

Initial Suction, $u_0$ = 3.07 pF

Relative Humidity = 66.4%

Atmospheric Suction, $u_a$ = 5.76 pF

Diffusion Coefficient, $\alpha = 9.16E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 43447, $\pi_{v0}$ = 58 @ 25ºC

Setup Time & Date: 5:05 PM, 10/23/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 55.90 | 3.5 | 2.1 | 3.33 | 330 | 11:35 PM | 10/23/2003 |
| 2 | 22.0 | 55.90 | 6.5 | 6.6 | 3.83 | 1754 | 11:19 AM | 10/24/2003 |
| 3 | 21.5 | 55.55 | 15.0 | 19.4 | 4.30 | 2808 | 5:45 AM | 10/26/2003 |
| 4 | 21.5 | 55.55 | 26.0 | 36.0 | 4.57 | 3370 | 2:23 PM | 10/27/2003 |
| 5 | 21.5 | 55.55 | 32.0 | 45.1 | 4.66 | 4812 | 2:25 PM | 10/28/2003 |
| 6 | 22.0 | 55.90 | 36.0 | 51.1 | 4.72 | 6056 | 11:09 AM | 10/29/2003 |

Psychrometer 2:

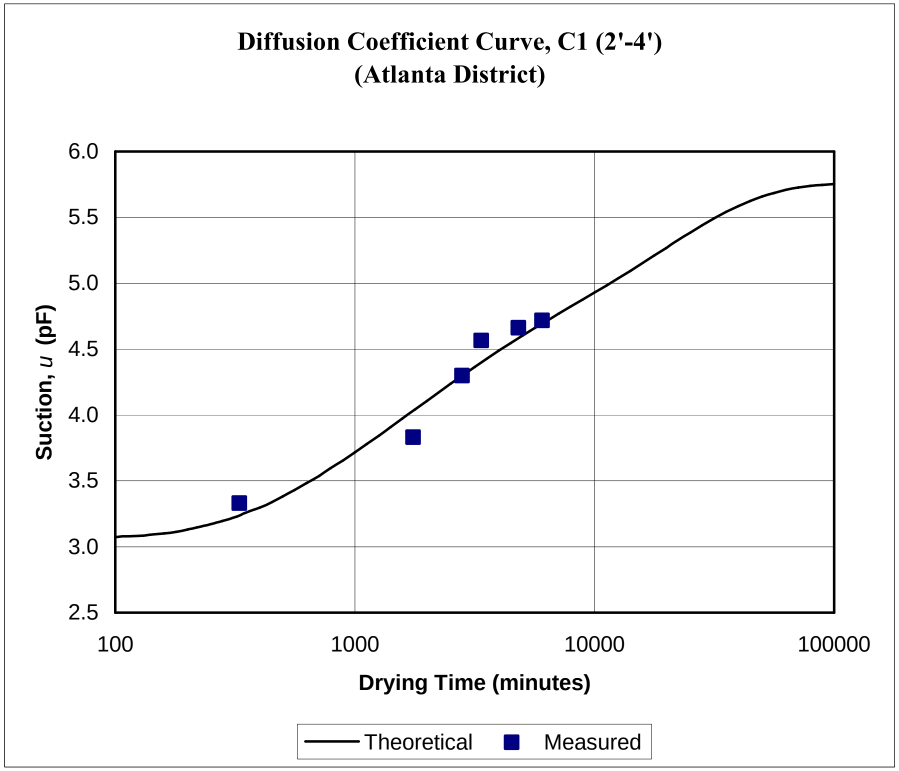
No.: 43448, $\pi_{v0}$ = 54 @ 25ºC

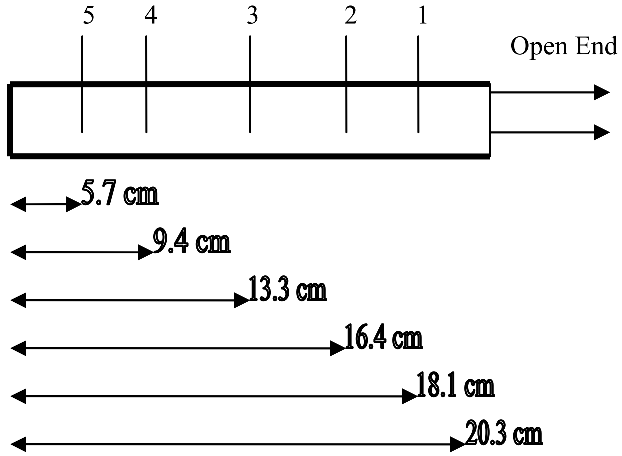
Setup Time & Date: 5:05 PM, 10/23/03

**Project: Atlanta District**
**Bore Hole: C1**
**Sample Depth: 2'-4'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.5 | 51.55 | 7.5 | 8.2 | 3.92 | 1037 | 11:20 AM | 10/23/2003 |
| 2 | 21.5 | 51.55 | 12.5 | 15.5 | 4.20 | 2143 | 5:48 AM | 10/26/2003 |
| 3 | 21.0 | 51.20 | 9.0 | 10.4 | 4.03 | 2660 | 2:25 PM | 10/27/2003 |
| 4 | 21.5 | 51.55 | 10.0 | 11.8 | 4.08 | 4093 | 2:30 PM | 10/28/2003 |
| 5 | 21.5 | 51.55 | 12.0 | 14.7 | 4.18 | 5319 | 11:11 AM | 10/29/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: C2**
**Sample Depth: 9'-11'**

Total Length of the sample, L = 20.3 cm

Distance of psychrometer 2 from closed end, x = 18.1 cm

Initial Suction, $u_0$ = 3.43 pF

Relative Humidity = 66.4%

Atmospheric Suction, $u_a$ = 5.76 pF

Diffusion Coefficient, $\alpha = 13.10E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40316, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 5:05 PM, 10/23/03

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 50.90 | 2.5 | 0.7 | 2.88 | 337 | 11:42 PM | 10/23/2003 |
| 2 | 22.0 | 50.90 | 11.0 | 13.4 | 4.13 | 1045 | 11:30 AM | 10/24/2003 |
| 3 | 21.5 | 50.55 | 24.0 | 32.7 | 4.52 | 2160 | 6:05 AM | 10/26/2003 |
| 4 | 21.5 | 50.55 | 39.0 | 55.0 | 4.75 | 2958 | 2:35 PM | 10/27/2003 |

Psychrometer 2:

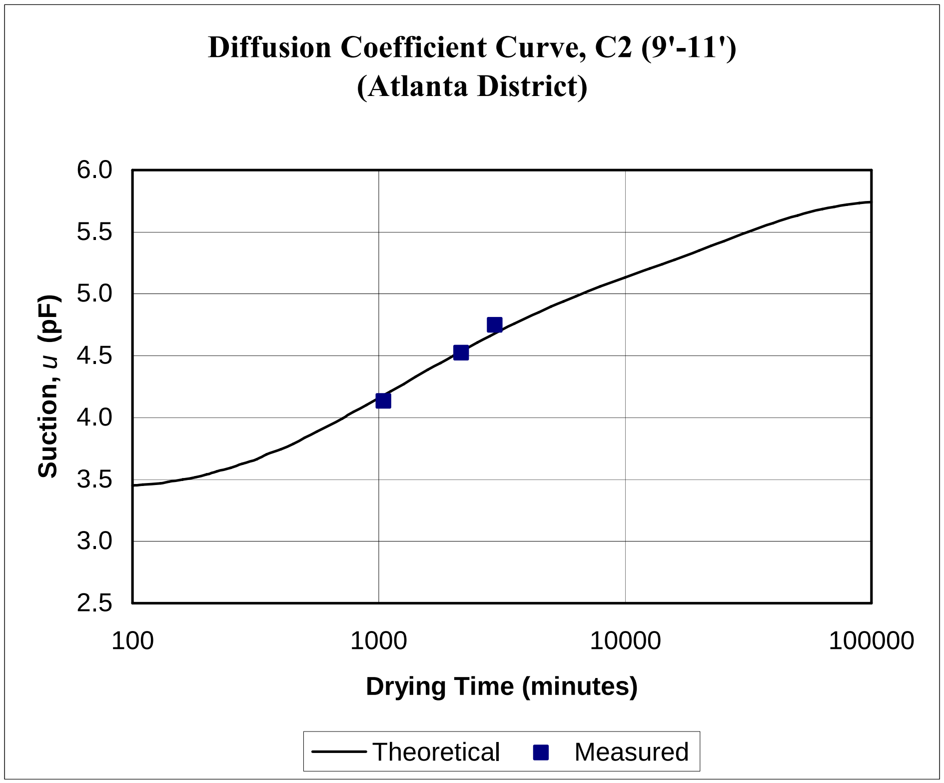
No.: 40316, $\pi_{v0}$ = 58 @ 25ºC

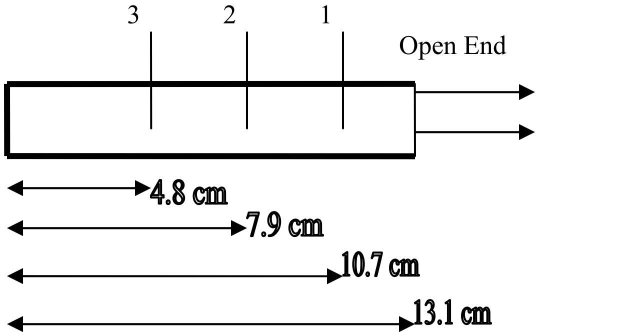
Setup Time & Date: 5:05 PM, 10/23/03

**Project: Atlanta District**
**Bore Hole: C2**
**Sample Depth: 9'-11'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 53.90 | 7.5 | 6.9 | 3.85 | 1048 | 11:31 AM | 10/23/2003 |
| 2 | 22.0 | 53.90 | 12.5 | 14.3 | 4.17 | 2163 | 6:08 AM | 10/26/2003 |
| 3 | 21.5 | 53.55 | 9.0 | 9.1 | 3.97 | 2672 | 2:37 PM | 10/27/2003 |
| 4 | 22.0 | 53.90 | 10.0 | 10.6 | 4.03 | 4120 | 2:45 PM | 10/28/2003 |
| 5 | 22.0 | 53.90 | 12.0 | 13.6 | 4.14 | 5355 | 11:20 AM | 10/29/2003 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Atlanta District**
**Bore Hole: C3**
**Sample Depth: 11'-13'**

Total Length of the sample, L = 13.1 cm

Distance of psychrometer 2 from closed end, x = 10.7 cm

Initial Suction, $u_0$ = 3.99 pF

Relative Humidity = 66.4%

Atmospheric Suction, $u_a$ = 5.76 pF

Diffusion Coefficient, $\alpha = 4.26E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40334, $\pi_{v0}$ = 53 @ 25ºC

Setup Time & Date: 5:25 PM, 10/23/03

| **No.** | **T** | **$\pi_v$** | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 51.25 | 8.0 | 7.7 | 3.89 | 380 | 11:45 PM | 10/23/2003 |
| 2 | 22.0 | 50.90 | 14.5 | 17.5 | 4.25 | 1065 | 11:10 AM | 10/24/2003 |
| 3 | 22.0 | 50.90 | 30.0 | 41.1 | 4.62 | 3635 | 6:15 AM | 10/26/2003 |

Psychrometer 2:

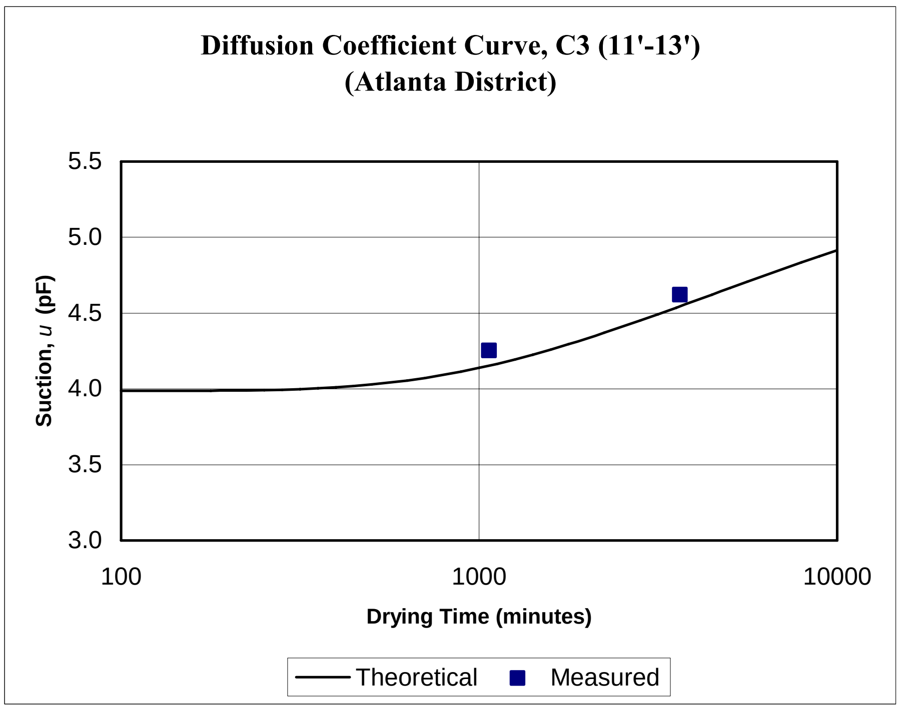
No.: 40337, $\pi_{v0}$ = 49 @ 25ºC

Setup Time & Date: 5:25 PM, 10/23/03

**Project: Atlanta District**
**Bore Hole: C3**
**Sample Depth: 11'-13'**

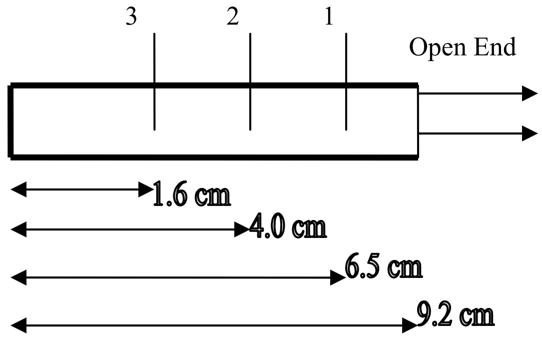
| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 46.90 | 7.3 | 10.4 | 4.03 | 1069 | 11:14 AM | 10/24/2003 |
| 2 | 22.0 | 46.90 | 10.5 | 14.8 | 4.18 | 3640 | 6:20 AM | 10/26/2003 |
| 3 | 21.5 | 46.55 | 12.5 | 17.5 | 4.25 | 4836 | 2:16 PM | 10/27/2003 |
| 4 | 21.5 | 46.55 | 14.5 | 20.2 | 4.31 | 6280 | 2:20 PM | 10/28/2003 |
| 5 | 22.0 | 46.90 | 17.0 | 23.6 | 4.38 | 7525 | 11:05 AM | 10/29/2003 |

Diffusion Coefficient Curve for Psychrometer 1:



# APPENDIX A-3

**Project: Austin District**
**Bore Hole: B1**
**Sample Depth: 2'-3.5'**




Total Length of the sample, L = 9.2 cm

Distance of psychrometer 2 from closed end, x = 6.5 cm

Initial Suction, $u_0$ = 3.45 pF

Relative Humidity = 60.9%

Atmospheric Suction, $u_a$ = 5.84 pF

Diffusion Coefficient, $\alpha = 10.60E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40362, $\pi_{v0}$ = 50 @ 25ºC

Setup Time & Date: 4:35 PM, 02/26/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 47.90 | 12.0 | 18.1 | 4.27 | 950 | 12:45 PM | 2/27/04 |
| 2 | 22.0 | 47.90 | 12.0 | 18.1 | 4.27 | 1431 | 4:46 PM | 2/27/04 |
| 3 | 22.5 | 48.25 | 21.5 | 33.0 | 4.53 | 2714 | 2:09 PM | 2/28/04 |
| 4 | 22.0 | 47.90 | 25.5 | 39.2 | 4.60 | 3040 | 7:33 PM | 2/28/04 |
| 5 | 22.5 | 48.25 | 31.5 | 48.6 | 4.70 | 4187 | 2:40 PM | 2/29/04 |
| 6 | 22.5 | 48.25 | 33.0 | 50.9 | 4.72 | 4527 | 8:20 PM | 2/29/04 |

Psychrometer 2:

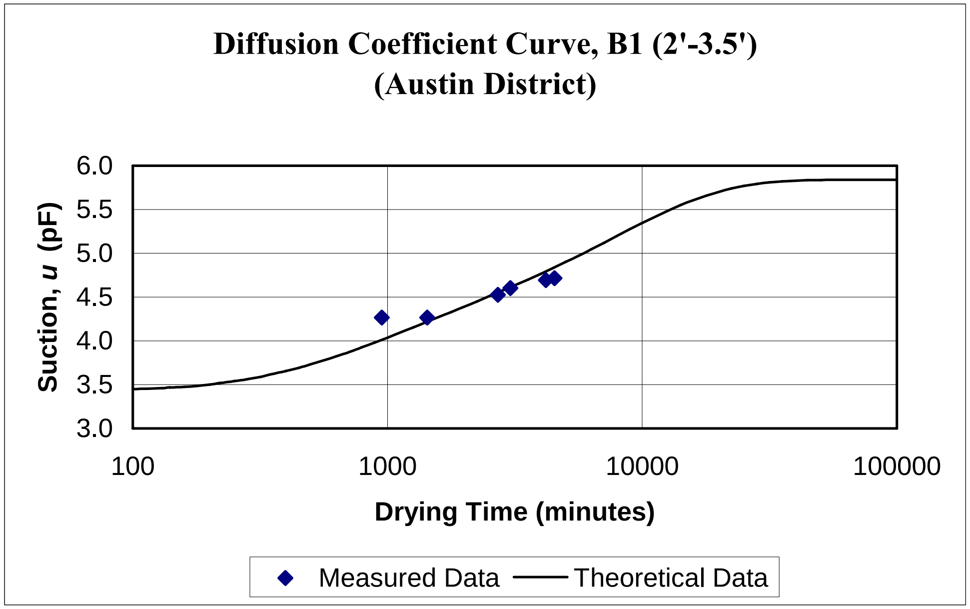
No.: 40325, $\pi_{v0}$ = 49 @ 25ºC

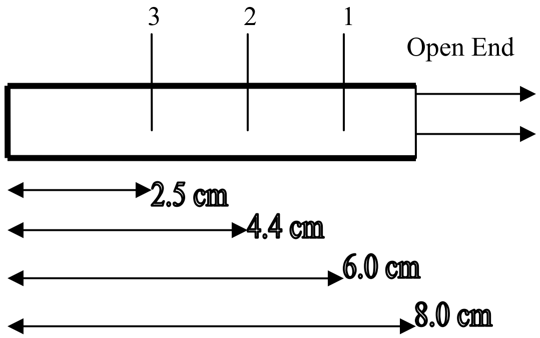
Setup Time & Date: 4:35 PM, 02/26/04

**Project: Austin District**
**Bore Hole: B1**
**Sample Depth: 2'-3.5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 47.25 | 4.5 | 5.4 | 3.74 | 951 | 12:46 PM | 2/27/04 |
| 2 | 23.0 | 47.60 | 4.5 | 5.4 | 3.74 | 1435 | 4:50 PM | 2/27/04 |
| 3 | 23.0 | 47.60 | 11.0 | 14.9 | 4.18 | 2716 | 2:11 PM | 2/28/04 |
| 4 | 23.0 | 47.60 | 11.5 | 15.6 | 4.20 | 3043 | 7:36 PM | 2/28/04 |
| 5 | 23.0 | 47.60 | 15.5 | 21.4 | 4.34 | 4191 | 2:44 PM | 2/29/04 |
| 6 | 23.0 | 47.60 | 18.0 | 25.1 | 4.41 | 4532 | 8:25 PM | 2/29/04 |
| 7 | 23.0 | 47.60 | 24.0 | 33.8 | 4.54 | 5504 | 12:37 PM | 3/1/04 |
| 8 | 23.5 | 47.95 | 31.0 | 44.0 | 4.65 | 6122 | 10:55 AM | 3/2/04 |
| 9 | 22.5 | 47.25 | 32.0 | 45.5 | 4.67 | 6443 | 4:16 PM | 3/2/04 |
| 10 | 23.0 | 47.60 | 41.0 | 58.6 | 4.78 | 7692 | 1:05 PM | 3/3/04 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Austin District**
**Bore Hole: B1**
**Sample Depth: 3.5'-5'**

Total Length of the sample, L = 8.0 cm

Distance of psychrometer 2 from closed end, x = 6.0 cm

Initial Suction, $u_0$ = 3.53 pF

Relative Humidity = 60.9%

Atmospheric Suction, $u_a$ = 5.84 pF

Diffusion Coefficient, $\alpha = 5.65E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40293, $\pi_{v0}$ = 57 @ 25ºC

Setup Time & Date: 4:33 PM, 02/27/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.0 | 54.90 | 10.5 | 12.9 | 4.12 | 1293 | 2:16 PM | 2/28/04 |
| 2 | 22.5 | 55.25 | 17.0 | 22.1 | 4.35 | 1617 | 7:40 PM | 2/28/04 |
| 3 | 22.0 | 54.90 | 23.0 | 30.6 | 4.49 | 2688 | 2:31 PM | 2/29/04 |
| 4 | 22.0 | 54.90 | 28.0 | 37.7 | 4.58 | 3046 | 8:29 PM | 2/29/04 |
| 5 | 23.0 | 55.60 | 33.0 | 44.7 | 4.66 | 4742 | 12:45 PM | 3/1/04 |
| 6 | 23.0 | 55.60 | 37.0 | 50.4 | 4.71 | 5342 | 10:45 AM | 3/2/04 |

Psychrometer 2:

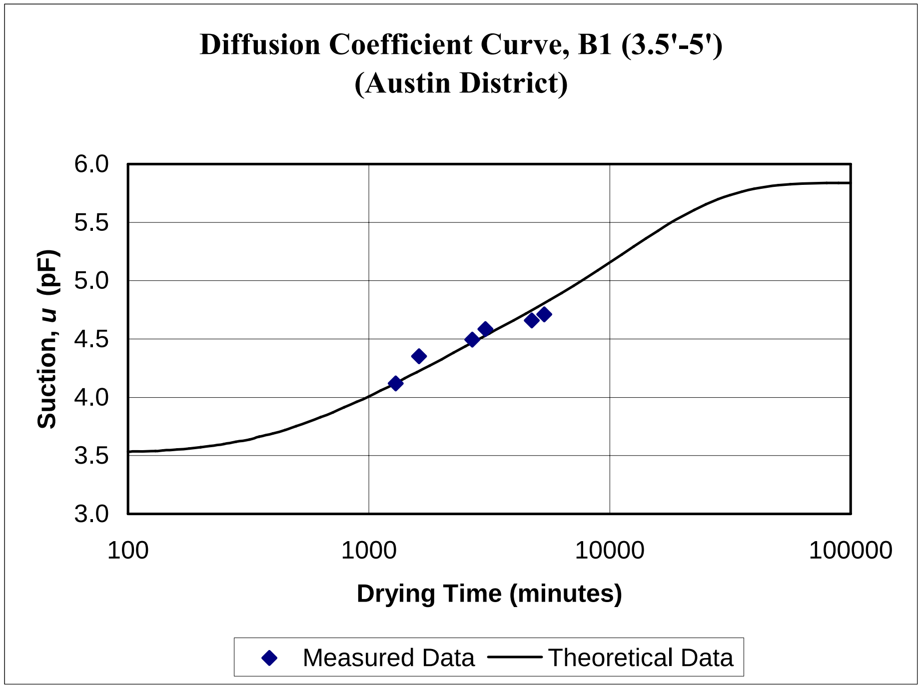
No.: 40305, $\pi_{v0}$ = 60 @ 25ºC

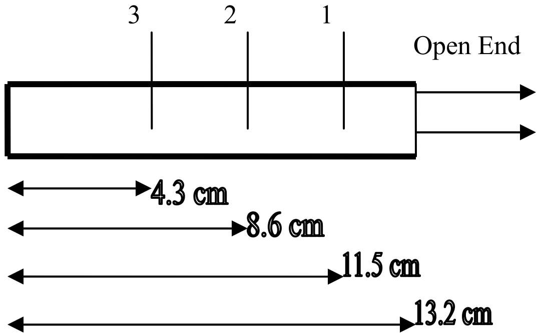
Setup Time & Date: 4:33 PM, 02/27/04

**Project: Austin District**
**Bore Hole: B1**
**Sample Depth: 3.5'-5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 58.25 | 5.0 | 6.1 | 3.79 | 1301 | 2:24 PM | 2/28/04 |
| 2 | 23.0 | 58.60 | 9.5 | 12.4 | 4.10 | 1622 | 7:45 PM | 2/28/04 |
| 3 | 22.5 | 58.25 | 13.0 | 17.4 | 4.25 | 2691 | 2:34 PM | 2/29/04 |
| 4 | 22.5 | 58.25 | 14.5 | 19.5 | 4.30 | 3049 | 8:32 PM | 2/29/04 |
| 5 | 23.0 | 58.60 | 22.0 | 30.0 | 4.49 | 4747 | 12:50 PM | 3/1/04 |
| 6 | 23.0 | 58.60 | 28.0 | 38.5 | 4.59 | 5347 | 10:50 AM | 3/2/04 |
| 7 | 23.5 | 58.95 | 30.0 | 41.3 | 4.62 | 5682 | 4:25 PM | 3/2/04 |
| 8 | 23.0 | 58.60 | 35.0 | 48.4 | 4.69 | 6917 | 1:00 PM | 3/3/04 |

Diffusion Coefficient Curve for Psychrometer 1:






Project: Austin District
Bore Hole: B2
Sample Depth: 3.5'-5'

Total Length of the sample, L = 13.2 cm

Distance of psychrometer 2 from closed end, x = 11.5 cm

Initial Suction, $u_0$ = 3.21 pF

Relative Humidity = 66.4%

Atmospheric Suction, $u_a$ = 5.76 pF

Diffusion Coefficient, $\alpha = 8.33E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40321, $\pi_{v0}$ = 51 @ 25ºC

Setup Time & Date: 6:12 PM, 04/20/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.5 | 49.95 | 9.0 | 12.4 | 4.10 | 1123 | 12:55 PM | 4/21/2004 |
| 2 | 23.0 | 49.60 | 11.0 | 15.3 | 4.19 | 1413 | 5:45 PM | 4/21/2004 |
| 3 | 23.5 | 49.95 | 22.5 | 32.1 | 4.52 | 2473 | 11:25 AM | 4/22/2004 |
| 4 | 23.5 | 49.95 | 24.5 | 35.1 | 4.55 | 2996 | 8:09 PM | 4/22/2004 |
| 5 | 23.5 | 49.95 | 37.0 | 53.4 | 4.74 | 4173 | 3:46 PM | 4/23/2004 |
| 6 | 24.0 | 50.30 | 39.0 | 56.3 | 4.76 | 4327 | 6:20 PM | 4/23/2004 |

Psychrometer 2:

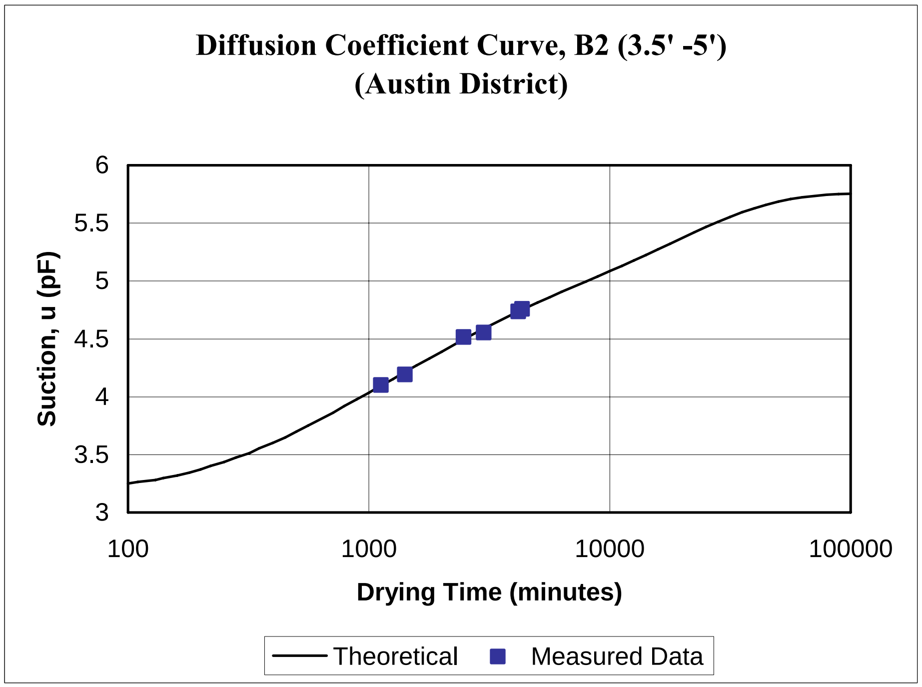
No.: 40338, $\pi_{v0}$ = 50 @ 25ºC

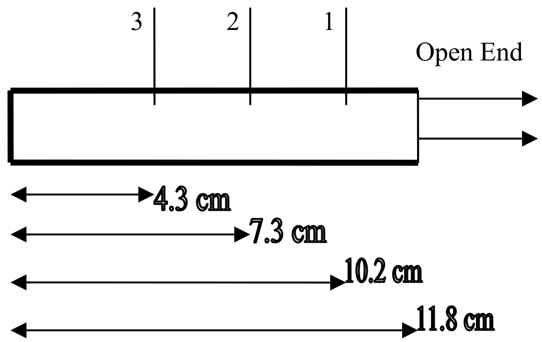
Setup Time & Date: 6:12 PM, 04/20/04

**Project: Austin District**
**Bore Hole: B2**
**Sample Depth: 3.5'-5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 24.0 | 49.30 | 5.0 | 6.9 | 3.85 | 1128 | 1:00 PM | 4/21/2004 |
| 2 | 23.5 | 48.95 | 6.5 | 9.2 | 3.97 | 1415 | 5:47 PM | 4/21/2004 |
| 3 | 24.5 | 49.65 | 10.0 | 14.5 | 4.17 | 2477 | 11:29 AM | 4/22/2004 |
| 4 | 24.0 | 49.30 | 11.5 | 16.8 | 4.23 | 2998 | 8:11 PM | 4/22/2004 |
| 5 | 24.5 | 49.65 | 18.0 | 26.6 | 4.43 | 4174 | 3:47 AM | 4/23/2004 |
| 6 | 24.5 | 49.65 | 18.5 | 27.4 | 4.45 | 4329 | 6:22 PM | 4/23/2004 |
| 7 | 24.0 | 49.30 | 26.5 | 39.5 | 4.61 | 5648 | 4:21 PM | 4/24/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Austin District**
**Bore Hole: B2**
**Sample Depth: 6.5'-8'**

Total Length of the sample, L = 11.8 cm

Distance of psychrometer 2 from closed end, x = 10.2 cm

Initial Suction, $u_0$ = 3.27 pF

Relative Humidity = 66.4%

Atmospheric Suction, $u_a$ = 5.76 pF

Diffusion Coefficient, $\alpha = 5.66E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 43311, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 6:52 PM, 04/20/04

| **No.** | **T** | $\pi_v$ | **µV** | **Total Suction (bar)** | **Total Suction (pF)** | **Time (minutes)** | **Time** | **Date** |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 50.60 | 6.5 | 7.4 | 3.88 | 1113 | 12:45 PM | 4/21/2004 |
| 2 | 23.0 | 50.60 | 8.5 | 10.3 | 4.02 | 1418 | 5:50 PM | 4/21/2004 |
| 3 | 23.0 | 50.60 | 19.5 | 26.0 | 4.42 | 2464 | 11:16 AM | 4/22/2004 |
| 4 | 23.5 | 50.95 | 22.5 | 30.3 | 4.49 | 2984 | 8:13 PM | 4/22/2004 |
| 5 | 23.5 | 50.95 | 35.0 | 48.2 | 4.69 | 4155 | 3:40 PM | 4/23/2004 |
| 6 | 24.0 | 51.30 | 37.0 | 51.1 | 4.72 | 4309 | 9:20 PM | 4/23/2004 |
| 7 | 23.0 | 50.60 | 45.0 | 62.5 | 4.80 | 5441 | 4:14 PM | 4/24/2004 |

Psychrometer 2:

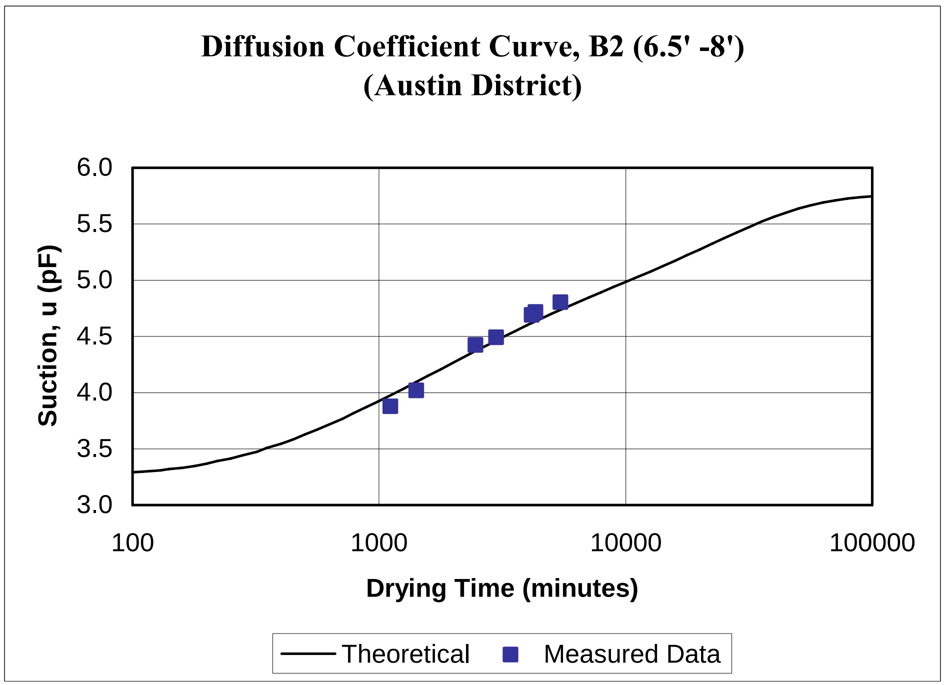
No.: 40321, $\pi_{v0}$ = 49 @ 25ºC

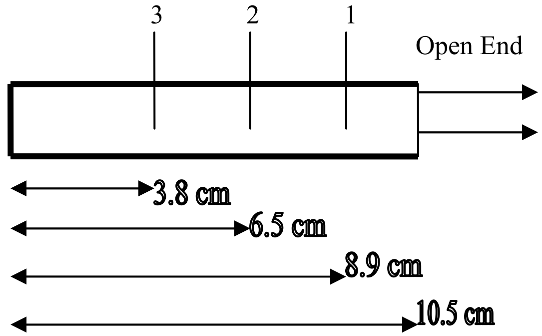
Setup Time & Date: 6:52 PM, 04/20/04

**Project: Austin District**
**Bore Hole: B2**
**Sample Depth: 6.5'-8'**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.5 | 47.95 | 3.5 | 4.6 | 3.67 | 1115 | 12:47 PM | 4/21/2004 |
| 2 | 23.5 | 47.95 | 3.5 | 4.6 | 3.67 | 1421 | 5:53 PM | 4/21/2004 |
| 3 | 24.0 | 48.30 | 6.0 | 8.4 | 3.93 | 2468 | 11:20 AM | 4/22/2004 |
| 4 | 24.0 | 48.30 | 9.0 | 13.0 | 4.12 | 2986 | 8:15 PM | 4/22/2004 |
| 5 | 24.0 | 48.30 | 9.5 | 13.7 | 4.15 | 4159 | 3:44 PM | 4/23/2004 |
| 6 | 24.0 | 48.30 | 10.0 | 14.5 | 4.17 | 4320 | 9:31 PM | 4/23/2004 |
| 7 | 24.0 | 48.30 | 13.0 | 19.0 | 4.29 | 5442 | 4:15 PM | 4/24/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Austin District**
**Bore Hole: B2**
**Sample Depth: 9.5'-10.7'**

Total Length of the sample, L = 10.5 cm

Distance of psychrometer 2 from closed end, x = 8.9 cm

Initial Suction, $u_0$ = 3.21 pF

Relative Humidity = 66.4%

Atmospheric Suction, $u_a$ = 5.76 pF

Diffusion Coefficient, $\alpha = 10.70E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 43450, $\pi_{v0}$ = 52 @ 25ºC

Setup Time & Date: 2:00 PM, 04/07/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 50.60 | 7.0 | 8.1 | 3.92 | 510 | 10:30 PM | 4/7/2004 |
| 2 | 23.0 | 50.60 | 16.5 | 21.7 | 4.35 | 1268 | 11:08 AM | 4/8/2004 |
| 3 | 23.0 | 50.60 | 19.0 | 25.3 | 4.41 | 1545 | 3:45 PM | 4/8/2004 |
| 4 | 23.5 | 50.95 | 24.0 | 32.5 | 4.52 | 2140 | 1:40 AM | 4/9/2004 |
| 5 | 23.5 | 50.95 | 32.0 | 43.9 | 4.65 | 2784 | 12:56 PM | 4/9/2004 |
| 6 | 24.0 | 51.30 | 34.0 | 46.8 | 4.68 | 3174 | 7:26 PM | 4/9/2004 |
| 7 | 24.0 | 51.30 | 38.0 | 52.5 | 4.73 | 3472 | 12:24 PM | 4/10/2004 |

Psychrometer 2:

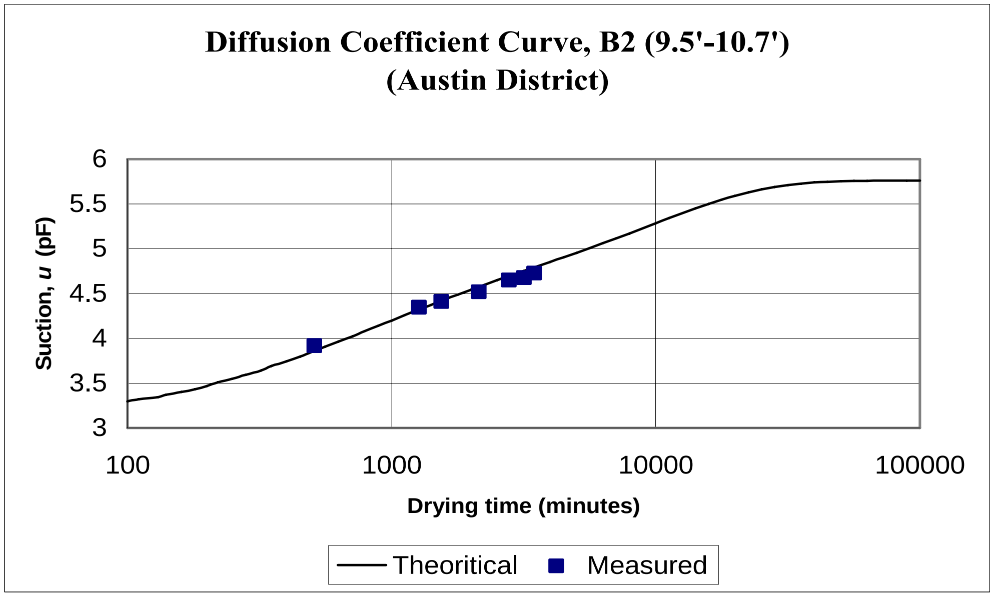
No.: 40321, $\pi_{v0}$ = 51 @ 25ºC

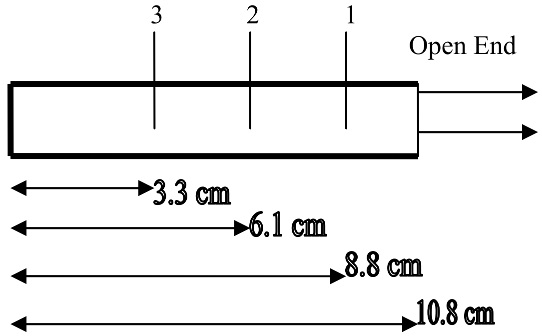
Setup Time & Date: 2:00 PM, 04/07/04

**Project: Austin District**
**Bore Hole: B2**
**Sample Depth: 9.5'-10.7'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.5 | 49.95 | 6.5 | 8.7 | 3.95 | 512 | 10:32 PM | 4/7/2004 |
| 2 | 23.5 | 49.95 | 12.5 | 17.5 | 4.25 | 1270 | 11:10 AM | 4/8/2004 |
| 3 | 23.5 | 49.95 | 13.0 | 18.2 | 4.27 | 1555 | 3:55 PM | 4/8/2004 |
| 4 | 23.0 | 49.60 | 19.0 | 27.0 | 4.44 | 2143 | 1:43 AM | 4/9/2004 |
| 5 | 24.0 | 50.30 | 23.0 | 32.9 | 4.53 | 2786 | 12:58 PM | 4/9/2004 |
| 6 | 24.0 | 50.30 | 23.0 | 32.9 | 4.53 | 3176 | 7:28 PM | 4/9/2004 |
| 7 | 23.0 | 49.60 | 29.0 | 41.7 | 4.63 | 3478 | 12:30 PM | 4/10/2004 |
| 8 | 24.0 | 50.30 | 30.0 | 43.1 | 4.64 | 3891 | 7:23 PM | 4/10/2004 |
| 9 | 23.5 | 49.95 | 35.0 | 50.5 | 4.71 | 5029 | 2:21 PM | 4/11/2004 |
| 10 | 23.5 | 49.95 | 38.0 | 54.9 | 4.75 | 5504 | 10:16 PM | 4/11/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Austin District**
**Bore Hole: B3**
**Sample Depth: 3.5'-5'**

Total Length of the sample, L = 10.8 cm

Distance of psychrometer 2 from closed end, x = 8.8 cm

Initial Suction, $u_0$ = 3.46 pF

Relative Humidity = 56.8%

Atmospheric Suction, $u_a$ = 5.9 pF

Diffusion Coefficient, $\alpha = 3.20E^{-5}$ $cm^2/sec$

Psychrometer 1:

No.: 40316, $\pi_{v0}$ = 58 @ 25ºC

Setup Time & Date: 5:30 PM, 03/24/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 56.25 | 10.5 | 11.0 | 4.05 | 1380 | 4:30 PM | 3/25/2004 |
| 2 | 22.5 | 56.25 | 13.5 | 15.4 | 4.19 | 1865 | 12:35 AM | 3/26/2004 |
| 3 | 22.5 | 56.25 | 21.5 | 27.0 | 4.44 | 2612 | 1:02 PM | 3/26/2004 |
| 4 | 23.5 | 56.95 | 16.0 | 19.0 | 4.29 | 2962 | 6:52 PM | 3/26/2004 |
| 5 | 23.0 | 56.60 | 18.5 | 22.7 | 4.36 | 4731 | 12:21 AM | 3/27/2004 |
| 6 | 23.5 | 56.95 | 23.0 | 29.2 | 4.47 | 5725 | 5:47 PM | 3/27/2004 |
| 7 | 23.5 | 56.95 | 26.5 | 34.3 | 4.54 | 7128 | 5:10 PM | 3/28/2004 |
| 8 | 23.5 | 56.95 | 28.0 | 36.5 | 4.57 | 8821 | 9:23 PM | 3/28/2004 |
| 9 | 22.5 | 56.25 | 37.0 | 49.6 | 4.70 | 9887 | 3:09 PM | 3/29/2004 |

Psychrometer 2:

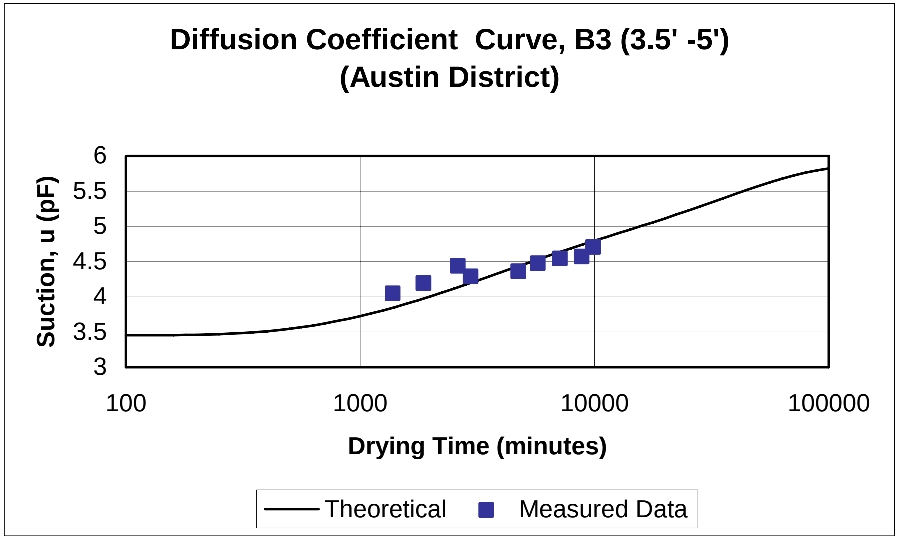
No.: 40325, $\pi_{v0}$ = 49 @ 25ºC

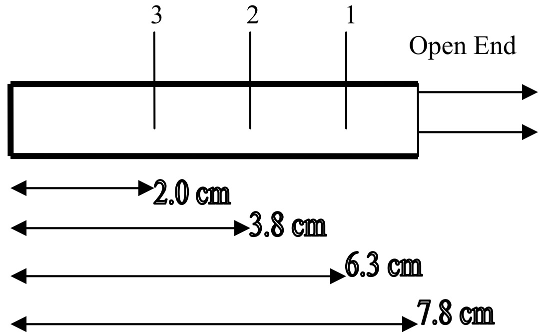
Setup Time & Date: 5:30 PM, 03/24/04

**Project: Austin District**
**Bore Hole: B3**
**Sample Depth: 3.5'-5'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 47.60 | 3.0 | 3.2 | 3.52 | 1385 | 4:35 PM | 3/25/2004 |
| 2 | 23.5 | 47.95 | 3.0 | 3.2 | 3.52 | 1870 | 12:40 AM | 3/26/2004 |
| 3 | 23.5 | 47.95 | 9.0 | 12.0 | 4.09 | 2616 | 1:06 PM | 3/26/2004 |
| 4 | 24.5 | 48.65 | 10.5 | 14.2 | 4.16 | 2968 | 6:58 PM | 3/26/2004 |
| 5 | 23.5 | 47.95 | 10.5 | 14.2 | 4.16 | 4733 | 12:23 AM | 3/27/2004 |
| 6 | 24.0 | 48.30 | 15.0 | 20.7 | 4.32 | 5728 | 5:50 PM | 3/27/2004 |
| 7 | 24.0 | 48.30 | 15.0 | 20.7 | 4.32 | 7130 | 5:12 PM | 3/28/2004 |
| 8 | 24.0 | 48.30 | 17.0 | 23.6 | 4.38 | 8823 | 9:25 PM | 3/28/2004 |
| 9 | 23.5 | 47.95 | 20.5 | 28.7 | 4.47 | 9890 | 3:12 PM | 3/29/2004 |
| 10 | 23.5 | 47.95 | 25.0 | 35.3 | 4.56 | 11141 | 1:03 PM | 3/30/2004 |
| 11 | 23.5 | 47.95 | 33.0 | 46.9 | 4.68 | 11680 | 10:02 PM | 3/30/2004 |
| 12 | 24.0 | 48.30 | 38.0 | 54.2 | 4.74 | 12555 | 12:37 PM | 3/31/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Austin District**
**Bore Hole: B3**
**Sample Depth: 6.5'-8'**

Total Length of the sample, L = 7.8 cm

Distance of psychrometer 2 from closed end, x = 6.3 cm

Initial Suction, $u_0$ = 3.64 pF

Relative Humidity = 56.8%

Atmospheric Suction, $u_a$ = 5.9 pF

Diffusion Coefficient, $\alpha = 1.56E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40293, $\pi_{v0}$ = 57@ 25ºC

Setup Time & Date: 5:00 PM, 03/24/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.0 | 55.60 | 9.0 | 10.8 | 4.04 | 1192 | 4:52 PM | 3/25/2004 |
| 2 | 23.0 | 55.60 | 11.0 | 13.6 | 4.14 | 2385 | 12:45 PM | 3/26/2004 |
| 3 | 23.0 | 55.60 | 16.5 | 21.4 | 4.34 | 3855 | 1:15 PM | 3/26/2004 |
| 4 | 24.0 | 56.30 | 20.0 | 26.3 | 4.43 | 5625 | 6:45 PM | 3/26/2004 |
| 5 | 23.5 | 55.95 | 23.5 | 31.3 | 4.50 | 5839 | 12:11 AM | 3/27/2004 |
| 6 | 23.5 | 55.95 | 24.0 | 32.0 | 4.51 | 6918 | 6:10 PM | 3/27/2004 |
| 7 | 24.0 | 56.30 | 25.0 | 33.4 | 4.53 | 8288 | 5:00 PM | 3/28/2004 |

Psychrometer 2:

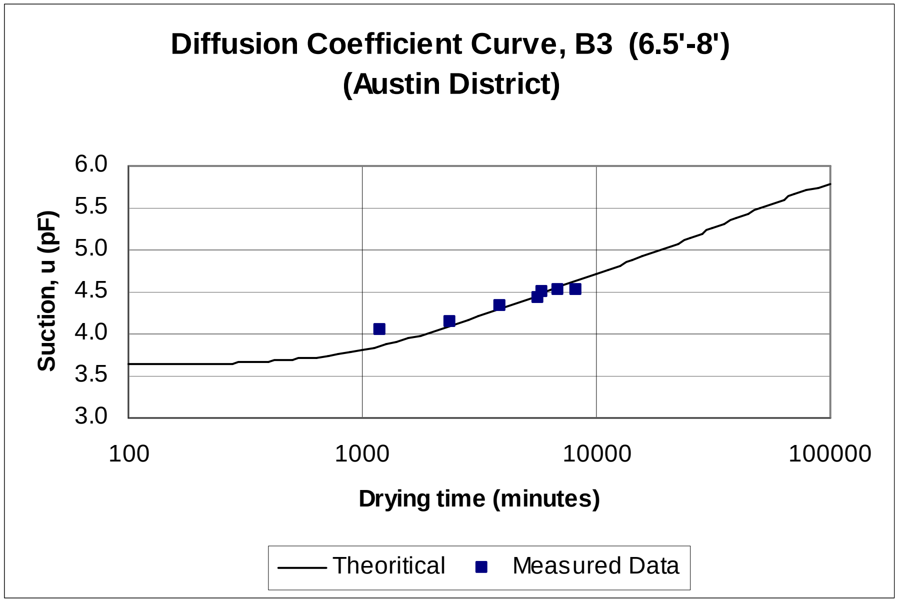
No.: 40325, $\pi_{v0} = 49$ @ 25ºC

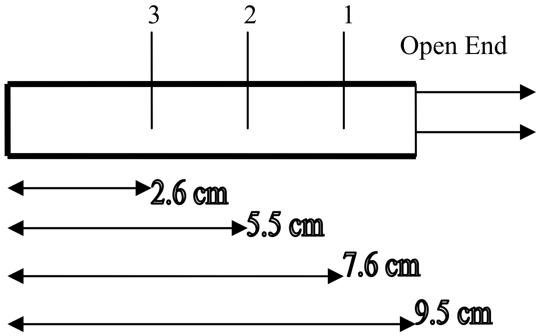
Setup Time & Date: 5:00 PM, 03/24/04

**Project: Austin District**
**Bore Hole: B3**
**Sample Depth: 6.5’-8’**

| No. | T | $\pi_v$ | μV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 24.0 | 59.30 | 8.0 | 10.3 | 4.02 | 1198 | 4:58 PM | 3/25/2004 |
| 2 | 24.0 | 59.30 | 12.0 | 16.0 | 4.21 | 2390 | 12:50 PM | 3/26/2004 |
| 3 | 24.0 | 59.30 | 25.0 | 34.3 | 4.54 | 3890 | 1:20 PM | 3/26/2004 |
| 4 | 24.0 | 59.30 | 20.0 | 27.2 | 4.44 | 5636 | 6:46 PM | 3/26/2004 |
| 5 | 23.5 | 58.95 | 18.5 | 25.1 | 4.41 | 5842 | 12:14 AM | 3/27/2004 |
| 6 | 24.0 | 59.30 | 26.0 | 35.7 | 4.56 | 6919 | 6:11 PM | 3/27/2004 |
| 7 | 24.0 | 59.30 | 34.0 | 47.0 | 4.68 | 8290 | 5:02 PM | 3/28/2004 |
| 8 | 24.0 | 59.30 | 36.0 | 49.8 | 4.71 | 8562 | 9:34 PM | 3/28/2004 |
| 9 | 23.5 | 58.95 | 40.0 | 55.4 | 4.75 | 9611 | 3:03 PM | 3/29/2004 |

Diffusion Coefficient Curve for Psychrometer 1:






**Project: Austin District**
**Bore Hole: B3**
**Sample Depth: 9.5'-11'**

Total Length of the sample, L = 9.5 cm

Distance of psychrometer 2 from closed end, x = 7.6 cm

Initial Suction, $u_0$ = 3.77 pF

Relative Humidity = 60.87%

Atmospheric Suction, $u_a$ = 5.84 pF

Diffusion Coefficient, $\alpha = 4.66E^{-5}$ $cm^2$/sec

Psychrometer 1:

No.: 40338, $\pi_{v0}$ = 49@ 25ºC

Setup Time & Date: 2:10 PM, 04/07/04

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.5 | 47.25 | 10.0 | 14.5 | 4.17 | 492 | 10:22 PM | 4/7/04 |
| 2 | 23.5 | 47.95 | 15.5 | 22.8 | 4.37 | 1250 | 11:00 AM | 4/8/04 |
| 3 | 23.5 | 47.95 | 19.0 | 28.1 | 4.46 | 1525 | 3:35 PM | 4/8/04 |
| 4 | 23.0 | 47.60 | 20.5 | 30.4 | 4.49 | 2126 | 1:36 AM | 4/9/04 |
| 5 | 23.5 | 47.95 | 22.5 | 33.4 | 4.53 | 2811 | 1:01 PM | 4/9/04 |
| 6 | 24.5 | 48.65 | 26.5 | 39.5 | 4.61 | 3505 | 12:35 PM | 4/10/04 |
| 7 | 24.0 | 48.30 | 28.0 | 41.8 | 4.63 | 3967 | 7:17 PM | 4/10/04 |
| 8 | 23.0 | 47.60 | 34.0 | 50.9 | 4.72 | 5124 | 2:34 PM | 4/11/04 |
| 9 | 24.0 | 48.30 | 38.0 | 56.9 | 4.76 | 5580 | 10:10 PM | 4/11/04 |

Psychrometer 2:

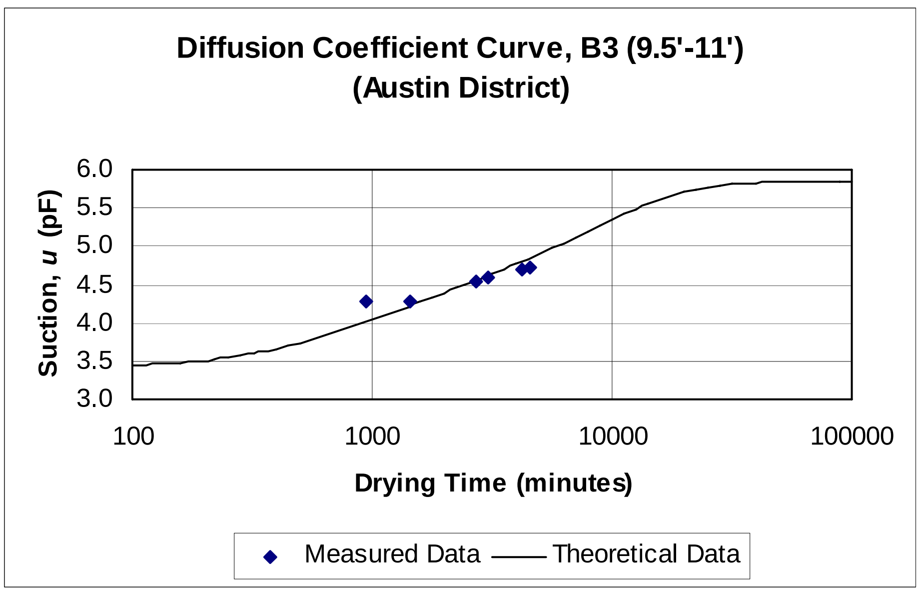
No.: 40330, $\pi_{v0}$ = 51 @ 25ºC

Setup Time & Date: 2:10 PM, 04/07/04

**Project: Austin District**
**Bore Hole: B3**
**Sample Depth: 9.5'-11'**

| No. | T | $\pi_v$ | µV | Total Suction (bar) | Total Suction (pF) | Time (minutes) | Time | Date |
|---|---|---|---|---|---|---|---|---|
| 1 | 23.5 | 49.95 | 7.5 | 10.0 | 4.01 | 495 | 10:25 PM | 4/7/04 |
| 2 | 24.0 | 50.30 | 11.5 | 15.9 | 4.21 | 1252 | 11:02 AM | 4/8/04 |
| 3 | 23.5 | 49.95 | 12.0 | 16.7 | 4.23 | 1530 | 3:40 PM | 4/8/04 |
| 4 | 23.5 | 49.95 | 16.0 | 22.6 | 4.36 | 2125 | 1:35 AM | 4/9/04 |
| 5 | 24.0 | 50.30 | 16.5 | 23.4 | 4.38 | 2814 | 1:04 PM | 4/9/04 |
| 6 | 24.5 | 50.65 | 20.0 | 28.6 | 4.47 | 3510 | 12:40 PM | 4/10/04 |
| 7 | 24.5 | 50.65 | 22.0 | 31.6 | 4.51 | 3970 | 7:20 PM | 4/10/04 |
| 8 | 24.0 | 50.30 | 29.0 | 42.1 | 4.63 | 5127 | 2:37 PM | 4/11/04 |
| 9 | 24.5 | 50.65 | 30.0 | 43.5 | 4.65 | 5584 | 10:14 PM | 4/11/04 |

Diffusion Coefficient Curve for Psychrometer 1:



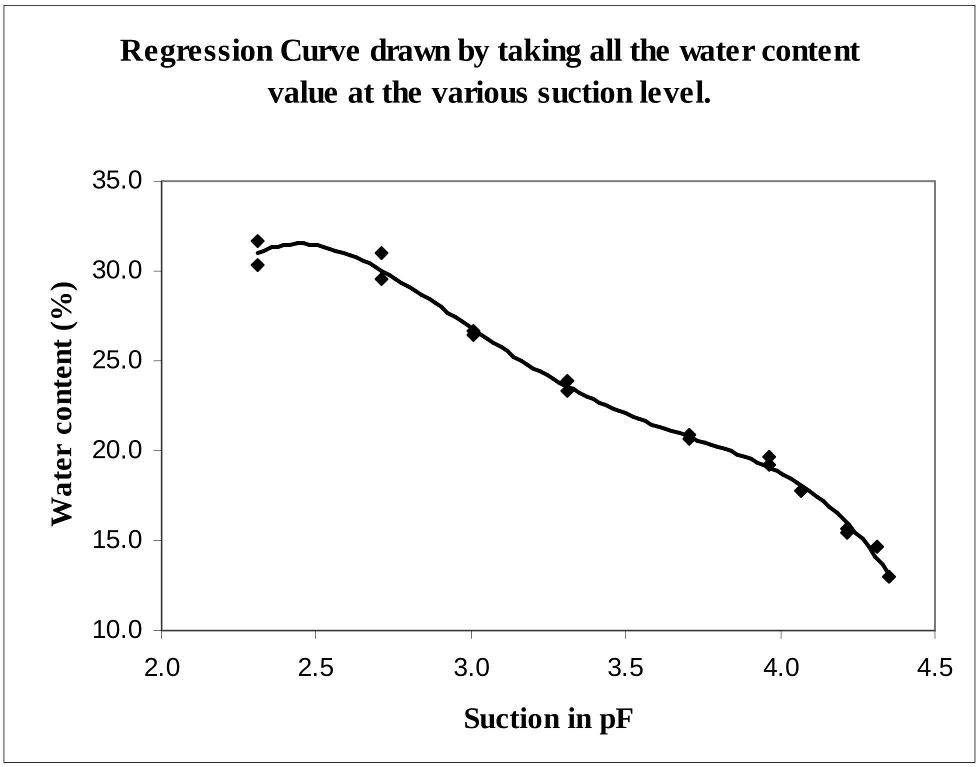
# APPENDIX B

This appendix includes the suction versus water content values of different soil samples obtained from the pressure plate and pressure membrane tests carried out in laboratory. There are three subparts: APPENDIX B-1, APPENDIX B-2, and APPENDIX B-3, that shows the data of Fort Worth, Atlanta, and Austin Districts respectively.

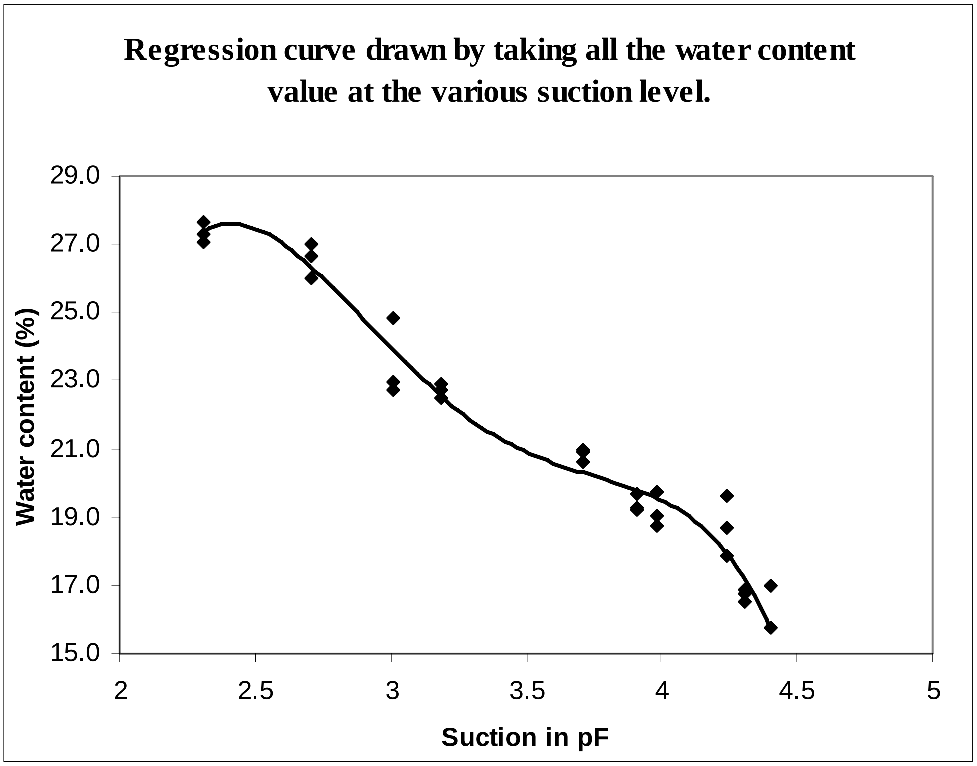
# APPENDIX B-1

## FORT WORTH DISTRICT

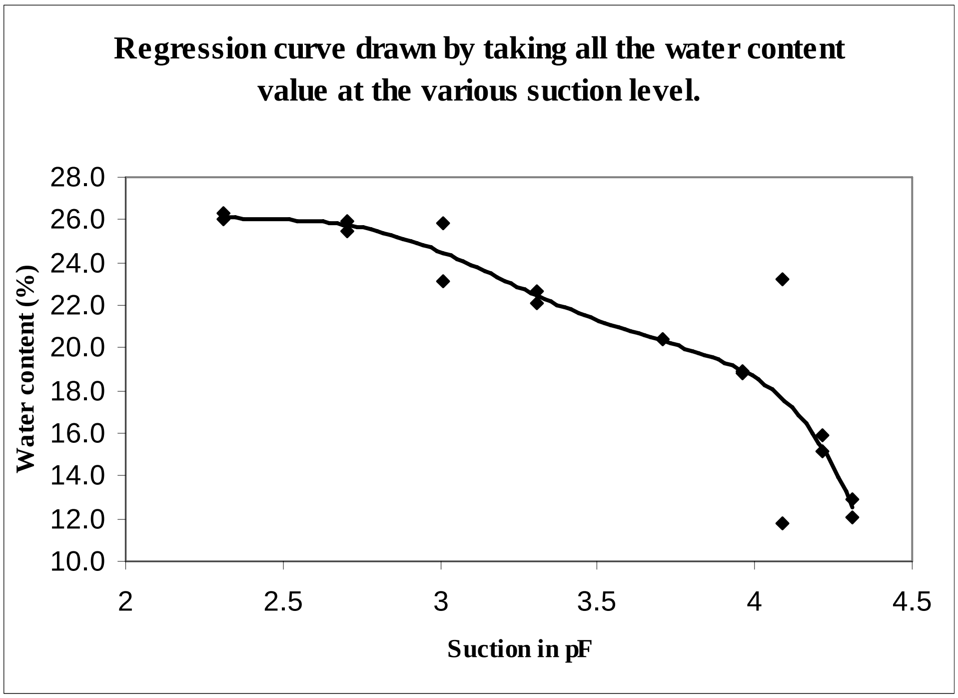
**Sample: BH- A1.**
**Depth: 11'-12'.**
**Slope, 'S': -8.60.**
**Air Entry Value, '$h_o$': 512.86 cm.**



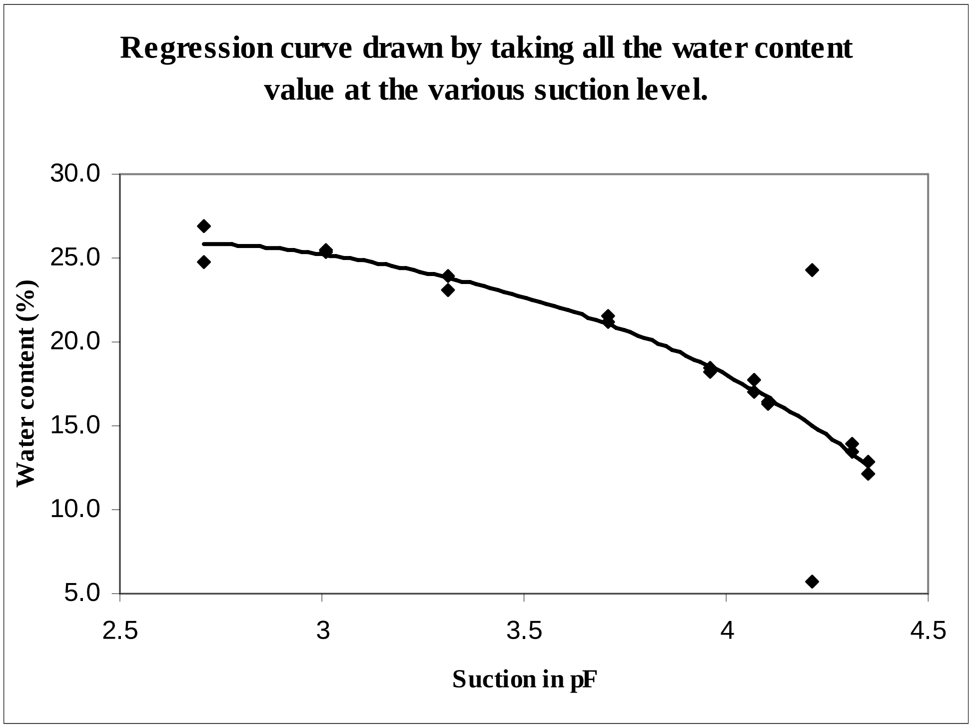
**Sample: BH- A2.**
**Depth: 12’-13’.**
**Slope, ‘S’: -8.57.**
**Air Entry Value, ‘$h_o$’: 501.19 cm.**



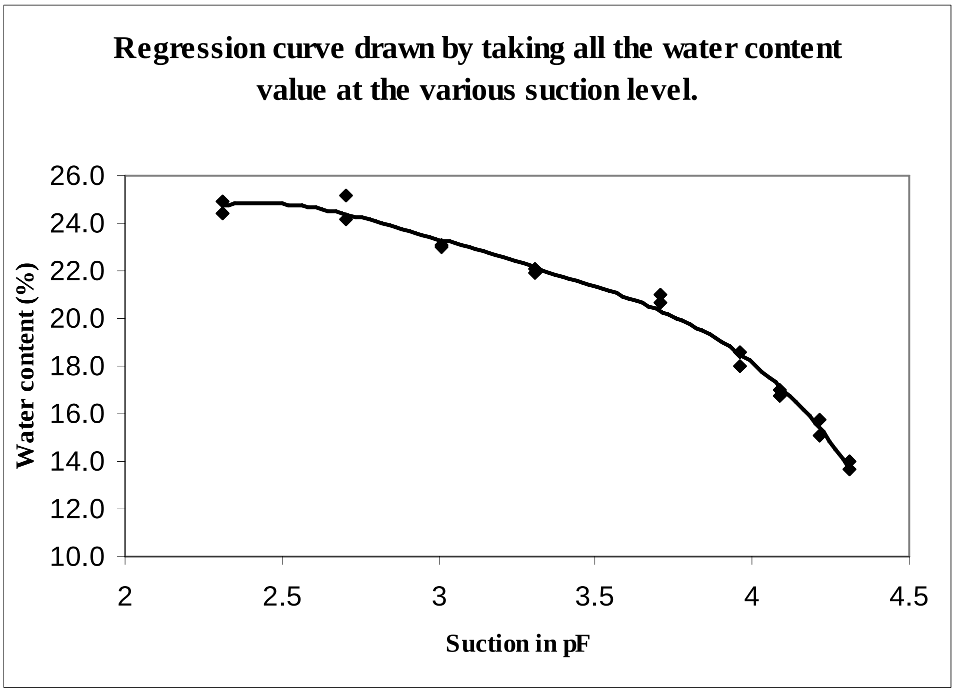
**Sample: BH- A2.**
**Depth: 6'-7'.**
**Slope, 'S': -6.55.**
**Air Entry Value, '$h_o$': 707.95 cm.**



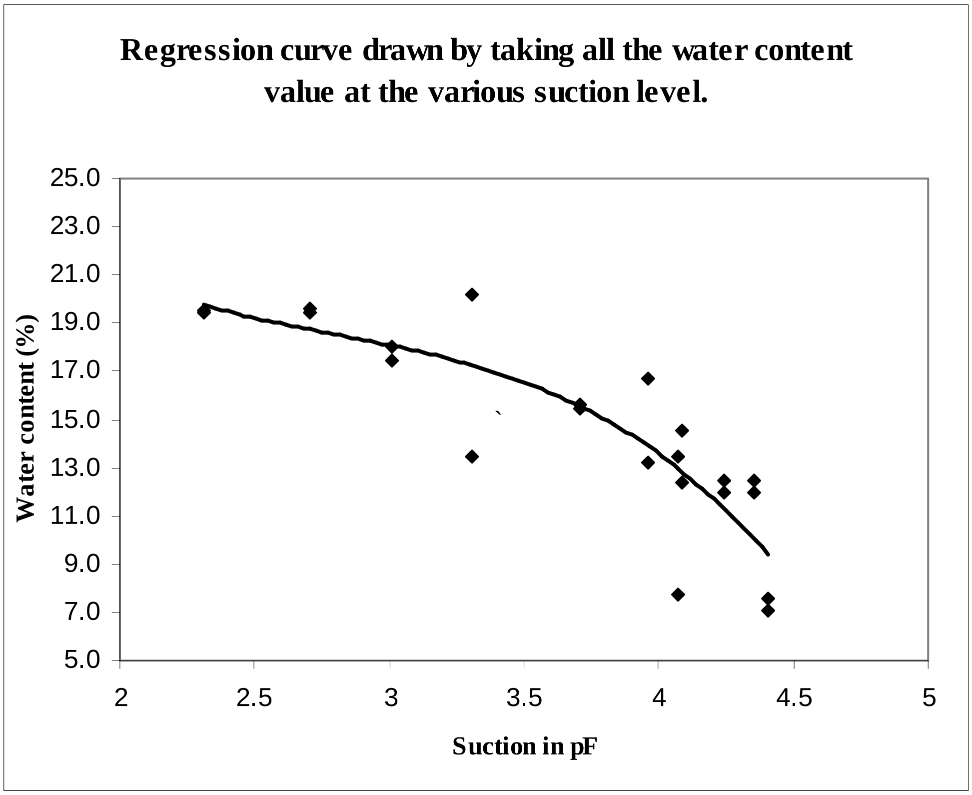
**Sample: BH- A3.**
**Depth: 11’-13’.**
**Slope, ‘S’: -6.8.**
**Air Entry Value, ‘$h_o$’: 562.34 cm.**



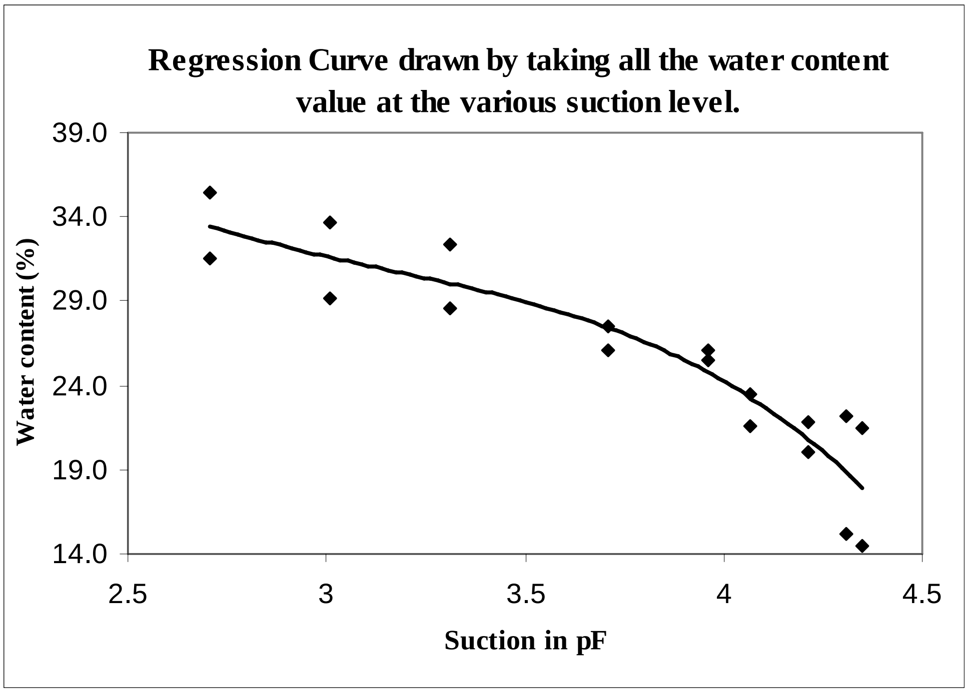
**Sample: BH- B2.**
**Depth: 10'-11'.**
**Slope, 'S': -7.38.**
**Air Entry Value, '$h_o$': 398.11cm.**



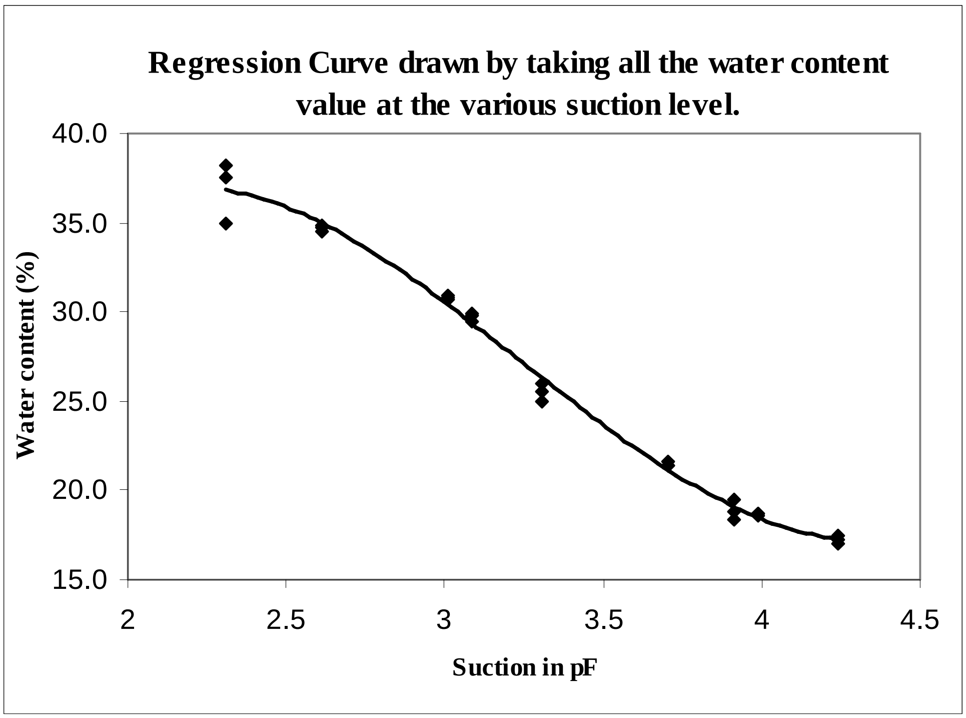
**Sample: BH- B5.**
**Depth: 6’-7’.**
**Slope, ‘S’: -6.43.**
**Air Entry Value, ‘$h_o$’: 524.81cm.**



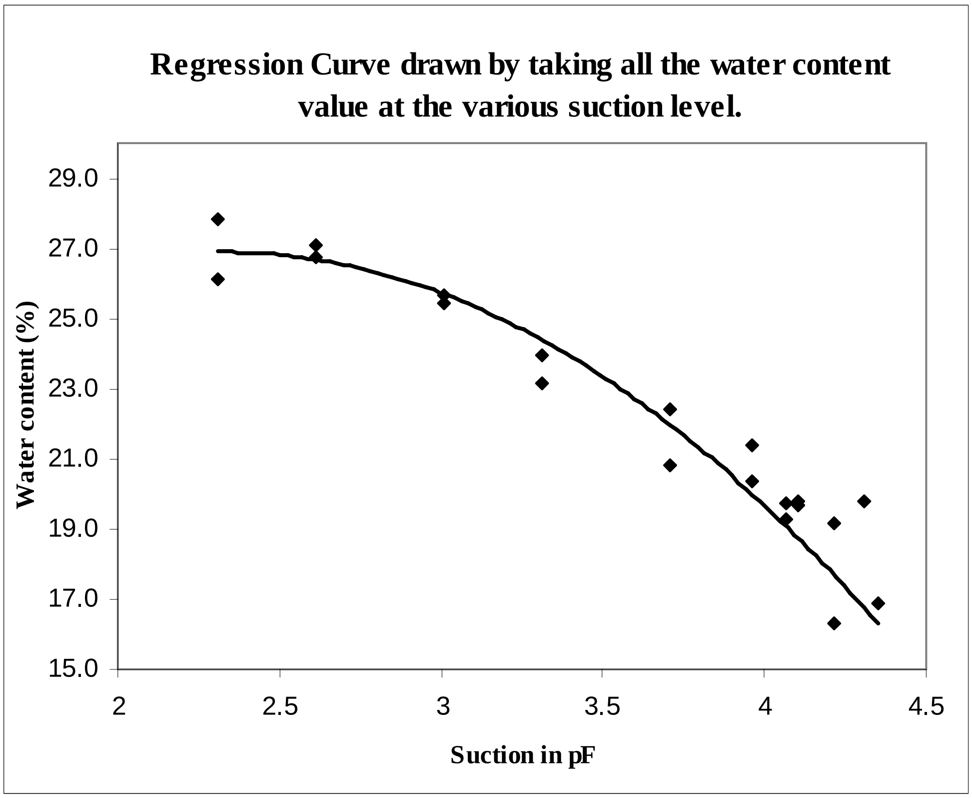
**Sample: BH- C2.**
**Depth: 4’-5’.**
**Slope, ‘S’: -8.23.**
**Air Entry Value, ‘$h_o$’: 524.81cm.**



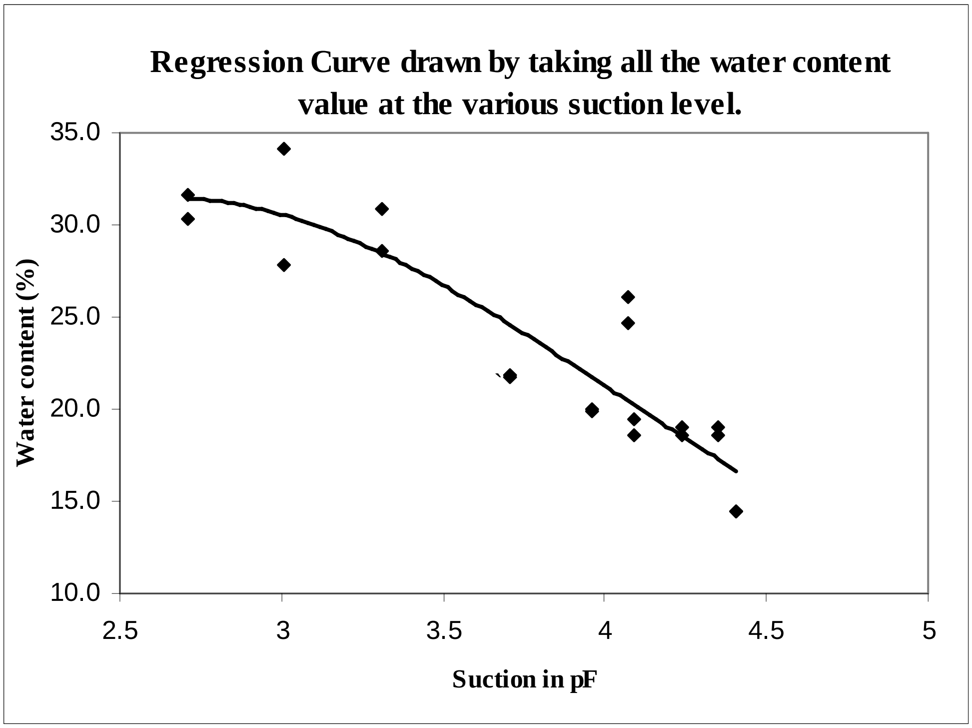
**Sample: BH- C2.**
**Depth: 5'-6'.**
**Slope, 'S': -12.00.**
**Air Entry Value, '$h_o$': 380.19cm.**



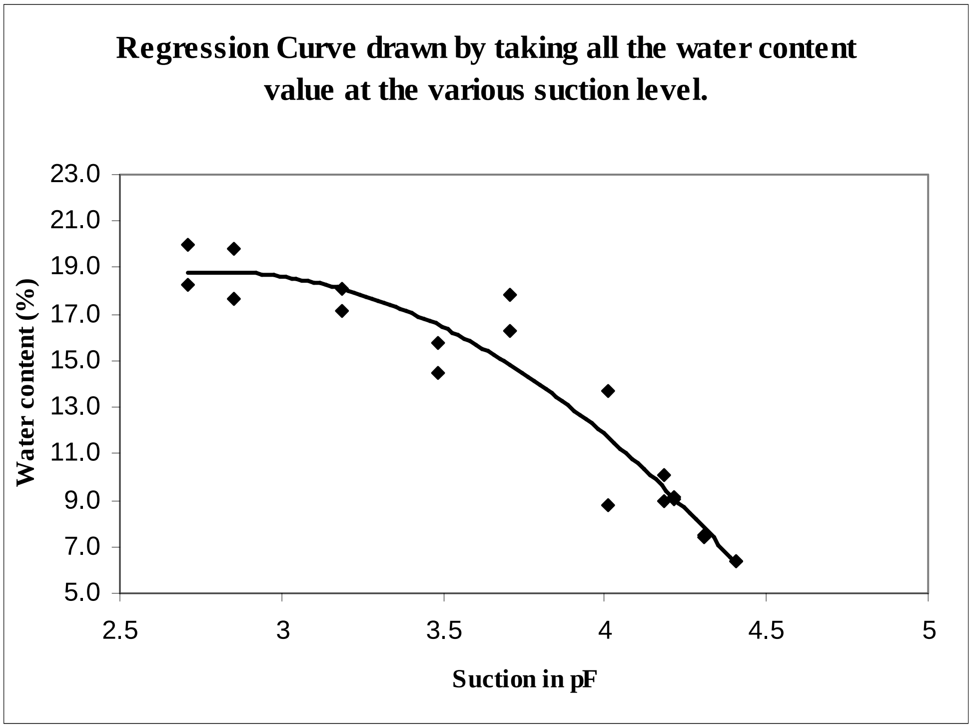
**Sample: BH- C3.**
**Depth: 6'-7'.**
**Slope, 'S': -6.60.**
**Air Entry Value, '$h_o$': 446.68cm.**



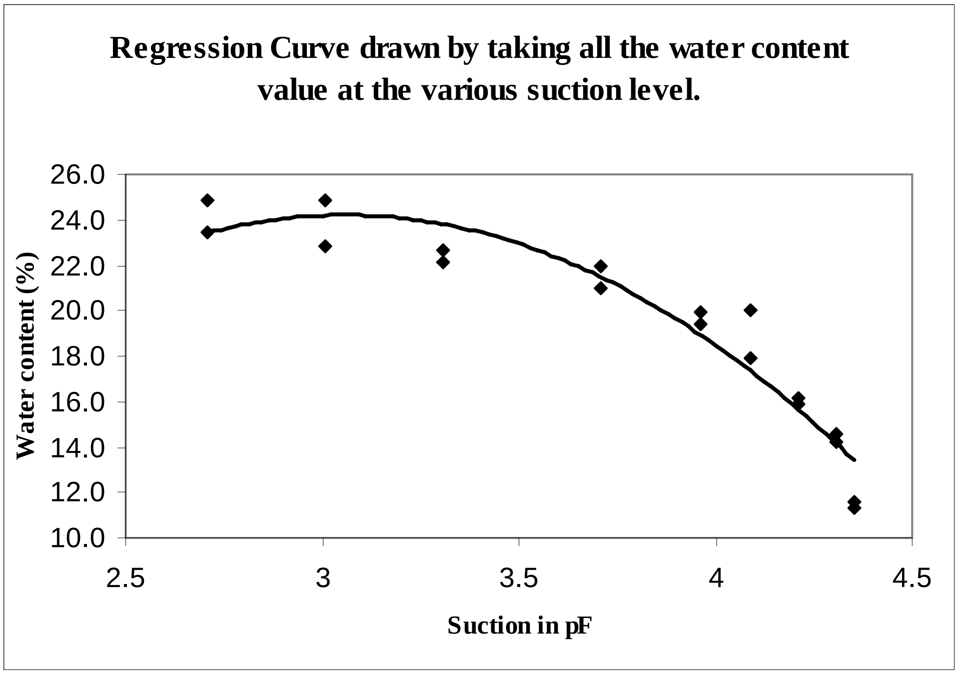
**Sample: BH- C1.**
**Depth: 2’-3’.**
**Slope, ‘S’: -8.8.**
**Air Entry Value, ‘$h_o$’: 776.25 cm.**



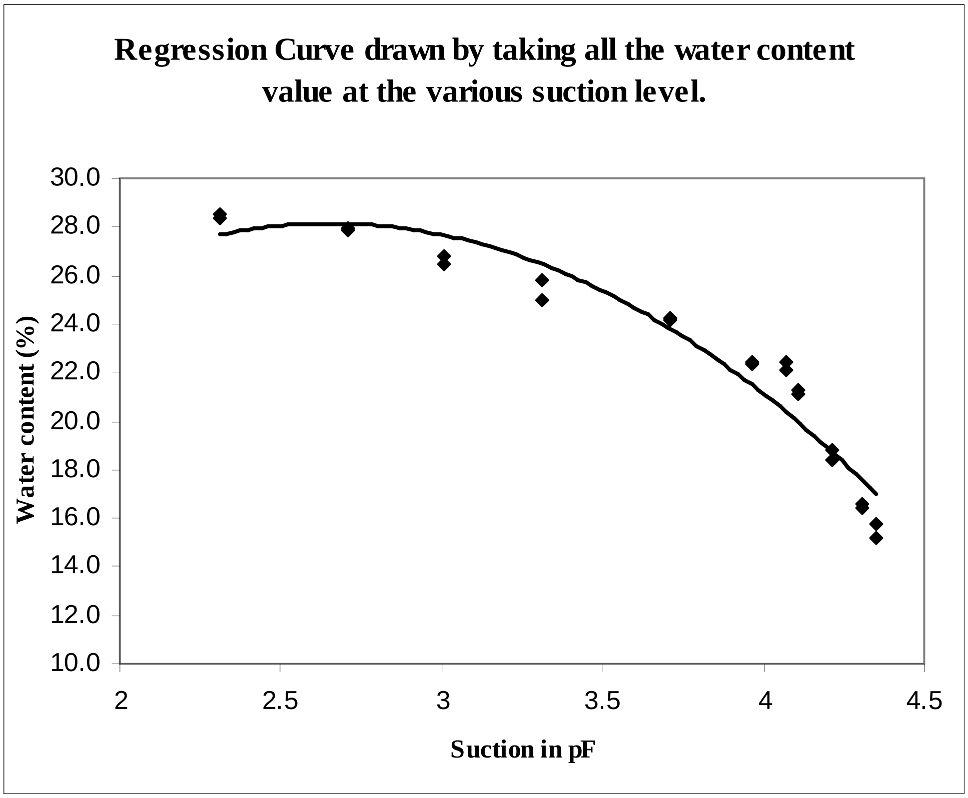
**Sample: BH- C4.**
**Depth: 5'-6'.**
**Slope, 'S': -8.3.**
**Air Entry Value, '$h_o$': 562.34 cm.**



**Sample: BH- C5.**
**Depth: 10'-11'.**
**Slope, 'S': -7.16.**
**Air Entry Value, '$h_o$': 794.33 cm.**



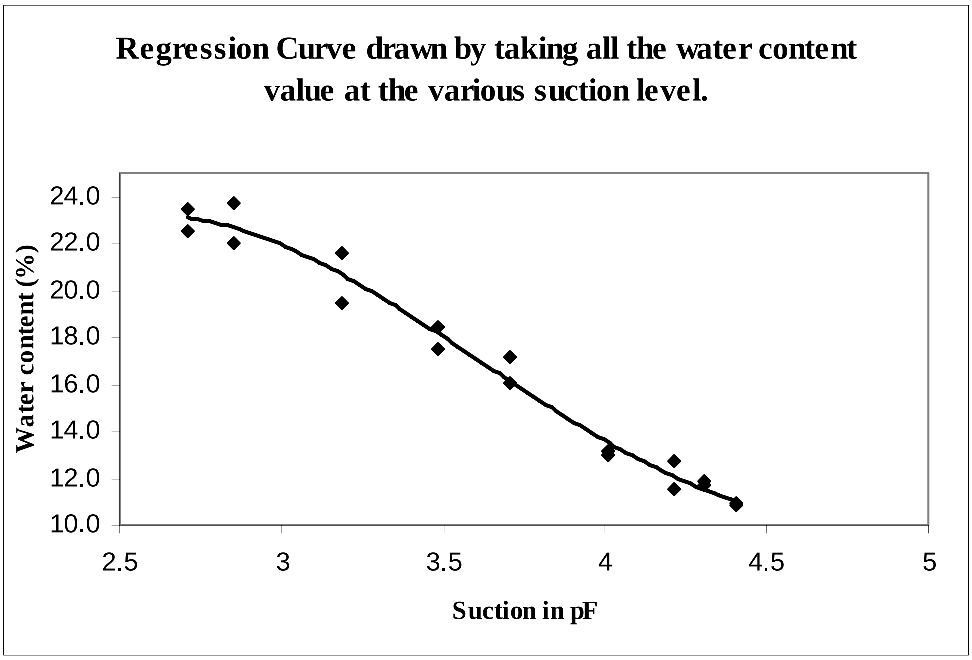
**Sample: BH- C5.**
**Depth: 7’-8’.**
**Slope, ‘S’: -7.08.**
**Air Entry Value, ‘$h_o$’: 501.19 cm.**



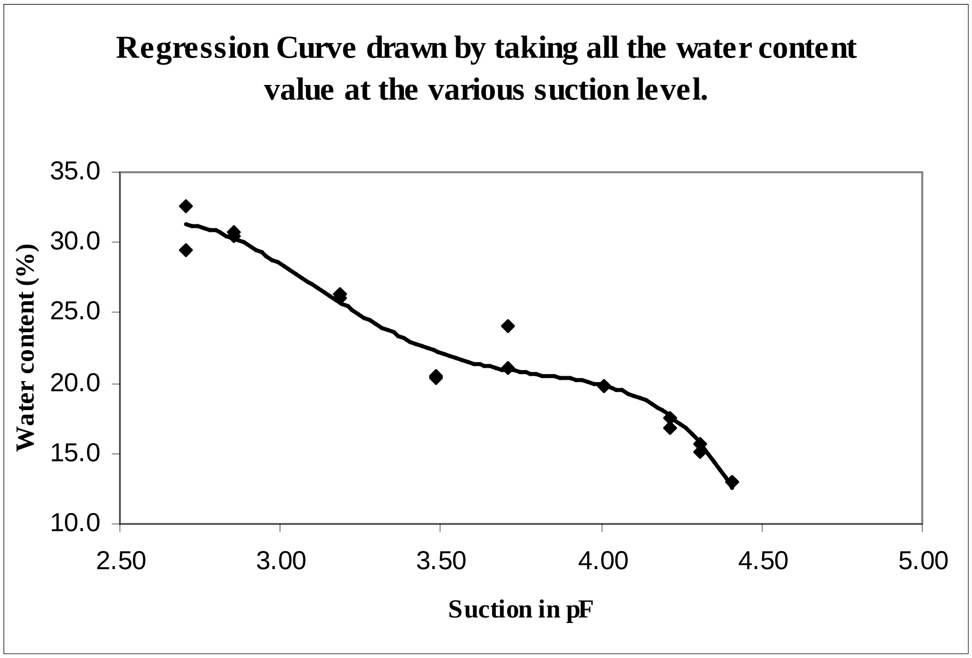
# APPENDIX B-2

# ATLANTA DISTRICT

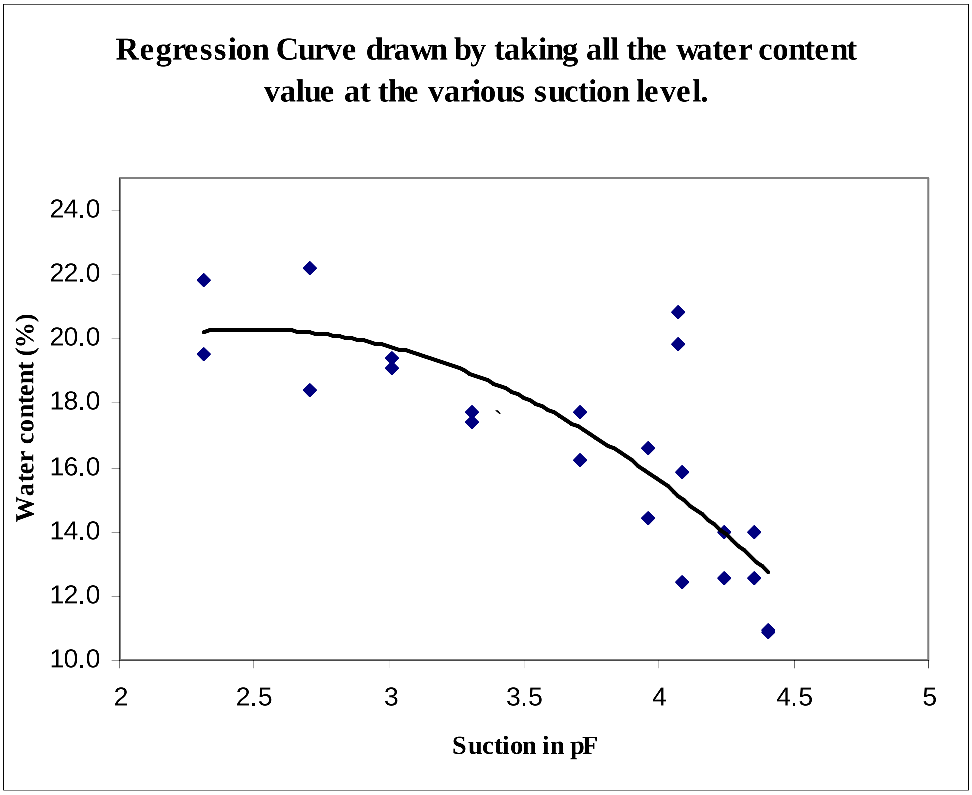
**Sample: BH- C5.**
**Depth: 7'-8'.**
**Slope, 'S': -8.12.**
**Air Entry Value, '$h_o$': 316.23 cm.**



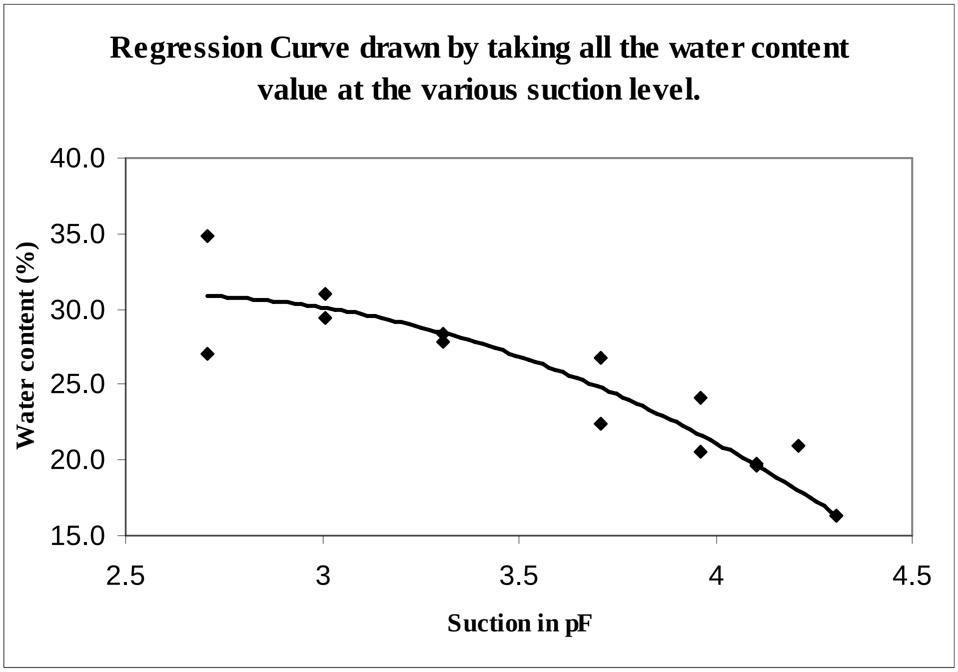
**Sample: BH- B2.**
**Depth: 7'-9'.**
**Slope, 'S': -12.50.**
**Air Entry Value, '$h_o$': 660.69 cm.**



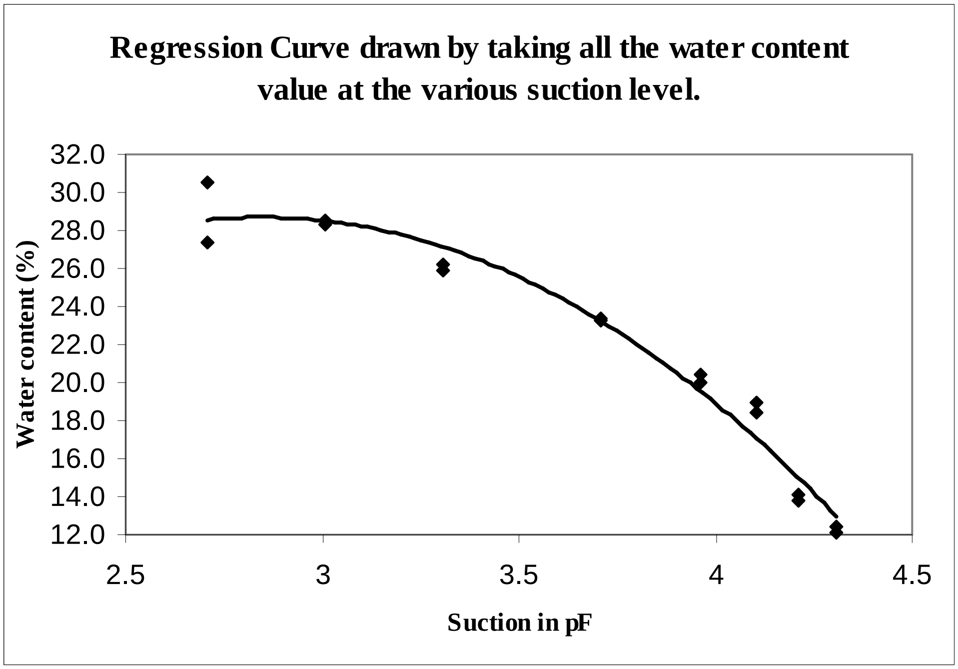
**Sample: BH- B2.**
**Depth: 11’-13’.**
**Slope, ‘S’: -6.36.**
**Air Entry Value, ‘$h_o$’: 630.96 cm.**



**Sample: BH- C1.**
**Depth: 2'-4'.**
**Slope, 'S': -8.41.**
**Air Entry Value, '$h_o$': 501.19 cm.**



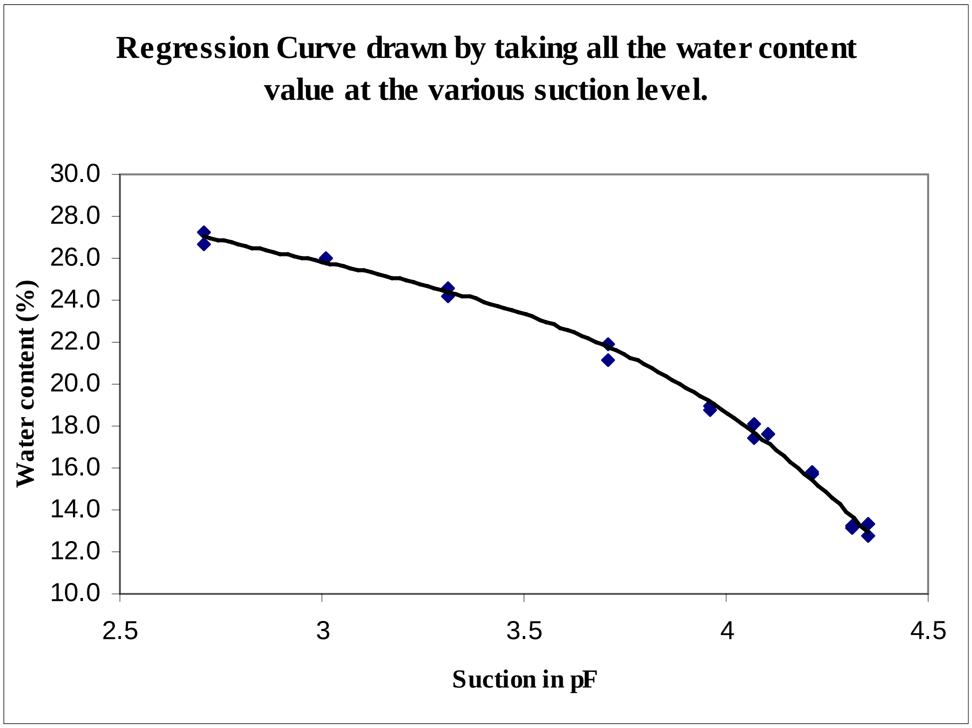
**Sample: BH- C2.**
**Depth: 9'-11'.**
**Slope, 'S': -8.11.**
**Air Entry Value, '$h_o$': 741.31 cm.**



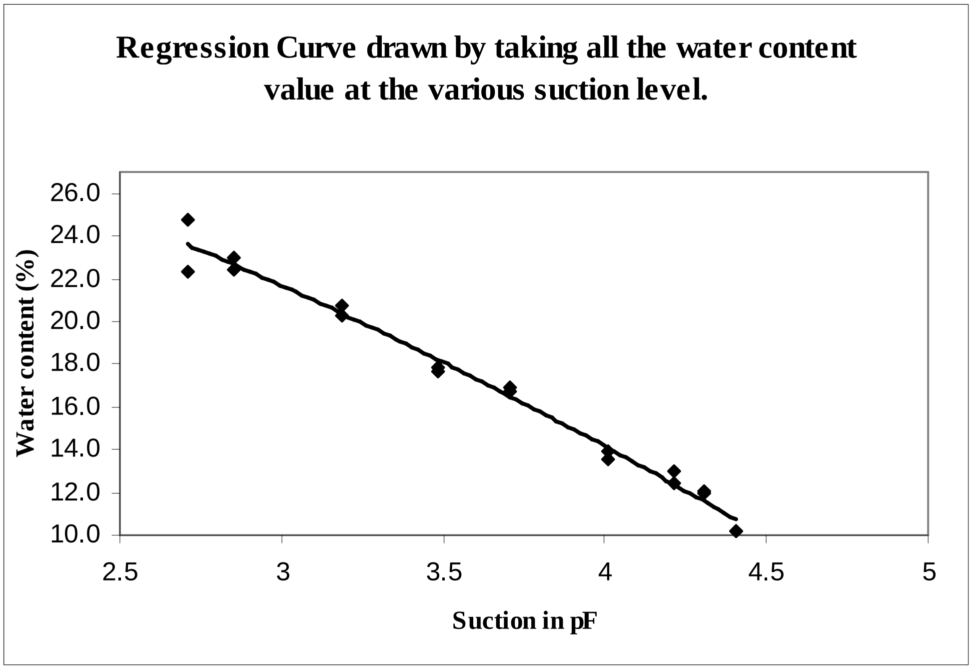
# APPENDIX B-3

## AUSTIN DISTRICT

**Sample: BH- B1.**
**Depth: 3.5’-5’.**
**Slope, ‘S’: -8.05.**
**Air Entry Value, ‘$h_o$’: 512.86 cm.**



**Sample: BH- B3.**
**Depth: 9.5'-11'.**
**Slope, 'S': -7.3.**
**Air Entry Value, '$h_o$': 501.19 cm.**



# APPENDIX C

This appendix includes the raw data of the one-dimensional consolidation test of different soil samples tested in laboratory. There are three subparts: APPENDIX C-1, APPENDIX C-2, and APPENDIX C-3, that shows the data of Fort Worth, Atlanta, and Austin Districts respectively.

# APPENDIX C-1

# FORT WORTH DISTRICT

**Sample Detail:**
**Remolded specimen**

BH C2 7'-8'

**Height of the sample=**22 mm
**Diameter of the sample =** 63 mm

| | | |
|---|---|---|
| **LL** | 52 | |
| **PL** | 19 | |
| **PI** | 33 | |
| **CF** | 25 | CF= Clay fraction= % finer than 2 microns |

**Water Content Calculation:**

*Initial:*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 346.2 gm
Weight of the soil sample= 129.8 gm

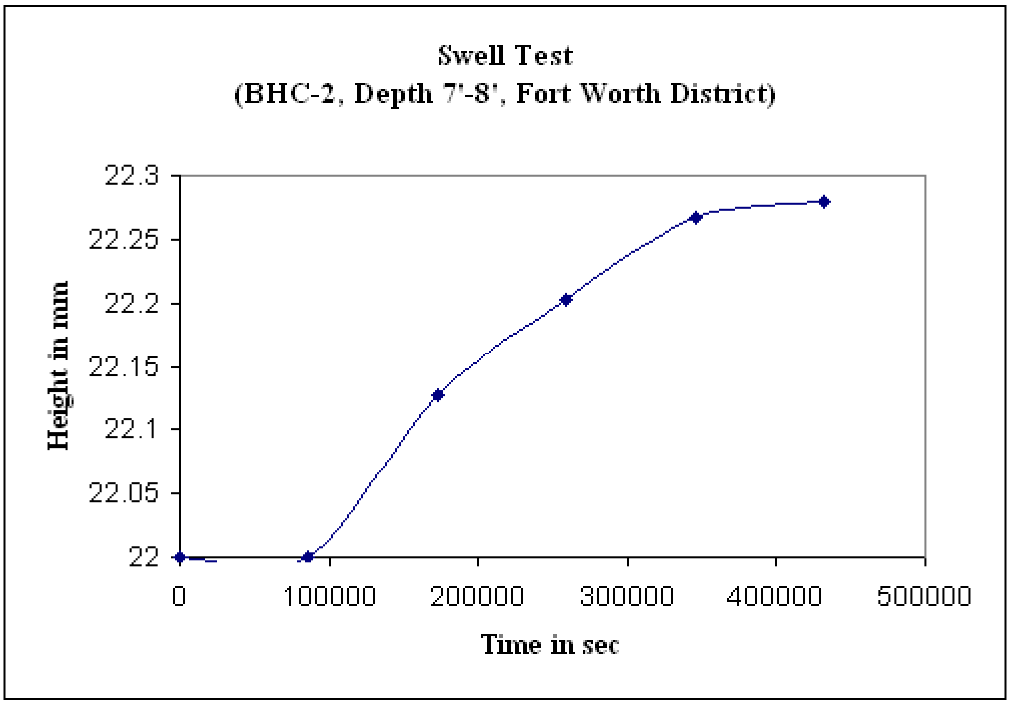
| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 10 | 8.6 | 19.17 |

*Final*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 346.9 gm
Weight of the soil sample= 130.5 gm

| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 6.8 | 5.89 | 19.82 |

**SWELL TEST:**

| S No | Time (hr) | Time (sec) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 22 | 0.667857 |
| 2 | 24 | 86400 | -3 | 22 | 0.667857 |
| 3 | 48 | 172800 | -5 | 22.127 | 0.677485 |
| 4 | 72 | 259200 | -8 | 22.2032 | 0.6832619 |
| 5 | 96 | 345600 | -10.5 | 22.2667 | 0.6880759 |
| 6 | 120 | 432000 | -11 | 22.2794 | 0.6890387 |



**1) Calculation of dry mass of total specimen:**

$$\boxed{M_d = \frac{M_{Tf}}{1 + W_{fp}}}$$

Here,
$M_{tf}$= moist mass of the specimen after test, g or kg =130.5 gm
$W_{fp}$= Water content (decimal form) wedge of specimen taken after test = 19.82 gm

So, $M_d$= 108.90 gm

**2) Calculation of volume of solids:**

$$\boxed{V_s = \frac{M_d}{G \rho_w}}$$

Here,
$M_d$= Dry mass of total specimen= 108.91 gm
G= specific gravity of the soild= 2.65 (assumed)
$\rho_w$= density of water= 1gm/cm$^3$

So, Vs= 41.10 cm$^3$

**3) Calculation of specimen area A (cm$^2$):** 31.16cm$^2$

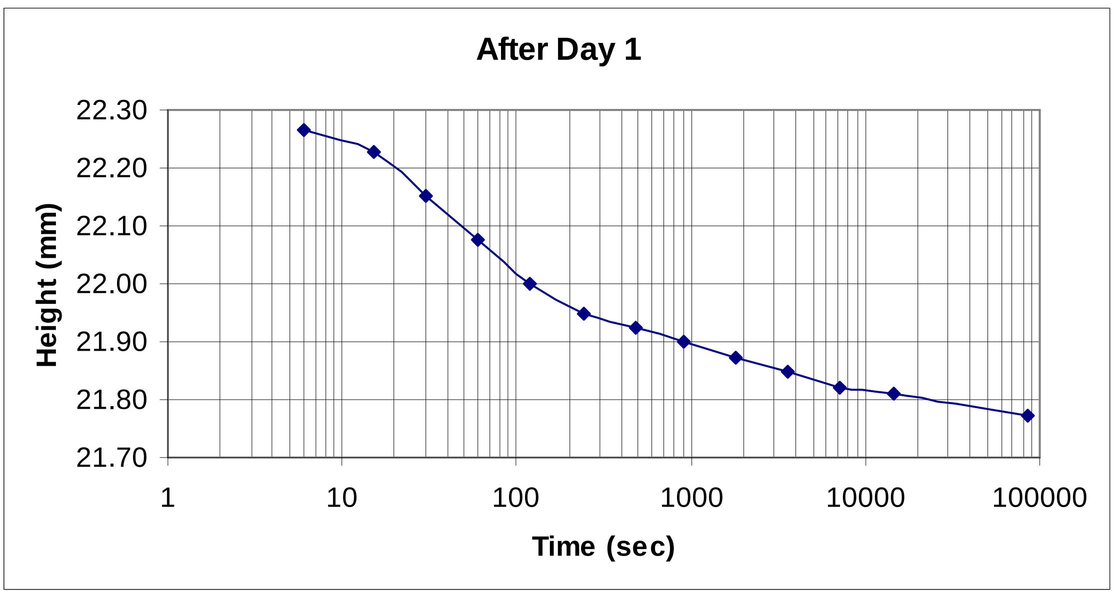
**4) Calculation of Equivalent height of solids ($H_s$)**

$$\boxed{H_s = \frac{Vs}{A}}$$

**So, $H_s$ =**1.32 cm

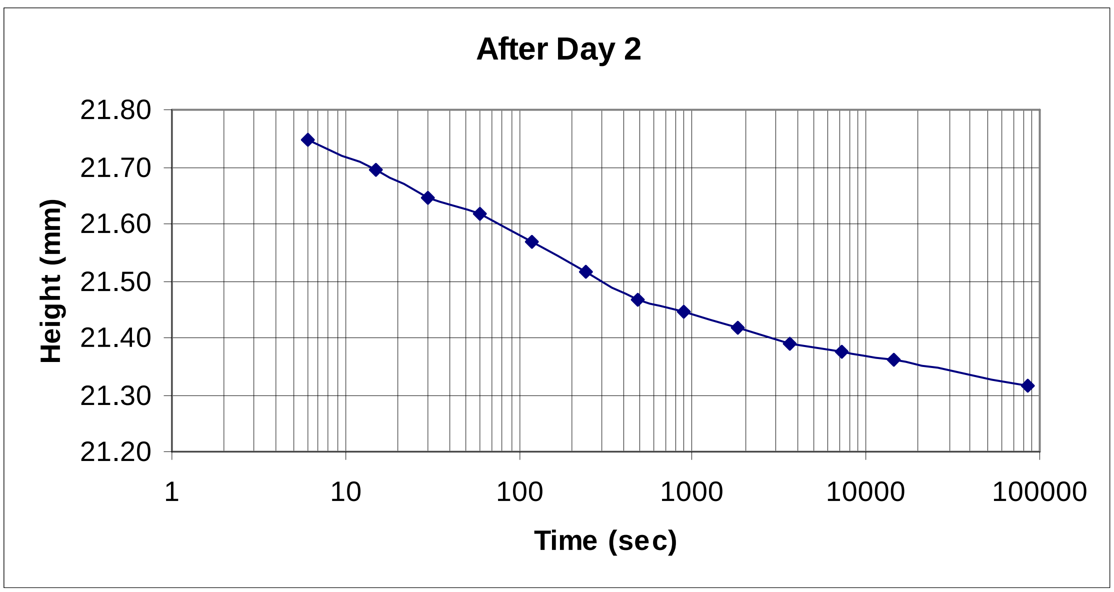
*Day 1*

| S.no. | Day | time (min) | time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.1 | 6 | 25 | 0.5 | 22.27 | 0.69 |
| | | 0.25 | 15 | | 2 | 22.23 | 0.69 |
| | | 0.5 | 30 | | 5 | 22.15 | 0.68 |
| | | 1 | 60 | | 8 | 22.08 | 0.67 |
| | | 2 | 120 | | 11 | 22.00 | 0.67 |
| | | 4 | 240 | | 13 | 21.95 | 0.66 |
| | | 8 | 480 | | 14 | 21.92 | 0.66 |
| | | 15 | 900 | | 15 | 21.90 | 0.66 |
| | | 30 | 1800 | | 16 | 21.87 | 0.66 |
| | | 60 | 3600 | | 17 | 21.85 | 0.66 |
| | | 120 | 7200 | | 18 | 21.82 | 0.65 |
| | | 240 | 14400 | | 18.5 | 21.81 | 0.65 |
| | | 1440 | 86400 | | 20 | 21.77 | 0.65 |



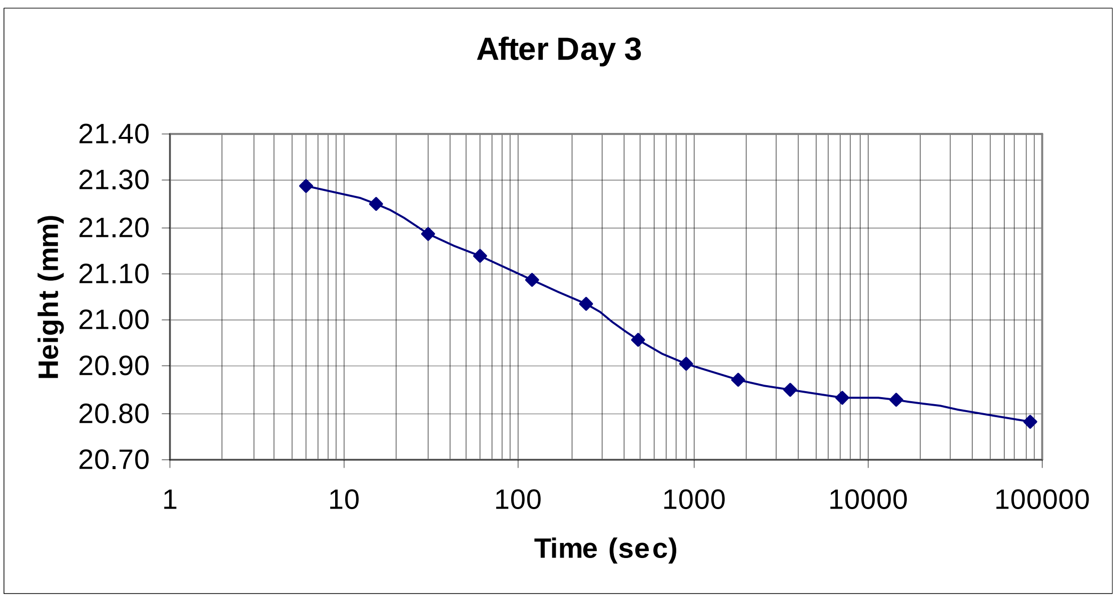
*Day 2*

| S.no. | Day | time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 0.1 | 6 | 50 | 1 | 21.75 | 0.65 |
| | | 0.25 | 15 | | 3 | 21.70 | 0.64 |
| | | 0.5 | 30 | | 5 | 21.64 | 0.64 |
| | | 1 | 60 | | 6 | 21.62 | 0.64 |
| | | 2 | 120 | | 8 | 21.57 | 0.64 |
| | | 4 | 240 | | 10 | 21.52 | 0.63 |
| | | 8 | 480 | | 12 | 21.47 | 0.63 |
| | | 15 | 900 | | 12.8 | 21.45 | 0.63 |
| | | 30 | 1800 | | 14 | 21.42 | 0.62 |
| | | 60 | 3600 | | 15 | 21.39 | 0.62 |
| | | 120 | 7200 | | 15.6 | 21.38 | 0.62 |
| | | 240 | 14400 | | 16.2 | 21.36 | 0.62 |
| | | 1440 | 86400 | | 18 | 21.31 | 0.62 |



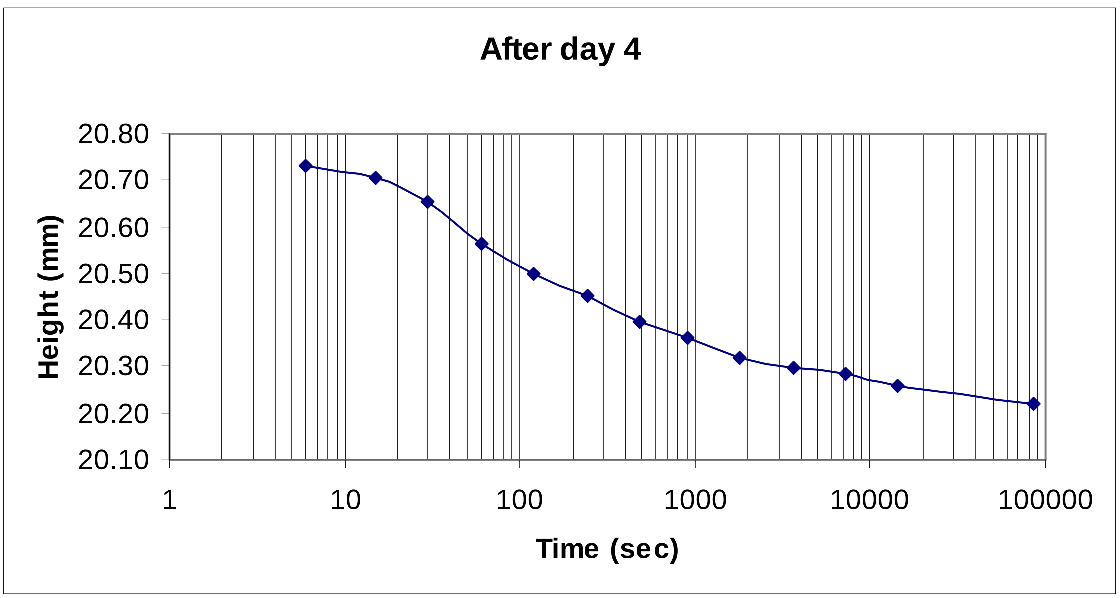
*Day 3*

| S.no. | Day | time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 3 | 3 | 0.1 | 6 | 100 | 1 | 21.29 | 0.61 |
| | | 0.25 | 15 | | 2.5 | 21.25 | 0.61 |
| | | 0.5 | 30 | | 5 | 21.19 | 0.61 |
| | | 1 | 60 | | 7 | 21.14 | 0.60 |
| | | 2 | 120 | | 9 | 21.09 | 0.60 |
| | | 4 | 240 | | 11 | 21.03 | 0.59 |
| | | 8 | 480 | | 14 | 20.96 | 0.59 |
| | | 15 | 900 | | 16 | 20.91 | 0.59 |
| | | 30 | 1800 | | 17.5 | 20.87 | 0.58 |
| | | 60 | 3600 | | 18.3 | 20.85 | 0.58 |
| | | 120 | 7200 | | 19 | 20.83 | 0.58 |
| | | 240 | 14400 | | 19.1 | 20.83 | 0.58 |
| | | 1440 | 86400 | | 21 | 20.78 | 0.58 |



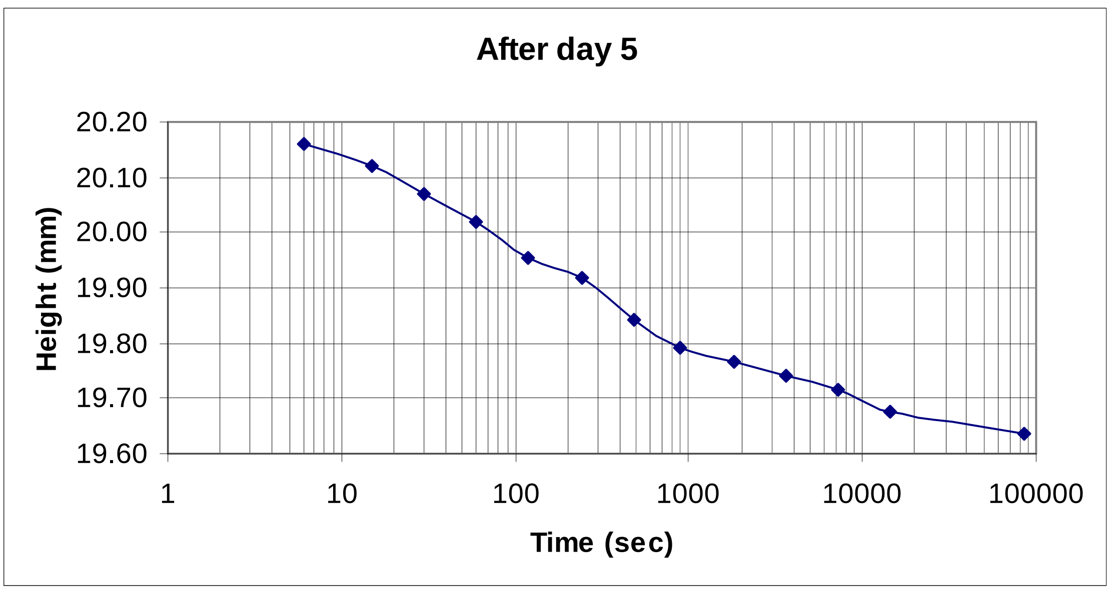
*Day 4*

| S.no. | Day | time (min) | time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 4 | 4 | 0.1 | 6 | 200 | 2 | 20.73 | 0.57 |
| | | 0.25 | 15 | | 3 | 20.70 | 0.57 |
| | | 0.5 | 30 | | 5 | 20.65 | 0.57 |
| | | 1 | 60 | | 8.5 | 20.56 | 0.56 |
| | | 2 | 120 | | 11 | 20.50 | 0.55 |
| | | 4 | 240 | | 13 | 20.45 | 0.55 |
| | | 8 | 480 | | 15.2 | 20.39 | 0.55 |
| | | 15 | 900 | | 16.5 | 20.36 | 0.54 |
| | | 30 | 1800 | | 18.2 | 20.32 | 0.54 |
| | | 60 | 3600 | | 19 | 20.30 | 0.54 |
| | | 120 | 7200 | | 19.5 | 20.29 | 0.54 |
| | | 240 | 14400 | | 20.5 | 20.26 | 0.54 |
| | | 1440 | 86400 | | 22 | 20.22 | 0.53 |



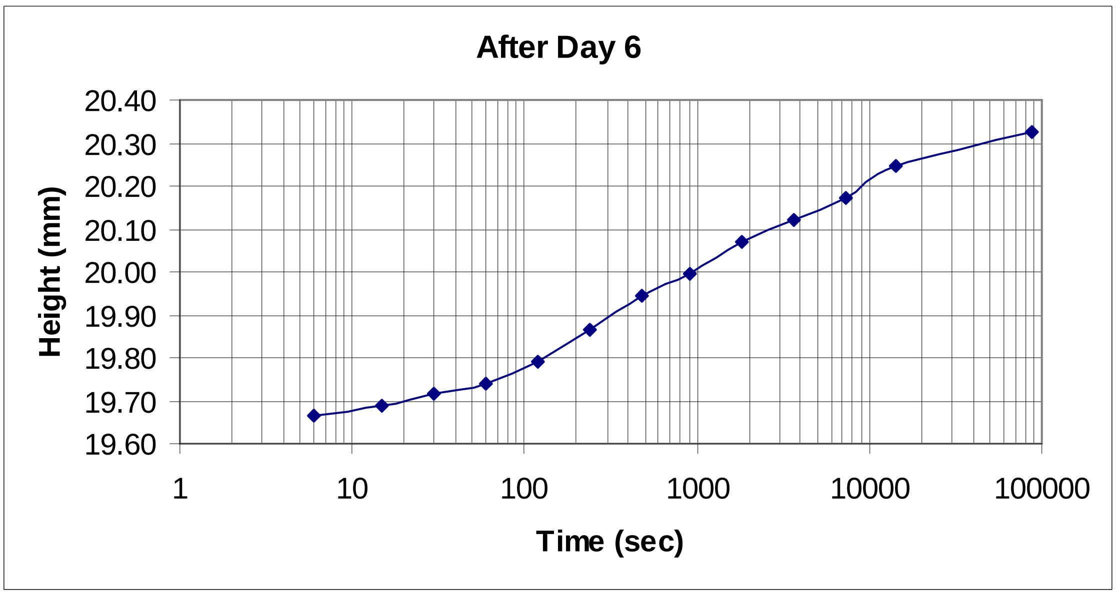
*Day 5*

| S.no. | Day | time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 5 | 5 | 0.1 | 6 | 400 | 2.5 | 20.16 | 0.53 |
| | | 0.25 | 15 | | 4 | 20.12 | 0.53 |
| | | 0.5 | 30 | | 6 | 20.07 | 0.52 |
| | | 1 | 60 | | 8 | 20.02 | 0.52 |
| | | 2 | 120 | | 10.5 | 19.96 | 0.51 |
| | | 4 | 240 | | 12 | 19.92 | 0.51 |
| | | 8 | 480 | | 15 | 19.84 | 0.50 |
| | | 15 | 900 | | 17 | 19.79 | 0.50 |
| | | 30 | 1800 | | 18 | 19.76 | 0.50 |
| | | 60 | 3600 | | 19 | 19.74 | 0.50 |
| | | 120 | 7200 | | 20 | 19.71 | 0.49 |
| | | 240 | 14400 | | 21.5 | 19.68 | 0.49 |
| | | 1440 | 86400 | | 23 | 19.64 | 0.49 |



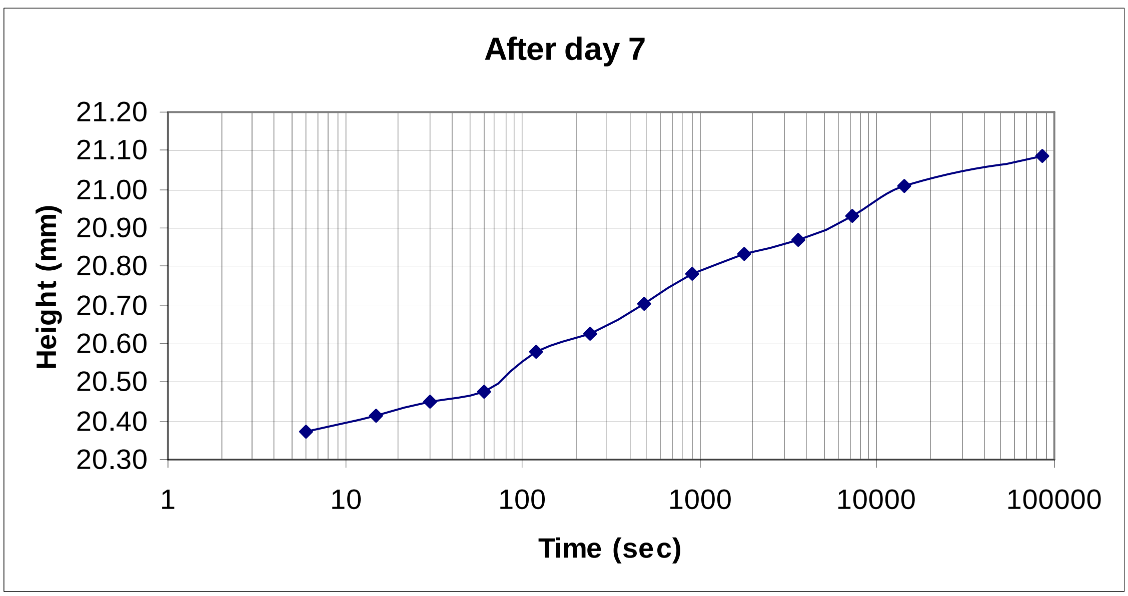
*Day 6*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 6 | 6 | 0.1 | 6 | 25 | -1 | 19.66 | 0.49 |
| | | 0.25 | 15 | | -2 | 19.69 | 0.49 |
| | | 0.5 | 30 | | -3 | 19.71 | 0.49 |
| | | 1 | 60 | | -4 | 19.74 | 0.50 |
| | | 2 | 120 | | -6 | 19.79 | 0.50 |
| | | 4 | 240 | | -9 | 19.87 | 0.51 |
| | | 8 | 480 | | -12 | 19.94 | 0.51 |
| | | 15 | 900 | | -14 | 19.99 | 0.52 |
| | | 30 | 1800 | | -17 | 20.07 | 0.52 |
| | | 60 | 3600 | | -19 | 20.12 | 0.53 |
| | | 120 | 7200 | | -21 | 20.17 | 0.53 |
| | | 240 | 14400 | | -24 | 20.25 | 0.53 |
| | | 1440 | 86400 | | -27 | 20.32 | 0.54 |



*Day 7*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 7 | 7 | 0.1 | 6 | 5 | -2 | 20.37 | 0.54 |
| | | 0.25 | 15 | | -3.5 | 20.41 | 0.55 |
| | | 0.5 | 30 | | -5 | 20.45 | 0.55 |
| | | 1 | 60 | | -6 | 20.48 | 0.55 |
| | | 2 | 120 | | -10 | 20.58 | 0.56 |
| | | 4 | 240 | | -12 | 20.63 | 0.56 |
| | | 8 | 480 | | -15 | 20.70 | 0.57 |
| | | 15 | 900 | | -18 | 20.78 | 0.58 |
| | | 30 | 1800 | | -20 | 20.83 | 0.58 |
| | | 60 | 3600 | | -21.5 | 20.87 | 0.58 |
| | | 120 | 7200 | | -24 | 20.93 | 0.59 |
| | | 240 | 14400 | | -27 | 21.01 | 0.59 |
| | | 1440 | 86400 | | -30 | 21.09 | 0.60 |



**Sample Detail:**
**Remolded sample**

BH A3 9'-10'

**Height of the sample=**22 mm
**Diameter of the sample =**62mm

| | | |
|---|---|---|
| **LL** | 67 | |
| **PL** | 22 | |
| **PI** | 45 | |
| **CF** | 30 | CF= Clay fraction= % finer than 2 microns |

**Water Content Calculation:**
*Initial:*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 345.2gm
Weight of the soil sample=128.8 gm

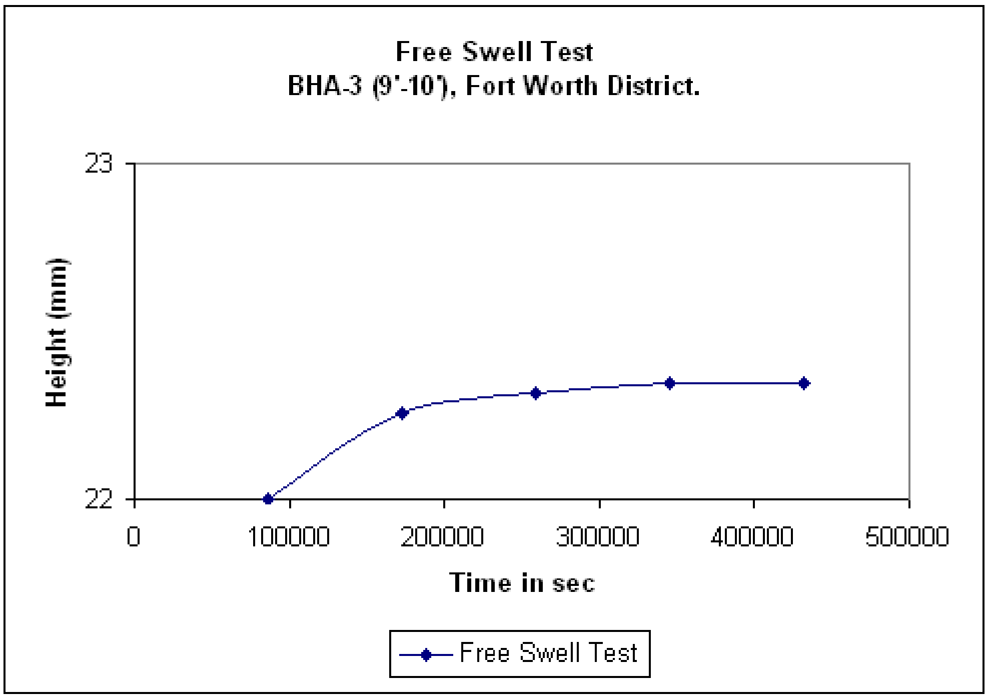
| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 14.7 | 12.08 | 24.30 |

*Final*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 344.8 gm
Weight of the soil sample=128.4 gm

| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 10.5 | 8.7 | 24.32 |

**SWELL TEST:**

| S No | Time (hr) | Time (sec) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|
| 1 | 24 | 86400 | 0 | 22 | 0.7033844 |
| 2 | 48 | 172800 | -10 | 22.254 | 0.7230508 |
| 3 | 72 | 259200 | -12.5 | 22.3175 | 0.7279674 |
| 4 | 96 | 345600 | -13.5 | 22.3429 | 0.729934 |
| 5 | 120 | 432000 | -13.5 | 22.3429 | 0.729934 |



**1) Calculation of dry mass of total specimen:**

$$M_d = \frac{M_{Tf}}{1 + W_{fp}}$$

Here,
$M_{tf}$= moist mass of the specimen after test, g or kg =128.4 gm
$W_{fp}$= Water content (decimal form) wedge of specimen taken after test = 24.32

So, $M_d$=103.2782609 gm

**2) Calculation of volume of solids:**

$$V_s = \frac{M_d}{G \rho_w}$$

Here,
$M_d$= Dry mass of total specimen= 103.28 gm
G= specific gravity of the soild=2.65 (assumed)
$\rho_w$= density of water=1gm/$cm^3$

So, Vs=38.97$cm^3$

**3) Calculation of specimen area A ($cm^2$):**30.18 $cm^2$

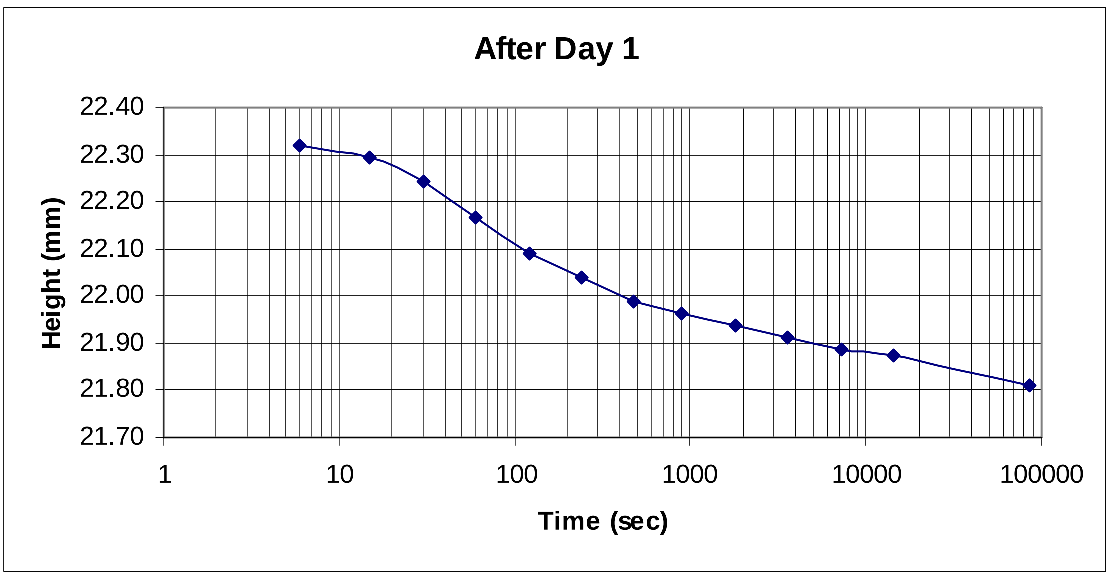
**4) Calculation of Equivalent height of solids ($H_s$)**

$$H_s = \frac{Vs}{A}$$

**So, $H_s$=**1.29 cm

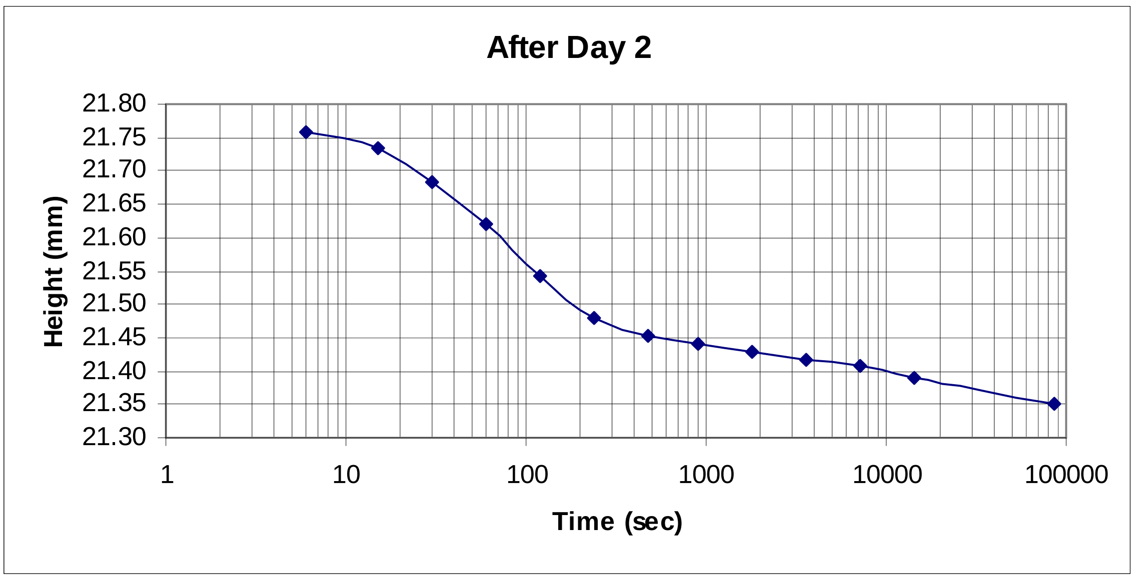
*Day 1*

| S.no. | Day | time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.1 | 6 | 25 | 1 | 22.32 | 0.73 |
| | | 0.25 | 15 | | 2 | 22.29 | 0.73 |
| | | 0.5 | 30 | | 4 | 22.24 | 0.72 |
| | | 1 | 60 | | 7 | 22.17 | 0.72 |
| | | 2 | 120 | | 10 | 22.09 | 0.71 |
| | | 4 | 240 | | 12 | 22.04 | 0.71 |
| | | 8 | 480 | | 14 | 21.99 | 0.70 |
| | | 15 | 900 | | 15 | 21.96 | 0.70 |
| | | 30 | 1800 | | 16 | 21.94 | 0.70 |
| | | 60 | 3600 | | 17 | 21.91 | 0.70 |
| | | 120 | 7200 | | 18 | 21.89 | 0.69 |
| | | 240 | 14400 | | 18.5 | 21.87 | 0.69 |
| | | 1440 | 86400 | | 21 | 21.81 | 0.69 |



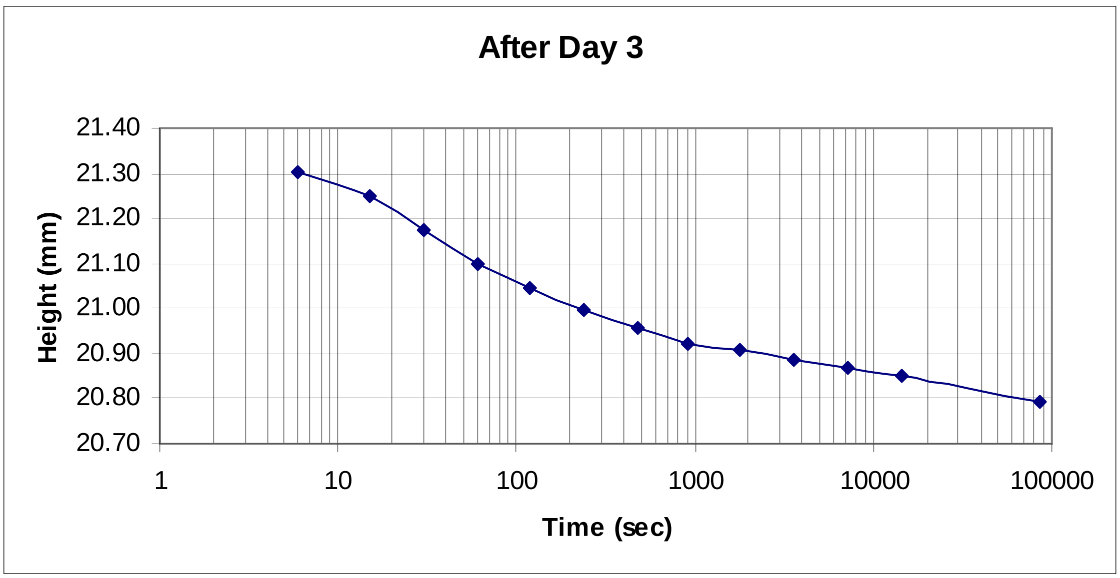
*Day 2*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 0.1 | 6 | 50 | 2 | 21.76 | 0.68 |
| | | 0.25 | 15 | | 3 | 21.73 | 0.68 |
| | | 0.5 | 30 | | 5 | 21.68 | 0.68 |
| | | 1 | 60 | | 7.5 | 21.62 | 0.67 |
| | | 2 | 120 | | 10.5 | 21.54 | 0.67 |
| | | 4 | 240 | | 13 | 21.48 | 0.66 |
| | | 8 | 480 | | 14 | 21.45 | 0.66 |
| | | 15 | 900 | | 14.5 | 21.44 | 0.66 |
| | | 30 | 1800 | | 15 | 21.43 | 0.66 |
| | | 60 | 3600 | | 15.5 | 21.42 | 0.66 |
| | | 120 | 7200 | | 15.8 | 21.41 | 0.66 |
| | | 240 | 14400 | | 16.5 | 21.39 | 0.66 |
| | | 1440 | 86400 | | 18 | 21.35 | 0.65 |



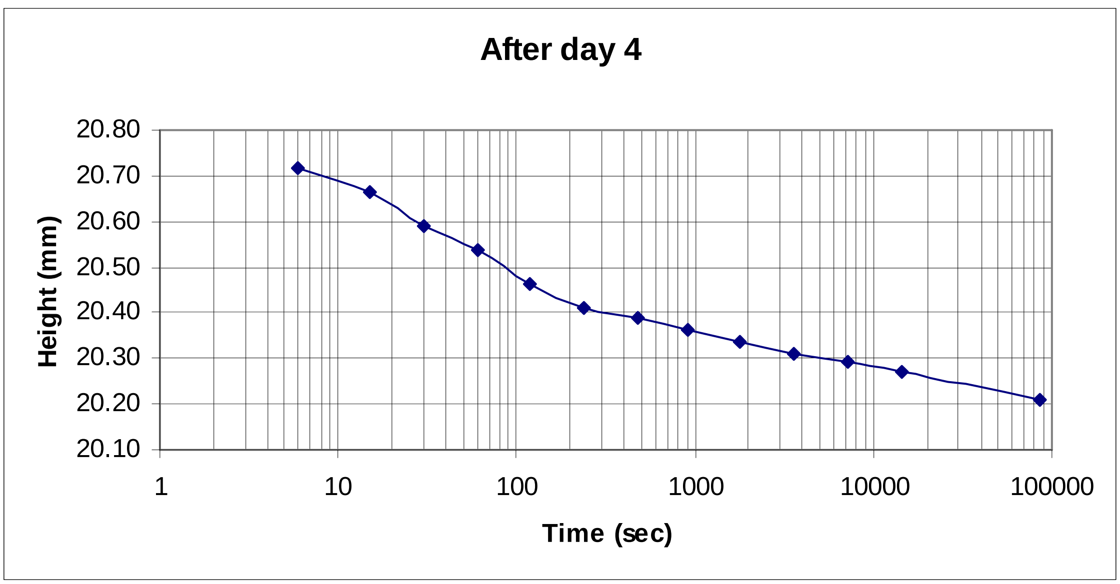
*Day 3*

| S.no. | Day | time (min) | Time (sec) | Load kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 3 | 3 | 0.1 | 6 | 100 | 2 | 21.30 | 0.65 |
| | | 0.25 | 15 | | 4 | 21.25 | 0.65 |
| | | 0.5 | 30 | | 7 | 21.17 | 0.64 |
| | | 1 | 60 | | 10 | 21.10 | 0.63 |
| | | 2 | 120 | | 12 | 21.05 | 0.63 |
| | | 4 | 240 | | 14 | 21.00 | 0.63 |
| | | 8 | 480 | | 15.5 | 20.96 | 0.62 |
| | | 15 | 900 | | 17 | 20.92 | 0.62 |
| | | 30 | 1800 | | 17.5 | 20.91 | 0.62 |
| | | 60 | 3600 | | 18.3 | 20.89 | 0.62 |
| | | 120 | 7200 | | 19 | 20.87 | 0.62 |
| | | 240 | 14400 | | 19.8 | 20.85 | 0.61 |
| | | 1440 | 86400 | | 22 | 20.79 | 0.61 |



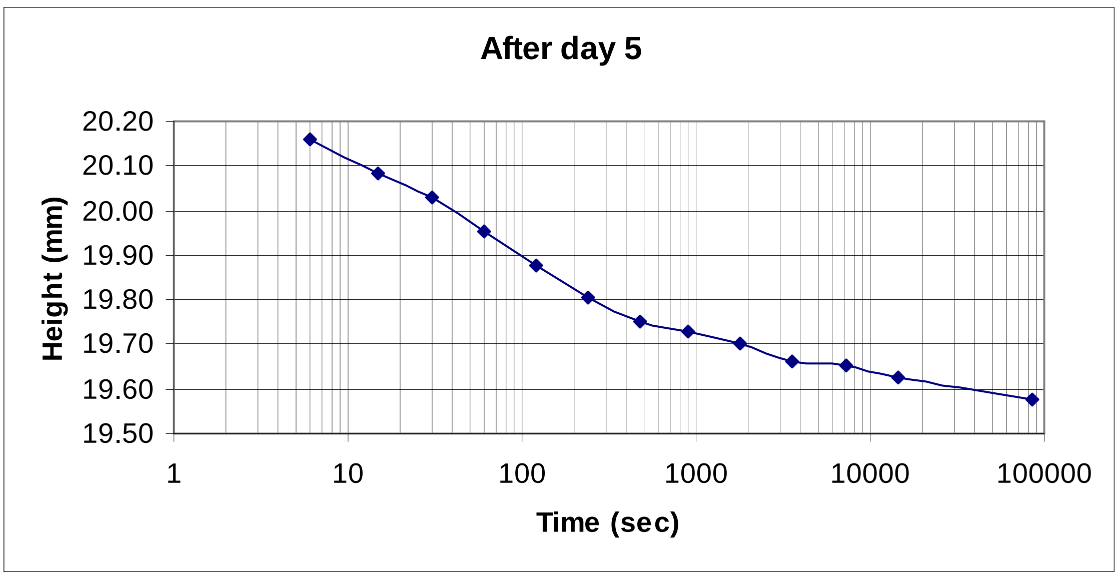
*Day 4*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 4 | 4 | 0.1 | 6 | 200 | 3 | 20.72 | 0.60 |
| | | 0.25 | 15 | | 5 | 20.67 | 0.60 |
| | | 0.5 | 30 | | 8 | 20.59 | 0.59 |
| | | 1 | 60 | | 10 | 20.54 | 0.59 |
| | | 2 | 120 | | 13 | 20.46 | 0.58 |
| | | 4 | 240 | | 15 | 20.41 | 0.58 |
| | | 8 | 480 | | 16 | 20.39 | 0.58 |
| | | 15 | 900 | | 17 | 20.36 | 0.58 |
| | | 30 | 1800 | | 18 | 20.34 | 0.57 |
| | | 60 | 3600 | | 19 | 20.31 | 0.57 |
| | | 120 | 7200 | | 19.8 | 20.29 | 0.57 |
| | | 240 | 14400 | | 20.5 | 20.27 | 0.57 |
| | | 1440 | 86400 | | 23 | 20.21 | 0.56 |



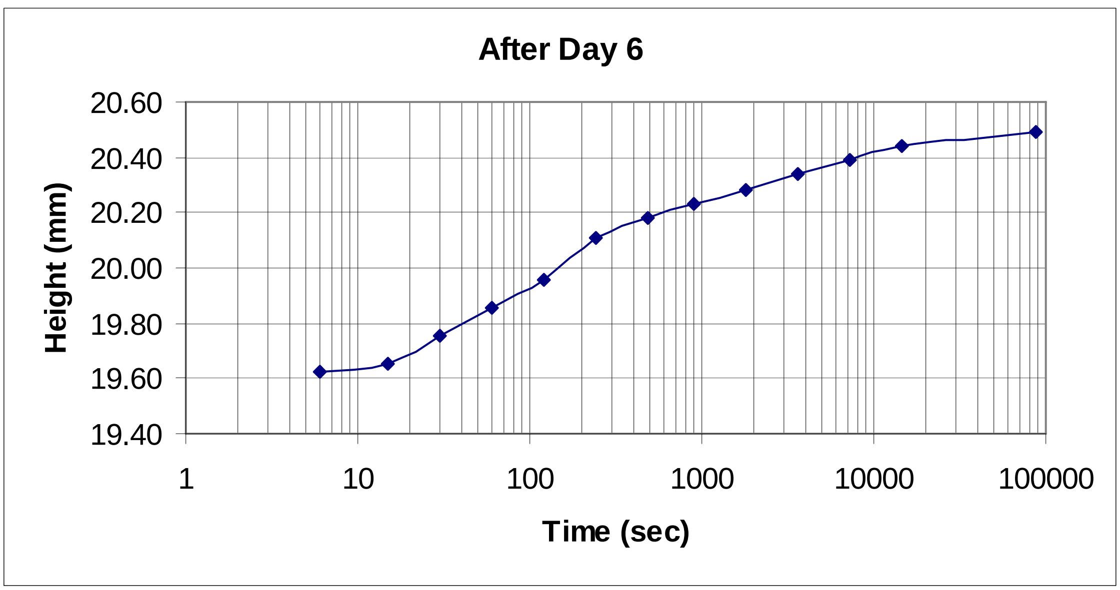
*Day 5*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 5 | 5 | 0.1 | 6 | 400 | 2 | 20.16 | 0.56 |
| | | 0.25 | 15 | | 5 | 20.08 | 0.55 |
| | | 0.5 | 30 | | 7 | 20.03 | 0.55 |
| | | 1 | 60 | | 10 | 19.96 | 0.55 |
| | | 2 | 120 | | 13 | 19.88 | 0.54 |
| | | 4 | 240 | | 16 | 19.80 | 0.53 |
| | | 8 | 480 | | 18 | 19.75 | 0.53 |
| | | 15 | 900 | | 19 | 19.73 | 0.53 |
| | | 30 | 1800 | | 20 | 19.70 | 0.53 |
| | | 60 | 3600 | | 21.5 | 19.66 | 0.52 |
| | | 120 | 7200 | | 22 | 19.65 | 0.52 |
| | | 240 | 14400 | | 23 | 19.63 | 0.52 |
| | | 1440 | 86400 | | 25 | 19.57 | 0.52 |



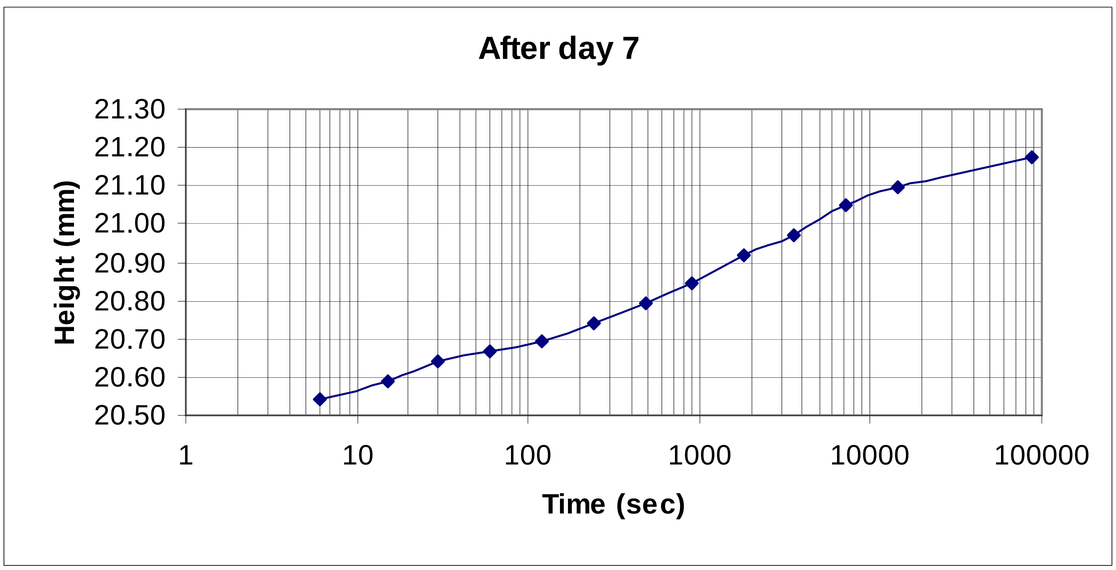
*Day 6*

| S.no. | Day | Time (min) | Time sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 6 | 6 | 0.1 | 6 | 25 | -2 | 19.63 | 0.52 |
| | | 0.25 | 15 | | -3 | 19.65 | 0.52 |
| | | 0.5 | 30 | | -7 | 19.75 | 0.53 |
| | | 1 | 60 | | -11 | 19.85 | 0.54 |
| | | 2 | 120 | | -15 | 19.96 | 0.55 |
| | | 4 | 240 | | -21 | 20.11 | 0.56 |
| | | 8 | 480 | | -24 | 20.18 | 0.56 |
| | | 15 | 900 | | -26 | 20.23 | 0.57 |
| | | 30 | 1800 | | -28 | 20.29 | 0.57 |
| | | 60 | 3600 | | -30 | 20.34 | 0.57 |
| | | 120 | 7200 | | -32 | 20.39 | 0.58 |
| | | 240 | 14400 | | -34 | 20.44 | 0.58 |
| | | 1440 | 86400 | | -36 | 20.49 | 0.59 |



*Day 7*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 7 | 7 | 0.1 | 6 | 5 | -2 | 20.54 | 0.59 |
| | | 0.25 | 15 | | -4 | 20.59 | 0.59 |
| | | 0.5 | 30 | | -6 | 20.64 | 0.60 |
| | | 1 | 60 | | -7 | 20.67 | 0.60 |
| | | 2 | 120 | | -8 | 20.69 | 0.60 |
| | | 4 | 240 | | -10 | 20.74 | 0.61 |
| | | 8 | 480 | | -12 | 20.79 | 0.61 |
| | | 15 | 900 | | -14 | 20.84 | 0.61 |
| | | 30 | 1800 | | -17 | 20.92 | 0.62 |
| | | 60 | 3600 | | -19 | 20.97 | 0.62 |
| | | 120 | 7200 | | -22 | 21.05 | 0.63 |
| | | 240 | 14400 | | -24 | 21.10 | 0.63 |
| | | 1440 | 86400 | | -27 | 21.17 | 0.64 |



# APPENDIX C-2

# ATLANTA DISTRICT

**Sample Detail:**
**Remolded specimen**

A3 11-13

**Height of the sample=**22 mm
**Diameter of the sample =** 62 mm

| | |
|---|---|
| **LL** | 37 |
| **PL** | 20 |
| **PI** | 17 |
| **CF** | 7.7 |

CF= Clay fraction= % finer than 2 microns

**Water Content Calculation:**
*Initial:*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 348.8gm
Weight of the soil sample=132.4gm

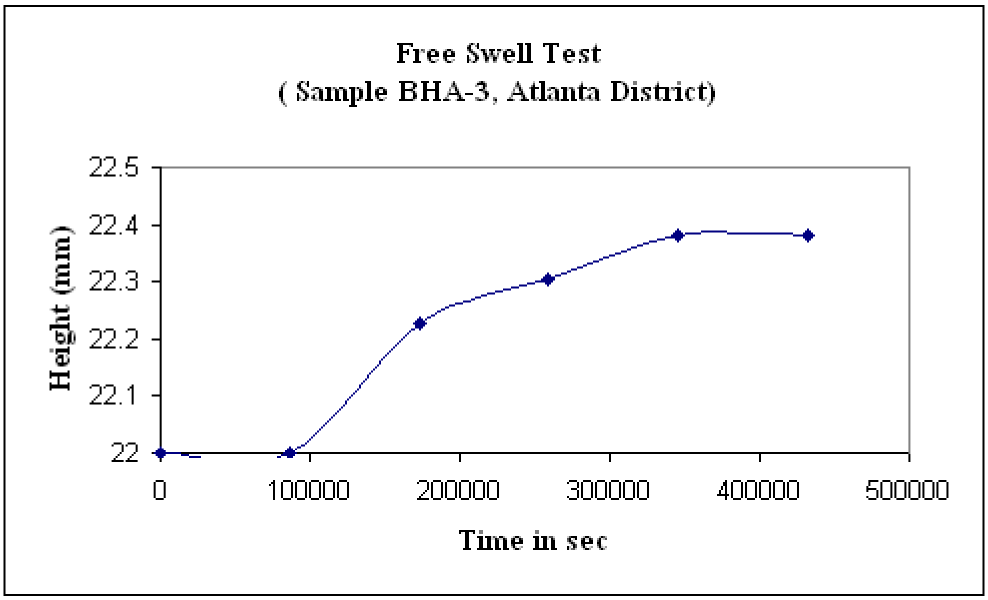
| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 11.4 | 9.82 | 18.54 |

*Final*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 348.1gm
Weight of the soil sample=131.7 gm

| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 12.6 | 10.8 | 18.95 |

**SWELL TEST:**

| S No | Time (hr) | Time (sec) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 22 | 0.5888784 |
| 2 | 24 | 86400 | -4 | 22 | 0.5888784 |
| 3 | 48 | 172800 | -9 | 22.2286 | 0.6053883 |
| 4 | 72 | 259200 | -12 | 22.3048 | 0.6108916 |
| 5 | 96 | 345600 | -15 | 22.381 | 0.6163949 |
| 6 | 120 | 432000 | -15 | 22.381 | 0.6163949 |



**1) Calculation of dry mass of total specimen:**

$$M_d = \frac{M_{Tf}}{1 + W_{fp}}$$

Here,
$M_{tf}$= moist mass of the specimen after test, g or kg =131.7 gm
$W_{fp}$= Water content (decimal form) wedge of specimen taken after test =18.95

So, $M_d$=110.7212389 gm

**2) Calculation of volume of solids:**

$$V_s = \frac{M_d}{G \rho_w}$$

Here,
$M_d$= Dry mass of total specimen=110.72 gm
G= specific gravity of the soild=2.65 (assumed)
$\rho_w$= density of water=1gm/cm$^3$

So, Vs=41.78cm$^3$

**3) Calculation of specimen area A (cm$^2$):**30.18 cm$^2$

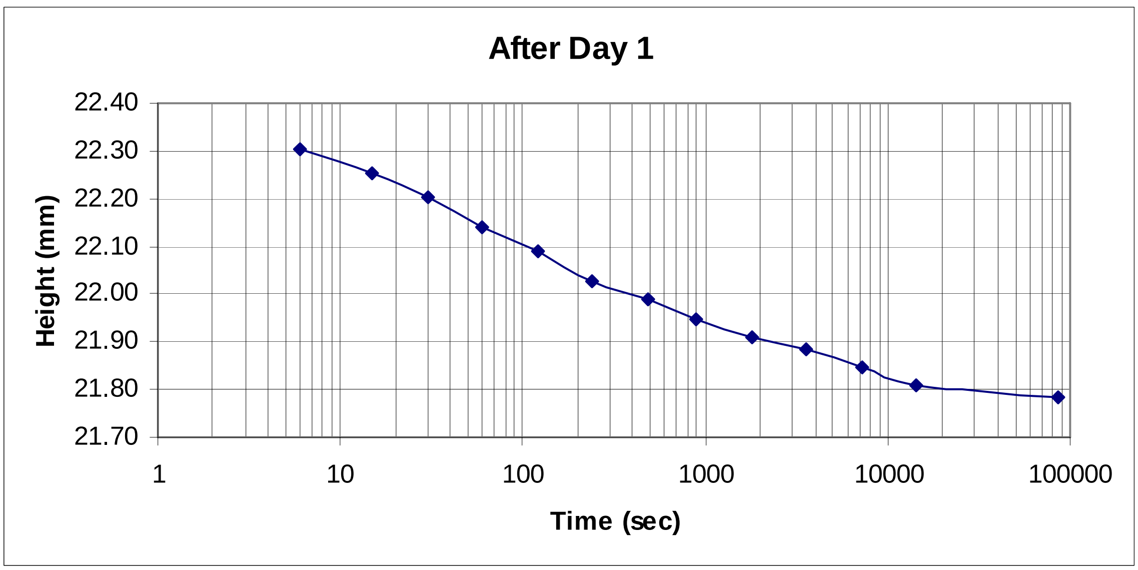
**4) Calculation of Equivalent height of solids ($H_s$)**

$$H_s = \frac{Vs}{A}$$

**So, $H_s$=**1.38 cm

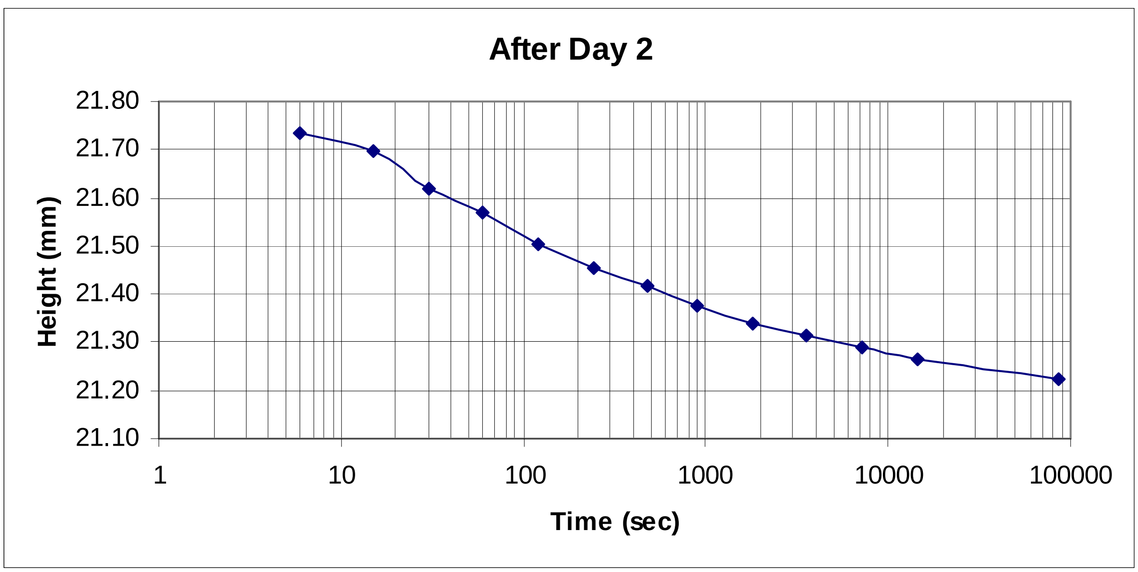
*Day 1*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.1 | 6 | 25 | 3 | 22.30 | 0.61 |
| | | 0.25 | 15 | | 5 | 22.25 | 0.61 |
| | | 0.5 | 30 | | 7 | 22.20 | 0.60 |
| | | 1 | 60 | | 9.5 | 22.14 | 0.60 |
| | | 2 | 120 | | 11.5 | 22.09 | 0.60 |
| | | 4 | 240 | | 14 | 22.03 | 0.59 |
| | | 8 | 480 | | 15.5 | 21.99 | 0.59 |
| | | 15 | 900 | | 17 | 21.95 | 0.59 |
| | | 30 | 1800 | | 18.5 | 21.91 | 0.58 |
| | | 60 | 3600 | | 19.5 | 21.89 | 0.58 |
| | | 120 | 7200 | | 21 | 21.85 | 0.58 |
| | | 240 | 14400 | | 22.5 | 21.81 | 0.58 |
| | | 1440 | 86400 | | 23.5 | 21.78 | 0.57 |



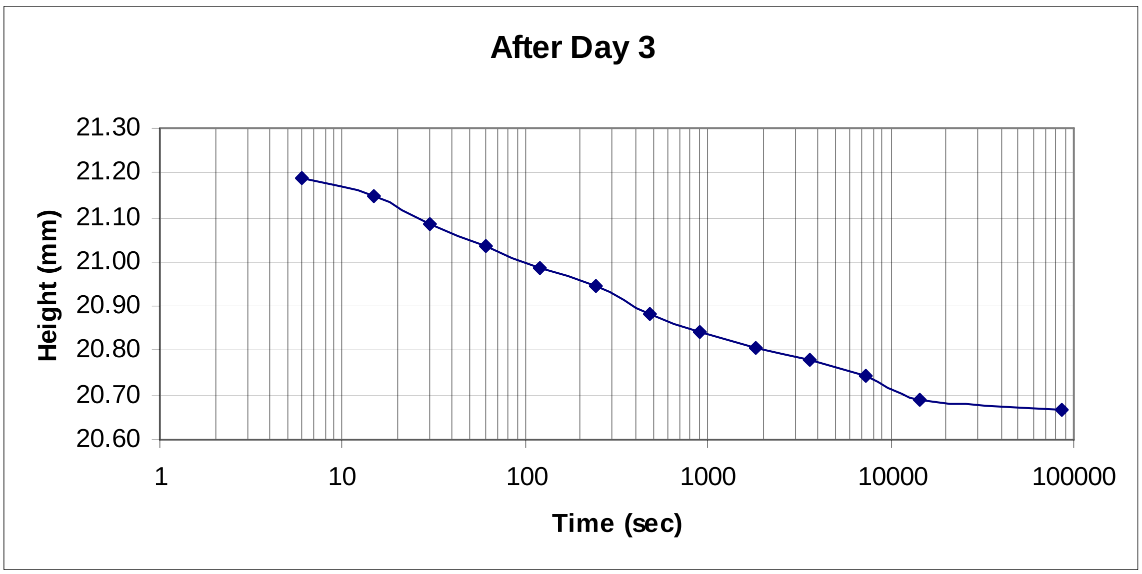
*Day 2*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 0.1 | 6 | 50 | 2 | 21.73 | 0.57 |
| | | 0.25 | 15 | | 3.5 | 21.70 | 0.57 |
| | | 0.5 | 30 | | 6.5 | 21.62 | 0.56 |
| | | 1 | 60 | | 8.5 | 21.57 | 0.56 |
| | | 2 | 120 | | 11 | 21.50 | 0.55 |
| | | 4 | 240 | | 13 | 21.45 | 0.55 |
| | | 8 | 480 | | 14.5 | 21.42 | 0.55 |
| | | 15 | 900 | | 16 | 21.38 | 0.54 |
| | | 30 | 1800 | | 17.5 | 21.34 | 0.54 |
| | | 60 | 3600 | | 18.5 | 21.31 | 0.54 |
| | | 120 | 7200 | | 19.5 | 21.29 | 0.54 |
| | | 240 | 14400 | | 20.5 | 21.26 | 0.54 |
| | | 1440 | 86400 | | 22 | 21.23 | 0.53 |



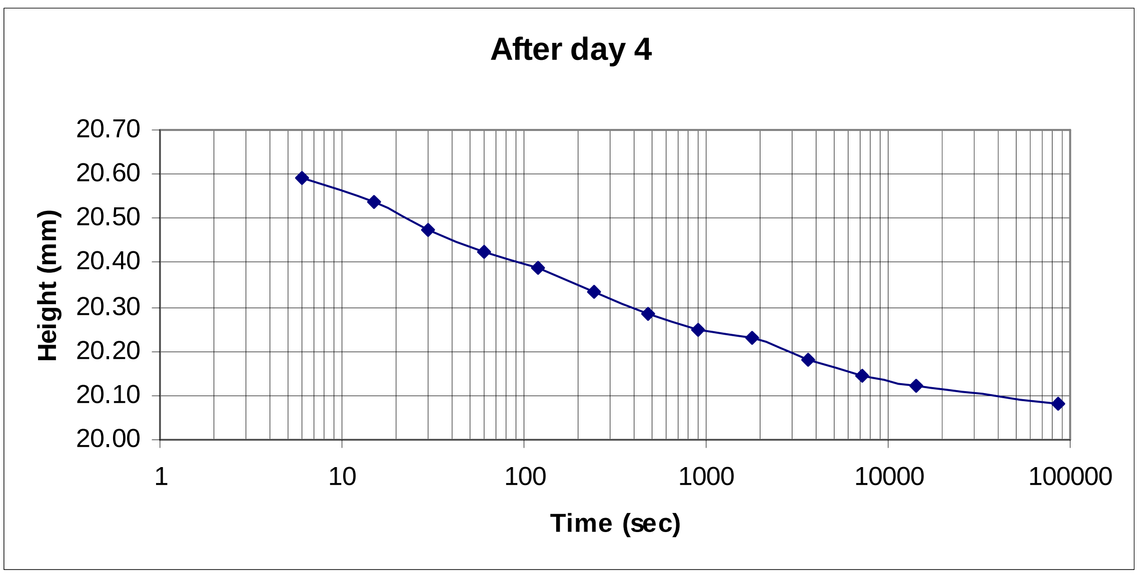
*Day 3*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 3 | 3 | 0.1 | 6 | 100 | 1.5 | 21.19 | 0.53 |
| | | 0.25 | 15 | | 3 | 21.15 | 0.53 |
| | | 0.5 | 30 | | 5.5 | 21.09 | 0.52 |
| | | 1 | 60 | | 7.5 | 21.03 | 0.52 |
| | | 2 | 120 | | 9.5 | 20.98 | 0.52 |
| | | 4 | 240 | | 11 | 20.95 | 0.51 |
| | | 8 | 480 | | 13.5 | 20.88 | 0.51 |
| | | 15 | 900 | | 15 | 20.84 | 0.51 |
| | | 30 | 1800 | | 16.5 | 20.81 | 0.50 |
| | | 60 | 3600 | | 17.5 | 20.78 | 0.50 |
| | | 120 | 7200 | | 18.9 | 20.75 | 0.50 |
| | | 240 | 14400 | | 21 | 20.69 | 0.49 |
| | | 1440 | 86400 | | 22 | 20.67 | 0.49 |



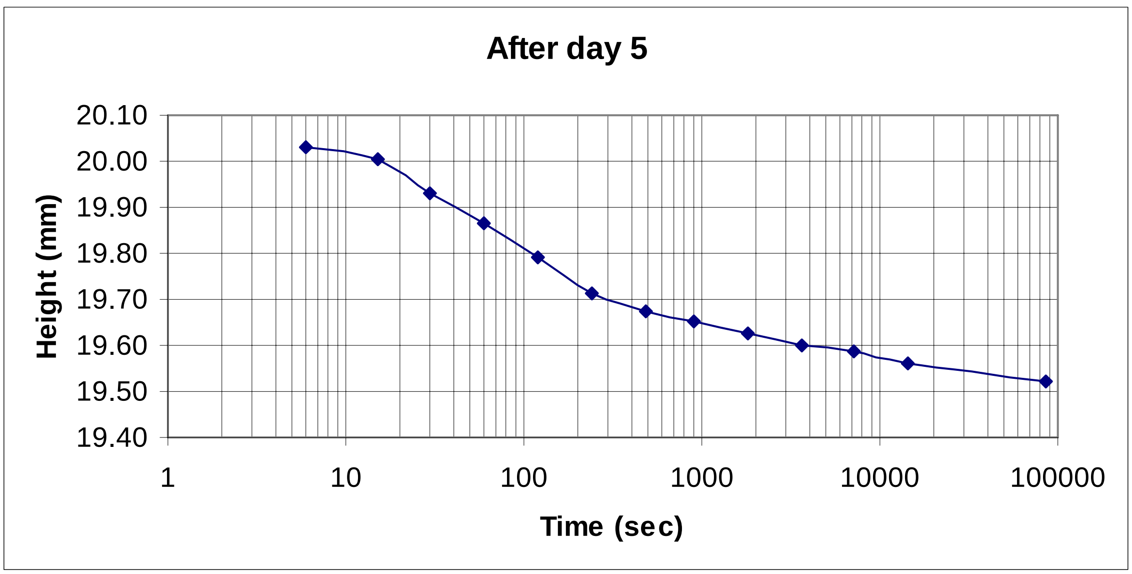
*Day 4*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 4 | 4 | 0.1 | 6 | 200 | 3 | 20.59 | 0.49 |
| | | 0.25 | 15 | | 5 | 20.54 | 0.48 |
| | | 0.5 | 30 | | 7.5 | 20.48 | 0.48 |
| | | 1 | 60 | | 9.5 | 20.43 | 0.48 |
| | | 2 | 120 | | 11 | 20.39 | 0.47 |
| | | 4 | 240 | | 13 | 20.34 | 0.47 |
| | | 8 | 480 | | 15 | 20.29 | 0.47 |
| | | 15 | 900 | | 16.5 | 20.25 | 0.46 |
| | | 30 | 1800 | | 17.2 | 20.23 | 0.46 |
| | | 60 | 3600 | | 19.1 | 20.18 | 0.46 |
| | | 120 | 7200 | | 20.5 | 20.15 | 0.45 |
| | | 240 | 14400 | | 21.5 | 20.12 | 0.45 |
| | | 1440 | 86400 | | 23 | 20.08 | 0.45 |



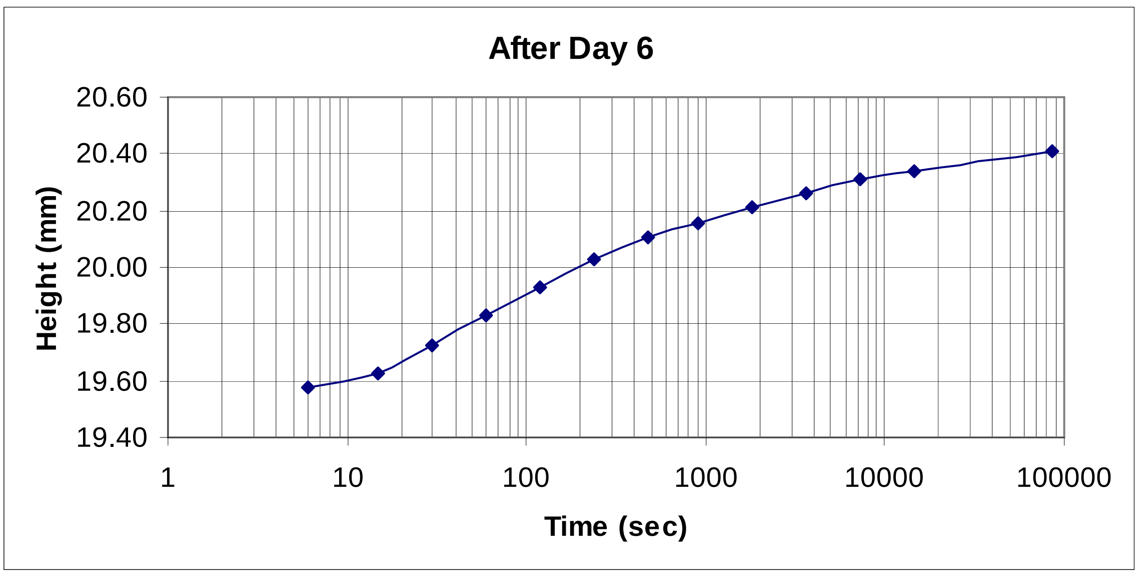
*Day 5*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 5 | 5 | 0.1 | 6 | 400 | 2 | 20.03 | 0.45 |
| | | 0.25 | 15 | | 3 | 20.01 | 0.44 |
| | | 0.5 | 30 | | 6 | 19.93 | 0.44 |
| | | 1 | 60 | | 8.5 | 19.87 | 0.43 |
| | | 2 | 120 | | 11.5 | 19.79 | 0.43 |
| | | 4 | 240 | | 14.5 | 19.71 | 0.42 |
| | | 8 | 480 | | 16 | 19.68 | 0.42 |
| | | 15 | 900 | | 17 | 19.65 | 0.42 |
| | | 30 | 1800 | | 18 | 19.63 | 0.42 |
| | | 60 | 3600 | | 19 | 19.60 | 0.42 |
| | | 120 | 7200 | | 19.5 | 19.59 | 0.41 |
| | | 240 | 14400 | | 20.5 | 19.56 | 0.41 |
| | | 1440 | 86400 | | 22 | 19.52 | 0.41 |



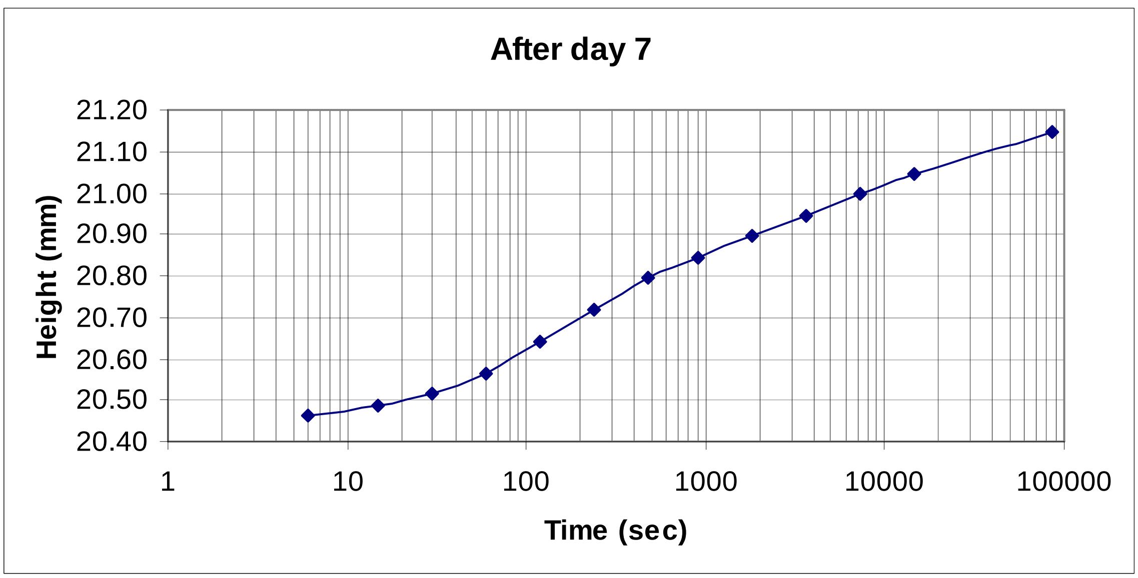
*Day 6*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 6 | 6 | 0.1 | 6 | 25 | -2 | 19.57 | 0.41 |
| | | 0.25 | 15 | | -4 | 19.63 | 0.42 |
| | | 0.5 | 30 | | -8 | 19.73 | 0.42 |
| | | 1 | 60 | | -12 | 19.83 | 0.43 |
| | | 2 | 120 | | -16 | 19.93 | 0.44 |
| | | 4 | 240 | | -20 | 20.03 | 0.45 |
| | | 8 | 480 | | -23 | 20.11 | 0.45 |
| | | 15 | 900 | | -25 | 20.16 | 0.46 |
| | | 30 | 1800 | | -27 | 20.21 | 0.46 |
| | | 60 | 3600 | | -29 | 20.26 | 0.46 |
| | | 120 | 7200 | | -31 | 20.31 | 0.47 |
| | | 240 | 14400 | | -32 | 20.34 | 0.47 |
| | | 1440 | 86400 | | -35 | 20.41 | 0.47 |



*Day 7*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 7 | 7 | 0.1 | 6 | 5 | -2 | 20.46 | 0.48 |
| | | 0.25 | 15 | | -3 | 20.49 | 0.48 |
| | | 0.5 | 30 | | -4 | 20.51 | 0.48 |
| | | 1 | 60 | | -6 | 20.56 | 0.49 |
| | | 2 | 120 | | -9 | 20.64 | 0.49 |
| | | 4 | 240 | | -12 | 20.72 | 0.50 |
| | | 8 | 480 | | -15 | 20.79 | 0.50 |
| | | 15 | 900 | | -17 | 20.84 | 0.51 |
| | | 30 | 1800 | | -19 | 20.90 | 0.51 |
| | | 60 | 3600 | | -21 | 20.95 | 0.51 |
| | | 120 | 7200 | | -23 | 21.00 | 0.52 |
| | | 240 | 14400 | | -25 | 21.05 | 0.52 |
| | | 1440 | 86400 | | -29 | 21.15 | 0.53 |



# APPENDIX C-3

# AUSTIN DISTRICT

**Sample Detail:**
**Remoled specimen**

B1 3.5-5

**Height of the sample=**22 mm
**Diameter of the sample =** 62 mm

| | | |
|---|---|---|
| **LL** | 47 | |
| **PL** | 18 | |
| **PI** | 29 | |
| **CF** | 18 | CF= Clay fraction= % finer than 2 microns |

**Water Content Calculation:**
*Initial:*
Weight of the consolidometer ring=216.4 gm
Weight of the consolidometer ring + soil = 344.2 gm
Weight of the soil sample=127.8 gm

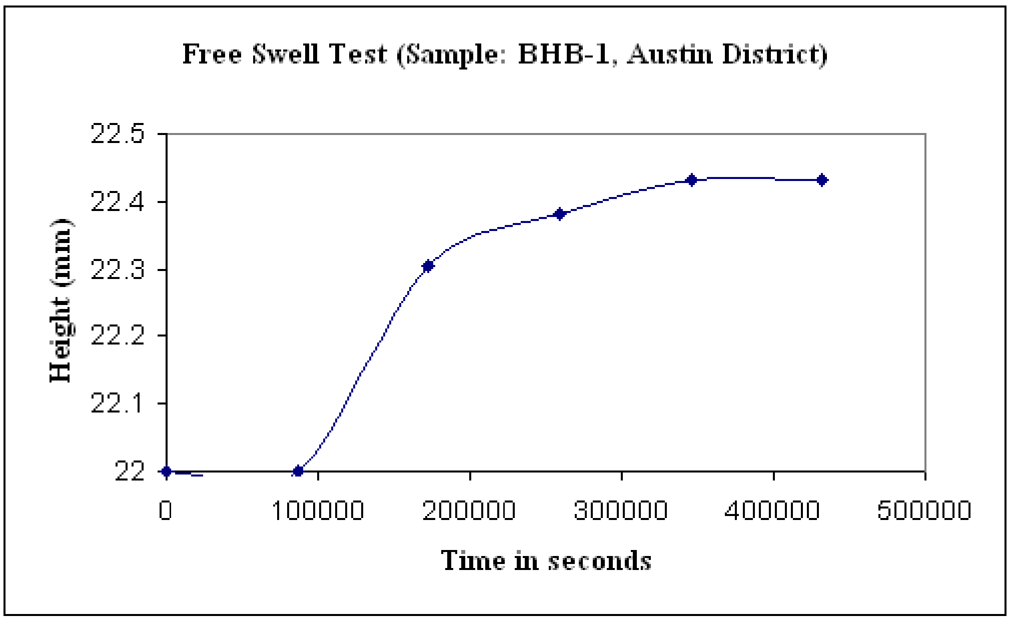
| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 15 | 12.8 | 19.13 |

*Final*
Weight of the consolidometer ring= 216.4 gm
Weight of the consolidometer ring + soil = 343.8 gm
Weight of the soil sample=127.4 gm

| Can wt | Can + Wet soil | Can + Dry soil | Water Content |
|---|---|---|---|
| 1.3 | 11.3 | 9.63 | 20.05 |

**SWELL TEST:**

| S No | Time (hr) | Time (sec) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 22 | 0.6577047 |
| 2 | 24 | 86400 | -7 | 22 | 0.6577047 |
| 3 | 48 | 172800 | -12 | 22.3048 | 0.6806714 |
| 4 | 72 | 259200 | -15 | 22.381 | 0.6864131 |
| 5 | 96 | 345600 | -17 | 22.4318 | 0.6902409 |
| 6 | 120 | 432000 | -17 | 22.4318 | 0.6902409 |



**1) Calculation of dry mass of total specimen:**

$$M_d = \frac{M_{Tf}}{1+W_{fp}}$$

Here,
$M_{tf}$= moist mass of the specimen after test, g or kg = 127.4 gm
$W_{fp}$= Water content (decimal form) wedge of specimen taken after test =20.05

So, $M_d$=106.12 gm

**2) Calculation of volume of solids:**

$$V_s = \frac{M_d}{G\rho_w}$$

Here,
$M_d$= Dry mass of total specimen= 106.12 gm
G= specific gravity of the soild= 2.65 (assumed)
$\rho_w$= density of water=1gm/$cm^3$

So, Vs=40.05 $cm^3$

**3) Calculation of specimen area A ($cm^2$):**30.1754 $cm^2$

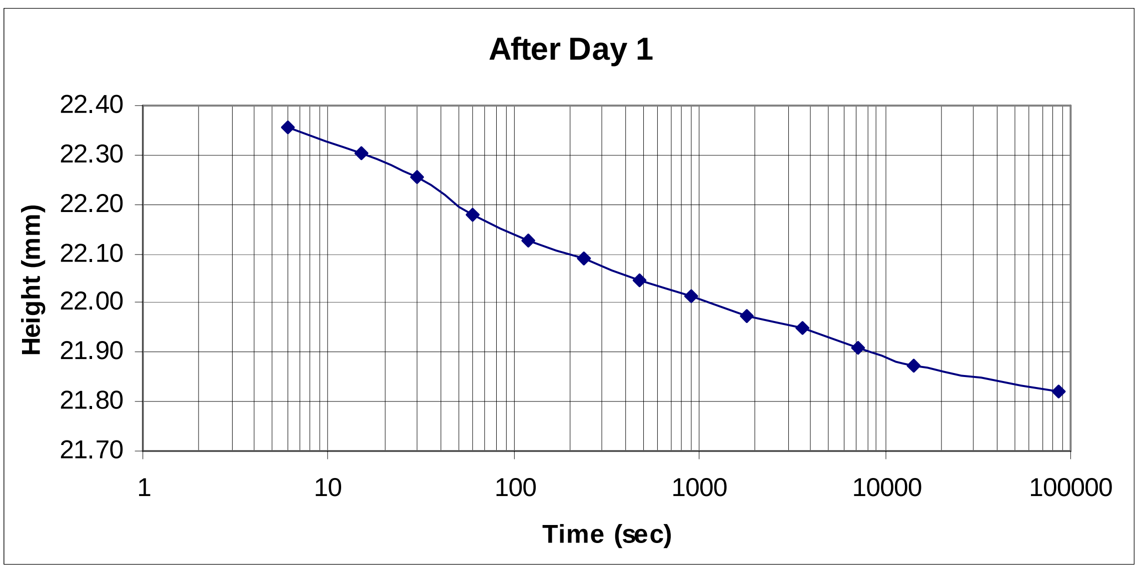
**4) Calculation of Equivalent height of solids ($H_s$)**

$$H_s = \frac{Vs}{A}$$

**So, $H_s$ =**1.33 cm

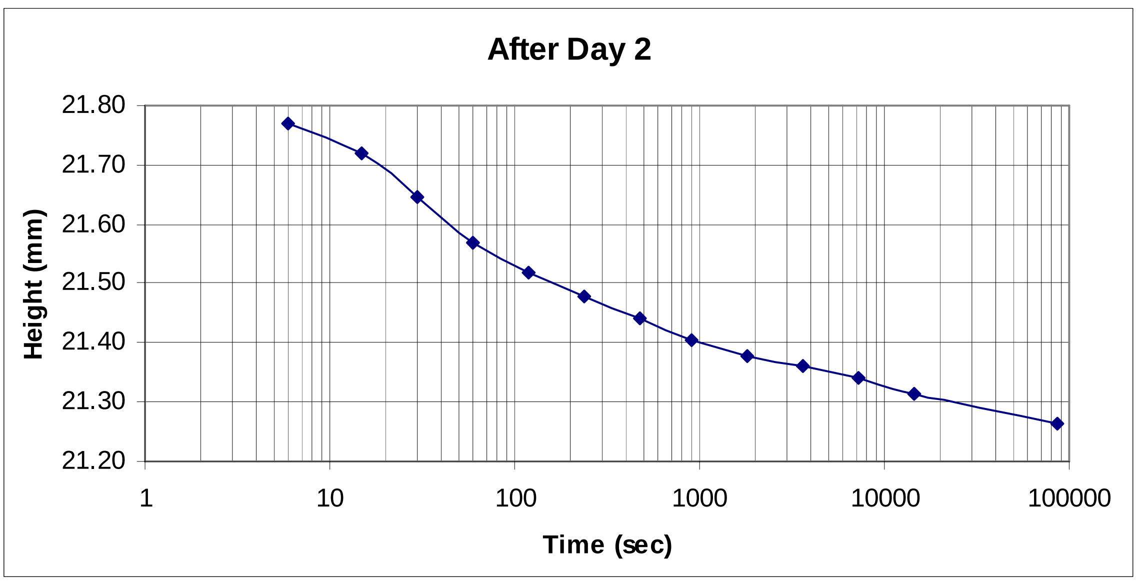
*Day 1*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.1 | 6 | 25 | 3 | 22.36 | 0.68 |
| | | 0.25 | 15 | | 5 | 22.30 | 0.68 |
| | | 0.5 | 30 | | 7 | 22.25 | 0.68 |
| | | 1 | 60 | | 10 | 22.18 | 0.67 |
| | | 2 | 120 | | 12 | 22.13 | 0.67 |
| | | 4 | 240 | | 13.5 | 22.09 | 0.66 |
| | | 8 | 480 | | 15.2 | 22.05 | 0.66 |
| | | 15 | 900 | | 16.5 | 22.01 | 0.66 |
| | | 30 | 1800 | | 18 | 21.97 | 0.66 |
| | | 60 | 3600 | | 19 | 21.95 | 0.65 |
| | | 120 | 7200 | | 20.5 | 21.91 | 0.65 |
| | | 240 | 14400 | | 22 | 21.87 | 0.65 |
| | | 1440 | 86400 | | 24 | 21.82 | 0.64 |



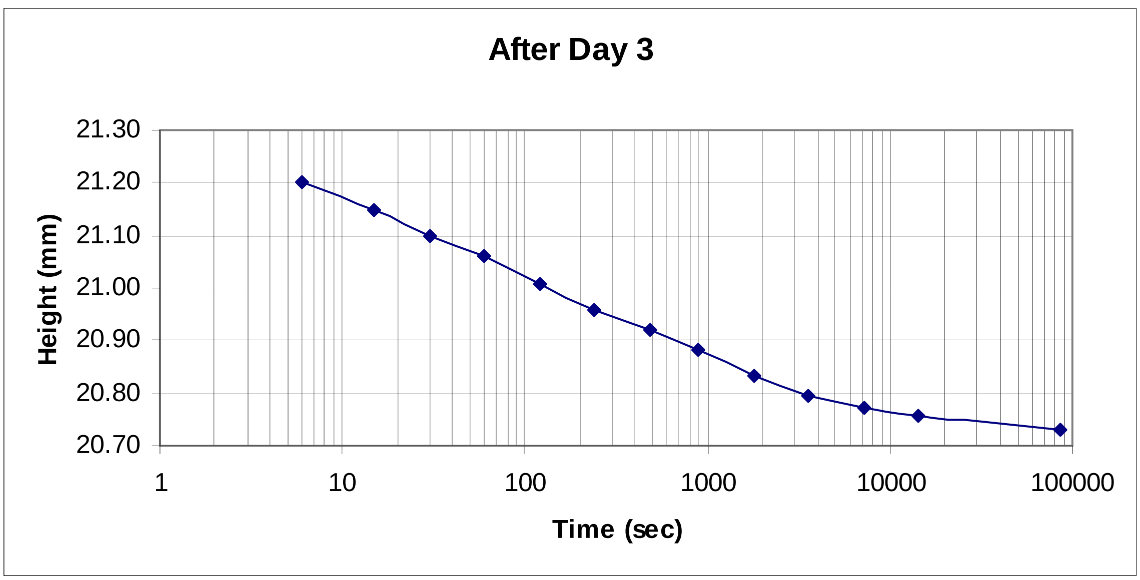
*Day 2*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 0.1 | 6 | 50 | 2 | 21.77 | 0.64 |
| | | 0.25 | 15 | | 4 | 21.72 | 0.64 |
| | | 0.5 | 30 | | 7 | 21.64 | 0.63 |
| | | 1 | 60 | | 10 | 21.57 | 0.63 |
| | | 2 | 120 | | 12 | 21.52 | 0.62 |
| | | 4 | 240 | | 13.5 | 21.48 | 0.62 |
| | | 8 | 480 | | 15 | 21.44 | 0.62 |
| | | 15 | 900 | | 16.5 | 21.40 | 0.61 |
| | | 30 | 1800 | | 17.5 | 21.38 | 0.61 |
| | | 60 | 3600 | | 18.2 | 21.36 | 0.61 |
| | | 120 | 7200 | | 19 | 21.34 | 0.61 |
| | | 240 | 14400 | | 20 | 21.31 | 0.61 |
| | | 1440 | 86400 | | 22 | 21.26 | 0.60 |



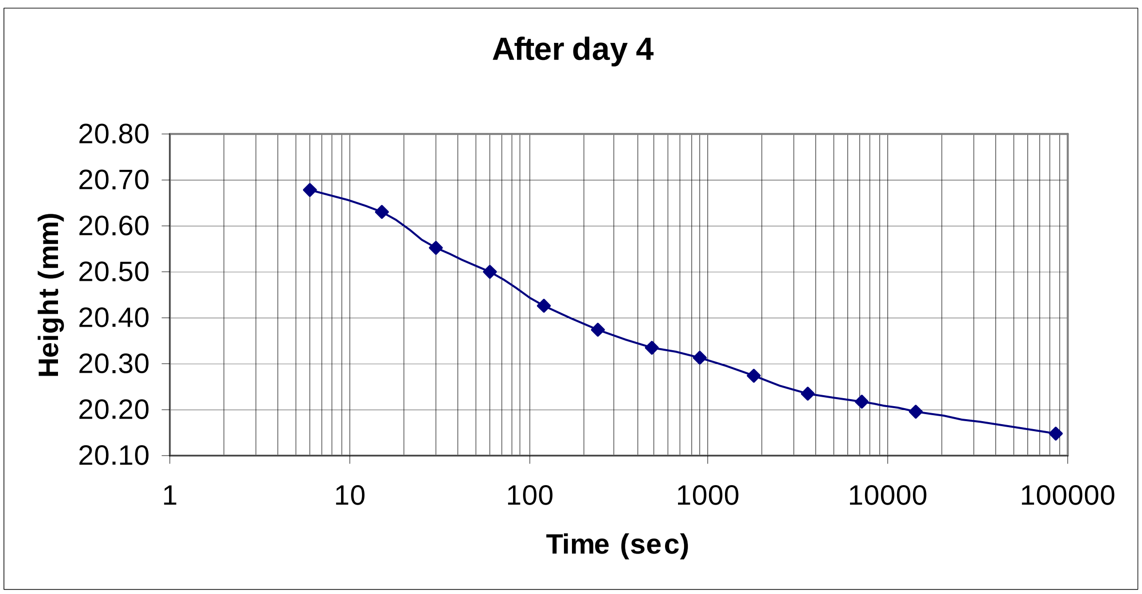
*Day 3*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 3 | 3 | 0.1 | 6 | 100 | 2.5 | 21.20 | 0.60 |
| | | 0.25 | 15 | | 4.5 | 21.15 | 0.59 |
| | | 0.5 | 30 | | 6.5 | 21.10 | 0.59 |
| | | 1 | 60 | | 8 | 21.06 | 0.59 |
| | | 2 | 120 | | 10 | 21.01 | 0.58 |
| | | 4 | 240 | | 12 | 20.96 | 0.58 |
| | | 8 | 480 | | 13.5 | 20.92 | 0.58 |
| | | 15 | 900 | | 15 | 20.88 | 0.57 |
| | | 30 | 1800 | | 17 | 20.83 | 0.57 |
| | | 60 | 3600 | | 18.5 | 20.79 | 0.57 |
| | | 120 | 7200 | | 19.3 | 20.77 | 0.57 |
| | | 240 | 14400 | | 20 | 20.76 | 0.56 |
| | | 1440 | 86400 | | 21 | 20.73 | 0.56 |



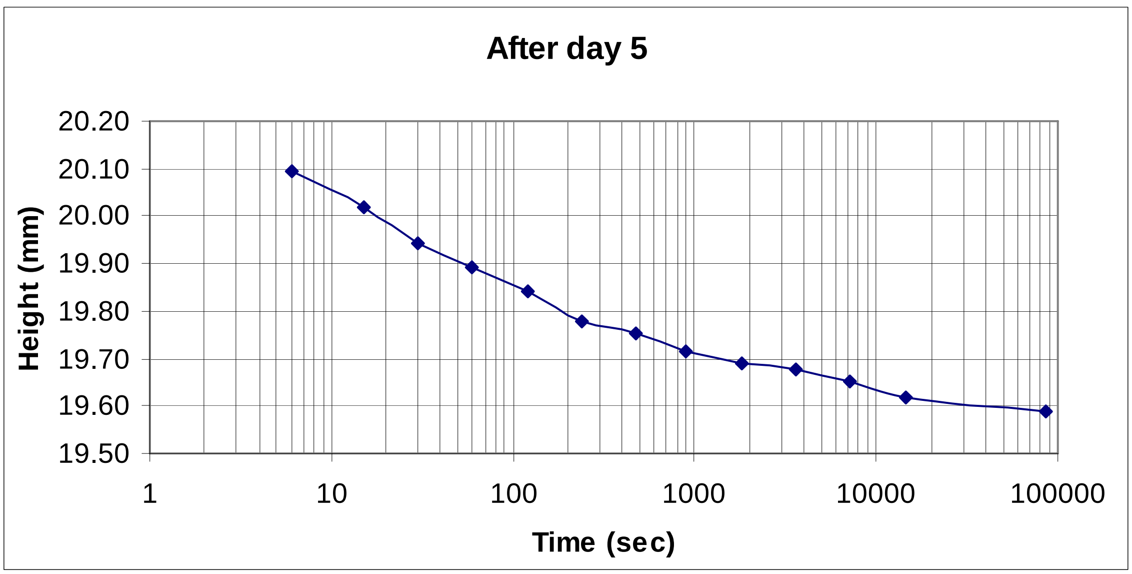
*Day 4*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 4 | 4 | 0.1 | 6 | 200 | 2 | 20.68 | 0.56 |
| | | 0.25 | 15 | | 4 | 20.63 | 0.55 |
| | | 0.5 | 30 | | 7 | 20.55 | 0.55 |
| | | 1 | 60 | | 9 | 20.50 | 0.54 |
| | | 2 | 120 | | 12 | 20.43 | 0.54 |
| | | 4 | 240 | | 14 | 20.37 | 0.54 |
| | | 8 | 480 | | 15.5 | 20.34 | 0.53 |
| | | 15 | 900 | | 16.5 | 20.31 | 0.53 |
| | | 30 | 1800 | | 17.9 | 20.28 | 0.53 |
| | | 60 | 3600 | | 19.5 | 20.23 | 0.52 |
| | | 120 | 7200 | | 20.2 | 20.22 | 0.52 |
| | | 240 | 14400 | | 21 | 20.20 | 0.52 |
| | | 1440 | 86400 | | 23 | 20.15 | 0.52 |



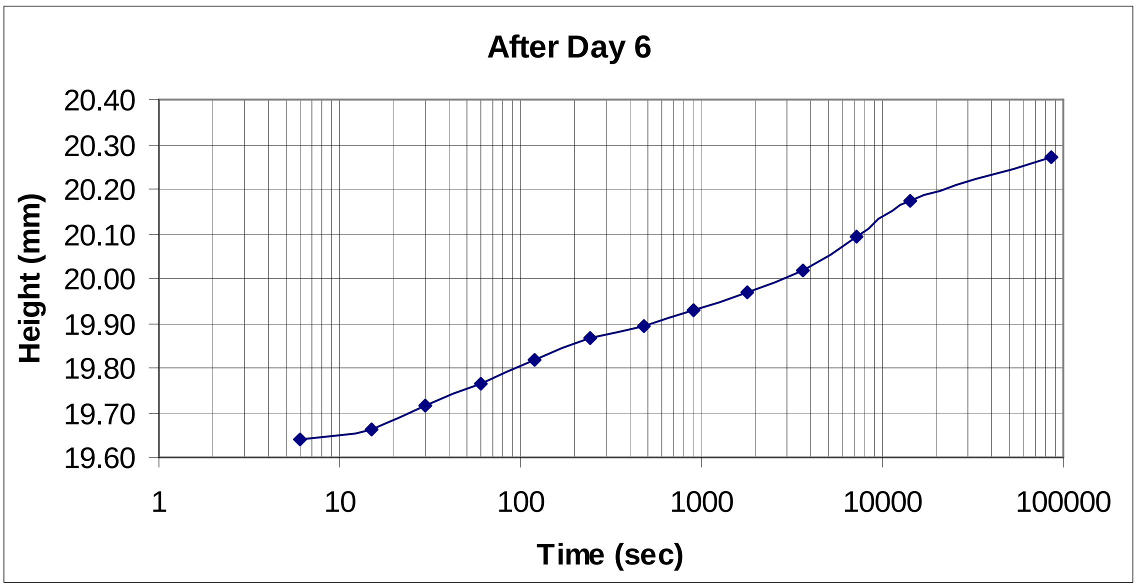
*Day 5*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 5 | 5 | 0.1 | 6 | 400 | 2 | 20.10 | 0.51 |
| | | 0.25 | 15 | | 5 | 20.02 | 0.51 |
| | | 0.5 | 30 | | 8 | 19.94 | 0.50 |
| | | 1 | 60 | | 10 | 19.89 | 0.50 |
| | | 2 | 120 | | 12 | 19.84 | 0.50 |
| | | 4 | 240 | | 14.5 | 19.78 | 0.49 |
| | | 8 | 480 | | 15.5 | 19.75 | 0.49 |
| | | 15 | 900 | | 17 | 19.71 | 0.49 |
| | | 30 | 1800 | | 18 | 19.69 | 0.48 |
| | | 60 | 3600 | | 18.5 | 19.68 | 0.48 |
| | | 120 | 7200 | | 19.5 | 19.65 | 0.48 |
| | | 240 | 14400 | | 20.8 | 19.62 | 0.48 |
| | | 1440 | 86400 | | 22 | 19.59 | 0.48 |



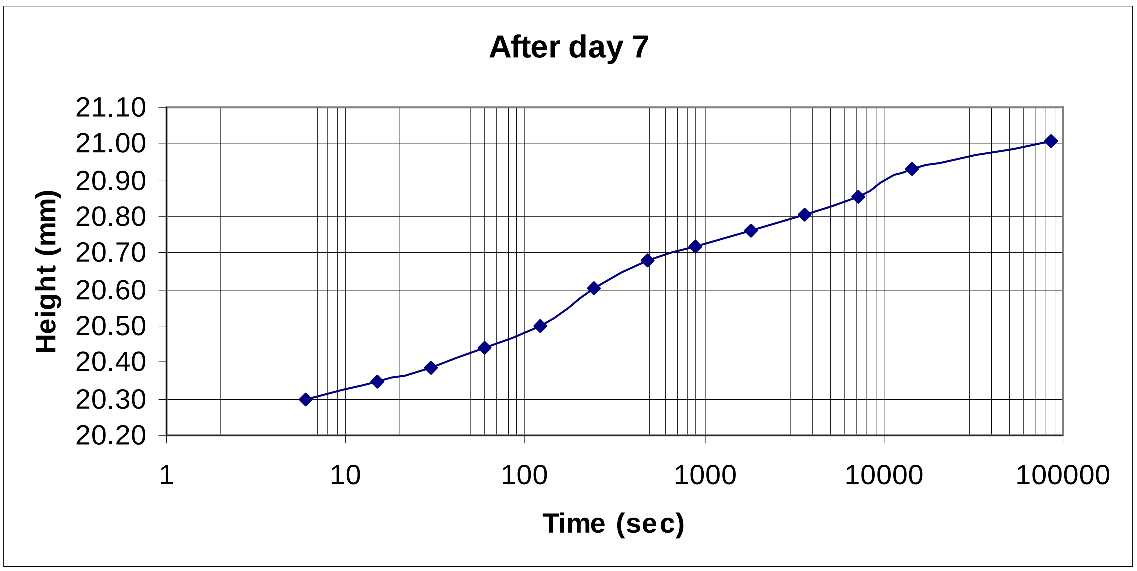
*Day 6*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 6 | 6 | 0.1 | 6 | 25 | -2 | 19.64 | 0.48 |
| | | 0.25 | 15 | | -3 | 19.66 | 0.48 |
| | | 0.5 | 30 | | -5 | 19.71 | 0.49 |
| | | 1 | 60 | | -7 | 19.76 | 0.49 |
| | | 2 | 120 | | -9 | 19.82 | 0.49 |
| | | 4 | 240 | | -11 | 19.87 | 0.50 |
| | | 8 | 480 | | -12 | 19.89 | 0.50 |
| | | 15 | 900 | | -13.5 | 19.93 | 0.50 |
| | | 30 | 1800 | | -15 | 19.97 | 0.50 |
| | | 60 | 3600 | | -17 | 20.02 | 0.51 |
| | | 120 | 7200 | | -20 | 20.10 | 0.51 |
| | | 240 | 14400 | | -23 | 20.17 | 0.52 |
| | | 1440 | 86400 | | -27 | 20.27 | 0.53 |



*Day 7*

| S.no. | Day | Time (min) | Time (sec) | Load (kPa) | Reading on dial gauge | ΔH (mm) | e |
|---|---|---|---|---|---|---|---|
| 7 | 7 | 0.1 | 6 | 5 | -1 | 20.30 | 0.53 |
| | | 0.25 | 15 | | -3 | 20.35 | 0.53 |
| | | 0.5 | 30 | | -4.5 | 20.39 | 0.54 |
| | | 1 | 60 | | -6.5 | 20.44 | 0.54 |
| | | 2 | 120 | | -9 | 20.50 | 0.54 |
| | | 4 | 240 | | -13 | 20.60 | 0.55 |
| | | 8 | 480 | | -16 | 20.68 | 0.56 |
| | | 15 | 900 | | -17.5 | 20.72 | 0.56 |
| | | 30 | 1800 | | -19.3 | 20.76 | 0.56 |
| | | 60 | 3600 | | -21 | 20.81 | 0.57 |
| | | 120 | 7200 | | -23 | 20.86 | 0.57 |
| | | 240 | 14400 | | -26 | 20.93 | 0.58 |
| | | 1440 | 86400 | | -29 | 21.01 | 0.58 |



# APPENDIX D

## Alphadrytest

The input variables for the program “alphadrytest” are outlined as:

alpha0 = Starting alpha in $cm^2$/min; typically 0.0001 can be used as the starting value.
alphaf = Final alpha in $cm^2$/min; typically 0.001 can be used as the final value.

NOTE: The starting and final alpha values may be changed depending on the output from the program.

nalpha = Number of alpha trials; typically a value of 11 is used.
he = 0.54 $cm^{-1}$; a constant evaporation coefficient.
ua = Atmospheric suction in pF.
u0 = Initial suction in pF.
x = Coordinate of the psychrometer in cm, from the closed end of the specimen.
L = Length of the specimen in cm.
tm = Suction measurement times in minutes.
um = Suction measurements in pF.
num = Number of suction measurements.

**The Matlab program “alphadrytest” is as follows:**

```
%program to estimate alpha from drying test
clear all
alpha0 = input('starting alpha    ');
alphaf = input('final alpha    ');
nalpha = input('number of alpha trials    ');
he      = input('he    ');
ua      = input('atmospheric suction, pF    ');
u0      = input('initial suction, pF    ');
x       = input('coordinate of psychrometer   ');
L       = input('length of specimen    ');
tm      = input('measurement times    ');
```

```
um     = input('suction measurements    ');
num   = input('number of measurements    ');

%evaluate zn
delta=.001*pi;
for n=1:20
   flag=0;
   zn=(n-1)*pi;
   for i=1:1000
      if(flag==0)
         zn=zn+delta;
         f=cot(zn)-zn/(he*L);
         if(f<0)
            fm1=cot(zn-delta)-(zn-delta)/(he*L);
            slope=(f-fm1)/delta;
            zn=zn-delta+fm1/slope;
            z(n)=zn;
            flag=1;
         end
      end
   end
end

%compute error as function of alpha
dalpha=(alphaf-alpha0)/(nalpha-1)
err(1:nalpha)=0
alpha=alpha0
for k=1:nalpha
      alph(k)=alpha;
   u=linspace(ua,ua,num);
   for n=1:20
      c1=z(n)*x/L;
      c2=(z(n))^2*tm*alpha/L^2;
      c3=2*(u0-ua)*sin(z(n))/(z(n)+sin(z(n))*cos(z(n)));
```

```
        du=c3*exp(-c2)*cos(c1);
        u=u+du;
    end
    errvector=um-u;
    err(k)=norm(errvector);
    alpha=alpha+dalpha;
end

alph=alph*1000
display(alph(1:nalpha)')
display(err(1:nalpha)')
```

**Drytest**

The input variables for the program “drytest” are outlined as:

alpha = Alpha value in $cm^2$/min as calculated by the program “alphadrytest.”
he = 0.54 $cm^{-1}$; a constant evaporation coefficient.
ua = Atmospheric suction in pF.
u0 = Initial suction in pF.
tstart = Start time in minutes; typically 100 min.
tstop = Stop time in minutes; typically 100,000 min.
num = Number of time increments per log cycle; typically 20.
x = Coordinate of the psychrometer in cm, from the closed end of the specimen.
L = Length of the specimen in cm.

**The Matlab program “drytest” is as follows:**

```
%program to plot theoretical curves for drying test
clear all

alpha=input('alpha    ');
he=input('he    ');
ua=input('atmospheric suction, pF    ');
u0=input('initial suction, pF    ');
```

```
tstart=input('start time    ');
tstop=input('end time    ');
num=input('number of time increments per log cycle   ');
x=input('coordinate of psychrometer   ');
L=input('length of specimen    ');

%select solution times
ncycle=log10(tstop/tstart);
num=num*ncycle+1;
logtstart=log10(tstart);
logtstop=log10(tstop);
logt=linspace(logtstart,logtstop,num);
t=10.^logt;

%evaluate zn
delta=.001*pi;
for n=1:20
   flag=0;
   zn=(n-1)*pi;
   for i=1:1000
      if(flag==0)
         zn=zn+delta;
         f=cot(zn)-zn/(he*L);
         if(f<0)
            fm1=cot(zn-delta)-(zn-delta)/(he*L);
            slope=(f-fm1)/delta;
            zn=zn-delta+fm1/slope;
            z(n)=zn;
            flag=1;
         end
      end
   end
end
%solution for suction
```

```
u=linspace(ua,ua,num);
for n=1:20
    c1=z(n)*x/L;
    c2=(z(n))^2*t*alpha/L^2;
    c3=2*(u0-ua)*sin(z(n))/(z(n)+sin(z(n))*cos(z(n)));
    du=c3*exp(-c2)*cos(c1);
    u=u+du;
end
display(t(1:num)')
display(u(1:num)')
```

# APPENDIX E

## Atterberg Limits

Atterberg limits comprises of liquid limit and plastic limit. It represents the water content at which defined levels of consistencies are achieved. The limits depend upon the clay mineralogy and hence vary according to the percentage of variety of clay present the mixture.

*Sample Preparation.* For liquid limit and plastic limit, the soil sample, was oven dried at 105 ºC. It was further ground to finer particles using grinding machines, after being broken into smaller pieces by using hand rammer. The ground sample was passed through a #40 sieve. The sample passing the sieve was used for obtaining the Atterberg limits.

*Liquid Limit.* Moisture conditioning of the samples was done before conducting the liquid limit test. The samples were mixed with distilled water and placed in a ceramic cup for 24 hrs. It was ensured that there is no moisture loss by covering the cup with a plastic wrap. ASTM D4318 (2001 a) was followed to conduct the liquid limit test after the moisture conditioning.

*Plastic Limit.* Plastic limit was performed on the soil sample (used for Liquid limit) as per ASTM D4318 (2001 a).

## Water Content

The soil samples provided by Texas Department of Transportation were stored in moisture-controlled rooms to avoid the loss of moisture from the samples. Water content for each sample was taken before and during the tests was being performed.

## Sieve Analysis

Wet sieving was done. Fine-grained plastic clay particles tend to adhere together when dried, even when subjected to grinding. Hence, a potential problem of mistaking aggregates of fine particles for coarse-grained particles can arise if a dry sieve analysis of such clays is done.

*Sample Preparation*. Chunk of Shelby tube soil sample was taken and oven dried for 24 hrs. The sample was ground. 200 gm of oven dried ground sample was taken out for sieve analysis.

*Procedure*. ASTM D1140-00 (2001 b) standards for wet sieving was followed. 200 gm of soil sample was taken in a container. The sample was soaked in water for 2 hrs. This helped in preventing the finer materials from adhering to the larger particles. The sample solution was then passed through a 75 µm (#200) sieve and water was passed through the sieve until clear water was passing the sieve. The soil sample retained on the sieve was obtained and oven dried. The percentage of soil passing a #200 sieve was obtained by calculating the loss in mass resulting from the wash treatment.

### Hydrometer Analysis

Stokes' law forms the basis of hydrometer analysis. This law relates the terminal velocity of a free-falling sphere in a liquid to its diameter .Hydrometer analysis is the test used to determine the grain size distribution of the soils passing a #200 sieve. When series of density measurements is available at known depths of suspension and times of settlement, than the percentages of particles finer than the diameters can be obtained by Stokes' law. Thus, the series of readings reflects the amount of different sizes of particles in the fine-grained soils.

*Sample Preparation.* A dispersing solution was prepared by mixing 40 gm of calgon in 1000 ml of distilled water. This solution was used for deflocculating the particles, as the clay particles have a tendency to adhere to each other and form larger masses.

50 gm of soil sample passing #200 sieve was taken for hydrometer analysis. The soil sample was mixed with 125 ml of dispersing solution. Distilled water was added to make total of 1000 ml volume of suspended solution.

*Procedure.* ASTM D422-63 (2001 c) standards were followed to carry out the hydrometer test. The suspended solution was kept undisturbed, and readings were taken at 2, 4, 15, 30, 60, 90, 120 sec and 5, 15, 30, 60 minutes. The combined sieve and hydrometer analyses permitted estimates of the clay fraction of the soil; i.e. the percentage of particles finer than 2 µm.

# VITA

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EDUCATIONAL BACKGROUND

- Bachelor of Engineering, Civil Engineering
  Visvesvaraya National Institute of Technology, Nagpur, India (Spring 2003)
- Master of Science, Civil Engineering
  Texas A&M University

WORK EXPERIENCE

- Texas A&M University, College Station, Texas, USA
  Research Assistant –
  1. Analyzed the current PVR method for expansive soils using software FLODEF and experimentation for Texas Department of Transportation.

  (Fall 2003-Spring 2005)
- Gujarat Guardian Ltd., Ankleshwar, Gujarat, India
  Managed a staff of 100 people as a production manager on site.
  (May 2003-July 2003)
- Indian Institute of Technology, Madras, India
  Summer Research Assistant –
  1. Analyzed and designed ‘Pile Foundation’ for “Konaseema power project”, Larson & Toubro project, Madras India.
  2. Analyzed stress distribution under ‘silos’ using shallow foundation.

  (May 2002-July 2002)