STANDARDIZING THE PRESSUREMETER TEST FOR DETERMINING P–Y CURVES FOR LATERALLY LOADED PILES

Final Report

Florida Institute of Technology

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The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Conversions To SI Units

Symbol	When you know	Multiply by	To find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1,000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
Temperature (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
Force and Pressure or Stress				
lbf	pound force	4.45	Newton’s	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract

The control unit of the Roctest® Pencel Pressuremeter (PPMT) has been instrumented to enable digital pressures and volumes to be recorded. This digital information is now acquired through a stand-alone software package, called APMT that incorporates the required calibrations to provide engineers with instantaneous reduced data along with pertinent engineering strength and stiffness parameters.

Pushed-in PPMT tests were performed in Florida sands and clays to standardize the testing procedure for the Florida Department of Transportation (FDOT). PPMT tests were conducted in soundings advanced using the FDOT Cone Penetrometer (CPT) testing rig. Pushing the PPMT combined with the automation allows engineers to efficiently use reduced stress–strain data to determine elastic moduli, limit pressures and lift-off pressures. These parameters were evaluated and proven to be realistic when compared to conventional pressuremeter (PMT) and dilatometer (DMT) data.

PPMT and DMT data from the Florida soils was used to determine p–y curves based on Robertson's methods (1986, 1989). These curves were compared and produced similar results.

Seven historical field sites with instrumented and tested laterally loaded piles; PMT and DMT tests were evaluated. PMT, mostly from PPMT tests, and DMT p–y curves, again based on Robertson's methods were developed and used with the FBMultiPier software to develop ground-line load-deflection data. The PMT and DMT predicted data was compared to measured load-deflection data from the instrumented piles. The PMT testing from these historical sites was performed without following a standard procedure and the resulting comparisons showed that the inconsistent testing produced highly variable predictions, highlighting the need for a standard PPMT test procedure. Regardless of these inconsistencies, both the PMT and DMT predictions were comparable to the measured data.

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Executive Summary
Standardizing the Pressuremeter Test for Determining p–y Curves for Laterally Loaded Piles

by

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An extensive research program was undertaken with the support of the Florida Department of Transportation to standardize the test procedure and automate the Pencel Pressuremeter manufactured by Roctest®. Both processes were undertaken with the goal of producing reduced PPMT data that could quickly be used for laterally loaded pile p–y predictions. This work resulted in a significant time savings for both the field operator and engineer involved.

Two hundred thirty five, pushed in PPMT tests were performed in sands and clays within Florida to standardize the testing procedure for the Florida Department of Transportation (FDOT). PPMT tests were conducted in soundings advanced using the FDOT Cone Penetrometer (CPT) testing rig. The use of this equipment combined with the automation allows engineers to efficiently use reduced stress–strain data to determine elastic moduli, limit pressures and lift-off pressures. These parameters were evaluated and proven to be realistic when compared to both conventional pressuremeter (PMT) data and dilatometer (DMT) data.

The control unit of the Roctest® Pencel Pressuremeter (PPMT) has been instrumented to enable digital pressures and volumes to be recorded. This digital information is now acquired through a stand-alone software package called APMT that incorporates the required calibrations to provide engineers with instantaneous reduced data along with pertinent engineering strength and stiffness parameters.

As part of the work, the equipment ruggedness was evaluated, indicating that the vent tube shaft at the ends of the probe on the solid probe model is vulnerable and could fail, therefore the hollow probe model is recommended. Membrane failure proved not to be a concern as a result of careful membrane sizing based on a 32-mm diameter calibration tube.

A proposed standard testing methodology has been prepared that includes proper saturation, assembly, calibration, testing and data reduction techniques. PPMT and DMT data from the Florida soils was used to determine p–y curves based on Robertson's methods (1986, 1989). These curves were compared and produced similar results.

The initial modulus and lift-off pressure obtained from PPMT tests were similar to DMT lift-off and moduli. PPMT tests were conducted with and without a friction reducer on the driving tip. This work led to the conclusion that the increased soil disturbance from the friction reducer decreases the engineering parameters and is not recommended.

Seven historical field sites with instrumented and tested laterally loaded piles; PMT and DMT tests were evaluated. PMT, mostly from PPMT tests, and DMT p–y curves, again based on Robertson's methods, were developed and used with the FBMultiPier software to develop ground-line load-deflection data. The PMT and DMT predicted data was compared to measured load-deflection data from the instrumented piles. The PMT testing from these historical sites was performed without following a standard procedure and the resulting comparisons showed that the inconsistent testing produced highly variable predictions, highlighting the need for a standard PPMT test procedure. Regardless of these inconsistencies, both the PMT and DMT predictions were comparable to the measured data.

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1 Chapter 1—INTRODUCTION

1.1 Problem Statement

The Florida Department of Transportation (FDOT) has made a significant soil testing advancement by using either drill rigs or cone penetrometer (CPT) trucks that rapidly push the Roctest Inc., Pencel Pressuremeter (PPMT), to the desired test depth. PPMTs are 1.35-inch diameter cone-tipped devices that can be connected to standard CPT rods. Standard pressuremeters (PMTs) are 3-inch diameter devices that are lowered into prebored holes requiring a significantly longer time per test. The PPMT data yields in-situ stress–strain properties that can be subsequently used for analysis and design of laterally loaded piles, settlement and bearing capacity, etc. The current FDOT recommendation is that reduced PPMT data be converted to the p–y curves developed based on Robertson's et al (1986) method. This advance results in significant time and cost savings for the engineer.

Originally developed in the 1950s by Ménard and modified by Briaud in the 1970s, various PMT models are currently available (Briaud, 1992). In additional to classical geotechnical applications, Cosentino (1987) used the PPMT to evaluate its potential use in pavement design. This device, which tests a large zone of soil, would be more widely used if a standardized procedure was implemented and the data reduction was modernized using current computer and instrumentation techniques. Most PMT testing is conducted once the drillers prepare the prebored test hole and the probe is lowered to the desired position. These larger diameter pressuremeters are naturally more cumbersome to work with than the Pencel PMT.

Following a series of calibrations, the PPMT probe is hydraulically pushed with the CPT rig to the desired test depth and a 10- to 15-minute test is performed. There are concerns about the quality of the engineering parameters obtained from pushed-in PPMT tests due to soil disturbance. These parameters include a lift-off or initial pressure (p_o) elastic moduli and a limit or ultimate pressure (p_L). Some operators push the probe with a small friction reducer on the cone tip and others push it without a friction reducer. The friction reducer is thought to help preserve the membranes during a sounding (i.e., a series of PPMT tests conducted in one hole, without removal of the equipment).

During a test, a strain-controlled process is performed that requires operators to inject equal volumes of water into the probe and record the corresponding pressures. Due to the PPMT probe inflation with water from a 138-cm^3 cylinder, 5 cm^3 of water is injected up to 90 cm^3, or until the limit of the pressure gauge is reached. The operators also determine the extent of the linear stress–strain response range before conducting one unload–reload cycle on the soil. This determination requires several steps and can be very difficult. With proper automation, the entire testing protocol would be simplified to yield more precise data and ease the operator's requirements.

FDOT envisions a standardized PPMT test procedure that reduces the time required to collect and reduce the field data needed to calculate p–y curves without compromising the quality of test results. Presently, there are no ASTM or AASHTO standards for performing the PPMT test.

1.1.1 Objective

The objective of this study is to develop a standard cone-pushed PPMT test method while automating the PPMT to enable the field operators to more rapidly and accurately conduct the standardized tests for analysis and design of laterally loaded piles.

1.1.2 Approach

To meet this objective, the work was divided into two areas encompassing ten tasks. One area involved data collection and processing that would enable automation and the second involved developing a standard cone-pushed PPMT test procedure based on testing at several sites with various Florida soils. Details of the tasks required to complete the research are given below.

Task 1 Development of PPMT Data Acquisition System Hardware—Two components of the system were instrumented, one for pressure and the second for volume measurement. The analog pressure gauge currently supplied with the control unit reads from –100 to + 2,500 kPa or about –15 to +360 psi. Therefore, instrumentation that could record from –15 to +500 psi was needed. The volume piston cylinder that is used to inflate the probe has a volume of 135 cm^3 and a displacement of about 4.5 inches. Both flow meters and displacement transducers were evaluated, however; the accuracy levels possible using current flow meters were not acceptable. A displacement transducer with sufficient travel for measuring the displacement of the volume piston was selected. Specialty components necessary for attaching these two instruments were designed. The accuracy and precision of the pressure and volume gauges supplied in the conventional PPMT control unit were evaluated. Calibrations were performed using the instrumented system. For data collection, a laptop computer was selected along with the appropriate data acquisition system hardware. This equipment was used throughout the project and delivered to FDOT as the final product upon completion of the project. Florida Tech purchased a matching laptop computer with this data acquisition system.

Task 2 Development of Data Acquisition and Reduction Software—Two separate computer packages have been developed, one based on the .net language and the second based on LabVIEW®. The .net software allows engineers to work independently of the automated PPMT, while the LabVIEW® software runs concurrently with the automated system, producing reduced data during testing. Both packages allow export of files to Excel®.

The stand-alone software package was assembled for use with non-automated PMT test data. The .net software called "ProvaFIT in-situ 2005" was refined and tested on various personal computers. It includes engineering calculations in terms of volumetric changes, volumetric or hoop strains for the elastic moduli, the lift-off or initial pressure and the limit pressure. This software enables elastic moduli to be determined between any two points along the entire reduced PMT plot. It also allows the user to determine the initial or lift-off pressures depending on the shape of the early portion of the curve and estimate the limit pressures associated with doubling the initial volume of the probe.

Data acquisition (DAQ) software was developed to enable a simple interface to be available to the field operators. National Instruments LabVIEW® software was used to develop the data acquisition system and the final package is a stand-alone program that does not require a LabVIEW® license. The acquired data can be exported to other software packages such as Excel® for additional work. There are three labels available to depict the x-axis: change in volume (ΔV), volumetric strain ($\Delta V/V_o$) and radial strain ($\Delta R/R_o$), all three available to the users. This software also allows users to quickly determine elastic moduli, the limit pressure and initial or at-rest horizontal pressures at the conclusion of a test.

Task 3 Field Evaluation of Automated System—Field trials were conducted with both the original and automated systems to verify the equipment functionality. Tests were conducted in the sand at the All Faiths Center on the Florida Tech campus, the Archer Landfill near Gainesville, Florida, and at the sand and clay site at the Puerto Del Rio Condominium in Cape Canaveral, Florida. Either a smooth cone tip or a cone tip with a small (≈ 1 mm) thick friction reducer, as shown in Figure 1.1, were used during pushing of the PPMT probe. This task was included to evaluate whether or not a friction reducer should be used. The soil properties at each site were determined by cone or split spoon sampling. The All Faiths site was subjected to a series of pressuremeter and spectral analysis of surface wave testing; enabling the upper 1 m (3 ft) to be previously categorized (Erbland, 1993).

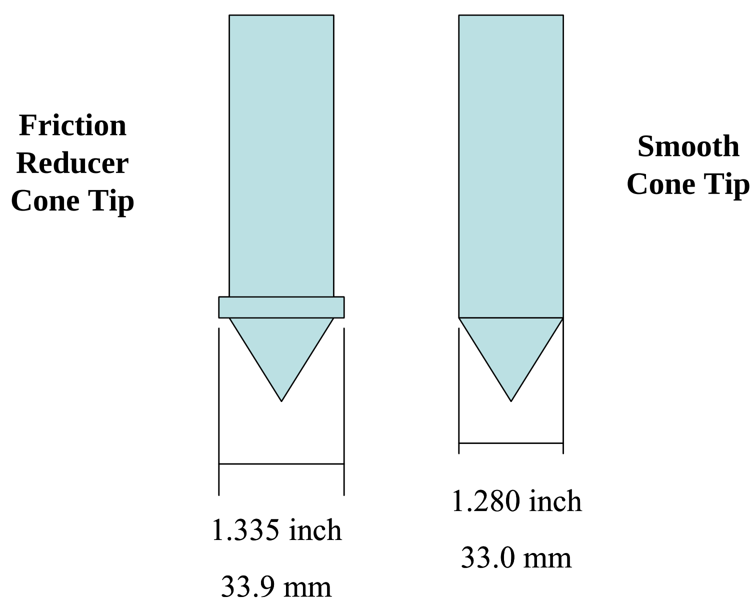


Figure 1.1 Schematic of Cone Tip with and without friction reducer

Task 4 Pressuremeter p–y Literature and Data Review—A thorough review of the literature on laterally loaded piles was conducted, emphasizing the use of the pressuremeter to predict p–y curves. In conjunction with the literature search, existing database information was evaluated to gain a thorough understanding of the accuracy of the PMT for predicting p–y curves.

This task included a 12-month subcontract with Dr. Brian Anderson from the Department of Civil Engineering at the University of North Carolina-Charlotte. The subcontract was for access and consulting on the data available dealing with laterally loaded piles with the following specific services to:

1) provide access to the UNCC laterally loaded pile database

2) receive input on work we are performing, which would require interaction with a graduate student and a yearly visit by Dr. Anderson to the Florida Tech campus

3) use the existing spreadsheet software developed by Dr. Anderson for PPMT data reduction into p–y curves

4) perform and evaluate predicted versus measured p–y curves from several sites within the UNCC database

Task 5 Development of Standard Cone-Pushed PPMT Test—A series of augured and cone-pushed PPMT tests were performed on the Florida Tech campus. The FDOT state materials office Cone Truck was used to conduct the cone-pushed PPMT tests. Several variables associated with the test were evaluated, including the length of the probe and the 30-second interval currently required between volume injections. Although theory suggests that a length-to-diameter ratio of seven should be maintained, work by Erbland (1993) indicates that the length of the probe affects the resulting stress–strain curves in terms of the initial slope and the ultimate capacity, termed limit pressure. To evaluate this ratio, the probe length will be varied in the laboratory from the existing 9 inches to a maximum length of about 12 inches. The interval between volume injections will be evaluated to allow it to be shortened from the 30 seconds currently recommended by Roctest®. If this change can be implemented, the duration of a test can be decreased.

Task 6 Lateral Load Field Testing Site(s)—After an exhaustive search for new field sites with lateral load testing failed to produce any viable sites, seven previously evaluated field sites were chosen for the field-testing and validation. These seven sites had existing laterally loaded pile tests, plus PMT and dilatometer (DMT) tests. The PMT data varied from pushed-in PPMT tests to the standard PMT testing in pre-bored holes. Because there was no standard PPMT testing procedure, the data from all seven sites had significant inconsistencies.

Task 7 Reduction and Analysis of Data—Data from the field-testing was reduced using the established Excel spreadsheets, plus the ProvaFIT 2005 and APMT software developed in Task 4. The results from these reductions were compared and then converted to p–y curves for the lateral load analysis. The common engineering parameters obtained from the tests, (i.e., elastic moduli, limit and initial pressures) were compared to published data.

Task 8 Verification of PPMT Testing Procedure—A standardized cone-pushed PPMT test procedure has been developed based on the field performance at three field sites within Florida. Two sites were predominately sand and the third consisted of two clay layers interbedded with sand layers.

Task 9 Developmental Specifications for the Cone-Pushed PPMT Test—The standardized cone-pushed PPMT test procedure has been written into a formal document that can be used as developmental specifications. The procedure also includes steps for conducting PPMT tests with the automated control unit.

Task 10 Reporting and Technology Transfer—In addition to the final report, key personnel from FDOT have been invited to the Florida Tech campus for a technology transfer meeting. The meeting will include a workshop of PPMT testing procedures and data reduction.

2 Chapter 2—THE PMT AND LATERALLY LOADED FOUNDATIONS

2.1 Pressuremeters

Mair et al (1987) defined PMTs as “cylindrical devices designed to apply uniform pressure to walls of a borehole by means of a flexible membrane”. Pressure is exerted on the borehole walls via an incompressible liquid or gas. If PMTs have sufficient length-to-diameter ratios, the soil expansion is assumed to be cylindrical, allowing plain strain assumptions to be used to reduce the data. The cavity expansion and corresponding pressure increase are reduced to stress–strain, from which strength-deformation properties are determined.

2.1.1 Historical Development of the PMT

Kögler is credited with developing the first PMT when, in 1933, he made a testing tool that could be used to measure soil deformation. It was a 1.25-m long, 0.1-m diameter mono-cell device consisting of a “bladder” stretched between two metal discs supported on a steel rod. However, because this device was developed before plastic tubing and synthetic rubber were available, Kögler experienced difficulty measuring the volume changes and interpreting the results, and therefore did not pursue his initiative further (Baguelin et al, 1978).

In the mid-1950s, Louis Ménard (1956) successfully developed a fully functional pre-boring PMT, later named the Ménard PMT to measure the in-situ deformation characteristics of soils. As shown in Figure 2.1, Ménard’s PMT consisted of a flexible, three-cell cylindrical probe mounted over a rigid metal tube. The central cell, called the measuring cell, was saturated with water and then inflated using gas pressure supplied through the tubing. Ménard used the change in volume of the measuring cell during expansion to determine the change in radius of the borehole. The upper and lower cells, independent of the measuring cell, are called guard cells, and were used to minimize possible end effects and ensure that the measuring cell expanded only radially as it was pressurized. The guard cells are pressurized to the same pressure as the measuring cell if inflated with water, or at slightly lower pressures if inflated by gas. Ménard’s early PMT measured 58 mm (2.28 in) in diameter and 42 cm (16.5 in) full-length; with a measuring cell length of 21.33 cm (8.4 in). Ménard’s standard tests were stress-controlled, meaning pressures were applied in equal increments during regular time intervals and the corresponding volume changes were recorded.

Ménard’s tri-cell PMT is relatively complex to use, as it requires separate pressure sources for the guard cells and the center measuring cell. Stress-controlled tests often produce less detailed stress–strain information than strain-controlled tests.

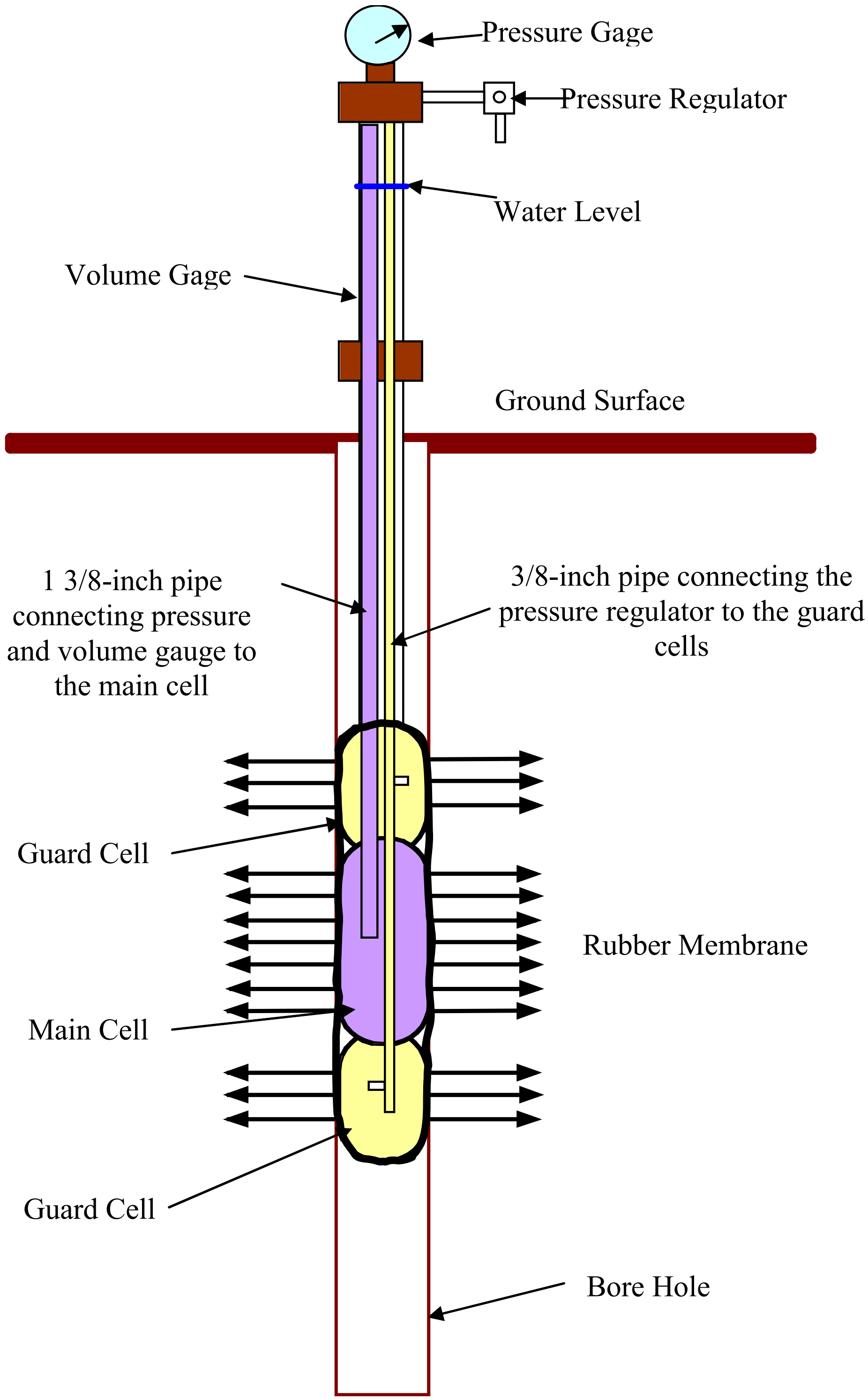


Figure 2.1 Sketch of the Ménard PMT (After Baguelin et al, 1978)

The limitations of Ménard's unit led to the development of other models. England's Self-Boring PMT, also called the Camkometer, and the pushed Shelby tube PMTs became available in 1971 and 1975, respectively. In 1978, the French-built PAM PMT was developed for offshore applications and the Russian-built PA108 also became available. That same year, Briaud and Shields at the University of Ottawa developed the mono-cell Pencel® PMT specifically for pavement evaluation and design. In 1982, the mono-cell Texam preboring and self-boring PMTs were developed by Briaud at Texas A&M University. Figure 2.2 is a schematic of the Texam mono-cell PMT depicting the control unit, actuator, tubing and probe inserted into the soil. High-pressure PMTs for testing in rock were introduced in 1984 (Briaud, 1992).

These mono-cell units allowed for strain-controlled testing. However, there have been concerns about the cylindrical expansion of the surrounding soil if the length-to-diameter ratio is not sufficiently large.

2.1.2 Types of PMT Equipment

The type of PMT is usually defined by the manner with which its probe is inserted into the soil; however, the plain-strain theory associated with reducing test data is the same. The installation procedure determines whether the test is on disturbed or undisturbed soil.

Briaud (1992) describes three major groups' commonly used PMTs. These are the pre-boring pressuremeter (PBPMT), the self-boring pressuremeter (SBPMT) and the cone pressuremeter (CPMT). A fourth group known as the pushed Shelby tube pressuremeter (PSPMT) is also available, but will not be discussed in this report.

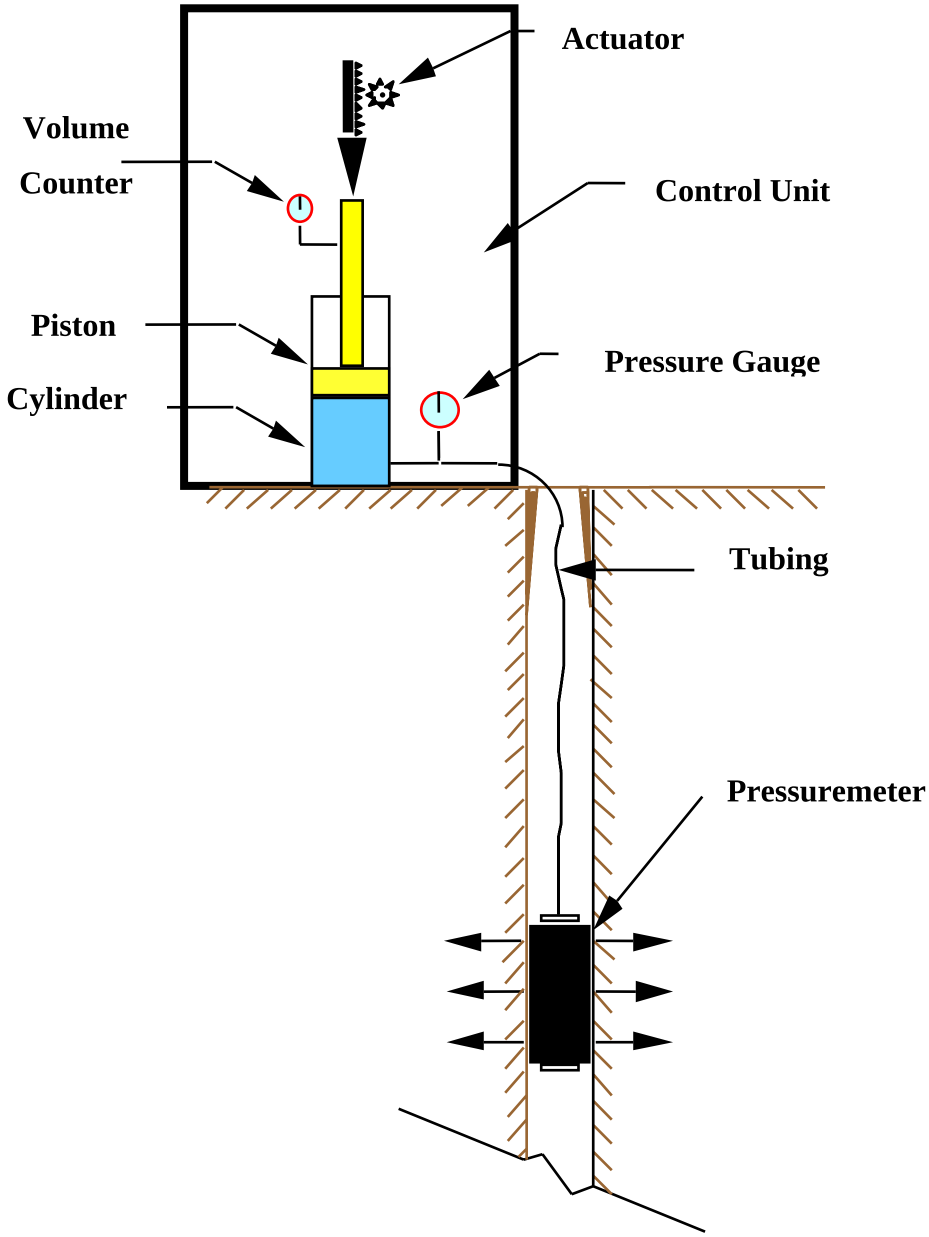


Figure 2.2 Schematic of Texam PMT

2.1.2.1 PBPMT

The PBPMT is lowered into a slightly oversized pre-drilled hole. There are essentially four PBMT models available today, the Ménard PMT, the Lateral Load Tester, the Texam and the Tri-Mod. The Ménard PMT, manufactured and sold by DGI-Ménard Inc., is also available from Roctest®. A photo of the Ménard PMT G-Am model is shown in Figure 2.3. The Lateral Load Tester manufactured by the Oyo Corporation is similar to the Ménard except for its longer, mono-cell probe, to help ensure that end-effect stress concentrations are negligible. The Texam and Tri-Mod manufactured by Roctest® also carry longer probes than the Ménard type PMT. Although both are mono-cell probes, the Texam is inflated with water and the Tri-Mod with gas. A photo of the Texam is shown in Figure 2.4.

Roctest's PMTs also fall under the PBPMT category of PMTs. The unit may be unable to induce yield of very dense rock but may provide sufficient data so that the rock's linear stress–strain characteristics may be determined.

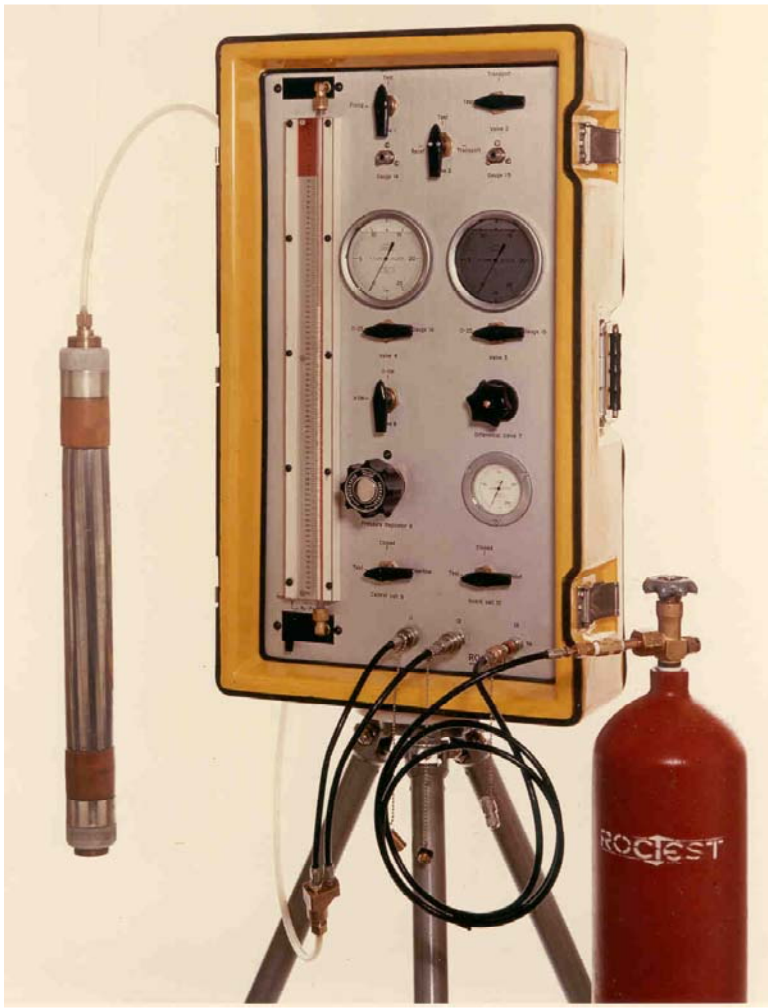


Figure 2.3 The Ménard G-AM PMT (Courtesy of Roctest Inc.)

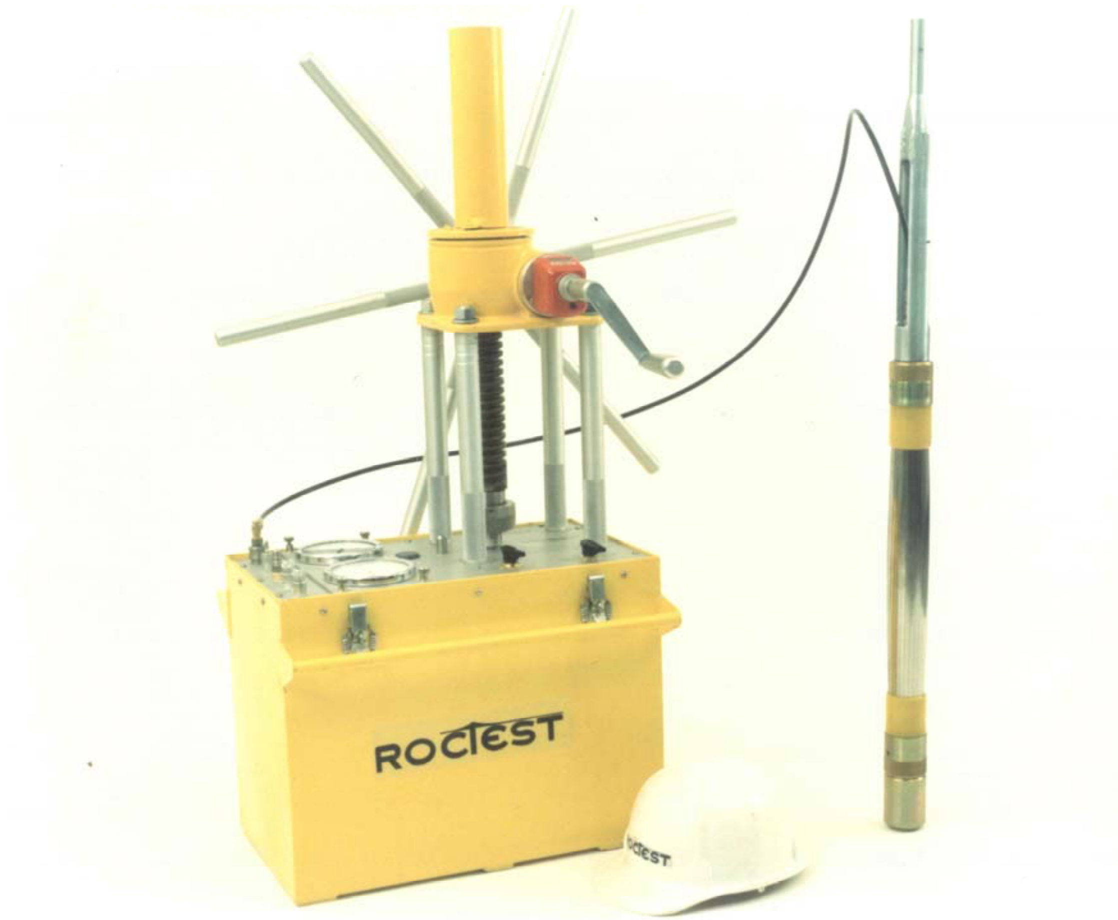


Figure 2.4 The Texam PMT (Courtesy of Roctest Inc.)

2.1.2.2 SBPMT

Although there are essentially three SBPMT models used today, all are inserted as drill rods are advanced. The SBPMT uses miniature cutters to bore into the soil to the required depth and flushes the cut soil to the surface (Figure 2.5). All three types use mono-cell probes; however two versions use water and the third uses gas to inflate the probe. In the former cases, the water pressure is generated by a screw-jack that pushes a piston. The volume increase is measured by a very small flow-meter for one model and by the displacement of a piston for the other. The third category of SBPMT uses either pressure transducers in the probe or pressure gauges, and three electric feelers located mid-height of the probe to measure the increase in the probe radius. The PAF, the Texam Boremac and the Camkometer are respective examples of the three types of SBPMT.

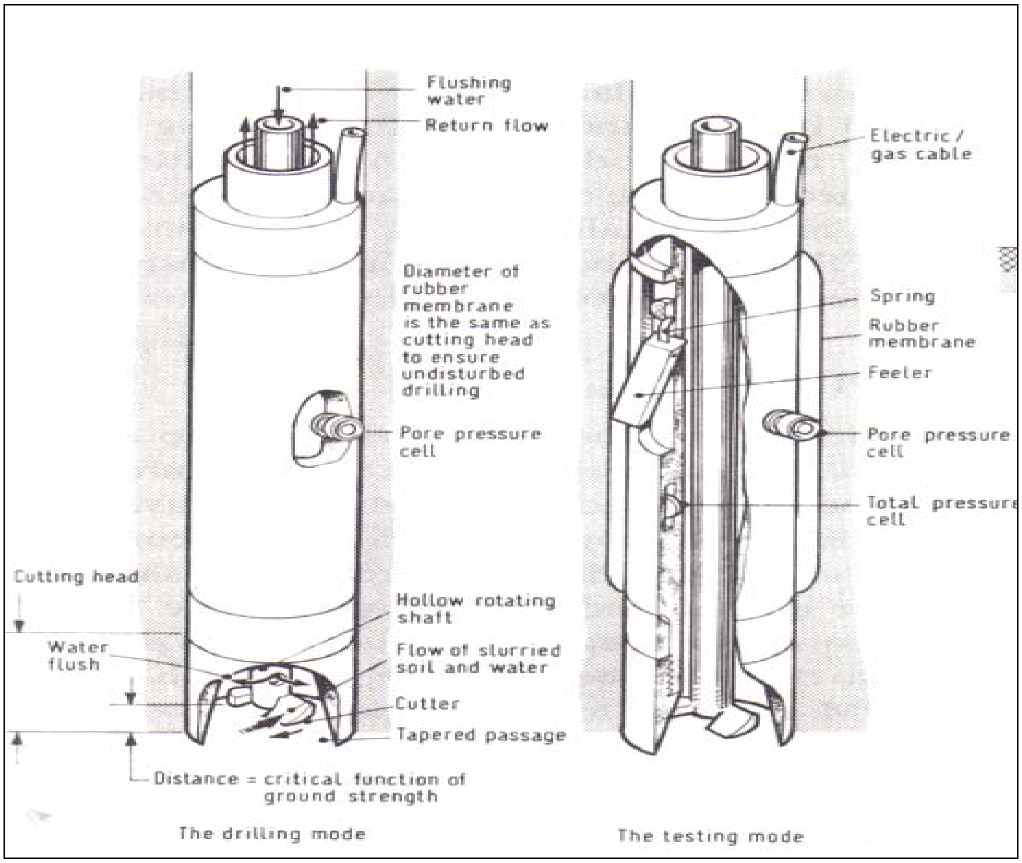


Figure 2.5 Typical SBPMT components in drilling and testing mode
(after Weltman and Head, 1983)

2.1.2.3 CPMT

The CPMT is a combination of equipment used for the cone penetrometer (CPT) test and the PMT test. The Roctest Pencel PMT (PPMT) shown in Figure 2.6 has been used in this capacity. The CPMT probe is either pushed into the soil at a rate of 20 mm/s using a CPT rig or by dropping a weight from a certain height. If the cone penetrometer is placed in series with the CPMT, it has the advantage of recording point and friction profiles during penetration and then conducting the PMT test once penetration has stopped.

The current PPMT as distributed by Roctest® consists of three main parts, the operators control unit placed at the ground surface, the probe inserted into the soil and the tubing connecting the probe to the readout unit. The control unit has pressure and volume displays. A rotation of the handle moves the piston inside the control unit, which forces water through the system and produces a measurable change in the probe volume and corresponding pressure. The PPMT control unit and probe are shown in Figure 2.6. This equipment is to be automated and standardized during this investigation.

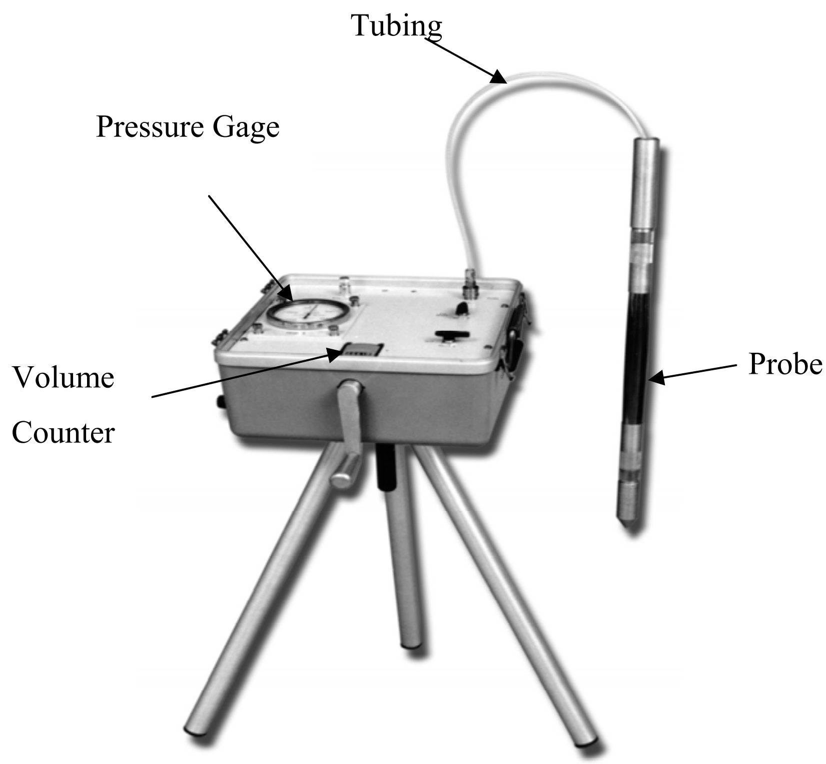
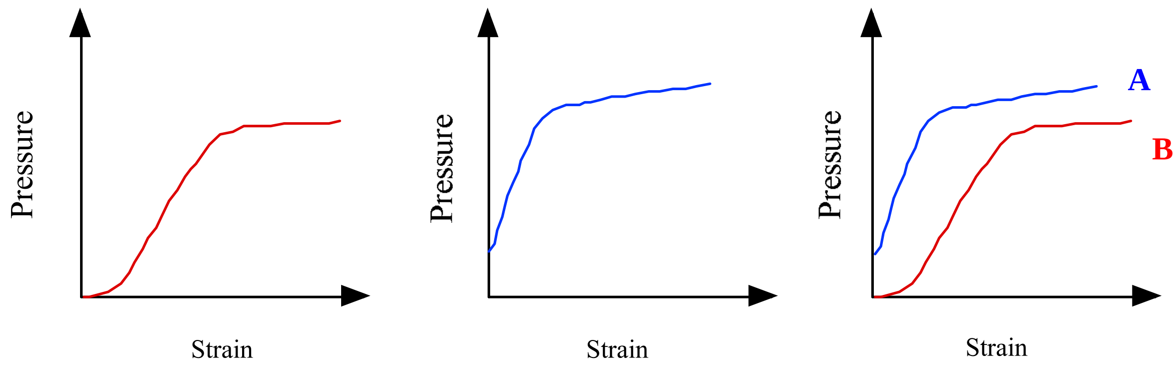


Figure 2.6 The Roctest® Pencel PMT for pushing or driving with cone rods

2.1.3 Comparison of Typical Tests from Various PMTs

Depending on the insertion technique used for a given soil, the resulting stress–strain curves can shift within the x-y axes. A curve should include information on the initial stress state in the soil, as well as the elastic and plastic responses. Figure 2.7a presents typical results from a properly prepared PBPMT hole. Initially, the stress or pressure increases slightly as the strain increases, until the probe firmly contacts the surrounding soil. Once contact is achieved, a linear response is observed within the elastic range up to the point of plastic deformation. Extrapolation of the plastic portion of the curve leads to the soil limit pressure. Figure 2.7b is a typical plot from the SBPMT. Note that the curve seems to have shifted upward and the initial stress appears larger than for PBPMT tests. In Figure 2.7c, both scenarios can occur. This is typical of PCPMT data. Curve A results from a slightly undersized cavity, and curve B from a slightly oversized cavity. Again, the initial stress or pressure for the undersized hole (A) is higher than for the oversized hole (B).



a) PBPMT b) SBPMT c) CPMT

Figure 2.7 Typical a) preboring b) self-boring c) cone PMT curves

2.1.4 Theoretical Interpretation of PMT Results

Normally, the PMT probe is inserted vertically into the ground and an incompressible fluid or gas is used to exert pressure against surrounding soil through the probe's flexible membrane. As the membrane expands, the soil deforms radially. The cavity expansion and the corresponding increase in pressure are used to determine a stress–strain response of the surrounding soil. Figure 2.8 shows the initial PMT radius and the expanded radii that occur during testing.

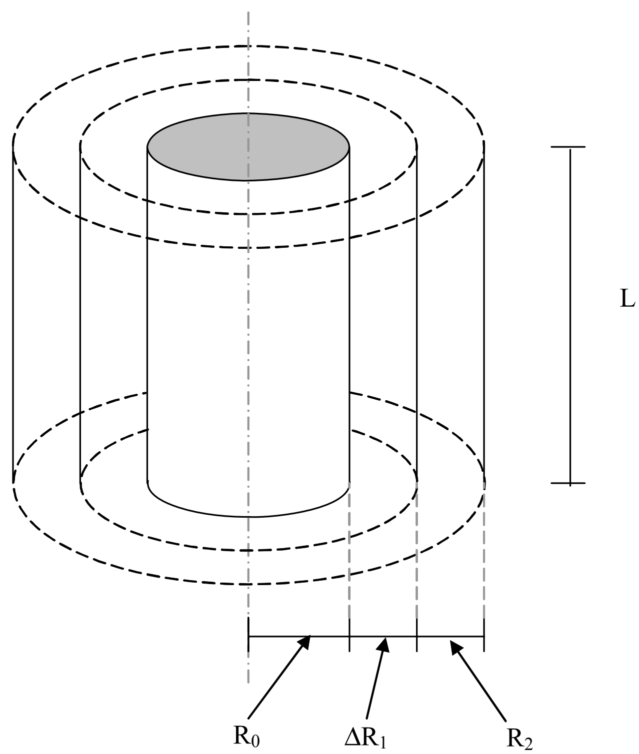


Figure 2.8 PMT plane-strain expansion

The theory associated with the radial expansion of a cylindrical cavity (Baguelin et al, 1978, Briaud, 1992) is recommended when analyzing PMT test data. In this analysis, it is assumed that the probe is an infinitely long cylinder, which expands radially into the soil. This assumption allows for plane-strain conditions to exist along the probe's longitudinal axis.

Engineers originally believed the tri-cell probes produced a cylindrical expansion more consistently than mono-cell units, because the mono-cell probe is of finite length and end-effect stress concentrations may exist. The Texam and Pencel mono-cell probes have length-to-diameter ratios of at least 7 to 1. The longer the expanding length of the probe, the more likely the deformation approximates an expanding cylinder. Studies conducted on the end effects show the difference between the actual and the assumed deformation is very small (Lair et al, 1975, Hartmann 1979). However, these studies were performed before those on the smaller diameter Pencel PMT. Erbland (1994) showed that both the elastic moduli and limit pressures varied as a function of the Pencel PMT probe length.

Engineers estimate the elastic responses, initial or in-situ stresses and the ultimate or limit pressures from the stress–strain data produced by the various probes. To determine these parameters, elastic theory is used with the assumption that small strains control the behavior of the structures supported by the soil.

For undrained tests on saturated soils (i.e., no volume change), the elasticity equation for radial expansion of cylindrical cavity in an infinite elastic medium subjected to small strains is (Lamé, 1852):

$$G = V_m \frac{\Delta P}{\Delta V} \tag{2.1}$$

where: G is the elastic shear modulus

V_m is the mean volume of the cavity at the desired point

ΔV is the change in volume over the corresponding change in pressure ΔP.

The Shear Modulus is related to the Elastic Modulus (E) and Poisson's Ratio (ν) using:

$$G = \frac{E}{2(1+\nu)} \tag{2.2}$$

The mean volume can be found with the original probe dimensions using:

$$V_m = V_o + \left(\frac{\Delta V_f + \Delta V_i}{2}\right) \tag{2.3}$$

where: V_0 is the initial probe volume prior to testing and

ΔV_i and ΔV_f are the initial and final volumes injected at the desired location along the PMT plot.

Equations 2.1 and 2.2 allow engineers to calculate moduli when PMT data is plotted as stress versus either change in volume (ΔV) or volumetric strain ($\Delta V/ V_0$). Note that the volumetric strain is found by using the initial probe volume and the change in volume at the point of interest along the stress–strain curve. The raw data recorded during testing is pressure versus change in volume and therefore, E, Young's Modulus, is often found by substituting Equation 2.2 into Equation 2.1 to produce:

$$E = 2(1+\nu)V_m(\frac{\Delta P}{\Delta V}) \qquad (2.4)$$

Because various PMT sizes are available and each size requires different volumes to be injected, is often useful to convert the plot to stress versus a more conventional strain. Either the radial (ε_r) or circumferential (ε_Θ) strains can be related to the applied stress. For small strains, elastic theory can be used to show that the radial strain (ε_r) is approximately equal to the circumferential strain as:

$$\varepsilon_r \approx -\varepsilon_\Theta \qquad (2.5)$$

Note that ε_Θ is a tensile strain (i.e., negative) while is ε_r a compressive strain (i.e. positive). The circumferential strain at the cavity wall is equivalent to the radial strain written in terms of cavity radii:

$$\varepsilon_\theta = \frac{2\pi R_f - 2\pi R_0}{2\pi R_0} = \frac{R_f - R_0}{R_0} = \frac{\Delta R}{R_0} \qquad (2.6)$$

where: ε_Θ = circumferential strain

R_o= initial cavity radius

R_f= final cavity radius

ΔR = change in cavity radius

Substituting Equation 2.3 into Equation 2.4 in terms of radii for the volumes produces the following for elastic moduli (Tucker and Briaud, 1986):

$$E = (1+\nu)\left[\left(1+\frac{\Delta R_1}{R_0}\right)^2 + \left(1+\frac{\Delta R_2}{R_0}\right)^2\right]\frac{\Delta P}{\left[\left(1+\frac{\Delta R_2}{R_0}\right)^2 - \left(1+\frac{\Delta R_1}{R_0}\right)^2\right]} \qquad (2.7)$$

Where:

R_0 = initial radius of the probe

ΔR_1 = increase in probe radii at the beginning of the pressure increment P_1

ΔR_2 = increase in probe radii at the end of the pressure increment P_2

$\Delta P = P_2 - P_1$ or pressure increment

P_1 = Radial stress at the cavity at the beginning of the pressure increment

P_2 = Radial stress at the cavity at the end of the pressure increment

This revised equation makes it possible to compare results from various-sized PMTs, because the reduced data is plotted as radial stress versus circumferential or hoop strain instead volume. This equation format allows the radial strains plotted on the x-axis to be used directly; if it were simplified further, this advantage would be lost.

2.1.5 Current PPMT Testing Procedure

The steps that describe testing with the PPMT follow, based on the procedures outlined in the latest Roctest® manual (2005) :

1) *Filling and saturation of the control unit:* After connection of the tubing and probe, the entire unit is saturated to insure that no air is trapped in the cylinder, filling lines or probe. During the saturation period, the pressure gauge is monitored to insure that the pressure stabilizes. If the pressure is not stabilized, it signals a leak in the system that must be fixed before proceeding.
2) *Calibration:* Two required calibrations are conducted separately, the pressure calibration and the volume loss calibration. The pressure calibration produces the inherent membrane resistance and the volume loss calibration yields the volume loss due to the expansion of the tubing and probe membrane, etc.
3) *Probe Insertion:* In addition to lowering into a prebored hole, the probe may also be positioned by pushing or light hammering. If a CPT drill rig is used, the probe is connected to hollow EW drill rods with an external diameter of 32 mm and internal diameter varying from 12.7 mm to 16 mm. The rod is then pushed into the soil.
4) *Test Execution:* Once the probe has reached the desired depth, the valves on the top of the reading unit are turned to the "Test" position. Testing is conducted by rotating the crank to inject equal volume increments of 5 cm^3. The corresponding pressure is usually noted after 15 seconds at the specified volume. To avoid membrane failure, the maximum volume injected for a test is usually 90 cm^3. Generally, the test duration is about 15 minutes. When the test is completed, the probe must be deflated by returning the water to the cylinder, before removing the probe from the hole or advancing it to the next depth.
5) *Interpretation:* The raw PMT data curve and the corrected PMT curve are plotted. For each point on the raw curve, there is a corresponding point on the corrected curve with coordinates of corrected pressure and corrected volume. Thus the corrected point is obtained by subtracting the volume and pressure correction from the corresponding raw volume and pressure data. In correcting the pressure, hydrostatic pressure exerted on the probe is also taken into consideration. Thus, the following calculations are performed on the data points:

Volume Correction = Volume read – Volume calibration (2.8)

Pressure Correction = Pressure read – Pressure calibration + Hydrostatic Pressure (2.9)

Once the corrected curves are obtained, the Elastic moduli (E), in-situ horizontal stress (σ_{oh}) and limit pressure (P_l) can then be calculated.

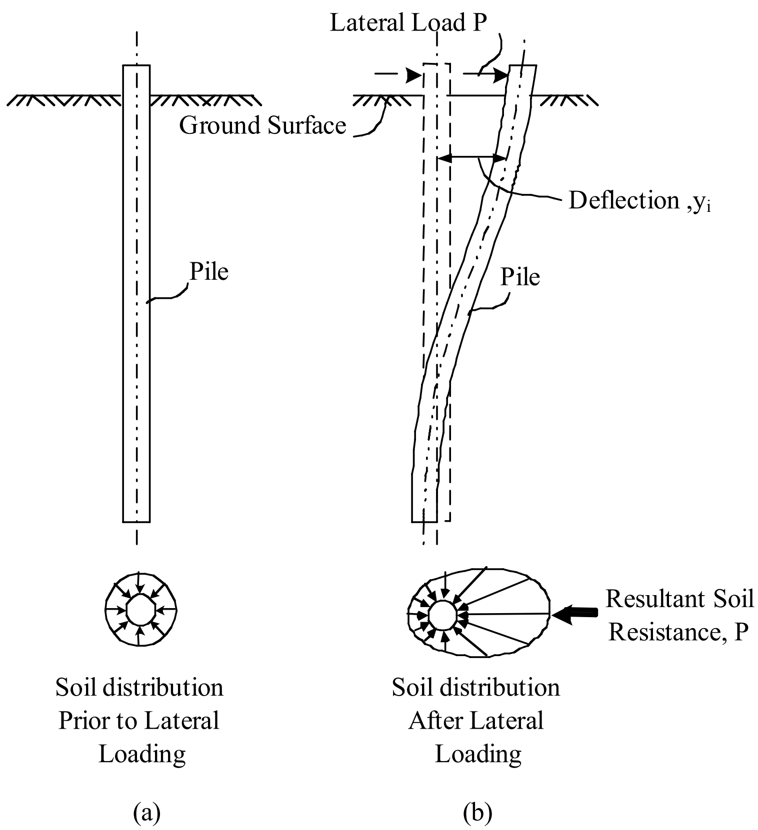
2.2 *Lateral Soil Reaction*

The soil behavior of piles under lateral load is nonlinear (Matlock et al, 1956; Matlock and Tucker, 1961; Reese et al, 1967a and b; Welch and Reese, 1972). This nonlinear behavior is generally modeled using a relationship between lateral force (p) on the soil and resulting pile deflection (y) at any point along a pile and is called a p–y curve. Matlock describes p–y curves as a relationship between the soil resistance (p) arising from the nonuniform stress field surrounding the pile, mobilized in response to lateral soil displacement (y).

The horizontal movement and resulting soil resistance associated with a laterally loaded pile is presented in Figure 2.9. There is more horizontal movement near the top of the pile than below and the movement can be either positive or negative along the pile length. Engineers often limit the amount of surface movement in pile designs.

Figure 2.9a shows a possible pressure distribution around the pile after installation but before applying a lateral load. This pressure distribution results if it is assumed the pile was installed perfectly straight and no bending occurred during driving. While neither of these assumptions is truly met in practice, it is believed that in most instances the assumption can be made without serious error.

Figure 2.9 Development of lateral soil pressures associated with the p–y concept for



a) Unloaded Pile; b) Laterally Loaded Pile (after Thompson, 1977)

The deflection of the pile through a distance (y_i), as shown in Figure 2.9b, would generate soil pressures against the pile. Integration of the soil pressures around the pile produces a force (p_i) per unit length of the pile. The pile deflection could also produce a minor soil resistance parallel to the axis of the pile, but it is assumed that such resistance would be quite small and it can be ignored in the analysis.

A family of p–y curves can be developed along the length, (z) of a single pile. A series of these curves for a soil that becomes progressively stiffer with depth is shown in Figure 2.10. Engineers simplify the problem by modeling the soil with an initial stiffness and an ultimate capacity as shown in Figure 2.11 (Reese, 1974). The stiffness can be either a tangent modulus (E_{si}) or a secant modulus (E_{si}), while the ultimate strength (P_u) may be extrapolated to a horizontal asymptote (Figure 2.11).

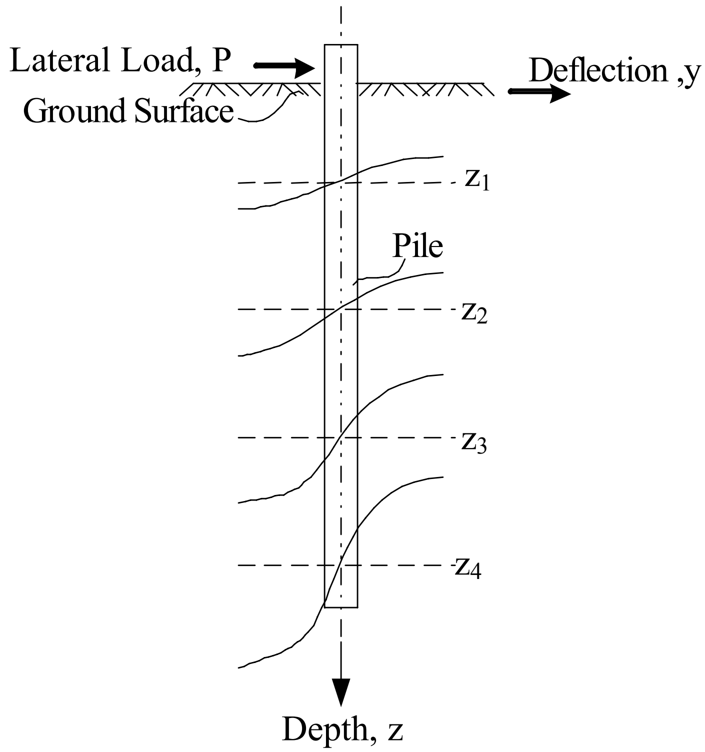


Figure 2.10 Typical Family of p–y curves in soil that is progressively stiffer with depth (after Meyer and Reese, 1979)

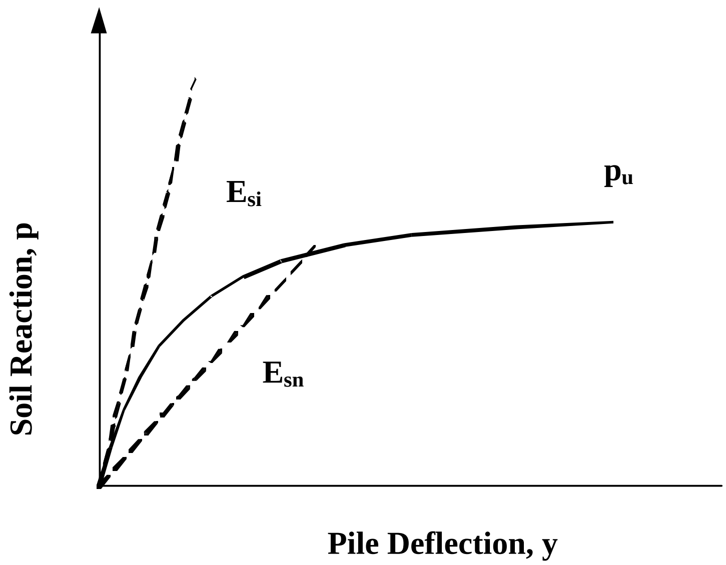


Figure 2.11 Definitions associated with p–y curves (from Reese, 1974)

2.3 P–y Curves

The governing differential equation relating the lateral force (*p*) on the soil and pile deflection (*y*) at any point along a pile is a fourth order equation. It requires the use of numerical methods and/or simplifying assumptions.

McClelland and Focht (1956) first proposed the use of p–y curves in the design and analysis of laterally loaded piles. Since then, studies were conducted to develop p–y curves in soft clay (Matlock and Hudson, 1970), in sand (Reese et al, 1974), and in stiff clay (Reese et al, 1975). Thus, methods for the development of p–y curves from empirical data are readily available.

The proper form of the p–y relationship is influenced by many factors, including:

1) the natural variation of soil properties with depth,
2) the general form of the pile deflection,
3) the corresponding state of stress and strain of the affected soil zone, and
4) the rate, sequence and history of cyclic loadings.

2.3.1 In-situ Tests

P–y curves can be estimated indirectly through CPT and SPT tests, and directly through PMT and Marchetti DMT tests. According to Campanella et al (1989), the latter can provide better predictions of lateral pile response.

2.3.2 Pressuremeter p–y Curves

During PMT tests, the soil deforms in a radial direction, while the displacement in the soil surrounding a laterally loaded pile is more complex as the soil moves radially away from the front face of the pile and inward toward the back face (Goldsmith, 1979). It is assumed that the soil in the center of the front face of the pile would deform in a manner similar to the PMT (Figure 2.12). Consequently, it is theorized that the geometric form of the pressure expansion curve obtained from the PMT would be similar to the in-situ load displacement p–y curve acting on the front of the pile (Robertson et al, 1986). This similarity is part of the motivation behind investigating the quality of the p–y curves obtained from PMT data.

The advantages of using the PMT to obtain p–y curves can be summarized as follows:

1) The PMT p–y curve is obtained point-by-point in-situ.

2) The PMT test can be performed in almost all soils and soft rock.

3) The method of installation of the driven pile is similar to the method of installation of the PMT.

4) The type of lateral loading can be simulated during the PMT test, including long-term sustained loads, cyclic loads and the rate of loading effect.

The diagrams associated with Figure 2.12 show when a circular pile is loaded laterally, virtually all the soil displacements occur radially away from or toward the pile. Hughes et al (1979), suggested that the PMT curve should be increased by a factor (α) to yield the correct p–y curves for the pile. This factor accounts for the fact that laterally loaded piles have limiting soil reactions higher than those for radially expanding PMTs.

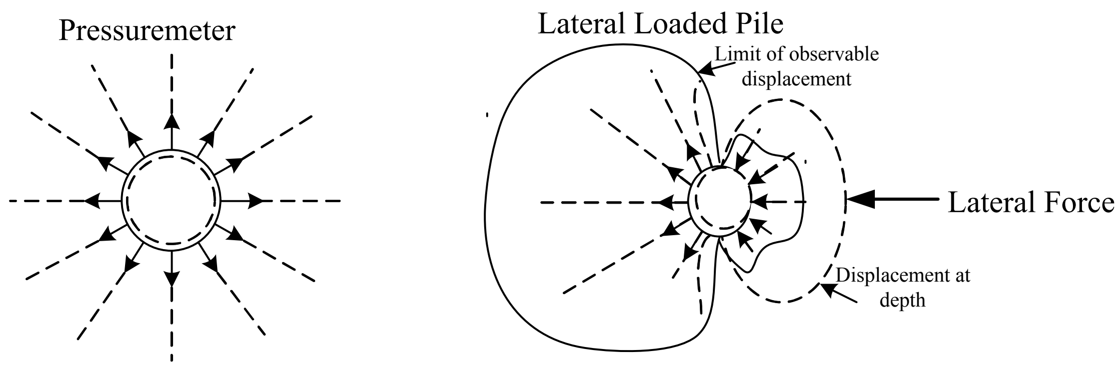


Figure 2.12 Displacements in soil radially expanding PMT and laterally loaded pile

Several methods have been proposed for the design of laterally loaded piles using PMT data (Baguelin et al, 1978; Baguelin, 1982; Imai, 1982; Briaud et al, 1983; and Robertson et al, 1983). Most of these methods were based on pre-boring PMT results. More recently, methods have been proposed that develop the p–y curves from pushed-in PMT tests (Robertson et al, 1986). Briaud et al (1992) suggested that the p–y curves might be obtained from the addition of the front and side resistance components.

The lateral stresses acting against the sides of the pile resulting from horizontal loads will be influenced by the in-situ stress and pile-driving techniques. With the application of a lateral load, the pile will immediately start to move. However, when the PMT is conducted, the pressure inside the probe is increased from zero until the membrane is in balance with the soil and the expansion starts. By installing the PMT in a manner similar to the pile foundations, the PMT expansion curve starts at an initial pressure or lift-off pressure (Figure 2.13a) approximately equivalent to the initial lateral stress surrounding the pile (Robertson et al, 1986). Therefore, to obtain the p–y curve for lateral loading, the pressure axis for the p–y curve is shifted up to the lift-off pressure from the PMT curve (Figure 2.13b).

The p–y curves required for the analysis are expressed as force (P) per unit length and displacement (y), whereas the PMT curves are in units of radial stress (σ_r) and circumferential strain $\left(\frac{\Delta R}{R}\right)$, where ΔR is the change in radius and R is the initial radius of the probe. To convert the PMT stress to force per unit length, the stress data is multiplied by the pile width and the PMT strain data is multiplied by the pile half-width to obtain the displacement (y) (Robertson et al, 1986), as shown in Figure 2.13c.

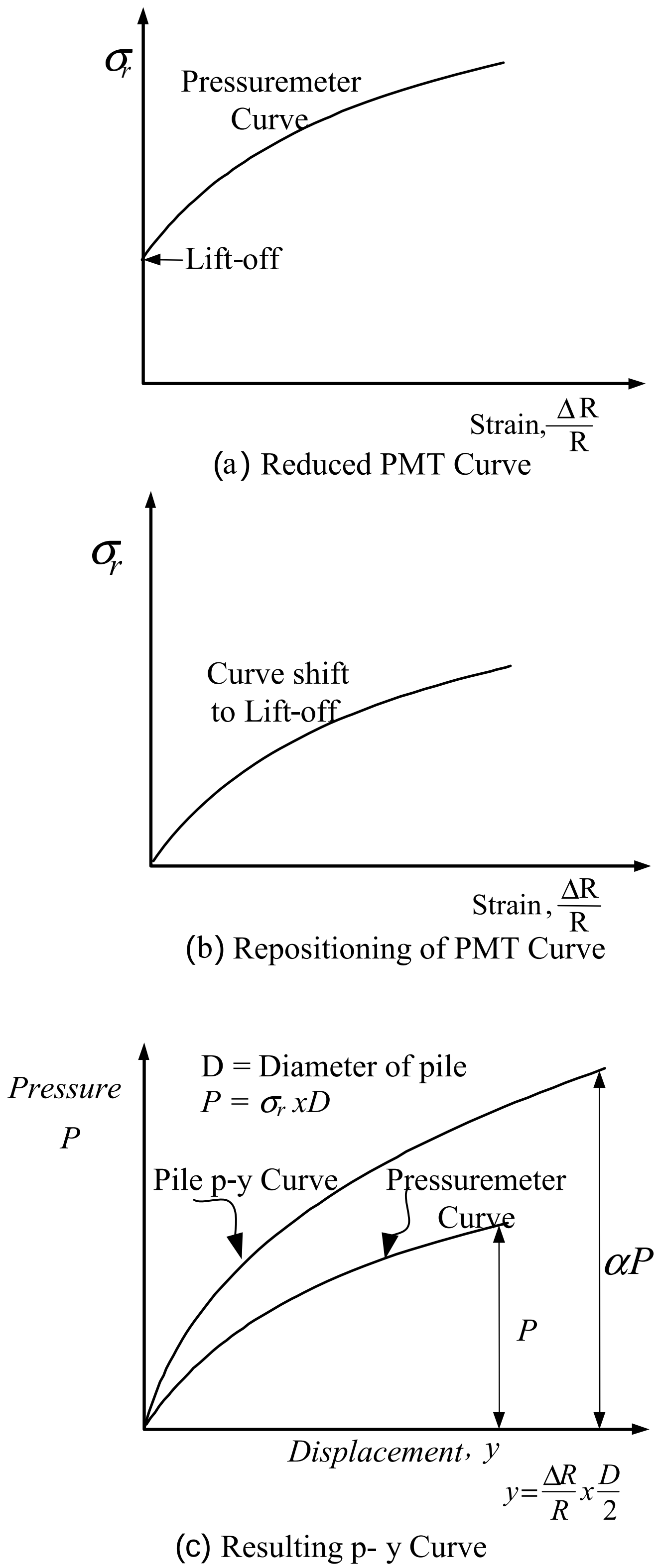


Figure 2.13 Pile p–y curve development from PMT data, based on Hughes et al (1979) multiplication factor, α

2.3.2.1 The Robertson et al, Pushed-in PMT Method (1986)

Robertson et al (1986) suggested a method that uses the results of pushed-in PMT to evaluate p–y curves of a driven pile. According to the authors, the results provide an excellent comparison with laterally loaded pile test measurements. The pressure component of the PMT curve is multiplied by an α-factor to obtain the corrected p–y curve. Using finite element analysis, Byrne and Atukorala (1983) confirmed this factor, which was initially suggested by Hughes et al (1979). Robertson et al (1986) corrected the factor α near the surface assuming that the PMT response is affected by the lower vertical stress. The factor increases linearly up to a critical depth, which is assumed to be four pile diameter (Dc = 4) as shown in Figure 2.14.

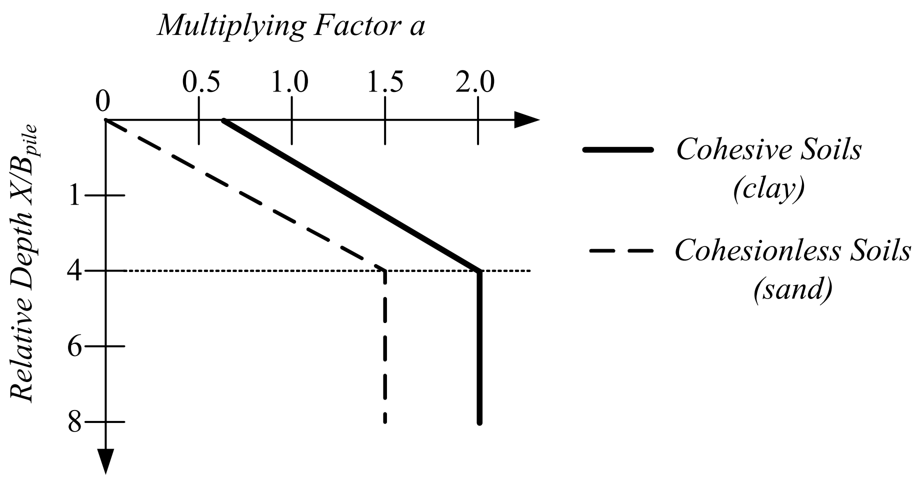


Figure 2.14 Correction factor α versus relative depth
(from Robertson et al, 1986)

To obtain the p–y curve, the PMT curve is re-zeroed to the lift-off pressure that is assumed to be equivalent to the initial lateral stress around the pile. The stress is multiplied by the pile width and the strain component $\left(\frac{\Delta R}{R}\right)$ is multiplied by the pile half-width. For a small strain condition $\left(\frac{\Delta R}{R}\right)$ is assumed equal to $\left(\frac{\Delta V}{2V}\right)$ where R and V are radius and volume of the PMT, respectively.

Since the installation of the pushed-in PMT produces an initial pressure on the probe, an unload–reload sequence is often used. The portion of the corrected PMT curve from the beginning of reload through the maximum volume is recommended for determining p–y curves of driven piles, while the initial slope from the PMT tests is recommended for constructing p–y curves for augured piles. The following equations outline the process for driven piles:

a) Determine the initial radius of the probe:

$$R_0 = \frac{\text{Initial Circumference of Probe}}{2\pi} \qquad (2.10)$$

b) Calculate the initial volume of the probe (V_o):

$$V_0 = \pi * R_P^{\;2} * \text{Length of Membrane} \qquad (2.11)$$

c) Determine P in units of force / length:

First a correction factor, α, is applied to P according to Figure 2.15, where the relative depth (z_{ppmt}) is the depth from the ground surface to the center of the membrane. Note that for $\frac{z_{ppmt}}{B_{pile}} \geq 4$ $\alpha = 1.5$ for sands and 2.0 for clays, and if $\frac{z_{ppmt}}{B_{pile}} < 4$ then α can be found as follows:

$$\alpha = \frac{1.5 * z_{ppmt}}{4 * B_{pile}} \quad \text{for sands} \qquad (2.12)$$

$$\alpha = 0.67 + \frac{2 * z_{ppmt}}{4 * B_{pile}} \quad \text{for clays} \qquad (2.13)$$

Then

$$P = (\text{Corr. Pressure from PMT}) * (B_{pile}) * (\alpha) \qquad (2.14)$$

where: B_{pile} = pile diameter or width.

d) Determine y in units of length according to the following equation:

$$y = \frac{(\text{Corr. Volume from PMT})}{2 * V_0} * \frac{B_{pile}}{2} \qquad (2.15)$$

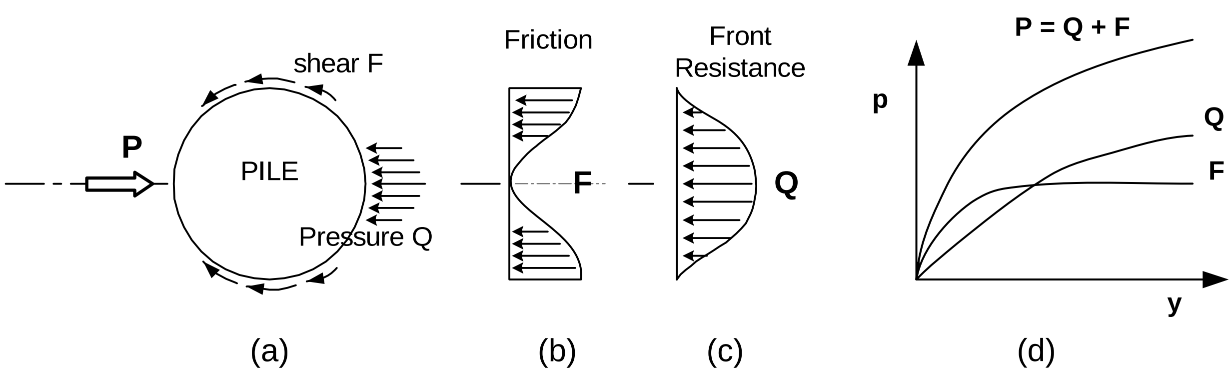


Figure 2.15 Front and side resistance components for p–y curve construction

2.3.2.2 The Briaud et al Method (1992)

Briaud et al (1992) recommended that the p–y curves be constructed from the addition of the front and side resistance components along the pile. The total soil resistance *P* as a function of lateral movement *y* of the pile, is given by the equation:

$$P = F + Q \tag{2.16}$$

Where:
F = friction resistance
Q = front resistance

Briaud suggested using the reload portion of the PMT curves for full displacement driven piles. Graphically, the p–y curve is shown as the addition of the F–y curve and the Q–y curve in Figure 2.15.

Smith (1983) showed excellent correlations between the pressures obtained from the PMT response and those acting on the pile. The front pressure contribution, Q, is found from the net limit pressure p_L* determined as:

$$p_L{}^* = p_L - p_0 \tag{2.17}$$

where p_L is the limit pressure and p_0 is the horizontal stress at rest pressure obtained from the PMT curve. The frontal resistance, Q is obtained by choosing pressure points from the reduced PMT plot and using the equation:

$$Q_{(front)} = p_{(pmt)} \times B_{(pile)} \times S_{(Q)} \tag{2.18}$$

The side friction, $F_{(\text{side})}$, of the pile is taken as a constant with depth and is given by the equation:

$$F_{(side)} = \tau_{(soil)} \times B_{(pile)} \times S_{(F)} \tag{2.19}$$

To obtain the associated lateral pile deflections, choose PMT deflections and apply the following equation. The deflections must be less than those obtained from the PMT test and would equate to the change in radii obtained during expansion.

$$y_{(pile)} = y_{(pmt)} \times \frac{R_{(pile)}}{R_{0(pmt)}} \tag{2.20}$$

Where:
$Q_{(front)}$ = soil resistance due to front reaction with unit of force / unit length of pile
$F_{(side)}$ = soil resistance due to friction resistance with unit of force/unit length of pile
$p_{(pmt)}$ = p_L* = net pressuremeter limit pressure (p_L-p_o)
$B_{(pile)}$ = pile width or diameter
$\tau_{(soil)}$ = maximum soil shear stress–strain at the soil-pile interface
$S_{(Q)}$ = shape factor (= 0.8 or π/4 for circular piles, 1.0 for square piles)
$S_{(F)}$ = shape factor (= 1.0 for circular piles, 2.0 for square piles)
$y_{(pile)}$ = lateral deflection of the pile
$y_{(pmt)}$ = increase in radius of the soil cavity in the PMT test or radial displacement.
$R_{(pile)}$ = pile half-width or radius
$R_{0(pmt)}$ = R_0 = initial radius of the soil cavity in PMT test

This method relies on an accurate estimate of the shear strength, which could be found from other field-testing performed during the site investigation.

The displacement of soil around the laterally loaded pile is also influenced by the ground surface. A reduction in the corrected PMT pressures is recommended for values near the ground surface. A critical depth (*Dc*), to which pressures and displacements are influenced, depends on the pile load, diameter and stiffness. Briaud suggested using a relative rigidity factor, *RR*, given by:

$$RR = \frac{1}{B_{(pile)}} \sqrt[4]{\frac{EI}{p_L *}} \tag{2.21}$$

EI = pile flexural stiffness (E= pile modulus, I = pile moment of inertia)

$B_{(pile)}$ = pile diameter or width

p_L* = net PMT limit pressure

The Briaud et al (1992) relationship results in relative rigidities slightly greater than 10 for most laterally loaded piles in soft clays, with the resulting critical depth near four. Therefore, Robertson's value of four is recommended. The critical depths for the PMT as recommended by (Baguelin et al, 1978) are 15 PMT diameters for cohesive soils, and 30 PMT diameters for cohesionless soils.

Briaud et al (1992) suggested reduction factor β is shown in Figure 2.16 as a function of relative depth (z/z_c). The PMT curve is then corrected by using:

$$p_{corr} = \frac{p}{\beta} \tag{2.22}$$

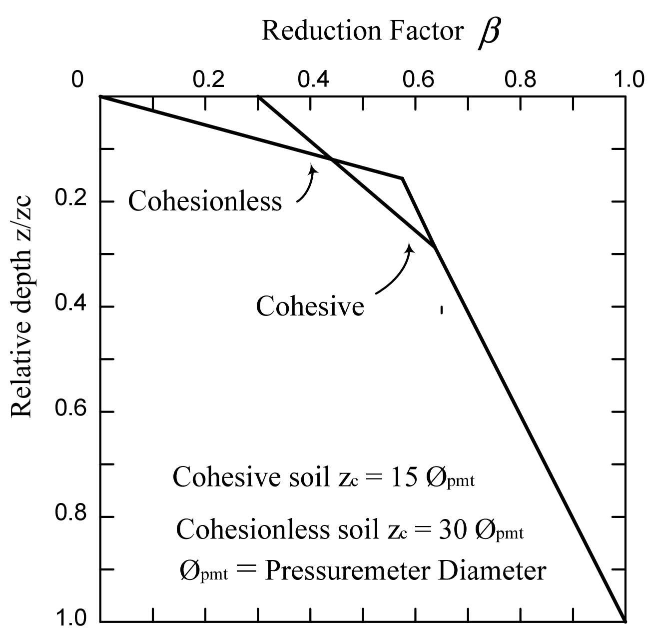


Figure 2.16 Briaud's recommended PMT pressure reduction factor for values near the ground surface

2.4 *Dilatometer p–y Curves*

Unlike the PMT, which produces a comparatively large radial deformation (approximately 3.5 mm over 24 cm in length), the DMT only produces 1.1 mm of lateral deformation at the center of a 60-mm ring. The deformation is produced by a single volume injection; therefore, there are no increments of pressure with which to develop a load-deformation curve.

The basic soil properties determined from the DMT indices are used in conjunction with a parabolic function to develop p–y curves. For this research, curves determined from DMT tests were developed based on the method presented by Robertson et al (1989).

2.4.1 Cohesive Soils

For cohesive soils, the following cubic parabola originally proposed by Matlock (1970) is suggested:

$$\frac{P}{P_u} = 0.5\left(\frac{y}{y_c}\right)^{0.33} \tag{2.23}$$

Where: $$y_c = \frac{23.67 S_u B_{pile}^{\;0.5}}{F_c E_D} \tag{2.24}$$

With y_c in cm, B_{pile} = pile diameter, cm, and an empirical stiffness factor, $F_c \approx 10$. The evaluation of the ultimate lateral resistance (P_{u}) is again given in a bearing capacity format as:

$$P_u = N_p S_u B_{pile} \tag{2.25}$$

At considerable depths $N_{\text{p}} \approx 9$, but near the surface it reduces to 2–4; the non-dimensional factor is calculated as:

$$N_p = 3 + \frac{\sigma_{vo}}{S_u} + \left(J\frac{z}{B_{pile}}\right) < 9.0 \tag{2.26}$$

where z = depth,

σ_{vo} = effective stress at *depth (z)*, and

J = empirical stiffness factor set to 0.5 for soft clay and 0.25 for stiff clay.

The value of S_{u} can either be obtained from DMT values, or PMT estimates as

$$S_{uPMT} = 0.67(p_L)^{0.75} \tag{2.27}$$

With S_{u} and p_L in kPa.

2.4.2 Cohesionless Soils

For cohesionless soils, use Matlock's (1970) cubic parabola, where P_u is based on the findings of Reese et al (1974), and Murchison and O'Neill (1984), and is the lesser of:

$$P_u = \sigma_{v0}'[B_{pile}(K_p - K_a) + zK_p \tan\phi' \tan\beta] \quad (2.28)$$

or $$P_u = \sigma_{v0}' B_{pile}[K_p^{\ 3} + 2K_a K_p^{\ 2} \tan\phi' - \tan\phi' - K_a] \text{ and } \beta \text{ is } 45^o + \phi'/2 \quad (2.29)$$

and y_c is:

$$y_c = \frac{4.17 \sin\phi' \sigma_{v0}'}{E_D F_\phi (1 - \sin\phi')} B_{pile} \quad (2.30)$$

where F_ϕ is an empirical factor equal to 1 for cohesionless soil.

3 Chapter 3—APPROACH

3.1 Testing Procedures

The testing procedures followed throughout this research for CPT, DMT and PPMT were based on those used by FDOT SMO personnel. Each procedure is described in the following sections.

3.1.1 Cone Penetrometer Testing

The cone penetrometer can be used in sands or clays, but not in rock or other extremely dense soils. To perform this test, the electrical cone is advanced into the subsoil at a standard rate of 20 mm/sec (0.8 in/sec). Wires from transducers are threaded through the center of the rods, and continuously give readings of the cone resistance, q_c, and side resistance, f_c. Several correlations are useful in estimating soil properties, for example the friction ratio, F_r, is defined as $F_r = f_c/q_c$. The penetrometer data is plotted showing the end-bearing resistance, the friction resistance and the friction ratio (friction resistance divided by end-bearing resistance) versus depth. The results should also be presented in tabular form indicating the interpreted results of the raw data. The friction ratio plot can be analyzed to determine the soil type and SPT based on University of British Columbia (UBC-1983). Many correlations of the cone test results to other soil parameters have been made, and design methods are available for spread footings and piles using these parameters.

3.1.2 Dilatometer Testing

This test procedure was described by Marchetti (1980) and requires an experienced operator. Following three calibrations, the first step is the insertion of the DMT into the ground. About one minute after penetration, the membrane is inflated and two readings are taken: the pressure required to begin to move the membrane (lift-off), *A*, and the pressure required to move the center of the membrane 1.1 mm (0.04 in) against the soil, *B*. A third reading, *C*, (closing pressure) can optionally be taken by slowly deflating the membrane soon after *B* is reached. The first correction, ΔA, is the external pressure which must be applied to the membrane in free air, to collapse it against its seating. The second correction, ΔB, is the internal pressure, which in free air, lifts the membrane center 1.1 mm (0.04 in) from its seating. The third correction, Z_m, is the gauge offset or gauge reading when vented to the atmosphere. The blade is then advanced to the next depth increment (typically 20 cm). The pressure readings *A* and *B* are corrected by the values ΔA and ΔB determined through two calibrations that take into account the membrane stiffness (Marchetti 1999). These values are then converted into a corrected contact stress, p_0, and a corrected expansion stress, p_1, using the equations below.

$$p_0 = 1.05(A - Z_M + \Delta A) - 0.05(B - Z_M - \Delta B) \tag{3.1}$$

$$p_1 = (B - Z_M - \Delta B) \tag{3.2}$$

Where:

ΔA, ΔB = corrections determined by membrane calibration
Z_m = gauge zero offset (gauge reading when vented to atmospheric pressure)

Using p_0 and p_1, the following three index parameters are often derived from the test:

The material index I_D (correlated to soil type)

$$I_D = \frac{p_1 - p_0}{p_0 - u_0} \tag{3.3}$$

The horizontal stress index K_D (correlated to the at-rest earth pressure coefficient, K_o)

$$K_D = \frac{p_0 - u_0}{\sigma'_{v0}} \tag{3.4}$$

The dilatometer modulus E_D (which is different from Young's modulus E')

$$E_D = 34.7\ (p_1 - p_0) \tag{3.5}$$

Where:

u_0 = in-situ pore pressure

σ'_{v0} = in-situ vertical effective stress

Several common soil parameters, including elastic moduli, undrained shear strength, and over consolidation ratio have been derived from these parameters. The equations used to determine these parameters are summarized in Table 3.1. The values of the in-situ equilibrium pore pressure, u_0, and of the vertical effective stress, σ'_{v0}, prior to blade insertion must also be calculated based on the water table elevation and the soil unit weight.

Young's modulus E of the soil can be derived from M_{DMT} using the theory of elasticity equation:

$$E = \frac{(1+\nu)(1-2\nu)}{(1-\nu)} M \tag{3.6}$$

Where ν = 0.3 to 0.4, and $M = M_{DMT}$

Table 3.1 DMT data reduction formulae and correlations (Marchetti, 1980)

Symbol	Description	Basic DMT Reduction Formulae
p_0	Corrected Contact Stress	$p_0 = 1.05(A - Z_M + \Delta A) - 0.05(B - Z_M - \Delta B)$
p_1	Corrected Expansion Stress	$p_1 = (B - Z_M - \Delta B)$
I_D	Material Index	$I_D = \dfrac{p_1 - p_0}{p_0 - u_0}$
K_D	Horizontal Stress Index	$K_D = \dfrac{p_0 - u_0}{\sigma'_{v0}}$
E_D	Dilatometer Modulus	$E_D = 34.7\ (p_1 - p_0)$. E_D is NOT a Young's modulus E. E_D should be used only after combining it with K_D. First obtain $M_{DMT} = R_M\ E_D$, then e.g. E » 0.8 M_{DMT}
OCR	Over-consolidation Ratio	$OCR_{DMT} = (0.5\ K_D)^{1.56}$
c_u	Undrained Shear Strength	$cu,_{DMT} = 0.22\ \sigma'_{v0}\ (0.5\ K_D)^{1.25}$
M	Constrained Modulus	$M_{DMT} = R_M\ E_D$ if $I_D \leq 0.6$ $R_M = 0.14 + 2.36 \log K_D$ if $I_D > 3$ $R_M = 0.5 + 2 \log K_D$ if $0.6 < I_D < 3$ $R_M = R_{M,0} + (2.5 - R_{M,0}) \log K_D$ with $R_{M,0} = 0.14 + 0.15\ (I_D - 0.6)$ if $K_D > 10$ $R_M = 0.32 + 2.18 \log K_D$ if $R_M < 0.85$ set $R_M = 0.85$

3.1.3 Pencel Pressuremeter Testing

The PMT is one of the most commonly used devices in in-situ testing. It produces stress–strain results, based on the assumption that the PMT probe is infinitely long and produces a plain-strain cylindrical expansion (Baguelin et al, 1978). The PPMT can be placed either by pressing or lightly driving.

The effects of length-to-diameter ratio on test results have been questioned (Erbland, 1993; Yao, 1996). The length-to-diameter ratio used for this research was 7.5. Both the length and the probe diameter can be varied. The standard probe length is relatively fixed by the metal o-rings at each end of the probe; however, the initial probe diameter can vary based on the amount of water injected into the probe during the saturation and calibration processes. Roctest (2005) states that this diameter should be set to 32.1 mm, however, no methodology is given to achieve this.

The driving tips used during advancement of the probe can be either smooth or include a friction reducer. When included, a thin (less than 2 mm or .062 in) friction reducer would be placed below the expanding probe. Very little documentation exists as to whether a friction reducer is necessary. This lack of information may be due to the fact that the PPMT was originally designed for shallow testing associated with pavements (Cosentino, 1987) and most of the materials tested were highly densified. Research on pavements (Cosentino, 1987) was conducted using a friction reducer during insertion.

In this research, two variations were made to the standard PPMT test:

1) Tests were conducted with both a smooth cone tip and a cone tip with a 1.59 mm (.062 in) friction reducer.
2) A 32 mm (1.26 in) diameter aluminum calibration tube was used to conduct the system expansion and to set the initial probe diameter.

The testing procedure followed throughout the research is the one outlined by Roctest (2005). During a sounding, the probe was pushed to the desired test depth. A test was conducted as the probe was inflated using 5 cm^3 volume increments and the corresponding pressure changes were recorded after waiting 15 seconds. The operator monitored the changes in stress for each volume increment and noted that equal stress increments resulted in a linear stress–strain response. An unload–reload loop was performed at the end other linear response range by decreasing the pressure to one-half of the exiting value and recording the corresponding volume. Note that this is a stress-controlled cycle. The complete test consists of 18 increments over a total injected volume of 90 cm^3.

As with other PMTs, the parameters determined are PMT modulus, the limit pressure and the initial pressure or at-rest pressure. A modulus value could be determined from many portions of the PPMT curve, although it is typically found during the initial linear response range and labeled as E_{si}. The unload–reload loop from this test may be used to determine a measure of stiffness called the rebound modulus, E_r. Figure 3.1 shows the portions of the curves used to determine these moduli, the limit pressure and the initial pressure from a PPMT test. The moduli are determined from the slopes (S) shown while the other parameters are determined directly. The PPMT limit pressure is defined as the pressure required to double the initial probe volume, which is never reached since the initial probe volume for the PPMT probe is about 200 cm^3 and the cylinder of water used during testing is only 138 cm^3. The PPMT test results can be used to obtain load transfer curves (p–y curves) for lateral load analyses.

Figure 3.1 also shows a curve with an initial portion associated with the probe pushing the soil back into its assumed original stress state (Point A), followed by the initial elastic response portion, from points A to B and then by the plastic response portion after point B.

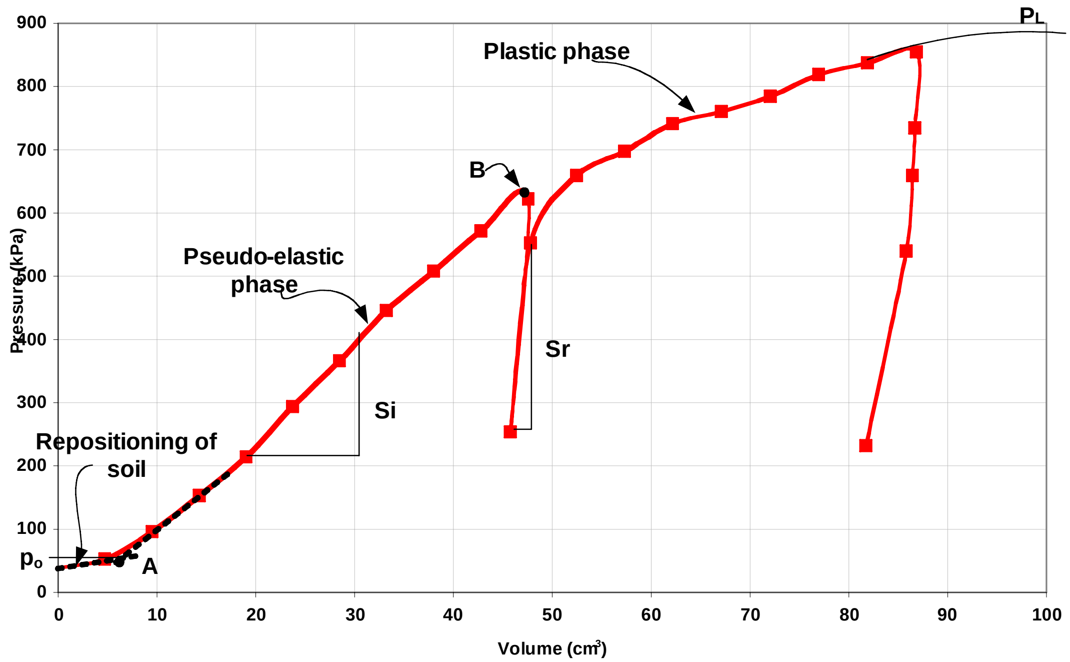


Figure 3.1 Typical PPMT curve showing portions of curve used to determine elastic responses, the limit pressure and the initial pressure

3.1.3.1 Calibrations

The test and calibration methods for the PPMT are based on the manual published by Briaud and Shields (1979) and outlined by Roctest (1980). The calibration of the system is conducted in the following steps. First, the membrane correction is determined by inflating the probe in air at the same elevation as the pressure gauge. This is the free air correction for the inherent membrane resistance. The second calibration is the system expansion or volume loss correction. For this calibration, the probe is inserted into a steel tube and inflated. Since there is an annular space between the probe and the tube, some adjustment must be made to the curve AB in Figure 3.2 so that it can be used to properly correct the PPMT volumes. Note that AB shows about 20–30 cm^3 of volume losses. In Figure 3.2, curve B is generated by detaching the probe and injecting water into the control unit and tubing. The initial portion of curve B includes some system play known as the conformity correction (λ) (Figure 3.2). By transposing λ from curve B to curve AB, an adjustment is made to the early portion of the data. Finally, curve AB is moved horizontally to the origin and used for the system expansion. Note that this transposed curve produces about 10 cm^3 of volume loss at 2,000 kPa. For tests in stiff or very dense soils, this would produce pressures over 90 cm^3 at the same level; about a 10 percent correction. The calibration tests should be performed at the start of each testing day, when the protective sheath is replaced, or when it has been used for a large number of tests. The tubing must be saturated in this instance.

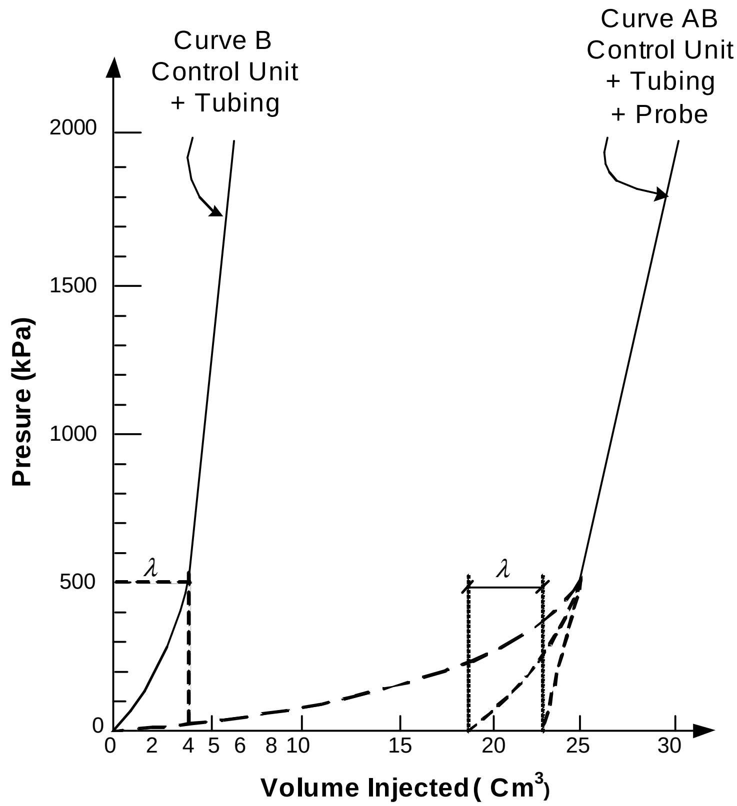


Figure 3.2 Calibration curve for system expansion during a PPMT test
(Briaud and Shields, 1979)

3.1.3.1.1 Membrane Calibration

The membrane calibration of the probe is performed with the probe at the same level as the control unit pressure gauge and is a measurement of the probe inertia. The calibration is carried out following the instructions cited by Roctest (2005).

1) The system is saturated and the probe is placed vertically at the same level of the control unit. The probe is then inflated by injecting 5 cm^3 of water at a rate of one crank revolution per nine seconds. The pressure is recorded 15 seconds after each injection is made.

2) This procedure is repeated until a total of 90 cm^3 of water is injected into the probe.

3) The probe is slowly deflated, by returning the volume counter to zero.

4) The resulting pressure calibration curve is plotted, as shown in Figure 3.3.

5) The membrane resistance pressure is subtracted from the pressure recorded in the borehole during the PPMT test.

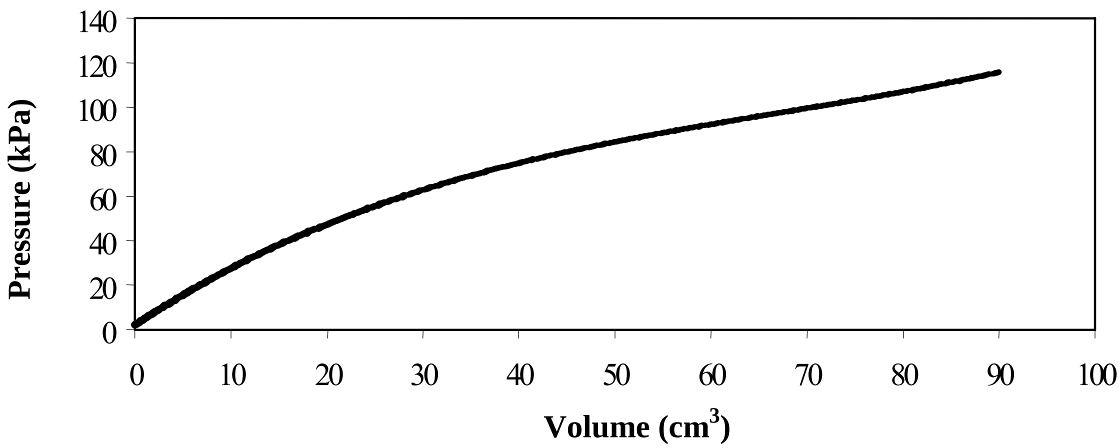


Figure 3.3 Typical membrane calibration curve from PPMT test

3.1.3.1.2 Volume Calibration

The volume calibration of the complete system including the probe, tubing and control unit system is required to correct the injected volume as read on the volumetric counter for the volume losses. This is achieved by following the steps:

1) The probe is inflated and deflated five times, in order to prepare the rubber membrane for use.

2) The probe is placed in a 32-mm diameter aluminum tube, called the calibration tube.

3) The probe is inflated by injecting water at rate of 1/3 cm^3/sec, which corresponds to one revolution per nine seconds and the pressure is noted for each increment of 5 cm^3 injected up to 2,000 kPa.

4) The probe is deflated, by bringing the volume counter back to zero.

5) The volume calibration curve is plotted as seen in Figure 3.4.

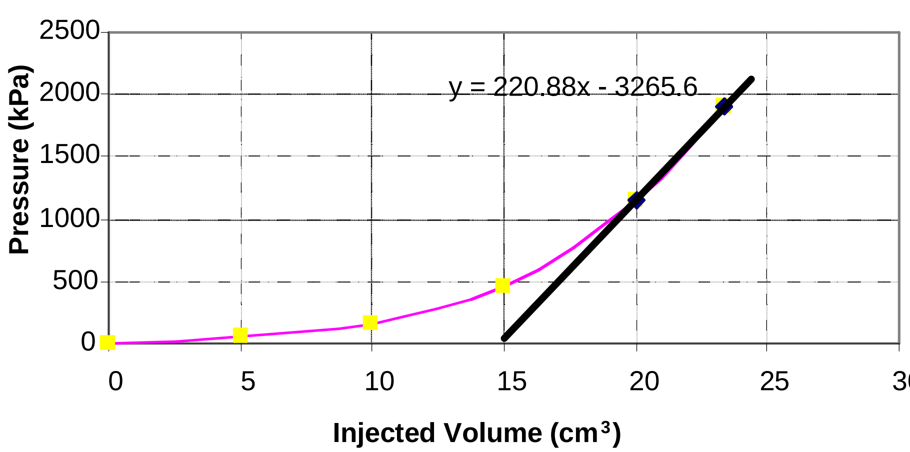


Figure 3.4 Typical PPMT volume calibration curve

The resulting volume correction curve is adjusted as shown in Figure 3.4, by deleting the first few points in order to achieve a straight line. This line is assumed to represent only the volumetric expansion of the system. Once a linear relation is achieved, the coordinates pressure and volume are re-zeroed and the volume correction is subtracted from the volume recorded during the in-situ PPMT test.

The basic effect of these calibrations is to shift the raw curve down and to the left. The hydrostatic pressure is a result of the column of fluid (water) in the tubing above the probe and equal to the unit weight of the inflating fluid multiplied by the elevation difference between the center of the probe and the pressure gauge. This pressure, which is constant for each test depth, should be added to the raw data, since it is not recorded by the pressure gauge.

3.1.3.2 Presentation and Evaluation of the PPMT Data

The raw data collected during the PPMT test consists of the pressure (p_r) and volume (v_r) from the gauge and volume counter of the control unit, respectively. This raw data should be corrected to obtain the reduced pressure (p_c) acting against the wall of the cavity of the soil and the increase of volume of the probe (v_c). For this purpose, an Excel spreadsheet was created to reduce the data and plot a pressure–volume curve or pressure versus relative increase in radius.

The corrections include the adjustments for membrane resistance, hydrostatic pressure, initial reading and system compressibility. The adjustments for membrane resistance and volume expansion are accounted for during the calibration procedure. In the reduction of the raw data, the following equations of the corrected pressure and volume are used:

$$p_c = p_r - p_m + p_h - p_i \tag{3.7}$$

$$V_c = V_r - V_s - V_0 \tag{3.8}$$

Where:

p_c = corrected pressure represent pressure on the wall of the cavity
p_r = raw test pressure
p_m = pressure necessary to overcome the resistance of the membrane
p_h = hydrostatic pressure
p_i = initial pressure reading on the gauge
V_c = corrected volume represent the increase in volume of the probe
V_r = raw test volume
V_s = system compressibility volume correction
V_0 = initial volume

Using the spreadsheet, the volume change can be converted into values of hoop strain. This is also referred to as the relative radial increase $\left(\Delta R / R\right)$ and found using the following equations:

The initial radius of the probe is:

$$R_o = \sqrt{\frac{V_o}{\pi L}} \tag{3.9}$$

The increase in radius is $\Delta R = \sqrt{\frac{V_o + V_c}{\pi L}} - \sqrt{\frac{V_o}{\pi L}}$

Finally, the relative increase in probe radius or the hoop strain is:

$$\frac{\Delta R}{R_o} = \sqrt{\frac{V_o + V_c}{V_o}} - 1 \tag{3.10}$$

Where:

ΔR = increase in the probe radius
R_o = initial probe radius
V_o = initial probe volume
V_c = corrected volume increase
L = inflatable portion length of the probe

3.1.3.3 Developing the Graphs

Once the data has been corrected and the volume changed to a hoop strain, the plot of pressure versus volume is developed as shown in Figure 3.5. From this graph, the points are selected for PMT initial modulus and PMT rebound modulus determination, using the following equation (2.1) cited in chapter 2:

$$E = 2(1+\nu)\frac{\Delta P}{\Delta V} V_m$$

Where:

E = Elastic modulus
$V_m = V_0 + \frac{V_f + V_0}{2}$ = average volume over ΔP
ΔV = Change in volume over ΔP
V_o = Initial volume of the probe.
V_f = Volume of the probe at the end of the pressure increment
ν = Poisson's ratio

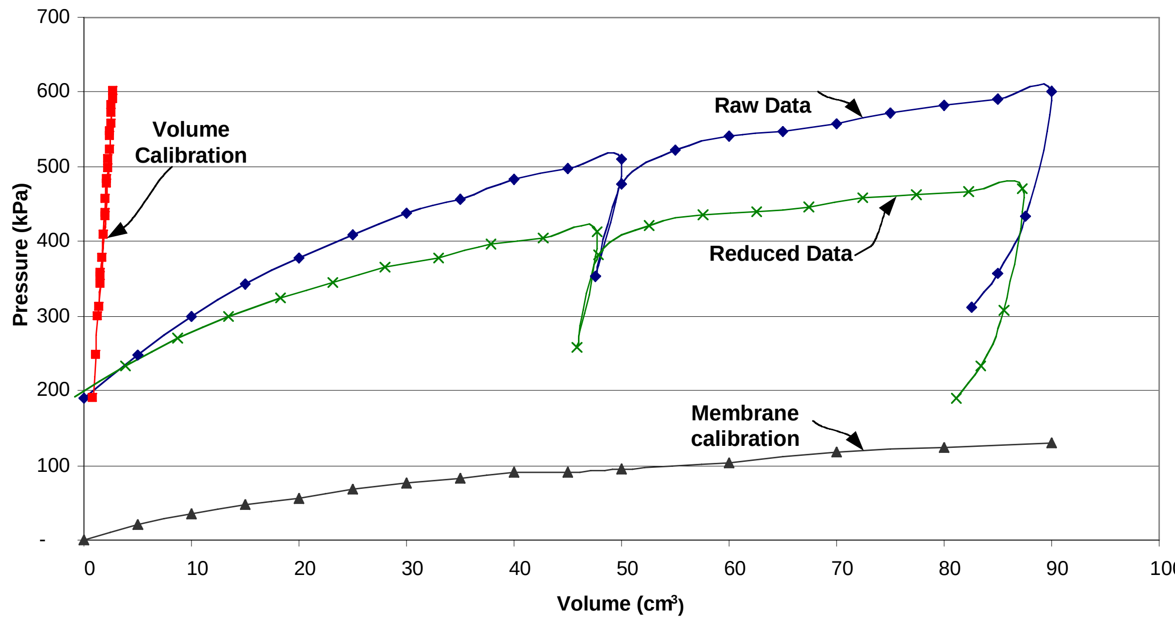


Figure 3.5 Typical resulting PPMT test

Tucker (1987) and Briaud (1992) suggested using the radial strain to determine moduli. In an effort to normalize the PPMT curve it is recommended that the curve be plotted as pressure versus relative increase on probe radius. Hence, Equation 2.19 cited in chapter 2 will be used:

$$E = (1+\nu)\left[\left(1+\frac{\Delta R_1}{R_0}\right)^2 + \left(1+\frac{\Delta R_2}{R_0}\right)^2\right]\frac{\Delta P}{\left[\left(1+\frac{\Delta R_2}{R_0}\right)^2 - \left(1+\frac{\Delta R_1}{R_0}\right)^2\right]}$$

Where:

ΔR_1 = increase in probe radii at the beginning of the pressure increment, P_1

ΔR_2 = increase in probe radii at the end of the pressure increment, P_2

ΔP = $P_2 - P_1$

R_o = initial radius of the probe.

ν = Poisson's ratio

This equation allows the reduced data to be presented in stress–strain format in addition to a stress–volume change format and can be used to determine all moduli values. However, the PMT modulus, E_o, is determined by using the slope of the straight-line portion of the PPMT curve. The rebound, E_r, modulus can be determined by using the rebound slope in the same manner.

3.2 *Development of Field Testing Program*

To evaluate the PPMT, a thorough field-testing program was established that included numerous tests in both sands and clays. After evaluating sites throughout the state, three were chosen. The first site on the Florida Tech campus consisted predominately of sand; the second site that included two clay layers was about an hour from the campus in Cape Canaveral, Florida, and the third site, the Archer Landfill near Gainesville, Florida, used in previous FDOT research, consisted of a uniform sand above the water table (Schmertmann, 1978).

Testing was conducted using the FDOT State Materials Office (SMO) Cone Penetrometer rig with the aid of FDOT field technicians. To categorize the soils, Standard Penetration (SPT) tests, CPT tests, Dilatometer (DMT) tests and PPMT tests were performed. Universal Engineering Services of Melbourne performed SPT tests at the All Faiths and Cape Canaveral sites.

3.2.1 PPMT Testing in Sands

The majority of the PPMT evaluation in sands was conducted at the field test site shown in Figure 3.6, located on Florida Tech's main campus in Melbourne. The site covers approximately 8,000 sq ft, and is located in the southeastern section of the campus, immediately east of the All Faiths Center (Figure 3.6). It consists of a relatively level rectangular plot of land with a uniform grass cover. Testing at this site was carried out in multiple phases. The initial phase was performed to evaluate the PPMT testing procedure and a second phase was performed to evaluate the instrumented control unit. Additional testing in sands was conducted at a site near Gainesville, Florida, known as the Archer Landfill.

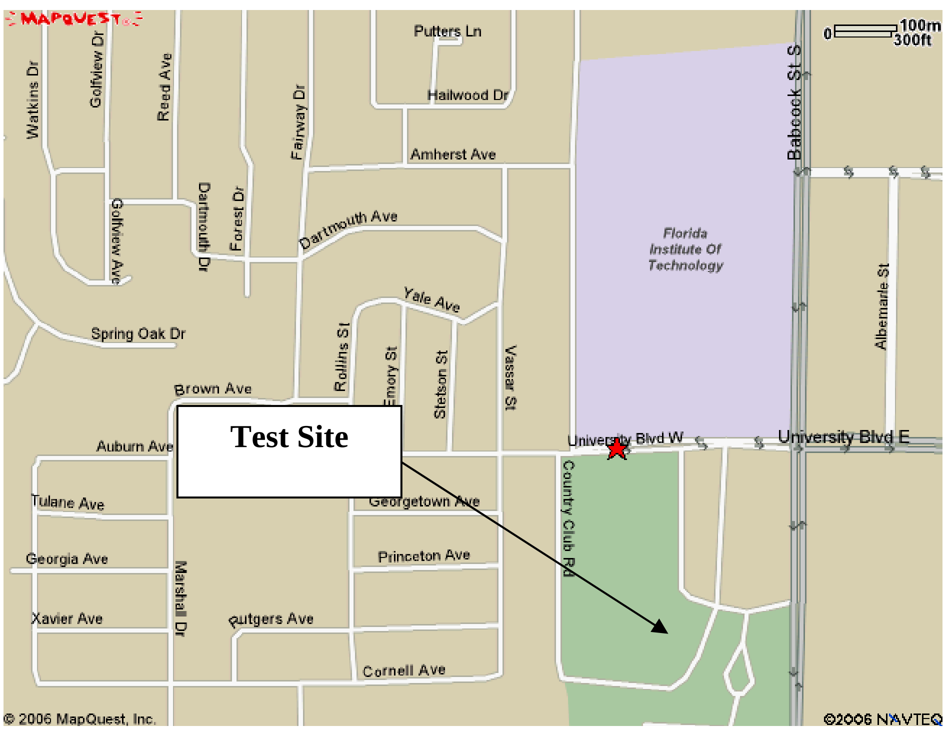


Figure 3.6 All Faiths sand site, Florida Tech, Melbourne, Florida

3.2.1.1 All Faiths Site Test Layout

Figure 3.7 depicts the the testing pattern and location of the grid as approximately 100 feet east of the Florida Tech All Faiths Center. More than 70 PPMT tests were conducted in 24 soundings between September 2003 and February 2004 (Figure 3.7). In addition to the PPMT tests, six DMT soundings, four CPT soundings and three SPT test borings were conducted (Figure 3.7). For both PPMT and DMT testing, a series of three tests were conducted at different depths in each sounding. The tests were performed at depths of 2.0 m (6.6 ft), 4.0 m (13.2 ft) and from 4.7 m to 5.5 m (15.4 ft to 18 ft). The third depth was not consistent because the equipment could not penetrate a very hard-cemented sand in this zone. The cone penetrometer tests provided continuous evaluations of the soil stratigraphy to a maximum depth of 5.5 m.

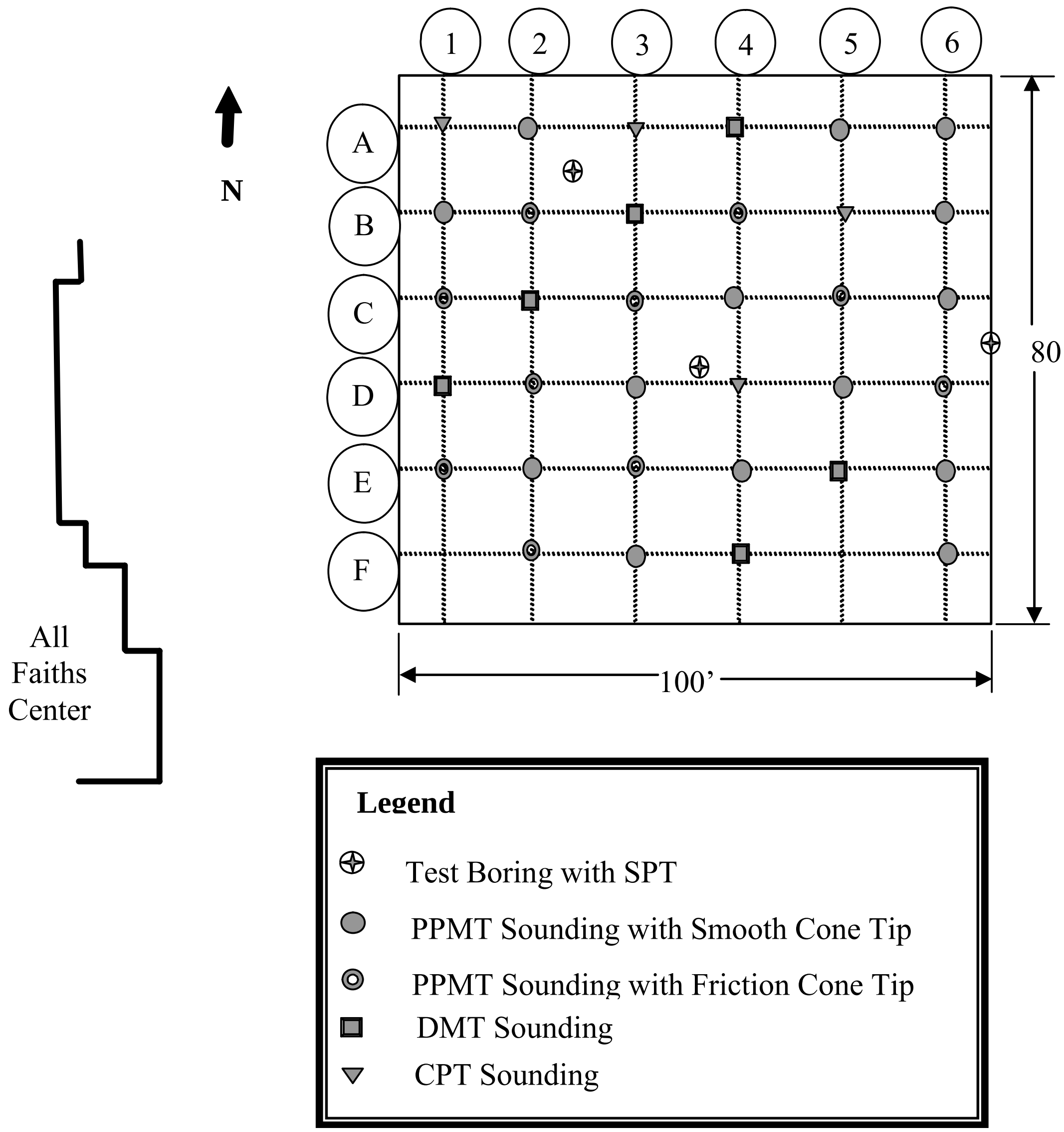


Figure 3.7 All Faith's Center site testing grid

A second series of 12 PPMT soundings were conducted at this site in June 2005 to evaluate the instrumented control unit. Three PPMT tests were performed in each sounding at depths of 1.8 m (6 ft), 3.25 m (10.66 ft) and 5.25 m (16.5 ft). These tests included six additional CPT soundings to improve the knowledge of the subsurface conditions in the top 7.0 m (23 ft). Tests were conducted in a 180-foot east-west profile across the site (Figure 3.8).

In summary, over 100 PPMT tests were performed at 36 sounding locations across the site.

3.2.1.2 All Faiths Site Stratigraphy

Based on the CPT tip resistance and friction values, the soil was divided into three different layers. Figure 3.8 shows the generalized subsurface profile of the site. All PPMT tests were conducted in the soils, within the crosshatched area shown (Figure 3.8).

The upper medium-dense sand layer, interbedded with silt and clay lenses, varies from the surface to 12 ft on the west side and to a depth of 5 ft on east side as shown in Figure 3.8. The CPT tip resistance, q_c,for this layer has a minimum of 50 tsf and occasionally reaches 175 tsf within the layer. Similarly the value of side friction has a minimum resistance of 0.6 tsf and reaches a maximum of 1.6 tsf within the layer.

The depth of the second layer varies from 12 ft to 20 ft on the west side and from 5 ft to 12 ft on the east side. This layer predominantly consists of silty sand. Based on the values of tip resistance and side friction for this layer, usually less than 50 tsf and 0.2 tsf, respectively, the soil in this layer was classified as loose, silty sand.

The third layer starts from a depth of 20 ft on the west side of the site to 12 ft at the east side of the site. This layer predominantly consists of dense cemented sands. The values of tip resistance and side friction are usually greater than 200 tsf and 1.7 tsf, respectively.

Based on the SPT tests at the Florida Tech site, the blow counts were correlated to relative density, D_r, of these soil layers. The relative densities were 45–70% in the medium dense sand, 0–40% in the loose, silty sand, and 65–85% in the dense, cemented sand layer.

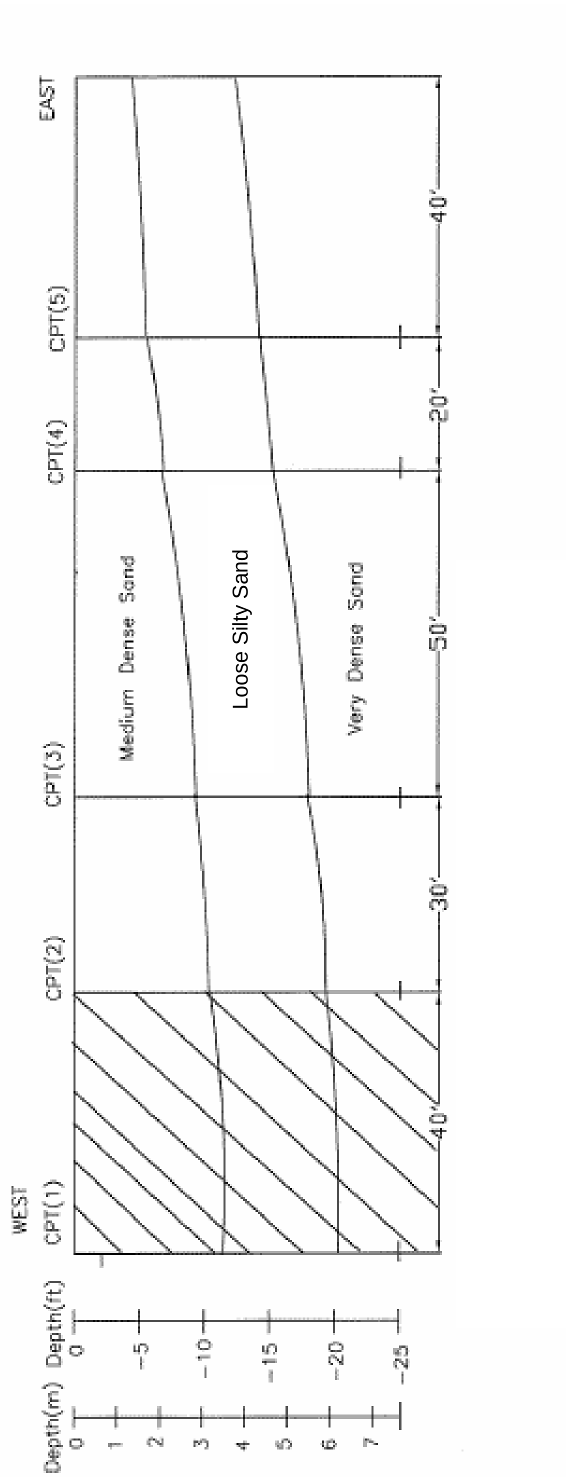


Figure 3.8 Generalized subsurface profile for the Florida Tech All Faiths Center sand site

3.2.2 Puerto Del Rio Condominium Clay and Sand Site

The Puerto Del Rio site covers an area of approximately 4,000 sq ft and lies north of Central Boulevard in Cape Canaveral, Florida (Figure 3.9). A detailed location of the site is shown as the area under Buildings 10 and 11 of the Puerto Del Rio Condominiums (Figure 3.10). It contains a clay layer from 10 m to 15 m (30 ft to 50 ft) below grade that was ideal for evaluating the PPMT test procedure. Cape Canaveral is 60 miles due east of Orlando on the Florida Space Coast. The site is adjacent to Port Canaveral.

Figure 3.9 Location of the Puerto Del Rio test site, Cape Canaveral, Florida

Four CPT soundings were performed in this site. Based on the CPT tip resistance and side friction values, the soil was divided into four layers. Figure 3.11 shows that the layers were relatively horizontal across the site. The first layer, to 2.1 m (0–5 ft) was predominantly sand, with tip resistance and side friction of approximately 175 tsf and 1.0 tsf, respectively. The second layer was clay and extended from, from 1.5 m to 3 m (5 ft to 9 ft), had approximate tip resistance and side friction of 20 tsf and 0.15 tsf, respectively. From 3 m to 10 m (9 ft to 32 ft), the third layer varied from silty sand to sandy silt with tip resistance of 75 tsf and side friction of 0.5 tsf. From 10 m to 15 m (32 ft to 50 ft), the fourth layer was sensitive clay with low CPT tip and side friction values.

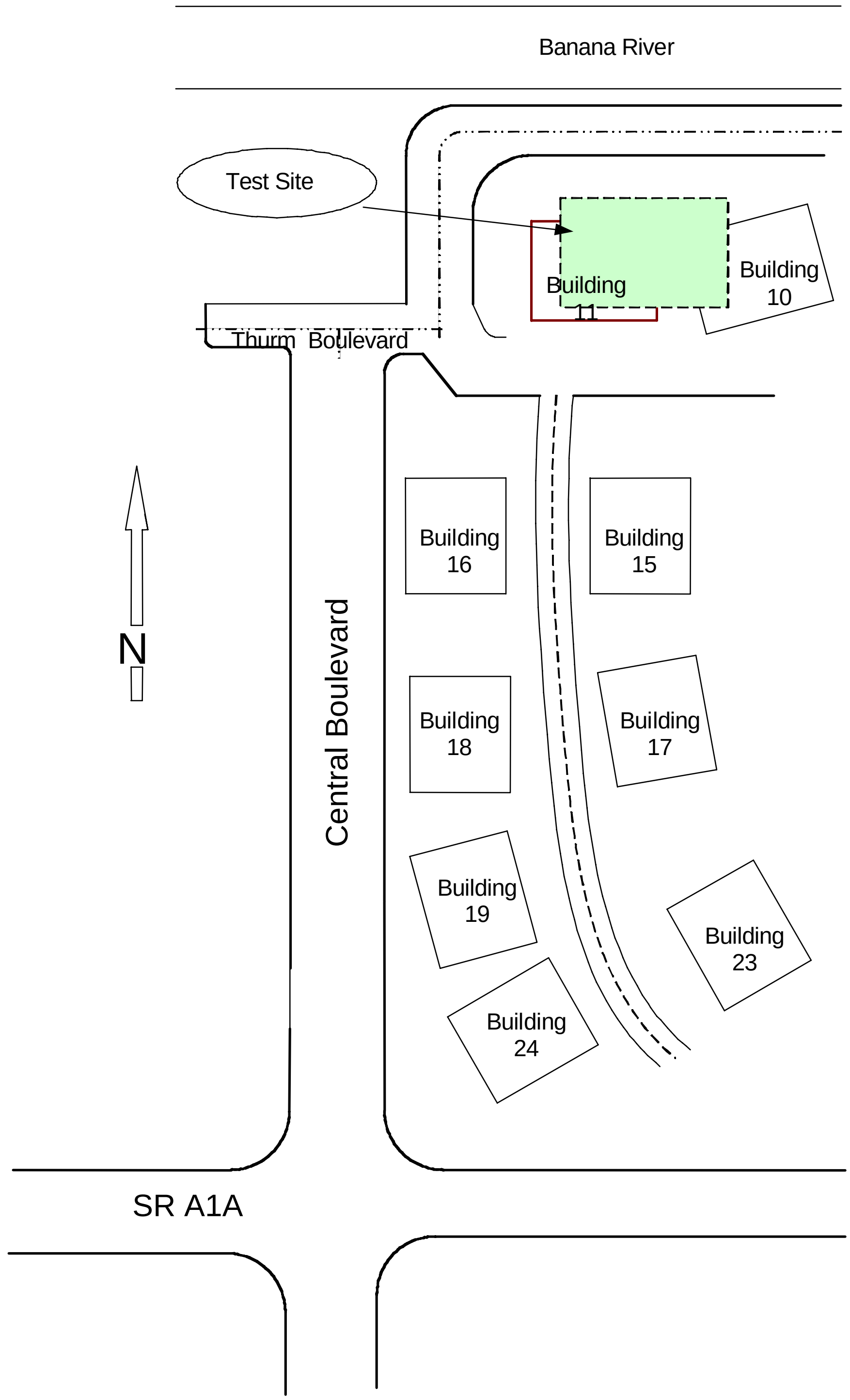


Figure 3.10 Location of Puerto Del Rio test site beneath Buildings 10 and 11

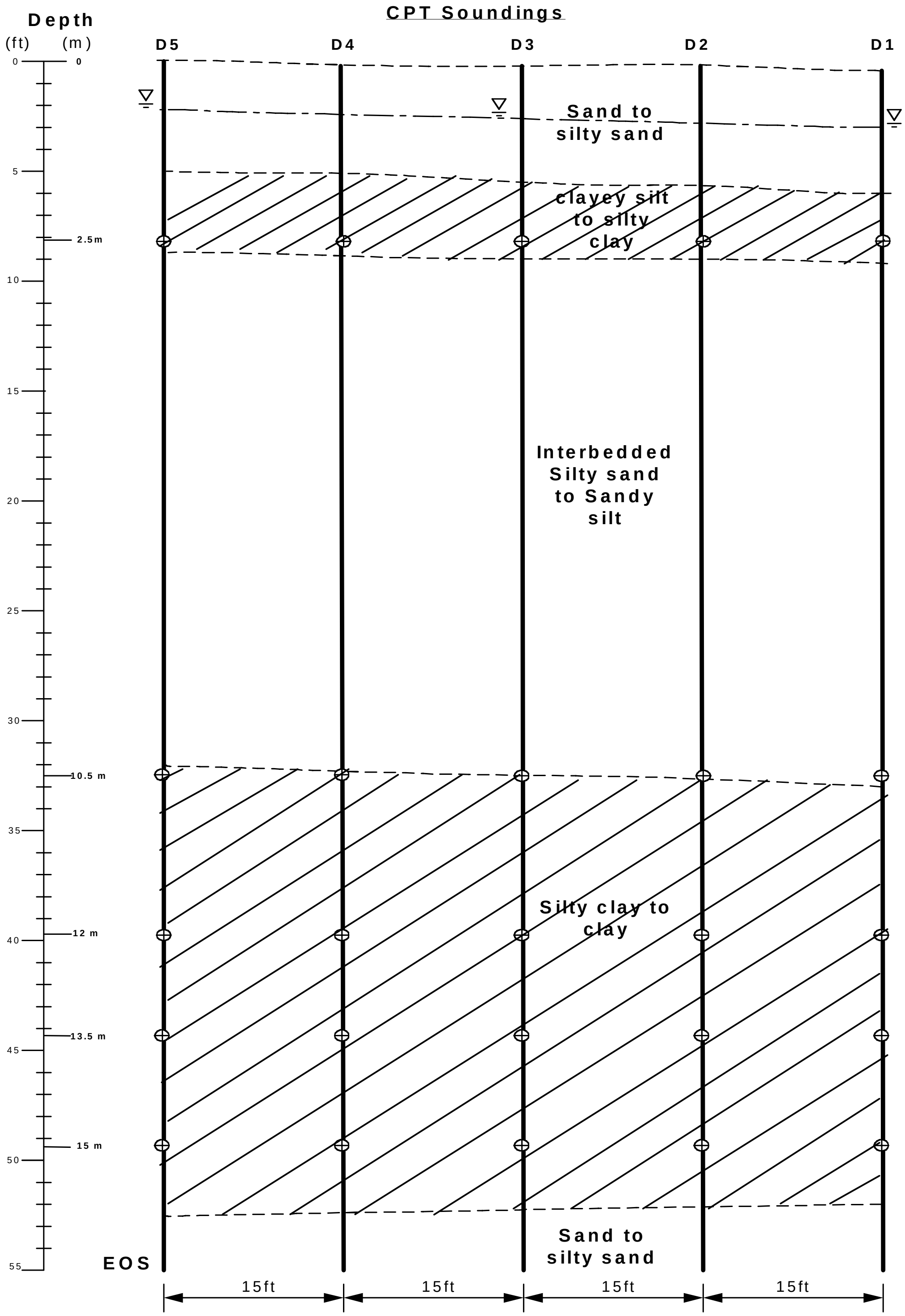


Figure 3.11 Generalized subsurface profile of Puerto Del Rio site

In June 2004, a 3,600-sq-ft rectangular field site was developed and tested with the assistance of FDOT (see Figure 3.12). A total of 24 soundings were conducted, each to a depth of 15 m (50 ft). Testing included four CPT soundings, which provided continuous evaluation of the soil to a maximum depth of 15 m (50 ft); four DMT soundings, which provided evaluation of the soil at 0.5 m (1.64 ft) intervals to the maximum depth of 16.5 m (54 ft); eight PPMT soundings with a smooth cone tip probe; and eight PPMT soundings with a friction reducer cone tip. Five depths were tested in each PPMT sounding at 2.5 m (8 ft), 10.5m (34.5 ft), 12m (39.5 ft), 13.5m (44.5 ft) and 15m (50 ft). All PPMT tests at this site were performed with probes calibrated using a 32 mm diameter calibration tube. The water table was encountered at a depth of 0.45 m to 0.67 m (1.5 ft to 2.2 ft) below the surface. Table 3.2 provides a summary of the overall number of tests performed at the Puerto Del Rio site. The following numbering system will be used throughout the report: Test Type: Sounding: Depth (i.e. DMT: C1: 2.5 m).

Table 3.2 Field Testing Summaries at Puerto Del Rio Complex, Cape Canaveral, Florida

Type of Test		June 2004 Test Dates Number of Soundings							Total Soundings
		9	**11**	**14**	**15**	**16**	**17**	**18**	
CPT		3	1						4
DMT		3				1			4
PMT	With Smooth Cone Tip	2			3	2	1		8
	With Friction Reducer			2	2	1	2	1	8

In September 2004, a second series of tests were conducted at the Puerto Del Rio site to evaluate the instrumented control unit. It included a series of six PPMT soundings with five tests per sounding carried out at depths 2.5 m (8.2 ft), 10.5 m (34.4 ft), 12 m (39.4 ft), 13.5 m (44.3 ft) and 15 m (49.2 ft). These depths were selected based on the CPT tests previously conducted at the site.

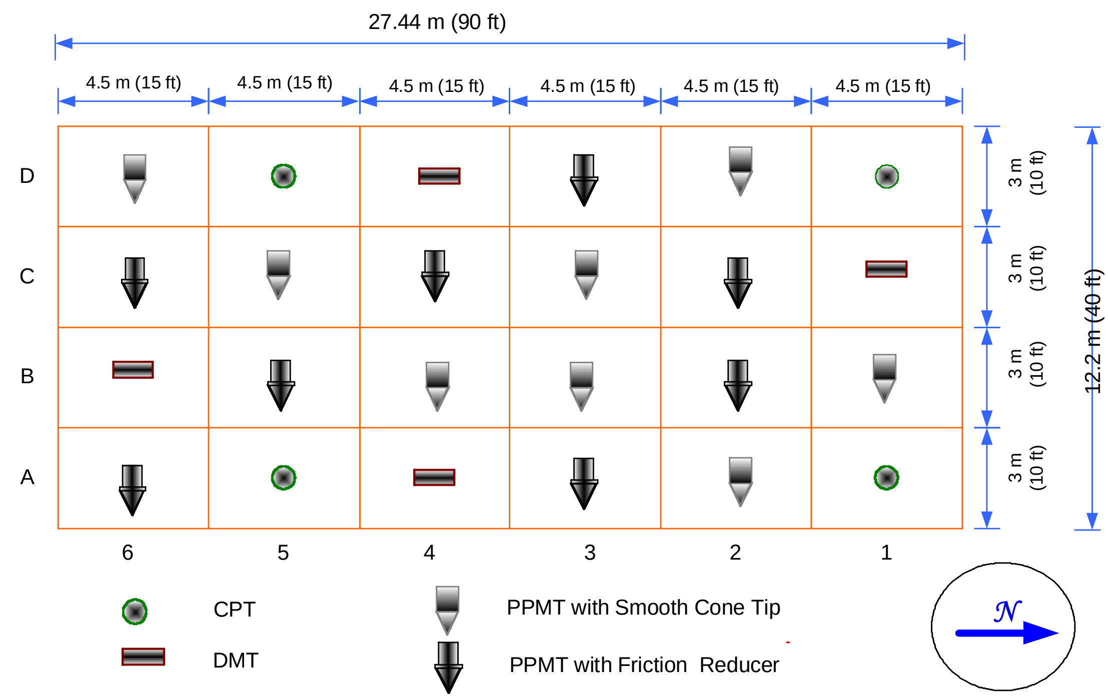


Figure 3.12 Testing plan for Puerto Del Rio site, Cape Canaveral, Florida

3.2.3 Archer Landfill Sand Site

The Archer Landfill site is near the entrance of the Archer Landfill close to the intersection of SR 24 in Gainesville, Florida (Figure 3.13). The testing site is located west of the landfill entrance and 150 feet from the landfill operations. It is covered with scattered low vegetation and is bordered by trees to the west. The ground surface is level and the site, located within a landfill, is above the ground water table.

CPT tests conducted by FDOT (Bixler, 2004) indicated that the sands at the Archer Landfill site were consistent throughout. The generalized subsurface profile of this site based on two CPT tests 20 ft apart is presented in Figure 3.14.

Using the CPT tip resistance and side friction, the soil was divided into three layers. The first layer to 2.1 m (0–7 ft) consisted of silty clay where tip resistance and side friction values were below 25 tsf and 0.2 tsf, respectively. From 2.1 m to 4.2 m (7 ft to 14 ft), the second layer was silty sand with tip resistance between 25 tsf and 80 tsf, and side friction between 0.2 tsp and 0.6 tsf. From 4.2 m to 9.1 m (14 ft to 30 ft) the third layer was predominantly sand to silty sand. The tip resistance and side friction values for this layer ranged from 80 to 160 tsf and 0.6 to 1.5 tsf, respectively.

A total of seven PPMT soundings were conducted at this site. For each sounding, three tests were performed at depths of 2.0 m (6.6 ft), 4.0 m (13.32 ft) and 5.8 m (19.0 ft). For consistent results, the soundings were conducted within 10 m (30 ft) of each other.

Figure 3.13 Archer Landfill site, Gainesville, Florida (Microsoft MapPoint 2005)

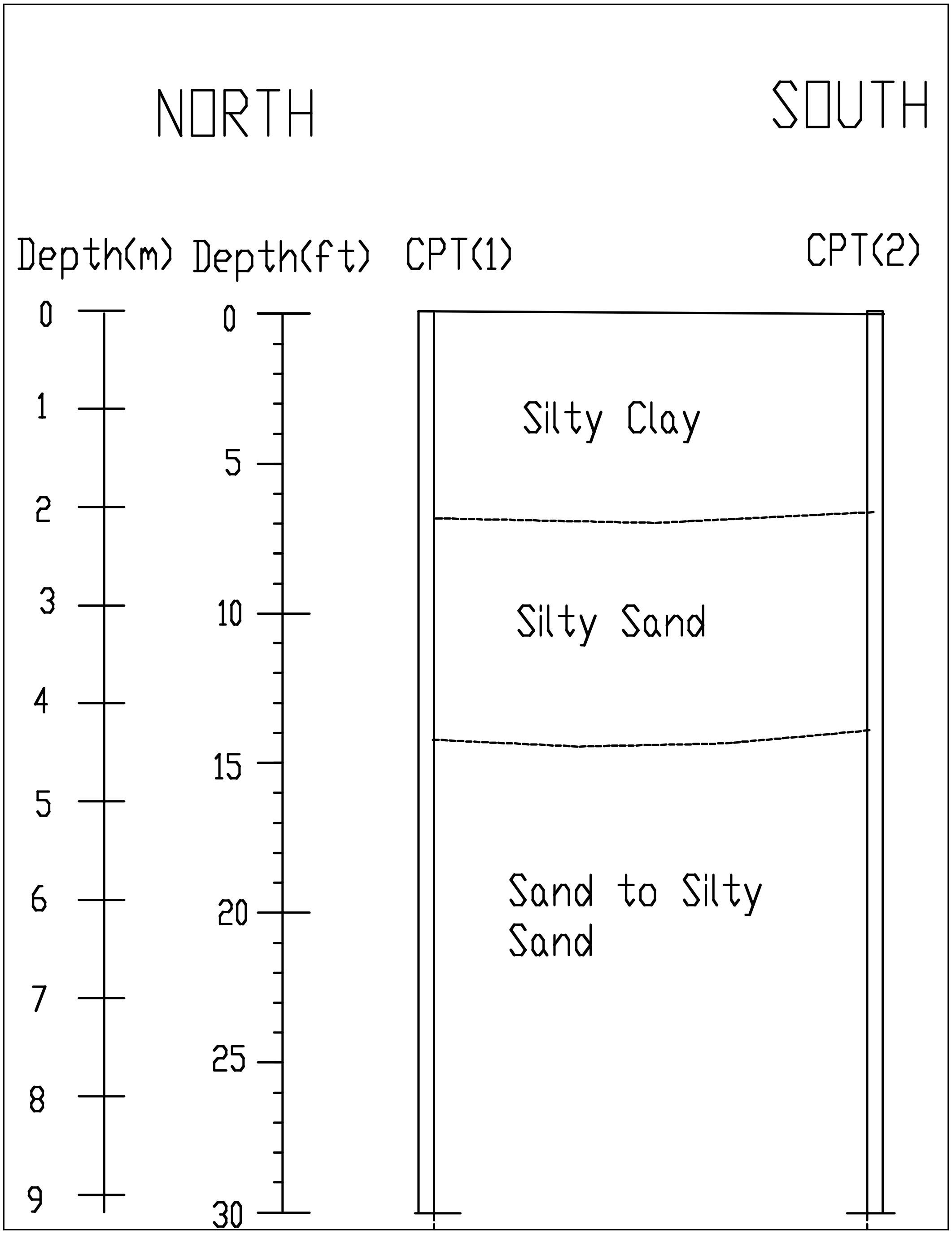


Figure 3.14 Generalized subsurface profile of Archer Landfill site, Gainesville, Florida

3.3 Digital Instrumentation and Calibration of the PPMT

The recommended test procedure for the PPMT presented in the 2005 Roctest manual was thoroughly studied (Roctest 2005). Based on this evaluation, two areas are identified where instrumentation could improve the productivity of the test. One area identified is to manually record readings onto a data sheet and process the data after completing the test. This would significantly improve the quality of the data produced. The second area involves identifying the time required for stabilization of the soil pressures following each injected volume. This time has been termed the *volume increment stabilization period (VISP).* In addition to improving the standard PPMT procedure, this time may be related to the engineering behavior of certain soils.

In an effort to reduce manual data recording and processing, instrumentation has been added to the current control unit that allows the operator to record the test data on a laptop computer. The objectives of the instrumentation are to:

1) Reduce the time needed for the test and data collection.
2) Reduce human error in reading and recording data.
3) Improve the precision of the data being collected.
4) Reduce the time for data analysis, reduction and presentation.
5) Reduce manpower required for the PPMT testing.

During development of this equipment, an engineering decision was made that digital data collection and analysis be achieved without altering manual data collection. The resulting PPMT control unit instrumentation produces digital pressures and volumes. A laptop computer was chosen for data collection, reduction and analysis to be conducted and evaluated by the engineer in the field.

3.3.1 Pressure Measurements

To record the pressure, a digital pressure transducer capable of sensing a maximum pressure of 2,500 kPa with a resolution of 2 kPa was connected in series with the existing pressure gauge. The selected pressure transducer (Setra-Model 522) has a pressure range of 500 psi (3,450 kPa), and offers stability and reliability with less than 0.2% drift per year and 0.25 % full-scale accuracy. The transducer is constructed of corrosion resistant 17-4 pH stainless steel. The input voltage (V) ranges from 7–35 V and gives output signals from 0–5 V.

3.3.2 Volume Measurements

The alternatives evaluated for measuring the volume of water injected into the probe were to:

1) measure the displacement of the volumetric piston and calibrate this displacement to the volume injected into the probe,
2) count the number of rotations of the shaft that changes the volume and calibrate the rotations to the volume injected, or
3) incorporate a flow meter into the output tubing line and calibrate the flow to the volume of water injected.

It was decided that measuring the displacement of the piston would yield more accuracy and could be achieved without a redesign of the existing control unit. A linear potentiometer with a full-stroke range greater than 4.5 in was selected to measure the displacement of the piston. The resolution of the system needed to sense 0.1 cc of the total volume. A linear potentiometer was selected instead of a LVDT for the lower cost and because the required resolution was more easily met by a potentiometer.

Based on the above factors, a CLP type 6-in linear-conductive potentiometer manufactured by Celesco was selected. This CLP potentiometer yields a linear output with a full-stroke range of 6 in. It has a combination of individually corrected conductive plastic elements and precious metal wipers, providing a cost effective measuring system. The potentiometer has a life expectancy of 10 million cycles with a linearity of 0.1–0.2% full stroke. The input voltage ranges from 5–25 V and gives the output signals from 0–5 V.

3.3.3 Assembly and Electronics of the Components

The assembly of the pressure transducer and linear potentiometer required an evaluation of the control unit interior space shown in Figure 3.15. After a thorough study, it was determined that sufficient space existed to allow the Setra pressure transducer to be connected in series between the volume cylinder and the pressure gauge in the control unit. A Swagelok® T-connection was added so the pressure transducer could be plumbed into the system.

For the volume measurements, a specific point on the piston in the volume cylinder was identified to produce a linear motion, as shown by point “A” in Figure 3.15. In the control unit, the potentiometer was connected in parallel with the piston or the volume cylinder and held in place by aluminum mounting blocks. An L-shaped linkage arm connected the potentiometer to the piston of the volume cylinder as shown in Figure 3.15. These components were fabricated in the Florida Tech Machine Shop. As the volume handle of the control unit is turned, the gearing moves the piston linearly. The potentiometer measures this displacement, which is calibrated to the volume of water injected into the probe.

The pressure transducer and the potentiometer electrical inputs and outputs were connected to an interface board, and in turn to a laptop computer through a serial port. The PC interface board, consisting of a PIC microprocessor and a MAX232A serial interface chip, included a 12-volt regulator used as the power source for the pressure transducer, and a 5-volt regulator used as the power source for the potentiometer. These components are mounted inside the electronics module shown in Figure 3.15. The processor and serial interface chip also operate using the 5-volt source. Either an extended-life rechargeable battery or a 12-volt AC adapter powers the regulators. The lightweight battery can be stored within the PPMT control unit case, allowing the system to remain portable.

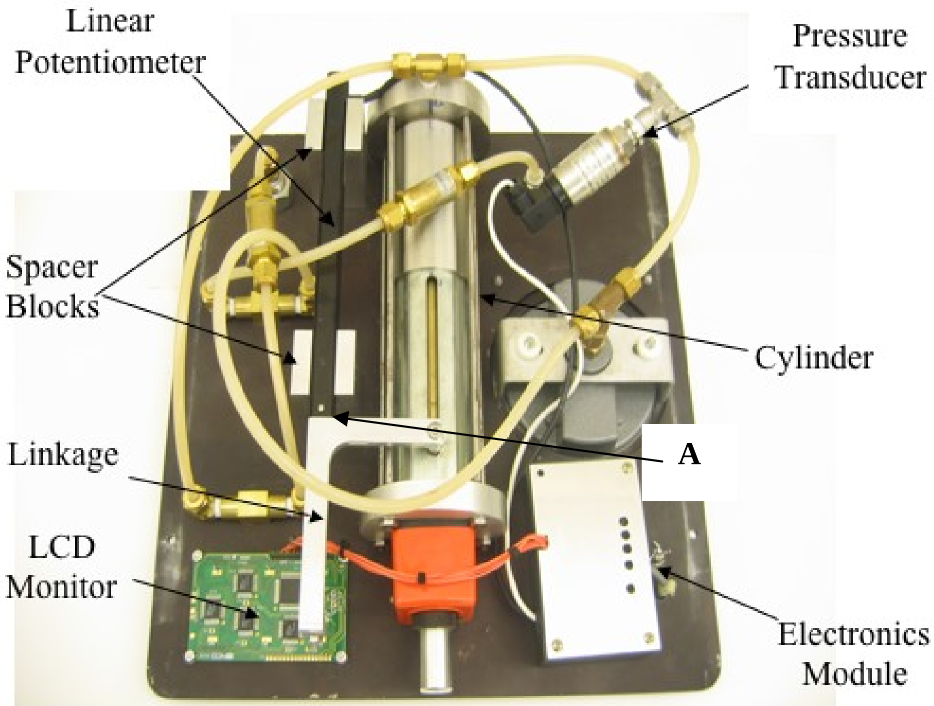


Figure 3.15 Interior of PPMT control unit with the instrumentation

The analog inputs on the PIC microprocessor are used to capture output from the linear potentiometer and pressure transducer. These values are converted to a 12-bit digital value and continuously routed out the PIC and through the MAX232A serial interface chip. The signal is converted to a RS232 format as ASCII characters via a two-wire cable to the computer's serial communications port. The ASCII characters are received by a LabVIEW® serial visa module and displayed in a chart format with an option of saving both readings to the hard drive or erase them. An LCD monitor directly connected to the PPMT control unit displays the digital pressure and volume readings in case the laptop is not connected.

3.3.4 APMT Data Acquisition Software Development

A stand-alone LabVIEW® program, Automated Pressuremeter (APMT), was developed and compiled into an executable package that does not require the purchase of a LabVIEW® license. APMT allows recording of digital pressures and volumes during testing and reducing the data using existing calibrations. The reduced data is displayed as a pressure versus volume plot on the screen during testing. A major concern with standardizing the test is to determine how long each load increment should be maintained. Based on several references, this time varies from 15sec to 60 sec (Cosentino, 1987; Roctest, 1986; Baguelin et al, 1978) and is actually a function of the soil type, density, saturation state and response. To address the question of increment load time, APMT includes a sequence of three lights, red, yellow and green that change, based on the rate of change of successive pressure samples. After evaluating the accuracy of the 500 psi digital pressure transducer and the sampling frequency used in the LabVIEW® software, it was determined that a red light would indicate that successive data samples are within 5 kPa. It was assumed that this change was small enough to suggest that the system was nearly stable at the desired pressure. The yellow light would indicate that successive data samples are within 0.3 kPa. The software would then record three successive pressures, average them and save them to a file. The green light would indicate the data was saved. The system has a sampling rate of four data samples per second. Figure 3.16 shows a screen from the APMT LabVIEW® program taken during a PPMT test.

LabVIEW® software is used to collect and analyze the data. Florida Tech has a site license for LabVIEW®, making it cost effective for this research.

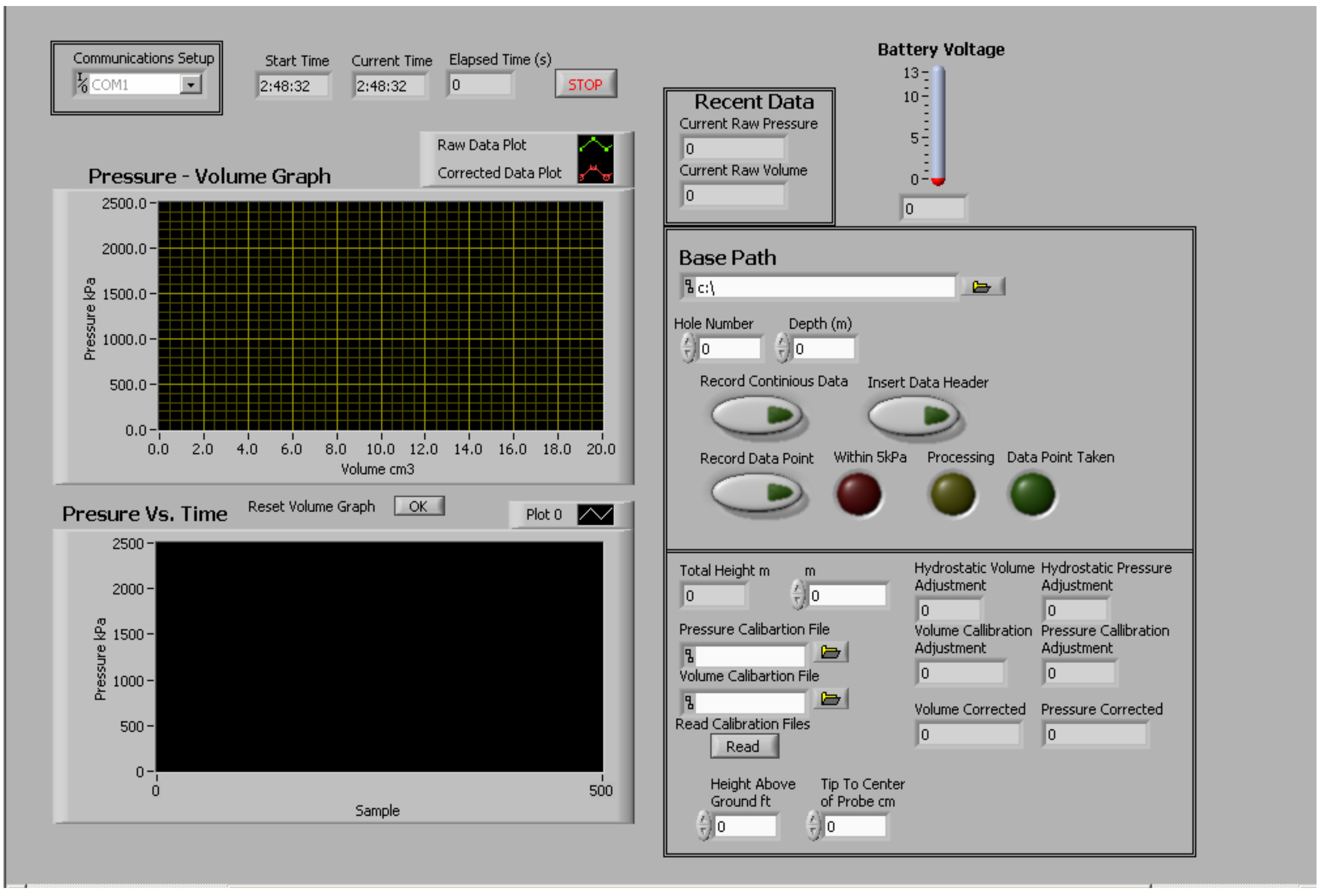


Figure 3.16 Executable APMT Labview® screen

3.3.5 Calibration of the Components

Calibration of the pressure transducer and potentiometer was conducted after installation of all components. The analog output signals from the pressure transducer and the potentiometer ranged from 0–5 V. They are converted into the digital signal in bits when connected with the serial port of the computer using APMT.

3.3.6 Calibration and Obtaining Digital Outputs for the Pressure Transducer

The signal from the digital pressure transducer was calibrated at the factory and used by the data acquisition software. By dividing the total number of bits (4,096) by the transducer range of 0–500 psi (3,445 kPa) the number of bits per kPa (1.18 bits per kPa) was used in the data acquisition system. The values from the digital readout gauge were compared with values from the control unit gauge as a check and the results were similar. Note that the digital gauge is accurate to 2 kPa, while the conventional pressure gauge is accurate to 12.5 kPa.

Using a permeability control panel manufactured by Durham Geo, an additional calibration check was performed for both the pressure transducer and pressure gauge. The PPMT control unit and the pressure transducer are attached to the permeability control panel shown in the Figure 3.17. The pressure in the permeability control panel is increased, causing an equivalent change in the number of bits of the pressure transducer. The change in pressure in the panel and the corresponding change in bits is recorded. Based on several trials, the pressure transducer was calibrated with the permeability control panel, resulting in a correlation between the permeability control panel and digital reading of $R^2 = 0.99$. In conclusion, the pressure readings from the permeability panel matched the digital and PPMT gauge readings, thereby confirming the results.

Figure 3.17 Calibration set-up of instrumented PPMT pressure transducer using Durham Geo permeability control panel

3.3.7 Calibration of Linear Potentiometer

Calibration of the potentiometer also involved correlating the number of bits read using APMT with the PPMT volume counter, which has a volume range up to138 cm^3. Thus the total number of bits (4,096) was equated to 138 cm^3 and a comparative output voltage per unit volume of 29.68 bits per cm^3 was obtained.

During calibration, test data indicated the initial change in the volume obtained from the control unit volume counter was not equal to the volume produced by the digital instrumentation during either inflation or deflation. It was observed that the initial 0.7 cm^3 volume on the control unit counter produced zero corresponding volume change on the digital display. After the initial 0.7 cm^3, the change in the control unit counter and the APMT digital display were equal.

In order to further evaluate the volume, a 50 cm^3-graduated burette was used. The control unit was initially saturated. After this saturation, the fill bleed tube was connected to the burette and again saturated to make sure no air was trapped in the tubing. The volume reading from the control unit volume counter was compared with the actual volume of water injected into the burette. This data is summarized in the comparative charts shown in Table 3.3. Once the researchers evaluated the data, a verification of the results was performed at FDOT's SMO in Gainesville, Florida. This data is summarized in Table 3.4.

Tables 3.3 and 3.4 show that for the initial 1.0 cm^3 produced on the volume counter during either inflation or deflation, there was only a 0.3 cm^3 change in the burette level. This signifies that the piston did not move for the initial 0.7 cm^3 shown on the counter. This error occurs both during the initial inflation and initial deflation processes. It is believed this behavior is backlash between mating gears in the system used to create volume changes by the piston used in the control unit. The rotational movement of the gear system attached to the crank handle and the volume counter produces the linear motion of the piston. During the initial rotation in both inflation and deflation, the counter registers a change, yet the piston that controls the volume is not moving. The use of high-resolution linear potentiometer to measure the displacement of the piston avoids this problem.

Table 3.3 Comparison between the actual burette reading and the volume counter reading during the volume calibration procedure performed at Florida Tech.

	Inflation increases volume in burette			
A	B	C	D	E
Control Unit Volume Counter Reading	**Control Unit Volume Change**	**Actual Burette Volume**	**Burette Volume Change**	**Delta**
(cm^3)	From column A (cm^3)	(cm^3)	From column C (cm^3)	(B-D) (cm^3)
0.0		0		
	0.5		0.1	0.4
0.5		0.1		
	0.5		0.2	0.3
1.0		0.3		
	0.5		0.5	0.0
1.5		0.8		
	0.5		0.5	0.0
2.0		1.3		
			Total Change	0.7

	Deflation decreases volume in burette			
A	B	C	D	E
Control UnitVolume Counter Reading	**Control Unit Volume Change**	**Actual Burette Volume**	**Burette Volume Change**	**Delta**
(cm^3)	From column A	(cm^3)	From column C (cm^3)	(B-D) (cm^3)
35.0		35.0		
	0.5		0.1	0.4
34.5		34.9		
	0.5		0.3	0.2
34.0		34.7		
	0.5		0.5	0.0
33.5		34.2		
	0.5		0.5	0.0
33.0		33.7		
			Total Change	0.7

Table 3.4 Comparison between the actual burette reading and the volume counter reading during the volume calibration procedure performed by FDOT SMO personnel.

	Inflation increases volume in burette			
A	B	C	D	E
Control Unit Volume Counter Reading	Control Unit Volume Change	Actual Burette Volume	Burette Volume Change	Delta
(cm^3)	From column A (cm^3)	(cm^3)	From column C (cm^3)	(B-D) (cm^3)
0.0		0		
	0.5		0.1	0.4
0.5		0.1		
	0.5		0.2	0.3
1.0		0.3		
	0.5		0.5	0.0
1.5		0.8		
	0.5		0.5	0.0
2.0		1.3		
			Total Change	0.7

	Deflation decreases volume in burette			
A	B	C	D	E
Control UnitVolume Counter Reading	Control Unit Volume Change	Actual Burette Volume	Burette Volume Change	Delta
(cm^3)	From column A	(cm^3)	From column C (cm^3)	(B-D) (cm^3)
35.0		35.0		
	0.5		0.1	0.4
34.5		34.9		
	0.5		0.2	0.3
34.0		34.7		
	0.5		0.5	0.0
33.5		34.2		
	0.5		0.5	0.0
33.0		33.7		
			Total Change	0.7

3.3.8 Volume Calibration

Volume calibration, also termed system expansion, adjusts the data for the expansion in the control unit tubing assembly and in the PPMT membrane. As the pressure increases, the tubing expands and the probe membrane thickness decreases, thereby producing extra volume. Roctest recommends a standard procedure for a volume calibration correction (Roctest manual, 2005). Each step of the procedure was evaluated for possible improvement or revisions. Based on the Roctest method, it was observed that the volume correction at pressures of 2,000 kPa was about 12 cm^3. Therefore, injecting a volume of 90 cm^3 would produce more than a 13 percent correction. This correction is relatively high and thus led to a revised procedure for conducting the volume calibration as presented in Figure 3.18.

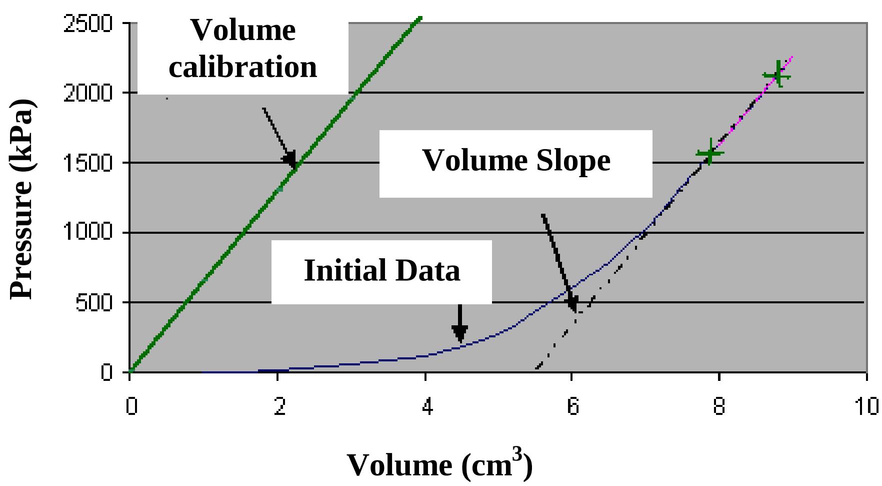


Figure 3.18 Recommended volume calibration of PPMT using 32 mm calibration sleeve

In Figure 3.18, the initial data represents the pressure versus volume data obtained during the volume calibration test with the probe inserted into a 32-mm diameter steel calibration sleeve. The initial nonlinear behavior is due to a gap that exists between the outside of the probe and the inside of the steel tube. As the probe begins to contact the tube, the response becomes linear. Using the last two recorded data points of this curve, a straight line is projected through them intersecting the x-axis, termed the volume slope. Shifting this to the origin yields the recommended linear volume correction. This representation yields approximately 8 cm^3 of correction over 90 cm^3 at pressure of 2,000 kPa or approximately 9 percent error. This extra volume is then subtracted from the raw volume to yield the corrected volume.

3.3.9 Pressure Calibration

The pressure calibration is the pressure correction necessary to overcome the inherent resistance from expansion of the membrane and protective metallic strips. This resistance must be subtracted from the raw pressure to determine the actual pressure exerted on the soil. The resistance to expansion is dependent on the type of rubber membrane and protective metallic strips used for the probe. This calibration must be conducted each time a membrane is changed. The pressure calibration explained in the Roctest manual (2005) is thorough and no suggestions for modification of the procedure were developed.

3.3.10 Hydrostatic Pressure Correction

The hydrostatic pressure is the pressure exerted on the soil due to the water table and is equal to the depth of the water table multiplied by the density of water. This pressure must be added to the raw pressure of the PMT curve as explained in the Roctest manual (2005).

To evaluate the validity of hydrostatic pressure correction, a series of tests were conducted by lowering the probe to approximately 26 m (80 ft) down a set of stairs in the Florida Tech Crawford Science Building. These tests included one using a bare rubber probe sealed with hose clamps and three using a probe with sheathing. One of the three tests with sheathing was conducted once an initial pressure of 300 kPa was applied to the probe using the metal calibration sleeve. This was done to simulate field tests for pushed-in PPMTs in clays and sands. The tests results from all these trials were compared with the theoretical value of hydrostatic pressure for different depths as shown in the Figure 3.19.

From Figure 3.19, it can be seen that the graphs from the probe with sheathing closely matched the results of the theoretical hydrostatic pressure, whereas a bare probe sealed with hose clamps deviated from the theoretical values after a depth of 8 m. It was assumed that hydrostatic correction works when the membrane is assembled. However, the sealed rubber-only membrane created a vacuum that could not be overcome as the probe was lowered, so the hydrostatic correction was only correct to about 8 m (26 ft). Theoretically, the maximum hydrostatic correction for a perfectly closed system would occur to a depth of 10.3 m (1 atm). Therefore, the measured value of 8 m seems reasonable. A thorough study is needed to fully understand the limits of the hydrostatic corrections to the PMT data.

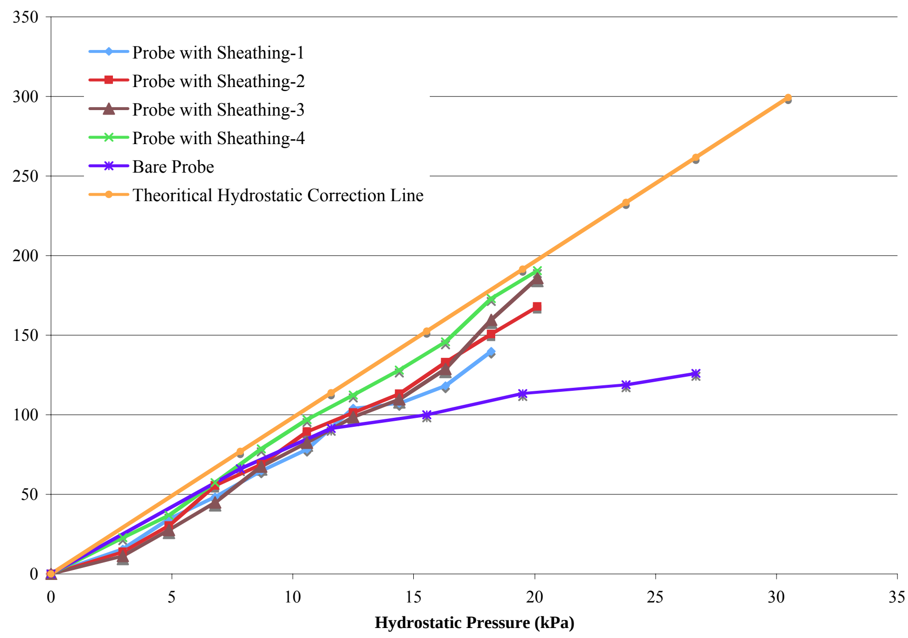


Figure 3.19 Comparison between theoretical hydrostatic pressure and the pressure obtained during PPMT tests for probe with and without sheathing

3.3.10.1 Length-to-Diameter Ratio Evaluation

A preliminary laboratory evaluation of the length-to-diameter (L/D) ratio for the PPMT probe was conducted. Erbland (1993) and Yao (1996) performed studies on this ratio to determine if a cylindrical expansion was truly occurring. Erbland (1993) showed some significant variations in the limit pressures as the L/D ratio increased.

To evaluate this concern, two approaches were undertaken. First, a qualitative analysis of the probe expansion was performed using the volume expansion calibration curves. A typical curve, which was shown in Figure 3.2, includes about 10 cm^3 of correction at 2,000 kPa, or about 10 percent. This was quite large, and therefore, a qualitative analysis of the components of this correction was performed. A second, quantitative analysis was performed in the laboratory. The membrane length was varied three times, from the standard 24 cm (9.5 in) to 26.9 cm (10 in), and finally to 30.48 cm (12 in). Using 10 cm^3 increments, the probe was expanded from zero to a volumetric strain of about 43 percent. For the standard probe, a total volume of 90 cm^3 was injected, while for the second length, 100 cm^3 was injected and for the final length, 110 cm^3 was injected. During expansion, measurements of the probe diameter were taken at five locations along its length. These values were then plotted as diameter versus length and the results of the three analyzed in Chapter 4.

3.4 Developing p–y Curves from PPMT and DMT data

Based on the literature review of laterally loaded piles, the methods proposed by Robertson et al (1986) and Briaud (1992) were considered the most reliable for PMT p–y curves and the method proposed by Robertson et al (1989) was considered the most reliable for DMT p–y curves. FDOT has recommended Robertson's methods for state funded projects and therefore, it was used for both the PPMT and DMT data. These procedures were outlined in Chapter 2.

4 Chapter 4—RESULTS

The fundamental engineering soil parameters obtained from 235 PPMT tests at three sites (i.e., initial pressure (p_o), initial elastic modulus (E_o), rebound elastic modulus (E_r) and limit pressure (p_L), shown in Figure 3.1) were analyzed. These parameters were compared with published data and, when possible, with DMT soil parameters. Over 200 DMT tests were conducted at the All Faiths and Puerto Del Rio sites. Of these 200 DMT tests, only those conducted at the same depth as the PPMT tests were compared.

Soil properties from the All Faiths Site varied significantly both horizontally and vertically. Therefore, comparisons were based on similar PPMT limit pressures. Soil properties at the Puerto Del Rio site were consistent with depth, enabling comparisons within each layer to be made.

The results of data collected manually from the conventional PPMT control unit were also compared to the data collected using the instrumented system. The data, in terms of pressures and volumes, was analyzed along with the fundamental engineering soil parameters. Comparisons between instrumented and manual data were based on data collected at the Archer site.

4.1 Equipment Ruggedness Evaluation

During the PPMT testing at the Puerto Del Rio clay site 84 PPMT tests were performed in 16 soundings. The cone truck operators took extreme care to ensure the probes were well maintained. After they were extracted from each borehole (i.e. at the conclusion of each sounding), the probe was thoroughly cleaned and the membrane was measured to ensure it maintained its shape. The average change was about 1% in diameter and 0.5% in length (see Appendix A). These percentages are relatively small and therefore assumed to have minimal affect on the engineering parameters.

Membrane failure is a primary concern with regard to equipment performance. After 70 of the 84 tests, a leak developed at the welded joint connecting the vent tube and shaft (Figure 4.1) in FDOT probe *A1* during testing in sounding *C4*. After switching to FDOT probe *B1*, 14 tests were performed before this connection again failed. At this point, the volume injected was 60 cm^3 and the pressure gauge recorded 2,170 kPa.

In summary, FDOT probe *A1* was used for 70 PPMT tests and probe *B1* was used for 14 PPMT tests. Therefore, the main problem faced during this testing was the weakness of the small-diameter tube used to transport the water through the hollow probe. This tube easily undergoes fatigue, or failure due to accidental contact or impacts. Negligible changes were recorded in the probe dimensions during the field-testing.

Figure 4.1 Photo of Vent Tube and Shaft for Solid Core Model

4.2 *Pressuremeter Data Analysis*

The PPMT field-testing evaluation in clay was based on volume calibrations with a 32-mm diameter tube. The results from 84 tests using both a smooth cone tip and friction reducer cone tip of .062 in are shown in Appendix A. The data reduction was performed using the third order polynomial equation with Excel. The curves of the adjusted pressure versus adjusted relative increase in radius are presented in Appendix A. The common PPMT parameters obtained from tests are the initial elastic modulus, E_o, the rebound modulus, E_r, the limit pressure, p_L, and the lift-off or initial pressure, p_o. The initial PPMT modulus was determined from the initial straight-line portion of the reduced plot, and the reload modulus was determined from the unload–reload loop at the end of the elastic phase. After reduction, the method proposed by Robertson et al (1986) was used to develop p–y curves for the design of laterally loaded piles.

4.2.1 Determination of Engineering Properties

Data from the All Faiths site was analyzed and engineering parameters from PPMT and DMT testing were compared. Figure 4.2 shows a correlation between the PPMT initial modulus, E_o, and limit pressure p_L. The correlation shown, 0.91, indicates these two parameters are related and that the PPMT tests were reliable. Figure 4.3 is a comparison between similar PPMT and DMT moduli for this site. It also indicates that the two devices produce similar stiffness values.

The engineering parameters from the Puerto Del Rio site have been summarized and are presented in Tables 4.1 to 4.5. The test results for PPMT sounding *A2* at the 2 m (6.5 ft) depth were not included in the analysis because it was believed the higher values from this test were a result of testing fine sand, while the remaining results were based on clays. The PPMT data for sounding *C4* produced lower values at all depths, which was attributed to the vent tube leak developed during the sounding, and are not included in the analysis. The mean values (AVG), standard deviations (STD) and coefficient of variation (COV = STD / AVG) from these parameters are summarized in Table 4.6.

The results in Table 4.1 show that tests performed in the soft sandy clay soil using the smooth cone tip at 2.5 m (8 ft) depth produced engineering parameters that were 8 to 28% greater than those from the friction reducer cone tip. Table 4.2 consists of the results from the loose silty fine sand layer, and shows a 33% greater initial modulus using the smooth cone tip than when using the friction reducer, but the other parameters are relatively constant, with only about a 6% difference. Tables 4.3 to 4.5, which refer to soft clay soil, indicate similarity in the percentage increase of all the parameters. There is an average of 8% difference for the initial moduli, E_o, and almost no difference for the rest of the parameters (E_r, p_L, and p_o), whether using the smooth or the friction reducer cone tip. This behavior is attributed to the slightly enlarged hole created by the friction reducer. In conclusion, the data indicates that the friction reducer decreases all four engineering parameters, which would imply an increase in soil disturbance.

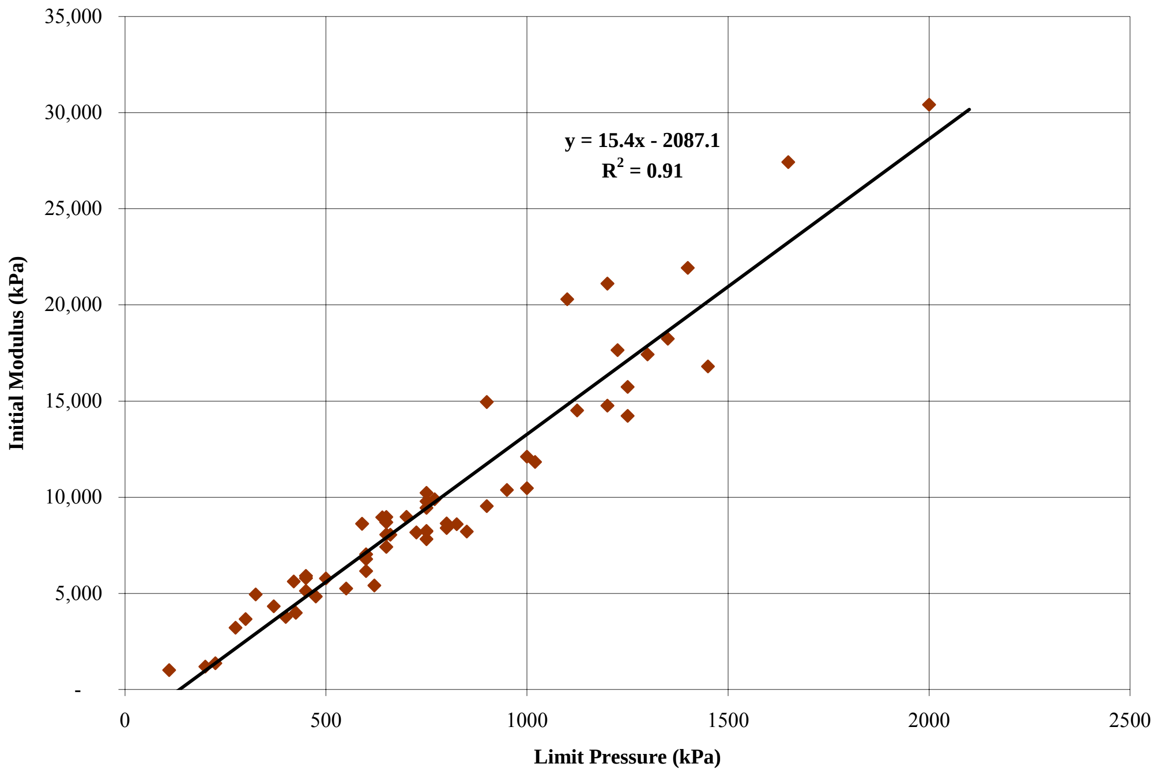


Figure 4.2 PPMT modulus and limit pressure comparison from All Faith sand site

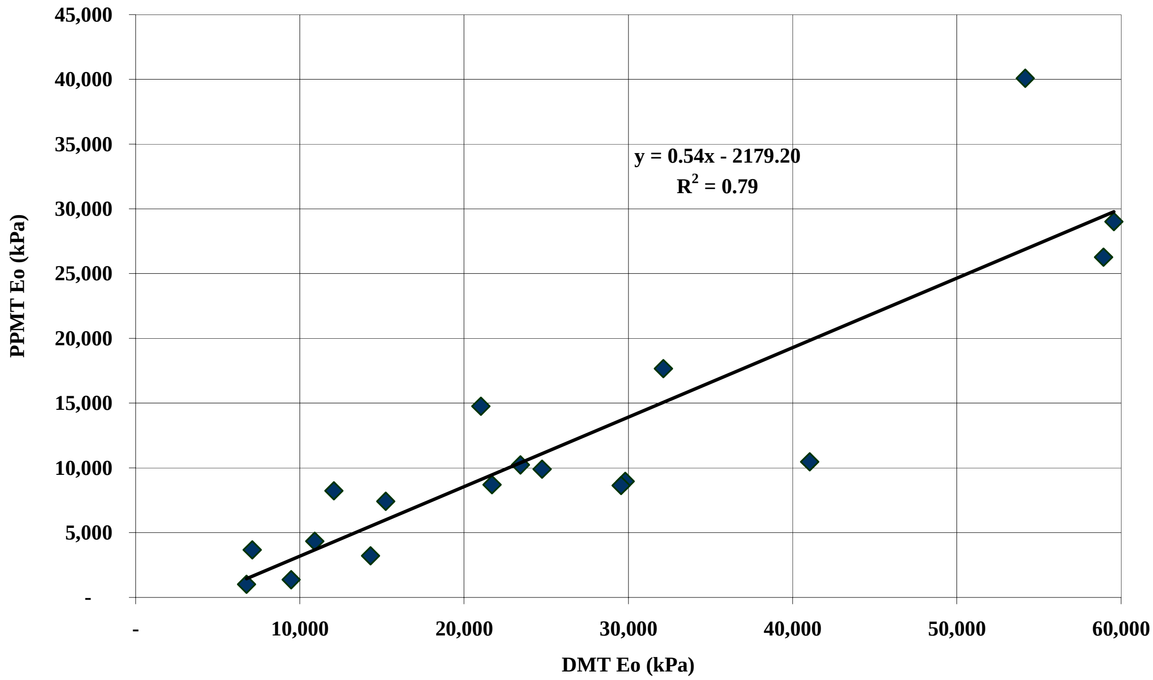


Figure 4.3 Elastic modulus comparison from PPMT and DMT data from All Faiths Sand site

Table 4.1 Soil Parameters obtained from PPMT Tests using Two Different Cone Tips in Soft Sandy Clay Layer at 2.5 m (8 ft).

Smooth Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C5	2240	6428	170	54
D6	2746	7745	150	83
D2	3108	9257	150	75
C3	2748	9225	160	75
B4	2356	7414	175	83
B3	3084	11980	140	70
B1	2478	8219	140	63
A2	5045*	5138*	550*	65*
AVG	**2680**	**8610**	**155**	**72**

Friction Reducer Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C6	2669	9447	130	49
B5	2026	6428	130	63
D3	2295	7752	125	55
C4**	1236	5160	115	30
C2	1858	7941	150	65
B2	1872	9863	155	57
A6	1101*	7643	115*	61
A3	2154	9800	160	84
AVG	**2146**	**8004**	**121**	**62**

Parameter	$\mathbf{E_{os}/E_{ofr}}$	$\mathbf{E_{rs}/E_{rfr}}$	$\mathbf{p_{Ls}/p_{Lfr}}$	$\mathbf{p_{os}/p_{ofr}}$
Ratio	1.25	1.08	1.28	1.16

* Values not included in analysis because:

- The sounding *A2* was at 2m (6.5 ft) depth, which corresponds to fine sand layer, based on CPT data.
- Lower values found in sounding *A6.*

** Values not included in analysis because the leak was found at vent tube of the probe A1 after test in sounding *C4*.

s = Smooth cone tip

fr = Cone tip with friction reducer

Table 4.2 Soil Parameters obtained from PPMT Tests using Two Different Cone Tips in Loose Silty Fine Sand Layer at 10.5 m (34.5 ft)

Smooth Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C5	2397	28112	430	170
D6	4393	41594	500	193
D2	4451	50906	540	194
C3	6619*	42908	520	206
B4	4597	57584	630	193
B3	2907	42791	480	195
B1	5675*	33994	480	187
A2	2809	32140	520	222
AVG	**3592**	**41254**	**524**	**195**

Friction Reducer Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C6	2653	28769	460	160
B5* **	/	/	/	/
D3	3180	43370	520	190
C4**	2474	22119	425	115
C2	3081	49077	540	201
B2	2755	35827	480	181
A6	2616	38070	480	190
A3	2214	38309	470	183
AVG	**2710**	**38904**	**492**	**184**

Parameter	$\mathbf{E_{os}/E_{ofr}}$	$\mathbf{E_{rs}/E_{rfr}}$	$\mathbf{p_{Ls}/p_{Lfr}}$	$\mathbf{p_{os}/p_{ofr}}$
Ratio	1.33	1.06	1.07	1.06

* Values not included in analysis because higher values found in soundings *C3* and *B1*.

** Values not included in analysis because the leak was found at vent tube of the probe A1 after test.

*** Values not included in analysis because the probe B1 failed.

s = Smooth cone tip

fr = Cone tip with friction reducer

Table 4.3 Soil Parameters obtained from PPMT Tests using Two Different Cone Tips in Soft Clay Layer at 12 m (39.5 ft)

Smooth Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C5	3716	11086	395	246
D6	3612	14395	440	282
D2	2791	12866	420	292
C3	5158*	9471	400	238
B4	2416	11051	410	292
B3	2399	11606	410	283
B1	4353*	12951	410	287
A2	2879	5138*	400	276
AVG	**2969**	**11918**	**411**	**285**

Friction Reducer Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C6	2858	10243	430	260
B5* **	/	/	/	/
D3	2607	12202	410	282
C4**	3247	10384	370	157
C2	2390	11719	400	277
B2	2445	11629	395	285
A6	1710*	12032	395	295
A3	2086*	12300	405	290
AVG	**2710**	**11501**	**406**	**282**

Parameter	E_{os}/E_{ofr}	E_{rs}/E_{rfr}	p_{Ls}/p_{Lfr}	p_{os}/p_{ofr}
Ratio	1.10	1.04	1.01	1.01

* Values not included in analysis because higher values found in sounding *C3* and *B1* and lower values in sounding *A6* and *A.3*

** Values not included in analysis because the leak was found at vent tube of the probe A1 after test.

*** Values not included in analysis because the probe B1 failed.

s = Smooth cone tip

fr = Cone tip with friction reducer

Table 4.4 Soil Parameters obtained from PPMT Tests using Two Different Cone Tips in Soft Clay Layer at 13.5 m (44.5 ft).

Smooth Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C5	2742	8025	405	307
D6	2762	8861	455	345
D2	3605	11611	445	353
C3	7233*	10368	420	205*
B4	2701	11982	455	346
B3	1970*	8511	450	339
B1	3001	9912	450	337
A2	1914	10507	425	342
AVG	**2962**	**10231**	**438**	**338**

Friction Reducer Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C6	3167	9404	430	312
B5**	/	/	/	/
D3	2592	10056	435	338
C4***	5397	10067	440	135
C2	2077	11236	435	343
B2	3191	12226	465	353
A6	3109	8155	430	326
A3	2277	10174	445	340
AVG	**2736**	**10208**	**440**	**335**

Parameter	E_{os}/E_{ofr}	E_{rs}/E_{rfr}	p_{Ls}/p_{Lfr}	p_{os}/p_{ofr}
Ratio	1.08	1.00	1.00	1.01

* Values not included in analysis because higher values found in sounding *C3* and lower values found in soundings *C3* and *B3*.
** Values not included in analysis because the leak was found at vent tube of the probe A1 after test.
*** Values not included in analysis because the probe B1 failed.
s = Smooth cone tip
fr = Cone tip with friction reducer

Table 4.5 Soil Parameters obtained from PPMT Tests using Two Different Cone Tips in Soft Clay Layer at 15 m (50 ft).

Smooth Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C5	3114	8841	470	357
D6	3576	11251	510	398
D2	3591	8585	500	398
C3	4195*	10657	470	264*
B4	3981	12612	480	379
B3	3480	10083	490	380
B1	3973	11245	490	393
A2	3398	10786	485	377
AVG	**3588**	**10508**	**487**	**383**

Friction Reducer Cone Tip				
Sounding #	E_o (kPa)	E_r (kPa)	p_L (kPa)	p_o (kPa)
C6	2878	9946	510	371
B5**	/	/	/	/
D3	3693	8277	500	393
C4***	6605	10967	480	150
C2	3691	11535	485	378
B2	3248	10991	485	381
A6	3390	9605	490	377
A3	2193*	9573*	485*	381*
AVG	**3380**	**10609**	**494**	**380**

Parameter	E_{os}/E_{ofr}	E_{rs}/E_{rfr}	p_{Ls}/p_{Lfr}	p_{os}/p_{ofr}
Ratio	1.06	0.99	0.99	1.01

* Values not included in analysis because higher values found in sounding *C3* and lower values found in soundings *C3* and *A3*.

** Values not included in analysis because the leak was found at vent tube of the probe A1 after test.

*** Values not included in analysis because the probe B1 failed.

s = Smooth cone tip

fr = Cone tip with friction reducer

4.2.1.1 Initial Elastic Moduli Analysis

The PPMT modulus, E_o, is calculated by using the slope of the straight-line portion of the PMT curve. The results of initial elastic modulus versus depth from PPMT tests using the smooth cone tip were compared to those with the friction reducer and were very similar (Figure 4.4). A slight but relatively constant increase in modulus occurs with depth throughout the soil profiles. At 10.5 m (34.5 ft), the high smooth cone value may be the result of testing silty fine sand, which is apparent in the CPT data.

The initial modulus, E_o, determined from PPMT tests with the smooth cone tip was found to be greater than the friction reducer cone tip by 6–10% for clays and 25–33% for sandy clay to fine sand. The graph indicates at 12–15 m (39.5–50 ft) the two sets of data coincide. This data is in soft clay, where there is no effect of using the friction reducer cone tip.

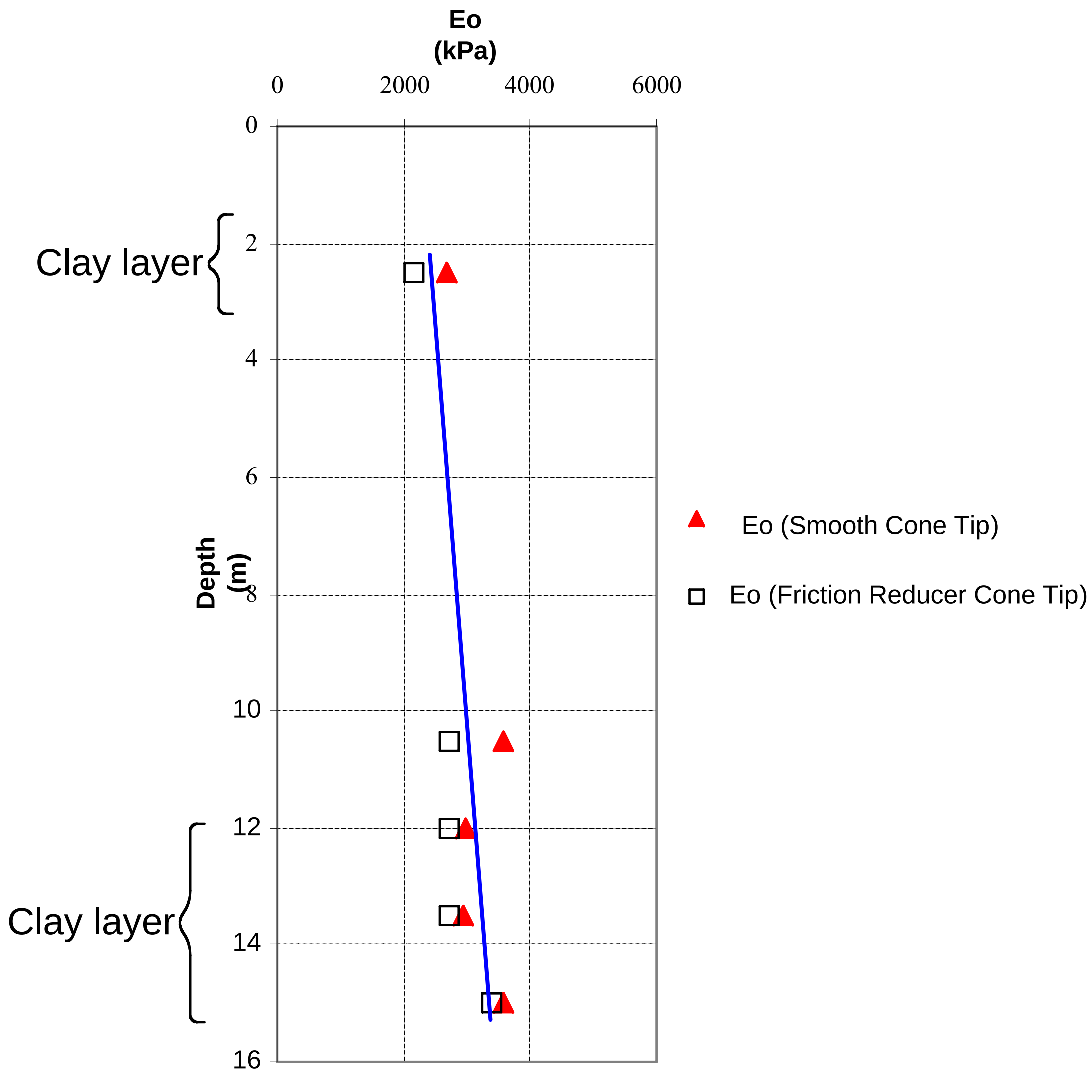


Figure 4.4 Average Initial Moduli versus Depth in clay using two different cone tips

4.2.1.2 Reload Moduli Analysis

The PMT reload modulus, E_r, was calculated from the straight-line rebound portion of the PMT curve. The reload modulus increased slightly with depth in the clays, from about 8,000 kPa to about 11,000 kPa, with the exception of a value near 40,000 kPa at 10.5 m (34.5 ft) as shown in Figure 4.5. Again, at the 10.5 m (34.5 ft) depth, values are high and could indicate loose silty fine sand. The graph pictorially shows minimal difference between the smooth cone or the friction reducer cone tip when analyzing the rebound moduli.

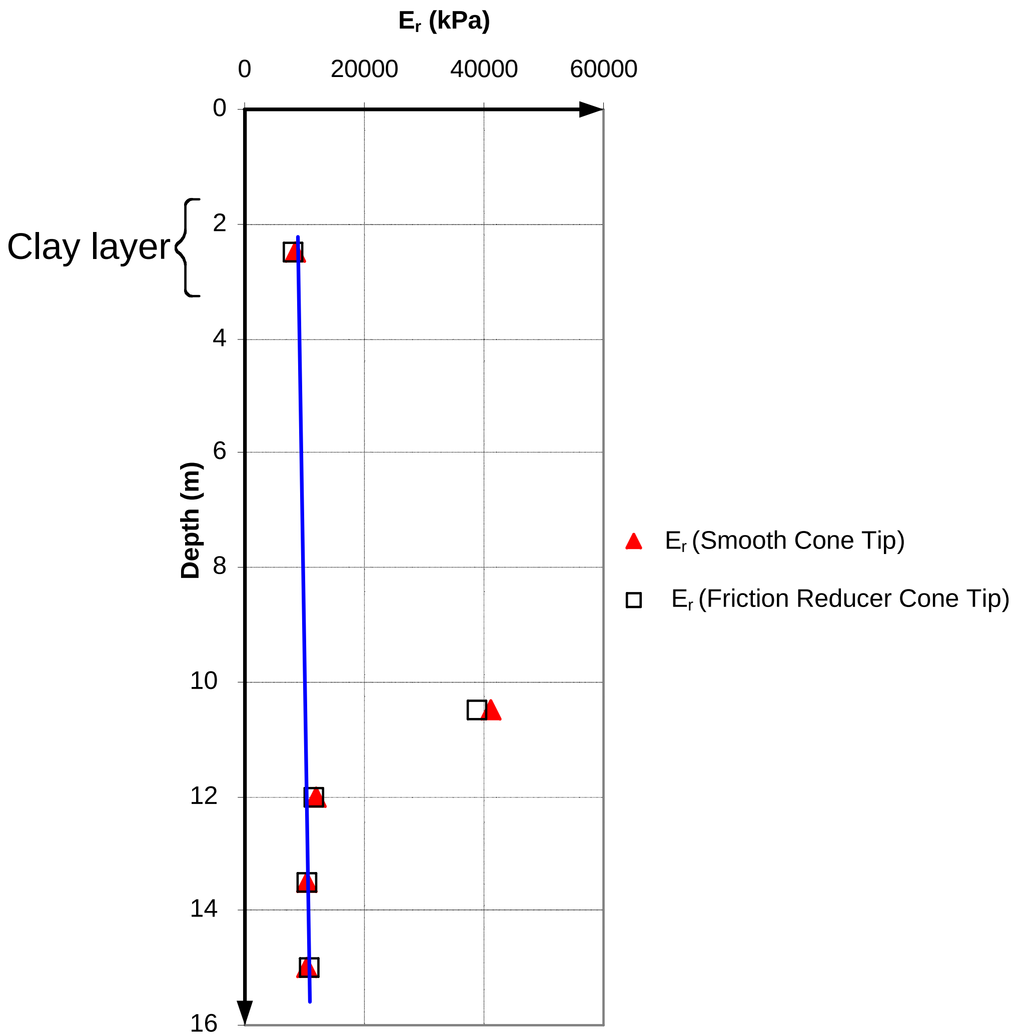


Figure 4.5 Average Reload Moduli versus Depth in clay using two different cone tips

4.2.1.3 Initial or Lift-off Pressures

The initial or lift-off pressure, p_o, corresponds to the pressure at which the probe contacts the borehole wall and balances the static earth pressure in the ground. This initial pressure indicates the first stress within the clay before the expansion of the PPMT probe occurs. Figure 4.6 shows the results of the PPMT lift-off pressure from both smooth cone and friction reducer tips. The data points drawn on this graph tend to vary linearly (Figure 4.6) and display a straight line passing through the origin, which indicates that the lift-off pressure in clays is linear and increases with depth. The results at 10.5 m (34.5 ft) are in silty sand and, therefore, do not follow the trend, which may be a result of the soil change. Both smooth and friction reducer cone tips results for the PPMT are very similar. Pictorially, there is very little difference between the lift-off pressures from PPMT tests conducted after insertion with either a friction reducer cone tip or smooth cone tip.

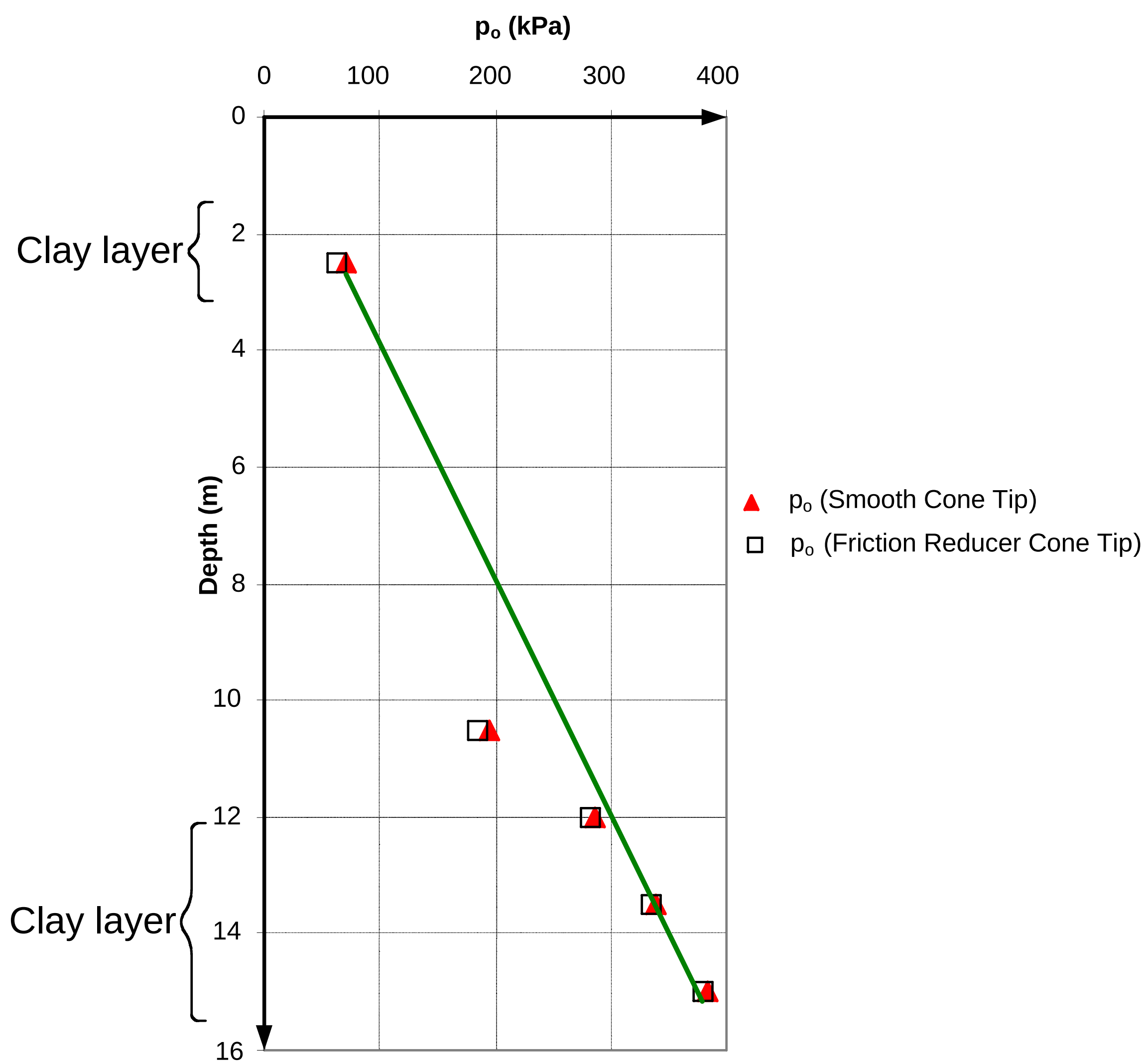


Figure 4.6 Lift-off Pressure versus Depth using two different cone tips

4.2.1.4 Limit Pressure

The pressure at which the cavity has doubled its volume is defined as limit pressure, p_L. The test cannot directly measure the limit pressure due to a limited water reservoir and the risk of damaging the tubing and the probe. In this case, the PPMT curve has to be extrapolated to estimate the limit pressure. These extrapolation results are summarized in Figure 4.7, and show that within the clay, the limit pressure linearly increased with depth. These values showed similar trends to the other parameters and again at 10.5 m (34.5 ft), the limit pressure is slightly higher, indicating this could be a different soil. Pictorially, no significant variation resulted between the limit pressures from PPMT tests conducted after insertion with either a friction reducer or smooth cone tip.

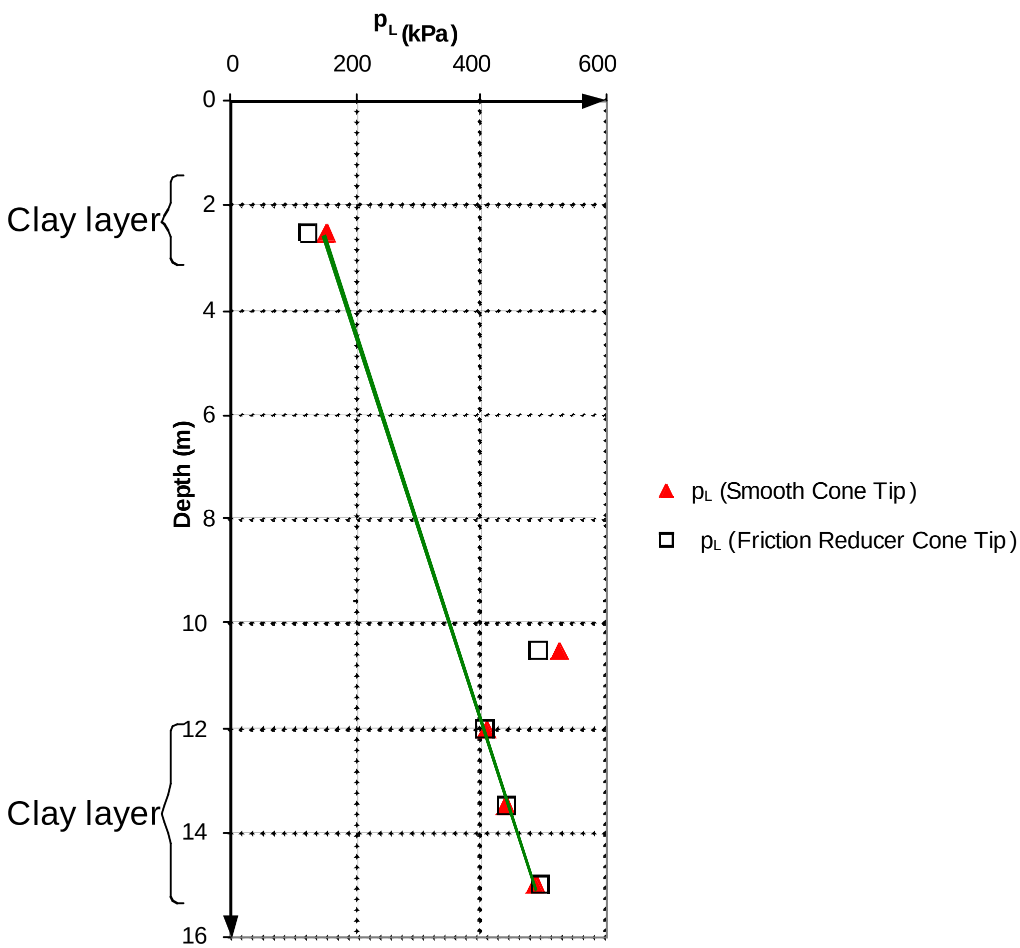


Figure 4.7 Limit Pressure versus Depth using two different cone tips

4.2.1.5 Statistical Analysis of Common PPMT Soil Parameters

Statistical analyses were conducted on the soil parameters to evaluate the performance of the two cone tips used to insert the PPMT. For both types of PPMT cone tips, the engineering parameters, standard deviation and coefficient of variation are summarized in Table 4.6. At about a 2.5 m (8 ft) depth, there is a statistical variation in the parameters, which is attributed to the nonuniform soil stiffness depicted in the CPT soil profiles (Appendix C).

Similar scatter in the rebound modulus was found for both cone tips in the fine sand and the clay layer. The COV was about 21% in the surface layer and 24% in the loose silty fine sand layer at 10.5 m (34.5 ft). COV values, about 11–15%, were found in the soft clay layers from 12–15 m (39.5–50 ft) deep.

Limit pressures in Table 4.6 show that COV from the smooth cone tip is greater than that from the friction reducer cone tip when tested in loose silty fine sand at 10.5 m (34.5 ft) and in soft clay at 12–15 m (39.5–50 ft). The opposite is true at the surface layer. There is also similar scatter in limit pressure in the clay layer from 12–15 m (39.5–50 ft) with either cone tip. Further, the COV in the limit pressure decreases with depth for both cone tips.

The COV for lift-off pressures shows large scatter for both cone tips. The friction reducer cone tip registered the higher COV, from 16% to 25%, almost twice that of the smooth cone tip, which ranged from 8% to 15%.

The variability of soil parameters found in the surface layer may indicate a change in soil type. In every case, the soft clay layer from 12–15 m (39.5–50 ft), produced higher COV values for the smooth cone tip, except in the case of the lift-off pressure, where the smooth cone tip COV is less than that of the friction reducer.

In summary, the limit pressure revealed the lowest COV and STD. The 10.5 m (34.5 ft) data shows the highest overall scatter for the moduli and limit pressures. There were no significant differences between data from the smooth and friction reducer cone tips. Six sets of data had approximately equal COV values, six had higher COV values for the smooth cone and eight had higher COV values for the friction reducer cone. In general, the largest COV values were associated with the initial moduli.

Table 4.6 Statistical Analysis of PPMT Soil Parameters using Two Different Cone Tips

Type Soil @ Depth	Statistical Parameters	E_o (kPa)		E_r (kPa)		p_L (kPa)		p_o (kPa)	
		Cone Tip Type							
		Smooth	Fri-Red	Smooth	Fri-Red	Smooth	Fri-Red	Smooth	Fri-Red
Soft Sandy Clay @ 2.5m	**AVG**	2680	2146	8610	8004	155	121	72	62
	STD DEV	340	522	1791	1670	14	18	11	15
	COV (%)	13	24	21	21	9	15	15	25
Loose Silty Fine Sand @ 10.5m	**AVG**	3592	2710	41254	38904	524	492	195	184
	STD DEV	1470	335	9809	8927	58	38	15	29
	COV (%)	41	12	24	23	11	8	8	16
Soft Clay @ 12m	**AVG**	2969	2710	11918	11501	411	406	285	282
	STD DEV	982	351	1614	847	15	18	23	48
	COV (%)	33	13	14	7	4	4	8	17
Soft Clay @ 13.5m	**AVG**	2962	2736	10231	10208	438	440	338	335
	STD DEV	1744	1101	1528	1293	20	12	49	77
	COV (%)	59	40	15	13	4	3	15	23
Soft Clay @ 15m	**AVG**	3588	3380	10508	10609	487	494	383	380
	STD DEV	358	1352	1425	1193	15	11	44	94
	COV (%)	10	40	14	11	3	2	12	25

Smooth = Smooth cone tip
Fri-Red = Cone tip with friction reducer

4.2.1.6 Cone Tip Comparison of Engineering Parameters

The results given in Tables 4.1 to 4.5 were converted into ratios of the engineering parameters to evaluate the effect of the cone tip. Both Table 4.7 and Figure 4.8 show the ratios. Table 4.7 shows the ratios of the parameters E_o, E_r, p_L, and p_o, obtained using the smooth cone tip to values obtained the friction reducer cone tip. These ratios generally decrease with depth.

At a depth of 2.5 m (8 ft), the results confirm the CPT information that the PPMT tests were performed in a variable soil. It was also shown that the smooth cone tip produced average ratios greater than those from the friction reducer cone tip. Specifically, the average E_o, E_r, p_L, and p_o, were 25%, 8%, 28% and 16% higher, respectively, from smooth cone tips than the same values from a friction cone tip. Based on this data, the smooth and friction reducer cones have the greatest effect on the initial modulus and the least effect on the rebound modulus.

In loose, silty fine sand at 10.5 m (34.5 ft), the ratio of smooth cone tip to friction reducer cone tip for E_o was about 1.33, while other ratios were about 1.06. From 12–15 m (39.5–50 ft), the data was very consistent, especially for the ratios associated with the rebound modulus, limit pressure and lift-off pressure.

The majority of the data shown in Table 4.7 indicate that the smooth cone produces higher engineering parameters from PPMT testing. This again suggests that the smooth cone causes less disturbance than the friction reducer, which would be expected.

Table 4.7 Soils Property Ratios obtained from PPMT Tests using Two Different Cone Tips.

Depth (m)	Parameters			
	$E_{o(smooth)}/E_{o(fri\ red)}$	$E_{r(smooth)}/E_{r(fri\text{-}red)}$	$p_{L(smooth)}/p_{L(fri\text{-}red)}$	$p_{o(smooth)}/p_{o(fri\text{-}red)}$
2.5	1.25	1.08	1.28	1.16
10.5	1.33	1.06	1.07	1.06
12	1.10	1.04	1.01	1.01
13.5	1.08	1.00	1.00	1.01
15	1.06	0.99	0.99	1.01

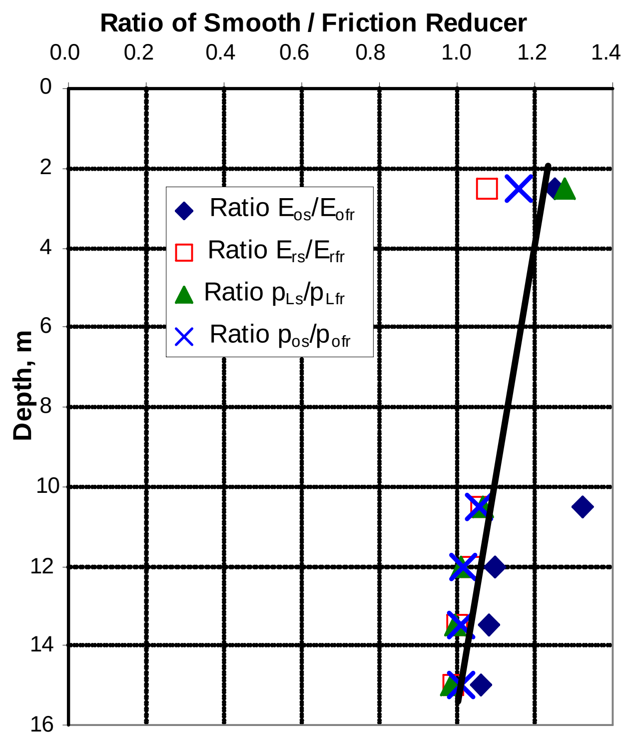


Figure 4.8 Variation of PPMT engineering properties versus depth for the smooth and friction reducer cone tip testing

The parameter ratios versus depth data presented in Figure 4.8 indicate the effect on all the engineering parameters is similar. As the test depth increases, the average ratio of the smooth cone tip to the friction reducer decreases, until it reaches a relatively constant value of one. This indicates that the effect of the friction cone or smooth cone tip for insertion in clays is minimized.

4.2.2 PPMT Soil Parameters and Common Values

An evaluation of the shapes of the PPMT curves shows that soft clays will generally exhibit a relatively sharp bend in the curve after the initial linear response and a distinct limit pressure as the curve levels off.

Table 4.8 presents the correlated results from various references relating point resistance, q_c, to elastic modulus, E_o, and to limit pressure, p_L. It includes correlations relating E_o to p_L from PPMT tests in clay at the Puerto Del Rio site and published values from Ménard and Rousseau (1962), Schmertmann (1978), and Bergado and A.Khaleque (1986). It is obvious that with either the smooth cone tip or the friction reducer cone tip the average ratio for E_o/p_L is still within the range of Ménard and Rousseau's published values of 6 to 16 (1962), while the average ratio for E_o/q_c was between 3 to 20 or 4.5 to 9 for clay or fine sand, respectively (Schmertmann, 1978; and Bergado and A. Khaleque, 1986), and the average ratio of q_c/p_L was about 1.5 to 6 (Schmertmann, 1978).

The values of initial moduli, E_o, and limit pressure, p_L, compare well to published ranges (Gambin and Rousseau, 1988). It was found that the soil at 2.5 m (8 ft) varies from silty sand according the CPT data in Appendix C, to clay according to the PPMT data, and at 12 m (39.5 ft), 13.5 m (44.5 ft) and at 15 m (50 ft) ranges, from soft silty clay to soft clay. At 10.5 m (34.5 ft) the soil is silty fine sand.

Table 4.8 Comparison between PPMT Data from Puerto Del Rio Clay Site and Published Data using Two Different Cone Tips

Depth	**E_o/p_L**			**E_o/q_c**			**q_c/p_L**		
(m)	**Smooth**	**Friction**	**Ref A**	**Smooth**	**Friction**	**Ref B & C**	**Smooth**	**Friction**	**Ref B**
2.5	16	14	6 to 16	19.4	12.4	3 to 20	1	1.1	1.5 to 6
10.5	8	6	↓	7.4	4.7	4.5 to 8.9	1.1	1.2	↓
12	8	6		5.7	4.1	↓	1.5	1.4	
13.5	7	8		5	5.2		1.5	1.5	
15	8	8		5.1	5.2		1.5	1.5	

Reference A Menard and Rousseau (1962)
Reference B Schmertmann (1978)
Reference C Bergado and Al Khaleque (1986)

Table 4.9 and Figure 4.7 show that the average ratio of E_r/E_o, based on test results in the soft clay, was approximately 3.4 using the smooth cone tip and 3.7 using the friction reducer. The E_r/E_o ratio was about 10 at 10.5 m (34.5 ft), corresponding to fine sand, according to Briaud (1992). These ratios compare well to published values of 1.5 to 5 in clay and 3 to 10 in sand (Briaud, 1992). Therefore, the common values of initial modulus, E_o, limit pressure, p_L, and the ratios of E_r/E_o, Eo/p_L, E_o/q_c and p_L/q_c can serve as indicators for soil identification (Briaud 1992).

Table 4.9 Ratio of Initial Moduli to Reload Moduli using Two Different Cone Tips

Depth (m)	**E_r/E_o** Smooth Cone Tip	Friction Reducer
2.5	3.21	3.73
10.5	11.48	14.35
12	4.01	4.24
13.5	3.45	3.73
15	2.93	3.14

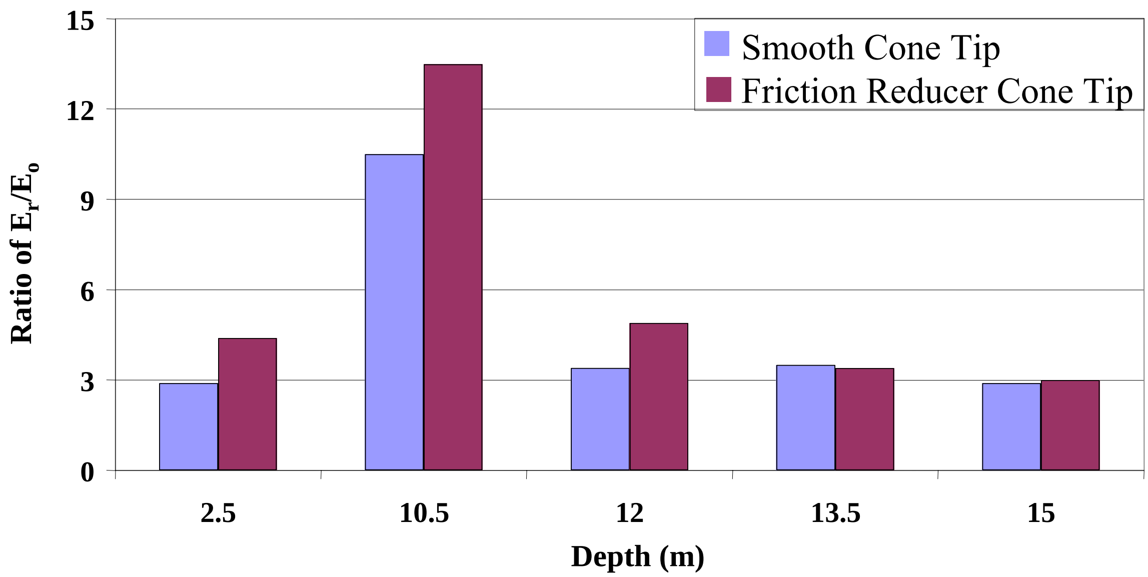


Figure 4.9 Ratio of initial moduli to reload moduli using two different cone tips

4.3 DMT Data Analysis

The properties determined from the DMT in Tables 4.10 and 4.11 were calculated using the Marchetti (1997) procedure. These parameters are used for comparison with PPMT–derived parameters. According to Marchetti, the soil can be identified using the material index, I_D. Based on this index, it was found that the soil layers are clay to silty clay. Table 4.10 shows the average elastic moduli ranged from 2,400 kPa at 2.5 m (8 ft), to 3,816 kPa at 12 m (39.5 ft). The elastic moduli from 10.5 m (34.5 ft) to 15 m (50 ft) are similar.

The standard deviation and COV for the initial moduli decrease with depth. Low values observed in soundings *A4* and *C1* compared to values in *D4* and *B6* at 2.5 m (8 ft), indicating that the soil may be variable in the upper layer.

Table 4.10 Elastic Moduli obtained from DMT Tests.

Depth (m)	Depth (ft)	E_o(kPa)				E_o avg (kPa)	STD. DEV	COV (%)
		DMT- Sounding #						
		DMT-*A4*	DMT-*C1*	DMT-*D4*	DMT-*B6*	DMT		
2.5	8	252 *	680 *	1868	2931	2400	752	31
10.5	34.5	4323	3531	2883	2696	3358	736	22
12	39.5	4410	4419	3104	3329	3816	698	18
13.5	44.5	2885	3802	2571	3380	3160	543	17
15	50	3101	3273	3129	3640	3286	248	8

* Values considered outliers and not included in analysis: DMT profile shows them as very soft muck

Table 4.11 shows that the average lift-off pressures range from 168 to 496 kPa. Lower values were encountered at a depth of 2.5 m (8 ft), than for the rest of the soil profile. The variations in the STD and COV are relatively small and indicate that the soil properties are consistent.

Table 4.11 Lift-off Pressure obtained from DMT Tests.

Depth (m)	Depth (ft)	p_o(kPa)				p_o avg (kPa)	STD. DEV	COV (%)
		DMT- Sounding #						
		DMT-*A4*	DMT-*C1*	DMT-*D4*	DMT-*B6*	DMT		
2.5	8	180	146	176	169	168	15	9
10.5	34.5	361	369	388	332	363	23	6
12	39.5	409	401	407	387	401	10	2
13.5	44.5	406	408	402	396	403	5	1
15	50	551	522	507	405	496	64	13

4.4 Comparison of PPMT and DMT Soil Parameters

The comparison between DMT and PPMT soil parameters was only based on initial moduli and lift-off pressures because the DMT data does not produce limit pressure or reload moduli. Ratios of the DMT to PPMT lift-off pressure and initial moduli were computed using PPMT data from Table 4.6 and average DMT values from Tables 4.10 and 4.11.

Examination of the ratios shown in Table 4.12 indicates two trends. First, the smooth cone tip results are lower than the friction cone tip results, and second, the lift-off pressure ratios are higher than the initial elastic moduli ratios. The lower smooth cone tip ratios again suggest that the smooth tip produces less disturbance than the friction reducer tip and the elastic moduli ratios suggest that moduli from these two tips may be comparable. The ratios associated with the lift-off pressures decrease with depth for both the smooth and friction reducer data.

Table 4.12 shows variations of DMT to PPMT lift-off pressures and initial modulus ratios in the upper layer, and consistency in the underlying layers. The ratios of DMT to PPMT lift-off pressures and DMT to PPMT initial moduli decrease with depth. This is not the case in the upper layer, where the E_o ratios for PPMT and DMT do not follow the trend, and again, this could be attributed to variations in the surface soil layer.

Table 4.12 Average Ratios of DMT to PPMT Lift-Off Pressures and Initial Elastic Moduli.

Depth (m)	DMT		PPMT				DMT / PPMT			
	p_o (kPa)	E_o (kPa)	p_o (kPa)		E_o (kPa)		p_o Ratio		E_o Ratio	
			Smooth	Fri-Red	Smooth	Fri-Red	Smooth	Fri-Red	Smooth	Fri-Red
2.5	168	2400	72	62	2680	2146	2.3	2.7	0.9	1.1
10.5	363	3358	195	184	3592	2710	1.9	2.0	0.9	1.2
12	401	3816	285	282	2969	2710	1.4	1.4	1.3	1.4
13.5	403	3160	338	335	2962	2736	1.2	1.2	1.1	1.2
15	496	3286	383	380	3588	3380	1.3	1.3	0.9	1.0

Schmertmann (1987) evaluated data from DMT and PMT tests and developed ratios between p_o and p_1 from DMT data, and p_L from PMT data. For clays, he suggests $p_o/p_L \approx 0.8$ and $p_1/p_L \approx 1.2$. These ratios were computed and are summarized in Table 4.13. In general, the p_o/p_L ratio in the table is larger than Schmertmann's reported value. However, the p_1/p_L ratios are relatively close to the reported value, with the exception of the data at the 10.5 (34.5 ft) depth. Recall that there are variable soil types at this depth and the data in the table may represent silty fine sand (Figure 3.11).

Table 4.13 Schmertmann (1987) Correlations Ratios of DMT to PPMT

Depth (m)	DMT		PPMT		Correlations DMT -PPMT			
	p_1	p_o	p_L (kPa)		p_o/p_L		p_1/p_L	
	(kPa)	(kPa)	Smooth	Fri- Red	Smooth	Fri- Red	Smooth	Fri- Red
2.5	192	168	155	121	1.08	1.39	1.24	1.59
10.5	452	363	524	492	0.69	0.74	0.86	0.92
12	505	401	411	406	0.98	0.99	1.23	1.24
13.5	498	403	438	440	0.92	0.92	1.14	1.13
15	588	496	487	494	1.02	1.00	1.21	1.19

4.4.1 Comparison of PPMT and DMT Lift-off Pressures

PPMT and DMT lift-off pressures are summarized in Table 4.14. The data at 10.5 m (34.5 ft) was eliminated so that only clays would be compared and plotted in Figure 4.10.

The plot shows that as the DMT lift-off increases, the PPMT lift-off pressures increase. Two trend lines were used to describe the data. A linear trend line indicates the data was offset at the origin by about 50 kPa while the one-to-one correlation line shows that the lift-off pressures from these two cone tips may be linearly related in clays.

Table 4.14 DMT and PPMT Lift-off Pressures using Two Different Cone Tips

Depth (m)	Soil Type	p_o (kPa)		
		DMT	PPMT	
			Smooth Cone Tip	**Friction Reducer**
2.5	Soft Sandy Clay	168	72	62
10.5	Loose Silty Fine Sand	363	195	184
12	Soft Clay	401	285	282
13.5	Soft Clay	403	338	335
15	Soft Clay	496	383	380

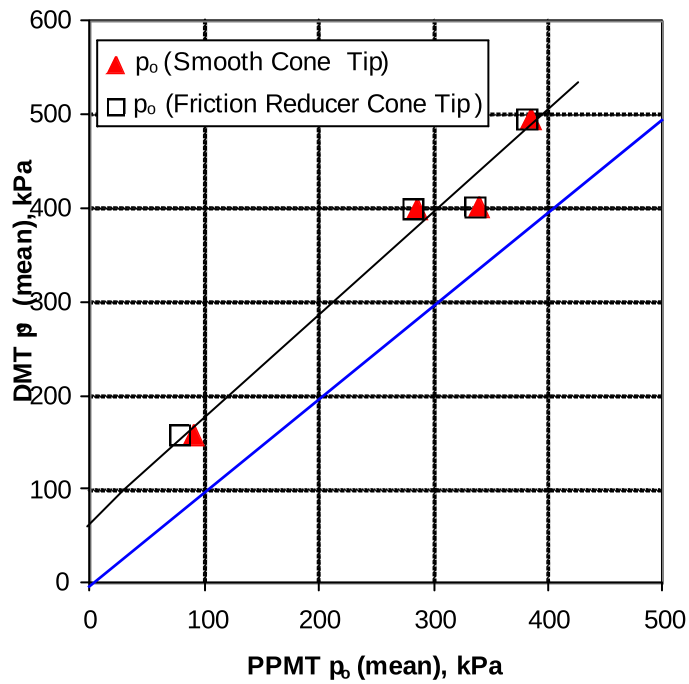


Figure 4.10 DMT versus PPMT lift-off pressures in Puerto Del Rio clay using two different cone tips

4.4.2 Comparison of PPMT and DMT Initial Moduli

The initial moduli from the DMT and PPMT are summarized in Table 4.15 and then plotted in Figure 4.11. A one-to-one correlation line was placed on the plot. The data from the 10.5 m (34.5 ft) depth was excluded so that only clay was compared. The data shows very little difference between data from the two insertion techniques when compared to the DMT moduli.

Table 4.15 DMT and PPMT Initial Moduli using two Different Cone Tips

Depth (m)	Soil Type	E_o (kPa)		
		DMT	PPMT	
			Smooth Cone Tip	**Friction Reducer**
2.5	Soft Sandy Clay	2400	2680	2146
10.5	Loose Silty Fine Sand	3358	3592	2710
12	Soft Clay	3816	2969	2710
13.5	Soft Clay	3160	2962	2736
15	Soft Clay	3286	3588	3380

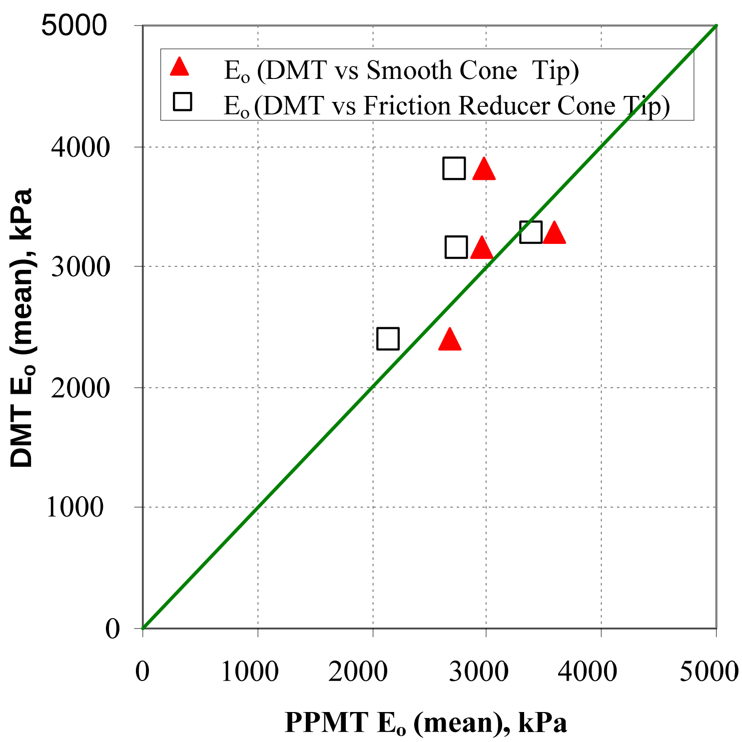


Figure 4.11 DMT versus PPMT initial moduli in clay using two different cone tips

4.4.3 Comparison of Initial Pressure and In-situ Vertical Stress

The DMT data included correlations to soil densities that were used to develop an effective stress profile versus depth. This data and the corresponding PPMT initial pressures were plotted in Figure 4.12. The PPMT data associated with the 10.5 m (34.5 ft) depth was excluded so that only clay was compared. Figure 4.12 shows that the initial PPMT pressures were from 4.3 to 4.8 times higher than the effective stress.

OCR values determined using the empirical DMT equations given in Chapter 3, are summarized in Table 4.16. Again, the 10.5 m (34.5 ft) data was excluded. The data associated with 2.5 m (8 ft) shows very larger OCR values. The variability of this layer, as shown from the CPT data in Appendix C and Figure 3.11 indicates the soil may change from clay silt to silty clay.

Comparing the OCR values to the ratio of PPMT lift-off to overburden stress indicates that the PPMT ratio is slightly higher. This correlation needs further study since more data may clarify any possible relationship that could exit.

Table 4.16 DMT Based OCR

DMT results using $OCR = (0.5*K_D)^{1.56}$				
Depth (m)	OCR			
	DMT- Sounding #			
	DMT-*A4*	DMT-*C1*	DMT-*D4*	DMT-*B6*
2.5	14	9	13	12
12	3	3	3	3
13.5	2	2	2	2
15	4	3	3	3

The trend lines in Figure 4.12 were used to determine a ratio of the PPMT initial pressure, p_o, to the effective stress σ_{vo}'. The soil unit weights used to determine effective stresses were obtained from DMT data. Consistent p_o/σ_{vo}' ratios between 4.3 and 4.8 were found, which are slightly larger than the DMT OCR values below 10.5m (34.5 ft). In conclusion, there may be a correlation between the PPMT p_o and OCR for soft clays.

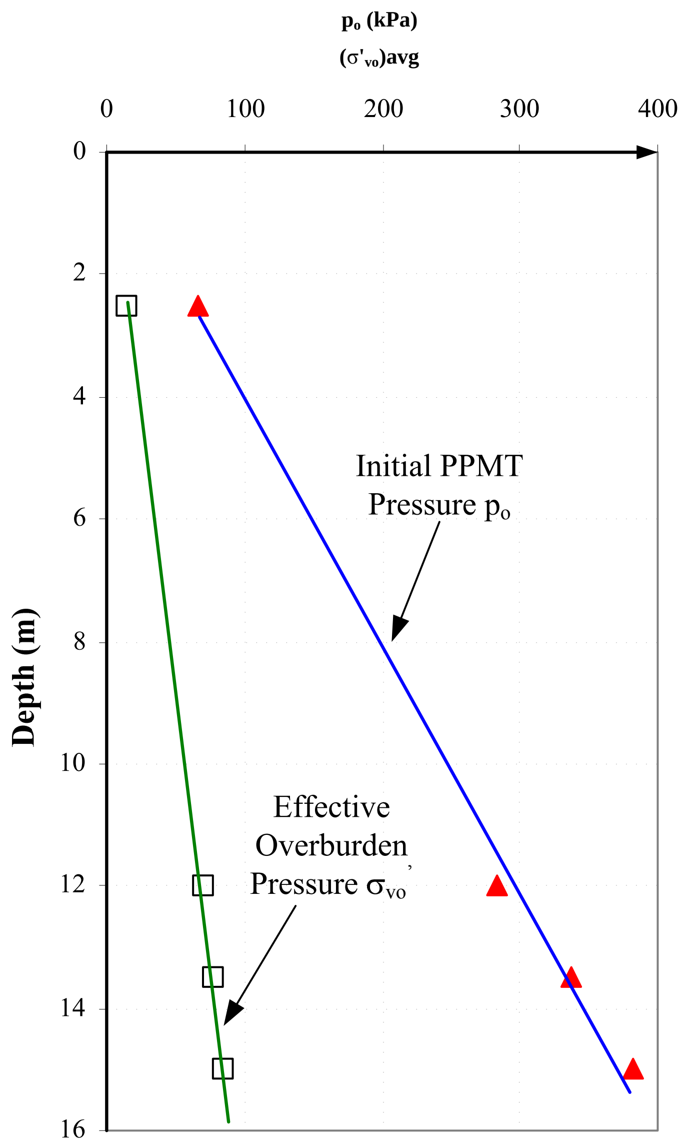


Figure 4.12 PPMT Initial Pressure, p_o, and Predicted In-situ Vertical Stress, σ_{vo}', versus Depth

4.5 Comparison between the Conventional and Instrumented Systems

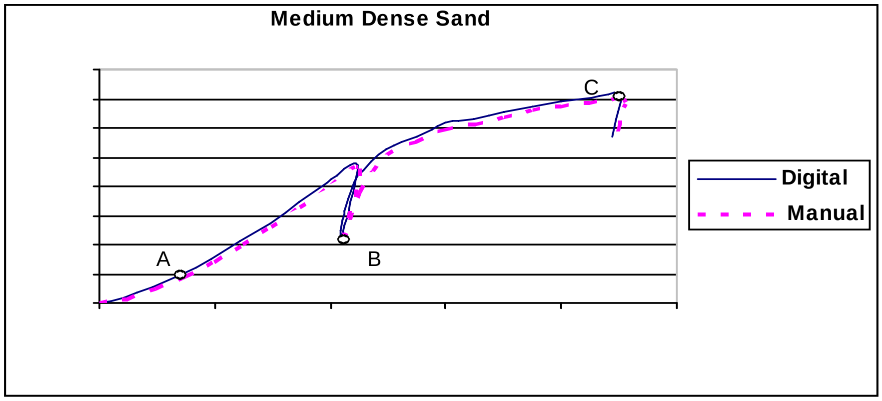
The conventional unit and the instrumented system were initially compared to evaluate the authenticity and accuracy of collected data, time taken to collect and reduce the data and time taken to reduce the field data to engineering parameters. Engineering parameters such as PMT modulus and limit pressures, VISP and operational errors, if any, were also compared.

Sixty PPMT tests were conducted at the Florida Tech and Puerto Del Rio sites in order to compare results from the conventional and instrumented systems in both sand and clay soils. Data from the remaining twenty tests conducted at the Archer Landfill site were recorded digitally without manual data collection and hence could not be used for comparison of the instrumented system.

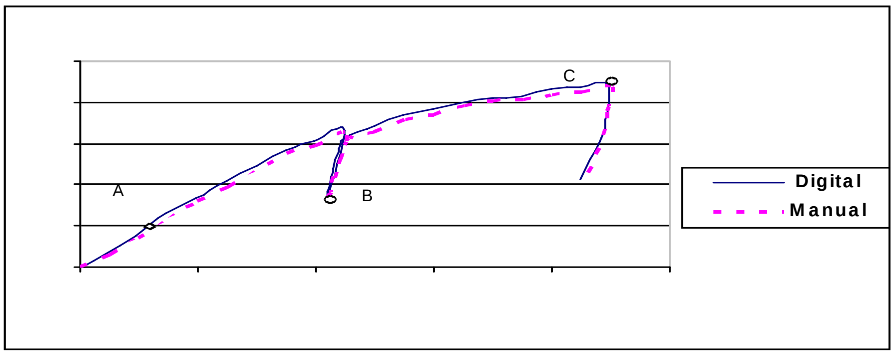
4.5.1 Accuracy of the Collected Data

The first field evaluation after completing the digital instrumentation was to identify the accuracy of data being collected with the digital instrument as compared to manual data recording. This comparison included collection of raw data from both conventional and instrumented systems. The graphs shown in Figure 4.13 (a), (b) and (c) are comparisons between raw pressure and volume data taken from the conventional and instrumented systems for three different soil types: a medium dense sand, a loose silty sand and a fat clay. It can be seen that there is a slight difference in the plots obtained from data collected by instrumented system (digital) and conventional system (manual). During the initial inflate and deflate period for 1.0 cm^3 shown on the volume counter, there is just 0.3 cm^3 water entering the probe. This error was shown during calibration. Three different points (A, B and C) on each curve represent three different pressures for each type of soil as shown in Figure 4.13 (a), (b) and (c). Points A, B and C signify, respectively, the initial stress exerted on the soil when the probe contacts the soil, stress condition during the reload condition and the ultimate stress exerted on the soil after which the soil begins to fail.

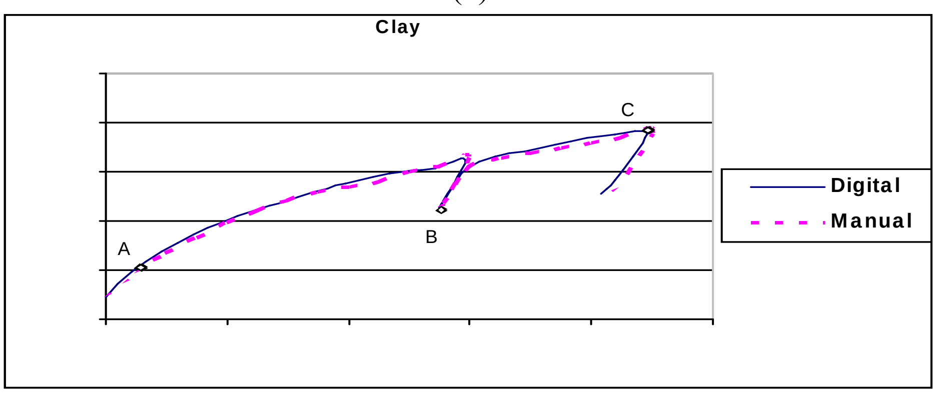
In Figure 4.13 (a) (medium dense sand), point A represents an initial pressure of 200 kPa, B represents the lower point of the reload curve with a pressure of 420 kPa and point C represents the maximum pressure of the curve, which is about 1,420 kPa. From Figure 4.13 (a) at point A, the volume recorded from the conventional gauge (manual reading) was 0.67 cm greater than the digital reading. At point B, the manual reading was 0.1 cm greater than the digital reading and at point C, the manual gauge reading was 0.71 cm greater than the digital reading. A similar behavior was observed with Figures 4.13 (b) and (c). Table 4.17 presents a comparison between the volume readings taken with the instrumented system (digital) and conventional system (manual) at these points (A, B and C). Table 4.17 shows that irrespective of the stress level at which the volume comparison was made; the change in volume at all three data points was similar. The percent change between the manual and instrumented digital systems is due to the backlash between mating gears in the system. Therefore, it is believed that digital data recording system yields a more accurate representation of the PPMT curve than the conventional PPMT system.



(a)



(b)



(c)

Figure 4.13 Comparison of raw pressure-volume data from PPMT conventional system (manual) and instrumented system (digital) conducted at Florida Tech and Puerto Del Rio (a) medium dense sand; (b) loose silty sand; (c) clay

Table 4.17 Summary of the volume comparison between the instrumented system and conventional system at three specific points A, B and C on the pressure versus volume curves for each type of soil.

Figure	Soil Type	Pressure (kPa)	Point	Manual Volume (cm^3)	Digital Volume (cm^3)	Difference in Volume (cm^3)	% Error
4.11(a)	Medium Dense Sand	200	A	15	14.33	0.67	4.47
		420	B	42	41.88	0.12	0.29
		1400	C	90	89.31	0.69	0.77
4.11(b)	Loose Silty Sand	115	A	15	14.34	0.66	4.40
		160	B	42	41.87	0.13	0.31
		440	C	90	89.30	0.70	0.78
4.11(c)	Clay	50	A	5	4.36	0.64	12.80
		110	B	55	54.86	0.14	0.25
		220	C	90	89.30	0.70	0.78

The APMT software allows the engineer to select the points on the PPMT curve to obtain the initial and reload slopes S_i and S_r (Figure 3.1). Equations given in Chapter 2 can be used to calculate a corresponding elastic modulus. For the calculation of the limit pressure of the soil the software uses the last two digitally recorded data points from the PMT curve and extends it to the required volume (≈180 cm^3) representing $p_{L(max)}$. A third or lower line is drawn parallel to the volume axis from the last point of the PMT curve and yields $p_{L(min)}$. The average of $p_{L(max)}$ and $p_{L\ (min)}$ yields the estimated limit pressure (p_L) of the soil. The engineering parameters obtained digitally and manually for three soils are shown in Table 4.18 (Cosentino et al 2006).

Table 4.18 Comparison between the engineering parameters obtained digitally and manually for three soils.

Type of Soil	Average Engineering Parameters	Manual (kPa)	Digital (kPa)	Difference (Digital-Manual) (kPa)	% Difference
Medium Dense Sand	E_o	14,617	14,972	355	2.43
	E_r	132,286	186,553	54,267	41.02
	p_L	1,436	1,433	-3	-0.21
Loose Silty Sand	E_o	5,230	6,256	1,026	19.62
	E_r	34,216	37,002	2,786	8.14
	p_L	432	433	1	0.23
Clay	E_o	1,876	2,338	462	24.63
	E_r	5,161	5,321	160	3.10
	p_L	140	142	2	1.43

In Table 4.18, the initial and rebound moduli obtained digitally are greater than those obtained manually. The elastic modulus of a soil depends on slope of the curve. Since the manual system volume is usually 0.7 cm^3 greater than the digital volume at the same pressure; the conventional modulus is less than the instrumented modulus. These produce moduli slightly higher for E_o and significantly higher for E_r. Both E_o and E_r determined by the digital system should be evaluated to determine if they are more representative of the actual soil parameters. The rebound modulus is used in several areas, specifically analysis and design of laterally loaded piles (Robertson et al, 1986). The values of limit pressure p_L are very similar for both the systems, as the small volume change is insignificant in calculating the limit pressure.

4.5.1.1 Time for Field Testing

Reducing time to complete PMT field testing and data evaluation is always desired by the engineer. This includes the time to drill a bore-hole, collect and record data, enter data points into a software application and obtain the reduced data. The data reduction would be typically conducted in the office by the engineer after field data collection. Once the reduced data is obtained, further calculations and engineering judgment produce the initial modulus, rebound modulus and limit pressure.

FDOT has reduced testing time for the PPMT by pushing the PMT probe rather than drilling the borehole. With instrumentation of the PMT, additional time is saved during the testing procedure, including time taken for data collection, data reduction and determination of engineering parameters. Table 4.19 exhibits a comparison between estimated times necessary to conduct specific tasks during tests with the two systems.

Table 4.19 Comparison of test time to conduct a conventional PMT and instrumented PMT per test.

	Estimated Time per Task	
Task	**Manual Control Unit**	**Instrumented Control Unit**
Collect Data	Time to read and record; 5 min	Automatically Recorded
Data Transfer and Reduction	25 minutes	Performed during test
Evaluate Engineering Parameters	20 minutes	10 minutes
Total	50 minutes	10 minutes

From the tasks shown in Table 4.19 it can be seen that the instrumented system saves about 40 minutes per test for these few selected tasks. It allows the engineer to field evaluate the test results and determine if the data collected is reasonable. The instrumented system saves time both in the field for data collection and removes the need for office processing of the field data and the preparation of report, thereby saving valuable additional time.

4.5.1.2 Volume Increment Stabilization Period

During the VISP, the pressure decreases with respect to time as the soil relaxes and becomes relatively constant. The APMT software allows the operator to evaluate the pressure versus volume data automatically for each increment.

The software within APMT checks the pressure reading corresponding to time, while the values are shown on the screen. When the pressure becomes constant with time APMT is programmed to automatically store the data in a specified file. Once the data is recorded, a green light signals that the operator can proceed to the next reading.

With the conventional PPMT it is difficult to select the correct VISP for different soils and different sites. A common value of 15 seconds for sands and 30 seconds for clays is typically used by the operator (Cosentino, 1987; Cosentino et al, 2006).

Using the instrumented system it was found that the VISP may vary from 10 to 80 seconds for different soils. A typical plot of pressure versus time at a selected volume for loose silty sand is shown in Figure 4.14. The pressure reading corresponding to a VISP of 15 seconds is 470 kPa, and the reading when the pressure is relatively constant or a VISP of 80 seconds is 435 kPa. This would produce an 8% difference in pressures.

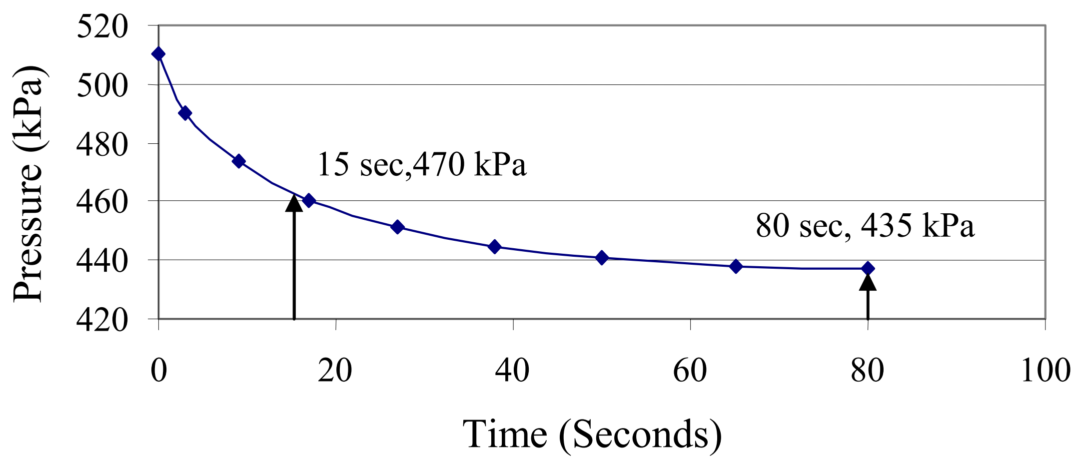


Figure 4.14 Pressure versus time at a selected volume in loose silty sand.

Testing in sands and clays at the three sites was used to produce VISP histograms. The histograms were used and a summary table was prepared showing the VISP range, average and standard deviation for each soil type. These results are summarized in Table 4.20.

Table 4.20 VISP Summary from various soils tested

Site	Soil Type	VISP (Seconds)		
		Range	**Average**	**Standard Deviation**
Archer Landfill	Silty Clay	20-60	26.1	7.4
	Silty sand	20-60	26.1	7.4
	Sand to silty sand	20-40	33.5	8.3
Puerto Del Rio	Clayey-silt	30-50	43.9	5.7
	Clay	30-60	46.3	6.8
	Clay	30-70	48.1	6.9

Preliminary testing was performed at the FIT site which enabled improvements in the APMT software when it was used at the Archer and Puerto Del Rio sites. For the Archer Landfill site, the VISP for the silty clay was 26 seconds with a standard deviation of 7.4 second which is close to the standard 30 second recommended for clay. The next two layers have an average VISP of 26 seconds for silty sand with standard deviation of 7.4 seconds and 33 seconds for fine grained silt with a standard deviation of 8.3 seconds. The average VISP for these two layers are greater than the recommended value of 15 seconds for sands.

For the Puerto Del Rio site the average VISP in the clayey silt was about 44 seconds and the standard deviation was about 6 seconds, for the Clay the average VISP was about 47 seconds and the standard deviation was about 7 seconds. These values are significantly larger than the 30 seconds recommended by Roctest in their 2005 Manual.

4.6 Comparison of Predicted p–y Curves from PPMT and DMT Data

Although no lateral load pile testing was conducted in conjunction with the research, a generic set of p–y curve comparisons was developed, assuming a 60 cm (24 in) diameter pile would be installed at the Puerto Del Rio site to a depth of at least 15m (50 ft). Because FDOT currently recommends the p–y approach developed by Robertson et al (1986, 1989), the approaches were used in the comparison.

The p–y curves derived from PPMT and DMT tests at this site are shown in Appendix D. The comparison between DMT and PPMT p–y curves was based on the slope of the initial portion of the curve, the ultimate soil resistance and the curve shape.

Figures 4.15, 4.16 and 4.17 present typical p–y curves derived from DMT soundings, PPMT soundings from both the smooth cone tip and the friction reducer cone tip, in the soft clay layer at 12 m (39.5 ft). The DMT-based equations are a cube root polynomial that will follow an increasing curve shape, while the PPMT-based equations will follow the same shape as the reduced PPMT plot. These trends are shown in the figures. Visually, the results show the initial slope from DMT data may not match the slope from PPMT data. However, the ultimate capacities are similar. The data from 12 m show ultimate capacities ranging from 0.438 kN/m to 0.482 kN/m (2.5 kips/in to 2.75 kips/in) and initial slopes from approximately 2,590 kN/m^2 to 4,430 kN/m^2 (4.5 kips/in^2 to 7.7 kips/in^2).

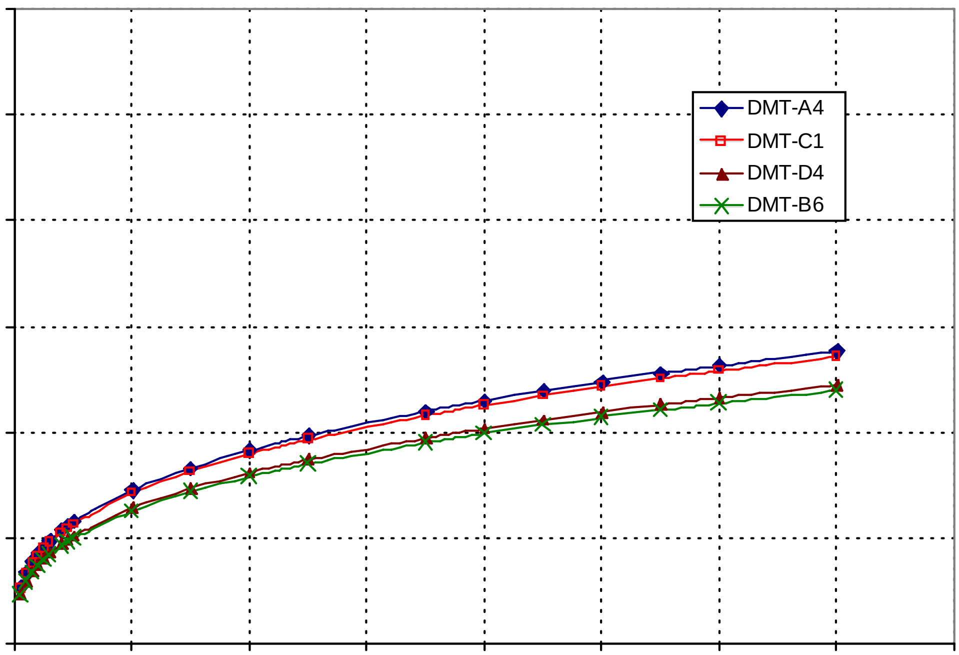


Figure 4.15 DMT p–y curves from 12 m (39.5 ft) soft clay layer with 60 cm (24 in) pile diameter based on Robertson et al (1989) method

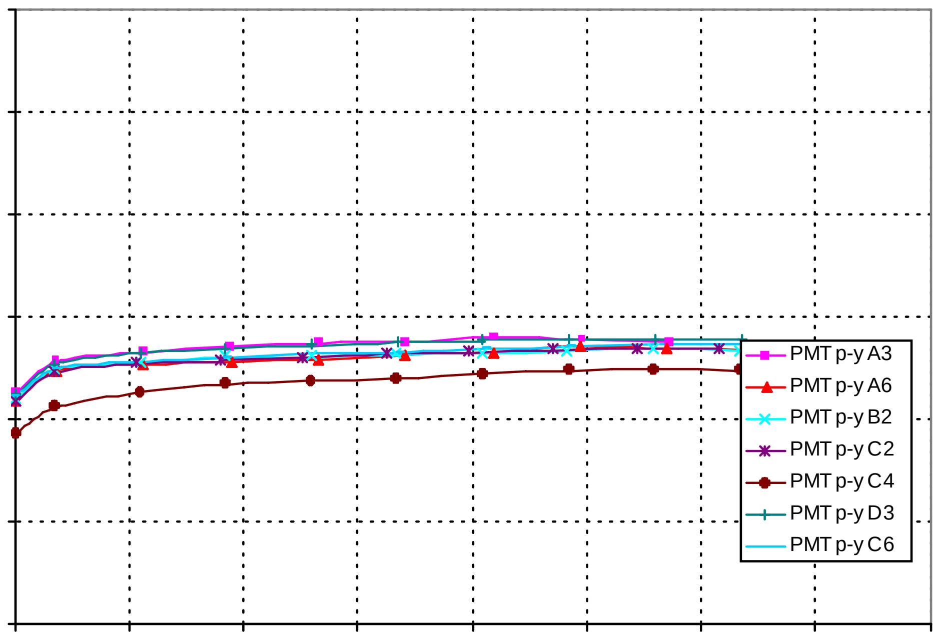


Figure 4.16 PPMT p–y curves, using friction reducer cone tip, from 12 m (39.5 ft) soft clay layer with 60 cm (24 in) pile diameter based on Robertson et al (1986) method

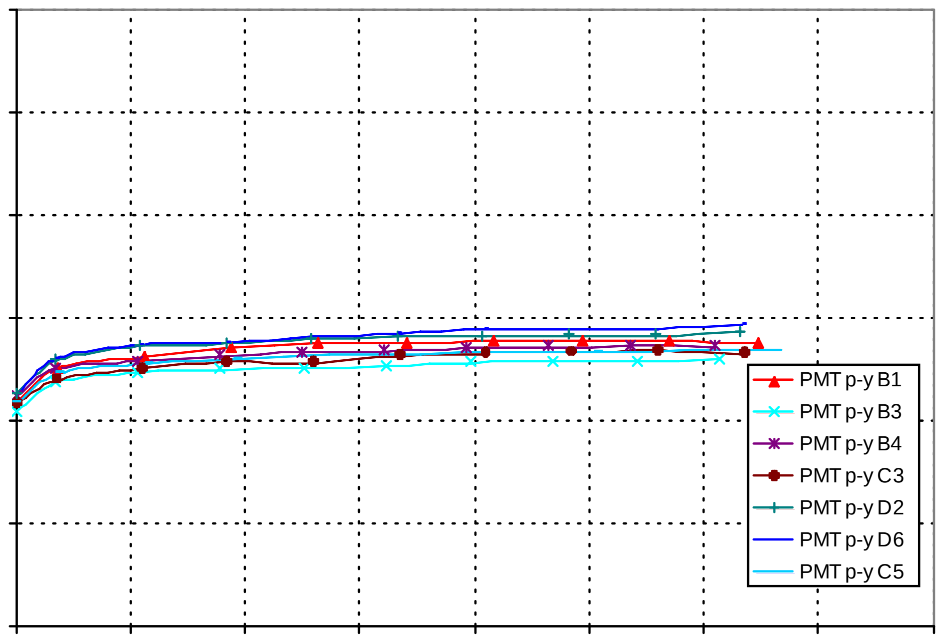


Figure 4.17 PPMT p–y curves, using smooth cone tip, from 12 m (39.5 ft) soft clay layer with 60 cm (24 in) pile diameter based on Robertson et al (1986) method

Robertson's et al (1989) proposed DMT method relies on several empirical correlations and proper estimation of key soil parameters. In clays, the major soil parameters are S_u and E_i. At small pile deflections, the most important parameter is the stiffness, E_i. The proposed analysis is therefore sensitive to changes in E_i. For clay, the critical pile deflection, y_c, is inversely proportional to E_i.

Based on the literature, both the PPMT and DMT p–y curves rely on estimating the ultimate load, P_u. The ultimate loads are defined as P_{u1} and P_{u2}, which are termed the lower and higher ultimate loads, as seen in Figure 4.18. The lower ultimate load is determined at the end of the straight-line portion of the p–y curve, representing the end of the elastic soil response. The higher ultimate load is defined as the intersection of the elastic–plastic response of the soil. Therefore, P_{u2} is found when the extension line the elastic portion meets the plastic portion of the curve, as seen in Figure 4.18. The maximum ultimate load is defined as P_{u1}, which correspond to the end of the elastic phase of the soil. At this point deformation of the soil is irreversible and failure results. The slope, k_s, is determined from the difference between the ultimate soil resistance, P_{u1}, and lift-off pressure, p_o, of the elastic phase of the soil to the deflection, y_1.

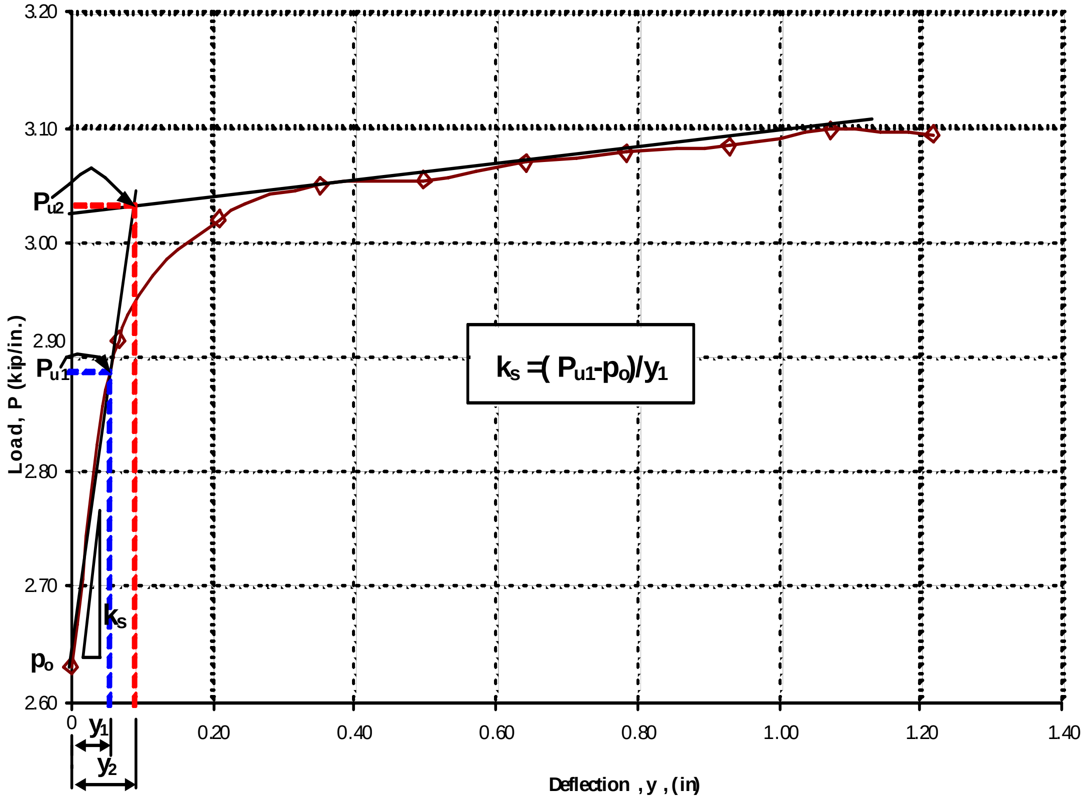


Figure 4.18 Depiction of ultimate loads P_{u1} and P_{u2} and the corresponding lateral defections in soft clays

Table 4.21 presents comparisons of the initial slopes and ultimate loads. The initial slopes were determined by constructing tangents through the average initial slopes of the p–y data presented in Appendix D and the average ultimate loads were determined from the p–y curves at one-inch deflection. The values shown for the initial slopes show several trends. First, the 10.5 m (34.5 ft) data produced higher values than the other layers due to the influence of the sandy layer at this depth (Figure 3.11). Second, the DMT slopes in the lower clay layers at 12–15 m (39.5–49.5 ft) are somewhat higher than the corresponding slopes from either PPMT test. Third, the slopes have a much higher variability than the ultimate loads, as evidenced by the standard deviations in the table. The ultimate loads for all depths were fairly similar. The data in this table was also used to determine ratios, which could be evaluated to further clarify the findings. This data is shown in Table 4.22. Again, the initial slopes showed higher variability and the ultimate loads were more consistent.

Table 4.21 Comparison of Average Initial Slope and Average Ultimate Loads at One-Inch Deflection from DMT and PPMT p–y Curves

Depth (m)	Initial Slopes DMT ($Kips/in^2$)	Initial Slopes PPMT Friction Cone ($Kips/in^2$)	Initial Slopes PPMT Smooth Cone ($Kips/in^2$)	Ultimate Loads DMT (Kips/in)	Ultimate Loads PPMT Friction Cone (Kips/in)	Ultimate Loads PPMT Smooth Cone (Kips/in)
2.5	3.43	3.83	3.5	0.95	0.95	1
10.5	16	14	16	4.4	3	3.3
12	7.5	4.7	4.1	2.3	2.7	2.75
13.5	6.1	3.9	3.4	2.2	3	3
15	10	2.9	3.5	2.75	3.3	3.3
Average	**8.61**	**5.87**	**6.10**	**2.52**	**2.59**	**2.67**
Std Dev	**4.8**	**4.6**	**5.5**	**1.2**	**0.9**	**1.0**

Table 4.22 Ratios of Average Initial Slope and Average Ultimate Capacities at One-Inch Deflection from PPMT and DMT p–y Curves

Depth (m)	Initial Slopes $DMT/PPMT_{fr}$	Initial Slopes $DMT/PPMT_{sm}$	Ultimate Loads $DMT/PPMT_{fr}$	Ultimate Loads $DMT/PPMT_{sm}$
2.5	0.90	0.98	1.00	0.95
10.5	1.14	1.00	1.47	1.33
12	1.60	1.83	0.85	0.84
13.5	1.56	1.79	0.73	0.73
15	3.45	2.86	0.83	0.83
Average	**1.73**	**1.69**	**0.98**	**0.94**
Std Dev	**1.0**	**0.8**	**0.3**	**0.2**

Fr= friction reducer insertion process
Sm=smooth cone insertion process

4.6.1 Conventional Pushed PPMT Testing Times

Conventional PPMT testing for each sounding, which included five PPMT tests at 2.5 m (8 ft), 10.5 m (34.5 ft), 12 m (39.5), 13.5 m (44.5 ft) and 15 m (50 ft), required an average time per sounding of 1.65 hours and five soundings per day. This time includes about 10 minutes for each PPMT test to record the data, three minutes to deflate the probe and the remaining time for pushing rods into the ground. A summary of the time for each test and sounding is shown in Appendix A. At each depth, the PPMT probe was expanded into the soil by injecting water and recording the data after waiting 15 seconds for the system to stabilize. The extent of the linear stress–strain response range was determined during the test in order to perform an unload–reload cycle.

4.6.2 Length-to-Diameter Ratio Evaluation

The L/D probe evaluation included changing the membrane lengths from the standard 24.1 cm (9.5 inches) to 30.48 cm (12 inches) and inflating the probe as the diameter readings were taken, then evaluating the volume calibration data. The data from the laboratory evaluation of the membrane was inconclusive because the original diameter of the probe could not be maintained from one length to the next.

An engineering evaluation of this problem was performed and it was concluded that changing the length of the membrane would result in questions about all PPMT data, which is beyond the scope of this current research. These questions would include the following;

1) The reliability of the limit pressure would be questioned and comparisons between different length probes would require extensive laboratory testing under controlled conditions, analytical analyses and field verifications.
2) The basic theory used to predict the elastic parameters from the cylindrical expansion of an infinitely long cavity would have to be updated. When the L/D ratio changes, the probe may or may not experience this cylindrical expansion.
3) Increasing the L/D ratio would require significant redesigns of the rubber probe with metal sheathing. The longer probe would be more likely to leak and fail from the stresses during pushing. Improved seals would have to be developed along the probes' metal core.

An evaluation of the volume calibration indicates that there may be a significant volume loss associated with the existing protective sheathing. This sheathing deforms easily and would indicate system expansion during the calibration process. Also the same sheathing is used on both the PPMT and the larger Texam or Ménard probes. The metal forms a ring around the rubber membrane and if unchanged would be significantly stiffer as the diameter of the probe decreased. This sheathing should be evaluated separately and possibly softened. This softening could be achieved if the metal strips were narrowed from the exiting 6 mm width to maybe 3 mm. The softer protective probe may undergo more failures during pushing, but it may also lead to a more realistic cylindrical expansion of the smaller probe.

4.7 Examination of p–y Curves from PPMT, DMT and Instrumented Piles

4.7.1 Background

The primary objective of this portion of the research program was to develop p–y curves from PPMT and DMT data and compare these curves to those developed from instrumented piles subjected to lateral loads. Seven case histories with PPMT and DMT tests performed prior to a lateral load test (LLT) were examined. Data from the PPMT and DMT testing is presented in Appendix A and B, respectively. This data was reduced and used to develop p–y curves for an analysis using the program FB-MultiPier (Hoit et al, 1997). The PPMT and DMT data was evaluated and the results of the load test simulations were plotted against the measured load test results to determine the quality of p–y curves (Cottingham, 2006).

Townsend et al, (1996) concluded that p–y curves derived from strain gauge or slope inclinometer measurements were the most accurate and efficient methods for determining load transfer.

4.7.2 Summary of Lateral Load Test Case Histories

There are seven case histories outlined below, where a full suite of soil in situ tests were performed along with a LLT. Six LLTs were conducted as design phase static lateral load tests, with the exception of the Statnamic LLT, conducted at the East Pascagoula River Bridge, Pascagoula, Mississippi. The cases are:

1) Roosevelt Bridge, Stuart, Florida
2) US 17 Bypass, Wilmington, North Carolina
3) Rio Puerto Nuevo, San Juan, Puerto Rico
4) Salt Lake City International Airport, Salt Lake City, Utah
5) East Pascagoula River Bridge, Pascagoula, Mississippi
6) Auburn NGES, Opelika, Alabama
7) Broadway Bridge, Daytona Beach, Florida

The load tests were separated into the following categories: piles and drilled shafts, as well as cohesionless and cohesive soils. Of the seven tests, three are on drilled shafts (Pascagoula, Auburn and Broadway) and the remaining four are on piles (Roosevelt, Wilmington, Puerto Nuevo and Salt Lake City). Of the soils tested, four are predominantly cohesionless (Roosevelt, Wilmington, Auburn and Broadway) and three cohesive (Pascagoula, Puerto Nuevo and Salt Lake City).

Based on the load-test geometry and subsurface conditions, these LLT case histories were thoroughly evaluated to produce p–y curves, load-deflection curves and FB-MultiPier predictions. The raw PPMT and DMT data obtained, as part of the geotechnical investigation for each site, is included in Appendix A and B, respectively. For each case, p–y curves were developed using methods published by Robertson et al (1985 and 1989) for PPMT and DMT, respectively. These curves are presented in Appendix D. Finally, the results of each test are compared and conclusions made.

Inspection of the reduced PPMT shows the following testing concerns:

1) Tests were carried out to several final volume levels, which varied from about 30 to over 100 cm^3.
2) Testing at the Roosevelt Bridge did not include an unload–reload loop which is recommended when the data is to be used for laterally loaded pile design or analysis.
3) The unload–reload loops were not conducted consistently during the testing. It is typically recommended that these loops be performed at the end of the linear portion of the stress–strain response from the final pressure in the linear range to half of that pressure.

4) Unloading data was included for six of the seven sites. Once the final volume was reached, however, the unloading sequence varied from test to test. There was no unloading data from the Roosevelt Bridge project.

5) No information is provided on how the PPMT was installed or if a friction reducer was used.

4.7.3 Roosevelt Bridge: Stuart, Florida

A submerged 4-by-4 free-head pile group consisting of 762 mm (30 in) square pre-stressed concrete piles was laterally loaded by FDOT as part of a test program for the construction of a new bridge over the St. Lucie River. The 16 piles in this group were numbered and arranged as shown in Figure 4.19. Prior to installation, Pile 1 was instrumented with strain gauges from 2.13 m to 8.53 m (7 ft to 28 ft) from the top of the pile. Following the tests on the pile group, an additional load test was performed on Pile 9, by pushing it in the opposite direction of the group load test shown in Figure 4.19 (Ruesta and Townsend, 1997). The loading details on Pile 9 are presented in Figure 4.20.

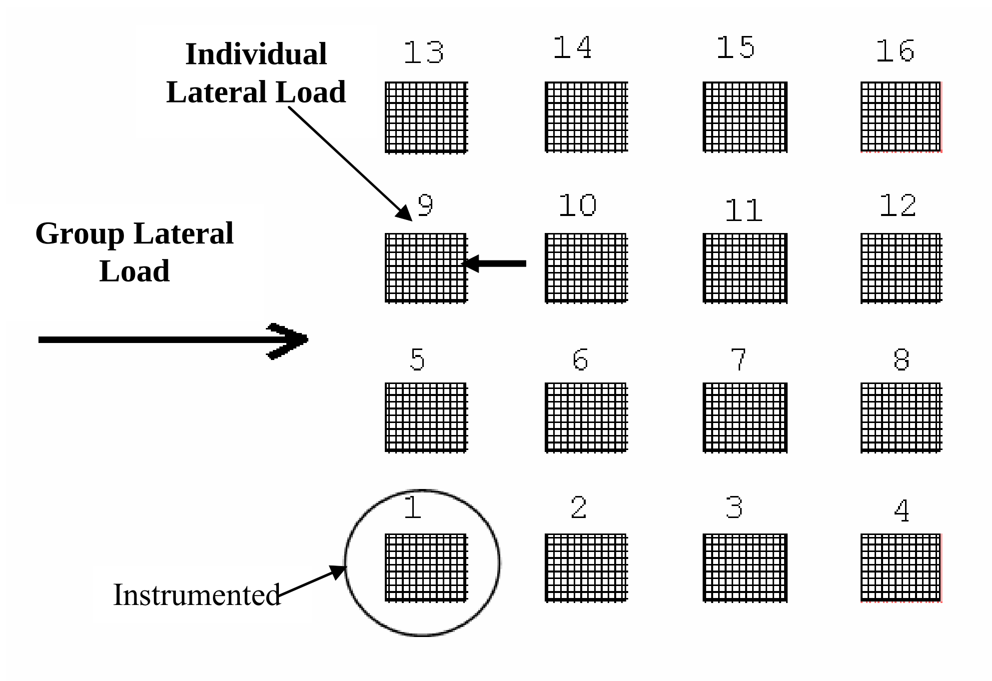
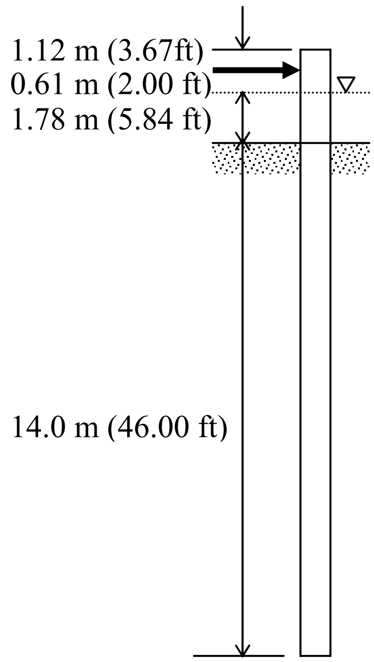


Figure 4.19 Schematic of 16 Piles at Roosevelt Bridge



Length: 17.5m (57 ft)
Type: Square, Pre-stressed
Width: 762mm (30 in)
Void: 457mm (18 in), circular
Material Properties:
Concrete:
f'_c = 44.8 MPa (6.5 ksi)
E_c = 31.7 GPa (4,600 ksi)
Steel:
f_y = 275.7 MPa (40 ksi)
E_s = 200 GPa (29,000 ksi)

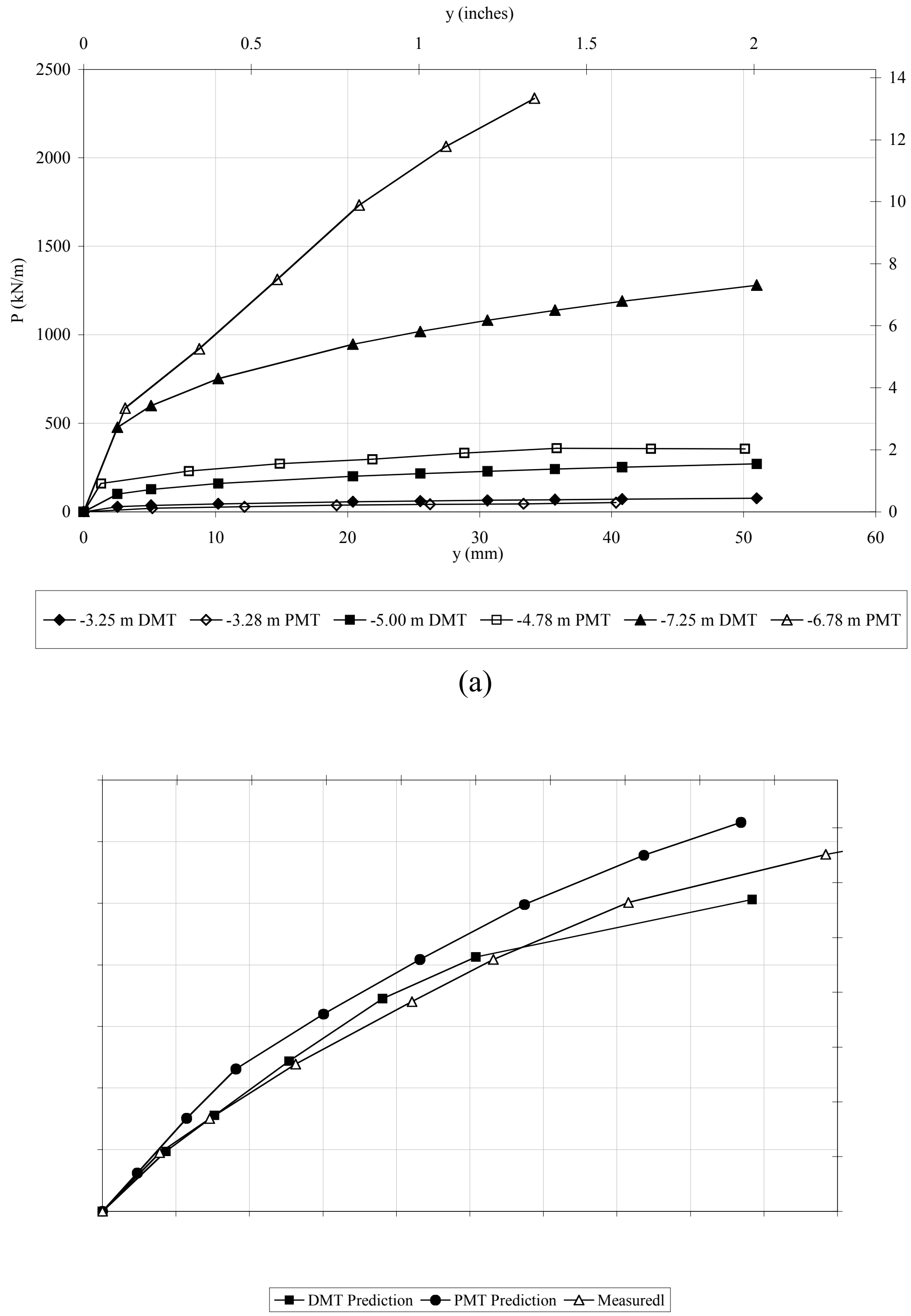
Figure 4.20 Roosevelt Bridge geometry and structural data for Pile Number 9

SPT borings and CPT soundings were used to produce the soil profile at Roosevelt, which consisted of layers of loose sand over cemented sand, both with shell fragments. The generalized soil profile for this site is presented in Appendix G. The original reduced PPMT and DMT results are included in Appendix A and B. Note that the PPMT results do not include an unload–reload loop as is commonly practiced. This loop is recommended and the elastic modulus determined from it is used to calculate the p–y curves for driven piles. In addition to the unload–reload loop, the total volume of water injected from each test shows significant variation. It is typically recommended that 90 cm^3 of water be injected in 5 cm^3 increments throughout the test and the majority of the data show that less than 60 cm^3 was injected for the tests conducted at this site.

All of the p–y curves generated from PPMT and DMT data are shown in Appendix D. Specific curves from PPMT and DMT are compared for three elevations, approximately -3.25 m (-10.7 ft), -5.0 m (-16.4 ft) and -7.0 m (-23.0 ft) in Figure 4.21(a). The shallow curves match well, showing a similar stiffness and ultimate capacity, while the p–y curves based on the deepest tests, -7.0 m (-23.0 ft), show different ultimate capacities with similar stiffness. The PPMT data also indicate there is a large difference in soil properties between 4.78 m and 6.78 m (15.68 ft and 22.25 ft). The limit pressures within this depth vary from 500 kPa to over 2,000 kPa (73 psi to 290 psi). This variation may have produced the inconsistencies in the p–y curve comparisons between the PPMT and DMT data.

The resulting predictions, shown in Figure 4.21(b), of the load test at Roosevelt Bridge indicate that the measured p–y curves compare well with PPMT and DMT p–y curves. The PPMT curves show slightly higher (about 15%) ultimate loads at 37.5 mm than the measured values and the DMT showed slightly lower (about 8%) ultimate loads than the measured value. Comparisons were also conducted at 12.5 mm and 25 mm, and show that the

PPMT curves predict from 15–30% higher loads than the measured data, while the DMT curves predict loads 10% below the measured data.



(a)

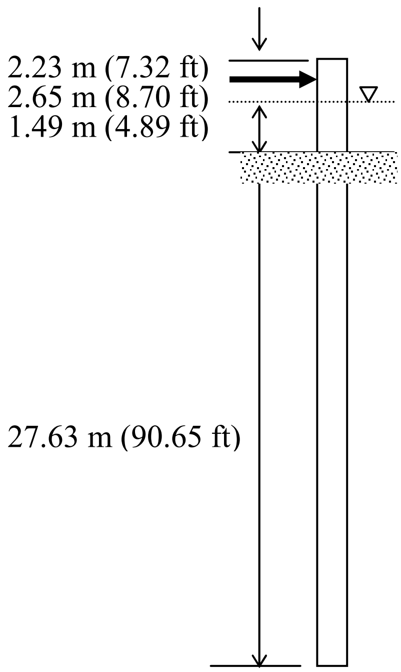
(b)

Figure 4.21 Roosevelt Bridge Pile Number 9: a) Comparison of pertinent PPMT and DMT p–y curves, and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.4 US 17 Bypass: Wilmington, North Carolina

This test program was funded by the North Carolina Department of Transportation (NCDOT) and the National Cooperative Highway Research Program (NCHRP), for a new US 17 bridge over the Northeast Cape Fear River near Wilmington, N.C. The case was originally published by Anderson et al (2002). A 915 mm (36 in) diameter concrete cylinder pile with a wall thickness of 152mm (6 in) and an embedded length of 26.4 m (86.6 ft) at Test Area 2 of this site was used as a reaction pile for a laterally loaded test of a 762 mm (30 in) square pre-stressed concrete pile embedded at 27.6 m (90.6 ft). The structural details of the square test pile are shown in Figure 4.22. The original reduced PPMT and DMT results are included in Appendix A and B, respectively.

An extensive geotechnical investigation revealed the soil profile contained two zones of sand, loose alluvial fine sand overlying dense fine sand, geologically termed the Pee Dee formation. The generalized soil profile shown in Appendix G indicates that the soils were subdivided with 3 m (9.8 ft) of very loose, gray silty sand, underlain by 10.5 m (34.5 ft) of very loose to medium dense coarse sand, underlain by 20.5 (67.3 ft) of the Pee Dee formation medium dense to dense micaceaous silty sand.

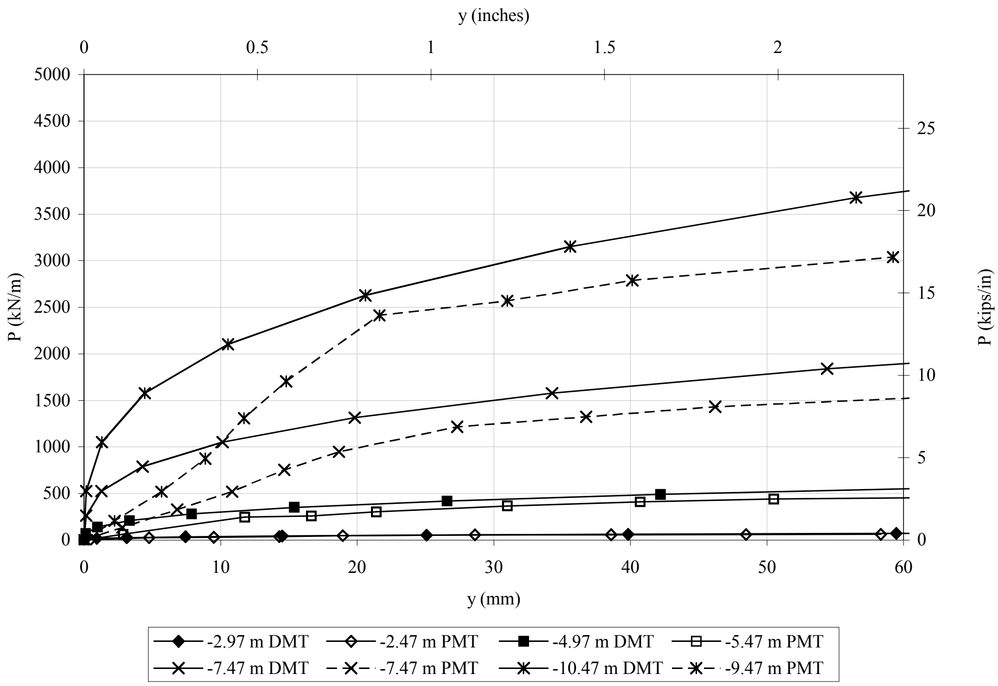


Length: 34m (110 ft)
Type: Square Pre-stressed
Width: 762mm (30 in)
Void: 424.2mm (16.75 in), circular
Material Properties:
Concrete:
f'_c = 41.8 MPa (6.1 ksi)
E_c = 30.4 GPa (4,400 ksi)
Steel:
f_y = 275.7 MPa (40 ksi)
E_s = 200 GPa (29,000 ksi)

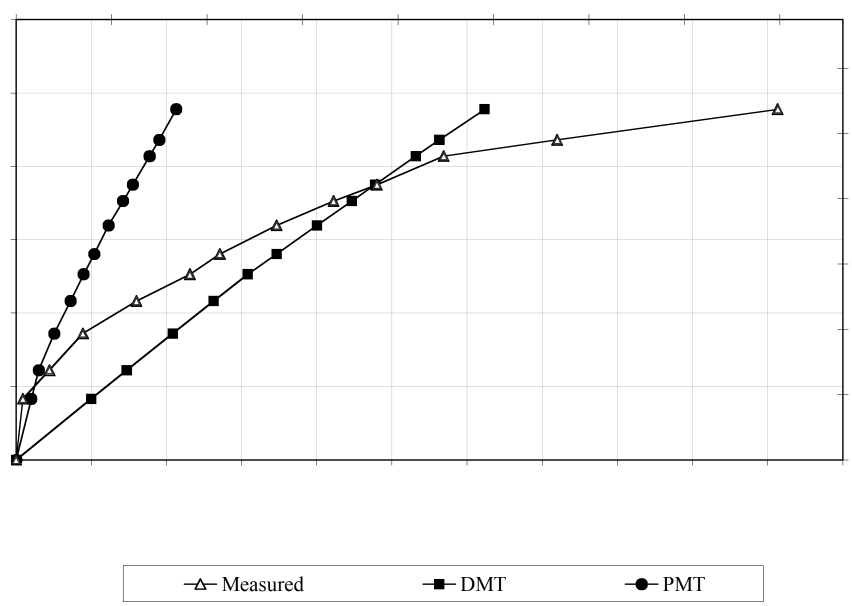
Figure 4.22 Wilmington N.C., US 17 bypass 762 mm (30 in) square pre-stressed concrete pile geometry and structural data

The PPMT data (Appendix A) show very similar soil properties up to the 7.5 m depth. After this depth, the soil strength increases significantly. The data from the unload–reload loops is inconsistent and could not be used to generate the p–y curves. The unload-reload loop was over a very large change in pressure or strains. Determining E_r over large strains would decrease it. These inconsistencies indicate the need for a standard PPMT testing procedure. The DMT data (Appendix B) show the same strength and stiffness increases at the larger depths.

All of the p–y curves generated from PPMT and DMT are shown for in Appendix D. P–y curves were compared in Figure 4.23(a) for elevations including -2.75m (-9.0 ft), -5.25m (-17.2 ft), -7.5m (-24.6 ft), and -10.0m (-32.8 ft). The PPMT and DMT p–y curves at the shallowest depths compare well, showing similar initial slopes and ultimate loads. The data associated with the 7.5 m and 10 m depths are comparable. However, the DMT data follows a smooth polynomial curve due to the basic format of the Robertson et al (1989) equation, while the PPMT data follows the shape of the PPMT curves. The resulting predictions of the lateral load test, in Figure 4.23(b), show the PPMT over-predicts the measured capacity by more than 65% at 12.5 mm (0.5 in), while the DMT under-predicts the measured capacity at 12.5 mm (0.5 in) by 25%. Initially, the PPMT curve matches the measured curve, while the DMT greatly under-predicts the loads. Both PPMT and DMT curves exceed the measured curve at some deflection. However, this deflection is 50 mm for the DMT data and about 5 mm for the PPMT data. As a result of this case study, the unload-reload slope should be used for generating p–y curves.



(a)



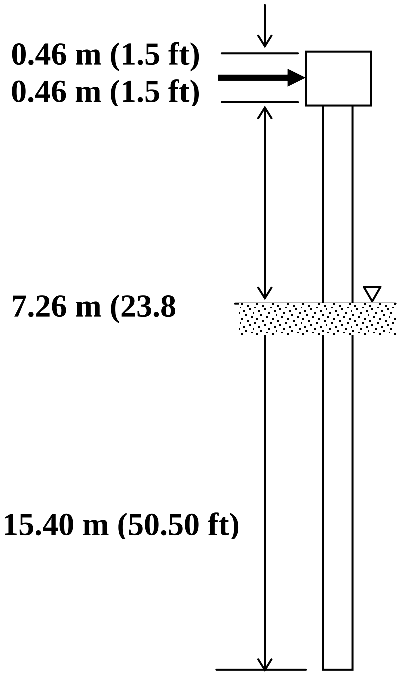
(b)

Figure 4.23 Wilmington bypass p–y data from a) PPMT and DMT data, and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.5 Rio Puerto Nuevo: San Juan, Puerto Rico

The test program consisted of pushing apart two 1,219 mm (48 in) piles with a 19 mm (0.75 in) thick wall, open-ended steel pipe piles separated by approximately 7.6 m (25.0 ft) as part of a test program for a cantilever wall system by the U.S. Army Corps of Engineers' Jacksonville District. One pile was driven to an elevation of -13.1 m (-43.0 ft) (short pile), while the other to elevation of -19.7 m (-64.6 ft) (long pile). Two static lateral load tests were performed on the piles. The first "pre-excavation" test was performed with the ground surface at an elevation of +0.7 m (2.30 ft). Subsequently, a cofferdam was installed and the soil excavated to an elevation of -5 m (-16.4 ft), to simulate planned dredging in front of the wall. The post-excavation load test, idealized in Figure 4.24, was considered in this study.

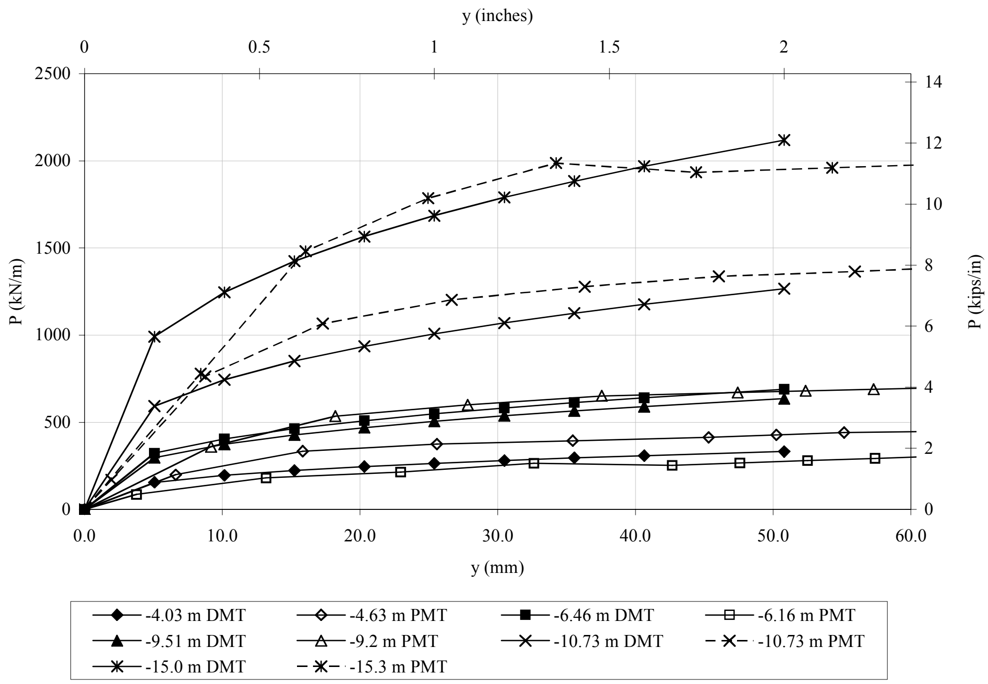
Borings revealed a subsurface profile at Puerto Nuevo consisting predominantly of fat clays with some trace fine sands. The subsurface profile is given in Appendix G. The original reduced PPMT and DMT results are included in Appendix A and B, respectively.



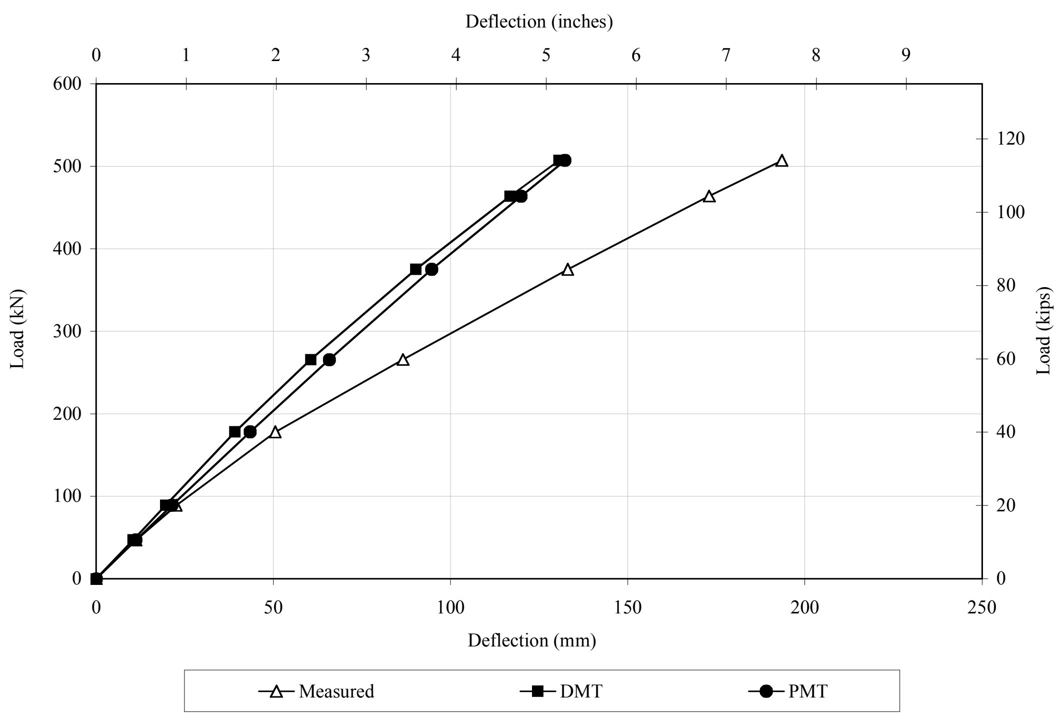
Length: 23.35m (76.6 ft)
Type: Steel Pipe
Diameter: 1,219 mm (48 in)
Thickness: 19.1 mm (0.75 in)
Material Properties:
Steel:
f_y = 275.7 MPa (40 ksi)
E_s = 200 Gpa (29,000 ksi)
Cap Concrete:
f'_c = 27.7 MPa (4.0 ksi)
E_c = 24.86 GPa (3,600 ksi)

Figure 4.24 Rio Puerto Nuevo pile geometry and structural data

All of the generated p–y curves for the PPMT and DMT data are shown in Appendix D. In Figure 4.25(a), the p–y curves were compared at elevations of -4.25 m (-14.0 ft), -6.4 m (-21.0 ft), -9.4 m (-31.0 ft), -10.75 m (-35.3 ft), and -15 m (-116 ft). The curves based on either the PPMT and DMT were similar. Simulations of the load test, shown in Figure 4.25(b), using the generated p–y curves yielded slightly conservative results for both the PPMT and DMT. This conservatism was attributed to a fast test method used for the PMT and the rapid nature of the DMT. This fast method means that the load-volume data was taken without waiting for system stabilization during each loading increment. In clays a significant increase in pore water pressure would occur during loading. This increase would affect the stress–strain response; therefore, the testing process should be decreased. According the to the results presented earlier in this chapter, each PPMT loading increment should be maintained at least 45 seconds in fat clays.



(a)



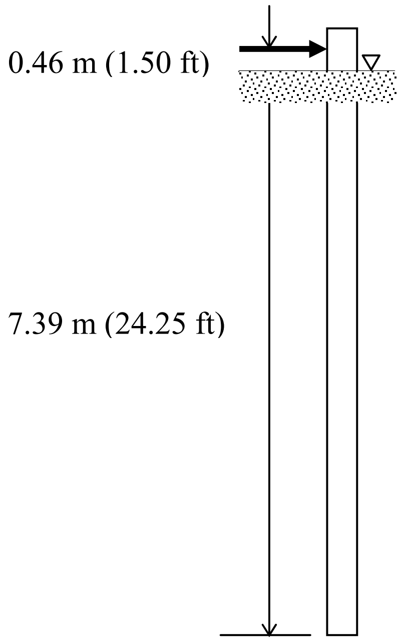
(b)

Figure 4.25 Puerto Nuevo Puerto Rico p–y data from a) PPMT and DMT data and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.6 Salt Lake City International Airport Salt Lake City, Utah

The project consisted of four lateral load tests: two static tests and two Statnamic tests. One static test was performed on a single pile and the other on a free-head pile group. According to Peterson (1996), the single-pile test, analyzed in this discussion, was performed to obtain the row-multipliers in order to normalize the pile group results. The closed-ended pipe pile was 305 mm (12 in) in diameter and 7.85 m (25.75 ft) long with a 9.5 mm (0.375 in) wall thickness. A schematic drawing of the pile is included as Figure 4.26. A sheet pile wall was used as a reaction structure.

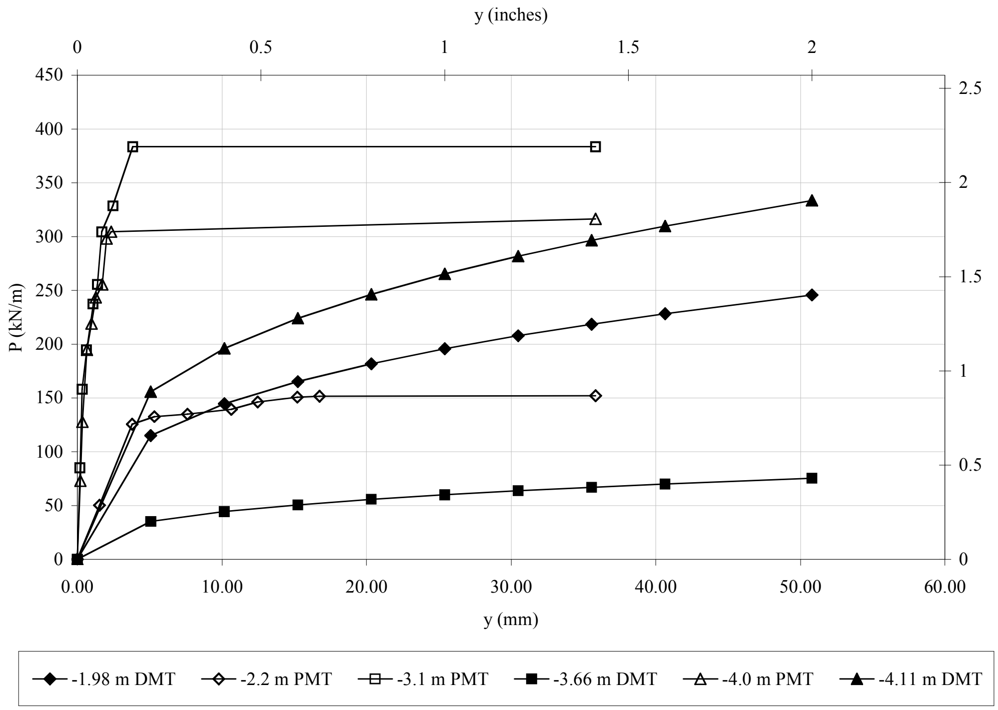
The soil profile at this site consists of interbedded layers of sand and clay. However, the predominant soil type at the critical depth for lateral analysis is clay. The subsurface profile is given in Appendix G. The original reduced PPMT and DMT results are included in Appendix A and B, respectively.



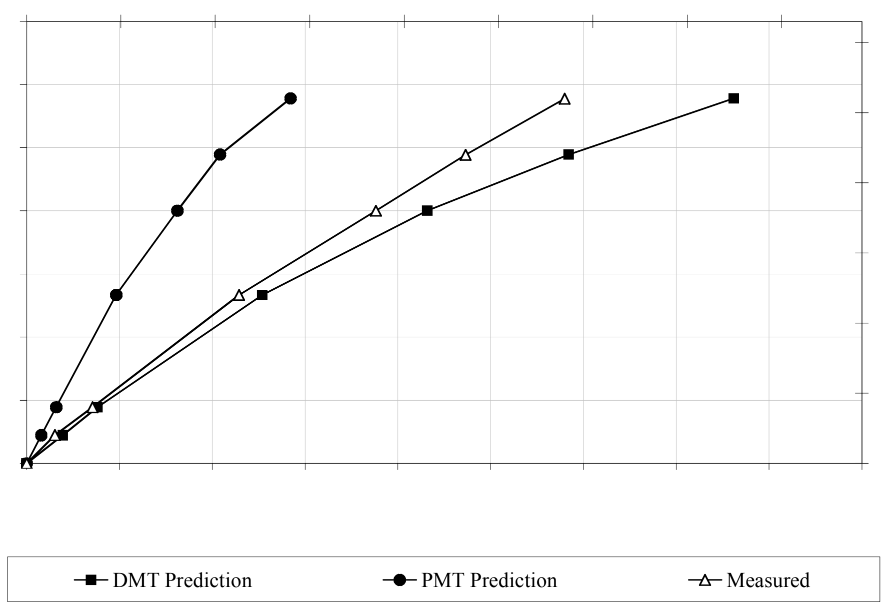
Length: 7.85m (25.75 ft)
Type: Closed End Concrete Filled Pipe
Diameter: 305mm (12 in)
Thickness: 9.5mm (0.375 in)
Material Properties
- Concrete:
  - f'_c = 18.6 MPa (2.70 ksi)
  - E_c = 17.2 GPa (2,500 ksi)
- Steel:
  - f_y = 275.7 MPa (40 ksi)
  - E_s = 200 GPa (29,000 ksi)

Figure 4.26 Salt Lake City pile geometry and structural data

The generated p–y curves are shown for the PPMT and DMT in Appendix D. Of the case histories evaluated, the data provided for Salt Lake City was the most inconsistent. In addition to the fact that there were only three pressuremeter tests, the type of pressuremeter used was a pre-bored model and no unload–reload loops were performed. The corresponding p–y curves deviated significantly between the DMT and PMT, as shown in Figure 4.27 (a). This is also reflected in the predictions, shown in Figure 4.27 (b), where the DMT provided slightly conservative results and the PMT results were unconservative.



(a)



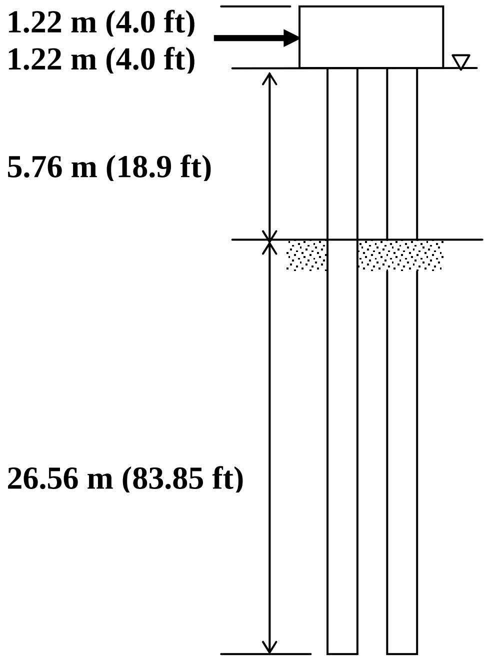
(b)

Figure 4.27 Salt Lake City Airport p–y data from a) PPMT and DMT data, and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.7 East Pascagoula River Bridge: Pascagoula, Mississippi

The test program consisted of laterally loading a submerged group of two 2,100 mm (84 in) drilled shafts (Figure 4.28), spaced at three diameters, against a group of six 762 mm (30 in) pre-stressed square concrete piles. Both groups were embedded into 2.4 m (8 ft) concrete caps and subjected to static and Statnamic lateral loadings (Anderson and Townsend, 1999). P–y multipliers of 0.8 (leading) and 0.4 (trailing) and were used for analysis of the piles and shafts (Ruesta and Townsend, 1997).

Soils at Pascagoula were interbedded layers of sand and clay with a single layer of organics with some decaying wood. The subsurface profile is given in Appendix G. The original reduced PPMT and DMT results are included in Appendix A and B, respectively.

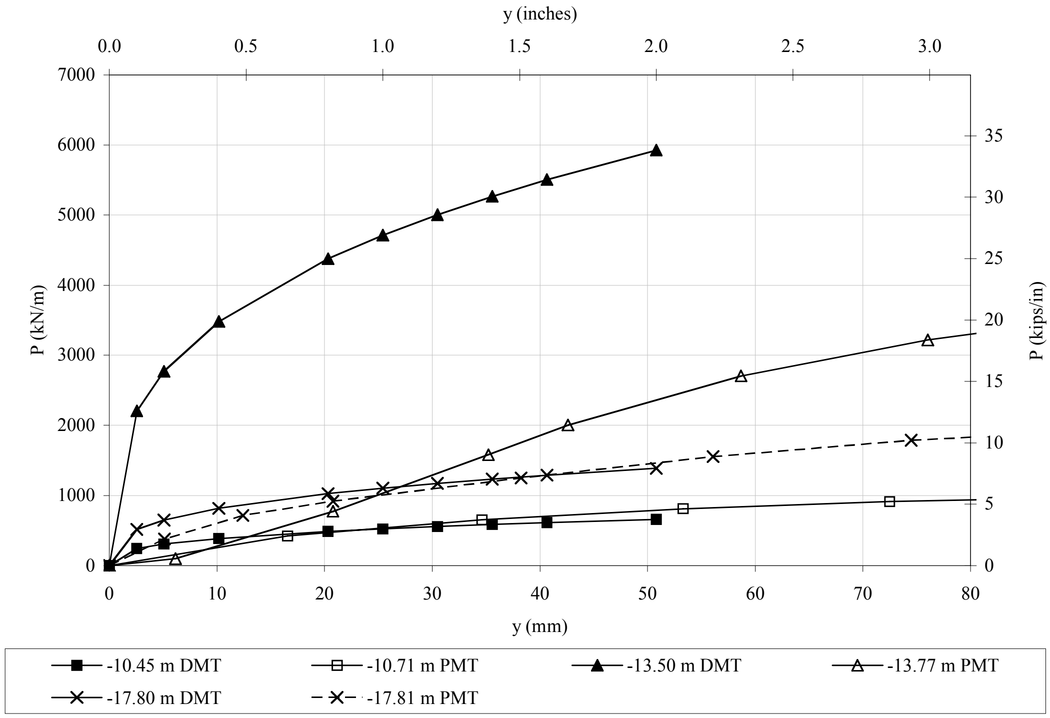


Length: 33.5m (110 ft)
Type: Drilled Shaft Group
Diameter: 2,134 mm (84 in)
Material Properties:
Concrete:
f'_c = 33.1 Mpa (4.8 ksi)
E_c = 27.2 Gpa (4,000 ksi)
Steel:
f_y = 275.7 MPa (40 ksi)
E_s = 200 GPa (29,000 ksi)

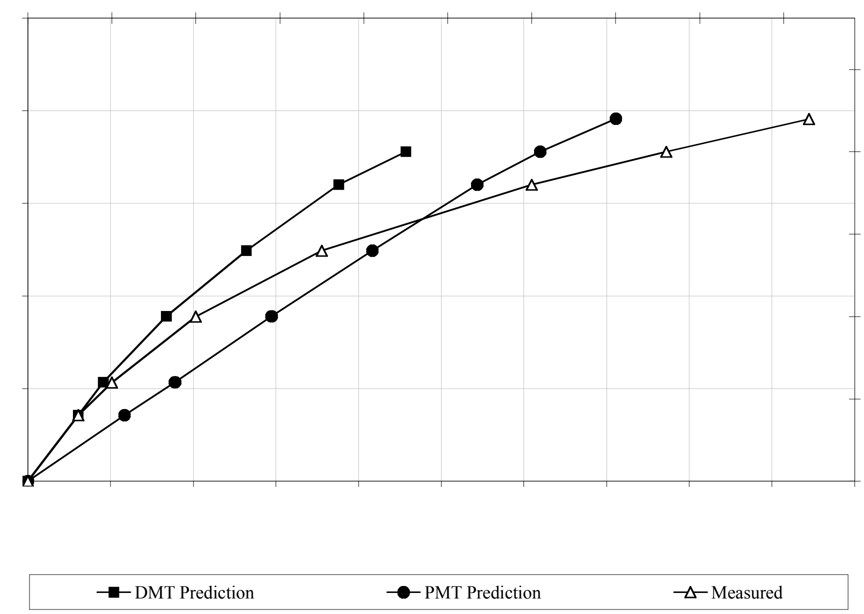
Reinforcement Details:
48 # 14 bars above elevation –7.6 m (-25 ft)
24 # 14 bars below elevation –7.6 m (-25 ft)
76 mm (3 in) clear cover.

Figure 4.28 East Pascagoula River Bridge shaft geometry and structural data

The p–y curves for the PPMT and DMT are shown in Appendix D. P–y curves were compared at elevations of -10.5 m (-34.5 ft), -13.6 m (-44.6 ft), and -17.8 m (-58.4 ft) in Figure 4.29(a). The results compared well except for tests at elevation -13.6 m (-44.6 ft). The predictions based on these curves (Figure 4.29(b)), indicated good agreement in the linear range with the DMT and better predictions at higher loads based on the PPMT. The deviation in the DMT and PPMT curves and higher predicted deflections was attributed to the effect of this large diameter shaft on the p–y curves. This shaft may have behaved as a rigid structure and the original equations were derived for smaller piles.



(a)



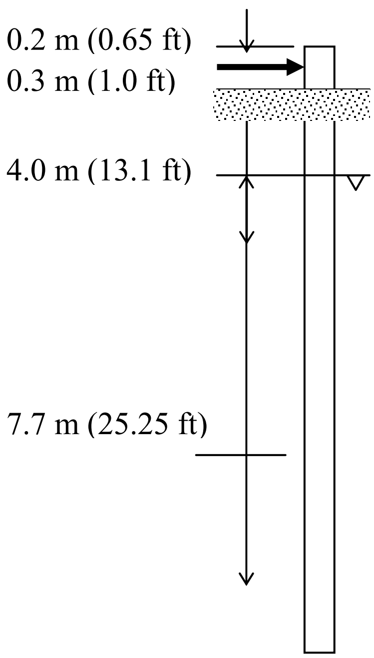
(b)

Figure 4.29 East Pascagoula River Bridge p–y data from a) PPMT and DMT data, and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.8 Auburn NGES: Opelika, Alabama

Six 915 mm (36 in) drilled shafts were laterally loaded as part of a static and Statnamic test program for a joint Alabama DOT and FHWA research project at Auburn University. Shaft 2, shown in Figure 4.30, in the southwest quadrant of the research site was analyzed for this study (Anderson et al, 1999; Brown and Vinson, 1998).

The soil at the Auburn site is characteristic of the Piedmont geological province of the southeastern United States. The subsurface profile, given in Appendix G, indicates layers of medium dense silty sand. These soils are derived from weathering of metamorphic rocks, predominantly gneisses and schists, and are composed of micaceous sandy silts. Detailed PMT and DMT soundings are included in Appendix A and B, respectively.

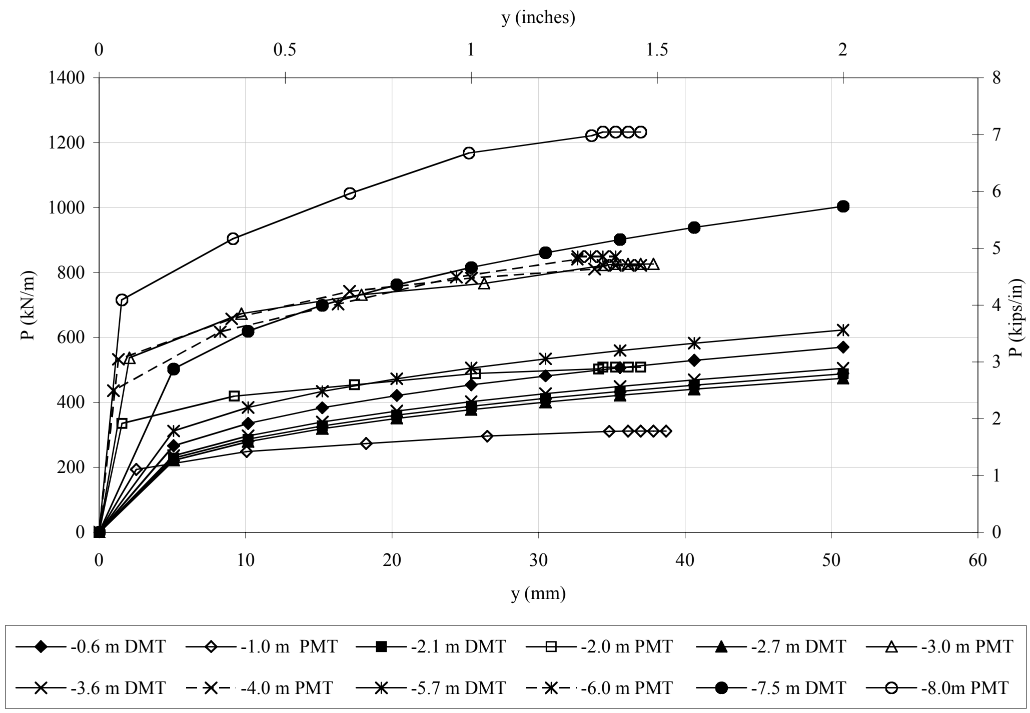


Length: 12m (40 ft)
Type: Drilled Shaft
Diameter: 915 mm (36 in)
Material Properties
Concrete:
f'_c = 33.1 MPa (4.8 ksi)
E_c = 27.7 GPa (4,000 ksi)
Steel:
f_y = 275.7 MPa (40 ksi)
E_s = 200 GPa (29,000 ksi)

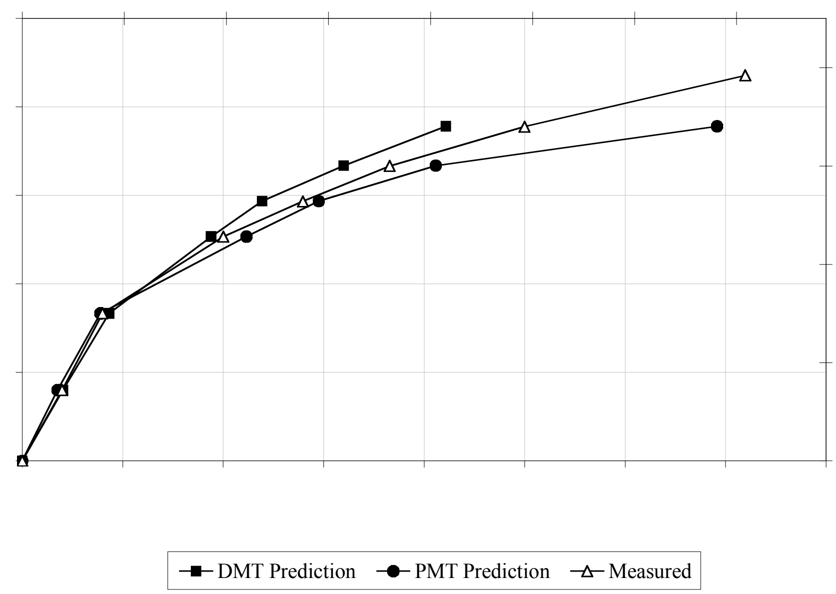
Reinforcement Details: 12 #11 Bars
76mm (3 in) clear cover

Figure 4.30 East Auburn NGES shaft geometry and structural data

The generated p–y curves are shown in for PPMT and DMT in Appendix D. P–y curves at the Auburn site were compared for multiple depths. Figure 4.31(a) shows reasonable agreement between the curves at shallow depths. However, curves developed from PPMT and DMT tests at greater depths were disparate. When the respective curves were used in FB-MultiPier simulations of the load test, the load versus deflection curves shown in Figure 4.31(b) were developed. In general, both the PPMT and DMT produced good load-deflection predictions, with the PPMT results being slightly conservative and the DMT results slightly unconservative.



(a)



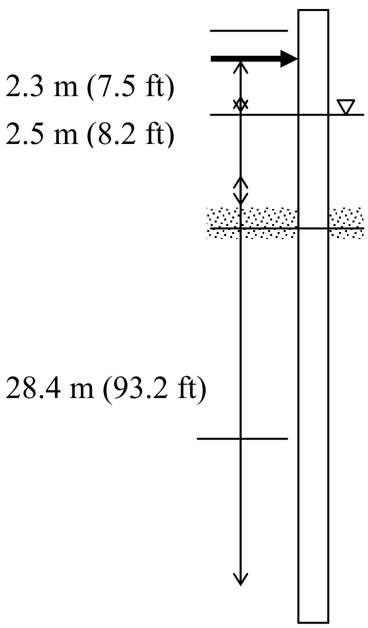
(b)

Figure 4.31 Auburn University test site p–y curves from a) PPMT and DMT data, and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.9 Broadway Bridge: Daytona Beach, Florida

The test program was part of the construction of a new bridge over the Halifax River by the Florida Department of Transportation. While the preceding six case histories utilized static lateral load data, only four lateral Statnamic load tests were used on a 1,500 mm (60 in) diameter drilled shaft. No static load testing was conducted. The load versus deflection information provided was "derived static" provided by Applied Foundation Testing. A sketch of the drilled shaft is shown in Figure 4.32.

The soils are predominantly coastal deposits of medium relative density sands above elevation -13.0 m (-42.5 ft), with soft clays interbedded with dense sands below that elevation. The limerock formation was found at approximately -25 m (-82.0 ft). The subsurface profile for this site is given in Appendix G. Appendices A and B contains PMT and DMT sounding information, respectively.

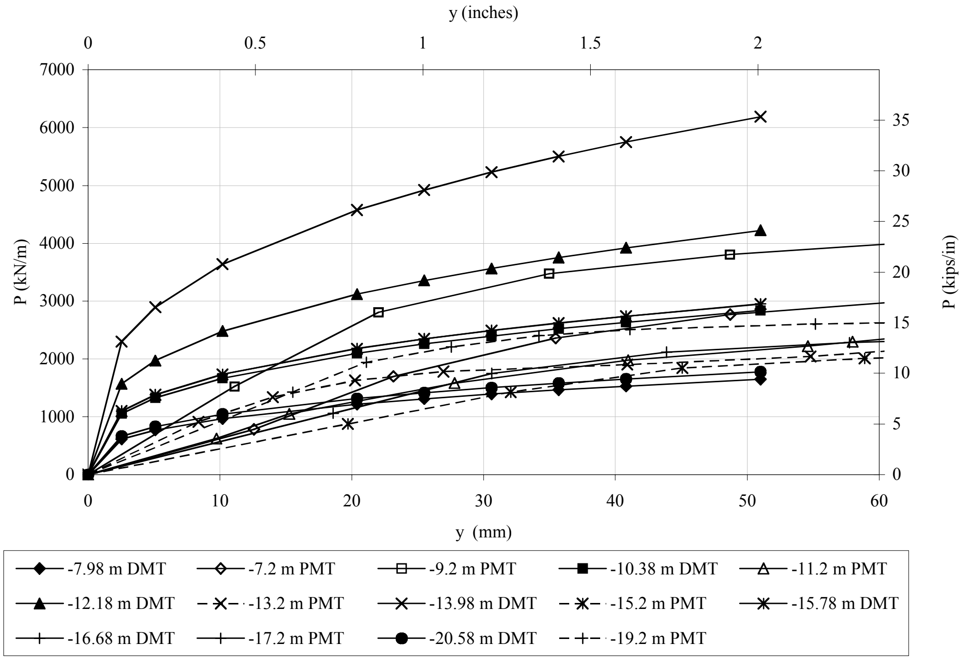


Length: 35.2m (115.4 ft)
Type: Drilled Shaft
Diameter: 1,500 mm (60 in)
Material Properties
Concrete:
f'_c = 40 MPa (5.8 ksi)
E_c = 30 GPa (4,350 ksi)
R/F Steel:
f_y = 275.7 MPa (40 ksi)
E_s = 200 GPa (29,000 ksi)
Casing:
f_y = 275.7 MPa (40 ksi)
E_s = 200 GPa (29,000 ksi)

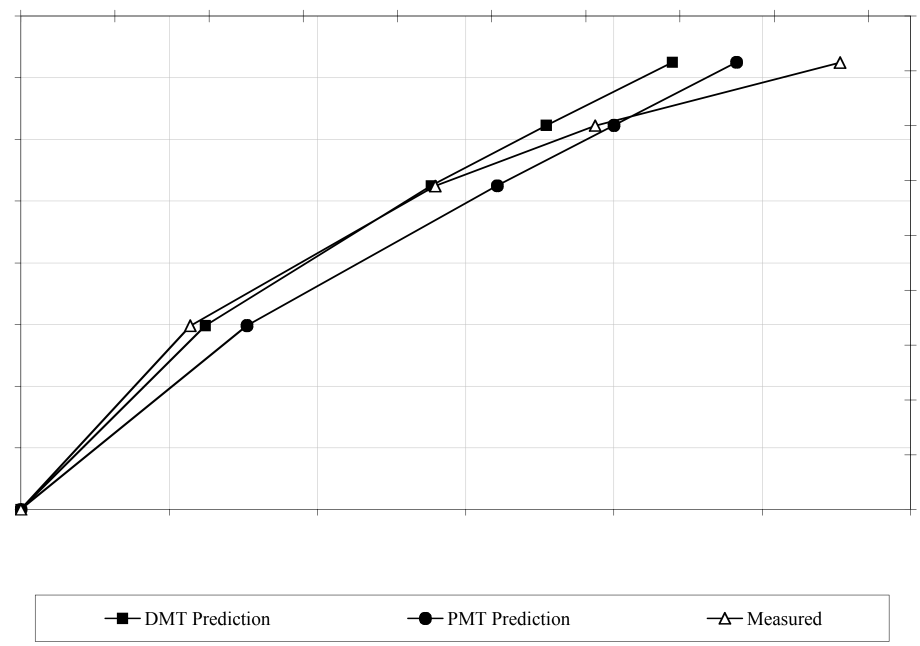
Reinforcement Details: 25 #10 Bars
76mm (3 in) clear cover
Casing from top to -25.0 m (-82 ft) elevation

Figure 4.32 Broadway Bridge shaft geometry and structural data

The p–y curves are shown in Appendix D for the PPMT and DMT data. Curves from around elevations of -7.5 m (-24.6 ft), -9.75 m (-32.0 ft), -11.75 m (-38.5 ft), -13.5 m (-44.3 ft), -15.5 m (-50.9 ft), -16.8 m (55.0 ft) and -20 m (65.6 ft) were plotted together in Figure 4.33(a). P–y curves at similar depths were produced poor comparisons between PPMT and DMT. Predictions of the pile head deflections using FB-MultiPier, shown in Figure 4.33(b) were good, using either set of p–y curves.



(a)



(b)

Figure 4.33 Broadway Bridge, Daytona Beach, Florida p–y data from a) PPMT and DMT data, and b) measured versus PPMT and DMT load-deflection data at pile head

4.7.10 P–y Curves Derived from Instrumentation

It has been suggested that the most representative p–y curves can be derived from strain gauge measurements (Ruesta and Townsend, 1997). By measuring strain, a function of strain or moment along the length of the pile can be developed for each incremental load. Derivatives and integrals of these functions are used to develop p–y curves using simple beam theory. Original work was published by Ruesta and Townsend (1997) where p–y curves were generated based on the load test at Roosevelt Bridge. This work was replicated to set up a framework for developing p–y curves for East Pascagoula River Bridge and the US 17 Bypass. This framework was checked by creating two fictitious load tests, where the input p–y curves were back-verified.

4.7.10.1 Basic Theory P–y Curves from Strain Gauges

The behavior of a pile subject to lateral and moment loadings is often represented in differential form, shown in Figure 4.34. If one of these quantities can be measured using differentiation and integration, the deflection and soil reaction can be determined. Since bending moments can be determined based on strain gauge measurements, it is most convenient to measure strain whereby the moment can be determined. A function of bending moment versus depth is generated. This function is differentiated twice and integrated twice to determine the soil reaction, p, and deflection, y, respectively. An alternative method employs the slope from slope inclinometer readings. However, this method results in a third derivative that is extremely sensitive to error. Solutions to this method are complex and somewhat subjective, Hidden (1992) and Pinto et al (1999), and have not been used in this discussion.

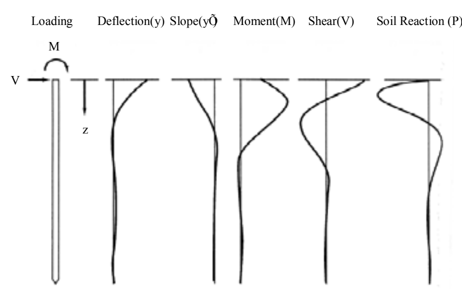


Figure 4.34 Family of curves for deflection, slope, moment, shear and soil reaction for a laterally loaded pile (Matlock and Reese, 1960)

Bending moments are determined using strain gauges, typically mounted on the reinforcing steel, by knowing one of two relationships. Curvature, which is the derivative of the slope, can be calculated as the difference in strains measured at two locations along the length, divided by the distance between these locations, which is defined as 2c. The curvature Φ is calculated from:

$$\phi = \frac{\varepsilon 1 - \varepsilon 2}{2c} \qquad (4.1)$$

If the pile is constructed of a linear elastic material, (i.e. steel), the bending moment is equal to curvature, Φ, times the stiffness, EI, and is given by equation 2.

$$M = EI\Phi \tag{4.2}$$

If the pile is constructed of nonlinear material, (i.e. concrete), this equation would only hold for small strains where the concrete exhibits nearly linear behavior. Thus, a more general relationship must be developed, where the bending moment is a function of the curvature or

$$M = f(\Phi) \tag{4.3}$$

4.7.11 Implementation and Verification of Method

This method was implemented in a spreadsheet for several reasons, including easy polynomial trendline development, availability of spreadsheet software and simplicity of programming within the spreadsheet. Since data, typically is provided as either raw strain readings or reduced bending moments, two parallel data structures were developed. The important input parameters are as follows:

1) pile dimensions
2) pile penetration
3) variation of strain or bending moment with depth
4) pile top lateral load
5) deflection at the load point
6) slope at the load point

The spreadsheet provides a set of p–y curves assembled from the derivatives and integrals of the moment functions for each lateral load step. The quality of the instrumented data was no sufficient to produce any meaningful p–y curves. Therefore, it was not used in this report.

4.7.12 Case History Summary

P–y curves, based on PPMT and DMT, were generated for the seven LLT case histories. Each load test was simulated using an earlier generation of the program that is currently distributed as FB-MultPier (Hoit et al, 1997). The models reflect the structural details associated with each pile or drilled shaft, including the shape, reinforcing details, strength and modulus.

The load tests were separated into the following categories: piles and drilled shafts, as well as cohesionless and cohesive soils. In total, three were on drilled shafts (Pascagoula, Auburn and Broadway) and four on piles (Roosevelt, Wilmington, Puerto Nuevo and Salt Lake City). Four of the sites were comprised of predominantly cohesionless soils (Roosevelt, Wilmington, Auburn and Broadway) and three were primarily cohesive soils (Pascagoula, Puerto Nuevo and Salt Lake City).

In addition to dividing the sites into categories, a regression analysis was performed on the accuracy of the PPMT- and DMT- derived load deflection data. A higher regression coefficient (R^2) would indicate a better fit between the predicted and measured data. This analysis produced the regression coefficients shown in Table 4.23. Based on the R^2 values, the most prominent conclusion might be that the DMT results are somewhat better than the PPMT results. Recall that both the Wilmington and Salt Lake City PPMT data were questionable and these results are reflected in the low R^2 values. If these sites are excluded from the comparisons, the regression coefficients are nearly the same, with the PPMT data producing a slightly better R^2 value than the DMT data.

Based on the variety of discrepancies associated with conducting the PPMT tests, there seems to be an obvious need to standardize the PPMT testing procedure. The number of problems facing the engineers who use this data included:

1) Not performing the unload–reload loop for the tests at either the Roosevelt Bridge or Salt Lake City Airport tests

2) improperly performing this loop at the US 17 Wilmington Bypass, Rio Puerto Nuevo and Broadway Bridge sites

3) using a pre-boring PMT for the Salt Lake City tests

4) performing rapid PPMT tests at Puerto Nuevo

According to the data in Table 4.23, the PPMT tests associated with drilled shafts produced more consistent regression results than the DMT tests. This conclusion was based on the range of R^2 values shown, 0.74 to 0.85 for the PPMT data versus 0.60 to 0.93 for the DMT data. This consistency was attributed to the fact the PPMT data used for drilled shaft p–y curves is the initial slope of the stress–strain curve and not the unload–reload slope, used for driven piles. Even though the PPMT testing at the seven sites was inconsistent because the unload-reload loops were improperly conducted, the initial slope was not adversely affected.

Considering the difference between cohesive and cohesionless soils, the data suggests that prediction in cohesionless materials using the DMT was best. The PPMT predictions in sands were good for all cases. For clays, PPMT was often unconservative; however, the Salt Lake City and Rio Puerto Nuevo tests were not consistent with the others. A critical factor might also be that the speed at which the in situ tests were performed was much faster than the load test. Thus, pore pressure dissipation effects may contribute to the differences.

Site No.	Site Name	R^2		Foundation Type		Soil Type	
		PPMT	**DMT**	**Piles**	**Drilled Shafts**	**Cohesive**	**Cohesionless**
1	Roosevelt Bridge Stuart, FL	0.84	0.90	Piles			Cohesionless
2	US 17 Bypass Wilmington, NC	0.41	0.76	Piles			Cohesionless
3	Rio Puerto Nuevo, San Juan PR	0.73	0.74	Piles		Cohesive	
4	Salt Lake City Airport, Utah	0.09	0.80		Drilled Shafts	Cohesive	
5	East Pascagoula River Bridge, MS	0.85	0.60		Drilled Shafts	Cohesive	
6	Auburn NGES, Opelika, AL	0.74	0.93		Drilled Shafts		Cohesionless
7	Broadway Bridge Daytona Beach, FL	0.91	0.86	Piles			Cohesionless
	Average (excluding No. 2 PPMT data)	**0.75**	**0.80**				
	Average (excluding Nos. 2 and 4 PPMT data)	**0.81**					

Table 4.23 Color coded summary of regression coefficients for the case histories

For the case histories based on piles, two were prestressed concrete and two were pipe piles. Predictions among the piles indicate slightly better prediction for concrete than steel pipe. However, this may be affected by the cohesionless versus cohesive behavior.

All of the results are summarized quantitatively in Table 4.24. The terminology associated with the quality of the PPMT and DMT predictions was developed by analyzing the measured and predicted pile tip deflections at ½ and 1 inch and converting the data to the following criteria:

1) *Very good* implies the measured and the predicted PPMT or DMT derived load-deflection curves closely coincide (i.e. predicted 10% below measured), such that the PPMT or DMT predictions would not yield unconservative (i.e. over predict) loads at given deflections.
2) *Acceptable* implies the measured and the predicted PPMT or DMT derived load-deflection curves are relatively close (i.e. predicted 25% below measured) and the predictions would not yield unconservative (i.e. over predict) loads at given deflections.
3) *Slightly unconservative* implies the measured and the predicted PPMT or DMT derived load-deflection curves are relatively close (i.e. predicted 10% above measured) but the predictions would yield unconservative (i.e. over predict) loads at given deflections.
4) *Unconservative* implies the measured and PPMT or DMT derived load-deflection curves would yield unconservative (i.e. predicted 25% above measured) loads at given deflections.

The pile head load-deflection plots are insensitive to variations in the individual p–y curves. If the PPMT testing is performed poorly as was the case with 3 of the sites (US 17, Puerto Nuevo and Salt Lake City) the PPMT pile head load-deflection data becomes unconservative. DMT derived p–y curves were about as accurate in predicting pile head deflections as PPMT derived p–y curves; although no standard procedure was followed for PPMT testing.

For drilled shafts, PPMT based p–y curves should be developed from the initial linear portion of the reduced stress–strain curve (i.e. based on E_o). For driven piles, PPMT based p–y curves should be developed from the rebound portion of the unload-reload loop from the reduced stress–strain curve (i.e. based on E_r).

Table 4.24 P–y curve comparisons at ½ and 1 inch pile head deflections

Project	Location	Type	L/D	Material	Soil	PPMT	DMT
Roosevelt Bridge	Stuart, Florida	Pile	23.0	Concrete	Cohesionless	Slightly Unconservative	Very Good
US17 Bypass	Wilmington, North Carolina	Pile	44.6	Concrete	Cohesionless	Unconservative	Acceptable
Rio Puerto Nuevo	San Juan, Puerto Rico	Pile	19.2	Steel	Cohesive	Very Good to Slightly Unconservative	Very Good to Slightly Unconservative
Salt Lake City International Airport	Salt Lake City, Utah	Pile	25.8	Steel	Cohesive	Unconservative	Acceptable to Very Good
East Pascagoula River Bridge	Pascagoula, Mississippi	Shaft	15.7	Concrete	Cohesive	Acceptable to Very Good	Unconservative
Auburn NGES	Opelika, Alabama	Shaft	13.3	Concrete	Cohesionless	Very Good	Slightly Unconservative
Broadway Bridge	Daytona Beach, Florida	Shaft	23.1	Concrete	Cohesionless	Acceptable	Slightly Unconservative

No reliable p–y curves were developed from the instrumentation data from any of the seven sites. Various issues caused problems with interpreting the data. The issue with East Pascagoula River Bridge was the position of the strain gauges versus the in situ tests, a more complex issue was observed with the US 17 Bypass. It is likely that failure to derive proper p–y curves is due to the poor data collection and reporting. There were several key items omitted from the final report that resulted in a load test with minimal value for determination of p–y curves. In order to produce any meaningful data results were interpreted from figures within the report. No digital information was provided making verification impossible. The primary conclusion in this case is p–y curves from in situ tests are more economical and have a much higher likelihood of providing useful information for designing deep foundations than instrumented based p–y curves.

5 Chapter 5—STANDARD PUSHED-IN PPMT TESTING PROCEDURES

The recommended procedures for equipment saturation, calibration, conducting the PPMT test and reducing the data are presented in the following sections. There are slight differences between tests conducted with an instrumented control unit and those conducted without the pressure and volume instrumentation. These variations will be described within each appropriate section, when necessary. In the following text, any references to volumes or pressures imply that either the digital or analog values should be monitored.

5.1 Description of PPMT

The Pencel PMT comes standard with a 2,500 kPa analog pressure gauge, and has an optional 5,000 kPa gauge for testing higher strength soils. This chapter contains the instructions for using the standard 0–2,500 kPa gauge. The current Roctest® instruction manual (2005) was used as the basis for this document.

The PPMT is comprised of three main elements: the control unit, probe and tubing. Each element must be properly maintained and calibrated to ensure accurate results.

5.2 Control Unit

The control unit should be placed in a convenient location on the ground near the hole or sounding. Its function is to allow the operator to control and monitor the expansion of the probe. The unit consists of the following components:

1) a 138 cm^3 piston cylinder assembly
2) a -100 kPa to +2,500 kPa analog pressure gauge
3) a 1,000 cm^3 volume counter, graduated in 0.1 cm^3 increments
4) valves and tubing for testing and saturating
5) a fiberglass enclosure
6) an aluminum tripod to support the control unit

Instrumentation of the control unit described in Chapter 3 included installation of a digital pressure transducer with a range from -100 kPa to 3,500 kPa and the potentiometer that allowed volumes to be monitored to within ± 0.1 cm^3. The analog pressure gauge should always read zero at the start of the test, unless the following steps are followed to set the needle to zero:

1) Unscrew the four chrome-plated screws holding the pressure gauge mounting plate
2) Unscrew the knurled plug located on the upper back face of the pressure gauge (This plug covers an adjustment screw for the pressure gauge)
3) Using a small screwdriver, set the pressure gauge to zero
4) Replace the knurled plug
5) Reattach the pressure gauge mounting plate

5.3 *Probe*

The mono-cellular probe is comprised of a cadmium-plated steel tube on which an inflatable rubber membrane covered with a metallic sheath is mounted. The membrane is held in place using two tapered metal rings and two lock nuts. The probe is fitted with quick disconnects at both extremities. One accepts the tubing leading from the pressure-volume control unit and the other accepts the saturation tubing. A cone drive point screws onto the base of the probe. Water is used to pressurize the cavity. The standard length of the assembled probe is 24 ± 2.5 cm and the standard diameter is 32± 0.5 mm. The cone drive point has the same dimensions as a standard cone penetrometer (CPT) cone.

5.4 *The Tubing*

The tubing links the probe to the pressure–volume control unit. Quarter-inch-diameter nylon tubing is used because it does not expand significantly during pressurization. Check that the tubing is free of defects and has not been damaged by equipment.

5.5 *Filling and Saturating the Control Unit, Tubing and Probe*

To fill and saturate the control unit, follow Steps 1 to 7 below. To fill and saturate the tubing and probe follow Steps 8 to 16 below.

5.5.1 Control Unit Saturation Process

1) When using the instrumented control unit, connect the control unit electronics to the laptop, turn the computer on and load the APMT software as per the details given in Appendix F. If the control unit is not instrumented, proceed to Step 2.

2) Connect a length of short tubing fitted with a male quick connect to port 1 identified as "Fill-bleed" on the control panel. This quick connect requires some extra force to insert. This tubing is referred to as the fill-bleed tubing (Figure 5.1).

3) Submerge the open end of the fill-bleed tubing into a container filled with about 1,000 cm^3 of de-aired, distilled water. If there is a risk of freezing, replace 50 % of the water with an anti-freeze (i.e. ethylene glycol solution). Do not use automotive windshield wiper fluid as it may damage the tubing.

4) Place valve 3 in the "Fill-bleed" position and valve 4 in the "Closed" position.

5) To remove all the water from the cylinder during control unit saturation, rotate the crank-handle clockwise or in the inflate direction until the internal cylinder completes its travel. This movement will correspond to a volume of about 138 cm^3 displayed on both the computer screen within the APMT data acquisition system and the volume counter on the control unit. As water is pumped out, the operator should note if air bubbles appear in the container. To aid in removal of the entrapped air gently tilt the control unit to angles of no more than 10 degrees from the horizontal. Remember that the instrumented unit contains delicate electronics. Once this step is completed, there should only be water remaining within the control unit tubing and connectors. Note that the analog counter has 0.1 cm^3 increments.

6) To complete the control unit saturation, rotate the crank-handle in the "Deflate" direction at a maximum speed of one revolution per second until both the digital and counter volume read-outs indicates 0 cm^3. This step draws de-aired water back into the cylinder. Note some air may remain trapped in the control unit tubing and connectors at the completion of this step.

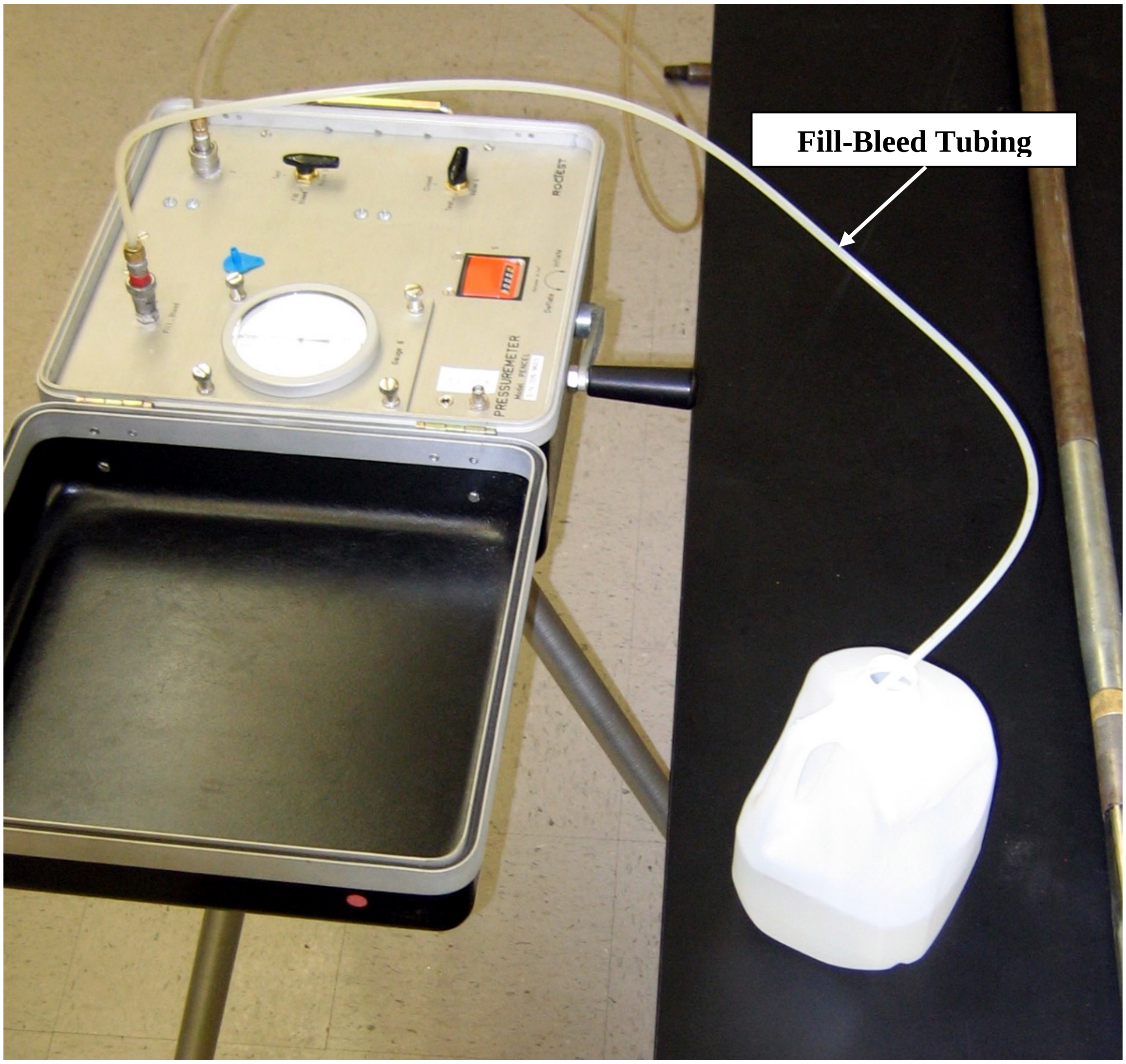


Figure 5.1 Control Unit with Fill-Bleed Tubing Submerged in De-aired Distilled Water

7) To remove any excess air, repeat Steps 5 and 6 at least 3 times; however, typically it is only necessary to remove 100 cm^3 of water in these subsequent operations. It is also advisable to "tilt" the control unit several times during this process, to allow any trapped air to move within the system. The operator should notice no air bubbles rising in the container once the control unit is saturated.

5.5.2 System Saturation Process (i.e. Control Unit, Tubing and Probe)

8) Place the required number of cone drive rods, side by side in the proper sequence for field-testing as shown in Figure 5.2. Be sure that the rod couplings alternate between male and female. The cone rods either must have been "drilled out" to allow the 16 mm diameter tubing coupling to pass through them, or this 16 mm Hansen® high pressure coupling must be filed down such that it will pass through the 15 mm inside diameter of the cone rods (Figure 5.3). If the coupling is filed, removing it will require a vise or vise-grip type pliers. Thread the tubing through each rod; being sure that the correct ends of the tubing are in the top and bottom locations during this operation.

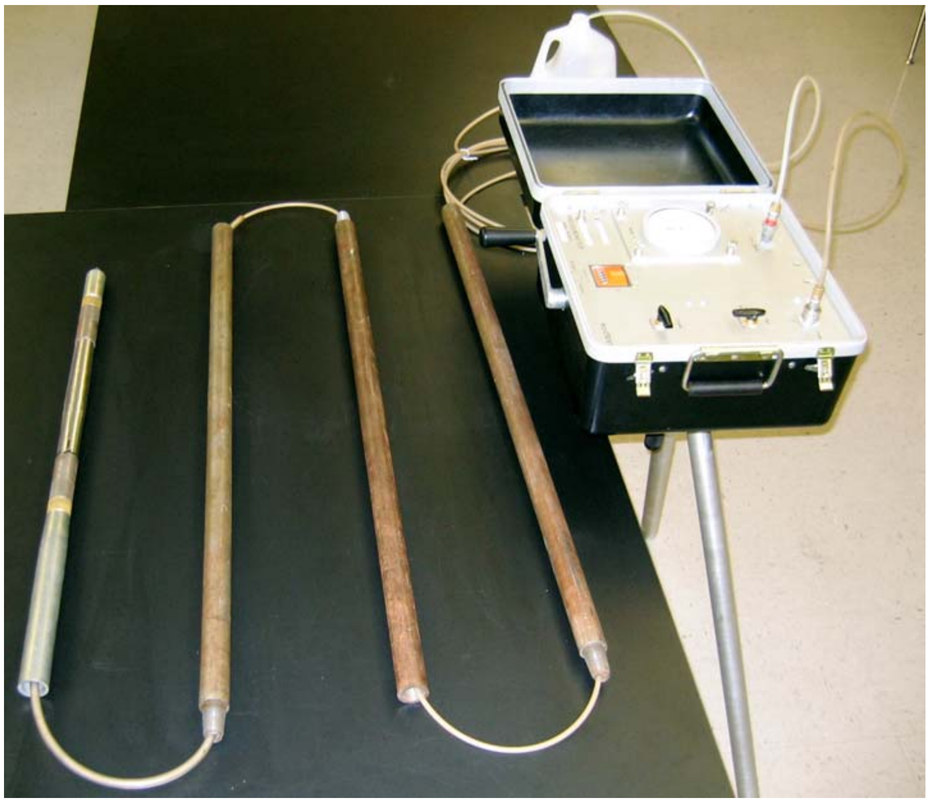


Figure 5.2 Photo of rods and tubing connected to control unit

Figure 5.3 Filed down 16 mm Hansen® high pressure coupling will pass through 15 mm inside diameter cone rods

9) If the cone drive point is attached, unscrew it from the base of the probe. Using the supplied length of control unit tubing; connect the top end to quick connect 2 identified as “Probe” on the control unit panel and the bottom end to the probe quick connect. If the solid model probe is being used, connect the short tubing fitted with the female quick connect to the base of the probe.

10) Place valves 3 and 4 in “Test” position as shown in Figure 5.4.

Figure 5.4 Photo of tubing connected to control unit with Valves 3 and 4 in Test position

11) To remove all the water from the cylinder prior to system saturation, rotate the crank handle in the "Inflate" direction until both the digital and counter volumes indicate 138 cm^3. During this operation, the probe must be held in an inverted position with its center at the same height as the control unit panel to ensure there is no hydrostatic pressure added to the system. For the hollow core model, make sure that the plug at the end of the probe has been removed and that water is coming out. For the solid core model, depress the point of the male quick connect during inflation to allow water and air to escape the system. If the short tubing is connected to the end of the solid core model, watch the end for air bubbles during inflation. Make sure that the open end of the fill-bleed tubing is in the container filled with about 1,000 cm^3 of de-aired, distilled water.

12) Place valve 3 on "Fill-bleed" and valve 4 on "Closed".

13) To begin the system saturation, rotate the crank-handle in the "Deflate" direction at a maximum speed of one revolution per second until the digital and counter volume readouts indicate 0 cm^3. This step draws de-aired water back into the sealed system. Note that some air may remain trapped in the system at the completion of this step.

14) To remove any excess air, repeat Steps 9 to 13 at least three times to make sure that no air is trapped in the system. Again, it is recommended that the probe and tubing, along with the control unit, be moved such that any trapped air can escape the system.

15) During the entire operation, make sure the free end on the filling tube remains submerged.

16) Once the entire system is believed to be saturated, screw the cap back onto the plug at the end of the hollow probe and disconnect the probe tubing from the front panel, Probe 2. If the solid probe was used, disconnect the short saturation tubing from the end of the probe. The probe and tubing can now be transported in a saturated condition.

5.5.3 Check for Control Unit Saturation

1) Following Step 16, place both valves 3 and 4 in the "Test" position. Note that no tubing should be connected to the control unit at this time.

2) Rotate the crank-handle in the "Inflate" direction, until both analog and digital pressures read about 2,500 kPa. To prevent damage to the analog pressure gauge do not exceed 2,500 kPa. If the pressure stabilizes between 2,000 and 2,500 kPa, and the digital and counter volumes read less than 5 cm^3, then the components within the control unit are saturated.

3) If these volumes read more than 5 cm^3, the saturation of the control unit is inadequate. Reduce the volume reading to 0 cm^3 by rotating the handle in the "Deflate" direction. Repeat Steps 4 to 15 to saturate the system. Then repeat the above saturation processes (i.e. Sections 5.5.1 and 5.5.2).

4) If the pressure cannot be stabilized, there is a leak in the internal circuitry. Open the apparatus by removing the front panel and locate the leak by pressurizing the cylinder. Repair the leak and repeat the steps for saturation and check for saturation. Note all connections are made with Swagelock® connectors. Be sure to follow Swagelock's recommended protocol (found in the Swagelock® company literature) for tightening each fitting or the connections will be compromised

5) Note that there is no check for the entire system saturation, other than watching for air bubbles at the bottom of the probe.

5.6 Calibrations

Two calibrations are required and they are performed using two separate operations. One is the pressure (or membrane) calibration and the other is the volume loss (or system expansion) calibration. These calibrations are required if the protective sheath is replaced, the tubing has been changed, a large number of tests have been performed with the same sheathing, or if the initial calibration temperature is substantially different from the current testing temperature. The calibrations have the following purposes:

1) The pressure or membrane calibration is the pressure correction necessary to overcome the elastic resistance from the expansion of the membrane and protective metallic strips. The resistance to expansion is dependent on the type of rubber membrane and protective metallic strips used on the probe.

2) The volume loss calibration determines the volume correction caused by the expansion in the control unit system, as well as in the probe membrane and the tubing. At high pressures, the tubing in the system and the probe membrane expand and the thickness decreases, thereby causing a change in the volume. Although this change is very small, it is significant in very dense or stiff soils. This calibration, which is performed inside a metal tube, also allows the operator to properly set the probe diameter.

5.6.1 Pressure Calibration

The following steps are recommended to produce the proper pressure (or membrane) calibration. Membranes are not supplied with a number; therefore, each user should develop a convenient numbering system. Operators should make a note of the membrane number, if possible.

1) After completing the saturation procedure, place the probe in an upright position so that its mid-height is at the level of the pressure gauge.

2) Place valves 3 and 4 in the "Test" position.

3) Inflate and deflate the probe to 95 cm^3 at least twice to ensure the membrane resistance is fairly constant. This process ensures that the rubber membrane has been "worked" and is pliable.

4) A strain-controlled calibration is used for the pressure calibration, as 5 cm^3 volumes of water are injected into the probe until it has been inflated to 95 cm^3. After each 5 cm^3 of water is injected into the probe, either wait 15 seconds and manually record the data or wait until the green light is highlighted and press the "Take Membrane Calibration Reading" button on the laptop APMT software screen as shown in the Figure 5.5. The data acquired is stored in the desired location once the user clicks on "Calibration Complete F8".

The pressures from the resulting membrane resistance curve are subtracted from the pressures at the same volumes obtained during the PPMT test.

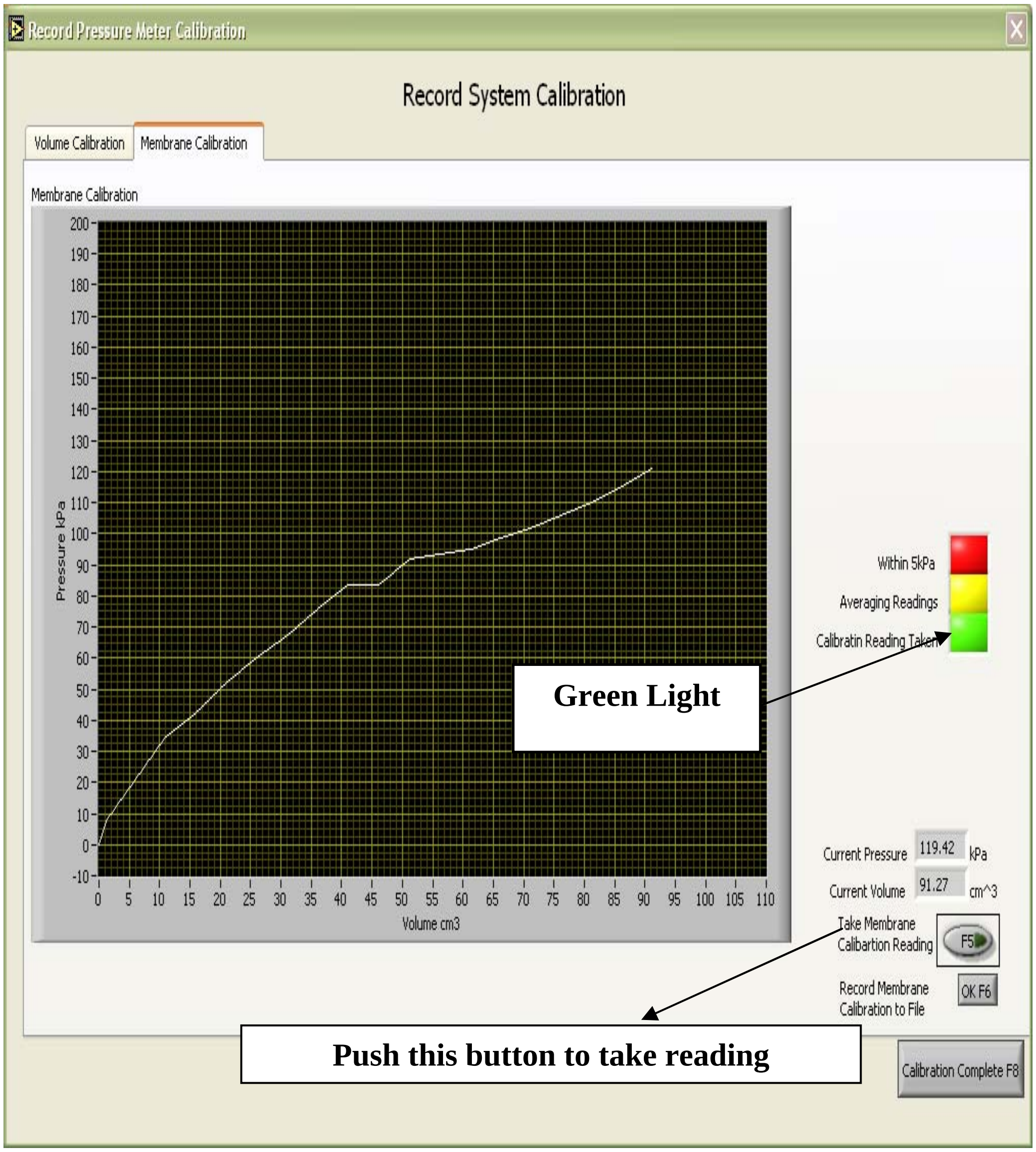


Figure 5.5 APMT membrane calibration screen with typical calibration data.

5.6.2 Volume Calibration

Two processes are needed to develop the recommended volume or system expansion calibration curve. The first process involves recording data and the second involves adjusting the data graphically. The procedure used is a stress-controlled one and is recommended because the critical data points from this process occur near the end of the test.

5.6.2.1 Volume Calibration Testing Procedure

The following steps are recommended to perform this calibration:

1) After completing the saturation procedure, place valves 3 and 4 in the "Test" position.

2) Insert the probe into the 32 mm internal diameter (I.D.) metal calibration tube. This diameter is recommended because it limits the initial diameter of the probe. A large probe diameter may produce membrane failure during pushing. Note: Roctest® recommends any thick-walled tube with an inside diameter of around 34 mm; however, this diameter may cause membrane failure.

3) To preset the probe diameter to approximately 32 mm, inflate the probe until it is snug inside the metal calibration tube. The operator should be able to remove the probe from the tube by hand. If the probe is too small, it will easily slide out of the tube or if it is too tight, the operator will not be able to remove it from the tube. This diameter is critical if the Pencel PMT is pushed into the soil, as it will prevent premature failure and allow the membrane to function for more tests than if the probe diameter is preset with a 34 mm I.D. diameter tube.

4) Inflate the probe by injecting water at the rate of 1/3 crank revolution per second. At 200 kPa increments for the standard 25,00 kPa gauge or 450 kPa increments for the special order 5,000 kPa high pressure gauge, either manually record volumes or press the record button on the APMT calibration screen. Note that a higher capacity pressure transducer is required for the 5,000 kPa gauge.

5) Inflate the probe until the pressure reaches a maximum value of 2,000 kPa. Again be careful to not exceed this value to prevent damage to the gauge. For the high-pressure gauge, increase the pressure up to 4,500 kPa.

6) Deflate the probe by rotating the handle in the reverse direction until the volume reads 0 cm^3.

5.6.2.2 Volume Calibration Data Reduction

7) Plot curve A, the original pressure versus volume curve, as shown in Figure 5.6. Note the APMT software (Appendix F) will automatically perform this data reduction.

8) Using the last two or three points along the straight-line portion of curve A, extrapolate them to the x-axis (volume axis). This line is defined as Line B (Figure 5.6).

9) To produce the recommended volume calibration, shift Line B to the origin and re-name it as Line C (Figure 5.6).

The volume correction curve is subtracted from the volume reading obtained during the PPMT test, which is conducted automatically by the data acquisition software.

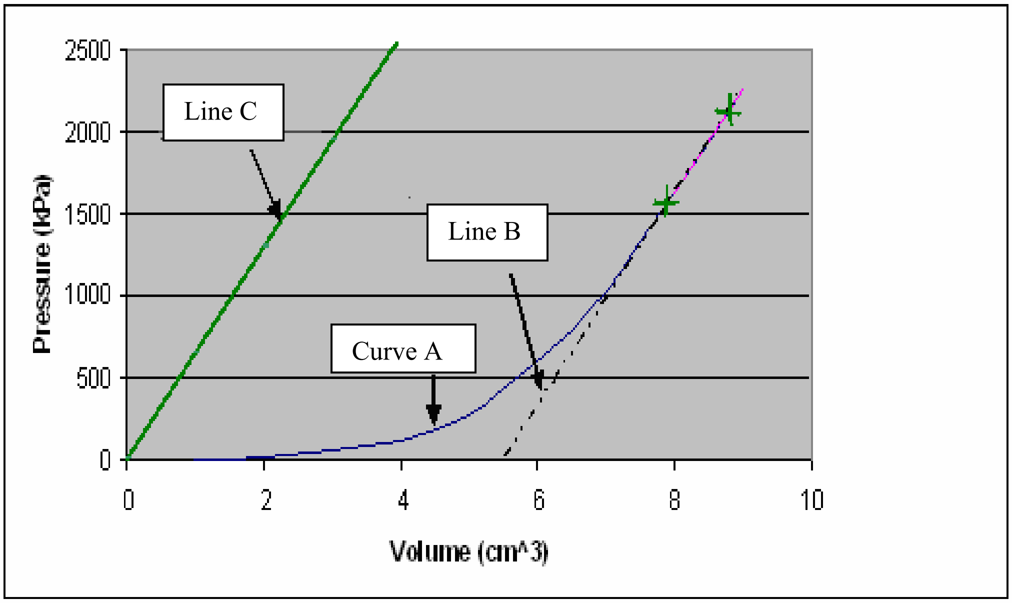


Figure 5.6 Recommended volume calibration of PPMT using 32 mm I.D. calibration sleeve showing initial data (curve A), adjusted volume slope (line B) and recommended volume calibration correction line (line C)

5.6.3 Probe Insertion

The Pencel® probe is designed for insertion by pushing or lightly driving. When pushing, CPT equipment is typically used and the probe is connected to hollow EW drill rods that have an external diameter of 34.9 mm (Figure 5.2). The tubing, beginning with the upper end that connects to the control panel, is strung or fed from bottom to top through the rods. The outside diameter of the Hanson® high-pressure quick connect at the upper end of the tubing is 15 mm.

Rods with an inside diameter of at least 16 mm can be used instead of EW rods. An EW male coupling must be fabricated for the connection to the probe. A slotted anvil adapted for the pushing system is screwed to the upper end of the rods. The slot allows the passage of the tubing while pushing rods.

5.6.4 Test Execution

The following steps are recommended for conducting a test:

1) When using instrumented control unit, turn on the laptop computer.

2) Connect the power input cable first to the control unit, then the computer's USB port to the power input port on the control unit as shown in Figure 5.7. Be sure to connect these cables in the order specified.

3) Connect the data transfer cable to the serial port of the laptop and the data output port on the control unit as shown in Figure 5.7.

4) Start the APMT software using the "Start: Programs: Florida Tech Automated Pressuremeter: Data Analysis" sequence of menus associated with Windows 2000 Operating System (please consult the APMT users manual (Appendix F) for complete installation and operation procedures).

5) Insert the probe to the required test depth. If pushing the PPMT with CPT equipment, push at a rate of 20 mm/sec and maintain a thrust below five tons to prevent buckling of the rods. Be sure the rods are secure and snug prior to insertion. Extra care should be taken when testing in very soft soils or through water, to prevent buckling. This may require casing, which may or may not be filled with sand to help prevent buckling.

6) Check that valves 3 and 4 are in the "Test" position.

7) Set the APMT program to the "Perform Automated Test" mode.

8) Fill all the tabs shown in the "Perform Automated Test", including sounding number and the test depth. This same information should be included on a standard data sheet. In addition, include such items as date, temperature, time, job description and operator.

9) Record the initial pressure reading either manually on the standard data sheet or automatically, by pressing "Record Data Point" on the computer screen at zero volume.

10) Begin a test by rotating the crank in the inflate direction in 5 cm^3increments of equal volume. Maintain a constant inflation rate of about 1 revolution per 9 seconds

11) Immediately after the crank is rotated to the desired volume, press the "Record Data Point" on the computer screen (Figure 5.8). Software modules within APMT were programmed to calculate the pressure changes over time and automatically record the pressure and volume data once the required change becomes relatively constant. The current software and hardware allows this change to be within 5 kPa or 1 bit. If data is to be recorded manually, wait 30 seconds in sands and 60 seconds in clays after the desired volume (or pressure) has been established and take an analog reading. The existing analog pressure gauges can only be read accurately to either 12.5 kPa for the 2,500 kPa model or 25 kPa for the 500 kPa model; therefore, the accuracy is improved by using the instrumentation. Note that in the event that the desired volume is exceeded; simply use the actual volume (i.e. 5.1 cm^3 or 25.3 cm^3). Do not deflate the probe, as this will affect the quality of the test.

12) Once the appropriate APMT module records a constant pressure, a green light turns on within the screen.

13) The operator must then rotate the crank to the next 5 cm^3 volume increment and repeat Step 11 again.

14) A software module within APMT produces a pressure versus volume curve, which is updated after every point is recorded.

15) During manual data collection of a strain-controlled test, the operator should track the changes in pressures associated with each volume increment. Once these pressure increments decrease, the soil is not within its linear response range and the pressure should be decreased from the current value to one-half of this value. The operator should wait 30 seconds and record the corresponding volume and then increase the pressure to the previous value and wait 30 seconds to take a reading and then continue the test.

Figure 5.7 Photograph of instrumented control unit

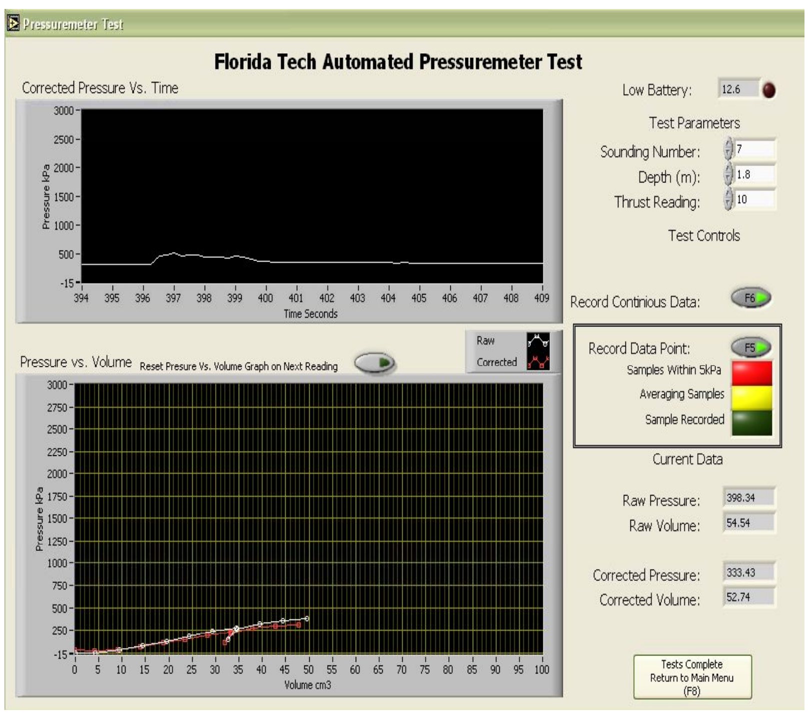


Figure 5.8 APMT screen showing the pressure–time and pressure–volume graph and the automatic recording of data point

16) During digital collection, the pressure versus volume curve will be displayed on the computer screen. In order to produce a consistent reload modulus as soon as the curve begins to deviate from the linear response, crank the handle in the deflate direction until the pressure becomes half the previous value (as shown in Figure 5.8).

17) Press the "Record Data Point" button on the computer screen and wait for the green light to turn on indicating the data has been recorded.

18) Crank the handle in the inflate direction until it reaches the same volume from where the deflate action was started as explained in step 15.

19) Continue the proper steps (i.e. injecting equal 5 cm^3 increments) until the volume reaches 90 cm^3 or until the limit of the pressure gauge has been reached.

20) From 90 cm^3, deflate to 85 cm^3 with readings every 1 cm^3 of volume. If data is collected digitally wait for the green light otherwise, wait 30 seconds between each 1 cm^3 increment before recording the pressure. If the test is stopped before 90 cm^3 is reached, unload from the final volume in 1 cm^3 increments for 5 cm^3.

21) Deflate to the zero volume reading by rotating the crank slowly at the speed of one rotation every three seconds. Extreme caution should be taken while deflating, so air does not enter the system.

22) Once the probe has been deflated, either continue pushing the device to the next desired test depth or remove it from the sounding and thoroughly clean all components as described below.

5.7 Probe Maintenance

Proper maintenance of the membrane will increase its useful life. Each time the probe is removed from a sounding or test boring, it should be thoroughly cleaned with water and mild soap (Figure 5.9). The protective membrane sleeves should be examined and straightened, if necessary. The black adhesive used to keep the protective metal strips in place on the rubber membrane will spread over time and should be cleaned so that soil and debris does not adhere to it during insertion.

Figure 5.9 Proper cleaning of membrane following probe removal from test boring or sounding

5.8 Interpretation of PPMT Data and Future Work

The APMT program directly converts the raw data to the reduced data. The details of the conversion and APMT software are explained in Appendix F.

After the test is completed, the initial modulus, rebound modulus, initial pressure and the limit pressure should be obtained using the reduced pressure versus volume data. This process is also explained in Appendix F.

The APMT software package developed could be upgraded to allow Robertson et al (1986) p–y methods to be included. The upgrade would most likely require the user to input a desired pile diameter and the module that would be added could produce a corresponding p–y curve for each PPMT test. The p–y curve format should be set such that it could be imported into FBMultipier for further use.

6 Chapter 6—CONCLUSIONS

The objectives for the research were met. The PPMT control unit was instrumented and the procedure for pushed-in PPMT test was standardized to allow development of p–y curves for laterally loaded deep foundations.

The instrumentation was accomplished by incorporating two cost-effective devices into the control unit to produce digital pressures and volumes that are used in a stand-alone LabVIEW® package (APMT) to yield a reduced stress–strain curve with easily obtainable engineering parameters. The combination of the instrumentation and data acquisition will result in significant time savings during testing. The instrumentation also improves the accuracy of the data, particularly the elastic moduli which are critical in determining p–y curves for laterally loaded piles.

The standardized procedure presented in Chapter 5 produced reliable data at three sites within Florida and realistic PPMT based p–y curves from the field-testing performed at Cape Canaveral, Florida.

The pile head load-deflection plots are relatively insensitive to variations in the individual p–y curves. If the PPMT testing is performed poorly the PPMT pile head load-deflection data becomes unconservative.

For drilled shafts, PPMT based p–y curves should be developed from the initial linear portion of the reduced stress–strain curve (i.e. based on E_o). For driven piles, PPMT based p–y curves should be developed from the rebound portion of the unload-reload loop from the reduced stress–strain curve (i.e. based on E_r).

6.1 Field Evaluation of PPMT

Cone-pushed PPMT data produces engineering parameters that matched published PMT data, where the PMT was inserted into a conventionally drilled borehole. Correlations were developed between PPMT parameters and DMT based parameters for sands and clays.

The APMT software, the ProvaFIT 2005 software or the Excel spreadsheet available from FDOT can be used to reduce raw PPMT data. The standalone APMT software yields field results, the ProvaFIT 2005 software reduces calculation mistakes associated with typical spreadsheet operations and is ideal for office or field data reduction. Analysis based on the Excel spreadsheet yielded errors and does not produce the elastic moduli, initial or limit pressures. Subroutines should be written (i.e. Macros) that would prevent the errors and allow the subsequent calculations to be performed. Data reduction with the spreadsheet software was the most tedious of the three methods.

Evaluation of the soil parameters produced from PPMT testing revealed that the friction reducer increases the disturbance in the soil surrounding the probe and subsequently causes a slight decrease in engineering parameters, and therefore, is not recommended.

The PPMT membranes proved to be very rugged when the membrane diameter was set to 32 mm, using the aluminum system calibration tube.

Of the two PPMT probe models available (i.e. solid and hollow core), the hollow core model would be the more rugged, because the thin vent tubes are not protruding from the probe ends.

Based on limited data a linear relationship was found between the PPMT lift-off pressure and in situ vertical effective stress in soft clay indicating that either overconsolidation ratios or in situ vertical stresses could be predicted.

The initial moduli, E_o, and the lift-off pressures, p_o, from the PPMT were similar to the DMT moduli and lift-off pressures in soft clays.

The average change in diameter and length from pushing are acceptable and as the correlations showed did not affect the engineering parameters.

6.2 Instrumentation of the PPMT

The control unit of the PPMT can be instrumented to digitally record and analyze the test data. A specific test procedure developed for conducting the PPMT test is presented in Chapter 5. The engineer has the ability to quickly evaluate the engineering parameters, such as the lift-off pressure, p_o, initial modulus, E_o, rebound modulus, E_r and limit pressure, p_L, for each soil tested. The raw data obtained from the APMT was in agreement with the data recorded manually using the conventional PPMT.

The APMT improves the precision of the data being collected and minimizes the potential for human error in recording the data. The APMT reduces the time required to collect and analyze PPMT data for one test to approximately 20 percent of the time taken by conventional system.

The actual volume of water injected into the probe during the initial inflate and deflate periods does not match displayed control unit volume. When the volume counter indicates 1.0 cm^3 of water is injected, only 0.3 cm^3 was measured. This difference is caused by the backlash between mating gears in the system used to produce volume changes in the piston and it affects elastic moduli, particularly the rebound moduli, E_r.

The APMT software allows the operator to control the VISP by evaluating the pressure versus time graph on the laptop screen and allows the operator to select times that yield more representative results.

When testing manually, the VISP, typically recommended as 15 seconds for sands or 30 seconds clays, may not be accurate. The APMT data indicates VISP's for various soils actually vary between 10 and 80 seconds; with sands averaging about 30 seconds and clays averaging about 45 seconds.

The initial elastic moduli obtained from the instrumented PPMT were slightly higher and the rebound moduli much higher than those from the manual PPMT, since the instrumentation corrects for the backlash in the gears. The error associated with the rebound moduli would adversely affect the corresponding p–y curves.

The laboratory length-to-diameter evaluation was inconclusive for variations in the probe length from 24.13 cm to 30.48 cm (9.5 in to 12 in). However, evaluations of the system calibration which are about 10 percent of the volume injected, implied that the squeezing of the existing metal sheathing may account a large percentage of this correction. The length-to-diameter ratio should not be altered; however, the stiffness of the protective metal sheathing should be redesigned.

6.3 P–y Curve Evaluations

Robertson's et al (1986) PPMT-based p–y curves produce comparable ultimate values, P_u, with Robertson's et al (1989) DMT-based p–y curves in soft clays and fine sands. The difference in the basic equations associated with each procedure produces two distinctly different curve shapes. The DMT equations yield a polynomial that continually increases while the PPMT equations yield curves that resemble the corresponding reduced curves. In sands both sets of equations may yield similar curves, while in clays the PPMT curves display clear limit pressures as they approach a horizontal asymptote.

The initial slopes from Robertson's et al (1986 and 1989) methods for PPMT and DMT p–y curves, respectively, were similar.

The seven lateral load test case histories clearly showed the need for a standard PPMT testing procedure. The most common errors associated with conventional PPMT testing were those associated with the unload–reload loop. This loop should be conducted as described in the standard procedure in Chapter 5, by unloading at the end of the linear stress–strain response range to one-half of the pressure at that point.

Properly conducted PPMT tests produced load-deflection predictions that were within 10 percent of the measured pile head load-deflections, while improperly conducted tests resulted in load-deflection predictions 25 percent or more higher than measured values

DMT derived p–y curves produced pile head deflections that were within 10 percent of the measured pile head load-deflections for six of the seven cases.

7 Chapter 7—RECOMMENDATIONS

The instrumented control unit with the stand-alone LabVIEW® package APMT is recommended for producing efficient, accurate in situ stress–strain data. ProvaFIT 2005 is recommended for reducing all PPMT data recorded manually. Both software packages should be upgraded to include the FDOT recommended p–y equations for laterally loaded piles.

The standard PPMT presented in Chapter 5 is recommended. It includes an unload–reload loop to half pressure at the end of the linear range, 5 cm^3 volume increments to 90 cm^3, a 15 second wait time per volume increment and an assumed linear system expansion based on 32 mm diameter calibration tube without a friction reducer on the cone tip.

A database of PPMT and DMT p–y curves should be developed for instrumented piles in various soils. Included within the database should be the methodology for conducting PPMT tests. For example, it should be noted whether or not unload-reload loops were performed and when they were conducted during the test, also it should be noted if the probe was inserted by pushing, etc.

In lieu of a length-to-diameter ratio evaluation, the stiffness of the protective metal sheath surrounding the PPMT probe should be evaluated. If softened, it may produce a more cylindrical probe expansion.

The PPMT with the instrumented control unit should be evaluated in conjunction with either existing or new lateral load tests. Several, of the seven sites evaluated during this research, could be retested with minimal efforts (i.e. Auburn, Salt Lake City Airport). It would not be necessary to evaluate deep foundations that were fully instrumented because this study showed that load-deflection comparisons at the pile head are adequate for comparing results. This evaluation should include evaluations of how the instrumentation performs under various soil conditions. The seven LLT sites should be retested with both the instrumented PPMT and DMT data.

To help disseminate these findings a short course should be offered to consultants in Florida.

8 Chapter 8—REFERENCES

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TABLE OF APPENDICES

A Appendix A PUSHED PRESSUREMETER DATA

A.1 Florida Institute of Technology Field Site

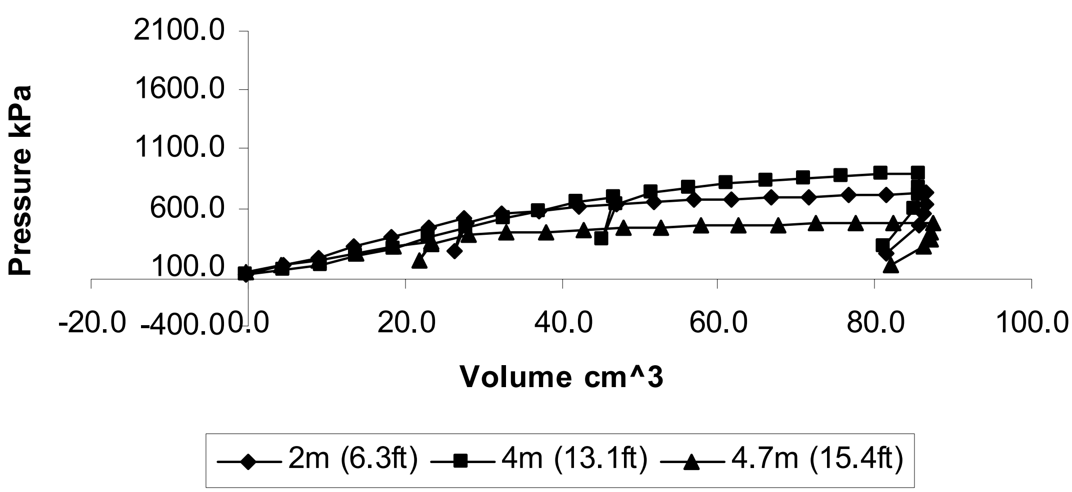
A.1.1 P. James – Reduced Data

A.1.1.1 Sounding B1

Sounding B1 - Smooth Tip

2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	5.57	38.4	-0.02	-0.3	5.54	38.2	-0.02	-0.4	8.71	60.0
0.27	4.4	15.73	108.4	0.28	4.5	9.89	68.2	0.27	4.4	15.96	110.0
0.55	9.1	26.61	183.4	0.57	9.3	17.86	123.2	0.56	9.1	23.21	160.0
0.83	13.7	39.65	273.4	0.85	13.9	28.00	193.1	0.84	13.8	32.62	224.9
1.11	18.3	51.98	358.4	1.14	18.6	38.15	263.1	1.13	18.5	40.60	279.9
1.40	22.9	62.84	433.3	1.42	23.2	51.19	352.9	1.43	23.4	46.38	319.8
1.69	27.6	72.99	503.3	1.70	27.9	62.79	432.9	1.34	22.0	23.46	161.8
1.61	26.4	34.89	240.6	1.98	32.5	74.41	513.1	1.43	23.4	43.48	299.8
1.70	27.8	67.19	463.3	2.27	37.2	83.82	577.9	1.72	28.1	54.36	374.8
1.98	32.4	78.81	543.4	2.56	42.0	93.25	642.9	2.02	33.0	55.82	384.9
2.27	37.3	83.87	578.3	2.85	46.7	101.21	697.8	2.32	37.9	57.98	399.8
2.57	42.1	88.22	608.3	2.76	45.2	47.55	327.8	2.61	42.8	60.88	419.8
2.87	47.0	91.84	633.2	2.87	47.0	91.06	627.8	2.92	47.8	63.04	434.6
3.17	51.9	94.04	648.4	3.15	51.6	105.60	728.1	3.22	52.7	63.80	439.9
3.47	56.9	96.91	668.2	3.44	56.4	111.36	767.8	3.52	57.7	64.49	444.6
3.77	61.8	96.94	668.4	3.74	61.2	116.47	803.1	3.82	62.6	65.25	449.9
4.07	66.7	99.82	688.2	4.04	66.1	119.34	822.8	4.13	67.6	66.66	459.6
4.37	71.7	101.28	698.3	4.34	71.0	122.26	842.9	4.43	72.6	67.41	464.8
4.67	76.6	103.17	711.3	4.63	75.9	126.33	871.0	4.73	77.5	67.85	467.8
4.98	81.5	103.60	714.3	4.93	80.8	128.21	884.0	5.03	82.5	68.29	470.8
5.28	86.5	104.76	722.3	5.23	85.7	130.10	897.0	5.34	87.5	68.70	473.7
5.27	86.4	90.36	623.0	5.23	85.7	112.79	777.7	5.33	87.3	57.22	394.5
5.26	86.2	80.31	553.7	5.22	85.5	102.02	703.4	5.31	87.0	49.34	340.2
5.22	85.6	65.28	450.1	5.19	85.0	84.82	584.8	5.26	86.3	39.40	271.6
4.98	81.6	31.49	217.1	4.96	81.3	40.87	281.8	5.00	81.9	17.93	123.6

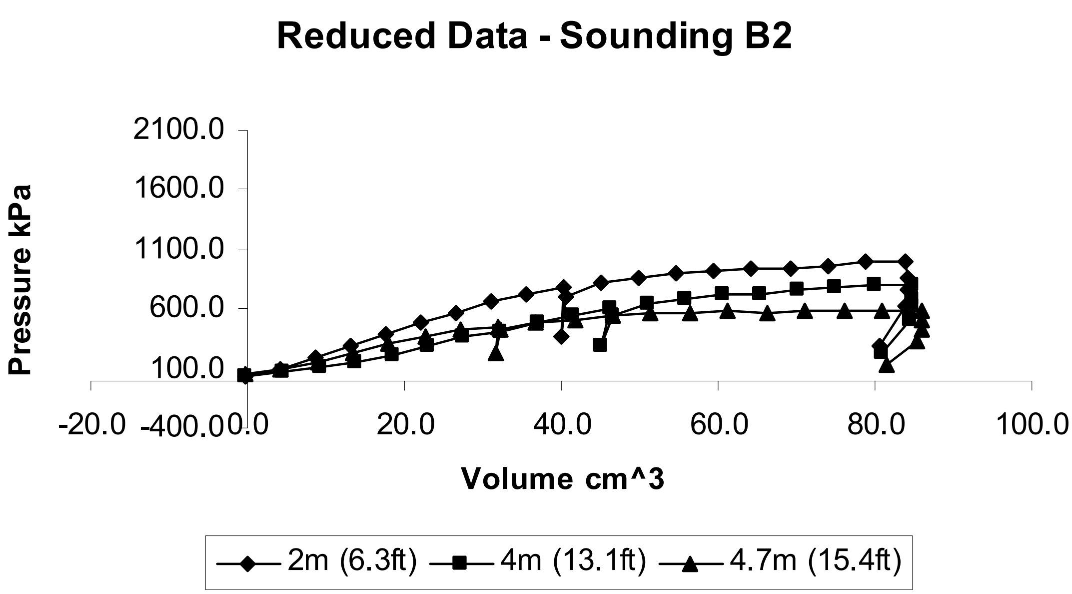
Reduced Data - Sounding B1



A.1.1.2 Sounding B2

Sounding B5 - Friction Reducer

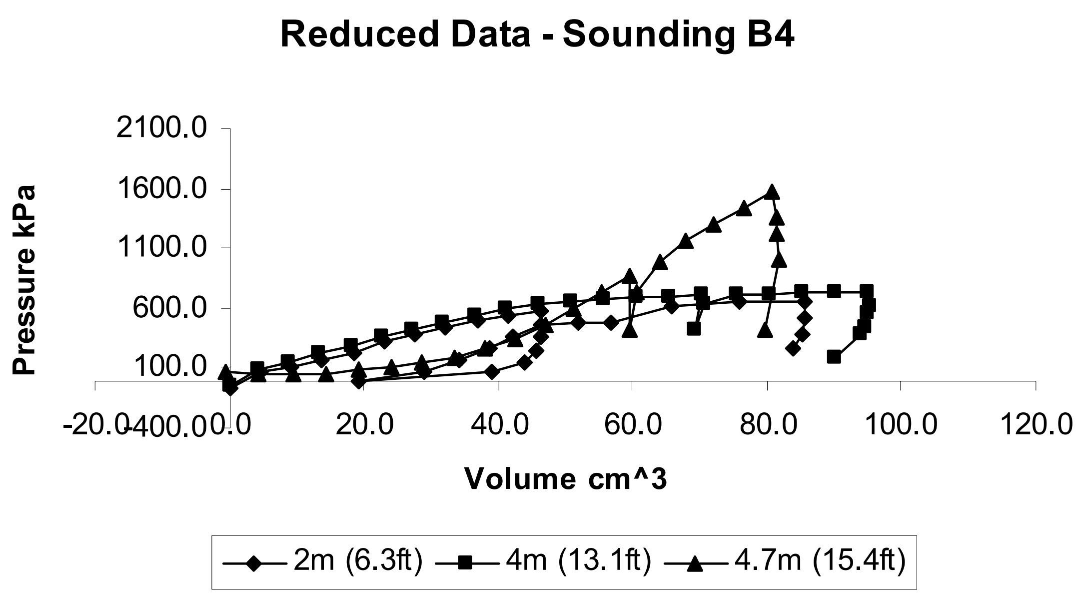
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	5.63	38.8	-0.02	-0.4	5.59	38.5	-0.03	-0.4	7.31	50.4
0.26	4.3	14.47	99.8	0.27	4.4	9.36	64.5	0.26	4.3	12.82	88.4
0.53	8.8	26.95	185.8	0.56	9.1	15.31	105.5	0.54	8.9	22.11	152.4
0.81	13.2	40.56	279.6	0.84	13.8	23.10	159.3	0.82	13.5	32.07	221.1
1.08	17.7	54.77	377.6	1.13	18.5	31.52	217.3	1.10	18.0	43.39	299.2
1.35	22.1	69.71	480.6	1.41	23.1	41.38	285.3	1.38	22.6	53.25	367.2
1.62	26.6	82.49	568.7	1.68	27.5	54.17	373.5	1.67	27.3	60.53	417.3
1.90	31.1	94.81	653.7	1.97	32.3	59.96	413.4	1.96	32.0	66.03	455.3
2.18	35.7	104.95	723.6	2.25	36.9	70.09	483.3	1.93	31.6	32.44	223.7
2.46	40.3	112.94	778.7	2.53	41.5	79.54	548.4	1.97	32.2	60.96	420.3
2.44	39.9	53.51	368.9	2.82	46.2	86.75	598.1	2.25	36.8	71.08	490.1
2.48	40.7	102.06	703.7	2.76	45.2	41.79	288.1	2.54	41.7	73.28	505.3
2.75	45.1	117.99	813.5	2.84	46.5	78.05	538.1	2.84	46.5	78.31	539.9
3.04	49.9	124.53	858.6	3.11	51.0	93.30	643.3	3.14	51.4	80.51	555.1
3.33	54.6	129.32	891.6	3.40	55.7	98.82	681.3	3.44	56.3	82.41	568.2
3.63	59.4	134.25	925.6	3.69	60.5	103.75	715.3	3.74	61.2	83.71	577.1
3.92	64.3	136.59	941.8	3.99	65.4	104.65	721.5	4.04	66.2	83.17	573.4
4.23	69.2	136.28	939.6	4.28	70.2	110.13	759.3	4.34	71.1	84.29	581.2
4.52	74.1	138.71	956.4	4.58	75.0	112.56	776.1	4.64	76.0	84.55	583.0
4.81	78.9	143.32	988.1	4.88	79.9	114.99	792.8	4.94	81.0	84.80	584.7
5.12	83.8	143.57	989.9	5.18	84.8	115.97	799.6	5.24	86.0	84.33	581.4
5.13	84.1	123.38	850.7	5.18	84.9	99.41	685.4	5.24	85.9	72.12	497.2
5.13	84.0	111.18	766.5	5.17	84.8	90.10	621.2	5.24	85.8	60.64	418.1
5.12	83.8	89.66	618.2	5.15	84.3	74.39	512.9	5.20	85.3	48.55	334.7
4.92	80.7	40.82	281.4	4.94	80.9	32.07	221.1	4.97	81.4	20.01	138.0



A.1.1.3 Sounding B4

Sounding B4 - Friction Reducer

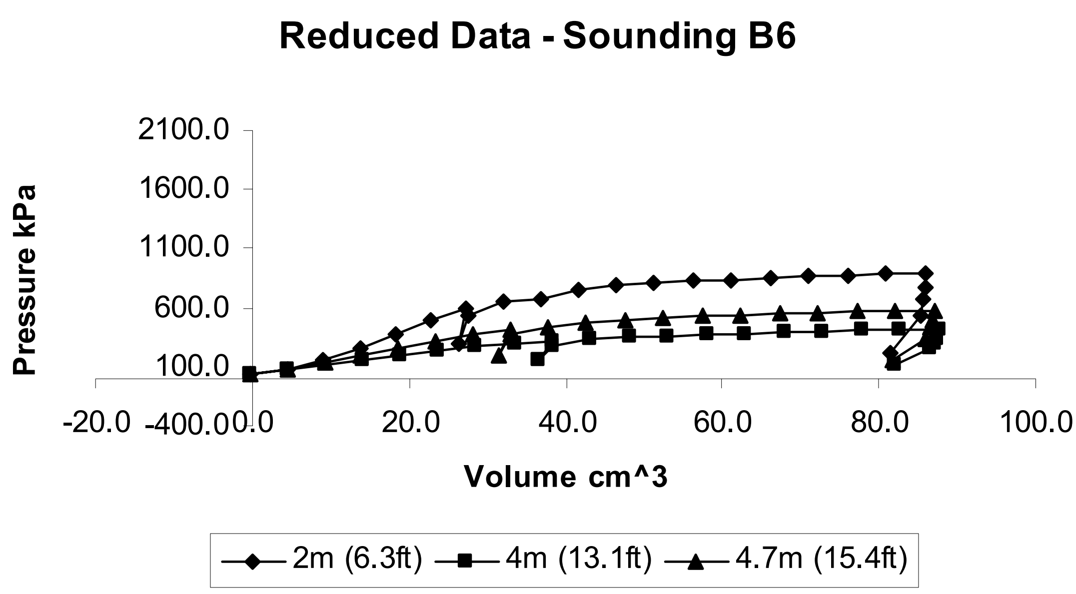
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.2	-8.94	-61.7	0.00	0.1	-6.08	-41.9	-0.03	-0.5	9.42	65.0
0.28	4.5	8.61	59.3	0.26	4.3	13.65	94.1	0.27	4.5	7.39	51.0
0.56	9.1	16.73	115.3	0.54	8.9	22.50	155.1	0.58	9.5	6.09	42.0
0.84	13.8	25.26	174.2	0.82	13.5	31.74	218.9	0.88	14.4	8.08	55.7
1.13	18.5	31.50	217.2	1.10	18.1	42.33	291.9	1.17	19.2	11.42	78.7
1.40	23.0	45.86	316.2	1.39	22.7	51.47	354.9	1.47	24.1	16.18	111.6
1.68	27.5	56.32	388.3	1.66	27.3	61.36	423.0	1.75	28.7	21.74	149.9
1.97	32.2	62.84	433.3	1.95	31.9	70.77	488.0	2.04	33.4	28.26	194.8
2.25	36.9	70.95	489.2	2.23	36.6	78.73	542.8	2.32	38.0	38.39	264.7
2.54	41.6	76.62	528.3	2.52	41.3	85.28	588.0	2.59	42.5	50.74	349.8
2.83	46.4	82.97	572.1	2.81	46.1	91.04	627.7	2.86	46.9	67.37	464.5
2.84	46.5	67.16	463.1	3.11	50.9	93.96	647.8	3.13	51.2	85.52	589.7
2.82	46.2	52.66	363.1	3.40	55.8	96.58	665.9	3.38	55.4	105.55	727.7
2.78	45.5	36.70	253.1	3.70	60.6	100.78	694.9	3.64	59.6	127.15	876.7
2.67	43.8	21.47	148.1	4.00	65.5	101.69	701.1	3.64	59.7	60.85	419.6
2.39	39.2	8.58	59.2	4.30	70.4	103.54	713.9	3.69	60.4	105.40	726.7
1.18	19.4	-0.35	-2.4	4.22	69.2	60.60	417.8	3.90	63.9	144.02	993.0
1.77	29.1	10.81	74.5	4.32	70.8	93.39	643.9	4.15	68.0	167.62	1155.7
2.10	34.3	24.29	167.5	4.60	75.4	103.07	710.7	4.41	72.2	188.91	1302.5
2.37	38.8	37.98	261.9	4.90	80.3	104.77	722.4	4.66	76.4	209.47	1444.2
2.58	42.3	52.74	363.7	5.20	85.2	105.75	729.1	4.93	80.8	228.55	1575.8
2.84	46.5	67.16	463.1	5.50	90.1	106.00	730.9	4.96	81.3	198.24	1366.8
3.18	52.1	69.32	477.9	5.80	95.1	106.98	737.6	4.98	81.5	178.05	1227.6
3.47	56.9	69.07	476.2	5.81	95.2	88.97	613.4	4.99	81.7	144.93	999.3
4.03	66.0	90.12	621.3	5.80	95.0	80.39	554.2	4.87	79.8	62.01	427.5
4.62	75.7	95.14	656.0	5.77	94.6	64.67	445.9				
5.22	85.6	96.37	664.4	5.74	94.0	54.03	372.5				
5.23	85.6	76.23	525.6	5.50	90.1	26.23	180.8				
5.20	85.2	56.21	387.6								
5.12	83.9	37.84	260.9								



A.1.1.4 Sounding B6

Sounding B6 - Smooth Tip

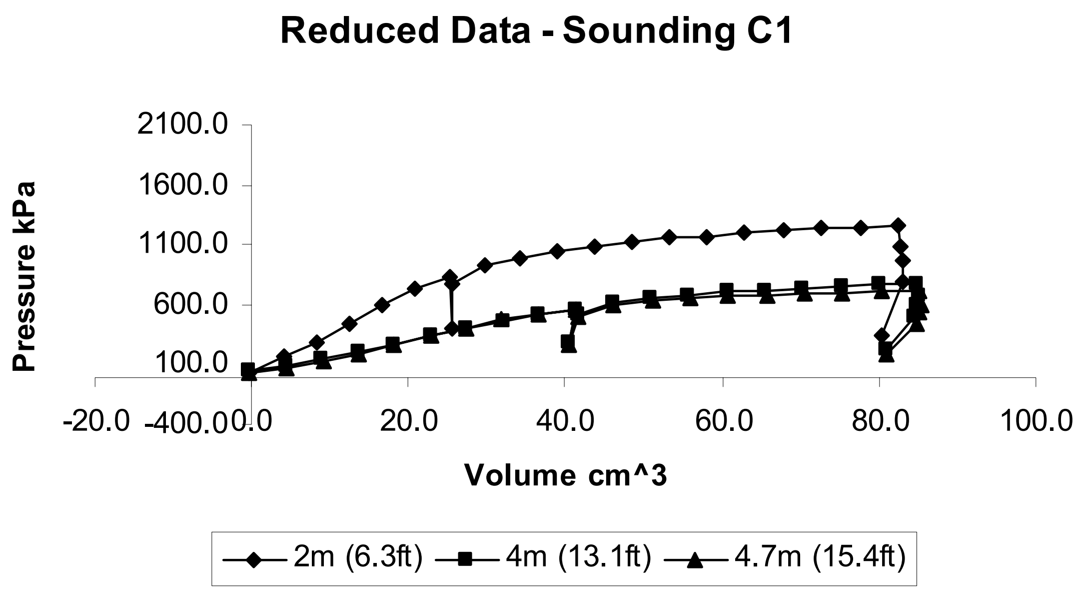
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	4.91	33.9	-0.02	-0.3	5.60	38.6	-0.02	-0.3	6.59	45.4
0.28	4.5	12.16	83.9	0.28	4.5	10.67	73.6	0.27	4.5	10.94	75.4
0.56	9.1	23.77	163.9	0.57	9.3	15.75	108.6	0.56	9.2	18.92	130.4
0.84	13.8	36.08	248.8	0.86	14.1	21.53	148.5	0.85	13.9	27.60	190.3
1.11	18.2	53.49	368.8	1.15	18.9	27.34	188.5	1.14	18.6	37.03	255.3
1.39	22.7	70.15	483.7	1.45	23.7	33.85	233.4	1.42	23.3	46.44	320.2
1.67	27.3	84.66	583.7	1.74	28.5	39.65	273.4	1.72	28.1	53.69	370.2
1.62	26.5	41.44	285.7	2.04	33.4	41.84	288.5	2.01	32.9	59.51	410.3
1.68	27.5	78.13	538.7	2.34	38.3	46.17	318.4	1.93	31.6	28.97	199.7
1.95	32.0	94.82	653.8	2.22	36.5	22.60	155.9	2.02	33.1	53.71	370.3
2.25	36.9	96.26	663.7	2.35	38.4	41.10	283.4	2.31	37.8	63.12	435.2
2.54	41.6	108.59	748.7	2.64	43.2	47.62	328.4	2.60	42.6	68.19	470.2
2.83	46.4	114.38	788.6	2.94	48.1	51.23	353.2	2.90	47.5	71.80	495.1
3.13	51.3	116.58	803.8	3.24	53.0	52.72	363.5	3.20	52.5	73.29	505.3
3.43	56.2	119.46	823.6	3.54	58.0	54.86	378.2	3.50	57.4	76.15	525.1
3.73	61.1	121.65	838.8	3.84	62.9	55.62	383.5	3.80	62.3	77.64	535.3
4.03	66.0	124.53	858.6	4.14	67.9	57.03	393.2	4.10	67.2	79.78	550.1
4.33	71.0	125.99	868.7	4.44	72.8	58.50	403.4	4.40	72.2	81.25	560.2
4.64	76.0	124.98	861.7	4.75	77.8	58.94	406.4	4.71	77.1	82.42	568.2
4.93	80.9	128.32	884.7	5.05	82.7	59.38	409.4	5.01	82.1	82.85	571.2
5.24	85.8	128.75	887.7	5.35	87.7	59.81	412.4	5.32	87.1	83.99	579.1
5.24	85.8	111.45	768.4	5.34	87.5	49.76	343.1	5.30	86.9	71.06	489.9
5.23	85.7	97.05	669.1	5.32	87.1	44.06	303.8	5.28	86.6	63.18	435.6
5.20	85.3	77.67	535.5	5.27	86.4	35.56	245.2	5.25	86.0	49.61	342.0
4.98	81.6	31.55	217.5	5.00	82.0	15.55	107.2	4.99	81.8	23.07	159.0



A.1.1.5 Sounding C1

Sounding C1 - Friction Reducer Tip

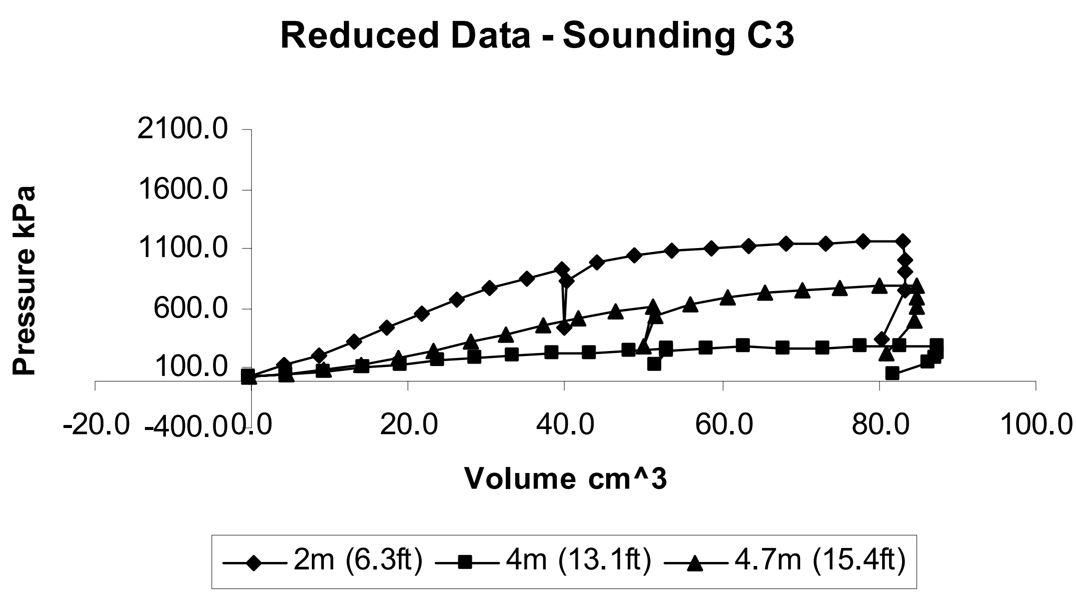
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	5.67	39.1	-0.03	-0.5	8.54	58.9	-0.02	-0.4	5.18	35.7
0.24	4.0	23.22	160.1	0.26	4.3	12.31	84.9	0.27	4.3	11.13	76.7
0.50	8.2	41.49	286.1	0.55	9.0	20.43	140.9	0.55	9.1	17.07	117.7
0.75	12.4	64.53	444.9	0.83	13.6	28.95	199.6	0.84	13.7	26.32	181.4
1.01	16.5	86.72	597.9	1.11	18.2	38.82	267.6	1.11	18.3	36.91	254.5
1.27	20.7	106.74	735.9	1.39	22.8	48.68	335.6	1.39	22.8	48.22	332.5
1.54	25.2	120.24	829.0	1.67	27.4	57.11	393.8	1.67	27.4	57.38	395.6
1.56	25.5	59.26	408.6	1.96	32.0	66.53	458.7	1.95	32.0	68.25	470.6
1.55	25.4	112.99	779.0	2.24	36.7	75.21	518.6	2.24	36.7	75.48	520.4
1.81	29.6	133.29	919.0	2.53	41.4	81.76	563.7	2.53	41.4	81.31	560.6
2.09	34.2	143.43	988.9	2.47	40.4	40.43	278.7	2.47	40.5	39.24	270.6
2.37	38.9	151.42	1044.0	2.54	41.7	73.78	508.7	2.54	41.7	73.33	505.6
2.66	43.6	158.64	1093.8	2.82	46.2	88.24	608.4	2.82	46.2	86.33	595.2
2.95	48.4	163.73	1128.9	3.11	50.9	94.07	648.6	3.12	51.1	91.42	630.3
3.25	53.2	167.80	1156.9	3.40	55.7	98.86	681.6	3.41	55.8	94.78	653.5
3.55	58.1	169.83	1170.9	3.70	60.6	102.34	705.6	3.70	60.7	97.53	672.4
3.84	62.9	173.62	1197.1	3.99	65.4	103.97	716.9	4.00	65.6	97.71	673.7
4.14	67.8	176.21	1214.9	4.29	70.3	106.55	734.6	4.30	70.5	100.29	691.5
4.43	72.7	178.64	1231.7	4.59	75.2	108.98	751.4	4.60	75.4	102.00	703.3
4.73	77.5	181.07	1248.4	4.88	80.0	110.68	763.1	4.90	80.3	102.25	705.0
5.03	82.4	182.05	1255.2	5.18	84.9	112.39	774.9	5.20	85.2	103.95	716.7
5.05	82.8	158.24	1091.0	5.19	85.0	96.55	665.7	5.21	85.3	87.39	602.5
5.06	83.0	140.23	966.8	5.18	84.9	86.52	596.5	5.20	85.2	78.08	538.4
5.06	83.0	113.63	783.5	5.15	84.5	71.53	493.2	5.17	84.7	63.10	435.0
4.90	80.4	49.57	341.7	4.94	80.9	33.57	231.4	4.95	81.1	28.03	193.3



A.1.1.6 Sounding C3

Sounding C3 - Friction Reducer Tip

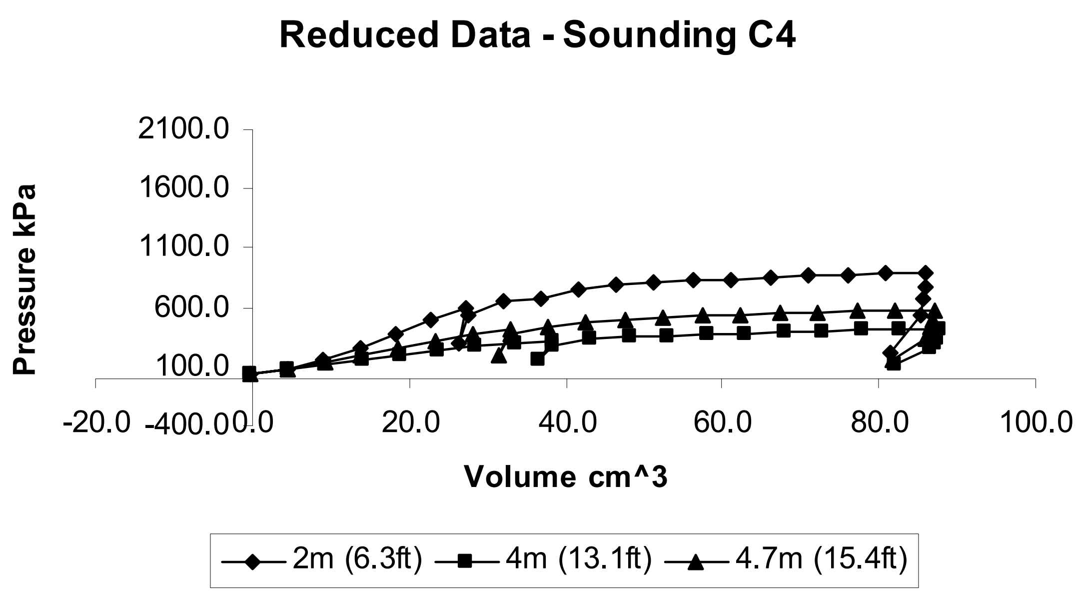
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	5.63	38.8	-0.02	-0.3	4.14	28.5	-0.02	-0.4	5.14	35.4
0.26	4.2	17.37	119.8	0.27	4.5	7.91	54.5	0.27	4.5	7.46	51.4
0.53	8.6	30.57	210.8	0.57	9.3	10.96	75.5	0.56	9.2	11.95	82.4
0.79	13.0	47.08	324.6	0.86	14.1	14.40	99.3	0.85	14.0	19.02	131.1
1.06	17.3	64.20	442.6	1.15	18.9	19.19	132.3	1.14	18.6	27.44	189.2
1.32	21.7	81.31	560.6	1.45	23.7	23.25	160.3	1.42	23.2	36.58	252.2
1.59	26.0	96.99	668.7	1.74	28.6	25.89	178.5	1.70	27.8	45.74	315.3
1.85	30.4	112.94	778.7	2.04	33.4	28.78	198.4	1.98	32.4	55.15	380.3
2.13	34.9	124.53	858.6	2.34	38.3	31.66	218.3	2.27	37.1	65.27	450.0
2.41	39.5	134.70	928.7	2.64	43.2	33.13	228.4	2.54	41.7	74.01	510.3
2.44	40.0	62.82	433.1	2.93	48.1	35.99	248.1	2.83	46.3	83.39	574.9
2.45	40.1	119.47	823.7	3.23	53.0	37.46	258.3	3.12	51.1	89.21	615.1
2.70	44.2	144.10	993.5	3.13	51.3	17.50	120.7	3.06	50.1	42.47	292.8
2.98	48.9	150.64	1038.6	3.24	53.1	35.28	243.3	3.14	51.5	76.89	530.1
3.27	53.7	156.15	1076.6	3.54	57.9	37.90	261.3	3.41	55.9	93.28	643.2
3.57	58.5	160.36	1105.6	3.83	62.8	39.93	275.3	3.70	60.6	100.39	692.1
3.87	63.3	161.98	1116.8	4.14	67.8	39.38	271.5	3.99	65.4	104.92	723.4
4.16	68.2	164.57	1134.6	4.44	72.8	39.06	269.3	4.28	70.2	108.95	751.2
4.46	73.1	165.55	1141.4	4.74	77.7	40.05	276.1	4.58	75.0	112.11	773.0
4.76	78.0	167.25	1153.1	5.04	82.6	40.30	277.8	4.88	79.9	113.81	784.7
5.06	82.9	168.95	1164.9	5.34	87.6	40.55	279.6	5.18	84.8	114.79	791.4
5.08	83.2	146.59	1010.7	5.33	87.4	31.97	220.4	5.18	84.9	99.68	687.2
5.08	83.3	131.48	906.5	5.31	87.0	27.73	191.2	5.18	84.8	88.19	608.1
5.08	83.2	107.79	743.2	5.26	86.3	22.17	152.9	5.15	84.4	71.75	494.7
4.91	80.4	48.80	336.4	4.99	81.8	7.42	51.1	4.93	80.9	33.79	233.0



A.1.1.7 Sounding C4

Sounding C4 - Smooth Tip

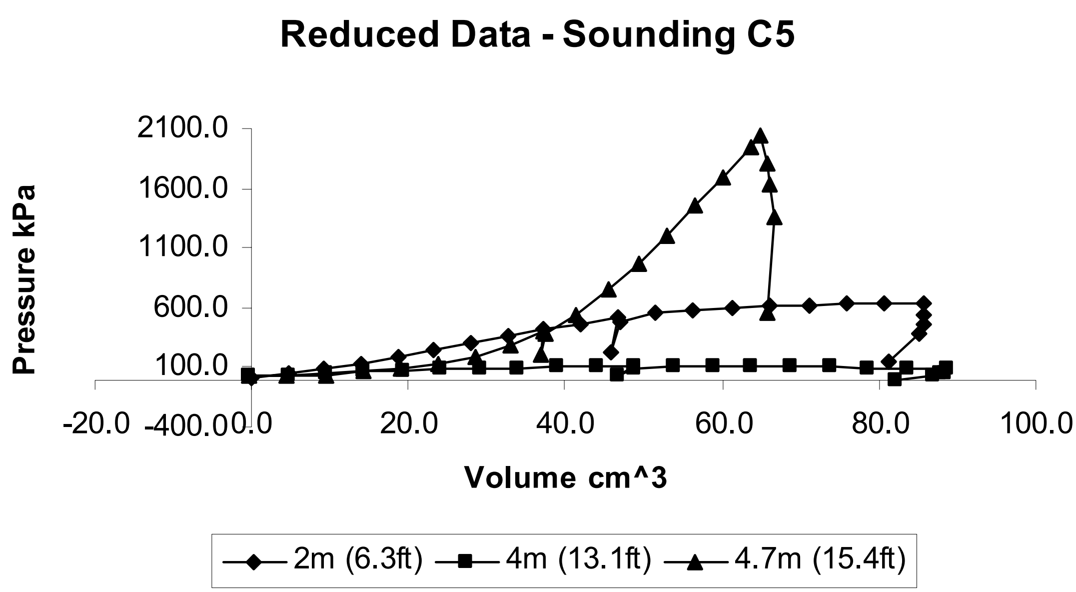
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	4.85	33.4	-0.02	-0.3	5.60	38.6	-0.02	-0.3	6.53	45.0
0.28	4.5	12.10	83.4	0.28	4.5	10.67	73.6	0.27	4.5	10.88	75.0
0.56	9.1	23.70	163.4	0.57	9.3	15.75	108.6	0.56	9.2	18.86	130.0
0.84	13.8	36.02	248.4	0.86	14.1	21.53	148.5	0.85	13.9	27.54	189.9
1.11	18.2	53.43	368.4	1.15	18.9	27.34	188.5	1.14	18.6	36.97	254.9
1.39	22.7	70.09	483.3	1.45	23.7	33.85	233.4	1.43	23.4	46.38	319.8
1.67	27.3	84.60	583.3	1.74	28.5	39.65	273.4	1.72	28.1	53.63	369.8
1.62	26.5	41.38	285.3	2.04	33.4	41.84	288.5	2.01	32.9	59.45	409.9
1.68	27.5	78.07	538.3	2.34	38.3	46.17	318.4	1.93	31.6	28.91	199.3
1.95	32.0	94.76	653.4	2.22	36.5	22.60	155.9	2.02	33.1	53.65	369.9
2.25	36.9	96.20	663.3	2.35	38.4	41.10	283.4	2.31	37.8	63.06	434.8
2.54	41.6	108.53	748.3	2.64	43.2	47.62	328.4	2.60	42.6	68.13	469.8
2.83	46.4	114.32	788.2	2.94	48.1	51.23	353.2	2.90	47.5	71.74	494.6
3.13	51.3	116.52	803.4	3.24	53.0	52.72	363.5	3.20	52.5	73.23	504.9
3.43	56.2	119.40	823.2	3.54	58.0	54.86	378.2	3.50	57.4	76.09	524.6
3.73	61.1	121.59	838.4	3.84	62.9	55.62	383.5	3.80	62.3	77.58	534.9
4.03	66.0	124.47	858.2	4.14	67.9	57.03	393.2	4.10	67.2	79.72	549.6
4.33	71.0	125.93	868.3	4.44	72.8	58.50	403.4	4.40	72.2	81.19	559.8
4.64	76.0	124.92	861.3	4.75	77.8	58.94	406.4	4.71	77.1	82.36	567.8
4.93	80.9	128.26	884.3	5.05	82.7	59.38	409.4	5.01	82.1	82.79	570.8
5.24	85.8	128.69	887.3	5.35	87.7	59.81	412.4	5.32	87.1	83.93	578.7
5.24	85.8	111.39	768.0	5.34	87.5	49.76	343.1	5.30	86.9	71.00	489.5
5.23	85.7	96.99	668.7	5.32	87.2	44.06	303.8	5.28	86.6	63.12	435.2
5.20	85.3	77.61	535.1	5.27	86.4	35.56	245.2	5.25	86.0	49.55	341.6
4.98	81.6	31.49	217.1	5.00	82.0	15.55	107.2	4.99	81.8	23.01	158.6



A.1.1.8 Sounding C5

Sounding C5 - Friction Reducer Tip

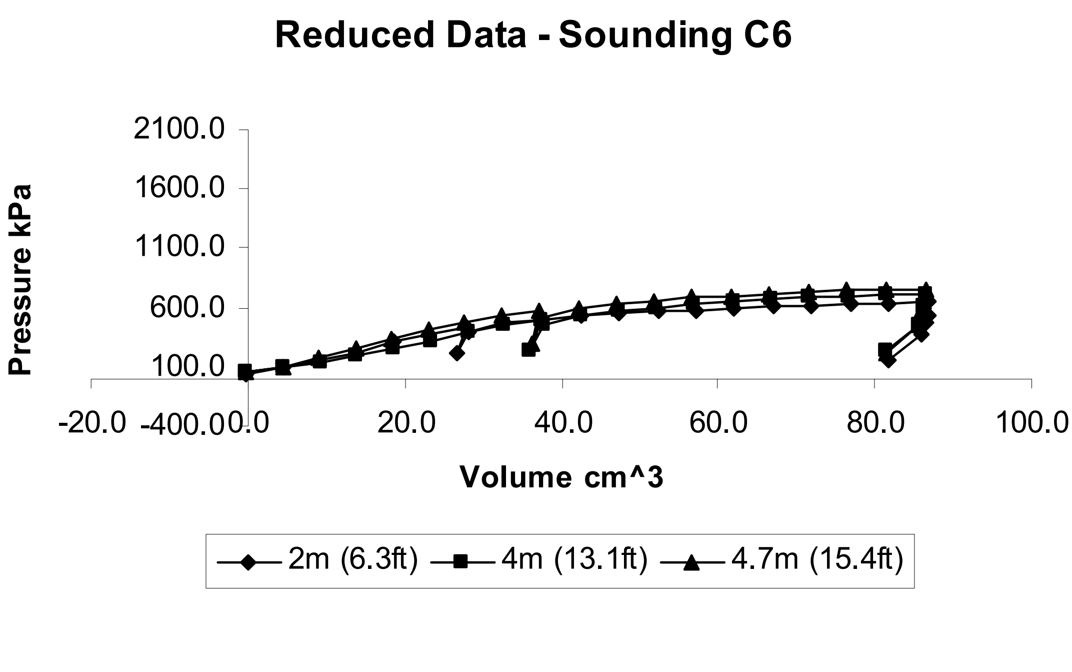
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	2.00	13.8	-0.02	-0.3	3.42	23.5	-0.02	-0.3	4.41	30.4
0.28	4.6	6.50	44.8	0.28	4.6	5.01	34.5	0.28	4.6	5.28	36.4
0.57	9.3	11.72	80.8	0.58	9.5	6.61	45.5	0.58	9.5	5.43	37.4
0.86	14.0	18.80	129.6	0.88	14.4	8.60	59.3	0.87	14.3	8.87	61.1
1.14	18.7	27.22	187.6	1.17	19.2	10.49	72.3	1.17	19.1	12.93	89.2
1.42	23.3	36.35	250.6	1.47	24.2	11.65	80.3	1.46	23.9	19.17	132.2
1.71	27.9	44.78	308.7	1.77	29.1	12.11	83.5	1.74	28.5	26.88	185.3
1.99	32.6	52.03	358.7	2.08	34.0	12.83	88.4	2.01	33.0	39.93	275.3
2.27	37.2	61.44	423.6	2.38	38.9	14.25	98.3	2.27	37.3	59.48	410.1
2.56	42.0	67.98	468.7	2.68	43.9	14.28	98.4	2.24	36.8	29.26	201.7
2.85	46.7	74.48	513.5	2.98	48.8	14.96	103.1	2.28	37.4	55.13	380.1
2.80	45.8	33.14	228.5	2.86	46.8	5.53	38.1	2.53	41.5	79.09	545.3
2.86	46.9	69.40	478.5	2.98	48.9	13.51	93.1	2.77	45.4	108.77	749.9
3.14	51.5	79.57	548.6	3.29	53.9	14.96	103.2	3.01	49.3	139.25	960.1
3.44	56.3	83.64	576.6	3.59	58.8	15.42	106.3	3.23	53.0	173.06	1193.2
3.73	61.2	87.11	600.6	3.89	63.7	15.27	105.3	3.45	56.6	210.62	1452.1
4.03	66.1	88.01	606.8	4.19	68.7	14.73	101.5	3.67	60.2	246.33	1698.4
4.33	71.0	89.15	614.6	4.50	73.7	14.41	99.3	3.89	63.8	282.99	1951.2
4.63	75.9	91.55	631.2	4.80	78.6	13.94	96.1	3.96	64.9	295.67	2038.6
4.93	80.8	91.83	633.1	5.10	83.6	13.47	92.8	4.01	65.6	262.43	1809.4
5.23	85.7	92.81	639.9	5.41	88.6	12.99	89.6	4.03	66.1	237.89	1640.2
5.23	85.7	78.42	540.7	5.39	88.3	8.03	55.4	4.06	66.5	197.50	1361.7
5.23	85.6	67.66	466.5	5.36	87.8	6.70	46.2	4.02	65.8	81.88	564.5
5.20	85.1	54.12	373.2	5.30	86.9	4.77	32.9				
4.97	81.4	21.97	151.4	5.01	82.1	-0.56	-3.9				



A.1.1.9 Sounding C6

Sounding C6 - Smooth Tip

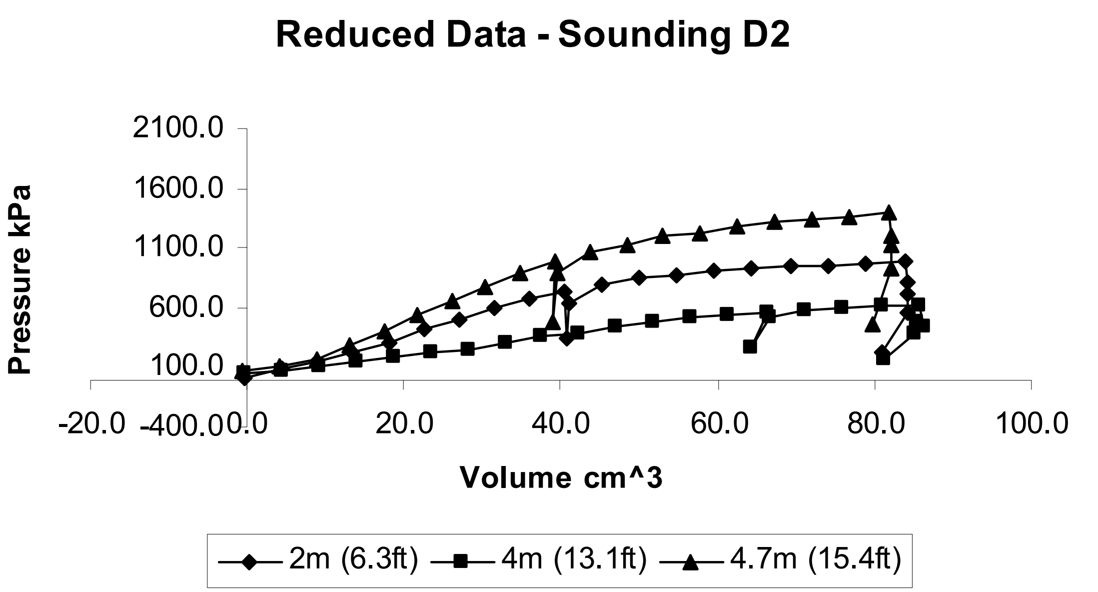
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	5.66	39.0	-0.02	-0.3	7.80	53.8	-0.02	-0.3	7.34	50.6
0.27	4.5	12.91	89.0	0.27	4.5	12.88	88.8	0.27	4.4	14.60	100.6
0.56	9.2	22.34	154.0	0.56	9.2	18.68	128.8	0.55	9.1	24.75	170.6
0.85	13.9	32.48	224.0	0.85	14.0	27.36	188.7	0.84	13.7	36.33	250.5
1.13	18.5	44.81	309.0	1.14	18.7	36.06	248.7	1.12	18.3	47.93	330.5
1.41	23.2	54.23	373.9	1.42	23.3	46.92	323.5	1.40	23.0	59.52	410.4
1.71	27.9	62.20	428.9	1.71	28.1	56.35	388.5	1.69	27.7	68.95	475.4
1.63	26.8	29.87	206.0	2.00	32.8	65.07	448.7	1.98	32.5	76.22	525.5
1.71	28.1	57.85	398.9	2.29	37.6	71.58	493.5	2.27	37.2	83.45	575.4
2.00	32.7	68.02	469.0	2.20	36.0	34.25	236.1	2.21	36.2	42.43	292.6
2.29	37.6	72.36	498.9	2.30	37.8	65.05	448.5	2.29	37.5	75.47	520.4
2.59	42.5	75.98	523.9	2.59	42.4	76.66	528.5	2.57	42.1	87.08	600.4
2.89	47.4	78.87	543.8	2.88	47.2	83.17	573.4	2.87	47.0	92.86	640.2
3.19	52.3	81.80	564.0	3.18	52.1	86.83	598.7	3.16	51.8	95.80	660.5
3.49	57.2	83.95	578.8	3.48	57.0	91.14	628.4	3.46	56.7	99.38	685.2
3.79	62.1	85.42	589.0	3.78	61.9	93.35	643.7	3.76	61.6	101.60	700.5
4.09	67.1	88.30	608.8	4.08	66.8	96.22	663.4	4.06	66.6	103.74	715.2
4.39	72.0	89.76	618.9	4.37	71.7	99.14	683.5	4.36	71.5	105.93	730.4
4.69	76.9	90.93	626.9	4.67	76.6	101.03	696.6	4.66	76.4	107.82	743.4
4.99	81.8	92.81	639.9	4.98	81.5	102.92	709.6	4.97	81.4	108.26	746.4
5.30	86.8	93.25	642.9	5.28	86.5	103.35	712.6	5.27	86.4	109.40	754.3
5.29	86.8	77.39	533.6	5.27	86.4	89.67	618.3	5.26	86.2	94.29	650.1
5.28	86.5	67.34	464.3	5.25	86.1	81.07	559.0	5.25	86.1	82.79	570.8
5.24	85.9	53.04	365.7	5.22	85.5	66.77	460.4	5.22	85.5	66.31	457.2
4.99	81.8	22.15	152.7	4.97	81.5	32.98	227.4	4.98	81.6	30.34	209.2



A.1.1.10 Sounding D2

Sounding D2 - Friction Reducer Tip

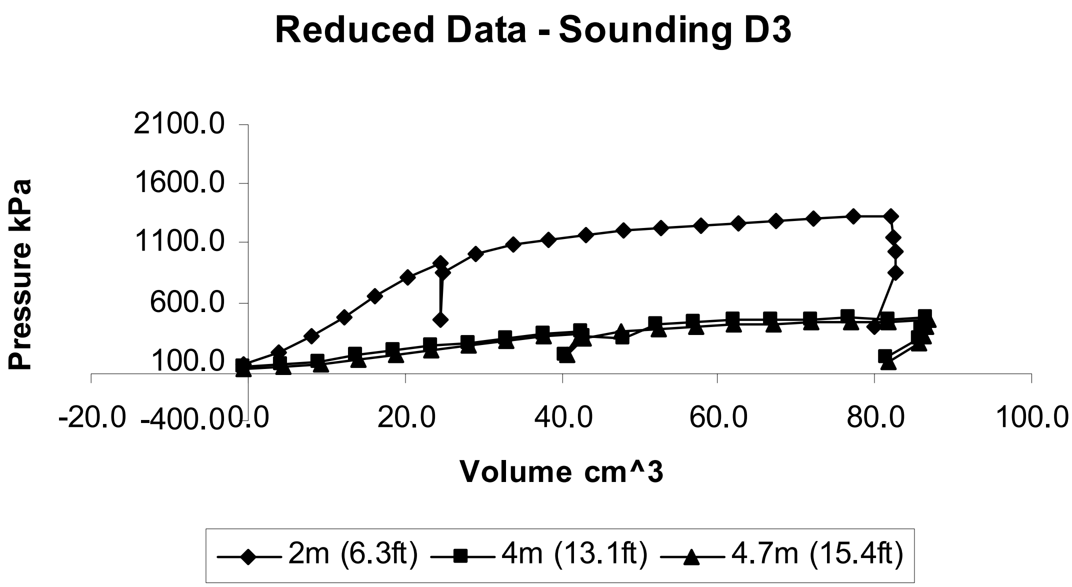
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	2.73	18.8	-0.02	-0.4	6.75	46.5	-0.03	-0.5	9.49	65.4
0.27	4.4	11.43	78.8	0.27	4.4	10.09	69.5	0.26	4.2	14.71	101.4
0.55	9.0	20.42	140.8	0.56	9.1	15.16	104.5	0.53	8.8	25.01	172.4
0.82	13.5	33.30	229.6	0.85	13.9	20.64	142.3	0.80	13.2	40.78	281.1
1.10	18.0	45.35	312.6	1.14	18.7	25.72	177.3	1.07	17.5	57.90	399.2
1.37	22.4	60.28	415.6	1.43	23.4	31.96	220.3	1.33	21.7	77.19	532.2
1.64	26.9	72.34	498.7	1.72	28.2	36.77	253.5	1.59	26.0	95.05	655.3
1.92	31.4	85.38	588.7	2.01	32.9	43.28	298.4	1.85	30.3	113.17	780.3
2.19	35.9	96.97	668.6	2.29	37.5	51.96	358.3	2.12	34.7	129.10	890.1
2.47	40.5	106.42	733.7	2.58	42.4	55.61	383.4	2.39	39.2	142.18	980.3
2.49	40.8	50.37	347.3	2.87	47.1	62.82	433.1	2.37	38.8	70.53	486.3
2.50	41.0	93.36	643.7	3.16	51.9	68.64	473.3	2.42	39.7	128.40	885.3
2.76	45.3	114.36	788.5	3.45	56.6	74.16	511.3	2.67	43.7	153.73	1059.9
3.05	49.9	122.35	843.6	3.75	61.4	78.36	540.3	2.95	48.3	163.91	1130.1
3.34	54.8	125.70	866.6	4.04	66.2	81.45	561.5	3.23	53.0	173.06	1193.2
3.63	59.5	132.08	910.6	3.92	64.3	37.95	261.6	3.52	57.8	177.98	1227.1
3.93	64.4	134.42	926.8	4.06	66.5	74.19	511.5	3.81	62.4	185.42	1278.4
4.22	69.2	137.01	944.6	4.34	71.2	82.28	567.3	4.10	67.2	190.90	1316.2
4.52	74.1	137.99	951.4	4.64	76.0	86.46	596.1	4.40	72.0	193.33	1333.0
4.82	79.0	141.29	974.1	4.94	80.9	88.16	607.8	4.69	76.8	197.93	1364.7
5.12	83.8	143.57	989.9	5.23	85.8	89.86	619.6	4.99	81.7	201.78	1391.3
5.14	84.3	119.03	820.7	5.26	86.3	62.42	430.4	5.01	82.2	174.37	1202.2
5.15	84.3	103.20	711.5	5.22	85.5	69.07	476.2	5.01	82.1	162.16	1118.1
5.14	84.2	80.23	553.2	5.19	85.0	56.26	387.9	5.01	82.1	134.85	929.7
4.94	81.0	32.12	221.4	4.95	81.2	25.55	176.1	4.86	79.6	67.15	463.0



A.1.1.11 Sounding D3

Sounding D3 - Smooth Tip

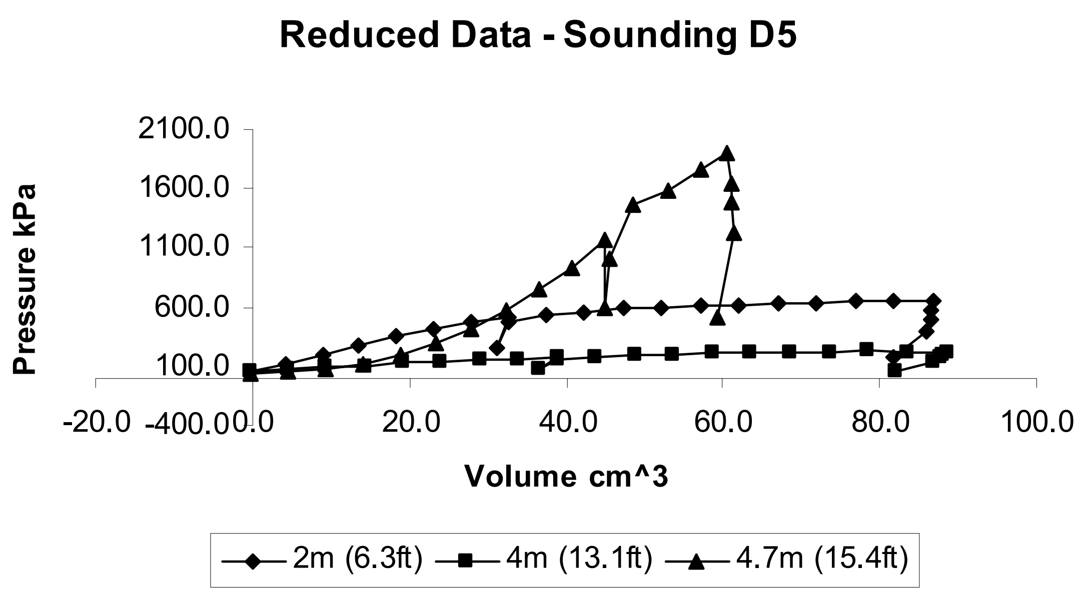
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.5	9.91	68.3	-0.03	-0.4	7.70	53.1	-0.02	-0.4	6.52	45.0
0.25	4.0	24.52	169.1	0.27	4.4	11.47	79.1	0.27	4.5	8.12	56.0
0.49	8.1	45.01	310.3	0.56	9.1	15.24	105.1	0.56	9.2	11.89	82.0
0.74	12.2	69.50	479.2	0.85	13.9	21.59	148.9	0.86	14.0	16.78	115.7
0.99	16.2	95.32	657.2	1.14	18.6	27.11	186.9	1.15	18.8	23.02	158.7
1.24	20.3	117.51	810.2	1.43	23.4	33.34	229.9	1.43	23.5	29.26	201.7
1.50	24.7	134.64	928.3	1.72	28.1	38.15	263.0	1.72	28.2	34.79	239.9
1.50	24.6	66.65	459.5	2.01	32.9	43.22	298.0	2.01	33.0	39.86	274.8
1.53	25.0	124.49	858.3	2.30	37.7	48.27	332.8	2.31	37.8	44.19	304.7
1.78	29.2	146.24	1008.3	2.59	42.5	51.92	358.0	2.60	42.6	47.84	329.8
2.06	33.7	157.10	1083.2	2.47	40.5	23.81	164.2	2.49	40.9	23.24	160.2
2.35	38.5	162.91	1123.3	2.61	42.7	46.12	318.0	2.61	42.8	42.76	294.8
2.64	43.2	170.14	1173.1	2.92	47.8	42.45	292.7	2.90	47.5	51.41	354.5
2.93	48.1	173.78	1198.2	3.18	52.2	59.87	412.8	3.20	52.4	54.34	374.7
3.22	52.8	178.57	1231.2	3.48	57.0	62.49	430.9	3.49	57.2	56.96	392.7
3.52	57.7	181.32	1250.2	3.78	61.9	65.25	449.9	3.79	62.1	59.71	411.7
3.82	62.6	183.67	1266.3	4.08	66.8	65.43	451.1	4.09	67.0	60.62	418.0
4.12	67.4	185.53	1279.2	4.38	71.8	66.56	458.9	4.39	71.9	61.75	425.7
4.41	72.3	188.69	1301.0	4.68	76.7	67.54	465.7	4.69	76.8	62.73	432.5
4.71	77.2	191.11	1317.7	4.98	81.6	67.06	462.4	4.99	81.8	63.71	439.2
5.01	82.1	192.09	1324.4	5.28	86.6	68.04	469.1	5.30	86.8	64.66	445.8
5.03	82.5	167.55	1155.2	5.27	86.4	58.73	404.9	5.28	86.5	56.10	386.8
5.04	82.6	149.54	1031.1	5.25	86.0	55.23	380.8	5.27	86.3	46.79	322.6
5.04	82.6	124.40	857.7	5.22	85.5	43.14	297.4	5.23	85.7	36.15	249.3
4.89	80.1	56.71	391.0	4.97	81.4	20.41	140.7	4.98	81.6	13.42	92.5



A.1.1.12 Sounding D5

Sounding D5 - Smooth Tip

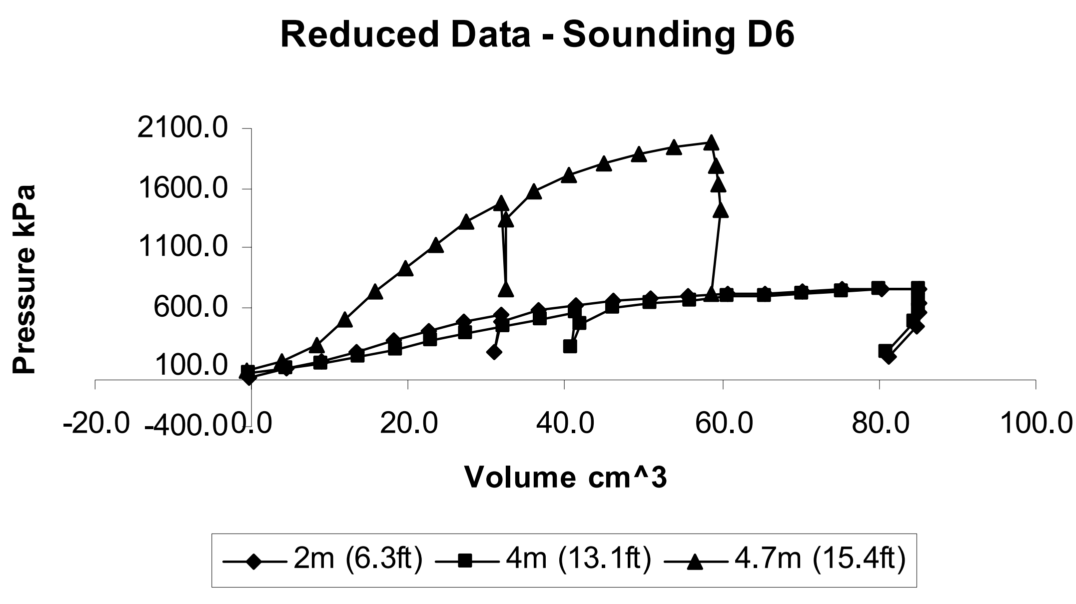
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	7.79	53.7	-0.02	-0.3	7.76	53.5	-0.02	-0.3	6.57	45.3
0.27	4.4	17.95	123.7	0.28	4.5	9.93	68.5	0.28	4.6	8.02	55.3
0.55	9.0	28.10	193.7	0.57	9.4	12.83	88.5	0.58	9.4	11.65	80.3
0.83	13.7	39.69	273.7	0.87	14.3	14.99	103.4	0.87	14.2	18.16	125.2
1.12	18.3	51.29	353.7	1.17	19.2	18.62	128.4	1.15	18.9	27.59	190.2
1.40	23.0	60.71	418.6	1.47	24.1	20.77	143.2	1.43	23.5	41.35	285.1
1.69	27.8	68.69	473.6	1.77	29.0	22.95	158.2	1.71	28.0	59.48	410.1
1.99	32.6	73.05	503.7	2.07	33.9	23.69	163.4	1.97	32.3	82.70	570.2
1.90	31.2	36.06	248.7	2.37	38.9	25.13	173.2	2.23	36.5	110.24	760.1
2.00	32.7	67.97	468.7	2.22	36.4	12.48	86.0	2.49	40.8	135.62	935.1
2.29	37.5	77.39	533.6	2.38	38.9	22.95	158.2	2.74	44.8	168.96	1164.9
2.58	42.4	80.29	553.6	2.68	43.8	25.85	178.2	2.74	44.9	84.84	584.9
2.88	47.2	84.63	583.5	2.98	48.8	28.01	193.1	2.77	45.4	147.20	1014.9
3.19	52.2	84.65	583.7	3.28	53.7	28.04	193.4	2.96	48.6	212.51	1465.2
3.48	57.1	88.26	608.5	3.58	58.7	30.18	208.1	3.24	53.1	230.60	1589.9
3.78	62.0	89.73	618.7	3.88	63.6	30.22	208.4	3.50	57.3	256.02	1765.2
4.09	67.0	91.16	628.5	4.19	68.6	31.64	218.1	3.70	60.6	274.84	1894.9
4.39	71.9	92.62	638.6	4.49	73.6	32.38	223.2	3.73	61.1	238.58	1644.9
4.69	76.8	94.51	651.6	4.79	78.5	32.82	226.3	3.74	61.2	216.10	1489.9
4.99	81.8	94.94	654.6	5.10	83.5	32.53	224.3	3.74	61.3	177.66	1224.9
5.29	86.8	94.65	652.6	5.40	88.5	31.51	217.3	3.61	59.2	74.93	516.6
5.29	86.6	81.70	563.3	5.38	88.1	27.99	193.0				
5.27	86.4	71.65	494.0	5.35	87.7	24.47	168.7				
5.24	85.8	57.35	395.4	5.30	86.8	19.59	135.1				
4.99	81.7	25.73	177.4	5.01	82.2	8.28	57.1				



A.1.1.13 Sounding D6

Sounding D6 - Friction Reducer Tip

2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	2.73	18.8	-0.02	-0.4	6.32	43.5	-0.03	-0.5	9.49	65.4
0.27	4.4	11.57	79.8	0.27	4.4	12.22	84.3	0.24	3.9	22.69	156.4
0.55	9.0	21.14	145.8	0.55	9.0	18.93	130.5	0.50	8.2	41.69	287.4
0.82	13.5	34.03	234.6	0.83	13.7	27.46	189.3	0.73	12.0	73.41	506.1
1.10	18.0	46.80	322.6	1.13	18.5	36.56	252.1	0.96	15.8	105.03	724.2
1.37	22.5	58.11	400.6	1.40	23.0	46.44	320.2	1.20	19.6	134.48	927.2
1.65	27.1	68.71	473.7	1.68	27.5	55.62	383.5	1.43	23.5	163.94	1130.3
1.94	31.7	76.68	528.7	1.96	32.1	65.04	448.4	1.67	27.4	191.49	1320.3
1.89	31.0	33.84	233.3	2.24	36.8	72.99	503.3	1.94	31.7	213.21	1470.0
1.95	32.0	70.16	483.7	2.53	41.5	79.54	548.4	1.97	32.3	107.81	743.3
2.22	36.5	83.19	573.6	2.49	40.8	37.39	257.8	1.97	32.3	195.09	1345.1
2.52	41.2	88.29	608.7	2.56	42.0	66.49	458.4	2.20	36.0	229.20	1580.3
2.81	46.0	94.06	648.5	2.82	46.2	86.02	593.1	2.46	40.3	247.28	1704.9
3.10	50.8	97.70	673.6	3.11	51.0	91.85	633.3	2.73	44.8	261.08	1800.1
3.40	55.7	100.31	691.6	3.41	55.8	95.92	661.3	3.01	49.3	272.41	1878.2
3.70	60.6	103.07	710.6	3.70	60.7	99.39	685.3	3.29	53.9	283.13	1952.1
4.00	65.5	103.96	716.8	4.00	65.5	101.03	696.5	3.58	58.7	286.95	1978.4
4.29	70.4	105.83	729.6	4.29	70.4	104.33	719.3	3.62	59.3	258.14	1779.8
4.59	75.2	108.26	746.4	4.59	75.3	105.31	726.1	3.63	59.5	236.63	1631.5
4.89	80.2	107.78	743.1	4.89	80.2	107.74	742.8	3.64	59.7	205.81	1419.0
5.19	85.1	108.76	749.9	5.19	85.0	109.44	754.6	3.57	58.5	103.64	714.5
5.20	85.2	92.93	640.7	5.20	85.1	93.61	645.4				
5.20	85.2	80.72	556.5	5.19	85.0	84.30	581.2				
5.17	84.8	64.28	443.2	5.16	84.5	69.31	477.9				
4.95	81.2	27.77	191.4	4.94	80.9	32.07	221.1				

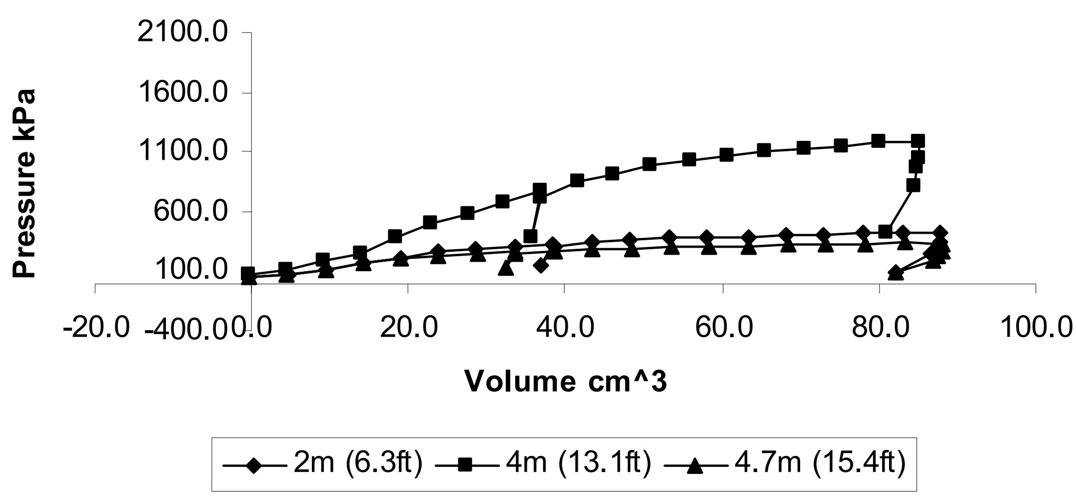


A.1.1.14 Sounding E1

Sounding E1 - Friction Reducer Tip

2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.2	5.76	39.7	-0.02	-0.3	9.35	64.4	-0.02	-0.3	8.17	56.3
0.28	4.6	10.11	69.7	0.27	4.4	15.87	109.4	0.28	4.5	11.07	76.3
0.57	9.4	15.90	109.6	0.56	9.1	26.74	184.3	0.57	9.3	16.85	116.2
0.87	14.2	23.85	164.5	0.84	13.8	36.86	254.1	0.86	14.1	24.07	166.0
1.16	19.0	30.40	209.6	1.12	18.3	54.29	374.3	1.16	19.0	28.45	196.2
1.45	23.8	36.91	254.5	1.40	22.9	70.94	489.1	1.45	23.8	33.50	231.0
1.75	28.6	41.28	284.6	1.68	27.5	84.75	584.3	1.75	28.7	34.98	241.2
2.05	33.5	44.88	309.5	1.96	32.2	98.50	679.1	2.05	33.6	37.85	261.0
2.35	38.4	47.79	329.5	2.24	36.8	112.28	774.1	1.99	32.5	18.50	127.6
2.26	37.0	21.26	146.6	2.17	35.6	54.64	376.7	2.06	33.7	34.95	241.0
2.35	38.5	44.16	304.5	2.26	37.0	103.57	714.1	2.36	38.6	39.30	271.0
2.64	43.3	50.70	349.6	2.53	41.5	122.44	844.2	2.66	43.5	41.49	286.0
2.95	48.3	51.42	354.5	2.82	46.2	131.87	909.2	2.96	48.5	41.49	286.1
3.25	53.2	55.03	379.4	3.11	51.0	141.99	979.0	3.26	53.5	42.91	295.8
3.55	58.2	55.76	384.5	3.40	55.8	149.26	1029.1	3.56	58.4	44.37	306.0
3.86	63.2	55.75	384.4	3.70	60.7	154.34	1064.1	3.87	63.4	44.37	306.0
4.15	68.1	59.38	409.4	4.00	65.5	159.40	1099.0	4.17	68.3	45.81	315.8
4.46	73.0	59.40	409.5	4.29	70.4	163.78	1129.2	4.47	73.3	46.57	321.1
4.76	78.0	60.11	414.5	4.59	75.3	166.67	1149.1	4.78	78.3	46.55	321.0
5.06	83.0	60.83	419.4	4.89	80.2	171.73	1184.0	5.08	83.2	48.71	335.8
5.37	87.9	61.23	422.2	5.19	85.1	172.57	1189.8	5.38	88.2	47.67	328.7
5.35	87.7	50.46	347.9	5.19	85.1	152.66	1052.6	5.37	88.0	38.35	264.4
5.33	87.4	43.31	298.6	5.18	84.9	139.71	963.3	5.35	87.6	32.65	225.1
5.29	86.6	34.10	235.1	5.15	84.5	118.90	819.8	5.30	86.8	25.61	176.6
5.01	82.1	13.69	94.4	4.94	80.9	61.50	424.0	5.01	82.1	12.45	85.8

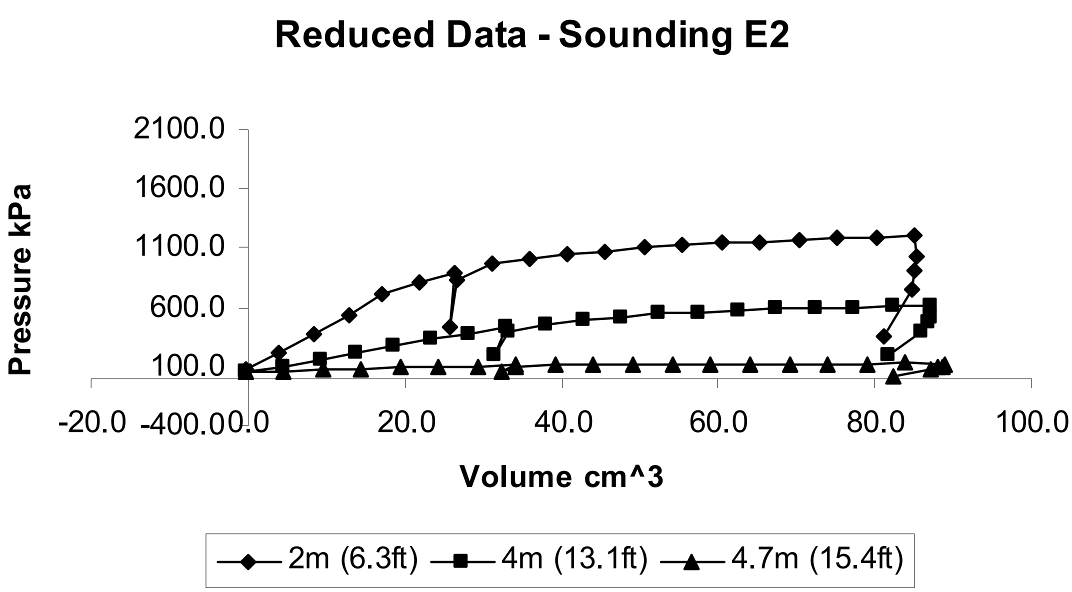
Reduced Data - Sounding E1



A.1.1.15 Sounding E2

Sounding E2 - Smooth Tip

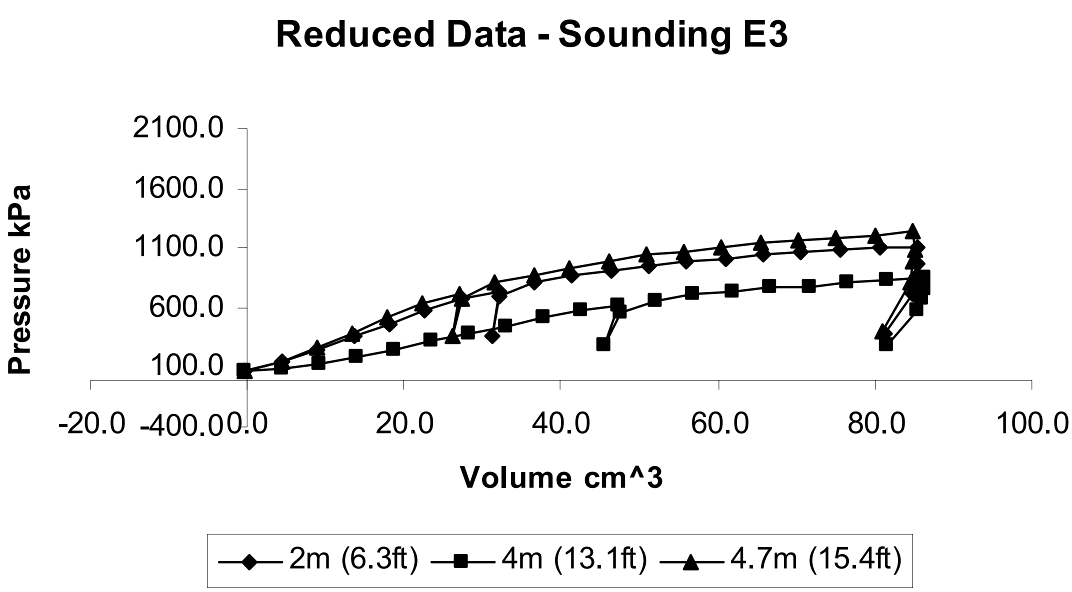
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.4	12.30	84.8	-0.02	-0.3	9.37	64.6	-0.02	-0.3	6.74	46.5
0.25	4.1	31.16	214.8	0.27	4.5	14.44	99.6	0.28	4.6	8.19	56.5
0.52	8.5	53.63	369.8	0.56	9.2	23.13	159.5	0.58	9.5	9.62	66.3
0.78	12.8	78.27	539.6	0.85	14.0	31.80	219.3	0.88	14.4	12.49	86.1
1.05	17.2	102.22	704.8	1.14	18.7	39.81	274.5	1.18	19.4	13.25	91.3
1.33	21.7	118.88	819.6	1.43	23.5	48.48	334.3	1.48	24.3	13.94	96.1
1.61	26.4	129.77	894.8	1.73	28.3	54.31	374.5	1.78	29.2	14.70	101.3
1.58	25.8	62.61	431.7	2.02	33.1	61.54	424.3	2.09	34.2	15.39	106.1
1.63	26.7	120.35	829.8	1.93	31.6	29.24	201.6	1.98	32.4	6.98	48.1
1.90	31.2	139.18	959.6	2.02	33.2	57.18	394.3	2.09	34.2	13.94	96.1
2.19	36.0	147.16	1014.6	2.31	37.9	66.61	459.3	2.39	39.2	15.39	106.1
2.49	40.8	150.80	1039.7	2.61	42.8	71.70	494.4	2.69	44.2	16.13	111.2
2.79	45.7	155.87	1074.7	2.91	47.7	75.33	519.4	3.00	49.1	15.41	106.2
3.09	50.6	160.20	1104.5	3.21	52.6	78.92	544.2	3.30	54.1	16.10	111.0
3.39	55.5	162.39	1119.6	3.51	57.5	80.39	554.3	3.61	59.1	16.84	116.1
3.69	60.4	165.29	1139.6	3.81	62.5	81.84	564.3	3.91	64.1	16.84	116.1
3.99	65.4	167.45	1154.5	4.11	67.4	84.73	584.2	4.21	69.0	17.55	121.0
4.29	70.3	168.20	1159.7	4.41	72.3	85.48	589.4	4.52	74.0	16.86	116.2
4.59	75.2	171.09	1179.6	4.72	77.3	86.92	599.3	4.82	79.0	16.11	111.1
4.89	80.2	172.53	1189.5	5.02	82.2	88.35	609.2	5.12	84.0	18.27	126.0
5.19	85.1	173.65	1197.3	5.32	87.2	88.76	612.0	5.43	89.0	17.96	123.8
5.20	85.2	149.10	1028.0	5.31	87.0	75.09	517.7	5.40	88.5	14.44	99.5
5.20	85.1	133.26	918.8	5.29	86.7	67.94	468.4	5.38	88.1	13.09	90.3
5.17	84.7	108.81	750.2	5.25	86.0	57.28	394.9	5.32	87.2	10.41	71.7
4.95	81.2	51.42	354.5	4.99	81.7	28.16	194.2	5.02	82.3	3.77	26.0



A.1.1.16 Sounding E3

Sounding E3 - Friction Reducer Tip

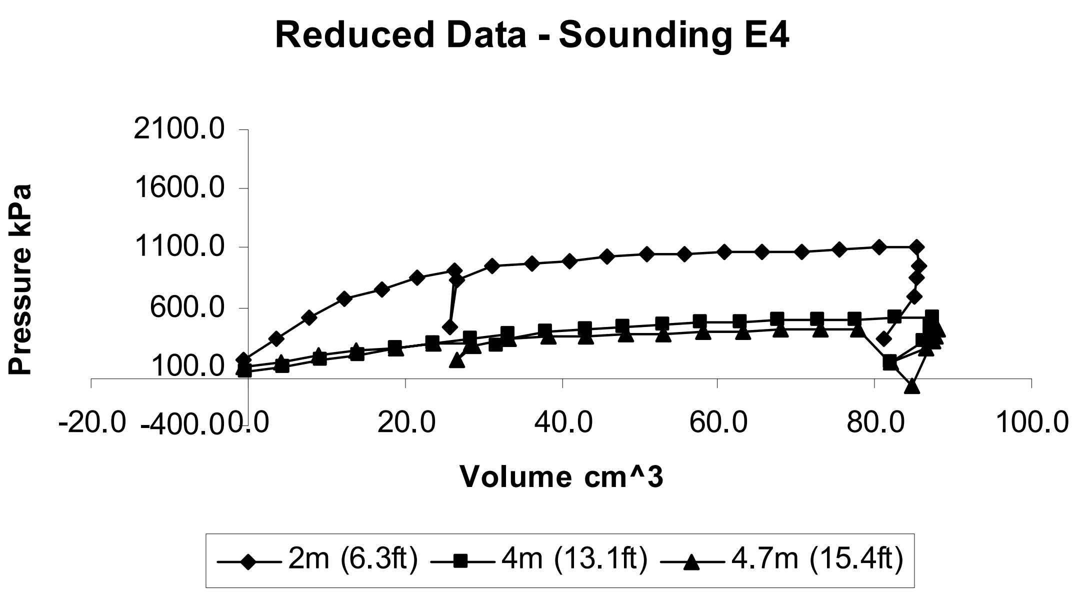
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	9.43	65.0	-0.02	-0.3	8.66	59.7	-0.02	-0.4	10.39	71.6
0.26	4.3	21.03	145.0	0.27	4.5	13.02	89.7	0.26	4.3	21.26	146.6
0.54	8.9	35.52	244.9	0.57	9.3	19.53	134.6	0.54	8.8	37.20	256.5
0.82	13.5	51.46	354.8	0.86	14.0	28.20	194.4	0.82	13.4	55.30	381.3
1.10	18.1	66.70	459.9	1.15	18.8	35.48	244.6	1.09	17.8	74.19	511.5
1.38	22.6	84.09	579.8	1.44	23.5	46.33	319.4	1.37	22.4	91.56	631.3
1.66	27.3	96.44	664.9	1.73	28.3	54.34	374.6	1.65	27.0	103.92	716.5
1.96	32.1	107.28	739.7	2.01	33.0	63.73	439.4	1.60	26.1	51.94	358.1
1.90	31.1	51.06	352.1	2.30	37.7	73.89	509.4	1.66	27.2	96.67	666.5
1.96	32.1	101.49	699.8	2.59	42.5	82.60	569.5	1.93	31.7	117.66	811.3
2.24	36.7	118.17	814.8	2.89	47.3	88.41	609.5	2.22	36.5	124.91	861.3
2.53	41.4	126.89	874.9	2.78	45.6	42.13	290.5	2.51	41.2	135.81	936.3
2.82	46.3	132.69	914.8	2.90	47.5	81.15	559.5	2.81	46.0	142.34	981.4
3.12	51.1	138.47	954.7	3.18	52.1	95.63	659.3	3.10	50.8	150.28	1036.1
3.41	56.0	144.28	994.8	3.48	57.0	102.17	704.4	3.39	55.6	155.37	1071.3
3.72	61.0	146.44	1009.7	3.77	61.9	105.79	729.4	3.69	60.5	160.45	1106.3
4.01	65.8	150.80	1039.7	4.07	66.7	111.58	769.3	3.99	65.3	166.23	1146.1
4.31	70.6	155.17	1069.8	4.38	71.8	113.02	779.2	4.29	70.3	168.44	1161.4
4.61	75.6	156.61	1079.8	4.67	76.5	117.40	809.4	4.58	75.1	172.78	1191.3
4.91	80.5	158.77	1094.7	4.97	81.4	121.01	834.3	4.89	80.1	174.93	1206.1
5.21	85.4	160.62	1107.5	5.27	86.4	122.86	847.1	5.18	84.9	178.97	1234.0
5.22	85.5	138.97	958.2	5.26	86.2	107.74	742.9	5.19	85.0	157.32	1084.7
5.21	85.3	126.03	868.9	5.25	86.0	96.97	668.6	5.18	84.8	142.92	985.4
5.18	84.9	104.48	720.4	5.21	85.4	82.68	570.1	5.15	84.5	118.48	816.9
4.95	81.1	54.35	374.7	4.97	81.4	41.24	284.3	4.94	81.0	58.18	401.1



A.1.1.17 Sounding E4

Sounding E4 - Smooth Tip

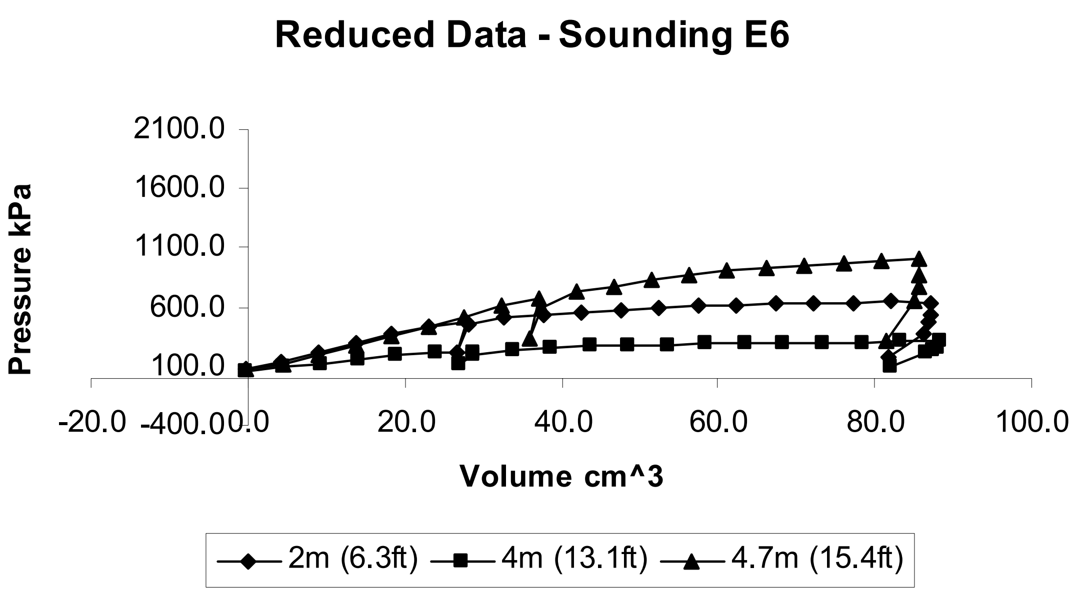
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.04	-0.6	21.75	150.0	-0.02	-0.3	9.39	64.7	-0.03	-0.4	12.56	86.6
0.22	3.6	49.31	340.0	0.27	4.4	15.19	104.7	0.26	4.3	19.81	136.6
0.49	8.0	73.96	509.9	0.56	9.2	22.43	154.6	0.55	9.1	27.05	186.5
0.76	12.4	96.42	664.8	0.85	14.0	29.65	204.4	0.85	13.9	33.54	231.3
1.04	17.0	110.22	759.9	1.15	18.8	36.93	254.6	1.15	18.8	36.48	251.5
1.32	21.6	123.25	849.8	1.44	23.6	43.43	299.4	1.44	23.6	41.52	286.3
1.61	26.4	131.25	904.9	1.73	28.4	48.53	334.6	1.74	28.5	43.73	301.5
1.57	25.8	64.08	441.8	2.03	33.3	52.85	364.4	1.63	26.7	22.29	153.7
1.63	26.7	120.37	829.9	1.94	31.7	39.35	271.3	1.75	28.6	39.38	271.5
1.91	31.2	136.30	939.8	2.04	33.4	48.50	334.4	2.04	33.4	49.49	341.3
2.20	36.1	140.65	969.8	2.33	38.2	57.21	394.4	2.34	38.3	50.94	351.3
2.50	41.0	144.29	994.9	2.63	43.1	59.40	409.5	2.64	43.3	52.41	361.3
2.80	45.9	147.92	1019.8	2.93	48.0	62.30	429.5	2.94	48.2	53.14	366.4
3.10	50.8	150.80	1039.7	3.23	52.9	64.44	444.3	3.24	53.1	55.28	381.1
3.40	55.8	152.26	1049.8	3.53	57.8	67.36	464.4	3.54	58.1	56.75	391.3
3.70	60.7	155.16	1069.8	3.83	62.8	68.81	474.4	3.85	63.1	57.47	396.3
4.01	65.6	155.87	1074.7	4.13	67.7	70.97	489.3	4.15	68.0	60.35	416.1
4.31	70.6	155.17	1069.8	4.44	72.7	70.27	484.5	4.45	72.9	60.39	416.4
4.61	75.6	157.33	1084.8	4.74	77.6	72.43	499.4	4.75	77.9	61.10	421.3
4.91	80.5	159.50	1099.7	5.04	82.6	74.59	514.3	5.17	84.6	-8.54	-58.9
5.22	85.5	159.90	1102.5	5.34	87.5	75.00	517.1	5.36	87.9	60.76	419.0
5.22	85.5	137.52	948.2	5.33	87.3	66.41	457.9	5.35	87.6	50.72	349.7
5.21	85.4	123.13	848.9	5.31	87.1	54.91	378.6	5.33	87.3	44.30	305.4
5.18	84.9	100.86	695.4	5.27	86.3	44.97	310.1	5.28	86.5	37.26	256.9
4.96	81.3	48.54	334.7	5.00	81.9	20.93	144.3	5.00	82.0	19.02	131.1



A.1.1.18 Sounding E6

Sounding E6 - Smooth Tip

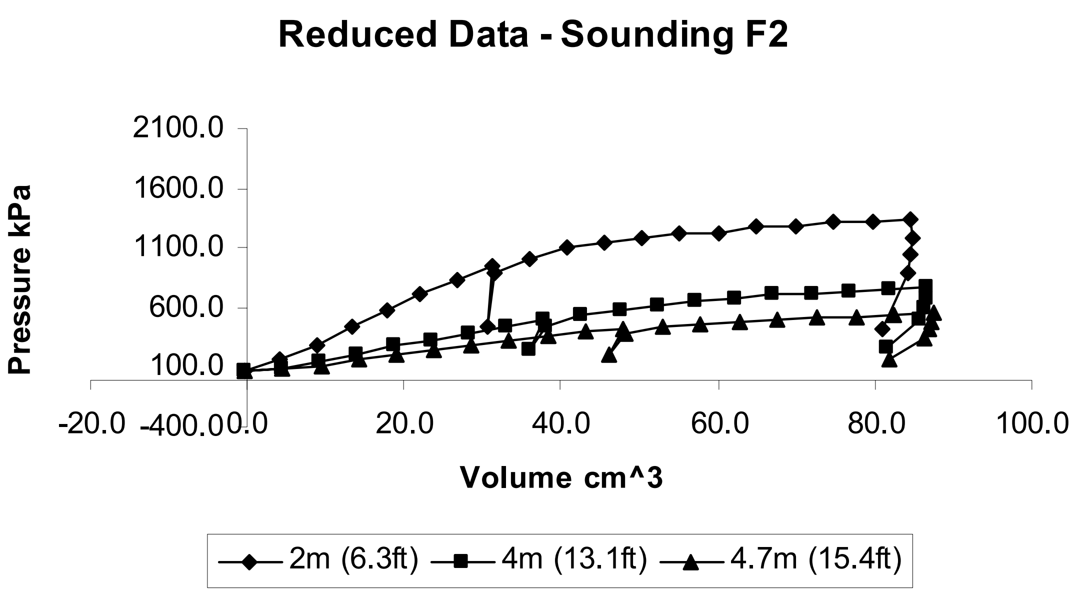
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	10.11	69.7	-0.02	-0.3	8.62	59.4	-0.02	-0.4	9.62	66.3
0.27	4.4	20.26	139.7	0.27	4.5	13.41	92.4	0.27	4.4	16.87	116.3
0.55	9.0	31.13	214.6	0.57	9.3	18.03	124.3	0.55	9.1	27.73	191.2
0.84	13.7	43.43	299.5	0.86	14.2	23.08	159.1	0.84	13.8	38.57	266.0
1.12	18.4	52.88	364.6	1.16	19.0	27.46	189.3	1.12	18.4	50.21	346.2
1.41	23.1	63.01	434.5	1.46	23.9	31.64	218.1	1.41	23.1	63.95	441.0
1.71	27.9	68.84	474.6	1.76	28.8	32.54	224.3	1.69	27.7	75.59	521.2
1.63	26.7	32.08	221.2	1.65	27.0	16.09	110.9	1.98	32.4	87.89	606.0
1.71	28.1	64.49	444.6	1.76	28.9	28.91	199.3	2.27	37.1	98.04	676.0
2.00	32.8	74.62	514.5	2.06	33.7	34.68	239.1	2.20	36.1	48.33	333.3
2.30	37.7	78.24	539.5	2.36	38.7	36.86	254.1	2.28	37.4	87.16	601.0
2.60	42.6	81.16	559.6	2.66	43.6	39.05	269.2	2.56	41.9	105.30	726.0
2.90	47.5	82.61	569.5	2.96	48.6	39.05	269.2	2.85	46.7	112.56	776.1
3.20	52.4	85.49	589.4	3.27	53.5	40.47	279.0	3.14	51.5	120.50	830.8
3.50	57.4	87.67	604.5	3.57	58.5	41.93	289.1	3.44	56.4	126.32	871.0
3.80	62.3	89.85	619.5	3.87	63.4	42.66	294.1	3.74	61.2	131.40	906.0
4.10	67.3	91.29	629.4	4.17	68.4	44.09	304.0	4.04	66.1	134.28	925.8
4.41	72.2	91.31	629.5	4.48	73.4	43.40	299.2	4.33	71.0	137.22	946.1
4.71	77.2	92.75	639.5	4.78	78.3	44.11	304.1	4.63	75.9	140.82	971.0
5.01	82.1	93.46	644.4	5.08	83.3	45.54	314.0	4.93	80.8	144.43	995.8
5.32	87.1	92.41	637.2	5.39	88.3	45.23	311.8	5.23	85.7	147.02	1013.7
5.31	87.0	77.29	532.9	5.37	88.0	38.08	262.6	5.23	85.7	126.82	874.4
5.29	86.8	67.97	468.6	5.34	87.6	34.56	238.3	5.22	85.6	113.15	780.1
5.25	86.1	55.13	380.1	5.29	86.7	30.42	209.8	5.19	85.1	93.78	646.6
4.99	81.8	26.02	179.4	5.01	82.1	13.64	94.0	4.96	81.3	44.36	305.8



A.1.1.19 Sounding F2

Sounding F2 - Friction Reducer Tip

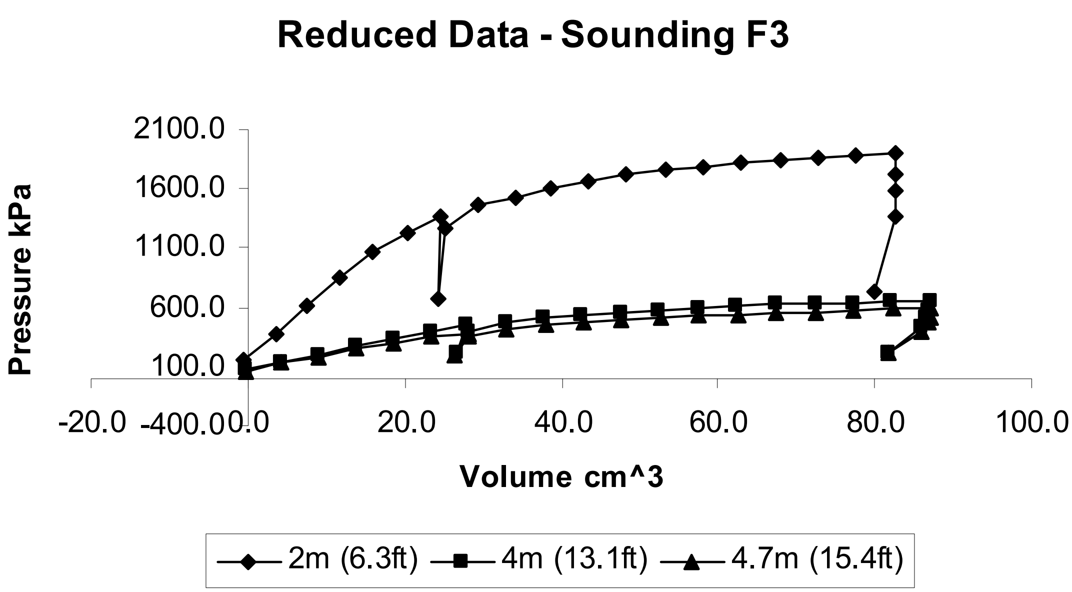
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.3	9.43	65.0	-0.02	-0.3	8.66	59.7	-0.02	-0.4	9.66	66.6
0.26	4.3	23.93	165.0	0.27	4.5	13.74	94.7	0.27	4.5	12.56	86.6
0.53	8.8	42.05	289.9	0.56	9.2	21.70	149.6	0.57	9.4	16.17	111.5
0.81	13.2	63.06	434.8	0.85	14.0	30.37	209.4	0.86	14.2	23.39	161.3
1.08	17.7	82.66	569.9	1.14	18.6	42.01	289.6	1.16	19.0	28.50	196.5
1.35	22.1	104.39	719.8	1.43	23.5	47.78	329.4	1.45	23.8	34.27	236.3
1.62	26.6	121.82	839.9	1.72	28.2	55.79	384.6	1.74	28.6	40.83	281.5
1.91	31.2	137.03	944.8	2.01	33.0	65.18	449.4	2.04	33.4	46.59	321.3
1.86	30.5	64.87	447.3	2.31	37.8	72.43	499.4	2.34	38.3	52.39	361.3
1.92	31.5	127.60	879.8	2.20	36.0	34.39	237.1	2.63	43.1	56.76	391.3
2.19	36.0	147.18	1014.8	2.32	38.0	65.18	449.4	2.93	48.0	60.39	416.4
2.48	40.6	158.80	1094.9	2.60	42.6	78.25	539.5	2.81	46.1	28.56	196.9
2.77	45.4	165.32	1139.8	2.90	47.5	83.33	574.5	2.94	48.2	54.59	376.4
3.07	50.3	172.55	1189.7	3.19	52.3	90.55	624.3	3.23	52.9	63.98	441.1
3.36	55.1	176.91	1219.8	3.49	57.1	94.92	654.4	3.53	57.8	66.90	461.3
3.67	60.1	178.36	1229.8	3.79	62.1	97.09	669.4	3.83	62.7	69.80	481.3
3.96	64.9	184.88	1274.7	4.08	66.9	102.88	709.3	4.13	67.7	73.41	506.1
4.26	69.9	186.35	1284.8	4.40	72.1	102.86	709.2	4.43	72.6	74.17	511.4
4.56	74.7	189.97	1309.8	4.69	76.8	105.07	724.4	4.73	77.5	76.33	526.3
4.86	79.7	192.13	1324.7	4.99	81.7	110.13	759.3	5.03	82.5	78.48	541.1
5.16	84.6	193.26	1332.5	5.29	86.6	111.26	767.1	5.33	87.4	80.34	554.0
5.17	84.7	170.16	1173.2	5.28	86.5	96.86	667.9	5.32	87.2	68.12	469.7
5.17	84.6	152.86	1053.9	5.26	86.2	87.54	603.6	5.30	86.9	60.25	415.4
5.14	84.3	128.42	885.4	5.22	85.6	73.25	505.1	5.26	86.2	49.59	341.9
4.94	80.9	61.60	424.7	4.97	81.5	37.61	259.3	4.99	81.8	24.10	166.1



A.1.1.20 Sounding F3

Sounding F3 - Smooth Tip

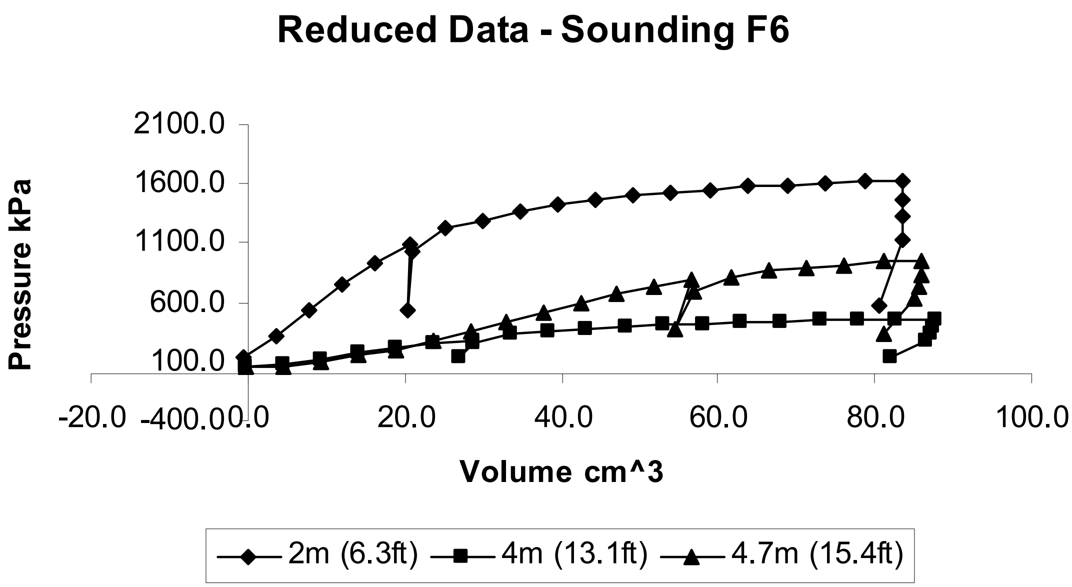
2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.04	-0.6	23.12	159.4	-0.02	-0.4	10.03	69.1	-0.02	-0.4	9.57	66.0
0.21	3.5	54.30	374.4	0.27	4.4	18.73	129.1	0.27	4.4	18.28	126.0
0.46	7.6	89.82	619.3	0.55	9.1	28.14	194.0	0.56	9.1	26.24	180.9
0.71	11.7	123.89	854.2	0.84	13.8	39.71	273.8	0.84	13.8	37.08	255.7
0.97	15.9	153.64	1059.3	1.13	18.5	48.45	334.0	1.13	18.6	43.64	300.9
1.24	20.3	179.00	1234.2	1.42	23.3	57.12	393.8	1.43	23.4	51.58	355.7
1.51	24.7	197.88	1364.3	1.71	28.0	64.40	444.0	1.72	28.2	55.24	380.9
1.48	24.3	97.66	673.3	1.62	26.6	32.04	220.9	1.61	26.4	28.77	198.4
1.53	25.1	183.37	1264.3	1.72	28.2	57.87	399.0	1.73	28.3	51.62	355.9
1.79	29.4	211.63	1459.2	2.01	32.9	68.72	473.8	2.02	33.1	59.56	410.7
2.08	34.1	222.51	1534.2	2.30	37.8	73.07	503.8	2.32	38.0	64.64	445.7
2.37	38.8	233.40	1609.3	2.60	42.6	78.16	538.9	2.62	42.9	67.55	465.7
2.66	43.6	240.65	1659.2	2.90	47.5	80.34	553.9	2.91	47.8	70.46	485.8
2.95	48.4	248.61	1714.1	3.20	52.4	83.94	578.7	3.22	52.7	73.32	505.5
3.25	53.2	254.42	1754.2	3.50	57.4	86.13	593.8	3.52	57.6	76.24	525.7
3.54	58.1	259.50	1789.2	3.80	62.3	87.58	603.8	3.82	62.5	78.41	540.7
3.84	62.9	264.56	1824.1	4.10	67.2	90.46	623.7	4.12	67.5	80.57	555.5
4.14	67.8	266.76	1839.2	4.42	72.4	90.45	623.6	4.42	72.4	81.33	560.8
4.44	72.7	271.10	1869.2	4.71	77.2	91.93	633.8	4.72	77.4	82.77	570.7
4.74	77.7	273.99	1889.1	5.01	82.1	94.09	648.7	5.02	82.3	85.65	590.5
5.04	82.6	276.57	1906.9	5.31	87.1	94.49	651.5	5.32	87.3	86.06	593.4
5.05	82.7	249.11	1717.6	5.30	86.9	82.27	567.3	5.31	87.0	74.56	514.1
5.05	82.8	228.92	1578.3	5.28	86.6	73.68	508.0	5.29	86.7	67.42	464.8
5.04	82.5	197.22	1359.8	5.24	85.9	61.56	424.5	5.25	86.0	57.48	396.3
4.87	79.8	105.75	729.1	4.98	81.7	31.00	213.7	4.98	81.7	31.26	215.5



A.1.1.21 Sounding F6

Sounding F6 - Smooth Tip

2m (6.3ft)				4m (13.1ft)				4.7m (15.4ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.5	18.77	129.4	-0.02	-0.3	7.85	54.1	-0.02	-0.3	7.40	51.0
0.23	3.7	44.87	309.4	0.28	4.5	11.48	79.1	0.28	4.6	8.85	61.0
0.48	7.9	76.77	529.3	0.57	9.4	16.54	114.0	0.57	9.4	13.91	95.9
0.74	12.1	108.66	749.2	0.86	14.1	24.49	168.8	0.87	14.2	21.12	145.7
1.00	16.4	135.51	934.3	1.16	18.9	30.32	209.0	1.16	19.0	29.14	200.9
1.27	20.8	157.97	1089.2	1.45	23.7	37.54	258.8	1.44	23.7	40.71	280.7
1.24	20.3	77.11	531.7	1.75	28.7	41.15	283.7	1.73	28.3	50.89	350.9
1.28	21.0	149.27	1029.2	1.65	27.0	20.35	140.3	2.02	33.0	62.46	430.7
1.54	25.2	177.57	1224.3	1.75	28.7	38.29	264.0	2.30	37.7	74.06	510.7
1.83	30.0	186.98	1289.2	2.04	33.4	47.69	328.8	2.59	42.4	85.68	590.7
2.11	34.7	199.31	1374.2	2.34	38.3	50.59	348.8	2.88	47.1	96.56	665.8
2.41	39.5	206.57	1424.3	2.64	43.2	53.51	368.9	3.17	51.9	105.95	730.5
2.70	44.3	212.37	1464.2	2.94	48.1	55.68	383.9	3.46	56.7	113.95	785.7
3.00	49.1	217.43	1499.1	3.24	53.1	59.28	408.7	3.34	54.7	54.27	374.2
3.30	54.0	221.06	1524.2	3.54	58.0	60.74	418.8	3.48	57.0	100.17	690.7
3.60	58.9	225.41	1554.2	3.84	62.9	62.20	428.8	3.76	61.6	116.85	805.7
3.89	63.8	229.03	1579.1	4.15	67.9	62.91	433.7	4.05	66.4	124.81	860.5
4.20	68.8	230.50	1589.2	4.46	73.1	64.34	443.6	4.35	71.2	129.20	890.8
4.50	73.7	231.94	1599.2	4.75	77.8	65.10	448.8	4.65	76.1	132.08	910.7
4.80	78.6	234.11	1614.1	5.05	82.8	66.53	458.7	4.94	81.0	136.41	940.5
5.10	83.6	236.68	1631.9	5.36	87.8	66.21	456.5	5.25	86.0	138.27	953.4
5.11	83.7	211.41	1457.6	5.34	87.5	56.89	392.3	5.24	85.9	120.25	829.1
5.10	83.6	193.38	1333.3	5.32	87.2	49.75	343.0	5.23	85.8	106.58	734.8
5.09	83.4	163.14	1124.8	5.27	86.4	40.53	279.5	5.19	85.1	92.29	636.3
4.91	80.4	83.27	574.1	5.00	82.0	19.39	133.7	4.96	81.3	47.21	325.5

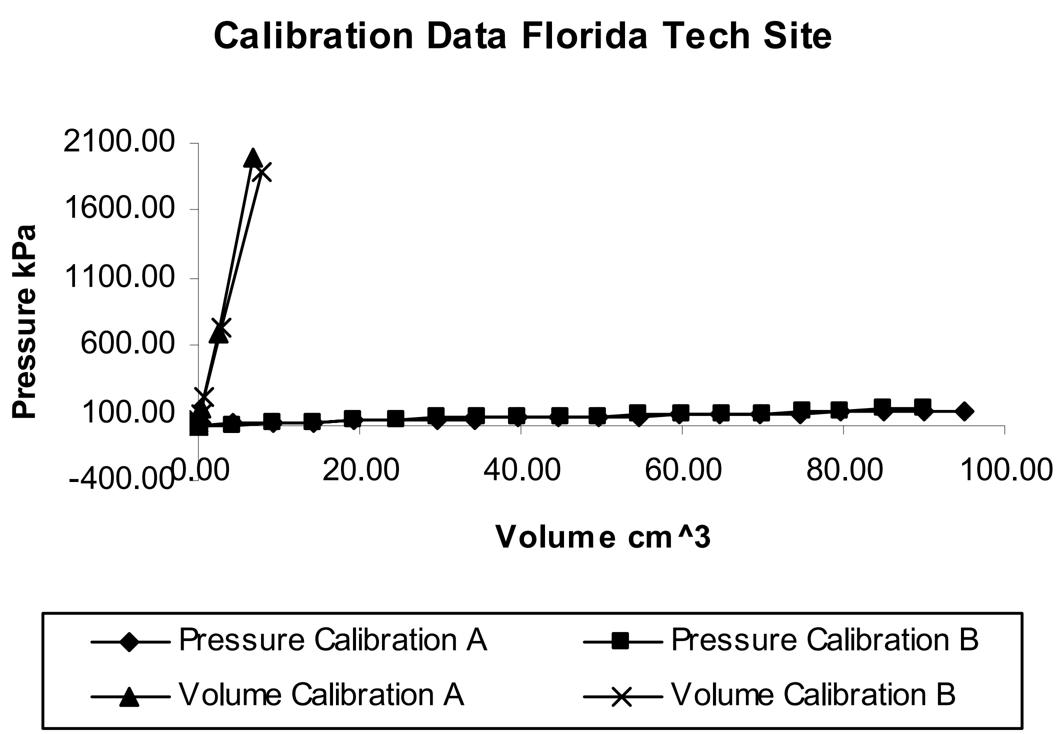


A.1.2 S. Sundaram – Raw and Reduced Data

A.1.2.1 Calibration Data

Calibration Data Florida Tech Site

Pressure Calibration								Volume Calibration							
Calibration A				Calibration B				Calibration A				Calibration B			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.16	0.15	1.00	0.01	0.16	0.08	0.55	0.00	0.00	0.00	0.00	0.00	0.03	0.89	6.12
0.27	4.40	2.58	17.82	0.26	4.34	1.13	7.79	0.00	0.06	2.47	17.00	0.00	0.06	1.82	12.53
0.57	9.27	3.47	23.94	0.57	9.36	3.63	25.05	0.01	0.10	4.21	29.00	0.01	0.12	3.92	27.00
0.88	14.40	4.93	33.96	0.88	14.36	4.56	31.46	0.01	0.20	8.88	61.24	0.01	0.16	5.61	38.69
1.18	19.36	6.14	42.31	1.19	19.45	6.42	44.26	0.03	0.47	20.31	140.02	0.02	0.37	12.92	89.08
2.10	34.38	7.06	48.71	1.49	24.49	7.51	51.78	0.14	2.33	101.58	700.37	0.05	0.86	30.40	209.61
1.80	29.49	7.83	54.00	1.81	29.58	8.92	61.52	0.41	6.64	289.28	1994.50	0.18	2.96	105.78	729.32
2.10	34.45	8.80	60.68	2.11	34.56	9.77	67.36					0.47	7.68	274.90	1895.40
2.42	39.60	9.53	65.69	2.42	39.58	10.38	71.54								
2.72	44.59	10.34	71.26	2.74	44.96	11.10	76.55								
3.03	49.63	10.58	72.93	3.04	49.74	11.59	79.89								
3.34	54.72	11.67	80.45	3.35	54.82	12.27	84.62								
3.65	59.80	11.91	82.12	3.65	59.85	13.12	90.47								
3.95	64.76	12.56	86.57	3.96	64.85	13.85	95.48								
4.26	69.76	13.28	91.58	4.26	69.85	14.78	101.88								
4.56	74.77	14.05	96.87	4.57	74.90	15.54	107.17								
4.87	79.79	15.22	104.94	4.87	79.81	16.88	116.36								
5.18	84.88	15.75	108.56	5.18	84.92	18.09	124.71								
5.48	89.86	16.61	114.52	5.49	89.96	19.30	133.06								
5.79	94.90	17.80	122.76												



A.1.2.2 Sounding 1

Sounding 1 - Friction Reducer Tip

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.17	1.78	12.25	0.00	-0.05	6.85	47.21	0.01	0.19	0.85	5.85	0.00	-0.08	7.98	55.03	0.01	0.22	0.00	0.00	-0.01	-0.12	9.98	68.80
0.27	4.34	13.89	95.76	0.23	3.85	18.81	129.67	0.27	4.36	15.18	104.67	0.23	3.77	22.16	152.80	0.27	4.46	6.98	48.16	0.24	3.95	16.81	115.89
0.58	9.49	33.51	231.04	0.52	8.55	38.24	263.65	0.58	9.49	28.87	199.03	0.52	8.58	35.66	245.87	0.57	9.38	13.57	93.53	0.53	8.72	23.21	160.03
0.88	14.43	56.28	388.04	0.79	12.97	60.83	419.41	0.88	14.45	45.78	315.67	0.80	13.16	52.40	361.26	0.88	14.43	18.89	130.28	0.83	13.66	28.35	195.50
1.19	19.43	80.30	553.67	1.06	17.41	84.55	582.93	1.19	19.55	61.77	425.90	1.09	17.88	68.07	469.31	1.19	19.43	24.43	168.41	1.13	18.53	33.58	231.56
1.50	24.52	107.31	739.90	1.34	21.89	110.99	765.26	1.50	24.66	77.32	533.07	1.38	22.64	83.05	572.60	1.50	24.60	33.11	228.26	1.43	23.50	41.69	287.45
1.81	29.65	134.20	925.29	1.61	26.40	137.50	948.02	1.81	29.67	89.23	615.19	1.67	27.38	94.59	652.15	1.81	29.65	39.08	269.46	1.73	28.41	47.29	326.06
2.12	34.75	155.68	1073.38	1.89	31.00	158.59	1093.45	2.12	34.71	100.81	695.08	1.96	32.15	105.79	729.41	2.11	34.62	45.06	310.66	2.03	33.24	52.89	364.68
1.93	31.70	69.05	476.10	1.83	29.94	72.20	497.79	2.43	39.78	112.24	773.86	2.26	36.96	116.78	805.17	2.42	39.65	51.11	352.41	2.33	38.13	58.51	403.44
2.12	34.67	148.53	1024.11	1.90	31.09	151.45	1044.22	2.74	44.93	119.26	822.30	2.56	41.95	123.29	850.07	2.73	44.69	54.50	375.80	2.63	43.09	61.41	423.40
2.43	39.75	177.97	1227.04	2.17	35.48	180.45	1244.14	2.55	41.79	58.22	401.40	2.45	40.20	62.59	431.53	3.05	49.97	59.19	408.09	2.95	48.26	65.46	451.35
2.74	44.95	197.14	1359.26	2.46	40.25	199.10	1372.78	2.62	42.91	85.27	587.91	2.48	40.71	89.53	617.27	2.87	47.08	28.58	197.08	2.81	46.08	35.22	242.82
3.04	49.89	213.46	1471.73	2.73	44.82	214.82	1481.16	2.67	43.75	97.18	670.03	2.52	41.27	101.34	698.73	2.92	47.83	38.60	266.12	2.84	46.60	45.14	311.26
3.36	55.10	223.35	1539.92	3.04	49.79	224.02	1544.56	2.74	44.82	108.04	744.91	2.57	42.09	112.08	772.77	2.98	48.90	47.28	325.97	2.90	47.47	53.70	370.26
3.67	60.11	231.91	1598.94	3.33	54.61	232.04	1599.85	3.05	49.91	126.37	871.29	2.85	46.76	129.80	894.95	3.05	49.99	52.57	362.43	2.96	48.44	58.84	405.68
3.95	64.78	239.74	1652.94	3.61	59.10	239.20	1649.24	3.35	54.91	131.74	908.31	3.15	51.64	134.50	927.33	3.35	54.93	61.65	425.07	3.24	53.17	67.26	463.72
4.28	70.07	245.59	1693.30	3.92	64.26	244.35	1684.72	3.66	60.02	136.26	939.49	3.46	56.65	138.47	954.71	3.65	59.87	64.19	442.60	3.54	58.05	69.27	477.58
4.58	75.13	253.34	1746.75	4.22	69.14	251.00	1730.57	3.96	64.96	141.19	973.45	3.75	61.48	142.69	983.81	3.96	64.91	67.42	464.87	3.85	63.02	71.79	494.94
4.88	79.98	257.46	1775.14	4.51	73.89	254.64	1755.68	4.27	70.02	145.35	1002.12	4.05	66.43	146.17	1007.84	4.27	69.91	68.88	474.89	4.15	67.98	72.57	500.36
5.14	84.15	262.35	1808.83	4.76	77.95	258.42	1781.73	4.58	75.11	148.74	1025.50	4.36	71.45	148.46	1023.57	4.57	74.94	72.47	499.67	4.45	72.93	75.06	517.49
5.09	83.46	225.00	1551.34	4.77	78.12	221.18	1525.01	4.88	80.03	152.77	1053.34	4.65	76.28	152.01	1048.07	4.88	79.92	75.30	519.15	4.75	77.85	77.39	533.61
5.06	82.94	205.70	1418.28	4.76	78.04	201.97	1392.53	5.19	85.11	154.51	1065.31	4.96	81.31	152.49	1051.40	5.18	84.96	76.31	526.11	5.06	82.86	77.16	532.02
5.00	81.96	174.01	1199.76	4.75	77.79	170.49	1175.51	5.50	90.20	155.52	1072.27	5.27	86.38	152.74	1053.09	5.50	90.07	78.08	538.36	5.37	87.93	78.17	538.97
4.94	80.93	146.80	1012.14	4.72	77.39	143.74	991.02	5.80	95.10	159.40	1098.99	5.57	91.20	155.93	1075.09	5.80	95.09	80.30	553.67	5.67	92.90	79.69	549.44
4.94	80.93	146.80	1012.14	4.72	77.39	143.74	991.02	6.11	100.05	161.62	1114.30	5.86	96.09	157.62	1086.73	6.11	100.08	81.23	560.07	5.97	97.88	80.08	552.12
4.94	80.93	146.80	1012.14	4.72	77.39	143.74	991.02	6.07	99.39	143.29	987.92	5.85	95.86	139.35	960.75	6.05	99.20	65.20	449.56	5.94	97.36	64.13	442.15
4.88	79.92	128.15	883.54	4.69	76.80	125.33	864.10	6.04	98.90	129.56	893.28	5.84	95.68	125.66	866.41	6.04	98.92	61.57	424.51	5.93	97.17	60.52	417.27
								5.97	97.86	110.50	761.89	5.80	95.07	106.70	735.68		97.95		357.70	5.88	96.42	50.92	351.07
								5.91	96.92	96.94	668.36	5.76	94.45	93.22	642.74		96.96		310.10	5.83	95.58	44.11	304.09
								5.79	94.94	76.10	524.72	5.67	92.94	72.66	500.98		94.95		246.08	5.72	93.79	35.09	241.97

A.1.2.3 Sounding 2

Sounding 2 - Smooth

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.24	15.54	107.17	-0.02	-0.29	20.61	142.11	0.01	0.24	0.08	0.56	0.00	0.00	7.21	49.73	0.02	0.30	0.00	0.00	0.00	0.05	7.13	49.16
0.27	4.36	48.81	336.55	0.19	3.07	53.73	370.45	0.28	4.53	11.14	76.83	0.25	4.03	18.12	124.92	0.27	4.46	4.08	28.12	0.25	4.12	11.06	76.22
0.58	9.47	80.67	556.18	0.45	7.45	85.40	588.79	0.57	9.42	23.74	163.68	0.53	8.63	30.54	210.54	0.58	9.47	9.29	64.02	0.55	9.01	16.08	110.87
0.89	14.51	111.43	768.29	0.72	11.78	115.98	799.64	0.88	14.45	35.65	245.80	0.82	13.39	42.26	291.39	0.88	14.43	15.54	107.17	0.84	13.83	22.16	152.76
1.19	19.53	139.81	963.98	0.99	16.14	144.05	993.17	1.19	19.55	48.09	331.53	1.11	18.20	54.38	374.95	1.19	19.47	20.83	143.64	1.14	18.75	27.14	187.11
1.53	25.03	163.11	1124.60	1.29	21.11	166.75	1149.70	1.50	24.58	60.84	419.50	1.40	22.94	66.58	459.06	1.50	24.51	25.15	173.42	1.45	23.68	30.90	213.03
1.81	29.67	183.54	1265.45	1.54	25.28	186.83	1288.18	1.81	29.62	73.36	505.79	1.69	27.69	78.72	542.78	1.80	29.54	28.79	198.48	1.75	28.64	34.16	235.50
2.12	34.75	197.59	1362.33	1.83	30.04	200.50	1382.39	2.11	34.62	81.80	563.97	1.98	32.49	86.78	598.35	2.12	34.67	31.81	219.35	2.06	33.70	36.80	253.70
1.92	31.51	94.27	649.99	1.78	29.17	97.43	671.77	2.43	39.84	90.28	622.43	2.29	37.52	94.81	653.71	2.43	39.90	34.60	238.56	2.37	38.86	39.13	269.81
2.00	32.72	142.68	983.75	1.79	29.27	145.75	1004.91	2.74	44.84	96.65	666.41	2.59	42.37	100.69	694.26	2.73	44.80	36.86	254.15	2.67	43.71	40.90	282.02
2.06	33.70	167.71	1156.34	1.81	29.67	170.71	1177.00	2.44	39.91	30.12	207.66	2.38	38.98	34.65	238.90	3.04	49.82	39.04	269.18	2.97	48.68	42.49	292.94
2.12	34.69	183.26	1263.51	1.85	30.31	186.17	1283.61	2.55	41.86	58.22	401.40	2.46	40.28	62.58	431.48	3.35	54.91	41.22	284.21	3.28	53.72	43.98	303.23
2.43	39.78	207.72	1432.20	2.13	34.84	210.20	1449.27	2.64	43.32	74.53	513.86	2.52	41.36	78.74	542.90	3.65	59.89	41.87	288.67	3.58	58.68	44.09	303.99
2.75	44.99	215.07	1482.86	2.43	39.87	217.03	1496.35	2.74	44.84	85.07	586.52	2.60	42.64	89.11	614.37	3.35	54.85	15.30	105.50	3.31	54.26	18.07	124.56
3.06	50.10	221.89	1529.90	2.74	44.83	223.23	1539.14	3.04	49.87	99.97	689.24	2.89	47.33	103.40	712.94	3.66	59.91	35.45	244.41	3.59	58.85	37.67	259.72
3.37	55.23	227.75	1570.27	3.04	49.82	228.41	1574.81	3.36	55.06	107.03	737.95	3.19	52.36	109.77	756.86	3.96	64.89	41.79	288.11	3.89	63.68	43.30	298.55
3.66	60.06	236.91	1633.46	3.32	54.44	237.05	1634.41	3.66	59.98	110.99	765.23	3.49	57.19	113.20	780.48	4.26	69.89	43.77	301.75	4.19	68.64	44.61	307.58
3.97	65.00	239.78	1653.22	3.62	59.32	239.21	1649.29	3.97	65.00	113.85	784.99	3.79	62.14	115.35	795.32	4.58	75.00	45.42	313.16	4.50	73.71	45.15	311.31
4.28	70.13	242.16	1669.64	3.93	64.39	240.91	1661.01	4.27	70.04	117.33	808.93	4.09	67.10	118.15	814.63	4.88	79.98	46.59	321.24	4.80	78.66	45.83	316.01
4.59	75.18	244.75	1687.46	4.23	69.39	242.39	1671.24	4.58	75.03	120.35	829.81	4.40	72.03	120.08	827.93	5.19	85.01	47.56	327.92	5.11	83.68	45.56	314.11
4.89	80.15	246.40	1698.87	4.53	74.31	243.56	1679.29	4.88	80.00	123.22	849.58	4.69	76.92	122.46	844.33	5.50	90.12	51.40	354.36	5.41	88.70	48.63	335.26
5.19	85.09	250.03	1723.92	4.83	79.17	245.95	1695.78	5.19	85.05	124.59	859.04	5.00	81.94	122.58	845.19	5.46	89.54	39.85	274.75	5.39	88.38	37.16	256.23
5.51	90.22	251.33	1732.83	5.14	84.27	246.48	1699.39	5.50	90.12	127.46	878.80	5.31	86.95	124.69	859.70	5.37	88.01	29.80	205.43	5.31	87.08	27.33	188.45
5.46	89.43	224.40	1547.16	5.13	84.10	219.66	1514.51	5.80	95.07	129.20	890.77	5.61	91.85	125.73	866.91	5.19	84.98	20.91	144.19	5.14	84.25	18.92	130.43
5.43	88.91	203.69	1404.36	5.13	84.06	199.02	1372.23	6.11	100.05	130.97	903.02	5.91	96.79	126.97	875.45								
5.37	87.97	174.98	1206.44	5.11	83.78	170.45	1175.24	6.07	99.39	112.28	774.14	5.89	96.57	108.34	746.97								
5.18	84.94	115.87	798.91	5.01	82.10	111.81	770.93	6.04	98.90	101.42	699.26	5.88	96.33	97.52	672.39								
								5.95	97.46	79.98	551.44	5.82	95.38	76.21	525.47								
								5.92	96.98	71.58	493.54	5.80	95.09	67.86	467.88								
								5.80	94.97	57.65	397.51	5.70	93.40	54.21	373.73								

A.1.2.4 Sounding 3

Sounding 3 - Friction Reducer

1.8m (5.9ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.21	0.00	0.00	0.00	-0.01	5.07	34.97
0.27	4.46	7.07	48.71	0.25	4.05	11.78	81.23
0.58	9.51	15.91	109.68	0.54	8.85	20.27	139.75
0.89	14.51	28.71	197.92	0.82	13.50	32.86	226.54
1.19	19.45	45.86	316.22	1.10	17.96	49.81	343.41
1.50	24.54	68.39	471.55	1.37	22.42	72.12	497.26
1.81	29.67	91.93	633.84	1.64	26.90	95.12	655.82
2.11	34.65	118.09	814.22	1.90	31.15	120.89	833.51
2.43	39.75	142.92	985.42	2.17	35.54	145.43	1002.69
2.74	44.87	166.26	1146.31	2.44	40.02	168.45	1161.39
2.80	45.90	163.72	1128.78	2.51	41.12	165.80	1143.17
3.35	54.95	204.13	1407.42	2.99	49.04	205.40	1416.21
3.67	60.10	219.15	1510.97	3.28	53.77	220.03	1517.07
3.97	65.02	232.51	1603.11	3.56	58.32	232.86	1605.51
4.33	70.97	245.84	1694.97	3.90	63.90	245.27	1691.06
4.59	75.15	250.76	1728.94	4.15	67.94	249.56	1720.65
4.89	80.05	256.41	1767.91	4.44	72.68	254.25	1752.96
4.85	79.51	221.89	1529.90	4.46	73.10	219.84	1515.74
4.82	79.00	202.03	1392.95	4.46	73.15	200.09	1379.55
4.75	77.90	170.82	1177.77	4.45	72.92	169.12	1166.04
4.58	75.00	112.68	776.92	4.37	71.64	111.50	768.79

3.25m (10.7ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.30	0.00	0.00	0.00	0.00	7.13	49.16
0.27	4.40	2.79	19.21	0.25	4.02	9.57	66.00
0.58	9.44	9.61	66.25	0.54	8.87	16.04	110.58
0.88	14.45	17.24	118.86	0.83	13.67	23.46	161.73
1.19	19.47	26.32	181.50	1.13	18.44	32.33	222.91
1.50	24.56	36.30	250.25	1.42	23.25	42.09	290.18
1.81	29.67	46.71	322.07	1.71	28.07	51.97	358.30
2.11	34.63	57.77	398.34	2.00	32.72	62.64	431.88
2.42	39.71	68.47	472.11	2.29	37.50	73.05	503.63
2.73	44.76	78.04	538.08	2.58	42.29	82.31	567.48
2.55	41.77	35.89	247.47	2.47	40.47	40.34	278.17
2.64	43.32	58.34	402.24	2.53	41.39	62.70	432.32
2.74	44.87	71.70	494.38	2.60	42.58	75.96	523.70
3.04	49.82	85.71	590.97	2.88	47.13	89.49	616.98
3.35	54.87	93.38	643.86	3.17	51.97	96.73	666.93
3.66	59.98	101.38	698.98	3.47	56.86	104.34	719.37
3.96	64.94	107.07	738.23	3.76	61.66	109.49	754.94
4.27	69.94	112.44	775.25	4.06	66.51	114.12	786.83
4.58	75.07	116.32	801.97	4.36	71.53	117.19	808.02
4.88	79.96	121.52	837.88	4.65	76.27	121.44	837.31
5.19	85.11	123.26	849.85	4.97	81.37	122.39	843.83
5.50	90.05	125.04	862.10	5.26	86.26	123.55	851.82
5.46	89.47	109.86	757.44	5.25	86.10	108.44	747.65
5.43	89.00	99.44	685.62	5.24	85.93	98.08	676.24
5.37	87.99	83.82	577.89	5.21	85.35	82.58	569.38
5.18	84.96	55.76	384.42	5.07	83.10	54.90	378.53

5.25m (17.2ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.26	2.22	15.31	-0.01	-0.22	12.20	84.14
0.27	4.46	5.13	35.35	0.24	3.90	14.76	101.76
0.57	9.42	10.82	74.60	0.53	8.70	20.10	138.57
0.88	14.43	18.81	129.72	0.82	13.49	27.88	192.23
1.19	19.53	24.39	168.13	1.12	18.43	33.24	229.16
1.51	24.79	30.52	210.45	1.44	23.52	39.15	269.94
2.12	34.69	41.02	282.82	2.02	33.13	48.73	335.97
2.43	39.76	44.21	304.81	2.33	38.11	51.63	355.94
2.73	44.74	48.37	333.48	2.62	42.98	55.48	382.54
2.55	41.75	24.79	170.92	2.48	40.64	32.09	221.26
2.61	42.78	34.40	237.17	2.53	41.40	41.64	287.10
2.67	43.71	40.45	278.92	2.57	42.17	47.64	328.48
2.73	44.71	45.42	313.16	2.63	43.02	52.54	362.25
3.05	49.91	50.06	345.17	2.94	48.10	56.68	390.77
3.35	54.89	54.46	375.52	3.23	52.95	60.66	418.21
3.66	59.93	55.59	383.31	3.54	57.96	61.41	423.38
3.96	64.89	58.42	402.80	3.83	62.84	63.70	439.21
4.27	69.91	59.67	411.43	4.14	67.82	64.21	442.72
4.57	74.96	60.64	418.11	4.45	72.85	64.39	443.92
4.89	80.07	63.02	434.53	4.75	77.89	65.77	453.48
5.19	84.98	63.10	435.09	5.05	82.80	65.10	448.83
5.50	90.05	65.81	453.74	5.36	87.80	67.17	463.11
5.43	88.94	50.47	347.96	5.32	87.12	51.96	358.28
5.37	88.01	43.60	300.64	5.27	86.37	45.22	311.76
5.18	84.94	30.68	211.56	5.11	83.66	32.68	225.33

A.1.2.5 Sounding 4

Sounding 4 - Smooth

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.03	0.51	2.54	17.54	0.01	0.22	7.59	52.34	0.02	0.39	0.00	0.00	0.01	0.09	7.12	49.11	0.02	0.36	0.00	0.00	0.00	-0.06	9.97	68.77
0.29	4.76	16.27	112.18	0.25	4.09	20.96	144.53	0.28	4.62	6.82	47.04	0.25	4.14	13.59	93.71	0.28	4.59	5.05	34.80	0.25	4.03	14.67	101.12
0.59	9.74	31.37	216.29	0.53	8.65	35.72	246.30	0.61	9.98	19.58	135.01	0.56	9.13	25.99	179.18	0.58	9.59	13.81	95.20	0.54	8.78	23.08	159.12
0.90	14.79	49.26	339.61	0.81	13.20	53.40	368.15	0.89	14.60	32.86	226.59	0.82	13.39	39.08	269.42	0.89	14.57	22.21	153.10	0.83	13.53	31.27	215.57
1.22	20.05	69.44	478.79	1.09	17.90	73.36	505.80	1.20	19.69	47.08	324.58	1.10	18.08	53.07	365.92	1.20	19.71	30.08	207.38	1.13	18.46	38.92	268.35
1.51	24.77	88.46	609.90	1.35	22.09	92.18	635.54	1.52	24.86	62.70	432.30	1.39	22.81	68.48	472.15	1.51	24.75	37.71	259.99	1.42	23.28	46.34	319.50
1.83	29.94	106.18	732.10	1.63	26.76	109.34	753.88	1.82	29.84	76.71	528.90	1.67	27.40	81.95	564.99	1.81	29.71	44.09	303.98	1.71	28.06	52.19	359.83
2.13	34.90	123.62	852.36	1.91	31.23	126.41	871.55	2.12	34.82	88.62	611.01	1.96	32.05	93.47	644.48	2.12	34.80	48.89	337.10	2.02	33.02	56.59	390.21
2.44	40.04	138.12	952.29	2.20	35.98	140.61	969.44	2.43	39.90	98.31	677.82	2.25	36.85	102.87	709.27	2.43	39.88	54.22	373.85	2.32	37.95	61.63	424.93
2.75	45.01	150.23	1035.80	2.48	40.60	152.40	1050.79	2.74	44.91	107.27	739.62	2.54	41.62	111.52	768.92	2.74	44.84	57.98	399.73	2.61	42.80	65.08	448.73
2.58	42.24	58.46	403.07	2.46	40.39	60.82	419.35	2.56	42.01	52.24	360.21	2.46	40.25	56.68	390.81	2.56	41.94	28.10	193.74	2.49	40.73	35.39	244.01
2.63	43.17	87.93	606.28	2.47	40.51	90.24	622.19	2.62	42.97	73.24	504.96	2.48	40.62	77.62	535.18	2.62	42.89	39.85	274.75	2.52	41.36	47.08	324.64
2.70	44.20	105.01	724.03	2.51	41.06	107.26	739.53	2.68	43.94	87.89	606.00	2.51	41.19	92.22	635.84	2.68	43.90	47.84	329.86	2.57	42.15	55.02	379.35
2.82	46.19	130.08	896.90	2.58	42.34	132.14	911.10	2.74	44.93	98.19	676.99	2.56	41.89	102.44	706.27	2.75	45.08	52.93	364.94	2.64	43.19	60.01	413.77
3.06	50.10	154.91	1068.09	2.78	45.56	156.59	1079.67	3.05	49.97	113.53	782.77	2.84	46.50	117.29	808.68	3.05	50.02	61.77	425.90	2.92	47.88	68.37	471.42
3.37	55.25	164.89	1136.85	3.08	50.43	166.14	1145.48	3.36	55.06	119.87	826.47	3.14	51.42	123.20	849.44	3.36	55.04	63.75	439.54	3.22	52.84	69.93	482.16
3.69	60.39	173.97	1199.48	3.38	55.33	174.83	1205.42	3.67	60.21	124.27	856.81	3.44	56.44	127.21	877.09	3.67	60.10	67.34	464.32	3.53	57.80	73.14	504.29
3.98	65.30	179.99	1240.96	3.67	60.06	180.30	1243.11	3.97	65.08	129.64	893.84	3.73	61.16	132.05	910.43	3.97	65.02	69.60	479.90	3.82	62.66	74.87	516.20
4.29	70.24	185.11	1276.31	3.96	64.86	184.67	1273.27	4.28	70.13	133.68	921.67	4.03	66.10	135.32	933.03	4.27	70.02	72.19	497.72	4.12	67.59	76.71	528.88
4.59	75.26	188.87	1302.20	4.26	69.78	187.65	1293.80	4.58	75.13	136.10	938.37	4.33	71.03	136.97	944.36	4.58	75.05	73.84	509.13	4.43	72.58	77.57	534.85
4.90	80.26	191.61	1321.13	4.56	74.70	189.41	1305.96	4.89	80.16	139.85	964.26	4.64	75.96	139.74	963.45	4.88	80.01	75.26	518.88	4.73	77.50	78.02	537.90
4.86	79.66	168.80	1163.85	4.56	74.74	166.72	1149.46	5.20	85.20	142.64	983.47	4.94	80.92	141.75	977.36	5.19	85.09	75.22	518.60	5.04	82.57	77.19	532.24
4.83	79.13	152.45	1051.11	4.56	74.67	150.48	1037.52	5.51	90.27	144.62	997.11	5.24	85.94	143.10	986.63	5.51	90.29	78.53	541.42	5.35	87.68	79.86	550.58
4.76	78.05	130.08	896.90	4.53	74.21	128.35	884.94	5.47	89.58	127.30	877.69	5.23	85.73	125.86	867.81	5.47	89.58	65.57	452.07	5.33	87.33	66.98	461.84
4.59	75.28	86.68	597.65	4.43	72.65	85.46	589.23	5.44	89.11	115.59	796.96	5.22	85.59	114.22	787.49	5.43	89.02	58.95	406.42	5.31	86.96	60.43	416.67
								5.38	88.08	97.58	672.81	5.19	85.06	96.34	664.22	5.38	88.10	50.43	347.68	5.26	86.28	52.03	358.73
								5.18	84.94	63.87	440.38	5.06	82.86	63.02	434.49	5.19	85.05	34.64	238.84	5.11	83.67	36.62	252.51

A.1.2.6 Sounding 5

Sounding 5 - Friction Reducer

1.8m (5.9ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.32	0.00	0.00	0.01	0.11	5.06	34.91
0.28	4.59	9.69	66.81	0.25	4.10	14.40	99.25
0.59	9.60	22.41	154.49	0.53	8.77	26.77	184.54
0.89	14.58	36.82	253.87	0.81	13.34	40.97	282.47
1.20	19.66	53.21	366.89	1.10	17.96	57.15	394.01
1.51	24.77	71.18	490.76	1.38	22.57	74.90	516.40
1.82	29.79	92.70	639.13	1.65	26.99	95.87	661.02
2.13	34.86	111.07	765.79	1.93	31.55	113.85	785.00
2.43	39.80	127.98	882.42	2.20	36.02	130.49	899.67
2.74	44.97	148.62	1024.67	2.48	40.61	150.79	1039.68
2.56	42.01	72.67	501.06	2.43	39.77	75.05	517.43
2.62	42.93	101.50	699.81	2.43	39.88	103.82	715.82
2.68	43.94	123.58	852.08	2.46	40.28	125.85	867.68
2.75	45.06	138.44	954.52	2.50	40.99	140.61	969.47
3.05	50.04	160.69	1107.90	2.77	45.35	162.37	1119.52
3.36	55.12	173.53	1196.42	3.05	50.06	174.79	1205.12
3.68	60.23	184.55	1272.41	3.35	54.86	185.42	1278.44
3.97	65.08	193.75	1335.88	3.63	59.46	194.09	1338.23
4.27	69.98	198.40	1367.89	3.92	64.23	198.00	1365.17
4.59	75.22	207.16	1428.30	4.22	69.23	205.94	1419.93
4.90	80.22	212.24	1463.37	4.52	74.09	210.05	1448.25
5.19	85.13	213.46	1471.72	4.82	78.96	210.51	1451.43
5.16	84.55	189.84	1308.88	4.82	79.04	186.97	1289.12
5.12	83.98	173.49	1196.14	4.82	78.93	170.71	1176.98
5.07	83.05	145.43	1002.68	4.81	78.78	142.79	984.52
4.88	79.94	94.84	653.88	4.70	77.08	92.69	639.07

3.25m (10.7ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.39	0.00	0.00	0.01	0.09	7.12	49.11
0.28	4.55	0.65	4.45	0.26	4.23	7.42	51.16
0.61	9.92	6.06	41.76	0.58	9.46	12.46	85.94
0.89	14.62	11.39	78.50	0.85	14.01	17.60	121.32
1.20	19.71	20.75	143.08	1.15	18.84	26.75	184.42
1.51	24.69	29.96	206.55	1.44	23.56	35.74	246.44
1.82	29.75	39.36	271.41	1.73	28.35	44.61	307.58
2.12	34.78	48.33	333.20	2.02	33.14	53.18	366.68
2.43	39.80	61.37	423.12	2.31	37.79	65.93	454.60
2.74	44.91	71.22	491.04	2.60	42.63	75.47	520.34
2.56	41.92	31.01	213.79	2.49	40.75	35.45	244.43
2.62	42.98	47.08	324.58	2.52	41.37	51.46	354.79
2.69	44.01	58.54	403.63	2.57	42.08	62.86	433.44
2.76	45.17	67.18	463.20	2.62	43.00	71.41	492.32
3.04	49.84	79.01	544.76	2.89	47.33	82.78	570.76
3.36	55.00	87.45	602.94	3.19	52.26	90.78	625.94
3.66	60.02	94.64	652.49	3.48	57.08	97.59	672.87
3.97	65.08	99.52	686.17	3.78	62.00	101.93	702.77
4.27	70.00	102.95	709.84	4.08	66.83	104.62	721.35
4.58	75.07	108.24	746.30	4.38	71.75	109.12	752.34
4.89	80.11	110.83	764.12	4.68	76.72	110.72	763.37
5.20	85.24	114.78	791.40	4.99	81.74	113.89	785.26
5.51	90.24	117.08	807.26	5.29	86.67	115.57	796.82
5.47	89.64	100.85	695.36	5.28	86.52	99.41	685.43
5.40	88.57	82.32	567.59	5.25	85.97	81.02	558.58
5.38	88.16	75.42	519.99	5.23	85.76	74.16	511.33
5.19	85.05	49.13	338.77	5.09	83.38	48.27	332.79

5.25m (17.2ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.28	4.59	2.06	14.20	0.25	4.11	11.68	80.53
0.58	9.49	9.37	64.58	0.54	8.81	18.64	128.52
0.89	14.62	15.10	104.11	0.84	13.78	24.16	166.56
1.20	19.68	23.42	161.45	1.14	18.61	32.26	222.44
1.50	24.64	30.08	207.38	1.43	23.38	38.71	266.92
1.82	29.77	35.85	247.19	1.73	28.35	43.95	303.00
2.12	34.80	41.91	288.94	2.03	33.22	49.61	342.05
2.43	39.82	49.30	339.89	2.32	38.03	56.71	391.00
2.74	44.87	53.29	367.44	2.62	42.97	60.40	416.41
2.56	41.92	23.30	160.62	2.49	40.85	30.59	210.89
2.61	42.82	35.33	243.57	2.53	41.41	42.57	293.49
2.67	43.81	43.97	303.14	2.57	42.16	51.15	352.66
2.74	44.93	49.30	339.89	2.63	43.14	56.39	388.82
3.05	49.93	58.30	401.96	2.92	47.89	64.91	447.54
3.36	55.00	61.45	423.67	3.23	52.87	67.63	466.31
3.66	60.02	66.09	455.69	3.52	57.76	71.90	495.70
3.96	64.96	69.16	476.84	3.82	62.62	74.43	513.19
4.28	70.20	71.74	494.66	4.14	67.79	76.23	525.59
4.59	75.28	75.50	520.55	4.44	72.75	79.20	546.04
4.88	80.03	77.36	533.35	4.73	77.46	80.11	552.34
5.20	85.16	79.74	549.77	5.04	82.52	81.71	563.35
5.50	90.11	80.10	552.28	5.34	87.45	81.45	561.60
5.47	89.62	68.64	473.22	5.33	87.29	70.05	482.96
5.42	88.80	60.20	415.04	5.29	86.70	61.71	425.49
5.37	88.06	49.42	340.72	5.26	86.27	51.02	351.80
5.19	85.11	31.53	217.40	5.11	83.81	33.51	231.03

A.1.2.7 Sounding 6

Sounding 6 - Smooth

1.8m (5.9ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.34	0.65	4.45	0.01	0.11	5.71	39.35
0.28	4.57	14.62	100.77	0.24	3.95	19.32	133.22
0.58	9.57	34.28	236.33	0.51	8.40	38.64	266.39
0.89	14.58	56.73	391.11	0.78	12.79	60.87	419.70
1.20	19.66	80.67	556.18	1.05	17.19	84.60	583.30
1.50	24.66	106.10	731.55	1.31	21.48	109.83	757.22
1.82	29.82	130.41	899.12	1.58	25.97	133.58	920.99
2.13	34.86	151.64	1045.55	1.86	30.42	154.43	1064.76
2.44	39.97	167.83	1157.17	2.14	35.07	170.32	1174.35
2.75	44.99	183.05	1262.11	2.42	39.67	185.23	1277.12
2.56	42.03	94.68	652.77	2.39	39.18	97.05	669.13
2.62	42.89	129.24	891.05	2.38	39.07	131.56	907.07
2.68	43.94	155.32	1070.88	2.40	39.39	157.58	1086.48
2.77	45.46	173.85	1198.65	2.46	40.39	175.98	1213.34
3.05	50.00	191.05	1317.23	2.71	44.46	192.74	1328.87
3.37	55.21	202.07	1393.23	3.01	49.36	203.32	1401.88
3.67	60.13	209.05	1441.38	3.30	54.09	209.94	1447.46
3.99	65.32	216.36	1491.77	3.60	59.07	216.67	1493.91
4.29	70.22	221.89	1529.90	3.89	63.82	221.46	1526.89
4.60	75.32	227.99	1571.94	4.19	68.74	226.76	1563.48
4.89	80.16	227.10	1565.81	4.49	73.61	224.92	1550.75
5.20	85.20	233.48	1609.79	4.79	78.47	230.53	1589.44
5.16	84.53	208.21	1435.54	4.79	78.50	205.34	1415.80
5.12	83.98	190.08	1310.55	4.79	78.47	187.30	1291.39
5.07	83.07	163.19	1125.16	4.78	78.30	160.55	1106.98
4.88	80.03	108.65	749.08	4.69	76.79	106.48	734.16

3.25m (10.7ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.36	0.00	0.00	0.00	0.06	7.13	49.13
0.28	4.61	4.40	30.34	0.26	4.18	11.17	77.02
0.59	9.66	14.25	98.26	0.55	8.96	20.67	142.53
0.89	14.62	25.52	175.93	0.83	13.61	31.73	218.75
1.20	19.66	38.52	265.56	1.12	18.28	44.51	306.92
1.51	24.79	51.64	356.03	1.41	23.05	57.42	395.90
1.81	29.73	63.31	436.48	1.69	27.66	68.55	472.66
2.12	34.78	74.85	516.09	1.98	32.40	79.71	549.57
2.43	39.82	83.45	575.38	2.27	37.19	88.02	606.86
2.74	44.89	90.48	623.82	2.57	42.07	94.73	653.13
2.56	41.92	20.67	142.52	2.50	41.04	25.12	173.16
2.61	42.82	30.81	212.39	2.54	41.66	35.20	242.68
2.70	44.29	42.92	295.90	2.61	42.80	47.22	325.60
2.76	45.19	49.94	344.34	2.65	43.50	54.16	373.45
3.05	50.04	81.51	562.02	2.90	47.47	85.27	587.88
3.36	55.02	95.89	661.12	3.18	52.05	99.22	684.11
3.66	60.06	103.76	715.40	3.47	56.86	106.71	735.76
3.97	65.11	108.93	751.03	3.77	61.77	111.33	767.60
4.27	70.00	111.03	765.51	4.06	66.60	112.70	777.02
4.58	75.13	115.11	793.62	4.37	71.62	115.97	799.61
4.89	80.13	118.17	814.78	4.67	76.53	118.06	814.01
5.21	85.31	121.32	836.49	4.98	81.63	120.42	830.29
5.51	90.27	125.64	866.28	5.28	86.47	124.12	855.80
5.50	90.16	123.30	850.13	5.27	86.42	121.80	839.75
5.46	89.54	106.67	735.44	5.26	86.27	105.24	725.60
5.40	88.57	88.34	609.07	5.24	85.81	87.03	600.06
5.19	85.03	52.49	361.88	5.08	83.27	51.62	355.91

5.25m (17.2ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.36	0.00	0.00	0.00	-0.06	9.97	68.77
0.29	4.70	3.11	21.43	0.26	4.19	12.72	87.70
0.59	9.60	9.16	63.19	0.54	8.93	18.43	127.10
0.89	14.60	14.66	101.05	0.84	13.78	23.71	163.50
1.20	19.60	19.86	136.96	1.14	18.63	28.71	197.96
1.50	24.56	24.30	167.58	1.43	23.47	32.94	227.14
1.82	29.80	28.02	193.19	1.75	28.60	36.11	248.96
2.12	34.71	30.04	207.10	2.04	33.45	37.75	260.25
2.44	39.93	34.44	237.45	2.35	38.55	41.85	288.51
2.74	44.87	37.83	260.83	2.65	43.40	44.93	309.80
2.55	41.86	20.47	141.13	2.49	40.87	27.76	191.43
2.62	42.85	27.58	190.12	2.54	41.67	34.81	240.03
2.68	43.86	33.03	227.70	2.60	42.52	40.21	277.21
2.74	44.97	36.05	248.58	2.66	43.54	43.15	297.49
3.04	49.85	38.92	268.35	2.95	48.35	45.54	313.98
3.36	54.98	41.50	286.16	3.26	53.41	47.69	328.81
3.66	60.02	43.89	302.58	3.56	58.38	49.69	342.60
3.97	65.02	45.38	312.88	3.86	63.34	50.64	349.18
4.27	70.00	46.91	323.46	4.17	68.27	51.44	354.64
4.58	75.07	47.84	329.86	4.47	73.32	51.57	355.57
4.89	80.09	49.50	341.28	4.78	78.29	52.24	360.21
5.19	85.07	50.47	347.96	5.08	83.24	52.45	361.62
5.50	90.11	52.69	363.27	5.38	88.22	54.04	372.59
5.47	89.58	45.70	315.11	5.36	87.89	47.12	324.88
5.43	89.06	41.46	285.88	5.34	87.48	42.95	296.11
5.38	88.12	35.89	247.47	5.29	86.70	37.49	258.50
5.19	85.03	26.12	180.10	5.12	83.89	28.11	193.79

A.1.2.8 Sounding 7

Sounding 7 - Friction Reducer

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.06	0.00	0.00	-0.01	-0.16	5.09	35.06	0.01	0.09	0.00	0.00	-0.01	-0.20	7.15	49.28	0.01	0.13	0.00	0.00	-0.02	-0.29	9.99	68.90
0.26	4.27	5.53	38.14	0.24	3.90	10.26	70.76	0.27	4.40	2.58	17.82	0.25	4.03	9.37	64.61	0.27	4.44	2.26	15.59	0.24	3.96	11.89	82.00
0.57	9.30	16.07	110.79	0.53	8.64	20.44	140.92	0.57	9.29	11.91	82.12	0.53	8.66	18.35	126.49	0.57	9.40	7.11	48.99	0.54	8.78	16.38	112.96
0.87	14.23	28.42	195.97	0.81	13.22	32.59	224.67	0.88	14.38	23.21	160.06	0.82	13.43	29.44	202.95	0.88	14.40	11.47	79.06	0.83	13.66	20.53	141.57
1.18	19.30	43.44	299.52	1.09	17.88	47.39	326.75	1.19	19.51	36.74	253.31	1.11	18.18	42.74	294.71	1.20	19.62	15.87	109.40	1.14	18.76	24.71	170.40
1.49	24.43	61.00	420.61	1.37	22.52	64.74	446.35	1.50	24.51	51.15	352.69	1.39	22.78	56.95	392.64	1.49	24.41	20.39	140.58	1.43	23.43	29.03	200.18
1.80	29.50	79.74	549.77	1.65	27.07	82.95	571.89	1.80	29.56	67.71	466.82	1.67	27.37	72.97	503.14	1.80	29.47	24.26	167.30	1.73	28.37	32.39	223.34
2.10	34.47	100.05	689.79	1.92	31.46	102.85	709.16	2.11	34.50	82.85	571.21	1.95	31.89	87.72	604.80	2.11	34.63	27.70	190.96	2.04	33.44	35.41	244.13
2.42	39.60	119.91	826.75	2.20	36.04	122.42	844.08	2.41	39.54	95.56	658.89	2.23	36.57	100.15	690.48	2.41	39.56	30.93	213.23	2.34	38.28	38.35	264.44
2.73	44.78	137.80	950.07	2.49	40.72	139.99	965.21	2.73	44.76	108.65	749.08	2.53	41.43	112.91	778.48	2.72	44.59	33.39	230.21	2.64	43.24	40.52	279.37
2.55	41.71	63.43	437.31	2.42	39.73	65.82	453.80	2.55	41.73	45.46	313.44	2.45	40.16	49.92	344.15	2.54	41.62	18.21	125.54	2.48	40.69	25.52	175.94
2.60	42.55	92.05	634.68	2.43	39.77	94.39	650.83	2.60	42.65	65.93	454.57	2.47	40.51	70.33	484.92	2.60	42.57	25.03	172.59	2.53	41.46	32.29	222.60
2.66	43.62	114.46	789.17	2.45	40.21	116.74	804.90	2.66	43.56	82.36	567.87	2.50	40.97	86.71	597.85	2.66	43.55	29.43	202.93	2.58	42.31	36.63	252.56
2.73	44.78	127.42	878.53	2.50	41.01	129.62	893.67	2.73	44.73	94.39	650.82	2.55	41.79	98.66	680.24	2.73	44.71	32.06	221.02	2.65	43.39	39.18	270.11
3.04	49.74	152.77	1053.34	2.76	45.27	154.49	1065.16	3.04	49.76	117.04	806.98	2.82	46.20	120.82	833.03	3.03	49.70	35.37	243.85	2.95	48.30	42.00	289.58
3.35	54.83	164.85	1136.57	3.05	50.02	166.13	1145.42	3.35	54.97	125.56	865.72	3.12	51.16	128.90	888.74	3.34	54.76	37.67	259.72	3.25	53.29	43.87	302.48
3.66	59.96	179.06	1234.56	3.34	54.76	179.95	1240.72	3.66	59.95	132.47	913.32	3.41	55.95	135.43	933.74	3.34	54.70	36.58	252.20	3.25	53.27	42.79	295.00
3.96	64.85	182.93	1261.28	3.63	59.53	183.30	1263.82	3.96	64.81	138.76	956.75	3.70	60.64	141.20	973.56	3.65	59.78	39.57	272.80	3.55	58.26	45.39	312.94
4.27	69.91	189.51	1306.65	3.93	64.40	189.13	1304.02	4.28	70.09	144.42	995.72	4.01	65.76	146.07	1007.12	3.95	64.79	40.86	281.71	3.86	63.24	46.15	318.20
4.57	74.96	195.29	1346.46	4.23	69.30	194.11	1338.36	4.57	74.92	148.29	1022.44	4.30	70.49	149.19	1028.64	4.26	69.83	41.91	288.94	4.16	68.24	46.46	320.33
4.88	79.96	200.09	1379.59	4.53	74.16	197.94	1364.74	4.87	79.83	152.65	1052.50	4.59	75.27	152.60	1052.13	4.57	74.87	43.77	301.75	4.47	73.23	47.52	327.66
5.19	85.07	204.33	1408.81	4.83	79.16	201.39	1388.57	5.18	84.92	155.48	1071.99	4.90	80.28	154.63	1066.12	4.88	80.01	44.41	306.20	4.78	78.36	47.17	325.22
5.50	90.07	207.08	1427.74	5.13	84.08	203.52	1403.19	5.50	90.07	158.99	1096.21	5.21	85.33	157.50	1085.91	5.18	84.94	45.90	316.50	5.08	83.24	47.90	330.28
5.45	89.38	183.18	1262.95	5.13	84.05	179.70	1239.00	5.46	89.47	140.06	965.65	5.20	85.26	138.64	955.87	5.49	89.99	47.76	329.31	5.38	88.24	49.13	338.73
5.42	88.83	164.68	1135.46	5.13	84.02	161.28	1111.97	5.42	88.89	126.29	870.73	5.19	85.07	124.94	861.45	5.46	89.43	41.26	284.49	5.36	87.86	42.70	294.39
5.36	87.88	137.27	946.45	5.12	83.83	133.98	923.78	5.36	87.88	106.42	733.77	5.16	84.61	105.20	725.36	5.42	88.87	37.47	258.32	5.33	87.41	38.97	268.71
5.18	84.83	90.60	624.65	5.01	82.09	87.69	604.62	5.18	84.83	69.20	477.12	5.04	82.60	68.36	471.34	5.36	87.92	31.94	220.19	5.29	86.61	33.56	231.40
																5.18	84.92	24.26	167.30	5.12	83.83	26.26	181.09

A.1.2.9 Sounding 8

Sounding 8 - Smooth

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.06	0.73	5.01	-0.01	-0.18	5.81	40.07	0.00	0.07	0.00	0.00	-0.01	-0.22	7.15	49.29	0.01	0.09	0.00	0.00	-0.02	-0.32	10.00	68.92
0.26	4.32	15.06	103.83	0.23	3.69	19.79	136.43	0.27	4.40	6.50	44.82	0.24	3.92	13.29	91.61	0.27	4.38	5.25	36.19	0.23	3.82	14.89	102.64
0.59	9.60	35.00	241.34	0.51	8.42	39.36	271.39	0.57	9.30	20.03	138.07	0.52	8.45	26.46	182.44	0.57	9.34	13.08	90.19	0.52	8.56	22.36	154.18
0.88	14.40	55.80	384.70	0.77	12.63	59.95	413.36	0.88	14.40	35.77	246.63	0.80	13.10	41.99	289.52	0.88	14.40	20.43	140.85	0.82	13.41	29.50	203.37
1.18	19.36	77.96	537.53	1.04	16.97	81.91	564.74	1.19	19.47	53.33	367.72	1.08	17.68	59.34	409.13	1.20	19.62	27.49	189.57	1.12	18.44	36.34	250.57
1.50	24.58	99.28	684.50	1.32	21.60	103.01	710.20	1.50	24.58	72.87	502.45	1.36	22.25	78.67	542.38	1.49	24.45	35.04	241.62	1.41	23.05	43.69	301.22
1.81	29.60	115.35	795.29	1.60	26.17	118.54	817.33	1.81	29.60	90.92	626.88	1.63	26.76	96.18	663.17	1.80	29.50	41.14	283.66	1.70	27.94	49.26	339.67
2.11	34.60	131.25	904.97	1.87	30.72	134.06	924.28	2.12	34.71	106.87	736.84	1.92	31.43	111.73	770.34	2.11	34.54	47.88	330.14	2.00	32.79	55.60	383.35
2.45	40.14	142.07	979.57	2.19	35.96	144.56	996.68	2.42	39.67	120.48	830.65	2.20	36.01	125.05	862.18	2.41	39.54	50.27	346.57	2.30	37.72	57.69	397.79
2.74	44.84	149.91	1033.58	2.47	40.44	152.10	1048.68	2.73	44.78	131.25	904.97	2.49	40.82	135.52	934.36	2.73	44.69	52.69	363.27	2.61	42.80	59.81	412.36
2.55	41.75	72.23	498.00	2.41	39.52	74.62	514.47	2.55	41.71	57.77	398.34	2.43	39.80	62.23	429.06	3.04	49.80	57.45	396.12	2.92	47.78	64.08	441.79
2.60	42.63	103.20	711.51	2.41	39.54	105.53	727.63	2.60	42.65	81.43	561.47	2.45	40.08	85.84	591.81	2.55	41.79	14.09	97.15	2.50	40.98	21.39	147.48
2.67	43.70	126.13	869.62	2.44	39.96	128.40	885.31	2.66	43.60	99.92	688.96	2.47	40.51	104.27	718.93	2.60	42.68	21.60	148.93	2.54	41.66	28.85	198.90
2.73	44.80	139.25	960.09	2.48	40.70	141.44	975.22	2.73	44.80	114.30	788.06	2.52	41.31	118.56	817.43	2.73	44.74	32.14	221.58	2.65	43.43	39.25	270.64
3.04	49.89	157.01	1082.57	2.76	45.30	158.71	1094.29	3.04	49.87	137.75	949.79	2.79	45.73	141.52	975.76	3.04	49.80	49.26	339.61	2.93	48.01	55.88	385.28
3.35	54.87	162.26	1118.76	3.06	50.13	163.54	1127.58	3.35	54.93	146.15	1007.69	3.08	50.55	149.49	1030.72	3.34	54.76	56.32	388.32	3.22	52.77	62.52	431.09
3.66	59.98	167.43	1154.39	3.36	55.10	168.32	1160.54	3.66	59.98	152.57	1051.95	3.38	55.43	155.53	1072.34	3.65	59.81	59.43	409.76	3.52	57.74	65.25	449.88
3.96	64.91	169.93	1171.65	3.66	59.95	170.29	1174.14	3.96	64.89	156.81	1081.18	3.67	60.21	159.24	1097.93	3.96	64.83	61.04	420.89	3.83	62.71	66.33	457.35
4.28	70.09	172.64	1190.30	3.97	65.06	172.22	1187.44	4.27	69.94	161.86	1115.97	3.97	65.13	163.54	1127.55	4.26	69.81	63.18	435.64	4.13	67.63	67.74	467.05
4.57	74.96	175.91	1212.84	4.26	69.84	174.73	1204.75	4.58	75.07	165.90	1143.81	4.28	70.14	166.77	1149.85	4.57	74.81	64.48	444.55	4.43	72.59	68.24	470.52
4.88	79.98	178.69	1232.05	4.56	74.78	176.54	1217.19	4.88	80.00	169.57	1169.14	4.57	74.97	169.48	1168.51	4.87	79.86	67.46	465.15	4.73	77.56	70.26	484.40
5.19	85.07	180.39	1243.74	4.87	79.82	177.45	1223.50	5.19	84.99	172.03	1186.12	4.88	79.90	171.17	1180.19	5.18	84.96	68.64	473.22	5.04	82.62	70.63	486.98
5.50	90.09	184.63	1272.97	5.17	84.72	181.07	1248.40	5.50	90.20	175.26	1208.39	5.19	85.01	173.75	1197.98	5.49	89.90	69.97	482.41	5.34	87.53	71.35	491.91
5.45	89.32	161.45	1113.19	5.16	84.60	157.99	1089.28	5.45	89.34	155.60	1072.83	5.17	84.70	154.20	1063.15	5.46	89.43	59.87	412.82	5.33	87.34	61.31	422.72
5.42	88.89	145.26	1001.56	5.16	84.62	141.85	978.03	5.42	88.89	141.35	974.56	5.17	84.65	140.00	965.28	5.42	88.83	52.89	364.66	5.31	86.94	54.40	375.08
5.36	87.86	121.36	836.77	5.14	84.26	118.08	814.12	5.36	87.88	119.14	821.46	5.14	84.25	117.92	813.05	5.36	87.92	43.89	302.58	5.26	86.27	45.51	313.79
5.18	84.86	79.21	546.16	5.03	82.44	76.30	526.09	5.16	84.58	77.96	537.53	5.01	82.11	77.16	531.98	5.18	84.86	30.16	207.94	5.10	83.60	32.17	221.78

A.1.2.10 Sounding 9

Sounding 9 - Friction Reducer

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.28	4.51	9.45	65.14	0.25	4.04	14.16	97.63	0.00	0.04	0.00	0.00	-0.02	-0.26	7.15	49.31	0.00	0.04	0.00	0.00	-0.02	-0.38	10.00	68.96
0.57	9.42	23.94	165.07	0.52	8.54	28.31	195.17	0.27	4.46	2.02	13.92	0.25	4.10	8.80	60.68	0.27	4.42	1.70	11.69	0.24	3.95	11.33	78.12
0.88	14.42	42.59	293.68	0.79	13.01	46.75	322.32	0.57	9.40	9.21	63.47	0.54	8.84	15.64	107.81	0.57	9.42	9.41	64.86	0.53	8.74	18.68	128.82
1.19	19.43	64.60	445.39	1.06	17.42	68.54	472.58	0.88	14.40	17.76	122.48	0.83	13.60	23.98	165.37	0.89	14.51	17.76	122.48	0.83	13.60	26.83	184.97
1.50	24.54	88.26	608.51	1.33	21.87	91.98	634.21	1.19	19.53	27.41	189.01	1.13	18.46	33.42	230.41	1.19	19.45	26.24	180.94	1.12	18.30	35.10	241.99
1.81	29.62	109.94	757.99	1.61	26.34	113.13	780.02	1.49	24.47	37.39	257.77	1.41	23.13	43.18	297.73	1.49	24.38	35.08	241.90	1.40	22.98	43.73	301.52
2.12	34.67	127.50	879.08	1.89	30.90	130.30	898.37	1.80	29.52	47.60	328.19	1.70	27.90	52.87	364.54	1.80	29.54	42.76	294.79	1.70	27.93	50.88	350.77
2.42	39.67	140.82	970.94	2.17	35.53	143.33	988.24	2.11	34.56	56.48	389.43	1.99	32.68	61.35	423.00	2.11	34.56	50.18	346.01	2.00	32.74	57.90	399.21
2.73	44.80	151.28	1043.04	2.46	40.37	153.47	1058.17	2.42	39.60	62.90	433.70	2.29	37.54	67.48	465.26	2.42	39.67	56.00	386.09	2.30	37.69	63.42	437.26
2.54	41.69	65.53	451.79	2.42	39.65	67.92	468.28	2.72	44.65	70.13	483.52	2.59	42.39	74.40	513.00	2.72	44.59	60.24	415.32	2.59	42.50	67.37	464.48
2.61	42.74	95.16	656.11	2.43	39.87	97.49	672.19	2.55	41.71	28.42	195.97	2.48	40.62	32.88	226.69	2.55	41.71	27.17	187.34	2.47	40.54	34.48	237.70
2.66	43.64	119.02	820.62	2.45	40.11	121.30	836.34	2.60	42.63	41.02	282.82	2.51	41.19	45.42	313.18	2.60	42.53	39.24	270.57	2.50	41.02	46.50	320.60
2.73	44.80	133.88	923.06	2.49	40.85	136.07	938.19	2.66	43.58	50.59	348.79	2.56	41.87	54.94	378.77	2.67	43.71	47.32	326.25	2.56	41.98	54.51	375.81
3.05	49.91	156.25	1077.28	2.77	45.34	157.94	1088.98	2.73	44.74	58.34	402.24	2.61	42.82	62.61	431.65	2.73	44.67	53.33	367.72	2.61	42.76	60.46	416.83
3.35	54.87	164.36	1133.23	3.06	50.07	165.64	1142.06	3.04	49.78	73.64	507.74	2.89	47.43	77.42	533.78	3.04	49.84	63.14	435.37	2.91	47.66	69.76	481.01
3.66	59.93	169.93	1171.65	3.35	54.97	170.83	1177.83	3.34	54.78	78.73	542.82	3.19	52.28	82.08	565.93	3.34	54.80	66.86	460.98	3.20	52.51	73.06	503.72
3.97	65.04	175.18	1207.83	3.66	59.94	175.53	1210.21	3.65	59.76	82.89	571.49	3.49	57.15	85.86	592.00	3.65	59.85	69.28	477.68	3.51	57.50	75.10	517.78
4.26	69.77	179.38	1236.78	3.94	64.56	179.02	1234.31	3.96	64.87	87.69	604.61	3.79	62.12	90.12	621.38	3.95	64.78	72.07	496.88	3.80	62.35	77.36	533.39
4.58	75.07	182.09	1255.43	4.26	69.78	180.89	1247.22	4.26	69.76	88.14	607.67	4.09	67.00	89.85	619.48	4.26	69.81	73.36	505.79	4.11	67.35	77.91	537.20
4.88	80.01	184.18	1269.91	4.56	74.66	182.02	1255.00	4.57	74.89	90.80	626.05	4.40	72.05	91.70	632.28	4.57	74.90	77.15	531.96	4.41	72.33	80.91	557.83
5.19	84.98	188.18	1297.47	4.85	79.51	185.26	1277.30	4.87	79.85	95.48	658.34	4.69	76.88	95.43	657.93	4.87	79.86	77.32	533.07	4.72	77.29	80.11	552.32
5.50	90.11	190.16	1311.11	5.16	84.59	186.59	1286.52	5.18	84.84	95.36	657.50	5.00	81.89	94.52	651.70	5.18	84.86	78.37	540.31	5.02	82.26	80.37	554.15
5.45	89.36	166.38	1147.15	5.16	84.50	162.91	1123.21	5.49	89.96	96.61	666.13	5.31	86.96	95.13	655.93	5.49	89.97	80.26	553.39	5.33	87.32	81.63	562.83
5.42	88.85	150.51	1037.75	5.15	84.44	147.10	1014.25	5.46	89.39	84.14	580.12	5.29	86.75	82.73	570.40	5.45	89.38	69.77	481.02	5.31	87.01	71.21	490.97
5.36	87.84	124.07	855.42	5.14	84.17	120.79	832.79	5.42	88.89	75.26	518.88	5.28	86.49	73.91	509.59	5.36	87.90	52.65	362.99	5.25	86.01	54.28	374.21
5.18	84.84	79.09	545.32	5.03	82.43	76.18	525.27	5.36	87.86	64.23	442.88	5.23	85.77	63.02	434.48	5.18	84.83	35.41	244.13	5.09	83.42	37.42	258.00
								5.19	85.01	41.71	287.55	5.10	83.55	40.84	281.61								

A.1.2.11 Sounding 10

Sounding 10 - Smooth

1.8m (5.9ft)								3.25m (10.7ft)								5.25m (17.2ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.15	0.00	0.00	0.00	-0.06	5.08	35.01	0.01	0.13	0.00	0.00	-0.01	-0.17	7.14	49.26	0.01	0.09	0.00	0.00	-0.02	-0.32	10.00	68.92
0.27	4.40	5.45	37.58	0.25	4.04	10.17	70.13	0.28	4.53	0.65	4.45	0.26	4.21	7.42	51.17	0.27	4.44	0.00	0.00	0.25	4.02	9.63	66.42
0.57	9.40	14.66	101.05	0.54	8.78	19.02	131.15	0.57	9.40	6.34	43.70	0.54	8.92	12.77	88.04	0.58	9.51	2.95	20.32	0.55	9.01	12.22	84.26
0.88	14.42	25.40	175.09	0.82	13.49	29.55	203.74	0.89	14.57	13.00	89.63	0.85	13.90	19.21	132.47	0.88	14.42	6.06	41.76	0.84	13.83	15.12	104.27
1.19	19.55	37.22	256.65	1.12	18.29	41.16	283.81	1.18	19.34	21.48	148.09	1.13	18.44	27.49	189.54	1.19	19.45	8.88	61.24	1.15	18.79	17.74	122.29
1.50	24.62	50.27	346.57	1.40	23.00	53.99	372.25	1.49	24.38	30.52	210.45	1.42	23.23	36.32	250.43	1.49	24.43	11.83	81.56	1.45	23.68	20.47	141.16
1.80	29.52	63.95	440.93	1.68	27.53	67.16	463.03	1.80	29.54	42.47	292.84	1.71	28.06	47.74	329.17	1.80	29.52	14.86	102.44	1.75	28.69	22.98	158.44
2.12	34.69	77.56	534.74	1.97	32.31	80.35	554.02	2.12	34.78	52.85	364.38	2.01	33.01	57.70	397.86	2.11	34.58	17.32	119.42	2.06	33.68	25.04	172.61
2.42	39.61	92.54	638.02	2.25	36.82	95.05	655.34	2.42	39.67	63.79	439.82	2.29	37.59	68.36	471.35	2.42	39.60	19.14	131.95	2.36	38.64	26.56	183.14
2.73	44.71	107.11	738.51	2.53	41.51	109.31	753.70	2.73	44.67	74.57	514.14	2.58	42.29	78.84	543.60	2.72	44.65	21.20	146.14	2.66	43.64	28.32	195.26
2.55	41.86	46.91	323.46	2.46	40.34	49.30	339.89	2.55	41.79	31.69	218.52	2.48	40.60	36.14	249.21	3.03	49.69	21.96	151.43	2.97	48.66	28.60	197.18
2.60	42.65	69.04	476.01	2.47	40.51	71.38	492.12	2.73	44.73	67.38	464.59	2.60	42.55	71.65	494.02	2.85	46.71	12.56	86.57	2.80	45.94	19.48	134.31
2.66	43.53	86.04	593.20	2.50	40.91	88.32	608.96	3.03	49.69	86.12	593.76	2.87	46.98	89.90	619.86	2.92	47.80	17.00	117.19	2.86	46.90	23.82	164.21
2.73	44.69	96.69	666.69	2.55	41.78	98.90	681.89	3.35	54.82	97.10	669.47	3.16	51.81	100.45	692.57	2.97	48.69	19.98	137.79	2.91	47.72	26.72	184.20
3.04	49.74	113.21	780.54	2.83	46.37	114.92	792.36	3.65	59.83	106.75	736.00	3.45	56.56	109.72	756.47	3.03	49.72	21.24	146.42	2.97	48.71	27.87	192.14
3.35	54.82	122.21	842.62	3.12	51.19	123.50	851.47	3.96	64.85	116.68	804.48	3.74	61.30	119.11	821.27	3.34	54.72	24.10	166.18	3.27	53.63	30.31	208.97
3.65	59.83	129.56	893.28	3.42	56.01	130.46	899.51	4.26	69.85	121.65	838.72	4.04	66.16	123.34	850.41	3.65	59.74	25.35	174.81	3.58	58.61	31.18	214.98
3.96	64.89	132.91	916.38	3.72	60.97	133.27	918.89	4.57	74.90	128.15	883.54	4.33	71.03	129.05	889.75	3.95	64.79	26.89	185.39	3.88	63.63	32.18	221.88
4.27	69.94	137.19	945.89	4.02	65.90	136.80	943.21	4.87	79.85	133.88	923.06	4.63	75.81	133.82	922.66	4.26	69.76	28.14	194.02	4.18	68.55	32.71	225.50
4.57	74.96	143.81	991.54	4.32	70.73	142.64	983.44	5.18	84.94	136.79	943.11	4.93	80.82	135.93	937.22	4.56	74.79	29.39	202.65	4.49	73.55	33.16	228.64
4.88	79.90	145.79	1005.18	4.61	75.62	143.65	990.42	5.49	89.97	142.24	980.69	5.23	85.71	140.75	970.47	4.87	79.83	30.68	211.56	4.79	78.55	33.48	230.86
5.18	84.88	150.07	1034.69	4.91	80.48	147.16	1014.61	5.42	88.80	110.38	761.05	5.21	85.42	109.05	751.85	5.18	84.81	31.57	217.68	5.10	83.51	33.59	231.57
5.49	89.99	153.42	1057.79	5.22	85.50	149.87	1033.31	5.36	87.82	93.59	645.25	5.18	84.91	92.37	636.89	5.49	89.90	32.50	224.09	5.41	88.58	33.88	233.58
5.45	89.30	128.23	884.09	5.22	85.51	124.76	860.20	5.18	84.84	61.04	420.89	5.06	82.84	60.20	415.09	5.45	89.34	28.30	195.14	5.38	88.13	29.75	205.12
5.42	88.80	116.28	801.70	5.21	85.34	112.87	778.24									5.36	87.86	22.12	152.54	5.30	86.82	23.76	163.80
5.36	87.86	97.30	670.86	5.18	84.93	94.02	648.22									5.17	84.79	16.84	116.08	5.12	83.90	18.85	129.98
5.18	84.84	62.86	433.42	5.06	82.88	59.95	413.37																

A.1.2.12 Sounding 11

Sounding 11 - Friction Reducer

1.8m (5.9ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.06	0.00	0.00	-0.01	-0.16	5.09	35.06
0.27	4.44	11.10	76.55	0.24	3.92	15.82	109.08
0.57	9.40	26.12	180.10	0.52	8.46	30.49	210.21
0.90	14.68	46.63	321.51	0.80	13.16	50.78	350.08
1.18	19.32	69.93	482.13	1.05	17.16	73.88	509.35
1.50	24.60	96.65	666.41	1.32	21.69	100.38	692.10
1.81	29.62	127.06	876.02	1.58	25.86	130.25	898.05
2.11	34.62	158.95	1095.93	1.83	29.97	161.75	1115.24
2.42	39.73	186.81	1288.00	2.09	34.30	189.31	1305.28
2.73	44.73	215.68	1487.03	2.35	38.49	217.88	1502.21
2.55	41.82	109.57	755.49	2.35	38.55	111.96	771.93
2.61	42.72	151.52	1044.71	2.34	38.28	153.86	1060.79
2.67	43.70	183.50	1265.18	2.34	38.36	185.77	1280.87
2.73	44.80	204.45	1409.65	2.37	38.88	206.65	1424.78
3.04	49.78	240.87	1660.74	2.61	42.85	242.58	1672.53
3.35	54.95	261.34	1801.87	2.90	47.44	262.61	1810.65
3.66	59.98	282.41	1947.17	3.17	51.89	283.31	1953.33
3.98	65.19	296.30	2042.93	3.46	56.71	296.63	2045.18
3.93	64.44	251.85	1736.45	3.49	57.20	252.27	1739.34
3.90	63.97	228.35	1574.44	3.50	57.39	228.83	1577.73
3.83	62.79	192.34	1326.14	3.49	57.21	192.96	1330.43
3.77	61.84	162.95	1123.49	3.48	57.08	163.69	1128.59
3.72	60.90	140.42	968.16	3.46	56.77	141.24	973.84
3.66	59.91	120.03	827.58	3.44	56.35	120.93	833.78

3.25m (10.7ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.24	0.00	0.00	0.00	-0.05	7.14	49.19
0.27	4.44	4.80	33.13	0.24	4.00	11.59	79.90
0.58	9.45	15.62	107.73	0.53	8.72	22.05	152.05
0.88	14.38	29.23	201.54	0.81	13.26	35.45	244.43
1.19	19.58	39.32	271.13	1.11	18.19	45.33	312.51
1.49	24.49	53.13	366.33	1.39	22.71	58.93	406.28
1.81	29.62	65.61	452.35	1.68	27.49	70.87	488.62
2.11	34.62	78.65	542.26	1.96	32.12	83.51	575.80
2.73	44.73	101.54	700.09	2.54	41.59	105.81	729.52
2.55	41.84	48.57	334.88	2.45	40.19	53.02	365.54
2.62	42.95	71.82	495.21	2.48	40.64	76.21	525.44
2.66	43.62	81.64	562.86	2.50	41.04	85.98	592.82
2.73	44.73	90.48	623.82	2.56	41.90	94.74	653.24
3.04	49.76	107.68	742.40	2.84	46.46	111.45	768.45
3.35	54.93	114.02	786.11	3.14	51.45	117.36	809.14
3.66	59.91	120.84	833.15	3.43	56.24	123.80	853.59
3.96	64.89	126.69	873.51	3.73	61.05	129.12	890.27
4.27	69.91	130.16	897.45	4.03	65.97	131.85	909.08
4.58	74.98	134.20	925.29	4.33	70.94	135.09	931.43
4.87	79.86	137.80	950.07	4.62	75.72	137.73	949.63
5.18	84.94	140.66	969.83	4.93	80.71	139.81	963.95
5.49	89.99	143.04	986.25	5.23	85.70	141.56	976.02
5.45	89.34	128.02	882.70	5.22	85.47	126.62	873.03
5.42	88.87	116.32	801.97	5.21	85.33	114.97	792.71
5.36	87.84	98.35	678.10	5.17	84.80	97.13	669.72
5.18	84.84	66.58	459.03	5.05	82.69	65.73	453.23

5.25m (17.2ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.24	0.00	0.00	-0.01	-0.17	9.98	68.84
0.26	4.29	0.57	3.90	0.24	3.85	10.21	70.40
0.58	9.47	3.96	27.28	0.55	8.95	13.23	91.23
0.88	14.47	8.96	61.80	0.84	13.80	18.03	124.29
1.19	19.49	13.53	93.25	1.14	18.69	22.38	154.29
1.49	24.45	18.09	124.71	1.44	23.53	26.73	184.30
1.80	29.54	23.05	158.95	1.74	28.48	31.17	214.93
2.11	34.54	28.38	195.69	2.03	33.33	36.10	248.90
2.42	39.63	32.66	225.20	2.34	38.30	40.09	276.38
2.73	44.74	36.74	253.31	2.64	43.30	43.86	302.37
2.55	41.75	16.67	114.97	2.49	40.87	23.98	165.31
2.60	42.65	24.10	166.18	2.54	41.56	31.35	216.17
2.66	43.60	33.79	232.99	2.58	42.24	40.99	282.60
2.73	44.71	33.03	227.70	2.65	43.37	40.14	276.79
3.03	49.69	39.65	273.36	2.94	48.16	46.28	319.10
3.35	54.91	43.60	300.64	3.25	53.28	49.79	343.32
3.65	59.89	48.45	334.04	3.55	58.12	54.26	374.12
3.96	64.83	49.30	339.89	3.85	63.04	54.58	376.34
4.26	69.81	51.48	354.92	4.15	67.96	56.03	386.32
4.57	74.87	54.34	374.68	4.45	72.93	58.10	400.59
4.87	79.88	55.96	385.82	4.75	77.90	58.75	405.04
5.18	84.86	57.69	397.79	5.05	82.84	59.70	411.62
5.49	89.96	59.75	411.98	5.36	87.87	61.12	421.43
5.46	89.43	50.83	350.46	5.35	87.60	52.27	360.37
5.43	88.91	44.90	309.54	5.32	87.24	46.40	319.90
5.38	88.12	38.23	263.61	5.29	86.64	39.83	274.64
5.17	84.79	25.60	176.48	5.11	83.66	27.61	190.39

A.1.2.13 Sounding 12

Sounding 12 - Smooth

1.8m (5.9ft)								3.25m (10.7ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.13	1.05	7.24	-0.01	-0.11	6.13	42.26	0.02	0.28	0.00	0.00	0.00	-0.02	7.13	49.17
0.27	4.36	17.64	121.65	0.22	3.66	22.37	154.22	0.27	4.46	3.63	25.05	0.25	4.06	10.42	71.81
0.57	9.40	40.13	276.70	0.49	8.07	44.50	306.80	0.58	9.44	11.95	82.40	0.54	8.80	18.38	126.72
0.88	14.47	67.79	467.38	0.75	12.37	71.94	496.01	0.88	14.49	21.36	147.26	0.83	13.60	27.57	190.11
1.19	19.58	99.92	688.96	1.01	16.58	103.86	716.10	1.19	19.56	30.89	212.95	1.12	18.40	36.89	254.33
1.49	24.49	133.48	920.28	1.25	20.55	137.21	946.00	1.50	24.60	40.94	282.26	1.41	23.16	46.73	322.18
1.81	29.73	166.58	1148.54	1.52	24.87	169.76	1170.48	1.81	29.65	51.52	355.20	1.70	27.92	56.77	391.44
2.12	34.75	197.59	1362.33	1.77	29.02	200.38	1381.58	2.11	34.65	61.57	424.51	1.99	32.64	66.43	458.04
2.43	39.76	221.09	1524.34	2.04	33.38	223.59	1541.60	2.42	39.69	69.93	482.13	2.28	37.44	74.50	513.66
2.75	44.99	241.52	1665.19	2.32	38.04	243.69	1680.19	2.73	44.80	77.07	531.40	2.58	42.35	81.33	560.78
2.55	41.80	126.29	870.73	2.32	38.07	128.67	887.18	2.54	41.69	34.60	238.56	2.47	40.43	39.06	269.29
2.61	42.78	171.83	1184.73	2.30	37.77	174.16	1200.79	2.61	42.74	50.87	350.74	2.50	41.02	55.27	381.05
2.68	43.86	205.78	1418.83	2.31	37.91	208.05	1434.46	2.67	43.70	62.86	433.42	2.54	41.64	67.20	463.35
2.74	44.91	227.59	1569.15	2.34	38.35	229.77	1584.21	2.73	44.76	70.69	487.42	2.59	42.49	74.96	516.82
3.06	50.10	257.83	1777.65	2.61	42.69	259.51	1789.23	3.04	49.80	83.45	575.38	2.88	47.17	87.23	601.41
3.37	55.17	272.52	1878.98	2.89	47.35	273.78	1887.64	3.36	55.10	88.74	611.85	3.19	52.32	92.07	634.80
3.32	54.39	233.32	1608.68	2.91	47.66	234.64	1617.76	3.66	60.00	93.02	641.36	3.48	57.11	95.98	661.74
3.29	53.94	209.90	1447.23	2.92	47.87	211.25	1456.54	3.96	64.85	97.10	669.47	3.77	61.84	99.53	686.26
3.23	52.94	174.17	1200.87	2.92	47.87	175.60	1210.71	4.27	69.94	100.29	691.46	4.08	66.85	101.97	703.04
3.17	51.97	145.43	1002.68	2.91	47.70	146.93	1013.02	4.57	74.96	102.75	708.44	4.38	71.79	103.64	714.60
3.04	49.85	104.65	721.53	2.85	46.72	106.35	733.27	4.88	79.98	106.51	734.33	4.68	76.71	106.42	733.73
								5.18	84.94	107.68	742.40	4.98	81.64	106.82	736.52
								5.49	90.03	110.79	763.84	5.29	86.64	109.30	753.57
								5.45	89.32	87.13	600.72	5.28	86.59	85.73	591.06
								5.42	88.87	79.05	545.04	5.27	86.37	77.71	535.77
								5.36	87.92	66.78	460.42	5.23	85.75	65.55	451.97
								5.18	84.86	45.38	312.88	5.08	83.30	44.54	307.07

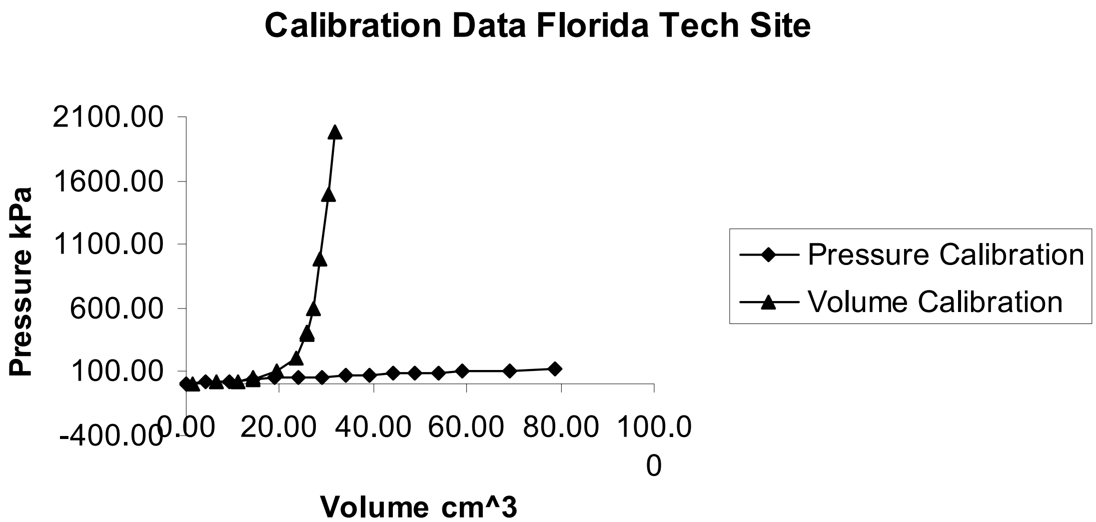
A.2 Puerto Del Rio Field Site

A.2.1 S. Sundaram – Raw Data

Calibration Data

Calibration Data Puerto Del Rio Site

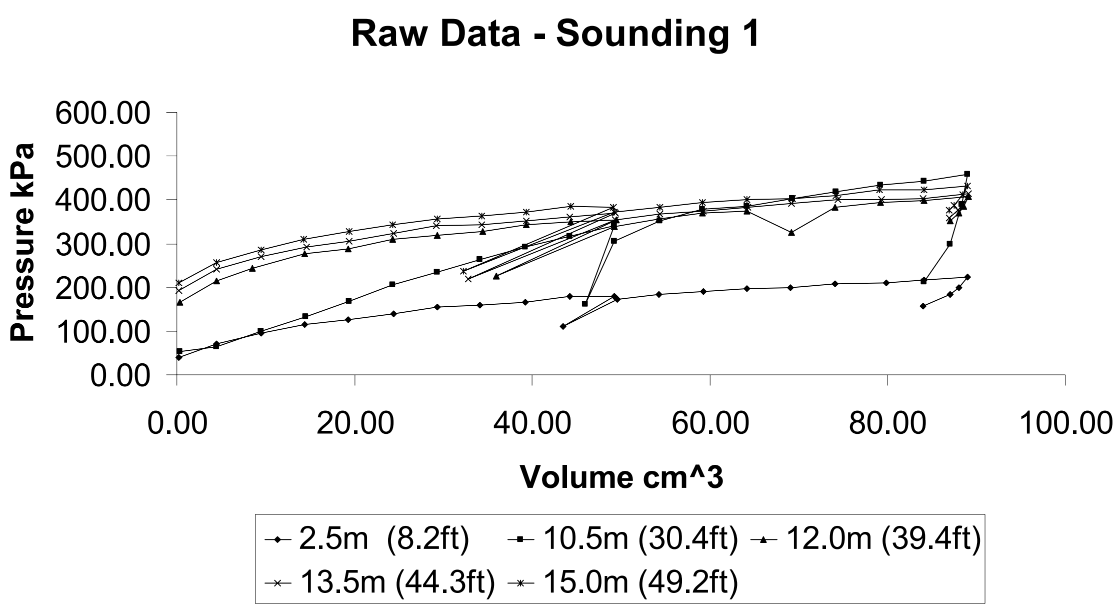
Pressure Calibration				Volume Calibration			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	0.00	0.00	0.09	1.50	0.37	2.53
0.26	4.26	2.56	17.68	0.39	6.42	2.32	15.99
0.56	9.19	4.15	28.62	0.68	11.08	4.39	30.30
0.87	14.23	5.49	37.88	0.87	14.23	6.96	47.98
1.17	19.11	6.96	47.98	0.88	14.40	6.59	45.45
1.47	24.15	8.06	55.56	1.19	19.44	14.41	99.33
1.78	29.13	9.28	63.97	1.42	23.32	29.55	203.71
2.09	34.17	9.89	68.18	1.57	25.70	58.97	406.6
2.39	39.10	10.87	74.92	1.57	25.75	58.85	405.7
2.69	44.14	12.03	82.92	1.57	25.70	58.36	402.4
2.99	49.07	12.70	87.54	1.65	26.97	87.41	602.7
3.30	54.11	13.43	92.59	1.76	28.80	143.94	992.4
3.61	59.09	14.28	98.49	1.85	30.35	216.58	1493.3
4.21	69.01	15.63	107.75	1.95	32.01	287.27	1980.7
4.81	78.87	16.97	117.00				



A.2.1.1 Sounding 1

Sounding 1 - Smooth Cone

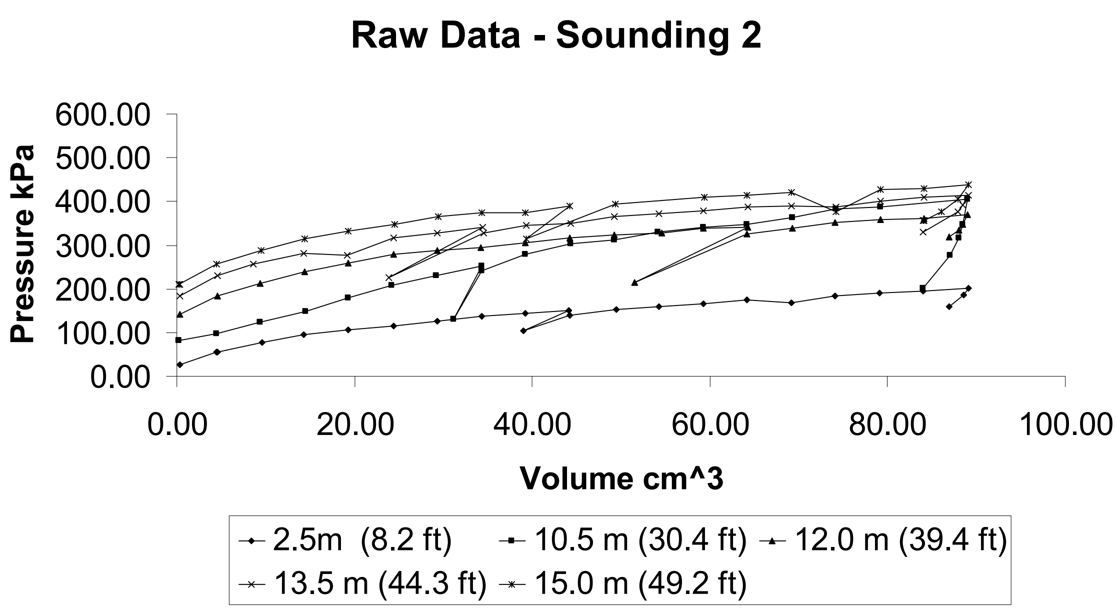
2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.17	5.86	40.40	0.02	0.28	7.81	53.87	0.02	0.33	24.05	165.83	0.01	0.22	27.96	192.76	0.01	0.22	30.52	210.44
0.27	4.49	10.38	71.55	0.27	4.49	9.40	64.82	0.27	4.43	31.25	215.49	0.27	4.49	35.04	241.58	0.27	4.49	37.24	256.74
0.58	9.47	13.67	94.28	0.58	9.47	14.41	99.33	0.52	8.47	35.41	244.11	0.58	9.47	39.07	269.36	0.58	9.47	41.27	284.51
0.88	14.34	16.60	114.48	0.88	14.46	19.29	133.00	0.88	14.40	40.17	276.94	0.89	14.57	42.24	291.25	0.87	14.29	44.93	309.77
1.18	19.33	18.44	127.11	1.19	19.44	24.30	167.51	1.18	19.33	41.88	288.72	1.18	19.38	44.44	306.40	1.19	19.44	47.61	328.29
1.49	24.37	20.14	138.89	1.48	24.31	29.91	206.23	1.48	24.31	45.05	310.61	1.49	24.37	46.88	323.24	1.48	24.31	49.69	342.60
1.79	29.35	22.59	155.73	1.79	29.30	34.06	234.85	1.79	29.35	46.27	319.03	1.78	29.24	49.45	340.91	1.79	29.30	51.76	356.91
2.08	34.12	23.07	159.09	2.08	34.12	38.34	264.31	2.10	34.39	47.61	328.29	2.09	34.28	49.81	343.44	2.09	34.28	52.74	363.64
2.40	39.27	23.93	164.98	2.39	39.21	42.49	292.93	2.40	39.32	49.81	343.44	2.40	39.32	51.03	351.85	2.40	39.32	54.08	372.90
2.70	44.20	26.13	180.14	2.70	44.20	45.90	316.50	2.70	44.31	50.67	349.33	2.70	44.25	52.50	361.96	2.70	44.31	55.79	384.68
3.00	49.24	26.13	180.14	3.01	49.29	49.32	340.07	3.01	49.40	51.52	355.22	3.01	49.35	53.72	370.37	3.00	49.13	55.67	383.84
2.65	43.48	16.12	111.11	2.81	45.97	23.44	161.62	2.20	36.00	32.84	226.43	2.00	32.79	31.74	218.86	1.97	32.29	34.43	237.38
3.02	49.57	25.03	172.56	3.00	49.24	44.44	306.40	3.00	49.24	49.20	339.23	3.01	49.35	51.52	355.22	3.00	49.24	53.84	371.22
3.31	54.28	26.61	183.50	3.32	54.33	50.91	351.01	3.31	54.22	51.76	356.91	3.32	54.33	53.35	367.85	3.32	54.33	55.43	382.16
3.61	59.21	27.71	191.08	3.61	59.15	55.06	379.63	3.61	59.15	53.47	368.69	3.61	59.21	54.33	374.58	3.61	59.15	57.14	393.94
3.91	64.13	28.45	196.13	3.92	64.19	55.92	385.53	3.92	64.19	54.33	374.58	3.92	64.30	55.55	383.00	3.92	64.19	58.11	400.68
4.21	69.06	29.06	200.34	4.22	69.23	58.60	404.04	4.22	69.17	47.13	324.92	4.22	69.17	56.77	391.42	4.22	69.23	58.48	403.20
4.52	74.10	30.28	208.76	4.53	74.16	60.68	418.35	4.52	74.10	55.67	383.84	4.54	74.38	57.99	399.84	4.53	74.16	59.46	409.94
4.88	79.90	30.52	210.44	4.83	79.14	63.00	434.35	4.83	79.14	57.14	393.94	4.84	79.25	58.24	401.52	4.83	79.09	61.29	422.56
5.13	84.07	31.62	218.02	5.13	84.07	64.10	441.92	5.13	84.13	57.87	398.99	5.13	84.02	58.60	404.04	5.13	84.07	61.41	423.40
5.43	89.00	32.48	223.91	5.43	89.00	66.54	458.76	5.44	89.11	59.21	408.25	5.44	89.11	60.19	414.99	5.43	88.95	62.75	432.66
5.37	88.01	28.81	198.65	5.39	88.39	56.40	388.89	5.40	88.56	55.79	384.68	5.40	88.45	56.65	390.58	5.40	88.45	59.58	410.78
5.31	87.01	26.49	182.66	5.31	87.01	43.46	299.67	5.37	88.01	53.72	370.37	5.37	87.95	54.57	376.27	5.34	87.51	56.16	387.21
5.13	84.02	22.71	156.57	5.13	84.13	30.77	212.12	5.31	87.01	51.15	352.70	5.31	86.95	52.01	358.59	5.30	86.90	54.69	377.11



A.2.1.2 Sounding 2

Sounding 2 - Smooth Cone

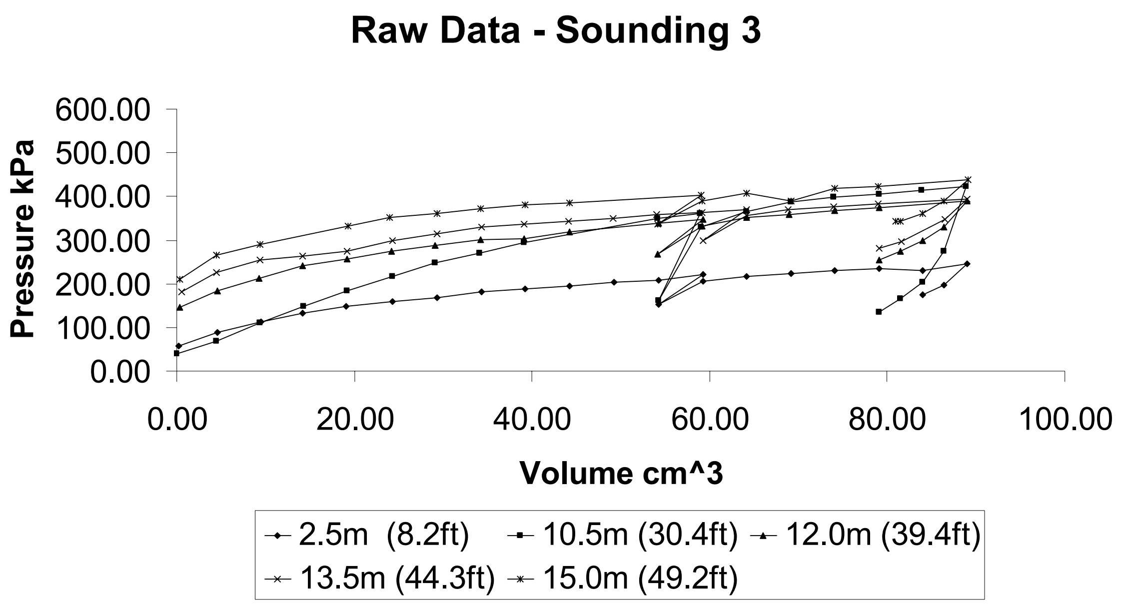
2.5m (8.2 ft)				10.5 m (30.4 ft)				12.0 m (39.4 ft)				13.5 m (44.3 ft)				15.0 m (49.2 ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.02	0.28	3.91	26.94	0.01	0.22	11.84	81.65	0.02	0.33	20.63	142.26	0.02	0.33	26.49	182.66	0.02	0.28	30.40	209.60
0.27	4.43	8.06	55.56	0.27	4.49	14.04	96.80	0.28	4.60	26.49	182.66	0.28	4.60	33.33	229.80	0.01	0.17	30.40	209.60
0.28	4.60	8.06	55.56	0.57	9.36	17.95	123.74	0.57	9.36	30.89	212.96	0.52	8.58	37.24	256.74	0.27	4.43	37.36	257.58
0.59	9.64	11.35	78.28	0.88	14.46	21.61	148.99	0.88	14.34	34.67	239.06	0.87	14.29	40.78	281.15	0.58	9.47	41.75	287.88
0.87	14.29	13.67	94.28	1.18	19.27	26.13	180.14	1.18	19.27	37.72	260.10	1.17	19.22	40.29	277.78	0.88	14.34	45.54	313.98
1.18	19.27	15.38	106.06	1.47	24.15	30.03	207.07	1.49	24.37	40.41	278.62	1.49	24.37	46.03	317.34	1.18	19.27	48.22	332.49
1.49	24.37	16.85	116.16	1.78	29.19	33.45	230.64	1.79	29.30	41.63	287.04	1.79	29.30	47.49	327.44	1.49	24.48	50.54	348.49
1.79	29.30	18.19	125.42	2.10	34.34	36.75	253.37	2.09	34.23	42.73	294.62	2.10	34.45	49.32	340.07	1.79	29.41	53.11	366.16
2.10	34.34	19.78	136.36	1.90	31.18	18.92	130.47	2.39	39.21	44.32	305.56	1.45	23.82	32.84	226.43	2.09	34.28	54.33	374.58
2.39	39.21	21.00	144.78	2.09	34.28	35.16	242.43	2.70	44.25	45.78	315.66	2.11	34.56	47.37	326.60	2.39	39.21	54.33	374.58
2.69	44.09	21.85	150.67	2.39	39.21	40.53	279.46	3.00	49.24	46.88	323.24	2.40	39.32	50.06	345.12	2.70	44.20	56.53	389.73
2.38	39.05	15.14	104.38	2.71	44.36	43.95	303.03	3.33	54.61	47.37	326.60	2.71	44.36	50.67	349.33	2.40	39.32	45.66	314.82
2.70	44.25	20.39	140.57	3.00	49.24	45.29	312.29	3.62	59.26	49.08	338.39	3.00	49.24	52.99	365.32	3.01	49.35	57.26	394.78
3.01	49.40	22.10	152.36	3.31	54.17	47.86	329.97	3.92	64.25	49.45	340.91	3.31	54.22	53.96	372.06	3.62	59.32	59.46	409.94
3.31	54.28	23.07	159.09	3.62	59.26	49.45	340.91	3.14	51.51	31.25	215.49	3.61	59.21	54.94	378.79	3.91	64.13	59.94	413.30
3.62	59.26	23.93	164.98	3.91	64.13	50.54	348.49	3.91	64.13	47.25	325.76	3.92	64.25	56.04	386.37	4.22	69.17	61.17	421.72
3.92	64.19	25.52	175.93	4.22	69.23	52.74	363.64	4.22	69.23	49.20	339.23	4.22	69.17	56.40	388.89	4.53	74.16	54.69	377.11
4.22	69.17	24.54	169.19	4.53	74.16	55.55	383.00	4.52	74.05	51.15	352.70	4.53	74.16	56.28	388.05	4.83	79.20	62.02	427.61
4.52	74.10	26.49	182.66	4.83	79.20	56.04	386.37	4.83	79.14	52.01	358.59	4.83	79.14	58.24	401.52	5.13	84.07	62.26	429.30
4.83	79.09	27.71	191.08	5.43	89.00	58.72	404.89	5.13	84.07	52.50	361.96	5.13	84.13	59.46	409.94	5.43	89.06	63.49	437.71
5.13	84.02	28.20	194.45	5.40	88.50	50.54	348.49	5.43	89.00	53.60	369.53	5.43	89.06	60.19	414.99	5.37	87.95	58.85	405.73
5.44	89.11	29.18	201.18	5.37	88.01	46.03	317.34	5.40	88.50	50.54	348.49	5.40	88.50	56.89	392.26	5.25	86.07	54.69	377.11
5.40	88.56	26.86	185.19	5.31	87.01	40.17	276.94	5.37	88.06	48.47	334.18	5.36	87.89	54.69	377.11	5.13	84.07	51.76	356.91
5.31	86.95	23.20	159.93	5.12	83.96	29.18	201.18	5.31	86.95	46.15	318.18	5.13	84.02	47.86	329.97	5.13	84.02	51.64	356.06



A.2.1.3 Sounding 3

Sounding 3 - Smooth Cone

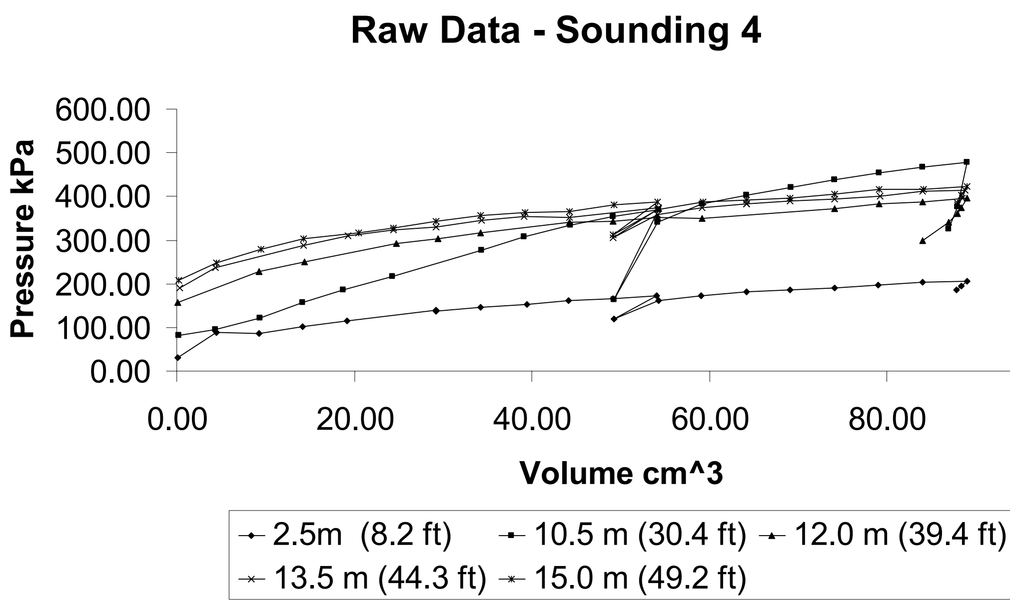
2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.22	8.42	58.08	0.00	0.00	5.80	40.00	0.02	0.28	21.24	146.47	0.03	0.55	26.25	180.98	0.02	0.28	30.40	209.60
0.28	4.60	12.70	87.54	0.27	4.49	10.01	69.02	0.28	4.54	26.61	183.50	0.27	4.49	32.84	226.43	0.27	4.43	38.58	266.00
0.58	9.53	16.24	111.95	0.57	9.42	16.12	111.11	0.56	9.25	30.77	212.12	0.57	9.42	36.99	255.05	0.57	9.42	42.12	290.41
0.87	14.18	19.17	132.16	0.87	14.29	21.49	148.15	0.87	14.18	34.92	240.74	0.87	14.18	38.09	262.63	1.18	19.33	48.10	331.65
1.16	19.05	21.37	147.31	1.17	19.16	26.61	183.50	1.17	19.22	37.36	257.58	1.17	19.16	39.92	275.25	1.46	23.93	50.91	351.01
1.48	24.31	23.20	159.93	1.48	24.26	31.62	218.02	1.47	24.15	39.92	275.25	1.48	24.31	43.46	299.67	1.79	29.30	52.25	360.27
1.79	29.35	24.42	168.35	1.78	29.13	36.02	248.32	1.78	29.13	41.75	287.88	1.79	29.30	45.54	313.98	2.09	34.23	53.84	371.22
2.09	34.28	26.37	181.82	2.08	34.12	39.19	270.20	2.09	34.17	43.83	302.19	2.09	34.28	47.86	329.97	2.39	39.21	55.18	380.47
2.39	39.21	27.35	188.55	2.39	39.16	42.61	293.77	2.39	39.16	44.07	303.87	2.39	39.10	48.71	335.86	2.70	44.20	55.92	385.53
2.70	44.20	28.32	195.29	3.31	54.17	50.79	350.17	2.70	44.25	46.15	318.18	2.69	44.09	49.93	344.28	3.61	59.09	58.60	404.04
3.00	49.24	29.67	204.55	3.60	58.93	52.38	361.11	3.31	54.22	49.20	339.23	3.00	49.18	50.67	349.33	3.31	54.17	48.71	335.86
3.31	54.22	30.28	208.76	3.31	54.28	23.44	161.62	3.61	59.21	50.54	348.49	3.30	54.05	51.89	357.75	3.61	59.15	56.65	390.58
3.61	59.21	31.99	220.54	3.61	59.09	47.86	329.97	3.31	54.17	38.95	268.52	3.61	59.15	52.74	363.64	3.92	64.19	59.09	407.41
3.31	54.28	22.10	152.36	3.92	64.19	53.11	366.16	3.61	59.15	48.22	332.49	3.91	64.13	53.60	369.53	4.22	69.12	56.65	390.58
3.62	59.26	29.79	205.39	4.22	69.12	56.28	388.05	3.91	64.13	51.03	351.85	3.61	59.21	43.22	297.98	4.52	74.05	60.56	417.51
3.91	64.13	31.62	218.02	4.52	73.99	57.87	398.99	4.21	68.95	52.01	358.59	3.91	64.13	51.64	356.06	4.82	78.98	61.41	423.40
4.22	69.12	32.35	223.07	4.82	79.03	58.85	405.73	4.52	74.05	53.23	367.01	4.20	68.90	53.60	369.53	5.43	89.06	63.61	438.56
4.52	74.10	33.33	229.80	5.12	83.91	60.07	414.15	4.82	79.03	54.33	374.58	4.52	73.99	54.69	377.11	5.27	86.40	56.53	389.73
4.83	79.09	33.94	234.01	5.42	88.89	61.41	423.40	5.43	88.95	56.40	388.89	4.82	78.92	55.55	383.00	5.12	83.96	52.25	360.27
5.13	84.02	33.45	230.64	5.27	86.34	39.68	273.57	5.27	86.40	47.86	329.97	5.43	88.95	57.01	393.10	4.97	81.53	49.69	342.60
5.43	88.95	35.65	245.79	5.12	83.96	29.67	204.55	5.12	83.96	43.22	297.98	5.28	86.45	50.30	346.80	4.94	80.97	49.69	342.60
5.27	86.40	28.69	197.81	4.97	81.53	23.93	164.98	4.97	81.47	39.92	275.25	4.98	81.58	43.10	297.14				
5.13	84.02	25.52	175.93	4.82	79.03	19.66	135.52	4.82	79.03	36.99	255.05	4.82	79.03	40.65	280.31				



A.2.1.4 Sounding 4

Sounding 4 - Smooth Cone

2.5m (8.2 ft)				10.5 m (30.4 ft)				12.0 m (39.4 ft)				13.5 m (44.3 ft)				15.0 m (49.2 ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.11	4.52	31.15	0.01	0.17	11.84	81.65	0.01	0.11	22.71	156.57	0.02	0.28	27.71	191.08	0.01	0.22	30.03	207.07
0.27	4.43	12.94	89.23	0.27	4.38	13.80	95.12	0.57	9.30	33.09	228.12	0.27	4.38	34.43	237.38	0.27	4.43	36.02	248.32
0.57	9.30	12.45	85.86	0.57	9.36	17.70	122.05	0.88	14.34	36.38	250.84	0.87	14.29	41.88	288.72	0.58	9.47	40.41	278.62
0.87	14.18	14.65	101.01	0.87	14.18	22.83	157.41	1.51	24.70	42.24	291.25	1.18	19.27	44.81	308.93	0.87	14.23	43.95	303.03
1.17	19.22	16.73	115.32	1.15	18.78	26.98	186.03	1.80	29.46	44.07	303.87	1.49	24.37	47.00	324.08	1.25	20.44	46.03	317.34
1.78	29.19	20.14	138.89	1.48	24.26	31.62	218.02	2.09	34.17	45.78	315.66	1.78	29.24	47.98	330.81	1.49	24.37	47.49	327.44
1.78	29.24	19.90	137.21	2.09	34.28	40.17	276.94	2.70	44.20	49.32	340.07	2.09	34.28	50.18	345.96	1.78	29.24	49.81	343.44
2.09	34.17	21.24	146.47	2.39	39.10	44.68	308.08	3.00	49.13	49.93	344.28	2.39	39.10	51.28	353.54	2.09	34.17	51.76	356.91
2.41	39.43	22.22	153.20	2.70	44.31	48.59	335.02	3.30	54.11	51.15	352.70	2.70	44.20	51.15	352.70	2.39	39.21	52.62	362.80
2.69	44.09	23.44	161.62	3.00	49.18	51.52	355.22	3.61	59.15	50.79	350.17	3.31	54.22	54.21	373.74	2.70	44.25	53.11	366.16
3.00	49.13	24.17	166.67	3.31	54.22	53.47	368.69	4.52	74.10	53.84	371.22	3.31	54.28	53.96	372.06	3.00	49.24	55.31	381.32
3.30	54.05	24.91	171.72	3.00	49.24	23.81	164.14	4.82	79.03	55.67	383.84	3.00	49.13	44.44	306.40	3.31	54.17	56.16	387.21
3.00	49.24	17.21	118.69	3.31	54.17	49.57	341.75	5.13	84.02	56.04	386.37	3.30	54.11	52.13	359.43	3.00	49.18	45.42	313.13
3.31	54.22	23.56	162.46	3.61	59.15	55.67	383.84	5.43	88.95	57.62	397.31	3.61	59.15	54.21	373.74	3.31	54.17	53.72	370.37
3.61	59.09	24.91	171.72	3.91	64.13	58.48	403.20	5.39	88.34	54.21	373.74	3.92	64.19	55.43	382.16	3.61	59.21	56.04	386.37
3.92	64.19	26.25	180.98	4.22	69.12	60.92	420.04	5.37	87.95	52.38	361.11	3.91	64.13	55.43	382.16	3.92	64.19	56.77	391.42
4.21	69.06	26.86	185.19	4.52	74.10	63.61	438.56	5.31	86.95	49.45	340.91	4.21	69.06	56.53	389.73	4.21	69.06	57.62	397.31
4.52	74.10	27.71	191.08	4.82	79.03	65.93	454.55	5.12	83.96	43.22	297.98	4.52	74.05	57.26	394.78	4.52	74.05	58.85	405.73
4.82	78.92	28.69	197.81	5.13	84.02	67.76	467.18					4.83	79.20	58.11	400.68	4.82	79.03	60.31	415.83
5.12	83.96	29.54	203.71	5.43	89.00	69.35	478.12					5.12	83.96	59.82	412.46	5.13	84.07	60.43	416.67
5.43	88.95	29.91	206.23	5.37	87.95	54.69	377.11					5.42	88.78	60.07	414.15	5.43	89.00	61.41	423.40
5.39	88.34	28.20	194.45	5.30	86.90	47.13	324.92					5.40	88.45	57.50	396.47	5.39	88.39	58.36	402.36
5.36	87.78	26.86	185.19									5.37	87.95	55.31	381.32	5.36	87.89	55.79	384.68

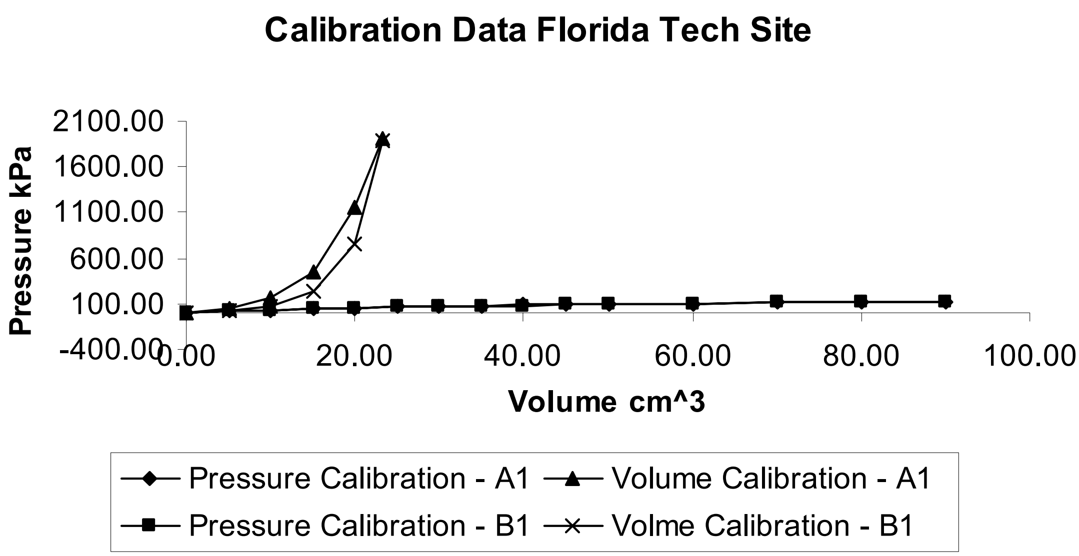


A.2.2 F. Messaoud – Reduced Data

A.2.2.1 Calibration Data

Calibration Data Puerto Del Rio Site

Pressure Calibration								Volume Calibration							
A1				B1				A1				B1			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.31	5.00	3.05	21.00	0.31	5.00	2.90	20.00	0.31	5.00	7.25	50.00	0.31	5.00	2.61	18.00
0.61	10.00	5.08	35.00	0.61	10.00	4.64	32.00	0.61	10.00	24.08	166.00	0.61	10.00	11.02	76.00
0.92	15.00	6.96	48.00	0.92	15.00	6.09	42.00	0.92	15.00	66.72	460.00	0.92	15.00	34.81	240.00
1.22	20.00	7.98	55.00	1.22	20.00	7.98	55.00	1.22	20.00	167.08	1152.00	1.22	20.00	110.23	760.00
1.53	25.00	10.01	69.00	1.53	25.00	9.43	65.00	1.43	23.40	276.01	1903.00	1.43	23.40	272.67	1880.00
1.83	30.00	11.02	76.00	1.83	30.00	10.15	70.00								
2.14	35.00	12.04	83.00	2.14	35.00	11.02	76.00								
2.44	40.00	13.05	90.00	2.44	40.00	11.89	82.00								
2.75	45.00	13.05	90.00	2.75	45.00	12.76	88.00								
3.05	50.00	13.92	96.00	3.05	50.00	13.63	94.00								
3.66	60.00	14.94	103.00	3.66	60.00	15.23	105.00								
4.27	70.00	16.97	117.00	4.27	70.00	16.68	115.00								
4.88	80.00	17.98	124.00	4.88	80.00	17.69	122.00								
5.49	90.00	18.85	130.00	5.49	90.00	18.85	130.00								

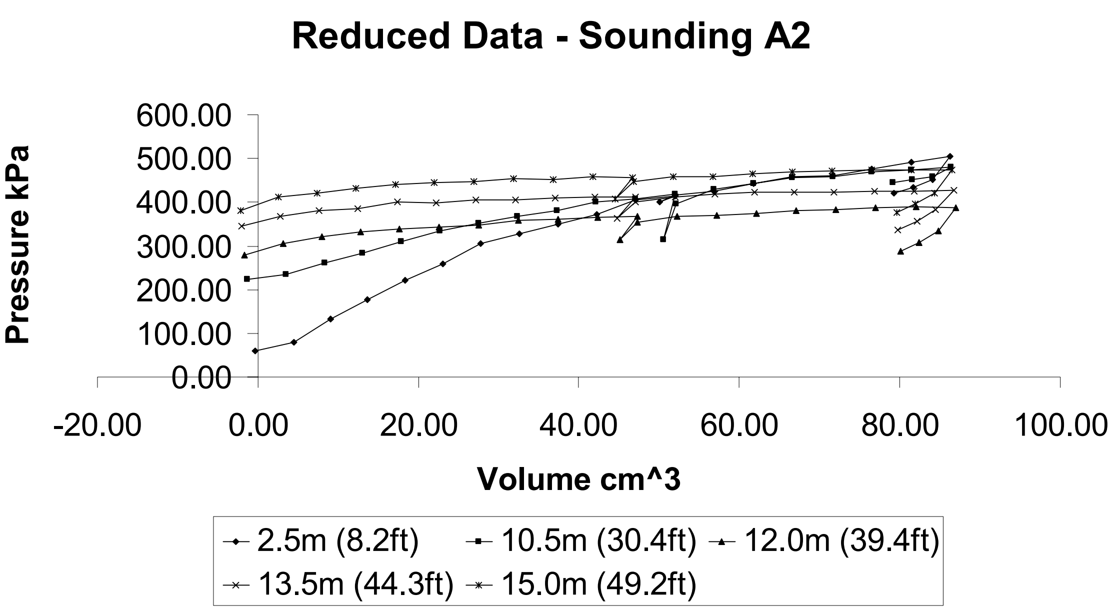


A.2.2.2 Sounding A2

Sounding A2 - Smooth Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.34	8.64	59.58	-0.08	-1.29	32.42	223.56	-0.10	-1.61	40.39	278.51	-0.12	-1.99	50.00	344.72	-0.13	-2.20	55.15	380.24
0.27	4.43	11.67	80.48	0.22	3.54	33.91	233.82	0.19	3.13	44.38	305.96	0.17	2.77	53.21	366.89	0.15	2.51	59.83	412.53
0.55	9.04	19.29	132.99	0.51	8.29	37.93	261.53	0.49	7.95	46.45	320.26	0.46	7.60	55.27	381.04	0.45	7.36	61.13	421.47
0.84	13.70	25.69	177.15	0.80	13.08	41.20	284.08	0.78	12.80	48.08	331.50	0.76	12.48	55.99	386.05	0.75	12.21	62.72	432.47
1.12	18.37	32.20	221.98	1.09	17.85	45.03	310.46	1.08	17.68	49.25	339.54	1.06	17.33	58.02	400.05	1.04	17.10	63.86	440.29
1.41	23.09	37.60	259.24	1.38	22.66	48.35	333.39	1.38	22.59	49.92	344.21	1.36	22.27	57.95	399.54	1.34	22.01	64.51	444.77
1.69	27.77	44.38	305.96	1.68	27.50	51.01	351.72	1.68	27.52	50.38	347.37	1.66	27.19	58.69	404.63	1.64	26.94	64.94	447.76
1.99	32.59	47.67	328.67	1.97	32.36	53.27	367.31	1.98	32.42	51.91	357.93	1.96	32.14	58.74	405.02	1.94	31.86	65.72	453.12
2.28	37.42	50.83	350.46	2.27	37.24	55.26	381.00	2.28	37.36	52.44	361.56	2.26	37.08	59.26	408.59	2.25	36.84	65.35	450.59
2.58	42.26	53.98	372.17	2.57	42.10	58.11	400.66	2.58	42.30	53.11	366.15	2.56	42.03	59.77	412.13	2.55	41.76	66.44	458.11
2.87	47.04	58.69	404.66	2.87	47.03	59.17	407.99	2.88	47.27	53.15	366.48	2.87	47.00	59.82	412.42	2.85	46.74	66.19	456.35
3.17	51.97	59.98	413.58	3.17	51.94	60.61	417.92	2.75	45.09	45.46	313.44	2.73	44.81	52.56	362.41	2.72	44.54	59.23	408.37
3.05	50.06	58.03	400.11	3.09	50.56	45.69	315.02	2.89	47.34	51.33	353.91	2.87	47.06	58.21	401.36	2.86	46.79	65.02	448.31
3.17	51.96	60.28	415.59	3.18	52.07	57.55	396.82	3.19	52.24	53.28	367.38	3.17	51.98	59.80	412.29	3.16	51.71	66.31	457.20
3.47	56.88	61.62	424.89	3.47	56.85	62.40	430.23	3.49	57.20	53.76	370.68	3.47	56.92	60.71	418.58	3.46	56.68	66.49	458.46
3.77	61.75	64.31	443.42	3.77	61.75	64.21	442.73	3.79	62.15	54.41	375.15	3.78	61.88	61.21	422.05	3.76	61.62	67.43	464.93
4.07	66.64	66.42	457.92	4.07	66.65	66.17	456.24	4.09	67.10	55.20	380.61	4.08	66.85	61.42	423.50	4.06	66.58	67.93	468.39
4.37	71.60	66.89	461.19	4.37	71.62	66.35	457.49	4.40	72.06	55.53	382.85	4.38	71.82	61.46	423.74	4.37	71.53	68.55	472.67
4.67	76.50	68.91	475.12	4.67	76.53	68.08	469.41	4.70	77.02	56.08	386.68	4.69	76.79	61.58	424.58	4.67	76.50	68.68	473.54
4.97	81.37	71.29	491.50	4.97	81.48	68.71	473.71	5.00	81.97	56.41	388.90	4.99	81.76	61.76	425.83	4.97	81.48	68.72	473.82
5.26	86.26	73.26	505.11	5.27	86.40	69.80	481.26	5.31	86.94	56.32	388.30	5.29	86.72	61.83	426.28	5.27	86.44	68.79	474.32
5.13	84.08	65.65	452.62	5.13	84.05	66.42	457.97	5.17	84.78	48.57	334.86	5.16	84.49	55.68	383.89	5.14	84.27	61.04	420.83
4.99	81.71	62.82	433.15	4.98	81.61	65.50	451.58	5.03	82.45	44.73	308.41	5.01	82.16	51.69	356.40	5.00	81.94	57.34	395.35
4.84	79.30	60.99	420.54	4.83	79.15	64.69	446.00	4.89	80.08	41.74	287.81	4.87	79.79	48.85	336.79	4.86	79.57	54.49	375.72

Data Reduced Using Calibration A1

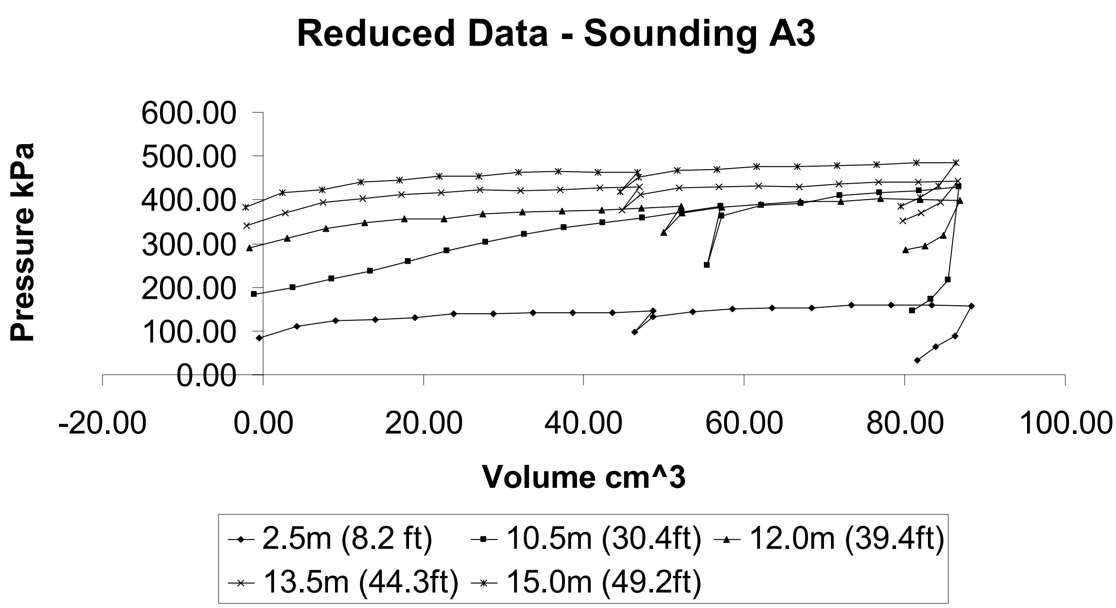


A.2.2.3 Sounding A3

Sounding A3- Friction Reducing Cone

2.5m (8.2 ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.49	12.20	84.12	-0.06	-1.06	26.65	183.74	-0.10	-1.68	42.19	290.87	-0.12	-1.97	49.49	341.22	-0.13	-2.21	55.46	382.37
0.26	4.26	15.96	110.05	0.23	3.75	28.74	198.18	0.19	3.08	45.42	313.18	0.17	2.76	53.52	369.02	0.15	2.48	60.44	416.69
0.55	9.09	17.96	123.83	0.52	8.53	31.89	219.88	0.48	7.87	48.53	334.59	0.46	7.52	57.05	393.34	0.45	7.35	61.29	422.57
0.85	13.99	18.33	126.39	0.81	13.35	34.44	237.45	0.78	12.71	50.45	347.83	0.76	12.38	58.51	403.40	0.74	12.16	64.06	441.70
1.15	18.91	18.82	129.79	1.11	18.15	37.69	259.87	1.07	17.58	51.76	356.85	1.05	17.26	59.72	411.78	1.04	17.07	64.46	444.43
1.45	23.79	20.15	138.90	1.40	22.95	41.18	283.91	1.37	22.53	51.55	355.42	1.35	22.18	60.31	415.81	1.34	21.95	65.84	453.95
1.75	28.73	20.36	140.39	1.70	27.78	43.99	303.33	1.67	27.41	53.18	366.64	1.65	27.08	61.34	422.89	1.64	26.91	65.69	452.89
2.06	33.68	20.62	142.17	1.99	32.64	46.41	319.99	1.97	32.33	53.97	372.12	1.96	32.05	60.95	420.22	1.94	31.81	67.05	462.28
2.36	38.65	20.60	142.04	2.29	37.51	48.70	335.76	2.28	37.29	54.20	373.72	2.26	37.00	61.32	422.77	2.24	36.75	67.41	464.77
2.66	43.62	20.57	141.82	2.59	42.40	50.53	348.42	2.58	42.23	54.72	377.29	2.56	41.94	61.97	427.30	2.55	41.73	67.18	463.22
2.96	48.57	21.08	145.34	2.89	47.32	51.90	357.81	2.88	47.19	55.21	380.63	2.86	46.90	62.16	428.58	2.85	46.71	67.07	462.46
2.83	46.36	14.11	97.26	3.19	52.21	53.92	371.78	3.18	52.14	55.77	384.54	2.73	44.73	54.47	375.56	2.71	44.48	60.55	417.50
2.97	48.64	19.26	132.78	3.49	57.11	55.93	385.61	3.05	49.99	47.32	326.25	2.87	47.00	59.83	412.50	2.85	46.76	65.62	452.41
3.27	53.55	20.94	144.35	3.38	55.42	36.16	249.35	3.19	52.23	53.59	369.47	3.17	51.89	61.85	426.44	3.15	51.66	67.63	466.33
3.57	58.50	21.79	150.22	3.49	57.24	52.65	363.02	3.49	57.13	55.52	382.81	3.47	56.85	62.32	429.71	3.46	56.62	67.96	468.58
3.87	63.46	22.07	152.20	3.79	62.08	56.21	387.58	3.79	62.06	56.61	390.29	3.77	61.82	62.68	432.17	3.76	61.56	68.90	475.05
4.18	68.44	22.13	152.60	4.09	67.04	56.71	391.03	4.09	67.01	57.40	395.75	4.08	66.80	62.45	430.61	4.06	66.54	68.97	475.50
4.48	73.38	23.03	158.76	4.39	71.90	59.52	410.35	4.39	71.98	57.58	396.99	4.38	71.74	63.36	436.88	4.36	71.50	69.44	478.78
4.78	78.35	23.12	159.44	4.69	76.84	60.29	415.71	4.69	76.91	58.57	403.85	4.68	76.70	63.78	439.74	4.67	76.47	69.64	480.15
5.08	83.33	22.98	158.44	4.99	81.78	61.13	421.47	5.00	81.90	58.17	401.05	4.98	81.67	63.82	439.99	4.97	81.41	70.34	484.97
5.39	88.30	22.86	157.59	5.29	86.70	62.36	429.97	5.30	86.89	57.64	397.45	5.29	86.63	64.17	442.47	5.27	86.38	70.27	484.47
5.26	86.22	12.93	89.16	5.22	85.46	31.54	217.44	5.18	84.86	46.39	319.84	5.15	84.42	57.30	395.04	5.14	84.21	62.65	431.98
5.12	83.88	9.26	63.84	5.08	83.25	24.94	171.93	5.04	82.53	42.70	294.40	5.01	82.09	53.60	369.56	5.00	81.88	58.66	404.48
4.98	81.57	4.97	34.29	4.94	80.92	21.08	145.35	4.89	80.10	41.32	284.87	4.86	79.71	51.05	351.96	4.85	79.51	55.82	384.85

Data Reduced Using Calibration A1

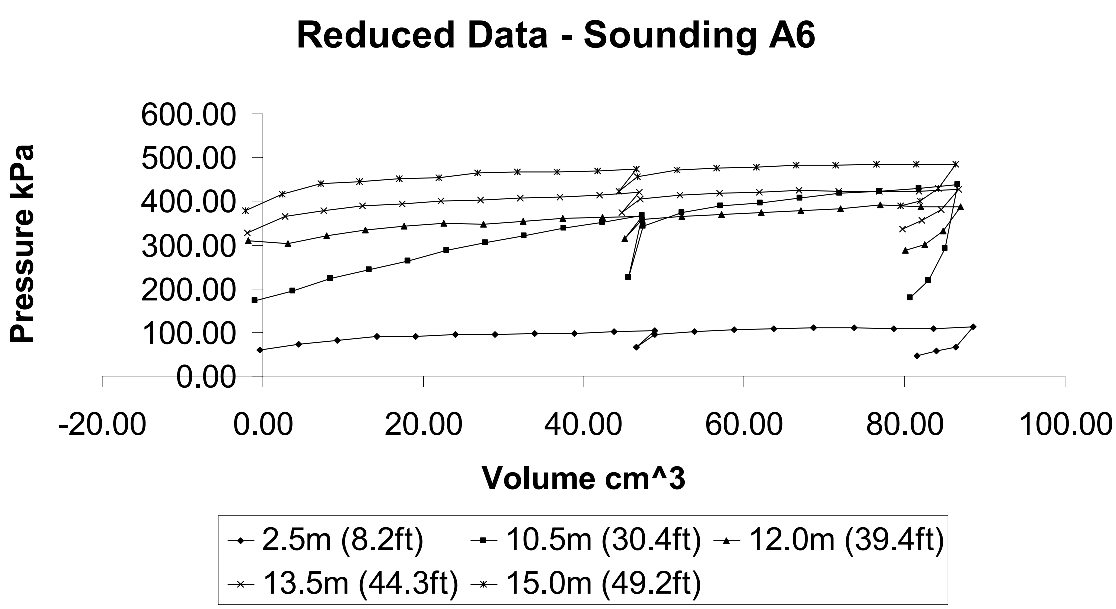


A.2.2.4 Sounding A6

Sounding A6- Friction Reducing Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.35	8.83	60.86	-0.06	-0.99	24.91	171.72	-0.11	-1.79	44.90	309.55	-0.12	-1.89	47.52	327.66	-0.13	-2.19	54.90	378.54
0.27	4.47	10.67	73.60	0.23	3.77	28.34	195.38	0.19	3.14	44.13	304.26	0.17	2.78	52.97	365.19	0.15	2.49	60.33	415.93
0.57	9.33	11.95	82.38	0.52	8.51	32.52	224.21	0.48	7.95	46.50	320.60	0.46	7.61	55.02	379.34	0.44	7.25	63.84	440.13
0.87	14.20	13.22	91.12	0.81	13.31	35.36	243.80	0.78	12.78	48.57	334.89	0.76	12.46	56.63	390.45	0.74	12.13	64.69	446.02
1.17	19.13	13.28	91.56	1.11	18.12	38.32	264.18	1.08	17.66	49.74	342.92	1.06	17.37	57.04	393.29	1.04	17.03	65.52	451.78
1.47	24.05	13.88	95.69	1.40	22.93	41.65	287.20	1.38	22.56	50.71	349.60	1.36	22.27	58.07	400.38	1.34	21.96	65.73	453.20
1.77	29.00	13.81	95.23	1.69	27.77	44.18	304.59	1.68	27.52	50.43	347.71	1.66	27.19	58.59	403.96	1.64	26.84	67.33	464.25
2.07	33.95	14.08	97.07	1.99	32.63	46.59	321.26	1.98	32.44	51.23	353.22	1.96	32.13	58.94	406.36	1.94	31.78	67.67	466.57
2.37	38.90	14.21	98.00	2.29	37.49	49.17	339.03	2.28	37.37	52.20	359.88	2.26	37.07	59.46	409.93	2.24	36.74	67.81	467.54
2.68	43.86	14.63	100.84	2.59	42.38	51.15	352.70	2.58	42.32	52.57	362.46	2.56	42.02	60.11	414.47	2.54	41.69	68.10	469.51
2.98	48.81	15.14	104.39	2.88	47.27	53.24	367.11	2.89	47.28	52.91	364.80	2.87	46.96	60.89	419.79	2.85	46.63	68.86	474.78
2.84	46.55	9.62	66.35	2.78	45.60	32.87	226.60	2.75	45.09	45.65	314.78	2.73	44.73	54.36	374.81	2.71	44.46	61.17	421.78
2.98	48.87	13.68	94.34	2.89	47.41	49.75	342.99	2.89	47.32	51.89	357.77	2.87	47.04	58.70	404.71	2.85	46.74	66.24	456.68
3.28	53.80	14.71	101.41	3.19	52.19	54.40	375.05	3.19	52.25	53.04	365.71	3.17	51.97	59.99	413.63	3.15	51.62	68.55	472.61
3.59	58.75	15.49	106.79	3.48	57.09	56.48	389.38	3.49	57.21	53.59	369.50	3.47	56.92	60.61	417.91	3.45	56.57	69.16	476.87
3.89	63.72	15.70	108.27	3.78	62.02	57.56	396.87	3.79	62.16	54.17	373.47	3.78	61.88	61.12	421.38	3.76	61.54	69.37	478.32
4.19	68.69	16.05	110.67	4.08	66.94	59.08	407.35	4.10	67.11	54.96	378.94	4.08	66.83	61.76	425.84	4.06	66.50	70.02	482.79
4.50	73.66	16.07	110.78	4.38	71.85	60.79	419.14	4.40	72.06	55.58	383.18	4.38	71.83	61.22	422.06	4.36	71.47	70.13	483.55
4.80	78.64	15.87	109.42	4.69	76.80	61.28	422.50	4.70	76.99	56.71	391.03	4.69	76.81	61.19	421.90	4.66	76.44	70.26	484.43
5.10	83.61	15.86	109.38	4.99	81.73	62.33	429.78	5.00	81.98	56.31	388.23	4.99	81.78	61.23	422.14	4.97	81.41	70.23	484.21
5.40	88.56	16.32	112.50	5.29	86.66	63.42	437.28	5.31	86.95	56.07	386.62	5.29	86.72	61.87	426.61	5.27	86.38	70.30	484.72
5.27	86.35	9.75	67.26	5.19	85.03	42.23	291.19	5.17	84.78	48.32	333.18	5.16	84.50	55.29	381.20	5.14	84.22	62.25	429.22
5.12	83.92	8.42	58.05	5.06	82.97	31.83	219.48	5.03	82.49	43.76	301.70	5.01	82.16	51.74	356.74	5.00	81.90	58.26	401.72
4.97	81.50	6.76	46.62	4.93	80.72	25.93	178.80	4.89	80.08	41.79	288.14	4.87	79.79	48.90	337.12	4.85	79.49	56.44	389.12

Data Reduced Using Calibration A1



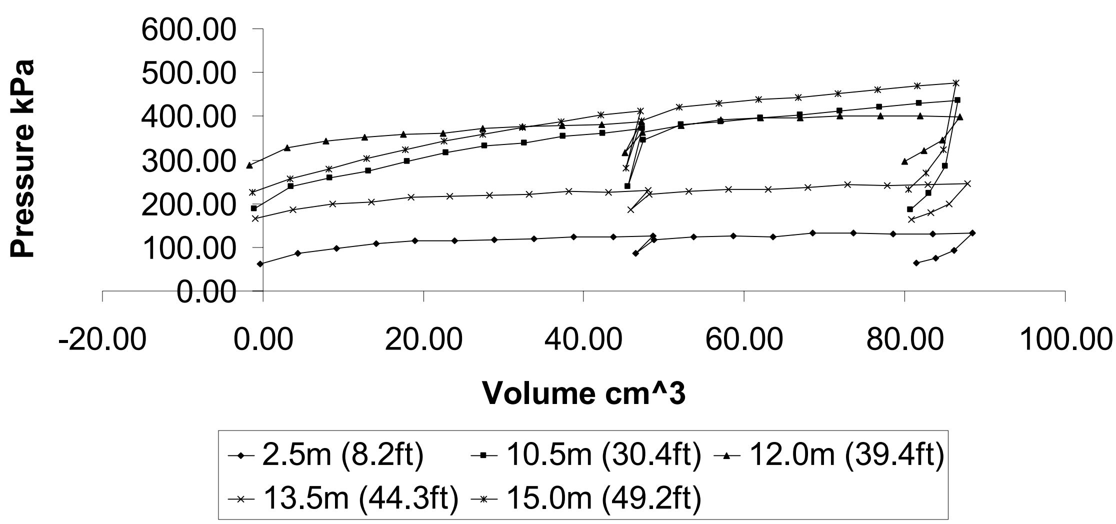
A.2.2.5 Sounding B1

Sounding B1 - Smooth Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.36	9.15	63.06	-0.07	-1.09	27.31	188.26	-0.10	-1.66	41.80	288.23	-0.06	-0.96	24.14	166.43	-0.08	-1.31	32.85	226.49
0.27	4.40	12.47	85.99	0.21	3.51	34.73	239.43	0.18	3.00	47.56	327.90	0.23	3.81	27.13	187.05	0.21	3.41	37.30	257.14
0.56	9.24	14.18	97.79	0.51	8.31	37.41	257.97	0.48	7.82	49.62	342.15	0.53	8.65	28.95	199.61	0.50	8.18	40.57	279.71
0.86	14.10	15.59	107.52	0.80	13.13	39.95	275.45	0.77	12.69	50.95	351.31	0.83	13.54	29.59	204.03	0.79	12.97	43.83	302.22
1.16	18.99	16.83	116.02	1.09	17.94	42.90	295.76	1.07	17.57	52.11	359.30	1.12	18.41	31.09	214.36	1.09	17.78	46.77	322.47
1.46	23.94	16.54	114.04	1.39	22.75	45.93	316.70	1.37	22.50	52.34	360.90	1.42	23.34	31.51	217.25	1.38	22.60	49.65	342.35
1.76	28.87	16.91	116.58	1.69	27.62	48.01	331.02	1.67	27.38	53.82	371.11	1.73	28.28	31.71	218.60	1.68	27.46	52.02	358.64
2.06	33.81	17.46	120.41	1.98	32.52	49.25	339.58	1.97	32.31	54.47	375.58	2.03	33.21	32.24	222.29	1.97	32.33	54.13	373.22
2.37	38.76	17.89	123.32	2.28	37.41	51.24	353.30	2.27	37.26	54.85	378.18	2.33	38.15	32.94	227.09	2.27	37.20	56.26	387.90
2.67	43.73	17.86	123.12	2.58	42.33	52.35	360.92	2.58	42.21	55.37	381.74	2.63	43.12	32.89	226.79	2.57	42.09	58.38	402.53
2.97	48.68	18.37	126.65	2.88	47.24	53.85	371.30	2.88	47.15	56.14	387.09	2.93	48.08	33.25	229.24	2.87	47.00	59.74	411.87
2.83	46.43	12.56	86.61	2.78	45.53	34.79	239.84	2.75	45.07	45.97	316.96	2.80	45.84	27.01	186.21	2.76	45.29	40.67	280.42
2.97	48.74	16.91	116.60	2.89	47.39	50.21	346.17	2.89	47.29	52.64	362.96	2.94	48.12	32.08	221.20	2.88	47.13	56.53	389.76
3.27	53.67	18.08	124.67	3.18	52.16	55.15	380.24	3.18	52.17	54.96	378.94	3.24	53.06	33.10	228.21	3.17	51.93	61.03	420.79
3.58	58.64	18.28	126.02	3.48	57.09	56.35	388.55	3.48	57.08	56.75	391.26	3.54	58.02	33.58	231.54	3.47	56.85	62.38	430.09
3.88	63.63	17.91	123.48	3.78	62.02	57.59	397.04	3.78	62.02	57.54	396.74	3.84	62.99	33.80	233.02	3.77	61.78	63.61	438.57
4.18	68.56	19.13	131.91	4.09	66.97	58.38	402.50	4.09	67.00	57.61	397.18	4.15	67.95	34.29	236.45	4.07	66.74	64.11	442.04
4.49	73.53	19.30	133.04	4.39	71.89	59.87	412.78	4.39	71.96	58.08	400.43	4.45	72.89	35.19	242.64	4.37	71.65	65.60	452.33
4.79	78.53	18.81	129.68	4.69	76.81	61.16	421.66	4.69	76.94	58.05	400.25	4.75	77.86	35.15	242.37	4.67	76.58	66.90	461.23
5.09	83.49	18.95	130.67	4.99	81.74	62.21	428.94	5.00	81.90	58.16	400.98	5.05	82.82	35.46	244.47	4.97	81.50	68.10	469.55
5.40	88.44	19.26	132.81	5.29	86.67	63.15	435.44	5.30	86.89	57.71	397.87	5.36	87.77	35.79	246.73	5.27	86.42	69.20	477.09
5.26	86.19	13.57	93.59	5.19	85.07	41.38	285.32	5.17	84.71	50.10	345.43	5.22	85.58	28.77	198.39	5.18	84.84	46.98	323.95
5.11	83.81	11.07	76.32	5.06	82.95	32.30	222.67	5.03	82.38	46.41	319.98	5.08	83.21	25.97	179.05	5.05	82.68	39.06	269.32
4.97	81.39	9.41	64.88	4.92	80.69	26.83	185.01	4.88	80.03	43.13	297.36	4.93	80.81	23.87	164.55	4.91	80.41	33.60	231.64

Data Reduced Using Calibration A1

Reduced Data - Sounding B1

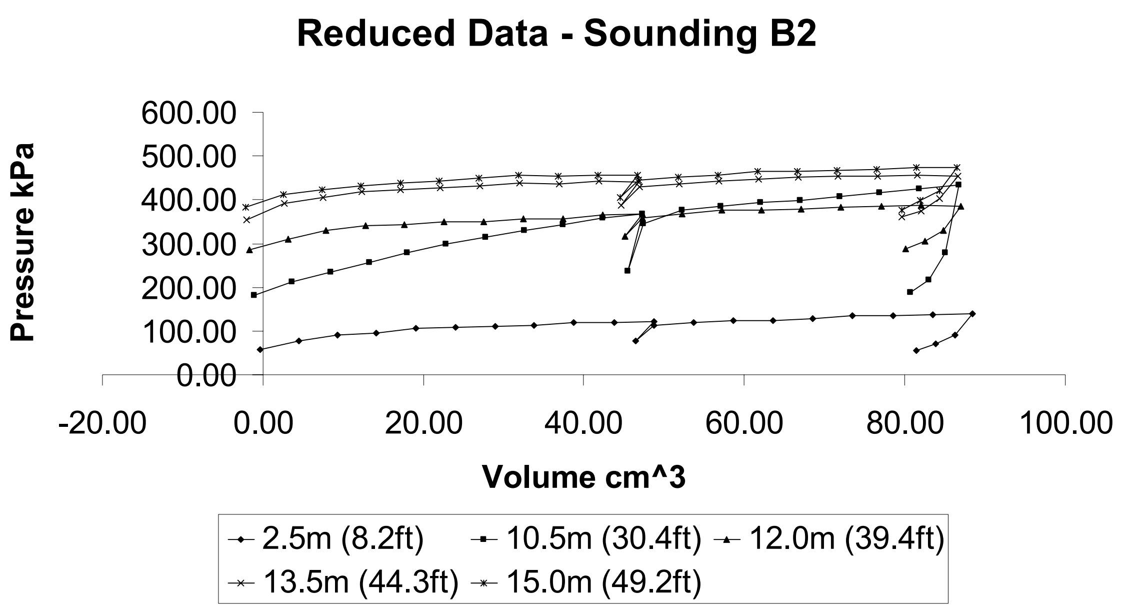


A.2.2.6 Sounding B2

Sounding B2- Friction Reducing Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.33	8.19	56.49	-0.06	-1.05	26.35	181.69	-0.10	-1.65	41.44	285.75	-0.12	-2.04	51.35	354.02	-0.13	-2.21	55.46	382.37
0.27	4.45	11.23	77.40	0.22	3.67	30.82	212.47	0.19	3.10	44.98	310.12	0.16	2.63	56.78	391.47	0.15	2.51	59.70	411.59
0.57	9.28	13.09	90.24	0.52	8.44	34.11	235.15	0.48	7.89	47.79	329.50	0.45	7.45	58.82	405.56	0.45	7.35	61.29	422.57
0.87	14.18	13.76	94.91	0.81	13.23	37.38	257.76	0.78	12.75	49.42	340.72	0.75	12.30	60.57	417.62	0.75	12.21	62.74	432.55
1.16	19.05	15.30	105.46	1.10	18.04	40.34	278.11	1.08	17.66	49.85	343.67	1.05	17.20	61.27	422.43	1.04	17.10	63.72	439.36
1.46	23.97	15.74	108.55	1.40	22.86	43.23	298.06	1.38	22.56	50.67	349.35	1.35	22.11	61.85	426.43	1.34	22.02	64.08	441.81
1.76	28.91	15.97	110.09	1.69	27.72	45.60	314.43	1.68	27.51	50.69	349.47	1.65	27.03	62.65	431.98	1.64	26.92	65.25	449.86
2.07	33.85	16.52	113.93	1.99	32.59	47.73	329.07	1.98	32.42	51.78	357.00	1.95	31.95	63.43	437.37	1.94	31.85	66.02	455.22
2.37	38.78	17.24	118.87	2.29	37.46	49.87	343.81	2.28	37.39	51.57	355.60	2.25	36.92	63.22	435.86	2.25	36.81	65.95	454.70
2.67	43.75	17.21	118.67	2.58	42.34	51.99	358.48	2.58	42.30	52.97	365.22	2.55	41.85	64.16	442.39	2.55	41.78	66.02	455.17
2.97	48.71	17.58	121.20	2.88	47.26	53.35	367.86	2.88	47.26	53.46	368.57	2.86	46.83	63.91	440.64	2.85	46.74	66.20	456.43
2.84	46.48	11.33	78.14	2.78	45.55	34.29	236.40	2.75	45.07	46.06	317.54	2.73	44.66	56.22	387.63	2.72	44.55	58.80	405.43
2.98	48.76	16.41	113.16	2.89	47.39	50.15	345.75	2.89	47.32	52.00	358.52	2.86	46.89	62.45	430.59	2.86	46.81	64.45	444.37
3.28	53.69	17.44	120.22	3.18	52.18	54.65	376.80	3.19	52.23	53.44	368.47	3.16	51.83	63.31	436.48	3.16	51.74	65.59	452.26
3.58	58.65	17.93	123.59	3.48	57.11	56.00	386.12	3.49	57.17	54.50	375.78	3.46	56.77	64.22	442.76	3.46	56.69	66.21	456.53
3.88	63.62	18.14	125.07	3.79	62.04	57.23	394.61	3.79	62.14	54.57	376.23	3.77	61.73	64.72	446.23	3.76	61.63	67.30	464.00
4.19	68.58	18.63	128.48	4.09	67.00	57.73	398.06	4.09	67.10	55.07	379.69	4.07	66.69	65.37	450.69	4.06	66.60	67.51	465.46
4.49	73.52	19.53	134.63	4.39	71.91	59.22	408.34	4.40	72.07	55.39	381.92	4.37	71.64	65.84	453.96	4.37	71.56	67.84	467.72
4.79	78.50	19.48	134.28	4.69	76.84	60.51	417.21	4.70	77.03	55.80	384.75	4.68	76.61	65.97	454.82	4.67	76.53	68.11	469.60
5.09	83.46	19.77	136.28	4.99	81.76	61.71	425.50	5.00	81.98	56.27	387.97	4.98	81.58	66.15	456.09	4.97	81.48	68.59	472.89
5.40	88.41	20.08	138.43	5.29	86.68	62.80	433.00	5.31	86.96	55.89	385.36	5.28	86.56	65.93	454.56	5.28	86.45	68.66	473.39
5.26	86.21	13.07	90.14	5.19	85.10	40.59	279.86	5.18	84.80	47.85	329.90	5.15	84.38	58.32	402.08	5.14	84.28	60.90	419.90
5.12	83.84	10.28	70.86	5.06	82.99	31.36	216.21	5.03	82.46	44.30	305.47	5.01	82.06	54.33	374.59	5.00	81.92	57.79	398.44
4.97	81.44	8.18	56.41	4.92	80.67	27.21	187.60	4.89	80.08	41.75	287.89	4.86	79.65	52.36	361.01	4.86	79.56	54.65	376.80

Data Reduced Using Calibration A1

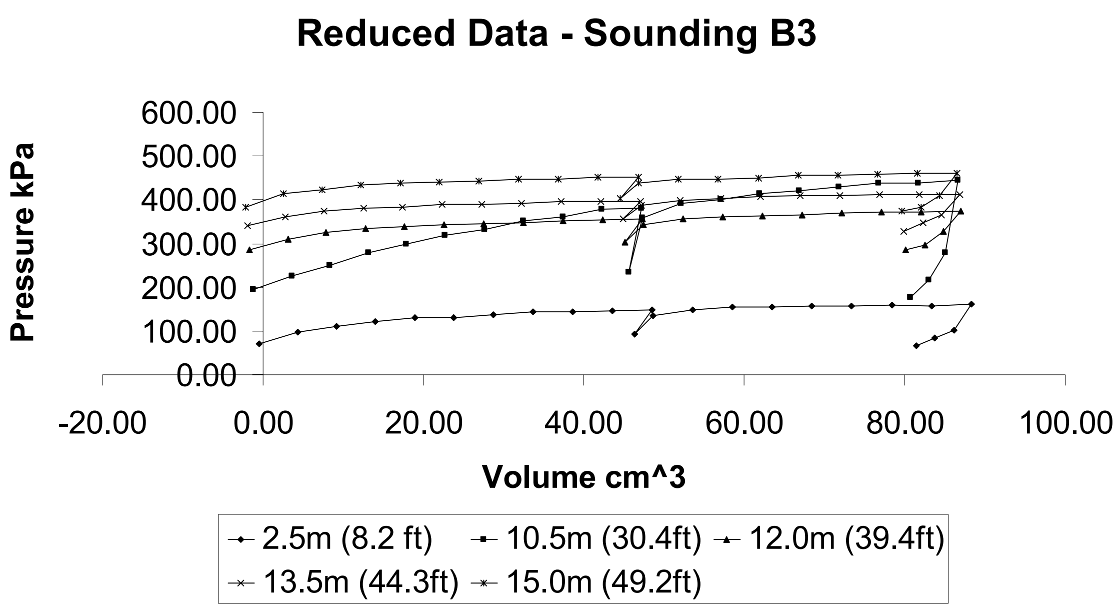


A.2.2.7 Sounding B3

Sounding B3 - Smooth Cone

2.5m (8.2 ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.41	10.26	70.73	-0.07	-1.13	28.42	195.94	-0.10	-1.64	41.28	284.65	-0.12	-1.97	49.40	340.63	-0.13	-2.21	55.52	382.81
0.26	4.33	14.17	97.72	0.22	3.58	32.88	226.67	0.19	3.10	44.97	310.04	0.17	2.81	52.33	360.77	0.15	2.50	60.05	414.06
0.56	9.17	16.03	110.51	0.51	8.35	36.31	250.34	0.48	7.91	47.34	326.37	0.47	7.63	54.38	374.94	0.45	7.35	61.35	423.00
0.86	14.02	17.58	121.22	0.80	13.11	40.32	277.99	0.78	12.79	48.38	333.54	0.76	12.51	55.26	380.97	0.74	12.20	63.09	435.01
1.15	18.91	18.81	129.70	1.09	17.92	43.26	298.30	1.08	17.68	49.25	339.54	1.06	17.43	55.52	382.82	1.04	17.10	63.64	438.77
1.45	23.84	19.11	131.73	1.39	22.75	46.15	318.22	1.38	22.60	49.78	343.20	1.36	22.33	56.48	389.43	1.34	22.03	63.99	441.23
1.75	28.75	19.91	137.27	1.68	27.61	48.23	332.53	1.68	27.54	50.09	345.36	1.66	27.27	56.64	390.50	1.65	26.96	64.28	443.22
2.05	33.67	20.90	144.10	1.98	32.45	51.08	352.18	1.98	32.48	50.45	347.85	1.97	32.21	56.99	392.92	1.95	31.89	64.92	447.58
2.36	38.63	21.03	144.97	2.28	37.36	52.34	360.86	2.28	37.42	50.98	351.49	2.27	37.16	57.36	395.50	2.25	36.86	64.84	447.07
2.66	43.59	21.14	145.75	2.58	42.23	54.90	378.52	2.59	42.37	51.36	354.08	2.57	42.12	57.59	397.04	2.55	41.80	65.49	451.57
2.96	48.55	21.65	149.26	2.88	47.18	55.24	380.85	2.89	47.33	51.70	356.43	2.87	47.10	57.34	395.33	2.85	46.77	65.39	450.82
2.83	46.39	13.51	93.14	2.78	45.56	33.98	234.31	2.76	45.16	43.86	302.38	2.74	44.84	51.83	357.39	2.72	44.57	58.43	402.84
2.97	48.63	19.46	134.19	2.89	47.32	51.89	357.73	2.89	47.41	49.65	342.36	2.88	47.15	56.17	387.29	2.86	46.84	63.64	438.76
3.27	53.53	21.36	147.27	3.18	52.10	56.83	391.80	3.19	52.30	51.68	356.34	3.18	52.05	57.90	399.24	3.16	51.77	64.78	446.66
3.57	58.46	22.57	155.65	3.48	57.02	58.18	401.11	3.49	57.26	52.31	360.64	3.48	57.01	58.53	403.52	3.46	56.74	64.96	447.91
3.87	63.45	22.50	155.12	3.78	61.92	60.13	414.61	3.80	62.22	52.66	363.10	3.78	61.96	59.03	406.99	3.77	61.71	65.18	449.37
4.17	68.42	22.70	156.52	4.08	66.86	61.07	421.09	4.10	67.19	53.02	365.55	4.08	66.92	59.53	410.45	4.07	66.66	66.11	455.84
4.48	73.39	22.72	156.66	4.38	71.79	62.27	429.36	4.40	72.13	53.78	370.79	4.39	71.90	59.56	410.68	4.37	71.63	66.30	457.10
4.78	78.36	22.96	158.34	4.68	76.71	63.56	438.25	4.71	77.10	53.90	371.60	4.69	76.87	59.69	411.52	4.67	76.59	66.57	458.97
5.09	83.33	22.82	157.34	4.98	81.68	63.60	438.50	5.01	82.07	54.07	372.81	4.99	81.84	59.72	411.75	4.98	81.56	66.75	460.24
5.39	88.27	23.43	161.53	5.29	86.61	64.54	445.01	5.31	87.02	54.42	375.21	5.30	86.80	59.78	412.18	5.28	86.53	66.68	459.72
5.26	86.14	14.82	102.15	5.19	85.10	40.58	279.79	5.18	84.82	47.55	327.81	5.16	84.60	52.90	364.76	5.15	84.33	59.50	410.26
5.11	83.76	12.16	83.87	5.06	82.98	31.49	217.14	5.04	82.51	43.13	297.34	5.02	82.22	50.38	347.35	5.00	82.01	55.52	382.77
4.97	81.39	9.48	65.39	4.93	80.74	25.59	176.46	4.89	80.10	41.31	284.79	4.87	79.85	47.39	326.74	4.86	79.58	54.13	373.20

Data Reduced Using Calibration A1



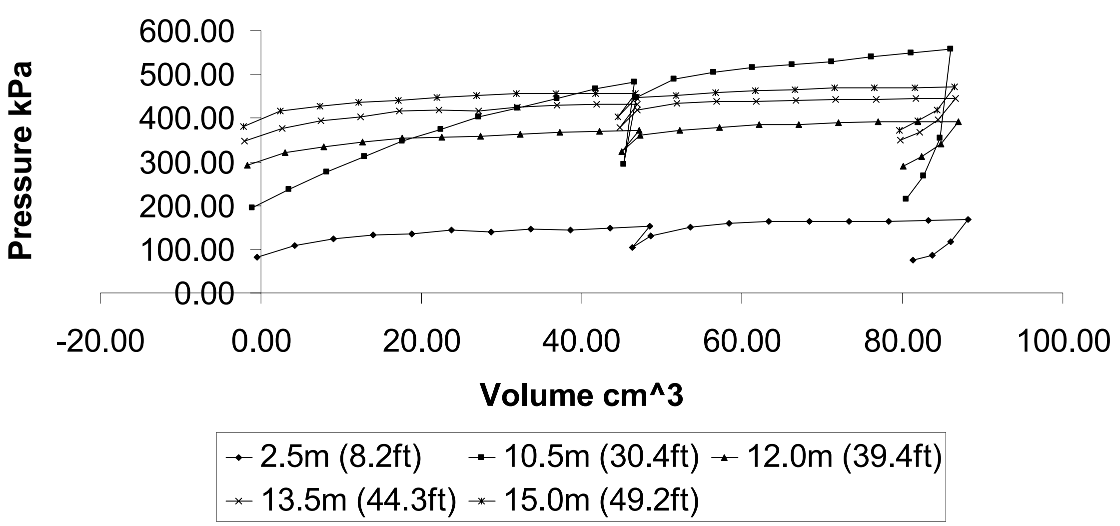
A.2.2.8 Sounding B4

Sounding B4 - Smooth Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.48	12.04	83.00	-0.07	-1.12	28.12	193.89	-0.10	-1.69	42.47	292.84	-0.12	-2.01	50.44	347.79	-0.13	-2.20	55.30	381.27
0.26	4.27	15.80	108.93	0.22	3.53	34.36	236.87	0.19	3.04	46.45	320.25	0.17	2.71	54.69	377.10	0.15	2.49	60.28	415.59
0.55	9.09	17.95	123.73	0.50	8.19	40.29	277.81	0.48	7.87	48.52	334.52	0.46	7.52	57.19	394.28	0.45	7.33	61.87	426.56
0.85	13.96	19.20	132.38	0.79	12.92	45.18	311.49	0.78	12.72	50.14	345.73	0.76	12.39	58.35	402.30	0.74	12.20	63.17	435.52
1.15	18.87	19.69	135.77	1.08	17.64	50.32	346.93	1.07	17.60	51.30	353.73	1.05	17.24	60.23	415.25	1.04	17.09	64.01	441.30
1.45	23.76	20.87	143.86	1.37	22.42	54.22	373.84	1.37	22.52	51.68	356.35	1.35	22.16	60.59	417.75	1.34	22.00	64.80	446.79
1.75	28.73	20.35	140.29	1.66	27.20	58.33	402.20	1.68	27.45	52.14	359.50	1.65	27.12	60.44	416.75	1.64	26.92	65.38	450.79
2.05	33.66	21.19	146.11	1.95	32.03	61.46	423.77	1.98	32.38	52.79	363.98	1.95	32.03	61.52	424.18	1.94	31.84	66.16	456.15
2.36	38.64	20.73	142.95	2.25	36.87	64.46	444.44	2.28	37.32	53.32	367.61	2.26	36.96	62.33	429.74	2.25	36.80	66.23	456.63
2.66	43.58	21.58	148.76	2.55	41.71	67.74	467.05	2.58	42.28	53.69	370.18	2.56	41.92	62.55	431.24	2.55	41.76	66.30	457.10
2.96	48.53	22.09	152.27	2.84	46.59	69.96	482.38	2.88	47.23	54.03	372.51	2.86	46.89	62.59	431.52	2.85	46.74	66.19	456.35
2.83	46.32	15.11	104.20	2.76	45.21	42.59	293.63	2.75	45.04	46.77	322.49	2.73	44.71	54.90	378.50	2.72	44.57	58.50	403.34
2.97	48.66	18.88	130.16	2.86	46.79	64.86	447.19	2.89	47.30	52.28	360.45	2.87	46.96	60.84	419.46	2.86	46.80	64.73	446.30
3.27	53.51	21.94	151.28	3.14	51.53	70.81	488.24	3.19	52.22	53.87	371.41	3.16	51.85	63.00	434.40	3.16	51.74	65.58	452.18
3.57	58.44	23.16	159.66	3.44	56.41	73.18	504.54	3.49	57.15	54.93	378.71	3.47	56.80	63.62	438.67	3.46	56.69	66.35	457.45
3.87	63.39	23.81	164.15	3.74	61.32	74.84	516.03	3.79	62.10	55.72	384.19	3.77	61.77	63.69	439.12	3.76	61.64	67.00	461.92
4.17	68.37	23.87	164.55	4.04	66.26	75.78	522.51	4.09	67.07	55.93	385.64	4.07	66.74	64.05	441.58	4.06	66.60	67.50	465.38
4.48	73.35	23.74	163.69	4.35	71.20	76.70	528.82	4.39	72.02	56.55	389.88	4.38	71.71	64.23	442.83	4.37	71.55	68.12	469.65
4.78	78.32	23.84	164.37	4.64	76.11	78.43	540.78	4.70	76.99	56.81	391.71	4.68	76.68	64.35	443.68	4.67	76.53	67.95	468.51
5.08	83.28	24.13	166.39	4.94	81.03	79.79	550.17	5.00	81.95	56.99	392.93	4.98	81.64	64.68	445.95	4.97	81.50	67.99	468.79
5.38	88.23	24.45	168.57	5.25	85.95	80.90	557.79	5.30	86.92	56.90	392.34	5.29	86.61	64.60	445.41	5.28	86.45	68.50	472.31
5.25	86.06	16.86	116.25	5.17	84.66	51.38	354.28	5.17	84.75	49.30	339.89	5.15	84.42	57.43	395.97	5.14	84.28	60.74	418.82
5.11	83.75	12.60	86.89	5.05	82.68	38.94	268.45	5.03	82.42	45.31	312.43	5.01	82.09	53.44	368.48	5.00	81.95	57.05	393.33
4.96	81.33	10.94	75.44	4.91	80.51	31.28	215.69	4.89	80.07	42.04	289.82	4.87	79.72	50.60	348.86	4.86	79.59	53.91	371.69

Data Reduced Using Calibration A1

Reduced Data - Sounding B4

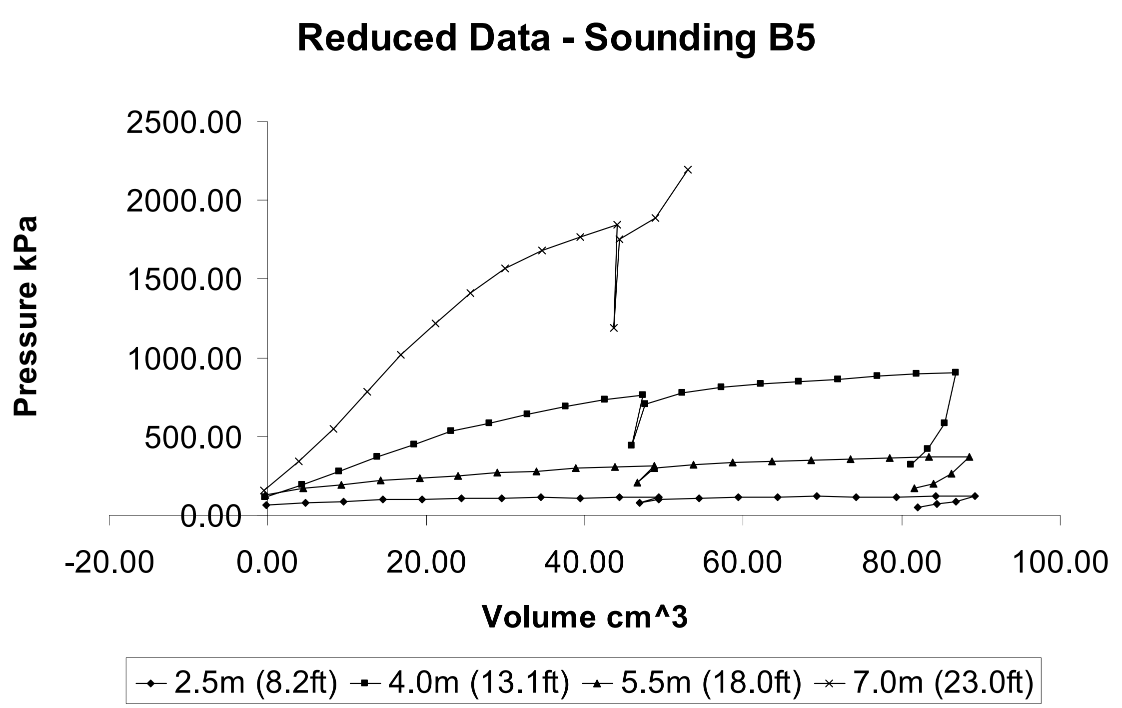


A.2.2.9 Sounding B5

Sounding B5- Friction Reducing Cone

2.5m (8.2ft)				4.0m (13.1ft)				5.5m (18.0ft)				7.0m (23.0ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.20	9.02	62.17	-0.02	-0.35	16.40	113.07	-0.02	-0.39	18.60	128.21	-0.03	-0.47	22.26	153.45
0.29	4.70	11.83	81.59	0.27	4.38	27.40	188.92	0.27	4.43	24.91	171.77	0.24	3.91	49.93	344.25
0.59	9.64	12.83	88.43	0.55	9.06	40.66	280.31	0.57	9.33	27.94	192.64	0.50	8.26	79.25	546.38
0.89	14.57	14.32	98.73	0.84	13.76	53.37	367.98	0.87	14.21	31.76	218.96	0.76	12.51	113.55	782.87
1.19	19.53	14.83	102.28	1.13	18.49	64.95	447.79	1.17	19.14	33.72	232.48	1.02	16.78	147.26	1015.35
1.49	24.49	15.38	106.02	1.42	23.21	76.98	530.73	1.47	24.05	36.58	252.22	1.29	21.13	176.74	1218.58
1.80	29.47	15.20	104.81	1.71	28.02	84.92	585.52	1.77	28.98	38.87	268.00	1.56	25.52	205.03	1413.67
2.10	34.43	16.18	111.57	2.00	32.82	93.44	644.25	2.07	33.92	40.71	280.70	1.83	30.02	227.76	1570.38
2.41	39.43	15.24	105.11	2.30	37.66	100.18	690.73	2.37	38.84	43.40	299.24	2.12	34.66	243.91	1681.67
2.71	44.39	16.30	112.38	2.59	42.52	106.01	730.89	2.67	43.81	44.16	304.44	2.40	39.39	255.78	1763.57
3.01	49.37	16.56	114.21	2.89	47.41	110.17	759.59	2.98	48.76	45.57	314.23	2.69	44.12	268.04	1848.09
2.87	46.99	10.97	75.61	2.80	45.89	63.55	438.18	2.84	46.60	29.80	205.44	2.66	43.63	172.25	1187.64
3.02	49.41	14.53	100.16	2.90	47.58	102.17	704.42	2.98	48.82	42.96	296.17	2.71	44.41	254.22	1752.78
3.32	54.37	15.87	109.45	3.19	52.34	113.09	779.75	3.28	53.72	46.91	323.46	2.99	48.98	273.83	1888.00
3.62	59.34	16.39	113.03	3.49	57.23	117.52	810.30	3.58	58.66	48.88	337.04	3.24	53.04	318.23	2194.09
3.93	64.32	16.65	114.80	3.79	62.15	120.97	834.05	3.88	63.64	49.28	339.79				
4.23	69.30	17.06	117.63	4.09	67.09	123.27	849.90	4.19	68.60	50.56	348.63				
4.53	74.30	16.44	113.37	4.40	72.03	125.27	863.74	4.49	73.57	51.69	356.42				
4.84	79.28	16.81	115.93	4.70	76.96	128.13	883.45	4.79	78.54	52.51	362.03				
5.14	84.26	17.14	118.17	5.00	81.91	129.79	894.89	5.10	83.49	53.86	371.35				
5.45	89.24	17.40	119.96	5.30	86.87	131.10	903.93	5.40	88.48	53.98	372.21				
5.30	86.84	12.84	88.53	5.21	85.35	84.19	580.49	5.27	86.32	37.78	260.49				
5.15	84.41	10.01	69.02	5.09	83.34	61.42	423.50	5.13	84.00	29.42	202.84				
5.00	81.97	7.46	51.41	4.95	81.16	46.35	319.60	4.98	81.61	24.54	169.17				

Data Reduced Using Calibration B1

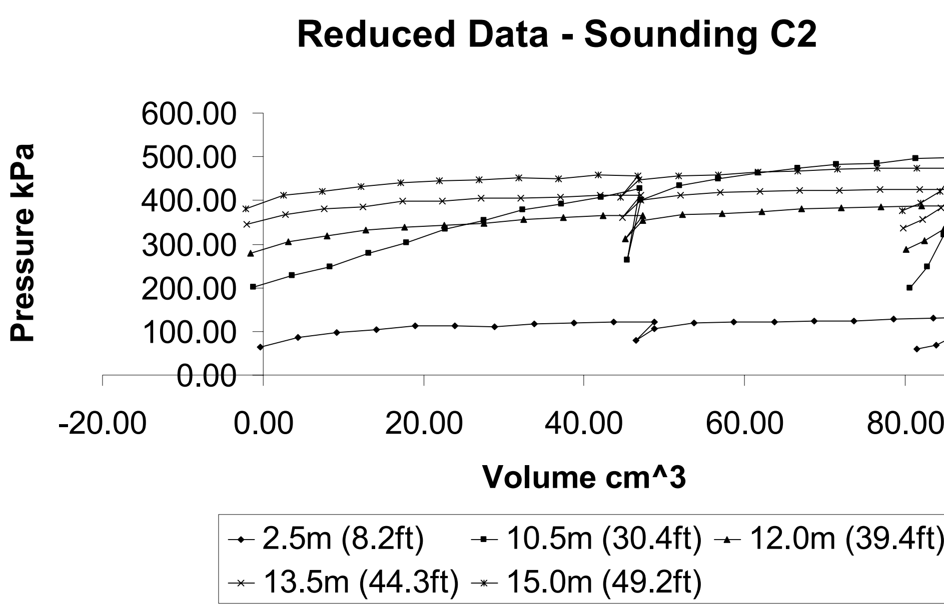


A.2.2.10 Sounding C2

Sounding C2- Friction Reducing Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.38	9.45	65.18	-0.07	-1.16	29.25	201.64	-0.10	-1.61	40.33	278.07	-0.12	-1.99	49.93	344.29	-0.13	-2.19	55.09	379.81
0.27	4.40	12.48	86.06	0.22	3.58	32.96	227.26	0.19	3.13	44.31	305.53	0.17	2.78	53.15	366.46	0.15	2.51	59.77	412.10
0.56	9.24	14.19	97.87	0.51	8.36	36.10	248.88	0.49	7.95	46.39	319.83	0.46	7.60	55.20	380.61	0.45	7.36	61.07	421.04
0.86	14.12	15.16	104.55	0.80	13.11	40.40	278.57	0.78	12.80	48.02	331.07	0.76	12.49	55.93	385.62	0.75	12.22	62.66	432.04
1.16	19.00	16.40	113.06	1.09	17.89	44.08	303.94	1.08	17.69	49.18	339.11	1.06	17.33	57.96	399.62	1.04	17.10	63.80	439.86
1.46	23.94	16.40	113.10	1.38	22.65	48.44	333.97	1.38	22.60	49.86	343.78	1.36	22.27	57.89	399.12	1.34	22.01	64.45	444.34
1.76	28.90	16.19	111.61	1.68	27.48	51.54	355.32	1.68	27.53	50.32	346.95	1.66	27.19	58.63	404.21	1.64	26.94	64.88	447.33
2.06	33.83	16.89	116.45	1.97	32.30	54.82	377.97	1.98	32.42	51.85	357.50	1.96	32.14	58.68	404.59	1.94	31.86	65.66	452.70
2.37	38.77	17.46	120.38	2.27	37.18	56.80	391.64	2.28	37.36	52.38	361.13	2.26	37.08	59.20	408.16	2.25	36.84	65.29	450.16
2.67	43.74	17.58	121.18	2.57	42.05	59.22	408.27	2.58	42.30	53.04	365.72	2.56	42.03	59.71	411.70	2.55	41.76	66.38	457.68
2.97	48.71	17.65	121.70	2.86	46.92	61.88	426.66	2.88	47.27	53.09	366.05	2.87	47.00	59.75	411.99	2.85	46.74	66.13	455.93
2.84	46.47	11.41	78.64	2.77	45.39	38.15	263.04	2.75	45.10	45.40	313.01	2.73	44.81	52.50	361.99	2.72	44.54	59.17	407.94
2.98	48.80	15.46	106.62	2.87	47.07	58.09	400.53	2.89	47.35	51.27	353.49	2.87	47.07	58.15	400.94	2.86	46.79	64.96	447.88
3.28	53.70	17.22	118.72	3.16	51.84	63.03	434.57	3.19	52.24	53.22	366.96	3.17	51.98	59.74	411.87	3.16	51.71	66.25	456.78
3.58	58.67	17.56	121.08	3.46	56.74	65.10	448.88	3.49	57.20	53.70	370.25	3.47	56.92	60.65	418.16	3.46	56.68	66.43	458.03
3.88	63.64	17.63	121.55	3.76	61.63	67.21	463.39	3.79	62.15	54.35	374.72	3.78	61.88	61.15	421.62	3.76	61.63	67.37	464.50
4.19	68.61	17.98	123.95	4.06	66.56	68.59	472.88	4.09	67.10	55.14	380.19	4.08	66.85	61.36	423.07	4.06	66.58	67.87	467.97
4.49	73.58	18.00	124.07	4.36	71.47	70.08	483.18	4.40	72.06	55.47	382.42	4.38	71.82	61.40	423.31	4.37	71.54	68.49	472.24
4.79	78.53	18.67	128.75	4.66	76.44	70.35	485.07	4.70	77.02	56.02	386.25	4.69	76.79	61.52	424.16	4.67	76.51	68.62	473.11
5.10	83.50	18.82	129.74	4.96	81.35	71.85	495.42	5.00	81.98	56.34	388.47	4.99	81.76	61.70	425.40	4.97	81.48	68.66	473.39
5.40	88.44	19.27	132.88	5.27	86.30	72.22	497.95	5.31	86.95	56.26	387.88	5.29	86.72	61.76	425.85	5.28	86.44	68.73	473.89
5.26	86.21	13.15	90.65	5.18	84.86	46.50	320.64	5.17	84.78	48.51	334.43	5.16	84.49	55.62	383.46	5.14	84.27	60.97	420.41
5.12	83.86	9.91	68.34	5.05	82.80	35.96	247.90	5.03	82.45	44.67	307.98	5.01	82.17	51.63	355.98	5.00	81.94	57.28	394.92
4.97	81.43	8.55	58.92	4.92	80.60	29.03	200.17	4.89	80.08	41.68	287.38	4.87	79.80	48.79	336.36	4.86	79.57	54.43	375.29

Data Reduced Using Calibration A1

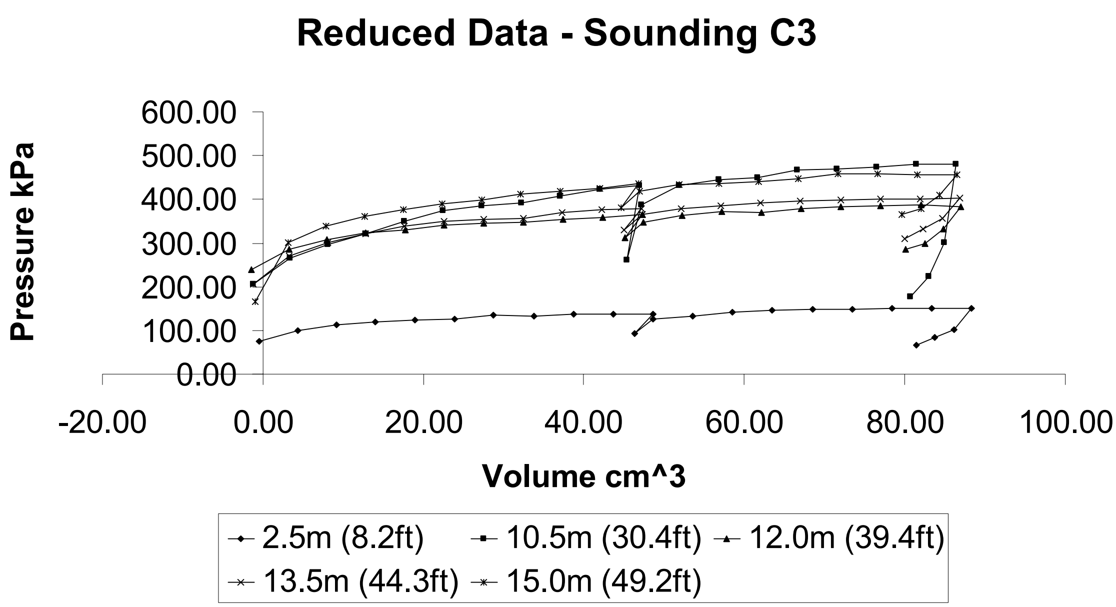


A.2.2.11 Sounding C3

Sounding C3 - Smooth Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.44	10.96	75.59	-0.07	-1.20	30.01	206.93	-0.08	-1.38	34.72	239.37	-0.07	-1.19	29.92	206.33	-0.06	-0.97	24.24	167.15
0.26	4.32	14.58	100.52	0.21	3.36	38.46	265.19	0.20	3.25	41.38	285.29	0.20	3.34	39.11	269.68	0.19	3.15	43.81	302.04
0.56	9.15	16.43	113.30	0.49	8.09	42.91	295.88	0.49	8.03	44.49	306.77	0.49	8.06	43.71	301.38	0.48	7.84	49.28	339.76
0.86	14.03	17.40	119.95	0.78	12.86	46.61	321.40	0.78	12.84	47.01	324.14	0.78	12.86	46.53	320.79	0.77	12.63	52.38	361.12
1.16	18.94	17.89	123.36	1.08	17.62	50.72	349.72	1.08	17.74	47.74	329.15	1.08	17.69	49.17	338.99	1.07	17.46	54.71	377.20
1.46	23.87	18.34	126.42	1.37	22.42	54.33	374.60	1.38	22.61	49.59	341.93	1.38	22.57	50.58	348.71	1.36	22.33	56.40	388.88
1.76	28.77	19.58	135.00	1.67	27.30	55.95	385.79	1.68	27.54	50.05	345.10	1.68	27.48	51.47	354.90	1.66	27.23	57.73	398.02
2.06	33.74	19.25	132.75	1.97	32.22	56.75	391.25	1.98	32.48	50.41	347.59	1.98	32.42	51.83	357.38	1.96	32.10	59.69	411.53
2.36	38.68	19.82	136.66	2.26	37.09	59.02	406.92	2.28	37.40	51.38	354.26	2.28	37.31	53.53	369.07	2.26	37.03	60.64	418.11
2.66	43.65	19.79	136.44	2.56	41.96	61.43	423.54	2.58	42.34	52.05	358.86	2.58	42.24	54.63	376.67	2.56	41.95	61.74	425.66
2.97	48.62	19.86	136.95	2.86	46.88	62.64	431.86	2.88	47.28	52.97	365.22	2.88	47.20	54.97	379.00	2.86	46.86	63.24	436.00
2.83	46.38	13.62	93.89	2.77	45.41	37.74	260.20	2.75	45.10	45.42	313.19	2.75	45.00	47.71	328.98	2.73	44.70	55.25	380.97
2.97	48.68	18.41	126.90	2.88	47.15	56.08	386.63	2.89	47.38	50.35	347.13	2.88	47.27	53.07	365.93	2.87	46.96	60.76	418.91
3.27	53.62	19.28	132.95	3.16	51.86	62.76	432.73	3.19	52.27	52.52	362.11	3.18	52.18	54.81	377.89	3.16	51.84	63.07	434.85
3.57	58.54	20.64	142.34	3.46	56.77	64.40	444.04	3.49	57.20	53.80	370.93	3.49	57.11	55.87	385.19	3.47	56.81	63.40	437.12
3.88	63.50	21.15	145.82	3.77	61.71	65.34	450.51	3.79	62.18	53.65	369.88	3.79	62.05	56.81	391.67	3.77	61.77	63.90	440.58
4.18	68.46	21.50	148.23	4.06	66.59	67.74	467.03	4.10	67.11	55.02	379.36	4.09	67.01	57.45	396.13	4.07	66.70	64.99	448.06
4.48	73.44	21.52	148.37	4.37	71.56	67.92	468.29	4.40	72.06	55.49	382.60	4.39	71.97	57.92	399.38	4.37	71.62	66.33	457.35
4.78	78.41	21.76	150.04	4.67	76.50	68.77	474.18	4.70	77.02	55.90	385.42	4.69	76.93	58.19	401.21	4.67	76.59	66.46	458.21
5.09	83.37	21.91	151.05	4.97	81.44	69.54	479.50	5.00	81.98	56.22	387.64	5.00	81.90	58.22	401.43	4.98	81.58	66.20	456.47
5.39	88.33	21.93	151.20	5.27	86.41	69.62	480.00	5.31	86.98	55.55	383.02	5.30	86.86	58.43	402.86	5.28	86.55	66.13	455.94
5.26	86.15	14.63	100.89	5.19	84.98	43.61	300.68	5.17	84.79	48.24	332.59	5.17	84.65	51.55	355.45	5.15	84.34	59.25	408.50
5.11	83.76	12.27	84.62	5.06	82.95	32.33	222.92	5.03	82.51	43.23	298.09	5.02	82.30	48.30	333.01	5.01	82.04	54.82	377.99
4.97	81.38	9.59	66.14	4.93	80.73	25.70	177.21	4.89	80.10	41.41	285.54	4.88	79.95	45.02	310.39	4.86	79.63	53.00	365.41

Data Reduced Using Calibration A1

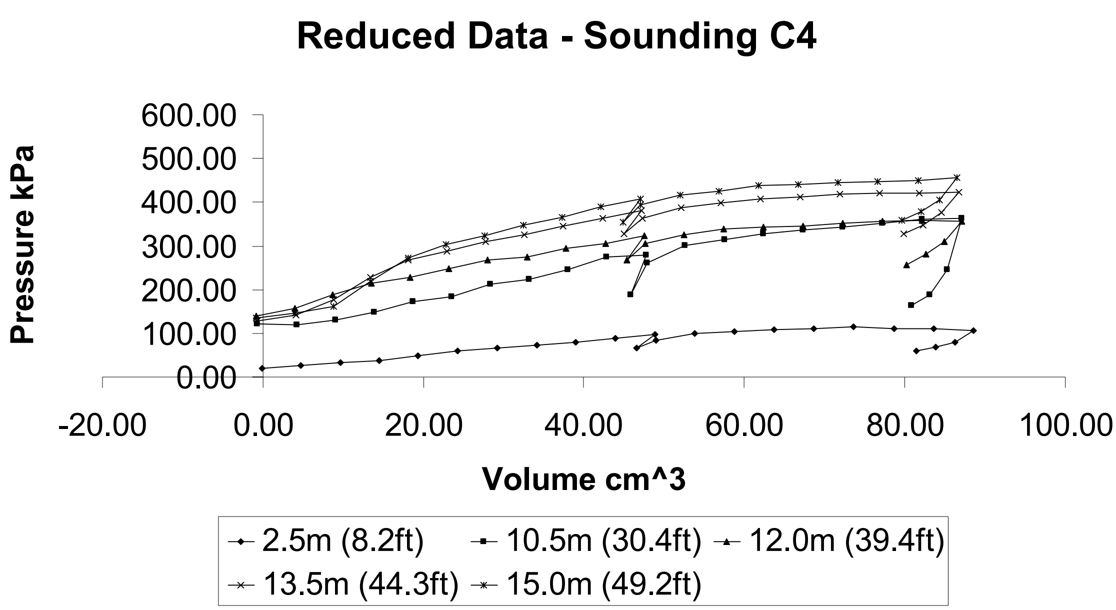


A.2.2.12 Sounding C4

Sounding C4- Friction Reducing Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.12	2.93	20.19	-0.04	-0.71	17.78	122.62	-0.05	-0.81	20.26	139.71	-0.05	-0.75	18.74	129.17	-0.05	-0.77	19.43	133.99
0.29	4.74	3.90	26.92	0.26	4.21	17.24	118.87	0.24	3.99	22.82	157.33	0.25	4.08	20.56	141.73	0.25	4.05	21.25	146.52
0.59	9.62	4.75	32.76	0.55	9.06	18.79	129.57	0.53	8.72	27.16	187.27	0.54	8.78	25.64	176.79	0.54	8.87	23.53	162.24
0.89	14.51	5.60	38.58	0.85	13.87	21.52	148.36	0.82	13.48	31.05	214.05	0.82	13.40	33.21	228.98	0.82	13.46	31.69	218.52
1.18	19.38	7.14	49.25	1.14	18.66	24.94	171.98	1.12	18.34	32.98	227.40	1.10	18.10	38.82	267.62	1.10	18.07	39.51	272.39
1.48	24.26	8.63	59.52	1.44	23.54	26.55	183.03	1.41	23.16	35.89	247.45	1.40	22.92	41.71	287.60	1.39	22.84	43.87	302.47
1.78	29.17	9.60	66.19	1.73	28.32	30.71	211.71	1.71	27.98	39.01	268.95	1.69	27.75	44.82	309.04	1.69	27.66	46.98	323.88
2.08	34.09	10.46	72.11	2.03	33.20	32.41	223.47	2.01	32.91	39.82	274.58	1.99	32.61	47.09	324.69	1.98	32.48	50.27	346.57
2.38	39.01	11.62	80.11	2.32	38.04	35.59	245.38	2.30	37.75	42.85	295.43	2.29	37.45	50.11	345.48	2.28	37.34	52.99	365.32
2.68	43.93	12.91	89.00	2.61	42.83	39.92	275.24	2.60	42.66	44.25	305.12	2.58	42.32	52.53	362.16	2.57	42.16	56.57	390.03
2.98	48.85	14.15	97.58	2.92	47.79	40.42	278.65	2.90	47.53	46.79	322.58	2.88	47.19	55.20	380.58	2.87	47.02	59.24	408.43
2.84	46.55	9.51	65.57	2.80	45.83	27.18	187.38	2.77	45.36	38.95	268.52	2.75	45.01	47.51	327.55	2.74	44.85	51.40	354.40
2.99	48.93	12.26	84.52	2.92	47.89	37.79	260.56	2.91	47.63	44.31	305.49	2.89	47.29	52.72	363.49	2.87	47.11	57.05	393.35
3.28	53.81	14.60	100.64	3.21	52.63	43.76	301.71	3.20	52.48	47.36	326.52	3.18	52.13	56.06	386.50	3.17	51.95	60.39	416.34
3.59	58.77	15.08	104.00	3.51	57.53	45.55	314.06	3.50	57.39	49.00	337.86	3.48	57.04	57.70	397.82	3.47	56.88	61.73	425.64
3.89	63.73	15.59	107.49	3.81	62.43	47.51	327.58	3.80	62.34	49.65	342.34	3.78	61.97	58.93	406.31	3.77	61.77	63.69	439.15
4.19	68.68	16.08	110.90	4.11	67.35	48.88	337.05	4.11	67.30	50.15	345.79	4.08	66.91	59.87	412.78	4.07	66.74	64.05	441.61
4.49	73.64	16.54	114.03	4.41	72.30	49.64	342.28	4.41	72.24	51.06	352.03	4.38	71.86	60.63	418.04	4.38	71.70	64.52	444.87
4.80	78.64	15.90	109.64	4.71	77.21	51.22	353.13	4.71	77.19	51.76	356.85	4.69	76.82	60.90	419.88	4.68	76.66	64.94	447.73
5.10	83.60	16.19	111.62	5.01	82.14	52.26	360.35	5.01	82.16	51.93	358.04	4.99	81.79	60.93	420.12	4.98	81.62	65.12	449.00
5.41	88.60	15.33	105.68	5.31	87.09	52.61	362.74	5.32	87.13	51.84	357.41	5.29	86.74	61.29	422.58	5.28	86.55	66.07	455.51
5.26	86.27	11.69	80.58	5.21	85.30	35.52	244.88	5.18	84.92	44.96	310.02	5.16	84.53	54.56	376.16	5.15	84.36	58.75	405.06
5.12	83.85	10.06	69.35	5.07	83.16	27.16	187.27	5.04	82.61	40.69	280.56	5.02	82.22	50.43	347.68	5.01	82.03	55.05	379.58
4.97	81.43	8.55	58.92	4.93	80.81	23.74	163.71	4.90	80.26	37.27	256.96	4.87	79.85	47.44	327.06	4.86	79.66	52.06	358.95

Data Reduced Using Calibration A1

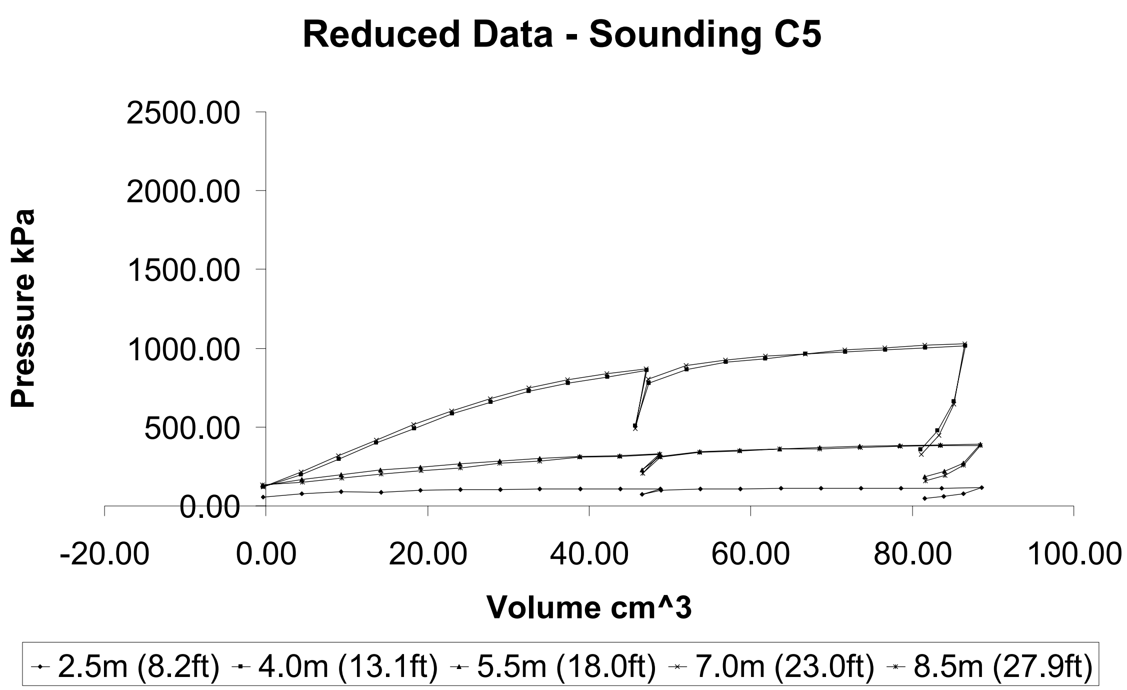


A.2.2.13 Sounding C5

Sounding C5- Friction Smooth Cone

2.5m (8.2ft)				4.0m (13.1ft)				5.5m (18.0ft)				7.0m (23.0ft)				8.5m (27.9ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.33	7.83	54.02	-0.02	-0.37	17.49	120.56	-0.02	-0.39	18.51	127.63	-0.02	-0.37	17.49	120.56	-0.02	-0.41	19.24	132.68
0.27	4.46	10.98	75.70	0.27	4.36	28.49	196.41	0.27	4.44	24.39	168.17	0.26	4.29	31.41	216.58	0.27	4.49	21.90	151.02
0.57	9.30	13.01	89.72	0.55	9.01	43.20	297.87	0.57	9.32	28.44	196.09	0.55	8.95	46.27	319.04	0.57	9.37	25.81	177.95
0.87	14.24	12.75	87.90	0.83	13.66	58.11	400.63	0.87	14.19	32.84	226.43	0.83	13.61	60.59	417.74	0.87	14.26	29.19	201.26
1.17	19.10	14.58	100.56	1.12	18.35	71.43	492.49	1.17	19.10	35.68	245.99	1.12	18.28	75.08	517.64	1.17	19.16	32.76	225.86
1.47	24.03	14.98	103.26	1.41	23.05	84.62	583.44	1.46	24.01	38.68	266.72	1.40	22.99	87.54	603.55	1.47	24.08	35.04	241.59
1.77	28.97	15.23	105.01	1.70	27.80	95.33	657.29	1.77	28.93	41.12	283.49	1.69	27.73	98.68	680.40	1.77	28.96	39.51	272.44
2.07	33.91	15.62	107.71	1.99	32.56	105.59	728.03	2.07	33.86	43.40	299.20	1.98	32.50	108.51	748.12	2.07	33.90	41.50	286.14
2.37	38.88	15.40	106.20	2.28	37.39	112.76	777.49	2.37	38.80	45.36	312.72	2.28	37.32	116.11	800.57	2.37	38.82	44.63	307.70
2.68	43.85	15.43	106.40	2.58	42.26	118.29	815.60	2.67	43.76	46.25	318.91	2.57	42.18	121.93	840.69	2.67	43.78	45.53	313.89
2.98	48.82	15.40	106.17	2.87	47.11	124.78	860.33	2.97	48.71	48.25	332.71	2.87	47.08	125.94	868.36	2.97	48.72	47.67	328.69
2.84	46.53	10.66	73.52	2.79	45.69	73.51	506.82	2.84	46.53	33.06	227.93	2.79	45.73	71.33	491.77	2.84	46.59	30.15	207.87
2.98	48.87	14.23	98.13	2.89	47.35	113.14	780.08	2.98	48.76	45.64	314.65	2.88	47.28	116.78	805.16	2.98	48.78	44.91	309.64
3.28	53.79	15.43	106.40	3.18	52.08	125.23	863.41	3.27	53.66	49.88	343.94	3.17	52.00	129.16	890.49	3.27	53.67	49.45	340.94
3.59	58.75	15.73	108.47	3.47	56.93	132.13	910.99	3.58	58.61	51.27	353.51	3.47	56.88	134.31	926.03	3.58	58.63	50.69	349.50
3.89	63.71	16.21	111.74	3.77	61.84	135.57	934.74	3.88	63.58	52.54	362.27	3.77	61.79	138.04	951.78	3.88	63.58	52.25	360.27
4.19	68.68	16.33	112.58	4.07	66.74	139.62	962.61	4.18	68.54	53.83	371.11	4.07	66.74	139.91	964.62	4.18	68.56	52.66	363.09
4.50	73.67	16.00	110.34	4.37	71.68	141.91	978.46	4.49	73.50	54.81	377.90	4.37	71.65	143.37	988.48	4.49	73.53	53.50	368.88
4.80	78.63	16.24	111.95	4.68	76.64	143.47	989.16	4.79	78.48	55.48	382.51	4.67	76.59	145.65	1004.20	4.79	78.49	54.75	377.50
5.10	83.61	16.13	111.24	4.98	81.58	145.42	1002.62	5.09	83.44	56.25	387.82	4.98	81.53	148.04	1020.67	5.09	83.46	55.52	382.81
5.40	88.56	16.55	114.13	5.28	86.53	147.17	1014.70	5.40	88.42	56.52	389.69	5.28	86.49	149.35	1029.75	5.40	88.44	55.50	382.67
5.27	86.30	11.10	76.53	5.19	85.11	95.89	661.16	5.27	86.29	39.30	270.95	5.20	85.16	93.71	646.11	5.27	86.32	37.70	259.91
5.12	83.91	8.55	58.94	5.08	83.17	69.34	478.09	5.12	83.95	32.10	221.32	5.08	83.26	64.98	448.00	5.13	84.04	27.88	192.24
4.97	81.50	6.71	46.28	4.95	81.05	51.51	355.12	4.98	81.56	27.07	186.64	4.95	81.13	47.58	328.05	4.98	81.64	23.14	159.56

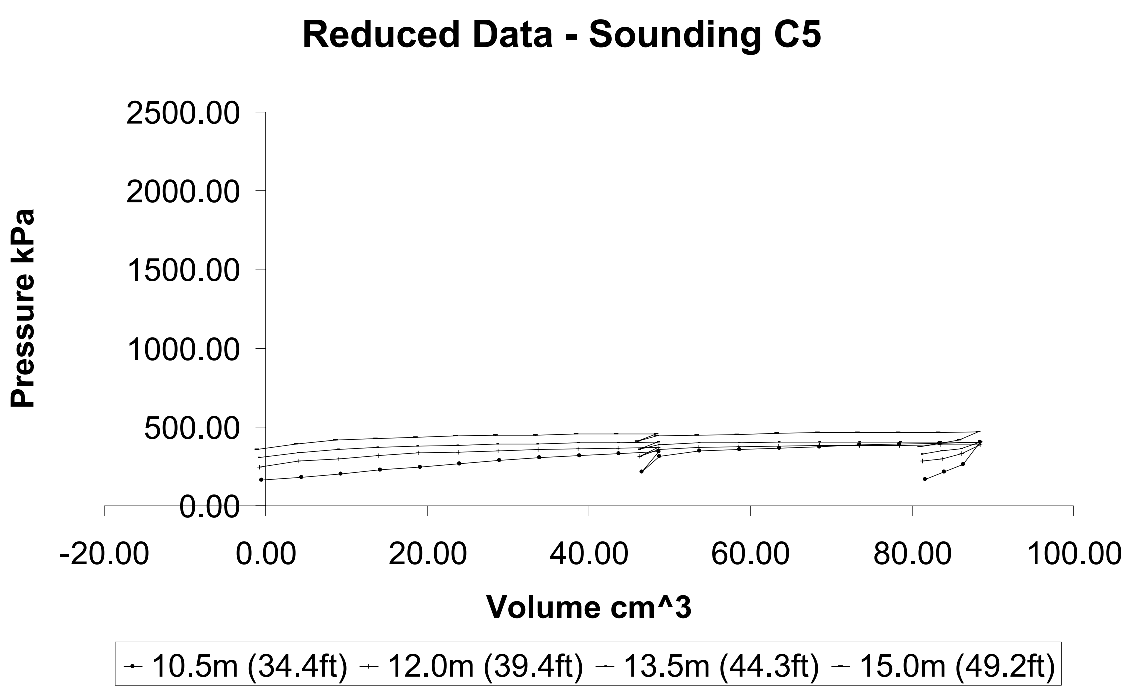
Data Reduced Using Calibration B1



Sounding C5- Friction Smooth Cone

10.5m (34.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.50	23.64	162.97	-0.05	-0.75	35.75	246.47	-0.06	-0.93	44.49	306.75	-0.07	-1.08	51.77	356.93
0.27	4.40	26.29	181.28	0.25	4.10	40.88	281.84	0.24	3.93	48.88	337.02	0.23	3.77	56.59	390.18
0.57	9.29	29.46	203.15	0.55	9.02	42.87	295.56	0.54	8.83	52.03	358.75	0.53	8.65	60.32	415.89
0.87	14.19	32.84	226.43	0.85	13.92	45.94	316.75	0.84	13.75	53.93	371.83	0.83	13.58	61.92	426.92
1.17	19.09	35.82	246.99	1.15	18.83	48.77	336.24	1.14	18.70	55.00	379.20	1.13	18.52	63.27	436.25
1.46	24.00	38.83	267.73	1.45	23.78	49.58	341.83	1.44	23.66	55.37	381.75	1.43	23.47	64.22	442.78
1.76	28.92	41.85	288.52	1.75	28.73	50.84	350.51	1.75	28.61	56.62	390.41	1.73	28.43	65.18	449.39
2.07	33.85	44.12	304.22	2.06	33.69	51.80	357.15	2.05	33.58	56.85	392.00	2.04	33.41	65.11	448.94
2.37	38.79	45.94	316.73	2.36	38.65	52.59	362.61	2.35	38.54	57.94	399.45	2.34	38.37	65.90	454.36
2.67	43.73	47.85	329.95	2.66	43.62	53.05	365.77	2.66	43.52	57.96	399.59	2.65	43.34	66.35	457.49
2.97	48.67	49.86	343.74	2.97	48.60	53.45	368.52	2.96	48.49	58.50	403.33	2.95	48.34	66.02	455.19
2.84	46.57	31.31	215.89	2.82	46.27	45.53	313.91	2.82	46.14	51.89	357.75	2.81	45.98	59.26	408.62
2.98	48.76	45.49	313.65	2.97	48.64	51.56	355.48	2.96	48.54	56.32	388.28	2.95	48.37	64.13	442.15
3.27	53.64	50.61	348.96	3.27	53.58	53.48	368.72	3.26	53.49	57.94	399.51	3.26	53.34	65.03	448.35
3.58	58.60	51.85	357.52	3.57	58.55	54.28	374.27	3.57	58.47	58.17	401.04	3.56	58.32	65.39	450.87
3.88	63.56	53.27	367.28	3.88	63.52	55.12	380.02	3.87	63.45	58.71	404.79	3.86	63.28	66.66	459.63
4.18	68.52	54.55	376.13	4.18	68.50	55.53	382.85	4.18	68.44	58.54	403.60	4.16	68.25	67.51	465.46
4.48	73.48	56.12	386.93	4.48	73.49	55.64	383.62	4.48	73.42	58.65	404.38	4.47	73.23	67.62	466.24
4.79	78.45	56.64	390.53	4.79	78.47	55.73	384.22	4.78	78.41	58.74	404.98	4.77	78.23	67.42	464.85
5.09	83.42	57.27	394.84	5.09	83.45	56.06	386.52	5.09	83.39	58.64	404.28	5.08	83.21	67.32	464.16
5.39	88.38	58.41	402.73	5.40	88.43	56.04	386.38	5.39	88.38	58.62	404.15	5.38	88.19	67.74	467.05
5.27	86.32	38.13	262.92	5.25	86.11	47.84	329.84	5.25	86.02	52.16	359.63	5.24	85.84	60.85	419.52
5.12	83.97	31.23	215.30	5.11	83.72	43.11	297.25	5.10	83.57	50.34	347.11	5.09	83.42	57.57	396.96
4.98	81.62	24.16	166.58	4.96	81.27	40.99	282.62	4.95	81.13	47.49	327.45	4.94	80.99	54.58	376.30

Data Reduced Using Calibration B1

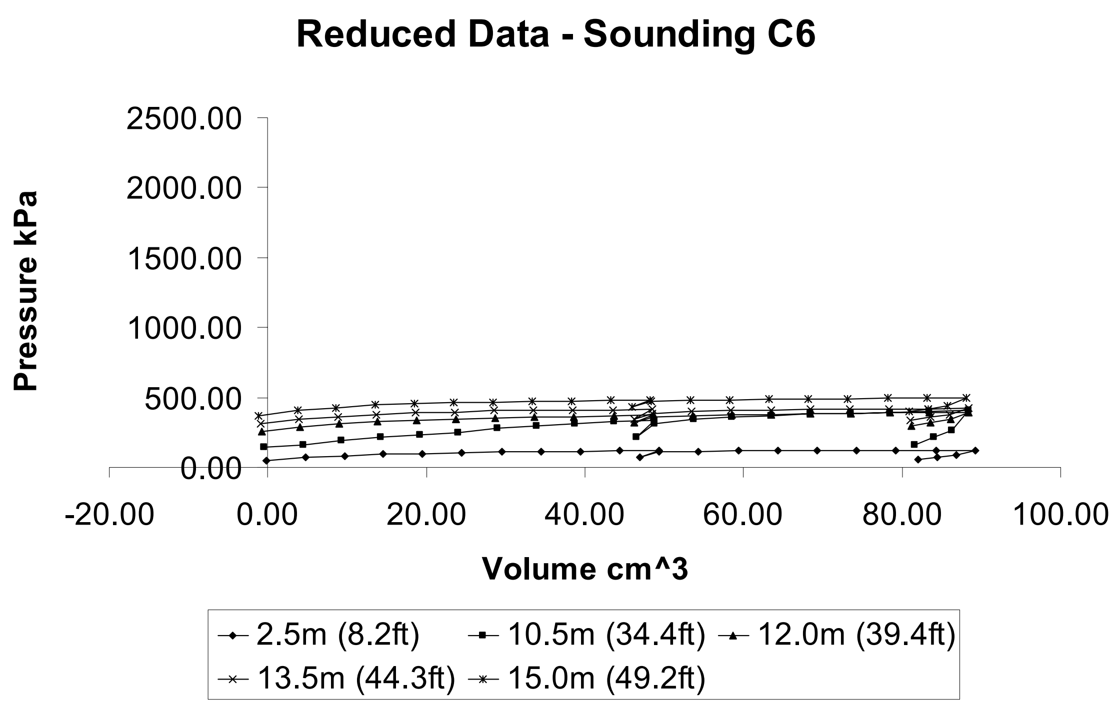


A.2.2.14 Sounding C6

Sounding C6- Friction Reducing Cone

2.5m (8.2ft)				10.5m (34.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.01	-0.16	7.11	49.05	-0.03	-0.43	20.35	140.33	-0.05	-0.79	37.59	259.16	-0.06	-0.95	45.16	311.37	-0.07	-1.12	53.76	370.64
0.29	4.72	10.81	74.53	0.27	4.46	23.60	162.70	0.25	4.08	41.99	289.49	0.24	3.92	49.55	341.64	0.23	3.72	59.02	406.91
0.59	9.66	12.10	83.40	0.57	9.33	27.94	192.64	0.55	8.96	45.44	313.27	0.54	8.83	51.97	358.32	0.53	8.62	62.16	428.57
0.89	14.58	14.03	96.71	0.87	14.22	31.32	215.94	0.85	13.89	47.34	326.40	0.84	13.74	54.45	375.44	0.82	13.51	65.51	451.67
1.19	19.54	14.40	99.26	1.17	19.13	34.16	235.50	1.15	18.82	48.85	336.82	1.14	18.67	56.40	388.84	1.13	18.45	66.57	458.97
1.49	24.49	15.52	107.03	1.47	24.05	36.44	251.21	1.45	23.77	50.25	346.43	1.44	23.61	57.49	396.40	1.43	23.42	66.93	461.46
1.80	29.46	15.78	108.83	1.77	28.95	40.33	278.04	1.75	28.71	51.65	356.12	1.74	28.56	58.75	405.06	1.73	28.37	67.89	468.06
2.10	34.43	16.18	111.57	2.07	33.87	42.90	295.76	2.05	33.67	52.47	361.74	2.05	33.54	58.83	405.63	2.03	33.33	68.98	475.63
2.40	39.40	16.70	115.14	2.37	38.80	45.59	314.30	2.36	38.64	52.82	364.19	2.35	38.50	59.77	412.07	2.34	38.31	68.90	475.01
2.71	44.38	16.88	116.39	2.67	43.74	47.21	325.51	2.66	43.61	53.43	368.36	2.65	43.49	59.35	409.20	2.64	43.28	69.35	478.13
3.01	49.36	17.00	117.21	2.97	48.70	48.34	333.28	2.96	48.58	54.11	373.11	2.96	48.46	59.89	412.93	2.95	48.26	69.45	478.84
2.87	47.00	10.68	73.61	2.84	46.57	31.25	215.47	2.82	46.25	46.63	321.51	2.82	46.18	50.08	345.29	2.80	45.92	62.55	431.27
3.01	49.38	15.84	109.19	2.98	48.76	45.72	315.23	2.97	48.62	52.22	360.07	2.96	48.56	55.24	380.83	2.95	48.29	67.99	468.81
3.32	54.35	16.60	114.47	3.27	53.66	49.82	343.52	3.27	53.58	53.56	369.30	3.26	53.48	58.61	404.10	3.25	53.25	69.62	480.01
3.62	59.33	17.12	118.05	3.58	58.60	52.08	359.10	3.57	58.55	54.37	374.84	3.57	58.45	59.27	408.64	3.55	58.22	70.13	483.54
3.92	64.32	17.09	117.81	3.88	63.55	53.64	369.87	3.88	63.52	55.06	379.60	3.87	63.42	59.81	412.38	3.86	63.19	70.96	489.28
4.23	69.30	17.35	119.63	4.18	68.51	55.22	380.71	4.18	68.50	55.32	381.42	4.17	68.40	60.22	415.21	4.16	68.18	70.79	488.10
4.53	74.29	17.32	119.38	4.48	73.48	56.06	386.50	4.48	73.48	56.01	386.20	4.48	73.38	60.48	416.99	4.46	73.16	71.20	490.88
4.84	79.26	17.83	122.95	4.79	78.44	57.16	394.12	4.79	78.45	56.68	390.81	4.78	78.37	60.42	416.59	4.77	78.14	71.58	493.50
5.14	84.24	18.01	124.19	5.09	83.40	58.37	402.44	5.09	83.43	56.87	392.11	5.09	83.35	60.90	419.90	5.07	83.12	71.62	493.82
5.44	89.23	17.98	123.97	5.39	88.36	59.37	409.33	5.40	88.41	57.00	392.98	5.39	88.33	61.17	421.78	5.38	88.10	72.04	496.73
5.30	86.84	13.13	90.54	5.27	86.30	38.65	266.51	5.25	86.07	49.96	344.46	5.25	85.96	55.01	379.27	5.23	85.77	64.42	444.18
5.15	84.41	10.16	70.03	5.12	83.97	31.17	214.88	5.10	83.65	46.25	318.89	5.10	83.54	51.74	356.71	5.09	83.35	60.71	418.60
5.00	81.97	7.60	52.41	4.98	81.63	23.81	164.15	4.96	81.24	42.67	294.23	4.95	81.10	49.18	339.06	4.94	80.92	57.86	398.94

Data Reduced Using Calibration B1

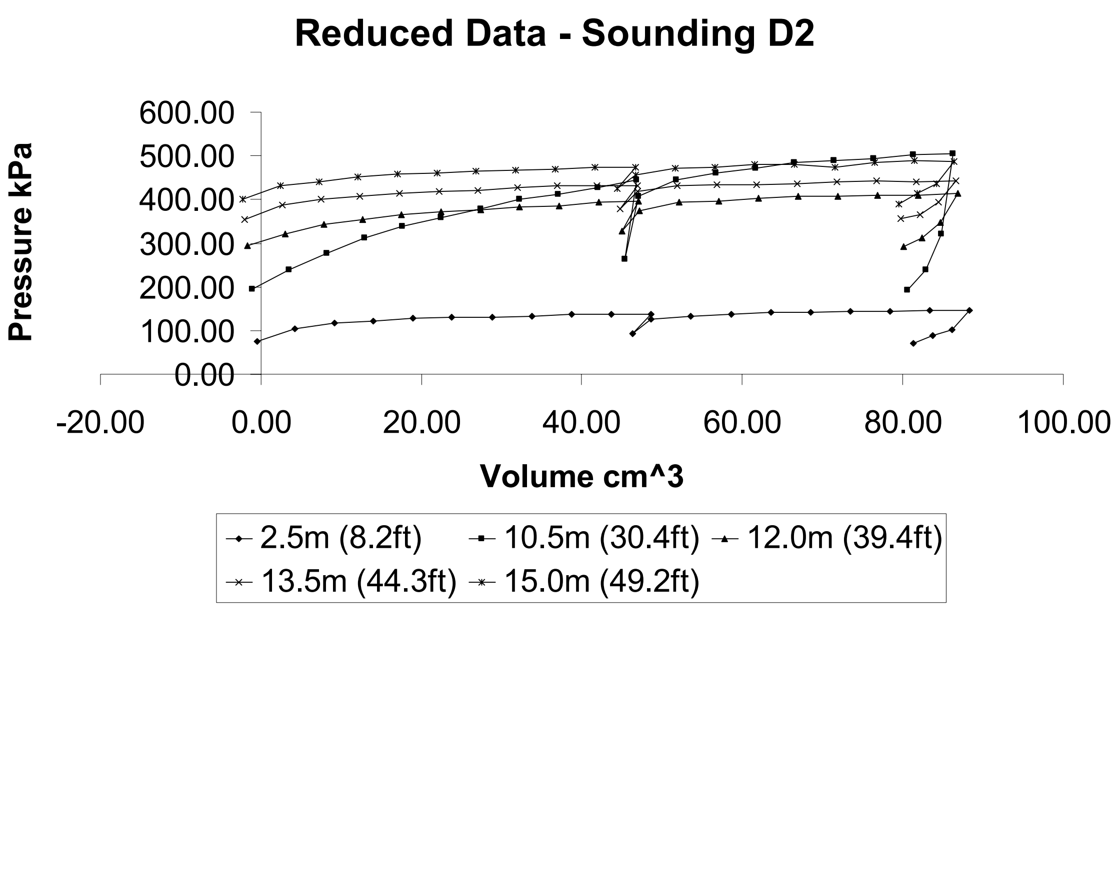


A.2.2.15 Sounding D2

Sounding D2 - Smooth Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.44	10.96	75.59	-0.07	-1.12	28.23	194.66	-0.10	-1.70	42.58	293.60	-0.12	-2.05	51.45	354.70	-0.14	-2.31	58.08	400.46
0.26	4.30	15.02	103.58	0.21	3.51	34.76	239.68	0.19	3.04	46.56	321.01	0.16	2.66	56.14	387.05	0.15	2.39	62.76	432.69
0.56	9.13	16.88	116.35	0.50	8.20	40.26	277.56	0.48	7.81	49.81	343.42	0.46	7.48	58.18	401.15	0.44	7.24	64.05	441.58
0.86	14.02	17.69	121.98	0.79	12.92	45.14	311.24	0.77	12.67	51.28	353.59	0.75	12.36	59.05	407.13	0.74	12.10	65.49	451.52
1.15	18.91	18.63	128.43	1.08	17.68	49.25	339.59	1.07	17.54	52.88	364.62	1.05	17.24	60.19	415.00	1.04	17.00	66.32	457.27
1.45	23.84	19.07	131.48	1.37	22.51	52.13	359.43	1.37	22.44	53.85	371.27	1.35	22.15	60.85	419.52	1.34	21.92	66.67	459.69
1.76	28.80	18.85	129.95	1.67	27.35	54.78	377.72	1.67	27.36	54.45	375.40	1.65	27.10	60.99	420.54	1.64	26.83	67.54	465.69
2.06	33.74	19.25	132.75	1.96	32.16	58.21	401.33	1.97	32.27	55.53	382.88	1.95	32.01	62.07	427.96	1.94	31.77	67.88	468.00
2.36	38.68	19.82	136.66	2.26	37.06	59.75	411.96	2.27	37.22	55.76	384.47	2.25	36.95	62.58	431.50	2.24	36.73	67.95	468.47
2.66	43.65	19.79	136.44	2.56	41.94	61.87	426.56	2.57	42.14	57.01	393.06	2.56	41.92	62.51	430.99	2.54	41.67	68.74	473.95
2.97	48.62	19.86	136.95	2.86	46.81	64.39	443.93	2.87	47.09	57.49	396.38	2.86	46.88	62.70	432.27	2.85	46.64	68.78	474.19
2.83	46.38	13.62	93.89	2.77	45.39	38.18	263.21	2.75	45.01	47.61	328.27	2.73	44.71	54.86	378.25	2.71	44.44	61.67	425.21
2.97	48.68	18.41	126.90	2.87	47.03	58.99	406.73	2.88	47.23	54.14	373.26	2.87	46.96	60.80	419.21	2.85	46.74	66.15	456.10
3.27	53.62	19.28	132.95	3.16	51.78	64.51	444.79	3.18	52.08	57.18	394.26	3.16	51.86	62.68	432.14	3.15	51.62	68.46	472.02
3.57	58.58	19.77	136.31	3.46	56.67	66.88	461.11	3.48	57.05	57.51	396.54	3.47	56.83	62.86	433.40	3.45	56.59	68.79	474.27
3.88	63.53	20.42	140.80	3.76	61.59	68.25	470.59	3.78	61.98	58.60	404.02	3.77	61.81	62.78	432.84	3.76	61.54	69.58	479.74
4.18	68.50	20.63	142.21	4.06	66.49	70.21	484.10	4.09	66.95	58.95	406.47	4.07	66.78	63.13	435.30	4.06	66.51	69.79	481.20
4.48	73.47	20.79	143.34	4.36	71.44	70.83	488.38	4.39	71.92	59.13	407.71	4.38	71.73	63.75	439.56	4.37	71.53	68.66	473.42
4.79	78.44	20.89	144.01	4.66	76.38	71.69	494.29	4.69	76.89	59.25	408.54	4.68	76.68	64.31	443.43	4.66	76.43	70.47	485.85
5.09	83.39	21.32	147.02	4.96	81.31	72.90	502.63	5.00	81.86	59.29	408.77	4.98	81.66	64.06	441.67	4.97	81.39	70.87	488.66
5.39	88.36	21.34	147.16	5.26	86.26	73.27	505.18	5.30	86.80	59.93	413.23	5.29	86.62	64.27	443.15	5.27	86.36	70.80	488.17
5.26	86.15	14.63	100.89	5.18	84.86	46.53	320.81	5.17	84.70	50.43	347.69	5.15	84.43	57.10	393.70	5.14	84.18	63.19	435.68
5.11	83.74	12.86	88.65	5.06	82.85	34.81	240.03	5.03	82.42	45.42	313.19	5.01	82.11	53.12	366.22	4.99	81.83	59.93	413.21
4.96	81.35	10.32	71.17	4.92	80.64	28.04	193.31	4.89	80.05	42.44	292.59	4.86	79.68	51.58	355.65	4.85	79.48	56.64	390.55

Data Reduced Using Calibration A1

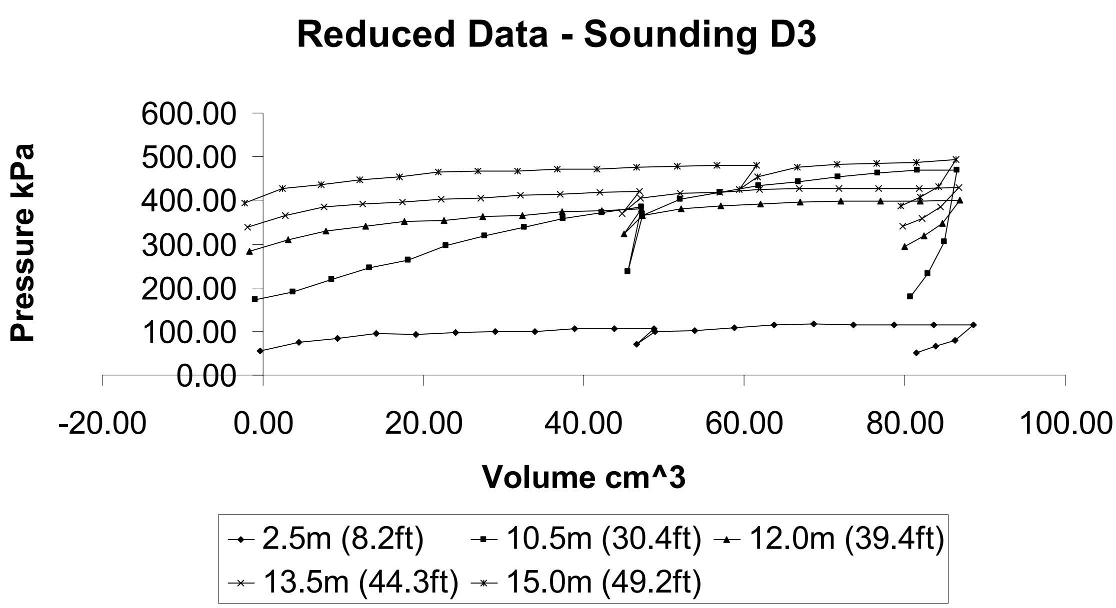


A.2.2.16 Sounding D3

Sounding D3- Friction Reducing Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.02	-0.32	7.97	54.96	-0.06	-1.00	25.20	173.76	-0.10	-1.63	41.04	282.93	-0.12	-1.96	49.16	338.92	-0.14	-2.28	57.28	394.91
0.27	4.46	11.00	75.87	0.23	3.80	27.60	190.28	0.19	3.10	45.02	310.38	0.17	2.78	53.11	366.21	0.15	2.42	62.10	428.18
0.57	9.32	12.28	84.64	0.52	8.54	31.63	218.10	0.48	7.89	47.83	329.76	0.46	7.57	55.90	385.45	0.44	7.28	63.24	436.06
0.87	14.18	13.69	94.40	0.81	13.30	35.65	245.82	0.78	12.75	49.45	340.98	0.76	12.45	56.78	391.46	0.74	12.13	64.84	447.03
1.17	19.12	13.46	92.80	1.11	18.12	38.31	264.17	1.07	17.61	51.06	352.03	1.06	17.35	57.63	397.34	1.04	17.01	65.97	454.82
1.47	24.03	14.20	97.94	1.40	22.87	42.97	296.29	1.38	22.53	51.44	354.66	1.36	22.25	58.44	402.91	1.34	21.89	67.34	464.32
1.77	28.97	14.43	99.49	1.69	27.70	46.08	317.71	1.67	27.43	52.63	362.85	1.66	27.19	58.74	404.96	1.64	26.82	67.77	467.28
2.07	33.93	14.48	99.82	1.99	32.53	49.08	338.39	1.98	32.38	52.84	364.31	1.96	32.10	59.81	412.41	1.94	31.77	67.82	467.57
2.37	38.86	15.42	106.28	2.28	37.38	51.95	358.16	2.28	37.28	54.24	373.97	2.26	37.04	60.19	414.96	2.24	36.71	68.47	472.07
2.67	43.83	15.39	106.10	2.58	42.26	54.07	372.81	2.58	42.24	54.61	376.54	2.56	42.00	60.55	417.49	2.54	41.68	68.39	471.52
2.98	48.80	15.46	106.62	2.88	47.15	56.01	386.20	2.88	47.18	55.24	380.88	2.87	46.95	61.03	420.79	2.85	46.63	69.01	475.78
2.84	46.52	10.24	70.60	2.78	45.54	34.47	237.65	2.75	45.04	46.82	322.82	2.73	44.76	53.63	369.78	3.15	51.59	69.42	478.63
2.98	48.84	14.30	98.58	2.89	47.28	52.95	365.10	2.88	47.27	53.06	365.80	2.87	47.04	58.84	405.71	3.45	56.55	69.75	480.88
3.28	53.80	14.89	102.64	3.18	52.04	58.33	402.17	3.18	52.16	55.37	381.78	3.17	51.95	60.43	416.64	3.75	61.53	69.81	481.33
3.58	58.74	15.81	109.03	3.47	56.92	60.70	418.50	3.48	57.10	56.29	388.08	3.47	56.91	60.76	418.91	3.62	59.36	61.77	425.86
3.89	63.68	16.76	115.52	3.77	61.80	63.09	435.02	3.79	62.05	56.79	391.55	3.78	61.86	61.55	424.39	3.76	61.69	65.88	454.21
4.19	68.65	16.96	116.92	4.07	66.73	64.32	443.50	4.09	67.00	57.58	397.01	4.08	66.83	61.91	426.84	4.06	66.54	69.00	475.75
4.49	73.63	16.83	116.04	4.37	71.65	65.67	452.79	4.39	71.97	57.76	398.24	4.38	71.80	61.94	427.08	4.36	71.48	69.91	482.04
4.80	78.61	16.78	115.68	4.67	76.56	67.25	463.71	4.70	76.94	57.88	399.07	4.68	76.77	62.07	427.93	4.66	76.43	70.48	485.93
5.10	83.58	16.63	114.64	4.97	81.50	68.02	469.01	5.00	81.91	57.91	399.29	4.99	81.74	62.10	428.17	4.97	81.40	70.52	486.22
5.40	88.55	16.64	114.75	5.28	86.47	68.10	469.50	5.30	86.88	57.97	399.71	5.29	86.70	62.31	429.63	5.27	86.33	71.47	492.78
5.26	86.27	11.69	80.58	5.18	84.95	44.28	305.28	5.17	84.70	50.51	348.27	5.16	84.48	55.87	385.22	5.14	84.20	62.69	432.23
5.12	83.87	9.47	65.32	5.06	82.89	33.73	232.56	5.03	82.39	46.09	317.79	5.01	82.16	51.89	357.74	5.00	81.86	59.14	407.75
4.97	81.47	7.38	50.87	4.93	80.72	26.08	179.80	4.88	80.04	42.81	295.18	4.87	79.77	49.33	340.14	4.85	79.50	56.15	387.11

Data Reduced Using Calibration A1

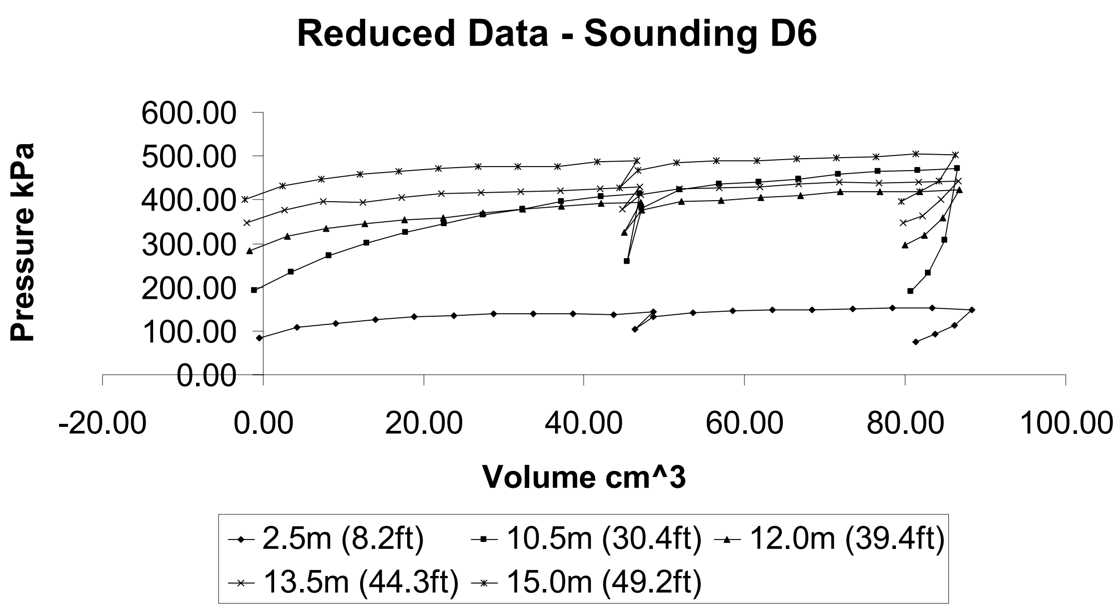


A.2.2.17 Sounding D6

Sounding D6 - Smooth Cone

2.5m (8.2ft)				10.5m (30.4ft)				12.0m (39.4ft)				13.5m (44.3ft)				15.0m (49.2ft)			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
-0.03	-0.48	12.15	83.77	-0.07	-1.12	28.08	193.63	-0.10	-1.64	41.10	283.37	-0.12	-2.00	50.26	346.51	-0.14	-2.31	58.08	400.46
0.26	4.27	15.76	108.68	0.22	3.54	34.02	234.58	0.19	3.07	45.82	315.91	0.17	2.72	54.66	376.85	0.15	2.39	62.76	432.69
0.56	9.12	17.17	118.39	0.50	8.23	39.37	271.45	0.48	7.86	48.63	335.28	0.46	7.51	57.44	396.06	0.44	7.22	64.78	446.67
0.85	14.00	18.28	126.04	0.79	12.98	43.67	301.09	0.78	12.71	50.25	346.49	0.76	12.43	57.28	394.94	0.74	12.07	66.37	457.62
1.15	18.88	19.36	133.49	1.08	17.77	47.05	324.39	1.07	17.60	51.41	354.49	1.06	17.30	58.87	405.88	1.03	16.95	67.50	465.38
1.45	23.82	19.51	134.51	1.38	22.58	50.22	346.28	1.37	22.51	52.09	359.13	1.35	22.19	59.97	413.45	1.33	21.85	68.43	471.83
1.75	28.74	20.31	140.04	1.67	27.42	53.03	365.60	1.67	27.39	53.71	370.35	1.66	27.12	60.26	415.49	1.63	26.77	69.01	475.79
2.06	33.69	20.28	139.81	1.97	32.30	54.84	378.14	1.97	32.30	54.80	377.84	1.96	32.07	60.61	417.88	1.94	31.73	68.97	475.56
2.36	38.67	20.11	138.67	2.27	37.15	57.56	396.85	2.27	37.22	55.91	385.48	2.26	37.01	61.12	421.43	2.24	36.68	69.11	476.53
2.66	43.64	19.94	137.45	2.57	42.06	58.95	406.44	2.57	42.15	56.72	391.05	2.56	41.95	61.78	425.96	2.54	41.59	70.49	486.03
2.96	48.58	20.88	143.98	2.87	46.99	60.01	413.77	2.87	47.11	57.20	394.37	2.86	46.90	62.26	429.26	2.84	46.55	70.82	488.27
2.83	46.32	15.08	103.95	2.77	45.42	37.45	258.19	2.75	45.02	47.32	326.26	2.73	44.71	55.01	379.26	2.71	44.42	62.11	428.23
2.97	48.65	19.13	131.92	2.88	47.18	55.35	381.60	2.88	47.21	54.57	376.28	2.87	47.01	59.63	411.16	2.85	46.67	67.90	468.16
3.27	53.57	20.59	141.99	3.17	51.91	61.31	422.69	3.18	52.08	57.33	395.26	3.17	51.89	61.80	426.11	3.15	51.55	70.36	485.08
3.57	58.52	21.23	146.36	3.47	56.81	63.38	437.01	3.48	57.03	57.80	398.54	3.47	56.86	61.98	427.37	3.45	56.51	70.83	488.33
3.87	63.48	21.59	148.84	3.77	61.77	63.88	440.47	3.78	61.97	58.89	406.03	3.77	61.83	62.34	429.83	3.75	61.48	71.04	489.78
4.18	68.46	21.65	149.24	4.07	66.71	64.82	446.94	4.08	66.92	59.54	410.49	4.07	66.77	63.28	436.30	4.05	66.44	71.54	493.25
4.48	73.43	21.81	150.38	4.37	71.62	66.46	458.24	4.38	71.86	60.59	417.76	4.38	71.73	63.75	439.56	4.36	71.40	71.87	495.52
4.78	78.39	22.05	152.05	4.67	76.56	67.32	464.13	4.69	76.83	60.71	418.60	4.68	76.71	63.73	439.41	4.66	76.36	72.29	498.42
5.09	83.36	22.20	153.06	4.97	81.51	67.79	467.42	4.99	81.80	60.75	418.83	4.98	81.68	63.77	439.66	4.96	81.30	73.06	503.75
5.39	88.35	21.64	149.18	5.28	86.45	68.45	471.94	5.29	86.74	61.39	423.30	5.29	86.62	64.27	443.15	5.26	86.27	72.99	503.27
5.25	86.07	16.53	113.98	5.18	84.93	44.63	307.72	5.16	84.63	52.03	358.77	5.15	84.39	58.12	400.75	5.13	84.14	64.21	442.73
5.11	83.71	13.44	92.67	5.06	82.89	33.79	232.98	5.03	82.39	46.15	318.22	5.01	82.12	52.68	363.20	4.99	81.80	60.66	418.24
4.96	81.32	11.05	76.20	4.92	80.65	27.60	190.29	4.88	80.04	42.87	295.60	4.87	79.73	50.56	348.61	4.85	79.45	57.37	395.58

Data Reduced Using Calibration A1



A.3 Archer Field Site

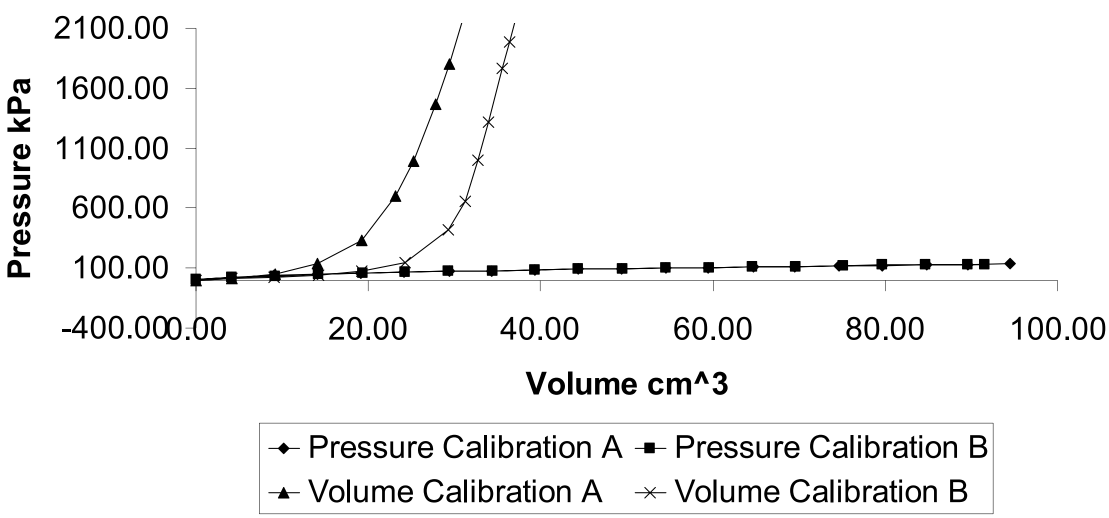
A.3.1 S. Sundaram – Raw and Reduced Data

Calibration Data

Calibration Data Florida Tech Site

Pressure Calibration								Volume Calibration							
Calibration A				Calibration B				Calibration A				Calibration B			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	0.73	5.01	0.00	0.00	0.44	3.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25	4.12	3.39	23.38	0.26	4.21	2.79	19.21	0.26	4.21	2.54	17.54	0.26	4.21	1.70	11.69
0.56	9.10	5.41	37.30	0.56	9.25	4.89	33.68	0.56	9.21	7.15	49.27	0.55	9.04	3.39	23.38
0.86	14.08	7.31	50.38	0.86	14.17	6.58	45.37	0.86	14.15	19.26	132.78	0.87	14.27	5.57	38.41
1.17	19.11	8.36	57.62	1.18	19.34	7.83	54.00	1.17	19.21	48.45	334.04	1.17	19.21	10.30	70.98
1.47	24.13	9.93	68.48	1.48	24.32	9.12	62.91	1.42	23.20	101.14	697.31	1.48	24.32	20.83	143.64
1.79	29.35	10.50	72.38	1.79	29.28	10.54	72.65	1.54	25.27	143.77	991.26	1.79	29.32	60.80	419.22
2.09	34.28	11.51	79.33	2.10	34.45	11.51	79.33	1.70	27.80	212.20	1463.1	1.91	31.28	94.96	654.72
2.40	39.33	12.39	85.46	2.40	39.39	12.35	85.18	1.80	29.43	261.02	1799.6	2.00	32.74	144.62	997.11
2.71	44.37	13.04	89.91	2.71	44.41	12.92	89.08	1.89	30.89	312.73	2156.2	2.07	33.98	190.52	1313.61
3.02	49.42	13.77	94.92	3.02	49.50	13.93	96.04	1.91	31.34	330.42	2278.2	2.17	35.55	255.44	1761.23
3.32	54.48	14.66	101.05	3.33	54.50	14.70	101.33					2.22	36.34	288.39	1988.37
3.63	59.50	14.90	102.72	3.64	59.57	15.38	106.06					2.27	37.12	317.22	2187.13
3.95	64.66	15.95	109.95	3.94	64.53	16.11	111.07								
4.24	69.53	16.23	111.90	4.25	69.57	16.63	114.69								
4.55	74.64	17.08	117.75	4.58	75.09	17.12	118.03								
4.86	79.64	17.85	123.04	4.86	79.60	18.25	125.82								
5.18	84.84	18.53	127.77	5.17	84.73	18.33	126.38								
5.47	89.56	19.02	131.11	5.47	89.64	18.98	130.83								
5.77	94.5	19.94	137.51	5.59	91.6	18.81	129.72								

Calibration Data

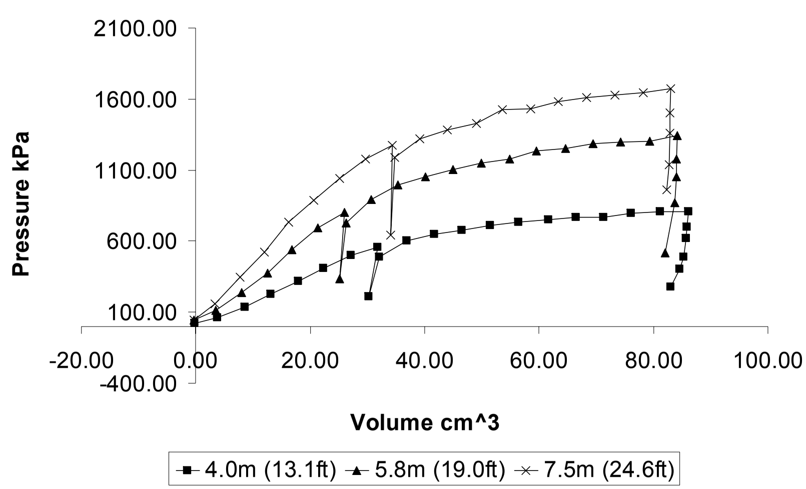


A.3.1.1 Sounding 1

Sounding 1 - Smooth Cone

1.8m (5.9ft)								4.0m (13.1ft)								5.8m (19.0ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	0.00	0.00	-0.01	-0.20	4.59	31.68	0.00	0.00	-4.35	-30.00	-0.01	-0.21	3.39	23.40	0.00	0.00	-3.63	-25.00	-0.02	-0.33	6.70	46.21
0.25	4.16	4.68	32.29	0.23	3.84	6.59	45.43	0.26	4.23	3.59	24.77	0.23	3.82	8.61	59.35	0.25	4.14	8.36	57.62	0.21	3.51	16.01	110.41
0.57	9.27	13.04	89.91	0.53	8.73	12.87	88.74	0.57	9.30	16.96	116.91	0.52	8.55	19.92	137.32	0.56	9.15	28.67	197.64	0.49	8.01	34.26	236.20
0.87	14.25	22.04	151.99	0.82	13.49	19.99	137.85	0.87	14.23	31.98	220.47	0.80	13.10	33.07	227.99	0.87	14.25	50.87	350.74	0.77	12.54	54.53	375.95
1.17	19.19	30.16	207.94	1.11	18.22	27.08	186.69	1.18	19.41	46.27	319.01	1.09	17.92	46.26	318.94	1.17	19.17	75.66	521.66	1.03	16.83	78.29	539.79
1.48	24.30	38.84	267.79	1.41	23.11	34.17	235.63	1.48	24.24	61.13	421.45	1.37	22.37	59.60	410.94	1.48	24.30	99.64	687.01	1.30	21.35	100.68	694.14
1.79	29.26	44.25	305.09	1.70	27.94	39.05	269.22	1.79	29.32	74.29	512.19	1.65	27.11	72.21	497.90	1.79	29.28	115.51	796.41	1.58	25.93	116.00	799.82
2.09	34.22	50.43	347.68	2.00	32.74	44.22	304.91	2.09	34.32	84.14	580.12	1.94	31.86	81.05	558.85	1.63	26.79	48.04	331.26	1.53	25.15	48.81	336.53
2.40	39.39	53.37	368.00	2.31	37.83	46.26	318.95	1.91	31.34	32.70	225.48	1.84	30.19	30.23	208.42	1.79	29.34	104.89	723.20	1.60	26.25	105.38	726.57
2.22	36.39	23.09	159.23	2.17	35.61	16.51	113.80	2.09	34.28	74.29	512.19	1.96	32.07	71.21	490.98	2.10	34.41	130.12	897.18	1.87	30.69	129.59	893.48
2.40	39.39	48.13	331.81	2.32	37.97	41.01	282.76	2.41	39.46	91.00	627.44	2.25	36.83	87.01	599.93	2.41	39.46	145.39	1002.40	2.16	35.35	143.96	992.58
2.71	44.43	55.55	383.03	2.61	42.81	47.79	329.52	2.72	44.52	98.31	677.82	2.54	41.70	93.67	645.84	2.72	44.52	154.39	1064.47	2.45	40.18	152.32	1050.18
3.02	49.42	60.40	416.44	2.91	47.69	51.92	357.97	3.02	49.46	103.80	715.68	2.84	46.50	98.45	678.80	3.02	49.56	162.50	1120.43	2.75	45.01	159.71	1101.14
3.33	54.63	62.01	427.57	3.23	52.85	52.63	362.89	3.33	54.61	109.13	752.43	3.14	51.52	102.88	709.34	3.33	54.61	170.58	1176.10	3.04	49.86	166.89	1150.69
3.63	59.55	65.08	448.73	3.52	57.70	55.46	382.40	3.64	59.63	112.84	778.03	3.44	56.44	106.35	733.26	3.64	59.68	174.98	1206.44	3.35	54.82	171.04	1179.29
3.94	64.59	65.97	454.85	3.83	62.71	55.33	381.49	3.96	64.91	116.48	803.09	3.76	61.63	108.93	751.05	3.94	64.64	183.66	1266.29	3.63	59.56	178.71	1232.19
4.25	69.64	68.72	473.78	4.13	67.70	57.76	398.22	4.26	69.74	118.90	819.79	4.05	66.40	111.06	765.75	4.25	69.72	186.85	1288.28	3.94	64.55	181.58	1251.95
4.55	74.62	71.02	489.65	4.43	72.62	59.23	408.39	4.56	74.70	120.19	828.70	4.35	71.32	111.53	768.98	4.56	74.72	192.18	1325.03	4.24	69.42	186.08	1282.98
4.86	79.57	71.99	496.33	4.73	77.54	59.44	409.83	4.86	79.62	124.71	859.87	4.65	76.13	115.30	794.94	4.86	79.58	194.84	1343.40	4.53	74.22	188.00	1296.20
5.16	84.62	71.18	490.76	5.04	82.61	57.96	399.65	5.17	84.75	127.30	877.69	4.95	81.20	117.20	808.07	5.17	84.79	196.70	1356.20	4.84	79.37	189.16	1304.24
5.47	89.67	73.84	509.13	5.35	87.60	60.10	414.35	5.47	89.69	128.11	883.26	5.26	86.12	117.49	810.09	5.48	89.77	203.04	1399.91	5.14	84.19	194.98	1344.34
5.44	89.09	63.14	435.37	5.33	87.29	49.46	341.02	5.44	89.08	111.84	771.08	5.24	85.91	101.29	698.36	5.43	89.02	179.14	1235.11	5.13	84.05	171.16	1180.12
5.41	88.63	56.08	386.65	5.31	87.00	42.44	292.64	5.41	88.61	100.05	689.79	5.23	85.75	89.55	617.41	5.40	88.46	160.57	1107.06	5.12	83.96	152.65	1052.46
5.35	87.65	46.67	321.79	5.26	86.27	33.14	228.47	5.35	87.60	80.95	558.13	5.20	85.22	70.55	486.45	5.34	87.50	133.60	921.12	5.11	83.69	125.78	867.19
5.28	86.60	39.24	270.57	5.21	85.41	25.82	177.99	5.28	86.60	68.39	471.55	5.16	84.55	58.10	400.58	5.16	84.58	82.08	565.92	5.01	82.08	74.57	514.14
5.17	84.68	30.93	213.23	5.11	83.69	17.70	122.06	5.16	84.62	50.75	349.91	5.07	83.01	40.67	280.41								

Reduced Data - Sounding 1



A.3.1.2 Sounding 2

Sounding 2 - Friction Reducer Cone

1.8m (5.9ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	21.60	148.93	-0.05	-0.75	26.20	180.65
0.26	4.27	35.93	247.75	0.19	3.15	37.79	260.57
0.57	9.29	44.77	308.71	0.48	7.95	44.60	307.53
0.87	14.30	49.46	341.00	0.78	12.85	47.40	326.83
1.18	19.26	55.23	380.81	1.08	17.66	52.13	359.44
1.48	24.28	58.10	400.57	1.38	22.60	53.44	368.47
1.79	29.39	60.76	418.94	1.69	27.65	55.55	383.03
2.10	34.39	64.68	445.94	1.99	32.55	58.45	402.99
1.94	31.81	34.44	237.45	1.88	30.73	28.74	198.14
2.10	34.39	59.27	408.64	1.99	32.68	53.04	365.69
2.52	41.26	67.26	463.76	2.40	39.35	59.91	413.09
2.74	44.91	68.23	470.44	2.62	42.98	60.41	416.49
3.02	49.50	70.53	486.31	2.90	47.51	62.05	427.81
3.33	54.52	71.95	496.05	3.20	52.49	62.58	431.48
3.64	59.63	75.14	518.04	3.51	57.52	65.51	451.67
3.94	64.61	75.42	519.99	3.81	62.49	64.78	446.65
4.25	69.57	75.66	521.66	4.12	67.44	64.72	446.21
4.56	74.75	77.36	533.35	4.43	72.59	65.56	451.99
4.86	79.72	80.34	553.95	4.73	77.47	67.78	467.34
5.15	84.47	81.72	563.41	5.02	82.19	68.53	472.48
5.47	89.69	82.20	566.75	5.33	87.40	68.46	472.00
5.44	89.08	71.99	496.33	5.31	87.05	58.31	402.05
5.41	88.61	65.36	450.68	5.29	86.75	51.74	356.73
5.35	87.67	55.27	381.08	5.25	86.07	41.74	287.80
5.16	84.62	37.83	260.83	5.09	83.46	24.62	169.76

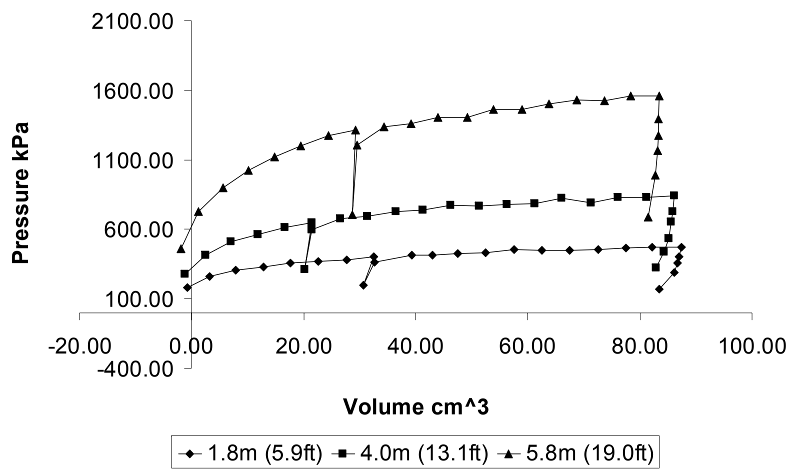
4.0m (13.1ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.02	32.86	226.59	-0.07	-1.14	40.61	279.99
0.26	4.29	54.95	378.86	0.16	2.57	59.95	413.32
0.56	9.17	71.46	492.71	0.43	7.04	74.48	513.52
0.87	14.19	80.06	552.00	0.72	11.84	81.17	559.63
1.17	19.23	89.27	615.47	1.02	16.64	89.32	615.86
1.48	24.26	95.81	660.56	1.31	21.51	94.29	650.09
1.32	21.62	46.07	317.62	1.23	20.13	45.37	312.82
1.47	24.08	88.05	607.12	1.31	21.52	86.59	597.01
1.79	29.41	99.97	689.24	1.62	26.55	97.89	674.92
2.10	34.37	104.04	717.35	1.92	31.41	100.95	696.06
2.42	39.58	109.37	754.10	2.23	36.48	105.38	726.54
2.72	44.50	112.00	772.19	2.52	41.33	107.37	740.27
3.03	49.57	117.33	808.93	2.82	46.27	111.97	771.98
3.33	54.55	117.25	808.38	3.13	51.25	111.01	765.39
3.64	59.68	119.67	825.08	3.44	56.32	113.17	780.27
3.95	64.66	120.96	833.99	3.74	61.27	113.45	782.20
4.25	69.61	127.38	878.25	4.03	66.05	119.57	824.38
4.56	74.72	123.34	850.41	4.35	71.26	114.68	790.72
4.86	79.70	130.00	896.34	4.64	76.07	120.58	831.38
5.17	84.79	130.77	901.63	4.95	81.15	120.68	832.03
5.48	89.79	132.47	913.32	5.25	86.10	121.84	840.08
5.44	89.13	115.87	798.91	5.24	85.87	105.33	726.20
5.41	88.61	105.13	724.87	5.22	85.62	94.64	652.53
5.35	87.69	87.65	604.33	5.20	85.14	77.25	532.65
5.28	86.55	73.96	509.97	5.15	84.35	63.68	439.09
5.16	84.60	56.56	389.99	5.06	82.84	46.49	320.56

5.8m (19.0ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.02	56.36	388.60	-0.11	-1.83	66.69	459.81
0.25	4.08	97.58	672.81	0.07	1.18	105.28	725.90
0.56	9.25	124.96	861.54	0.35	5.66	130.52	899.90
0.87	14.30	145.18	1001.01	0.62	10.20	148.83	1026.18
1.18	19.32	160.16	1104.28	0.91	14.83	162.76	1122.19
1.49	24.34	173.04	1193.08	1.19	19.52	174.08	1200.23
1.80	29.49	184.63	1272.97	1.49	24.38	185.11	1276.28
2.10	34.47	191.25	1318.62	1.78	29.19	190.71	1314.91
1.93	31.68	102.39	705.94	1.75	28.66	102.42	706.16
2.10	34.43	175.14	1207.55	1.80	29.56	174.61	1203.89
2.42	39.67	195.25	1346.18	2.09	34.29	193.80	1336.23
2.72	44.59	199.28	1374.02	2.39	39.11	197.21	1359.70
3.03	49.65	206.31	1422.45	2.68	43.99	203.50	1403.11
3.35	54.83	207.84	1433.03	3.00	49.14	204.15	1407.59
3.65	59.78	216.00	1489.26	3.29	53.87	212.05	1462.03
3.96	64.93	217.09	1496.78	3.60	58.99	212.11	1462.45
4.26	69.87	223.43	1540.48	3.89	63.77	218.14	1504.03
4.57	74.94	227.95	1571.66	4.19	68.73	221.82	1529.42
4.88	79.94	228.03	1572.21	4.50	73.73	221.14	1524.71
5.17	84.73	233.88	1612.58	4.78	78.37	226.36	1560.72
5.48	89.86	234.25	1615.08	5.09	83.49	226.18	1559.44
5.43	89.02	210.39	1450.57	5.08	83.26	202.42	1395.62
5.40	88.57	193.15	1331.71	5.08	83.24	185.22	1277.08
5.37	88.03	176.59	1217.58	5.07	83.12	168.73	1163.33
5.31	86.98	150.92	1040.53	5.05	82.73	143.16	987.03
5.16	84.60	107.35	740.18	4.97	81.46	99.85	688.43

Reduced Data - Sounding 2

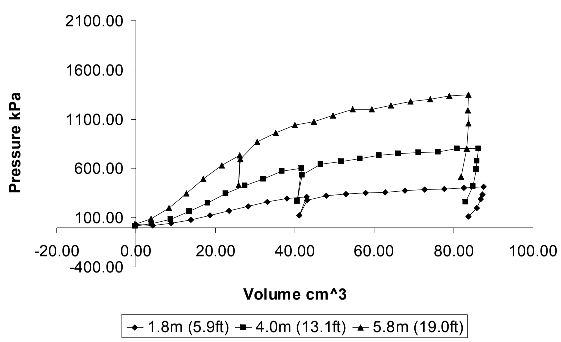


A.3.1.3 Sounding 3

Sounding 3 - Smooth Cone

1.8m (5.9ft)								4.0m (13.1ft)								5.8m (19.0ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.11	0.00	0.00	-0.01	-0.10	4.81	33.16	0.00	0.02	-5.80	-40.00	-0.01	-0.17	2.21	15.24	0.00	0.02	-5.80	-40.00	-0.02	-0.27	4.79	33.04
0.27	4.36	0.61	4.18	0.25	4.13	3.06	21.12	0.26	4.31	0.00	0.00	0.24	3.96	5.63	38.84	0.27	4.34	4.56	31.46	0.23	3.77	12.75	87.94
0.57	9.30	5.69	39.25	0.55	8.93	6.09	41.99	0.57	9.30	8.88	61.24	0.53	8.72	12.43	85.69	0.57	9.32	22.77	157.00	0.50	8.25	28.88	199.15
0.88	14.43	12.39	85.46	0.85	13.88	11.04	76.15	0.87	14.30	22.21	153.10	0.81	13.35	24.03	165.66	0.87	14.32	45.58	314.28	0.77	12.63	49.97	344.52
1.18	19.40	20.91	144.19	1.14	18.61	18.36	126.60	1.18	19.41	35.45	244.41	1.10	18.10	36.03	248.43	1.18	19.30	68.35	471.27	1.04	16.99	71.53	493.20
1.49	24.43	28.71	197.92	1.43	23.43	24.85	171.31	1.49	24.38	51.15	352.69	1.38	22.64	50.45	347.85	1.49	24.45	89.51	617.14	1.32	21.56	91.36	629.88
1.80	29.47	36.86	254.15	1.72	28.25	31.58	217.73	1.80	29.43	64.11	442.05	1.67	27.34	61.98	427.31	1.80	29.45	105.98	730.71	1.59	26.11	106.41	733.65
2.11	34.54	43.68	301.19	2.02	33.13	37.45	258.21	2.11	34.52	74.85	516.09	1.96	32.14	71.76	494.77	1.71	27.97	62.14	428.41	1.58	25.83	62.98	434.24
2.41	39.56	49.54	341.56	2.32	37.99	42.45	292.68	2.41	39.48	87.17	600.99	2.24	36.76	83.22	573.80	1.80	29.43	100.37	692.02	1.60	26.24	100.80	694.99
2.72	44.61	53.25	367.17	2.62	42.94	45.58	314.29	2.72	44.52	91.53	631.06	2.54	41.68	87.01	599.94	2.10	34.45	126.57	872.68	1.86	30.55	126.06	869.16
2.57	42.09	25.31	174.54	2.51	41.18	17.94	123.70	2.57	42.10	42.72	294.51	2.48	40.60	38.47	265.27	2.41	39.56	141.15	973.17	2.15	35.26	139.76	963.60
2.72	44.58	47.96	330.70	2.63	43.05	40.30	277.87	2.71	44.41	82.04	565.64	2.55	41.83	77.54	534.62	2.72	44.61	153.26	1056.68	2.44	39.98	151.30	1043.15
3.03	49.69	55.80	384.70	2.93	47.95	47.13	324.92	3.03	49.59	98.35	678.10	2.84	46.57	92.83	640.06	3.03	49.59	158.75	1094.54	2.73	44.81	155.80	1074.20
3.34	54.67	58.95	406.42	3.22	52.84	49.51	341.38	3.35	54.85	103.40	712.90	3.15	51.69	97.08	669.31	3.34	54.68	169.13	1166.08	3.03	49.62	165.39	1140.34
3.65	59.76	61.41	423.40	3.53	57.87	51.29	353.60	3.64	59.72	108.04	744.91	3.44	56.43	101.06	696.78	3.65	59.87	178.21	1228.71	3.33	54.56	173.77	1198.12
3.95	64.72	62.94	433.97	3.83	62.79	52.10	359.20	3.95	64.68	114.38	788.61	3.74	61.22	106.67	735.48	3.95	64.76	179.58	1238.17	3.63	59.41	174.43	1202.67
4.25	69.70	65.89	454.29	4.13	67.69	54.53	375.95	4.25	69.57	116.76	805.04	4.03	66.04	108.55	748.39	4.26	69.76	185.15	1276.59	3.92	64.26	179.48	1237.50
4.57	74.81	67.83	467.66	4.44	72.74	56.02	386.22	4.56	74.75	119.06	820.90	4.34	71.16	110.39	761.11	4.57	74.83	191.86	1322.80	4.22	69.15	185.74	1280.64
4.87	79.75	69.97	482.41	4.74	77.63	56.99	392.96	4.86	79.72	120.92	833.71	4.64	76.07	111.08	765.85	4.87	79.85	196.42	1354.25	4.52	74.04	189.14	1304.04
5.17	84.71	71.66	494.10	5.04	82.54	58.61	404.11	5.17	84.70	126.01	868.78	4.94	80.91	116.09	800.38	5.17	84.79	201.46	1389.05	4.81	78.84	194.10	1338.30
5.48	89.81	74.09	510.80	5.34	87.57	60.39	416.41	5.49	90.03	126.93	875.18	5.26	86.22	116.39	802.47	5.48	89.75	203.64	1404.08	5.11	83.75	195.64	1348.90
5.44	89.23	62.18	428.68	5.33	87.31	48.54	334.67	5.44	89.15	108.20	746.02	5.24	85.86	97.71	673.70	5.43	89.02	180.39	1243.74	5.10	83.65	172.48	1189.23
5.41	88.63	55.07	379.69	5.30	86.91	41.51	286.22	5.41	88.70	95.81	660.56	5.23	85.74	85.38	588.65	5.40	88.51	161.58	1114.02	5.11	83.66	153.74	1059.97
5.32	87.20	42.15	290.61	5.24	85.84	28.78	198.44	5.32	87.13	71.46	492.71	5.18	84.84	61.24	422.22	5.31	87.07	123.95	854.59	5.08	83.24	116.30	801.84
5.17	84.71	29.59	204.04	5.11	83.69	16.54	114.05	5.16	84.64	47.84	329.86	5.06	82.99	37.92	261.47	5.16	84.53	82.12	566.20	4.99	81.84	74.76	515.48

Reduced Data - Sounding 3

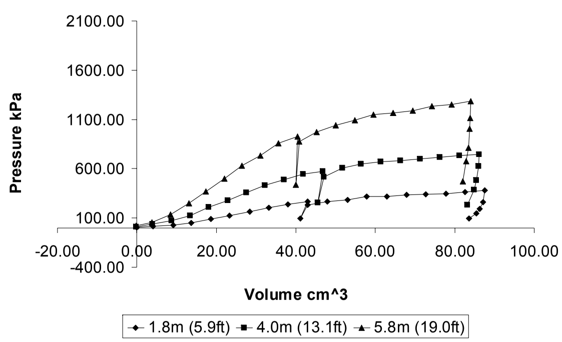


A.3.1.4 Sounding 4

Sounding 4 - Friction Reducer Cone

1.8m (5.9ft)								4.0m (13.1ft)								5.8m (19.0ft)							
Raw Data				Reduced Data				Raw Data				Reduced Data				Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	-4.35	-30.00	-0.01	-0.10	0.52	3.57	0.00	0.00	-6.53	-45.00	-0.01	-0.17	1.50	10.32	0.00	0.02	-7.25	-50.00	-0.01	-0.23	3.34	23.04
0.26	4.25	0.00	0.00	0.25	4.03	2.51	17.31	0.26	4.23	0.00	0.00	0.24	3.89	5.67	39.12	0.25	4.16	0.00	0.00	0.23	3.71	8.30	57.20
0.57	9.40	3.59	24.77	0.55	9.08	3.96	27.29	0.56	9.25	6.90	47.60	0.53	8.72	10.47	72.21	0.56	9.23	13.44	92.70	0.51	8.41	19.60	135.12
0.86	14.15	8.84	60.96	0.84	13.70	7.57	52.18	0.87	14.19	16.39	113.02	0.82	13.40	18.25	125.83	0.88	14.36	31.37	216.29	0.80	13.05	35.75	246.47
1.18	19.28	15.62	107.73	1.14	18.64	13.10	90.32	1.17	19.23	29.67	204.60	1.10	18.07	30.30	208.94	1.17	19.23	50.67	349.35	1.06	17.40	53.87	371.40
1.48	24.19	22.17	152.82	1.43	23.37	18.37	126.66	1.49	24.34	40.78	281.15	1.40	22.88	40.08	276.37	1.49	24.36	70.90	488.81	1.34	21.97	72.77	501.72
1.79	29.37	29.35	202.37	1.73	28.36	24.09	166.07	1.79	29.37	54.34	374.68	1.68	27.55	52.22	360.03	1.79	29.30	91.04	627.72	1.61	26.37	91.51	630.94
2.10	34.35	35.77	246.63	2.02	33.16	29.57	203.89	2.10	34.39	65.45	451.23	1.97	32.26	62.38	430.08	2.10	34.37	106.51	734.33	1.89	31.02	106.01	730.91
2.40	39.39	41.67	287.27	2.32	38.04	34.60	238.56	2.40	39.41	74.37	512.75	2.26	37.04	70.44	485.65	2.41	39.43	125.64	866.28	2.17	35.55	124.28	856.85
2.71	44.41	46.23	318.73	2.62	42.93	38.59	266.09	2.71	44.48	83.90	578.45	2.55	41.85	79.39	547.36	2.72	44.56	136.06	938.10	2.47	40.40	134.11	924.64
2.56	41.94	20.83	143.64	2.51	41.15	13.48	92.92	3.02	49.54	89.10	614.36	2.85	46.76	83.60	576.39	2.57	42.18	65.08	448.73	2.44	39.96	63.40	437.12
2.71	44.37	41.30	284.77	2.63	43.03	33.67	232.16	2.87	47.07	41.95	289.22	2.78	45.58	36.93	254.63	2.74	44.87	129.40	892.17	2.50	40.90	127.38	878.27
3.02	49.50	47.64	328.47	2.93	47.98	39.00	268.91	3.03	49.59	80.38	554.23	2.87	47.06	74.87	516.18	3.03	49.57	143.81	991.54	2.76	45.20	140.86	971.23
3.33	54.57	50.91	351.02	3.23	52.97	41.49	286.07	3.33	54.59	94.15	649.15	3.15	51.68	87.87	605.81	3.34	54.67	154.59	1065.87	3.05	50.00	150.86	1040.14
3.64	59.57	55.92	385.54	3.53	57.83	45.82	315.93	3.63	59.51	100.53	693.13	3.44	56.43	93.58	645.20	3.64	59.68	163.03	1124.04	3.34	54.79	158.62	1093.64
3.94	64.63	56.68	390.83	3.84	62.86	45.85	316.12	3.94	64.63	104.89	723.20	3.75	61.42	97.19	670.11	3.94	64.64	171.55	1182.78	3.63	59.52	166.41	1147.37
4.25	69.72	60.00	413.65	4.14	67.87	48.63	335.30	4.25	69.57	106.83	736.56	4.05	66.31	98.61	679.92	4.25	69.68	174.41	1202.54	3.93	64.47	168.75	1163.50
4.55	74.57	61.13	421.45	4.44	72.68	49.34	340.16	4.56	74.66	110.22	759.94	4.35	71.31	101.56	700.21	4.57	74.81	178.17	1228.43	4.24	69.50	172.06	1186.29
4.86	79.70	62.98	434.25	4.75	77.76	50.01	344.81	4.86	79.64	114.02	786.11	4.65	76.19	104.19	718.38	4.87	79.75	186.08	1282.99	4.53	74.23	178.80	1232.79
5.16	84.62	66.09	455.69	5.04	82.60	53.04	365.71	5.17	84.68	116.40	802.53	4.95	81.16	106.48	734.13	5.17	84.77	188.55	1299.97	4.83	79.18	181.18	1249.23
5.47	89.66	68.47	472.11	5.34	87.57	54.78	377.71	5.47	89.71	118.62	817.84	5.26	86.13	108.05	745.01	5.48	89.82	194.40	1340.34	5.13	84.07	186.39	1285.14
5.41	88.68	50.99	351.58	5.31	87.08	37.43	258.06	5.44	89.09	101.06	696.75	5.25	85.99	90.57	624.48	5.43	88.93	169.93	1171.65	5.12	83.84	162.04	1117.22
5.35	87.67	41.42	285.60	5.27	86.33	27.99	193.00	5.37	87.99	80.22	553.11	5.21	85.46	69.89	481.84	5.40	88.42	153.46	1058.07	5.11	83.79	145.63	1004.10
5.29	86.64	34.76	239.67	5.22	85.48	21.47	148.01	5.31	87.05	66.09	455.69	5.18	84.91	55.88	385.27	5.33	87.28	125.60	866.00	5.09	83.40	117.93	813.06
5.16	84.60	27.01	186.23	5.10	83.65	13.96	96.25	5.16	84.64	43.89	302.58	5.07	83.10	33.97	234.19	5.26	86.17	105.78	729.32	5.06	82.84	98.25	677.39
																5.16	84.49	75.78	522.49	5.00	81.97	68.43	471.78

Reduced Data - Sounding 4



A.3.1.5 Sounding 5

Sounding 5 - Smooth Cone

1.8m (5.9ft)

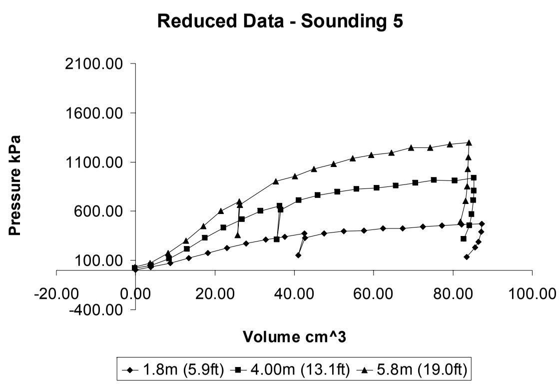
Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	-4.35	-30.00	-0.01	-0.10	0.52	3.57
0.25	4.08	1.78	12.25	0.23	3.82	4.38	30.20
0.56	9.19	10.25	70.71	0.53	8.70	10.70	73.77
0.86	14.17	19.42	133.89	0.82	13.43	18.14	125.07
1.17	19.15	27.74	191.24	1.11	18.18	25.24	174.05
1.48	24.28	36.54	251.92	1.41	23.07	32.72	225.59
1.79	29.32	44.86	309.27	1.70	27.88	39.60	273.06
2.10	34.39	51.52	355.20	2.00	32.77	45.31	312.41
2.40	39.33	56.44	389.16	2.29	37.58	49.39	340.51
2.71	44.43	61.57	424.51	2.60	42.53	53.93	371.85
2.56	41.95	29.35	202.37	2.50	40.94	21.99	151.64
2.71	44.44	55.03	379.41	2.61	42.73	47.39	326.74
3.02	49.46	62.94	433.97	2.90	47.53	54.31	374.47
3.33	54.54	66.74	460.14	3.20	52.50	57.32	395.23
3.64	59.59	68.64	473.22	3.51	57.50	58.54	403.60
3.94	64.57	72.75	501.62	3.81	62.37	61.93	426.96
4.24	69.55	73.32	505.51	4.11	67.33	61.97	427.27
4.56	74.66	75.98	523.89	4.42	72.37	64.19	442.54
4.86	79.58	78.49	541.14	4.71	77.23	65.54	451.86
5.16	84.64	80.18	552.84	5.02	82.24	67.13	462.86
5.47	89.66	81.92	564.81	5.32	87.21	68.23	470.40
5.45	89.24	70.05	482.97	5.32	87.12	56.41	388.94
5.38	88.18	55.59	383.31	5.28	86.44	42.10	290.25
5.31	87.09	46.83	322.91	5.22	85.60	33.48	230.83
5.16	84.60	32.82	226.31	5.09	83.49	19.77	136.34

4.00m (13.1ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	-5.08	-35.00	-0.01	-0.21	2.95	20.32
0.26	4.23	1.21	8.35	0.24	3.85	6.89	47.47
0.56	9.12	13.81	95.20	0.51	8.40	17.43	120.19
0.86	14.17	29.63	204.32	0.79	13.02	31.50	217.18
1.17	19.19	47.20	325.41	1.07	17.56	47.84	329.81
1.48	24.19	62.90	433.70	1.35	22.13	62.25	429.19
1.79	29.34	77.19	532.24	1.64	26.89	75.08	517.66
2.10	34.33	90.64	624.93	1.92	31.52	87.58	603.85
2.40	39.33	99.08	683.11	2.21	36.29	95.16	656.10
2.27	37.26	49.01	337.94	2.17	35.57	45.45	313.38
2.41	39.48	92.54	638.02	2.23	36.62	88.59	610.82
2.71	44.39	107.39	740.46	2.51	41.11	102.90	709.44
3.02	49.52	115.99	799.75	2.81	46.01	110.49	761.80
3.33	54.55	122.05	841.50	3.10	50.88	115.77	798.20
3.64	59.57	126.93	875.18	3.40	55.76	119.97	827.20
3.94	64.63	128.91	888.82	3.71	60.77	121.21	835.74
4.25	69.62	132.51	913.60	4.01	65.67	124.29	856.92
4.56	74.70	137.27	946.45	4.31	70.61	128.60	886.69
4.85	79.53	142.48	982.36	4.59	75.30	132.68	914.82
5.17	84.70	141.55	975.95	4.91	80.49	131.63	907.55
5.47	89.69	146.68	1011.31	5.21	85.35	136.12	938.49
5.44	89.15	127.38	878.25	5.21	85.33	116.89	805.92
5.41	88.65	113.57	783.05	5.20	85.20	103.15	711.18
5.35	87.62	92.74	639.41	5.17	84.74	82.45	568.48
5.28	86.53	76.39	526.67	5.13	84.10	66.24	456.73
5.17	84.68	56.24	387.76	5.05	82.80	46.32	319.37

5.8m (19.0ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.04	-5.80	-40.00	-0.02	-0.25	4.74	32.69
0.26	4.19	2.58	17.82	0.22	3.67	10.86	74.87
0.56	9.15	18.94	130.55	0.50	8.19	25.12	173.19
0.87	14.27	39.53	272.52	0.78	12.74	43.93	302.90
1.17	19.25	62.01	427.57	1.04	17.11	65.21	449.59
1.48	24.28	85.59	590.14	1.31	21.50	87.48	603.18
1.79	29.34	100.61	693.69	1.60	26.14	101.07	696.84
1.68	27.52	51.19	352.97	1.57	25.68	52.17	359.69
1.79	29.36	95.60	659.17	1.60	26.30	96.06	662.29
2.41	39.43	132.18	911.37	2.16	35.37	130.82	901.95
2.71	44.48	140.62	969.55	2.45	40.20	138.68	956.15
3.02	49.56	152.49	1051.39	2.74	44.95	149.55	1031.10
3.34	54.67	160.53	1106.79	3.04	49.84	156.79	1081.06
3.65	59.74	169.00	1165.24	3.34	54.68	164.59	1134.79
3.95	64.66	175.38	1209.22	3.63	59.43	170.24	1173.80
4.26	69.83	179.10	1234.83	3.94	64.50	173.42	1195.70
4.57	74.96	187.05	1289.67	4.24	69.41	180.93	1247.44
4.87	79.79	187.62	1293.57	4.53	74.22	180.33	1243.36
5.18	84.90	193.23	1332.26	4.83	79.18	185.86	1281.49
5.48	89.82	196.46	1354.53	5.13	84.02	188.45	1299.34
5.43	89.06	174.82	1205.33	5.12	83.84	166.91	1150.78
5.40	88.51	157.17	1083.68	5.11	83.78	149.33	1029.63
5.34	87.58	131.50	906.64	5.10	83.54	123.78	853.43
5.29	86.64	109.98	758.27	5.08	83.19	102.38	705.91
5.16	84.56	79.42	547.55	5.00	81.95	72.06	496.82



A.3.1.6 Sounding 6

Sounding 6 - Friction Reducer Cone

1.8 m (5.9 ft)

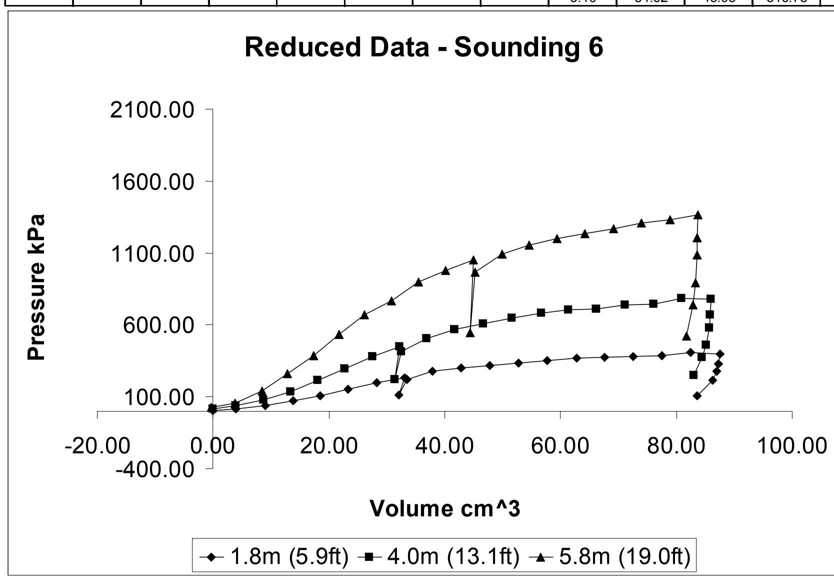
Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.04	-4.35	-30.00	0.00	-0.06	0.50	3.43
0.26	4.19	0.00	0.00	0.24	3.98	2.54	17.52
0.57	9.32	5.17	35.63	0.55	8.97	5.56	38.32
0.87	14.30	11.47	79.06	0.84	13.77	10.15	69.96
1.17	19.21	18.33	126.38	1.13	18.49	15.82	109.09
1.48	24.26	25.88	178.43	1.42	23.34	22.06	152.13
1.79	29.34	34.32	236.61	1.72	28.18	29.06	200.37
2.10	34.43	39.77	274.19	2.02	33.13	33.56	231.35
2.00	32.86	22.25	153.38	1.95	32.03	16.33	112.58
2.12	34.71	38.27	263.89	2.04	33.45	32.01	220.71
2.40	39.41	47.40	326.80	2.31	37.90	40.33	278.07
2.71	44.44	51.11	352.41	2.61	42.83	43.47	299.74
3.02	49.46	54.34	374.68	2.91	47.76	45.71	315.17
3.33	54.59	57.69	397.79	3.22	52.80	48.27	332.82
3.64	59.61	61.13	421.45	3.52	57.73	51.02	351.80
3.95	64.70	64.19	442.60	3.83	62.73	53.35	367.85
4.24	69.55	65.41	450.95	4.12	67.55	54.06	372.71
4.56	74.66	67.22	463.48	4.43	72.61	55.42	382.14
4.86	79.62	69.32	477.96	4.73	77.51	56.36	388.61
5.16	84.64	72.43	499.39	5.03	82.45	59.38	409.41
5.47	89.67	71.34	491.87	5.34	87.51	57.65	397.45
5.44	89.15	61.00	420.61	5.33	87.27	47.38	326.67
5.41	88.66	53.98	372.18	5.31	86.98	40.42	278.67
5.35	87.69	44.53	307.04	5.26	86.26	31.10	214.42
5.16	84.64	28.50	196.53	5.10	83.65	15.45	106.55

4.00 m (13.1 ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.01	0.19	-5.80	-40.00	0.00	0.00	2.12	14.60
0.26	4.25	0.00	0.00	0.24	3.91	5.66	39.05
0.56	9.25	7.51	51.78	0.53	8.70	11.08	76.39
0.87	14.28	18.21	125.54	0.82	13.44	20.04	138.14
1.17	19.25	30.20	208.22	1.10	18.08	30.82	212.53
1.48	24.28	43.56	300.36	1.39	22.75	42.88	295.68
1.80	29.43	57.37	395.56	1.68	27.52	55.23	380.82
2.10	34.35	67.95	468.49	1.96	32.16	64.89	447.39
1.99	32.61	34.44	237.45	1.91	31.33	31.70	218.60
2.11	34.54	63.23	435.92	1.98	32.47	60.13	414.58
2.40	39.41	77.56	534.74	2.25	36.95	73.63	507.64
2.71	44.41	86.76	598.21	2.54	41.70	82.26	567.18
3.02	49.50	94.07	648.59	2.84	46.59	88.57	610.68
3.33	54.63	100.17	690.63	3.15	51.55	93.88	647.25
3.66	59.91	105.82	729.60	3.46	56.68	98.81	681.28
3.95	64.66	110.18	759.66	3.74	61.31	102.48	706.54
4.25	69.57	111.27	767.18	4.04	66.19	103.05	710.54
4.56	74.70	116.16	800.86	4.34	71.19	107.49	741.10
4.86	79.66	117.65	811.16	4.64	76.11	107.82	743.40
5.17	84.66	123.66	852.64	4.94	80.94	113.74	784.24
5.47	89.69	123.26	849.85	5.25	85.99	112.70	777.04
5.44	89.15	107.56	741.57	5.24	85.87	97.07	669.24
5.41	88.65	94.84	653.88	5.23	85.71	84.41	582.02
5.35	87.63	77.15	531.96	5.20	85.19	66.86	461.01
5.28	86.55	64.27	443.16	5.15	84.45	54.13	373.20
5.16	84.62	45.95	316.78	5.07	83.02	36.03	248.39

5.8 m (19.0 ft)

Raw Data				Reduced Data			
Volume		Pressure		Volume		Pressure	
in^3	cm^3	psi	kPa	in^3	cm^3	psi	kPa
0.00	0.00	-6.53	-45.00	-0.02	-0.27	4.08	28.11
0.26	4.29	0.24	1.67	0.23	3.83	8.47	58.37
0.56	9.25	14.09	97.15	0.51	8.42	20.24	139.52
0.87	14.25	33.67	232.16	0.79	12.88	38.08	262.58
1.17	19.25	53.17	366.61	1.06	17.35	56.37	388.63
1.48	24.23	75.58	521.10	1.33	21.72	77.49	534.25
1.79	29.26	96.57	665.85	1.60	26.18	97.05	669.15
2.10	34.33	112.08	772.75	1.88	30.83	111.59	769.37
2.41	39.45	131.54	906.92	2.16	35.41	130.17	897.47
2.72	44.52	143.89	992.10	2.45	40.15	141.94	978.67
3.03	49.65	155.72	1073.66	2.74	44.95	152.76	1053.24
2.88	47.12	81.27	560.35	2.71	44.46	78.81	543.39
3.02	49.54	143.45	989.04	2.76	45.18	140.51	968.77
3.34	54.70	161.78	1115.42	3.04	49.84	158.04	1089.66
3.64	59.72	172.19	1187.23	3.33	54.58	167.78	1156.80
3.95	64.74	179.46	1237.34	3.62	59.39	174.31	1201.85
4.25	69.70	184.87	1274.64	3.92	64.21	179.21	1235.59
4.56	74.77	190.44	1313.06	4.22	69.13	184.33	1270.93
4.87	79.75	197.39	1360.93	4.51	73.92	190.11	1310.73
5.17	84.79	200.66	1383.48	4.81	78.87	193.30	1332.73
5.48	89.84	206.07	1420.78	5.11	83.77	198.06	1365.60
5.43	89.00	182.65	1259.33	5.10	83.57	174.75	1204.83
5.40	88.53	165.09	1138.24	5.10	83.58	157.25	1084.17
5.34	87.52	137.35	947.00	5.08	83.33	129.64	893.85
5.28	86.45	114.78	791.40	5.06	82.88	107.21	739.21
5.15	84.43	82.77	570.65	4.99	81.73	75.41	519.94



A.4 Puerto Del Rio Timing and Membrane Details

Date of Test	Membrane # & PMT type	Borehole #	PMT at Depth (m)	Time noted for each PMT test: Start Test	End Test	Deflate probe	Time per boring (H:mn)	Probe Dimensions Before Test: Li (cm)	øi (mm)	After Test: Lf (cm)	øf (mm)	Change in Dimensions: ΔL (cm)	Δø (mm)
6/11/2004	A1 using Calibraton tube	**A-2**	2	8:51	9:15	9:18							
			10.5	9:36	9:50	9:53							
			12	9:58	10:08	10:12							
			13.5	10:17	10:28	10:31							
			15	10:38	10:50	10:53	2:02	23.4	32	23.4	33	0	1
	Note: Test was successfully finished, probe intact												
06/14/2004	A1 using Friction Reducer	**A-3**	2.4	12:34	12:47	12:50							
			10.5	13:03	13:14	13:17							
			12	13:22	13:33	13:36							
			13.5	13:41	13:51	13:55							
			15	14:00	14:12	14:15	1:41	23.4	32.5	23.5	32.5	0.1	0
	Note: Test was successfully finished, probe intact												
06/14/2004	A1 using Friction Reducer	**A-6**	2.5	15:07	15:17	15:20							
			10.5	15:36	15:47	15:50							
			12	15:56	16:06	16:09							
			13.5	16:16	16:26	16:29							
			15	16:38	16:49	16:52	1:45	23.5	32.5	23.3	32.5	*-0.2*	0
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Calibraton tube	**B-1**	2.5	7:43	7:53	7:56							
			10.5	8:12	8:22	8:25							
			12	8:33	8:43	8:46							
			13.5	8:54	9:05	9:08							
			15	9:15	9:25	9:28	1:45	23.5	32.5	23.3	33	-0.2	0.5
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Friction Reducer	**B-2**	2.5	10:09	10:19	10:22							
			10.5	10:37	10:47	10:50							
			12	10:55	11:05	11:08							
			13.5	11:13	11:23	11:26							
			15	11:31	11:41	11:44	1:35	23.3	33	23.3	33	0	0
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Calibraton tube	**B-3**	2.5	12:26	12:36	12:39							
			10.5	12:52	13:03	13:06							
			12	13:11	13:21	13:24							
			13.5	13:27	13:38	13:41							
			15	13:45	13:56	13:59	1:33	23.3	33	23.3	33.5	0	0.5
	Note: Test was successfully finished, probe intact												

Li, Lf = initial and final probe length respectively

Øi, Øf = initial and final probe diameter respectively

Date of Test	Membrane # & PMT type	Borehole #	PMT at Depth (m)	Time noted for each PMT test: Start Test	End Test	Deflate probe	Time per boring (H:mn)	Probe Dimensions: Before Test: Li (cm)	øi (mm)	After Test: Lf (cm)	øf (mm)	Change in Dimensions: ΔL (cm)	Δø (mm)
6/11/2004	A1 using Calibraton tube	**A-2**	2	8:51	9:15	9:18							
			10.5	9:36	9:50	9:53							
			12	9:58	10:08	10:12							
			13.5	10:17	10:28	10:31							
			15	10:38	10:50	10:53	2:02	23.4	32	23.4	33	0	1
	Note: Test was successfully finished, probe intact												
06/14/2004	A1 using Friction Reducer	**A-3**	2.4	12:34	12:47	12:50							
			10.5	13:03	13:14	13:17							
			12	13:22	13:33	13:36							
			13.5	13:41	13:51	13:55							
			15	14:00	14:12	14:15	1:41	23.4	32.5	23.5	32.5	0.1	0
	Note: Test was successfully finished, probe intact												
06/14/2004	A1 using Friction Reducer	**A-6**	2.5	15:07	15:17	15:20							
			10.5	15:36	15:47	15:50							
			12	15:56	16:06	16:09							
			13.5	16:16	16:26	16:29							
			15	16:38	16:49	16:52	1:45	23.5	32.5	23.3	32.5	*-0.2*	0
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Calibraton tube	**B-1**	2.5	7:43	7:53	7:56							
			10.5	8:12	8:22	8:25							
			12	8:33	8:43	8:46							
			13.5	8:54	9:05	9:08							
			15	9:15	9:25	9:28	1:45	23.5	32.5	23.3	33	-0.2	0.5
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Friction Reducer	**B-2**	2.5	10:09	10:19	10:22							
			10.5	10:37	10:47	10:50							
			12	10:55	11:05	11:08							
			13.5	11:13	11:23	11:26							
			15	11:31	11:41	11:44	1:35	23.3	33	23.3	33	0	0
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Calibraton tube	**B-3**	2.5	12:26	12:36	12:39							
			10.5	12:52	13:03	13:06							
			12	13:11	13:21	13:24							
			13.5	13:27	13:38	13:41							
			15	13:45	13:56	13:59	1:33	23.3	33	23.3	33.5	0	0.5
	Note: Test was successfully finished, probe intact												

Li, Lf = initial and final probe length respectively

Øi, Øf = initial and final probe diameter respectively

Date of Test	Membrane # & PMT type	Borehole #	PMT at Depth (m)	Time noted for each PMT test: Start Test	End Test	Deflate probe	Time per boring (H:mn)	Probe Dimensions, Before Test: Li (cm)	øi (mm)	After Test: Lf (cm)	øf (mm)	Change in Dimensions: ΔL (cm)	Δø (mm)
06/15/2004	A1 using Calibraton tube	**B-4**	2.5	14:43	14:53	14:56							
			10.5	15:12	15:22	15:25							
			12	15:30	15:40	15:43							
			13.5	15:47	15:57	16:01							
			15	16:05	16:16	16:19	1:36	23.5	33.5	23.2	33.5	0.3	0
	Note: Test was successfully finished, probe intact												
06/15/2004	A1 using Friction Reducer	**C-2**	2.5	16:57	17:07	17:10							
			10.5	17:20	17:30	17:33							
			12	17:36	17:46	17:49							
			13.5	17:52	18:03	18:06							
			15	18:10	18:20	18:23	1:26	23.2	33.5	23.3	33	-0.1	0.5
	Note: Test was successfully finished, probe intact												
06/16/2004	A1 using Calibraton tube	**D-2**	2.5	7:35	7:45	7:48							
			10.5	8:04	8:14	8:17							
			12	8:22	8:32	8:35							
			13.5	8:39	8:49	8:52							
			15	8:56	9:06	9:09	1:34	23.3	33	23.2	33	0.1	0
	Note: Test was successfully finished, probe intact												
06/16/2004	A1 using Friction Reducer	**D-3**	2.5	9:49	9:59	10:03							
			10.5	10:13	10:23	10:26							
			12	10:31	10:41	10:44							
			13.5	10:48	10:58	11:01							
			15	11:05	11:18	11:21	1:32	23.2	33	23.2	33	0	0
	Note: Test was successfully finished, probe intact												
06/16/2004	A1 using Calibraton tube	**D-6**	2.5	12:03	12:14	12:17							
			10.5	12:31	12:41	12:44							
			12	12:49	12:59	13:02							
			13.5	13:07	13:18	13:21							
			15	13:26	13:38	13:41	1:38	23.2	33	23.2	33	0	0
	Note: Test was successfully finished, probe intact												
06/16/2004	A1 using Calibraton tube	**C-3**	2.5	16:20	16:30	16:33							
			10.5	16:48	16:58	17:01							
			12	17:08	17:18	17:21							
			13.5	17:25	17:35	17:38							
			15	17:43	17:53	17:56	1:36	23.2	33	23.2	33	0	0
	Note: Test was successfully finished, probe intact												

Li, Lf = initial and final probe length respectively

Øi, Øf = initial and final probe diameter respectively

Date of Test	Membrane # & PMT type	Borehole #	PMT at Depth (m)	Time noted for each PMT test: Start Test	End Test	Deflate probe	Time per boring (H:mn)	Probe Dimensions, Before Test: Li (cm)	øi (mm)	After Test: Lf (cm)	øf (mm)	Change in Dimensions: ΔL (cm)	Δø (mm)
06/17/2004	A1 using Friction Reducer	**C-4**	2.5	7:30	7:41	7:44							
			10.5	8:05	8:15	8:18							
			12	8:23	8:34	8:37							
			13.5	8:43	8:44	8:47							
			15	9:02	9:14	9:17	1:47	23.2	33	/	/	/	/
	Note: Test was finished . Developed leak at vent tube												
06/17/2004	B1 using Friction Reducer	**C-6**	2.5	10:52	11:02	11:05							
			10.5	11:24	11:35	11:38							
			12	11:42	11:52	11:55							
			13.5	11:58	12:08	12:11							
			15	12:16	12:26	12:29	1:37	23.6	32	23.6	32	0	0
	Note: Test was successfully finished, probe intact												
06/17/2004	B1 using Calibraton tube	**C-5**	2.5	13:19	13:29	13:32							
			4	13:37	13:48	13:51							
			5.5	13:56	14:06	14:09							
			7	14:14	14:25	14:28							
			8.5	14:35	14:45	14:48							
			10.5	14:52	15:02	15:05							
			12	15:10	15:20	15:23							
			13.5	15:27	15:37	15:40							
			15	15:44	15:54	15:57	2:38	23.6	32	23.6	32	0	0
	Note: Test was successfully finished, probe intact												
06/18/2004	B1 using Friction Reducer	**B-5**	2.5	7:39	7:49	7:53							
			4	7:57	8:07	8:10							
			5.5	8:15	8:25	8:28							
			7	8:34	/	/							
			8.5	/	/	/							
			10.5	/	/	/							
			12	/	/	/							
			13.5	/	/	/							
			15	/	/	/	/	23.6	32	/	/	/	/
	Note:Test failed at depth 7m , Developed leak at inside vent tube, no probe for switch,Test cancelled												

Average Time per Borehole Includes 5 depths (2,5m; 10,5; 12m; 13,5m; and 15m)	1:39
Time per Borehole Includes 9 depths (2,5m; 4m; 5,5m; 7m; 8,5m;10,5m;12m; 13,5m; and 15m)	2:38

Li, Lf = initial and final probe length respectively

Øi, Øf = initial and final probe diameter respectively

PPMT Test

Cone Tip Type	Sounding #	Date	Test Time Start	Test Time End	Time per Sounding	
Smooth	A2	6/11/2004	**8:51**	**10:53**	**2:02**	
Fri Red	A3	6/14/2004	**12:34**	**14:15**	**1:41**	
Fri Red	A6	6/14/2004	**15:07**	**16:52**	**1:45**	
Smooth	B1	6/15/2004	**7:43**	**9:28**	**1:45**	
Fri Red	B2	6/15/2004	**10:09**	**11:44**	**1:35**	
Smooth	B3	6/15/2004	**12:26**	**13:59**	**1:33**	
Smooth	B4	6/15/2004	**14:43**	**16:19**	**1:36**	
Fri Red	C2	6/15/2004	**16:57**	**18:23**	**1:26**	
Smooth	D2	6/16/2004	**7:35**	**9:09**	**1:34**	
Fri Red	D3	6/16/2004	**9:49**	**11:21**	**1:32**	
Smooth	D6	6/16/2004	**12:03**	**13:41**	**1:38**	
Smooth	C3	6/16/2004	**16:20**	**17:56**	**1:36**	
Fri Red	C4*	6/17/2004	**7:30**	**9:17**	**1:47**	Leak was found in the probe after test
Fri Red	C6	6/17/2004	**10:52**	**12:29**	**1:37**	
Smooth	C5	6/17/2004	**13:19**	**15:57**	**2:38**	
Fri Red	B5*	6/18/2004	**7:39**	**8:34**	**/**	Probe failed

*   Leak was found in the probe after the test.

** Probe failed during the test

CPT Test

Cone Type	Sounding #	Date	Test Time Start
DSA0481	A1	6/9/2004	**13:53**
DSA0481	A5	6/9/2004	**15:11**
DSA0481	D1	6/9/2004	**16:26**
DSA0481	D5	6/10/2004	**7:27**

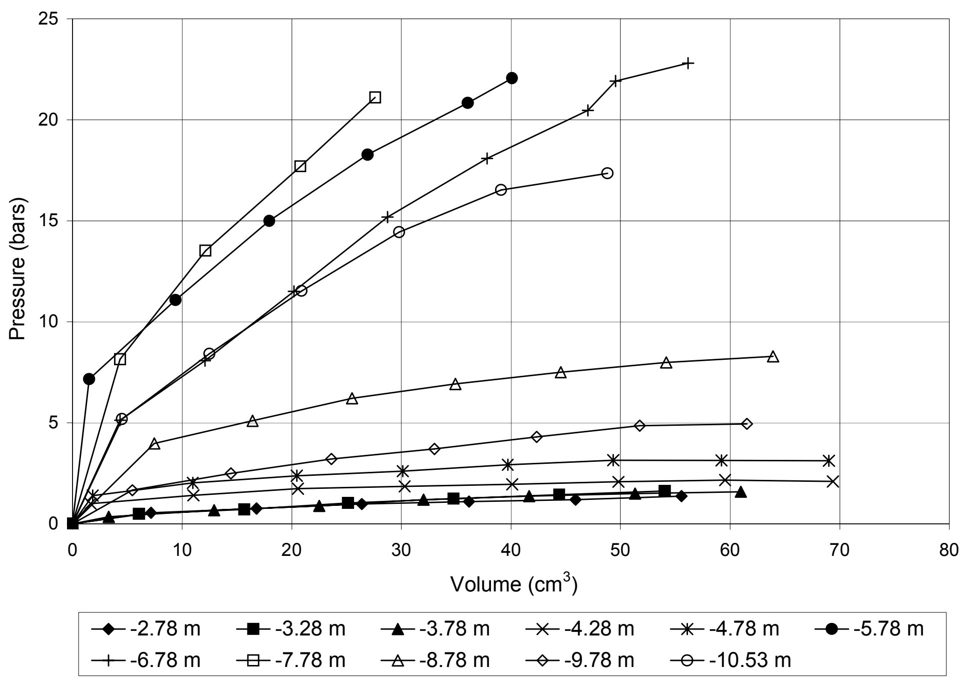
DMT Test

Blade #	Sounding #	Date	Blade Thicness
61370	A4	6/10/2004	15mm
61370	B6	6/10/2004	15mm
61370	C1	6/10/2004	15mm
61370	D4	6/16/2004	15mm

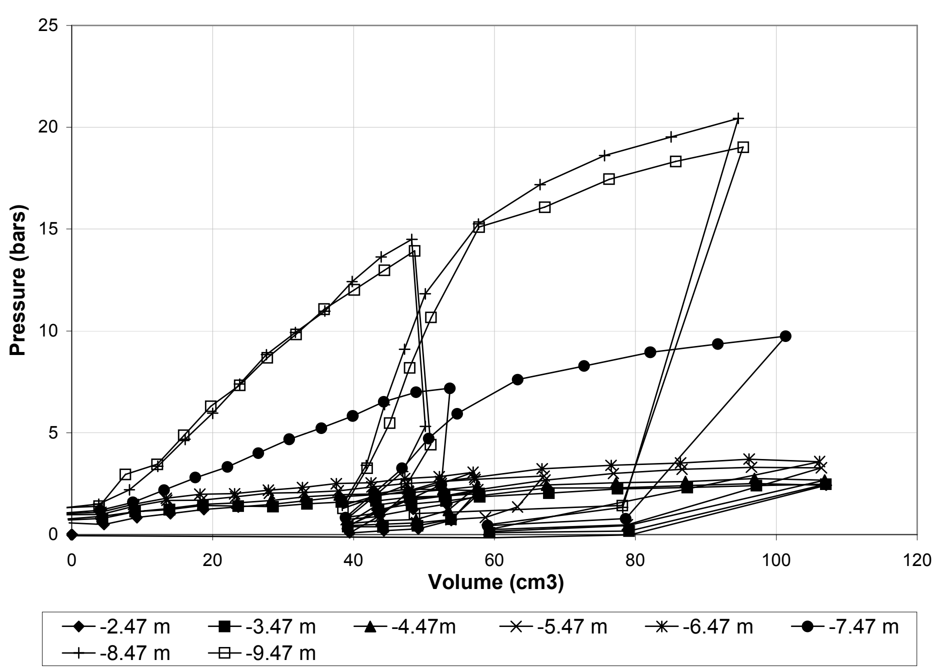
Note: Membrane facing west

A.4.1 University of North Carolina Charlotte Case Histories Data

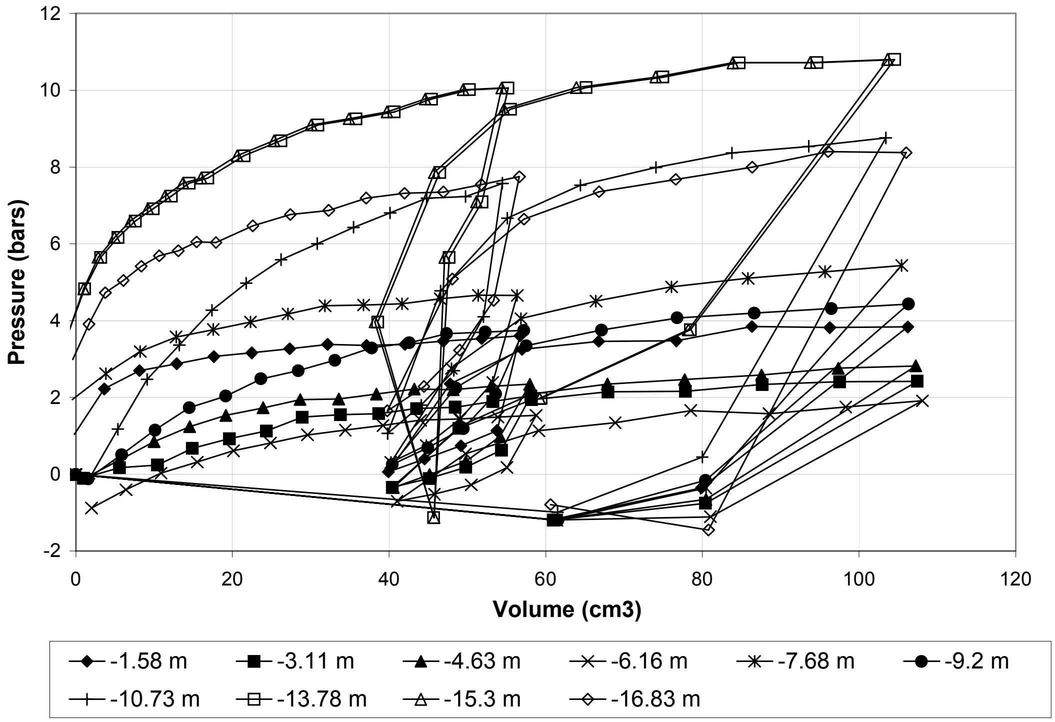
A.4.1.1 Roosevelt Bridge PPMT data



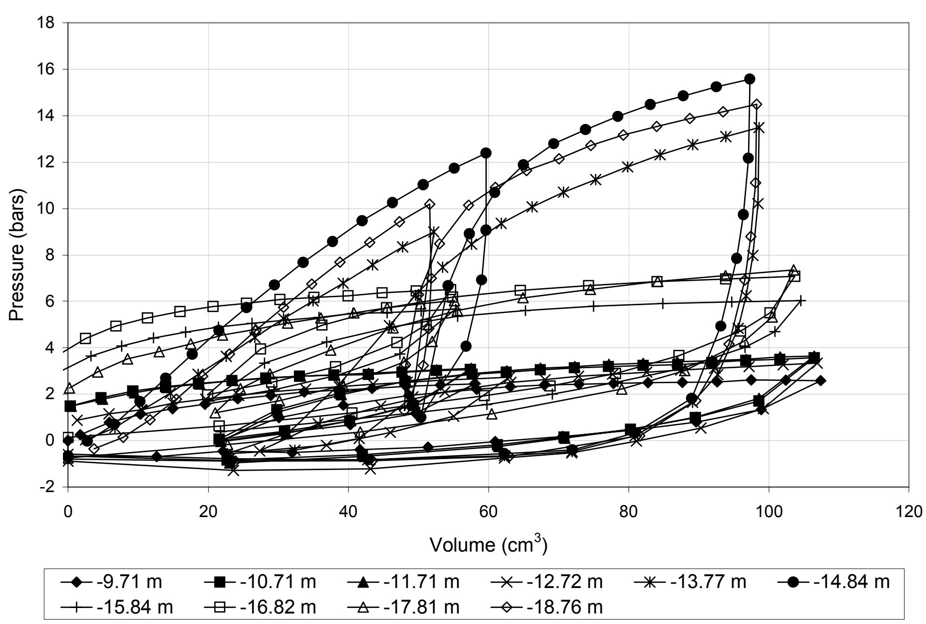
A.4.1.2 US17 Bypass PPMT Data



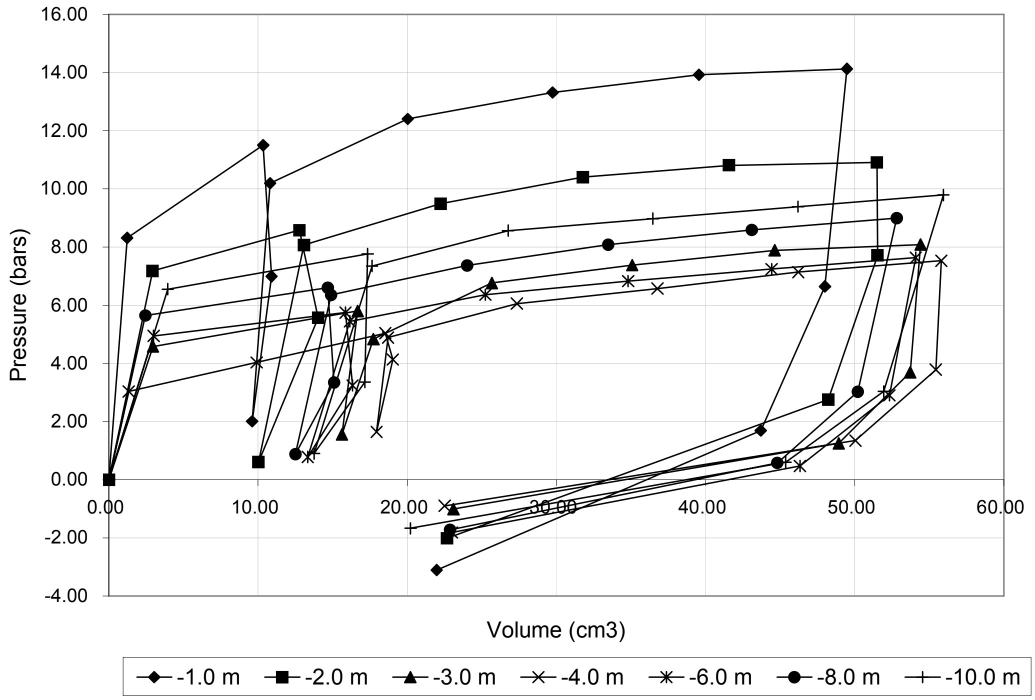
A.4.1.3 Rio Puerto Nuevo PPMT Data



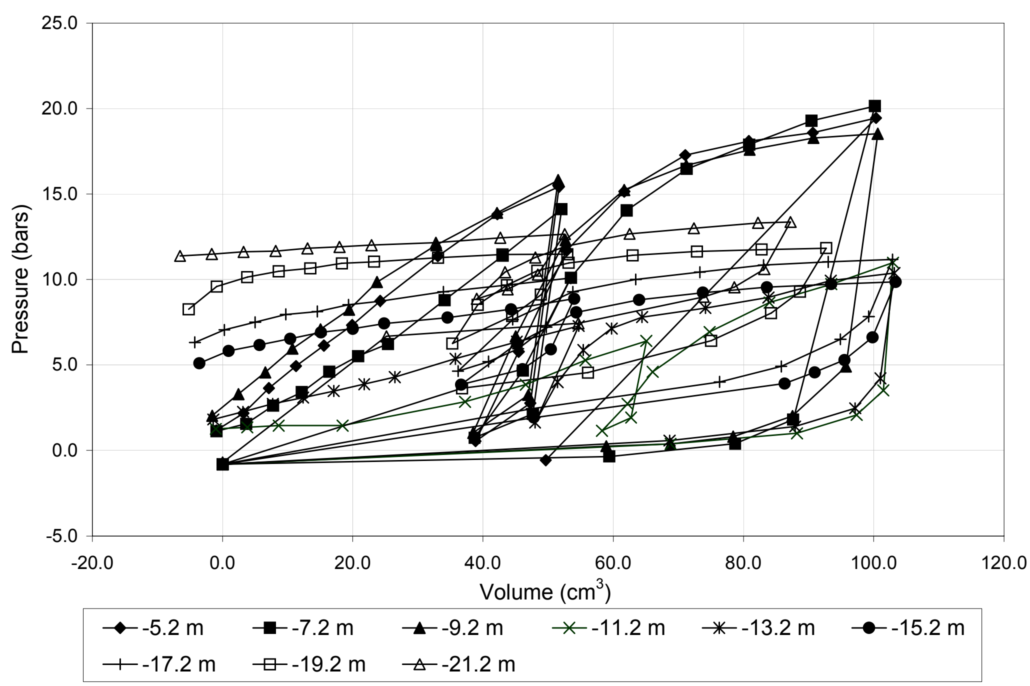
A.4.1.4 East Pascagoula River Bridge PPMT Data



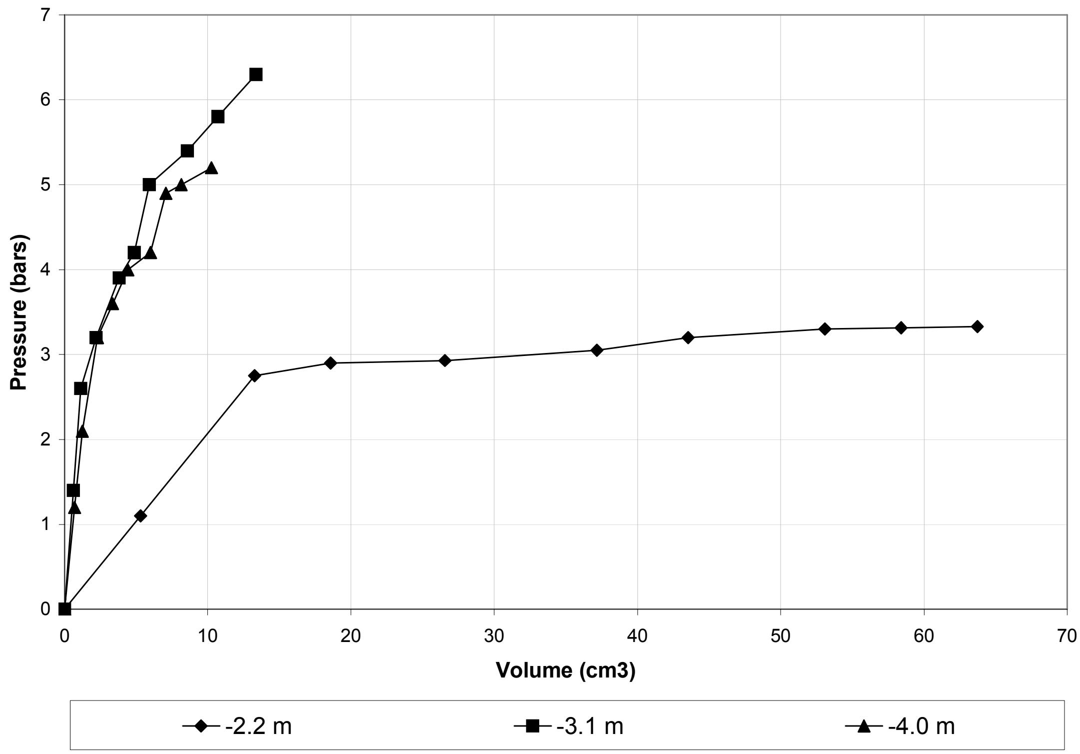
A.4.1.5 Auburn NGES PPMT Data



A.4.1.6 Broadway Bridge PPMT Data



A.4.1.7 Salt Lake City Bridge Pre-Boring Pressuremeter Data



B Appendix B DILATOMETER DATA

B.1 Florida Institute of Technology Field Site

B.1.1 P. James

B.1.1.1 Sounding A4

Dilatometer Data Reductior

Location: A-4 Date: 9/4/2003
Sounding#: F.I.T. Test Site
SP#: Vented= 0 bars
GSE= ft ΔA avg= 0.19 bars
GWE= -0.68 ft ΔB avg= 0.3 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	RM	Mdmt	E_0
0.50	1.64	110.00	1.60	10.20		6.28	16.04	295.49	2.91	860.05	580.47
1.00	3.28	118.00	7.60	25.80		2.72	56.89	645.26	4.01	2587.55	1746.41
1.50	4.92	106.00	4.50	15.20		2.65	26.06	372.00	3.33	1239.54	836.60
2.00	6.56	203.00	6.00	18.70		2.37	28.29	444.87	3.40	1514.07	1021.88
2.50	8.20	201.00	5.00	15.10		2.25	19.80	350.14	3.09	1083.13	731.03
3.00	9.84	92.00	2.20	8.00		3.01	7.06	193.47	2.20	425.27	287.03
3.50	11.48	71.00	1.35	5.30		3.48	3.51	126.07	1.59	200.52	135.34
4.00	13.12	57.00	1.25	4.65		3.31	2.85	106.03	1.41	149.37	100.81
4.50	14.76	36.00	1.20	4.45		3.49	2.37	100.56	1.25	125.65	84.80
5.00	16.41	306.00	3.00	12.20		4.00	5.92	317.35	2.04	648.69	437.82
5.50	18.05	802.00	10.70	28.00		1.85	22.02	612.47	3.19	1951.17	1316.90

B.1.1.2 Sounding B3

Dilatometer Data Reductior

Location: B-3
Sounding#: F.I.T. Test Site Date: 12/19/2003
SP#: Vented= 0.04 bars
GSE= ft ΔA avg= 0.25 bars
GWE= 0.61 ft ΔB avg= 0.21 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	RM	Mdmt	E_0
0.5	1.64	96	1.35	8.50		6.06	56.20	243.75	4.00	974.88	657.97
1.0	3.28	180	3.00	15.10		4.87	44.77	424.10	3.80	1612.44	1088.28
1.5	4.92	220	6.05	18.90		2.38	59.78	451.43	4.05	1829.67	1234.89
2.0	6.56	150	3.15	12.50		3.46	21.25	323.91	3.15	1021.89	689.70
2.5	8.20	140	2.65	11.60		4.10	13.36	309.33	2.75	851.17	574.48
3.0	9.84	190	3.72	11.90		2.51	16.32	281.28	2.93	822.79	555.32
3.5	11.48	190	2.91	9.40		2.58	10.52	219.70	2.54	558.93	377.24
4.0	13.12	120	1.86	6.20		2.78	5.54	141.37	1.99	280.87	189.56
4.5	14.76	39	1.22	3.81		2.59	2.97	77.61	1.44	112.11	75.67
5.0	16.41	380	5.60	17.90		2.64	14.22	431.39	2.81	1210.44	816.96
5.1	16.73	700	8.80	33.40		3.48	21.40	879.54	3.16	2779.93	1876.25

B.1.1.3 Sounding C2

Dilatometer Data Reductior

Location: C-2
Sounding#: F.I.T. Test Site Date: 12/19/2003
SP#: Vented= 0.04 bars
GSE= ft ΔA avg= 0.19 bars
GWE= 0.61 ft ΔB avg= 0.25 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	RM	Mdmt	E_0
0.5	1.64	95	1.87	9.50		4.74	77.31	243.75	4.28	1042.39	703.54
1.0	3.28	92	1.90	10.40		5.53	27.28	424.10	3.37	1430.01	965.15
1.5	4.92	230	5.40	19.10		2.95	51.55	451.43	3.92	1771.62	1195.71
2.0	6.56	220	5.00	18.60		3.23	33.66	323.91	3.55	1151.23	777.00
2.5	8.20	190	3.92	14.10		3.08	20.42	309.33	3.12	965.13	651.39
3.0	9.84	170	3.31	12.30		3.30	13.73	281.28	2.78	780.69	526.91
3.5	11.48	140	2.57	8.10		2.54	9.01	219.70	2.41	529.33	357.26
4.0	13.12	130	1.89	6.80		3.34	5.31	141.37	1.95	275.78	186.13
4.5	14.76	82	1.51	4.19		2.16	3.74	77.61	1.65	127.68	86.18
5.0	16.41	18	0.98	2.74		2.50	1.75	431.39	0.99	424.93	286.79
5.5	18.05	210	2.32	12.90		7.58	3.98	879.54	1.70	1494.65	1008.78

B.1.1.4 Sounding D1

Dilatometer Data Reductior

Location: D-1
Sounding#: F.I.T. Test Site Date: 12/19/2003
SP#: Vented= 0.04 bars
GSE= ft ΔA avg= 0.19 bars
GWE= 0.61 ft ΔB avg= 0.25 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	RM	Mdmt	E_0
0.5	1.64	120	2.00	11.20		5.59	79.81	319.17	4.30	1373.75	927.18
1.0	3.28	140	1.90	11.30		6.33	26.48	326.46	3.35	1092.30	737.22
1.5	4.92	280	9.10	24.60		1.90	90.96	548.71	4.42	2424.06	1636.06
2.0	6.56	180	2.55	11.60		4.40	16.17	313.71	2.92	915.23	617.71
2.5	8.20	240	3.20	14.90		4.68	15.52	410.26	2.88	1182.33	797.98
3.0	9.84	180	2.70	10.90		3.79	10.85	282.74	2.57	726.93	490.62
3.5	11.48	180	2.13	8.90		4.15	6.86	230.63	2.17	501.06	338.18
4.0	13.12	130	2.10	8.40		3.98	5.84	213.51	2.03	434.17	293.03
4.5	14.76	94	1.60	6.40		4.27	3.63	158.86	1.62	257.23	173.61
5.0	16.41	42	1.40	5.05		3.83	2.73	116.96	1.37	160.64	108.42
5.5	18.05	52	0.55	1.40		3.53	0.35	14.94	-0.41	-6.17	-4.16
6.0	19.69	360	2.35	14.90		9.87	3.35	441.23	1.55	684.05	461.69

B.1.1.5 Sounding E5

Dilatometer Data Reductior

Location: E-5
Sounding#: F.I.T. Test Site Date: 1/13/2004
SP#: Vented= 0.04 bars
GSE= ft ΔA avg= 0.16 bars
GWE= 0.61 ft ΔB avg= 0.25 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	RM	Mdmt	E_0
0.5	1.64	102	1.35	9.70		8.29	48.80	289.29	3.88	1121.56	756.97
1.0	3.28	220	5.00	15.00		2.23	80.64	349.41	4.31	1507.06	1017.15
1.5	4.92	160	3.80	13.40		2.93	35.98	334.84	3.61	1209.44	816.28
2.0	6.56	92	2.25	8.90		3.55	14.51	227.35	2.82	641.86	433.21
2.5	8.20	170	3.09	12.20		3.64	15.45	316.98	2.88	912.21	615.67
3.0	9.84	108	2.07	8.50		4.01	7.96	219.34	2.30	504.87	340.75
3.5	11.48	160	2.02	7.60		3.57	6.51	188.37	2.13	400.64	270.40
4.0	13.12	62	1.52	4.70		2.67	4.12	100.92	1.73	174.65	117.87
4.5	14.76	390	5.00	19.30		3.68	13.02	506.08	2.73	1381.29	932.27
4.8	15.81	700	9.20	31.80		3.02	23.09	808.49	3.23	2608.77	1760.72

B.1.1.6 Sounding F4

Dilatometer Data Reductior

Location: F-4
Sounding#: F.I.T. Test Site Date: 1/13/2004
SP#: Vented= 0.04 bars
GSE= ft ΔA avg= 0.16 bars
GWE= 0.61 ft ΔB avg= 0.24 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	RM	Mdmt	E_0
0.5	1.64	68	1.47	8.35		5.68	58.17	236.10	4.03	951.33	642.08
1.0	3.28	126	2.31	12.10		5.35	32.87	342.12	3.53	1208.96	815.96
1.5	4.92	266	6.90	27.20		3.57	63.97	725.06	4.11	2981.44	2012.25
2.0	6.56	160	4.00	14.00		2.94	26.96	349.78	3.36	1175.70	793.51
2.5	8.20	160	3.85	12.10		2.49	20.38	286.01	3.12	891.97	602.01
3.0	9.84	120	1.95	8.10		4.11	7.42	209.50	2.24	469.50	316.88
3.5	11.48	220	3.15	12.10		3.62	10.62	311.52	2.55	795.14	536.66
4.0	13.12	190	2.45	7.80		2.72	7.23	180.35	2.22	399.98	269.96
4.5	14.76	92	2.14	5.15		1.64	5.73	95.10	2.02	191.81	129.46
5.0	16.41	64	2.11	6.20		2.52	4.77	134.45	1.86	249.66	168.50
5.5	18.05	160	0.75	3.50		12.66	0.56	85.62	-0.01	-0.46	-0.31
5.7	18.64	64	13.00	37.80				889.01			

B.2 *Puerto Del Rio Field Site*

B.2.1 F. Massaoud

B.2.1.1 Sounding A4

Dilatometer Data Analysis

Performed by: Farid Messaoud

Location: **PDC. Clay Site** **Date:** **10/6/2004**

Sounding#: **DMT A4**

SP#:

GSE= **ft**

GWE= **1.45 ft**

Vented= **0 bars**

ΔA avg= **0.15 bars**

ΔB avg= **0.31 bars**

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	Rmo	RM	Mdmt	Eo (bars)
1	3.28	460	6.8	30.8		4.39	158.17138	857.6799		4.8982558	4201	2835
1.5	4.92	230	3.05	14.3		4.59	34.74225	393.13365		3.5817159	1408	950
2	6.56	28	1.75	4.65		1.67	14.434274	88.9014	0.54215	2.8120714	250	169
2.5	8.20	10	1.65	2.15		0.03	10.624233	1.4574		2.5620623	4	3
3	9.84	19	1.35	3.73		1.89	6.0058497	69.9552	1.0343	2.1754566	152	103
3.5	11.48	160	2.19	11.9		6.51	6.9975825	337.02375		2.1898961	738	498
4	13.12	240	2.68	15.7		7.47	7.1066405	457.6236		2.2033287	1008	681
4.5	14.76	160	2.7	11.1	0.075	4.24	6.929691	289.2939		2.1814277	631	426
5	16.41	190	1.5	3.8	0.1	1.89	3.2975159	67.0404	2.0186	2.2680552	152	103
5.5	18.05	180	2.43	3.49		0.32	5.911488	21.861		1.9612045	43	29
6	19.69	260	2.9	14.9	0.19	6.58	4.9995967	420.4599		1.89787	798	539
6.5	21.33	460	7.4	25.1	0.21	3.01	14.715304	628.1394		2.8355385	1781	1202
7	22.97	170	3.7	13.3	0.26	3.60	6.0020294	333.0159		2.0565962	685	462
7.5	24.61	140	3.55	12.5	0.33	3.57	5.2099975	309.33315		1.933675	598	404
8	26.25	40	2.19	3.85	0.47	0.87	2.8964777	43.722		1.2300137	54	36
8.5	27.89	62	2.15	5.6	0.68	2.46	2.3922653	108.94065	3.741125	3.2709753	356	241
9	29.53	22	2.61	3.25	1.3	0.10	3.3177486	6.5583		1.3691906	9	6
9.5	31.17	63	3.14	8.1	0.63	2.26	3.5964517	163.9575	4.233275	3.2697921	536	362
10	32.81	41	2.63	3.41	1.22	0.19	2.8842343	11.6592		1.2256721	14	10
10.5	34.45	24	3.52	5.1	2.33	0.46	4.0340175	40.8072		1.5695412	64	43
11	36.09	22	4	5.2	2.8	0.26	4.5559886	26.9619		1.694255	46	31
11.5	37.73	23	3.75	5.1	2.67	0.35	3.9298667	32.42715		1.5427317	50	34
12	39.37	27	4	5.6	2.8	0.42	4.0481521	41.5359		1.5731261	65	44
12.5	41.01	32	4.6	5.9	2.9	0.26	4.6705919	30.6054		1.7197177	53	36
13	42.65	32	4.03	5.35	2.93	0.32	3.6950268	31.3341		1.4795775	46	31
13.5	44.29	38	3.95	5.25	2.83	0.33	3.4083786	30.6054		1.3968129	43	29
14	45.93	44	4.4	6.1	2.84	0.42	3.7641206	45.1794		1.4985659	68	46
14.5	47.57	43	4.4	5.8	3.2	0.32	3.6049342	34.2489		1.4542777	50	34
15	49.22	54	5.4	6.6	3.74	0.19	4.6001082	26.9619		1.7041326	46	31
15.5	50.86	54.2	4.5	5.7	2.88	0.25	3.4042149	26.9619		1.3955601	38	25
16	52.50	56	3.29	4.8	1.61	0.62	1.9337529	38.25675		0.8159063	31	21
16.5	54.14	150	3.9	11.4	1.2	3.63	2.135989	256.5024		1.159198	297	201

B.2.1.2 Sounding C1

Dilatometer Data Reduction
Performed by: Farid Messaoud

Location: PDC. Clay Site **Date:** 10/6/2004
Sounding#: DMT C1
SP#: **Vented=** 0 bars
GSE= ft **ΔA avg=** 0.16 bars
GWE= 1.45 ft **ΔB avg=** 0.3 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	Rmo	RM	Mdmt	Eo (bars)
1	3.28	250	5.1	18.9		3.15	125.02947	486.0429		4.6940248	2281	1540
1.5	4.92	190	2.31	11.5		4.97	25.923344	318.07755		3.327382	1058	714
2	6.56	30	1.44	2.12		0.17	12.661125	8.0157	0.54215	2.7006254	22	15
2.5	8.20	6	1.31	1.89	0.37	0.11	8.273492	4.3722		2.3057457	10	7
3	9.84	26	1.3	3.85		2.16	5.7327266	76.14915	1.0343	2.1458301	163	110
3.5	11.48	62	1.88	7.2		3.62	6.6197696	177.0741		2.1416857	379	256
4	13.12	90	1.8	7.6		4.46	5.0588551	194.5629		1.9081045	371	251
4.5	14.76	110	2.2	9	0.1	4.27	5.5735746	230.9979		1.9922676	460	311
5	16.41	35	1.3	2.96		1.45	2.871121	43.722	2.0186	2.239106	98	66
5.5	18.05	21	2.23	3.61	0.79	0.55	5.4378477	33.5202		1.8756078	63	42
6	19.69	310	2.75	17.1	0.23	9.21	4.4068661	506.08215		1.7882597	905	611
6.5	21.33	230	3.95	15.8	0.21	4.18	7.2419749	414.99465		2.219714	921	622
7	22.97	190	3.39	13.8	0.3	4.50	5.3969557	362.52825		1.9642977	712	481
7.5	24.61	42	1.88	5.55	0.31	3.06	2.3854901	116.95635		1.2551552	147	99
8	26.25	21	2.24	3.69	0.9	0.68	3.1488273	36.07065		1.3156313	47	32
8.5	27.89	14	2.26	3.19	1.09	0.32	3.0049278	17.12445	3.741125	3.1480732	54	36
9	29.53	36	2.27	3.09	1.25	0.25	2.8153257	13.1166		1.2008876	16	11
9.5	31.17	62	2.12	3.83	0.69	1.06	2.2591951	45.54375	4.233275	3.6197758	165	111
10	32.81	44	2.5	3.6	1.08	0.42	2.8034862	23.3184		1.1965683	28	19
10.5	34.45	25	3.57	4.9	0.46	0.35	4.3648519	31.69845		1.6503281	52	35
11	36.09	32	2.9	5.2		1.05	2.9518971	67.0404		1.2494389	84	57
11.5	37.73	29	3.7	5	2.55	0.33	4.0600148	30.6054		1.5761252	48	33
12	39.37	46	3.91	5.5	2.8	0.42	4.1167309	41.17155		1.5903439	65	44
12.5	41.01	40	4.01	5.45	2.95	0.36	4.0443749	35.7063		1.5721693	56	38
13	42.65	46	4	5.4	2.95	0.35	3.8194404	34.2489		1.5135194	52	35
13.5	44.29	46	3.97	5.5	3.02	0.41	3.5727027	38.98545		1.4450726	56	38
14	45.93	55	4.21	5.6	3	0.34	3.7038525	33.88455		1.4820227	50	34
14.5	47.57	58	4.29	5.7	3.31	0.34	3.6193955	34.61325		1.4583811	50	34
15	49.22	66	5.1	6.36	3.82	0.23	4.4214052	29.148		1.6635223	48	33
15.5	50.86	61	4.15	5.15	3.19	0.21	3.1614252	19.6749		1.3197237	26	18
16	52.50	72	3.7	5	1.8	0.40	2.4995712	30.6054		1.0789626	33	22
16.5	54.14	280	5.5	18.4	1.2	3.87	3.6785712	453.2514		1.6313583	739	499

B.2.1.3 Sounding D4

Dilatometer Data Reduction

Performed by: Farid Messaoud
Location: PDC. Clay Site **Date:** 10/6/2004
Sounding#: DMT D4
SP#:
GSE= ft **Vented=** 0 bars
GWE= 1.45 ft **ΔA avg=** 0.16 bars
ΔB avg= 0.3 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	Rmo	RM	Mdmt	Eo (bars)
1	3.28	400	7.1	27.5		3.42	171.9337	726.5139		4.970722	3611	2437
1.5	4.92	200	3.95	14.8		3.21	47.822923	378.55965		3.8592722	1461	986
2	6.56	22	1.35	2.35		0.46	11.666661	19.6749	0.54215	2.6310713	52	35
2.5	8.20	6	1.61	2.37	0.61	0.21	10.321593	10.9305		2.5324423	28	19
3	9.84	28	1.5	4.22		1.96	6.8111404	82.3431	1.0343	2.2555503	186	125
3.5	11.48	170	2.17	11.8		6.48	6.9694225	334.10895		2.1863936	730	493
4	13.12	210	3.2	13.6		4.30	9.7659452	362.1639		2.4794286	898	606
4.5	14.76	110	2.1	8.35		4.09	5.3142814	210.95865		1.9508891	412	278
5	16.41	18	1.5	3.35		1.38	3.502426	50.64465	2.0186	2.2806592	116	78
5.5	18.05	19	2.45	3.4	0.55	0.26	6.1834354	17.85315		2.0073024	36	24
6	19.69	340	4.95	22.8		5.06	9.9185363	633.60465		2.4928952	1580	1066
6.5	21.33	450	7.6	24.9		2.83	15.447001	613.5654		2.8776884	1766	1192
7	22.97	180	2.35	10.4		5.69	3.2213916	276.54165		1.516087	419	283
7.5	24.61	160	3.45	10.9		2.96	5.2766434	254.68065		1.9447155	495	334
8	26.25	34	2.15	2.95	0.85	0.24	2.9751934	12.3879		1.2574959	16	11
8.5	27.89	36	1.95	4.75	0.35	2.20	2.150334	85.2579	3.741125	3.3284436	284	192
9	29.53	32	2.25	2.7	0.55	-0.01	2.7658755	-0.36435		1.182725	0	0
9.5	31.17	58	2.35	4.95		1.57	2.5349553	77.9709	4.233275	3.5330834	275	186
10	32.81	38	2.55	3.9	1	0.57	2.8036445	32.42715		1.1966261	39	26
10.5	34.45	19	3.75	4.9		0.26	4.5784695	25.14015		1.6993	43	29
11	36.09	20	3.75	4.5	2.47	0.11	4.3728147	10.56615		1.6521961	17	12
11.5	37.73	16	3.95	5.15	2.55	0.27	4.3912239	26.9619		1.656502	45	30
12	39.37	28	3.95	5.2	22.65	0.29	4.146376	28.78365		1.5976981	46	31
12.5	41.01	25	4.1	5.55	2.75	0.35	4.1193316	36.07065		1.5909911	57	39
13	42.65	35	4.25	5.45		0.25	4.124608	26.9619		1.5923031	43	29
13.5	44.29	32	3.9	5.1	2.85	0.29	3.4615521	26.9619		1.4126793	38	26
14	45.93	40	4.15	5.55		0.35	3.5861386	34.2489		1.4489199	50	33
14.5	47.57	40	4.5	5.7	3.2	0.25	3.8489088	26.9619		1.5213968	41	28
15	49.22	49	4.95	6.2	3.7	0.23	4.1984771	28.78365		1.6104966	46	31
15.5	50.86	47	3.9	5	3.05	0.27	2.8356962	23.3184		1.2082769	28	19
16	52.50	71	3.25	5.35	1.25	1.00	1.9153379	59.7534		0.8060991	48	33
16.5	54.14	240	5.95	15.6	1.35	2.42	4.2835586	334.83765		1.7636094	591	399

B.2.1.4 Sounding B6

Dilatometer Data Reduction

Performed by: Farid Messaoud
Location: PDC. Clay Site **Date:** 10/6/2004
Sounding#: DMT B6
SP#:
GSE= ft
GWE= 1.45 ft

Vented= 0 bars
ΔA avg= 0.16 bars
ΔB avg= 0.3 bars

Depth (m)	Depth (ft)	Thrust (N*100)	A (bars)	B (bars)	C (bars)	ID	KD	ED (bars)	Rmo	RM	Mdmt	Eo (bars)
1	3.28	440	4.5	25.2		6.06	98.487853	737.4444		4.4867653	3309	2233
1.5	4.92	260	3.7	16.1		4.08	43.216557	435.0339		3.7713003	1641	1107
2	6.56	38	1.55	3.85		1.40	12.933196	67.0404	0.54215	2.7187033	182	123
2.5	8.20	6	1.55	2.49	0.25	0.36	9.8359608	17.4888		2.4830476	43	29
3	9.84	28	1.2	3.55		2.14	5.2259003	68.86215	1.0343	2.0869088	144	97
3.5	11.48	180	2.4	13		6.39	7.8212616	369.4509		2.2865536	845	570
4	13.12	200	1.9	11.9	0.05	8.73	4.6163082	347.5899		1.8285896	636	429
4.5	14.76	108	1.8	9.1	0.075	6.34	4.0535801	249.2154		1.7156775	428	289
5	16.41	22	1.15	2.55	0.1	1.35	2.4171117	34.2489	2.0186	2.203119	75	51
5.5	18.05	14	2.35	3.9	0.79	0.61	5.7820839	39.71415		1.9385192	77	52
6	19.69	210	2.55	14.6	0.175	8.12	4.1703597	422.28165		1.740347	735	496
6.5	21.33	500	8.6	28.4	0.225	2.86	17.810167	704.6529		3.001336	2115	1427
7	22.97	220	2.49	13.2	0.25	7.65	3.2374898	373.45875		1.5204168	568	383
7.5	24.61	116	2.4	9.9	0.35	5.17	3.067838	256.5024		1.4736649	378	255
8	26.25	29	1.75	3.3	0.5	1.11	2.1058404	39.71415		0.9032841	36	24
8.5	27.89	38	2.4	3.9	0.5	0.67	3.1972828	37.8924	3.741125	3.1146286	118	80
9	29.53	29	1.9	3.45	0.3	1.06	2.0281726	39.71415		0.8647676	34	23
9.5	31.17	91	2.55	7.8	0.48	3.36	2.6547699	174.52365	4.233275	3.4983198	611	412
10	32.81	60	2.2	4.1	0.8	1.20	2.1589188	52.4664		0.9287977	49	33
10.5	34.45	29	3.2	4.4	1.9	0.35	3.70277	26.9619		1.4817231	40	27
11	36.09	24	3.65	5.4	2.1	0.52	4.1363213	47.00115		1.5952097	75	51
11.5	37.73	22	3.9	5.75	2.55	0.52	4.2663875	50.64465		1.6269423	82	56
12	39.37	32	3.75	5.1	2.65	0.35	3.8481777	32.42715		1.5212021	49	33
12.5	41.01	32	3.9	5.1	2.55	0.28	3.8567484	26.9619		1.5234823	41	28
13	42.65	38	4	5.4	2.7	0.35	3.7735682	34.2489		1.5011352	51	35
13.5	44.29	41	3.85	5.3	2.6	0.40	3.3800928	36.07065		1.3882715	50	34
14	45.93	46	3.85	4.4		0.04	3.2987343	3.27915		1.3632997	4	3
14.5	47.57	44	4.4	5.8	2.9	0.32	3.7555542	34.2489		1.4962307	51	35
15	49.22	58	4.8	6.2	3.4	0.29	4.0551226	34.2489		1.5748894	54	36
15.5	50.86	62	3.95	5.6	2.7	0.50	2.8763004	43.35765		1.2228488	53	36
16	52.50	200	2.3	9.5	1.2	13.86	0.5730063	245.5719		-0.430744	-106	-71
16.5	54.14	260	5	14.6	1.25	3.16	3.2818218	333.0159		1.53223	510	344

Dilatometer Data Reduction
Performed by: Farid Messaoud
Location: PDC. Clay Site
Sounding#: DMT A4 DMT C1 DMT D4 DMT B6

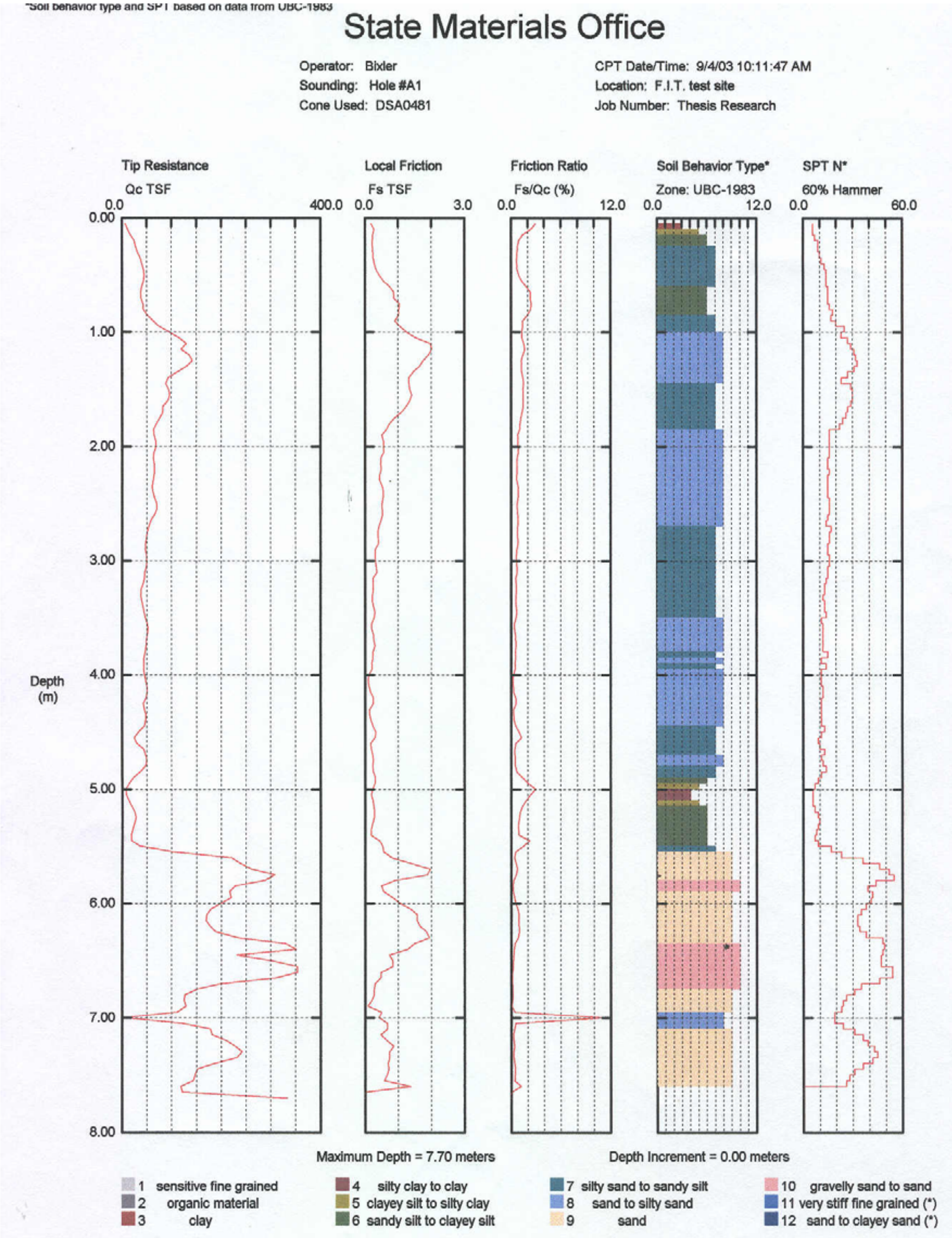
Depth (m)	Depth (ft)	DMT - A4 Eo(kPa)	DMT - C1 Eo(kPa)	DMT - D4 Eo(kPa)	DMT - B6 Eo(kPa)	DMT Eo avg(kPa)
1	3.28	283545	153984	243736	223315	226145
1.5	4.92	95036	71432	98604	110731	93951
2	6.56	17200	1480	3524	12474	8670
2.5	8.20	252	680	1868	2931	**1433**
3	9.84	9556	10179	11901	8803	10110
3.5	11.48	49813	25596	49303	57016	45432
4	13.12	68052	25056	60606	42898	49153
4.5	14.76	42593	31061	27777	28858	32572
5	16.41	7279	4419	5664	3142	5126
5.5	18.05	2894	4243	2419	5196	3688
6	19.69	53858	61081	106605	49601	67786
6.5	21.33	120212	62172	119168	142740	111073
7	22.97	46224	48062	28297	38323	40227
7.5	24.61	40371	9908	33428	25512	27305
8	26.25	3630	3203	1051	2421	2576
8.5	27.89	12330	2090	9296	4716	7108
9	29.53	606	1063	-29	2318	990
9.5	31.17	21890	5351	9471	21476	14547
10	32.81	964	1883	2619	3289	2189
10.5	34.45	4323	3531	2883	2696	**3358**
11	36.09	3083	5653	1178	5060	3744
11.5	37.73	3376	3256	3014	5561	3802
12	39.37	4410	4419	3104	3329	**3816**
12.5	41.01	3552	3789	3873	2772	3497
13	42.65	3129	3499	2898	3470	3249
13.5	44.29	2885	3802	2571	3380	**3160**
14	45.93	4570	3389	3349	302	2902
14.5	47.57	3362	3407	2769	3459	3249
15	49.22	3101	3273	3129	3640	**3286**
15.5	50.86	2540	1752	1902	3578	2443
16	52.50	2107	2229	3251	-7139	112
16.5	54.14	20068	49905	39856	34439	36067

C Appendix C CPT DATA

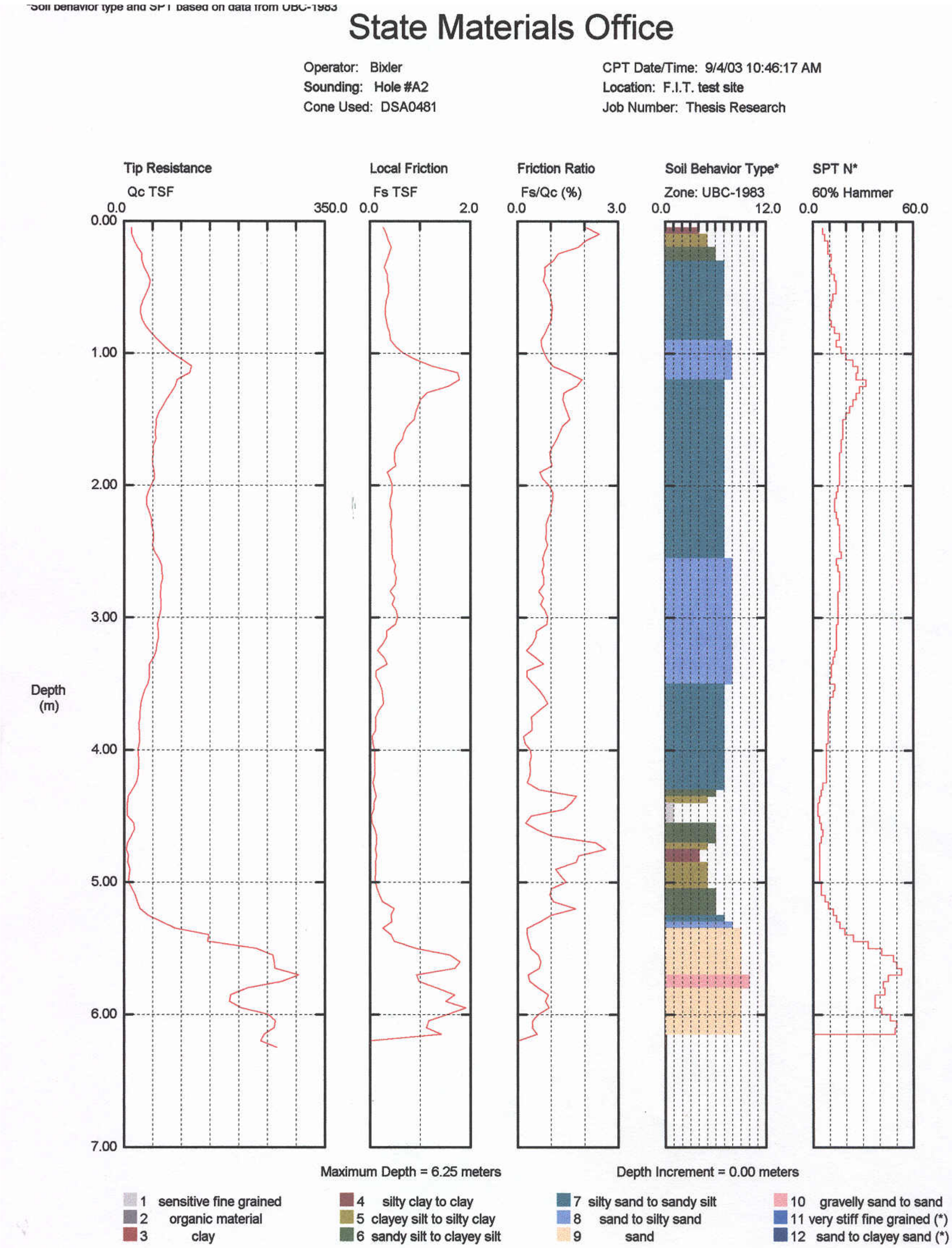
C.1 Florida Institute of Technology Field Site

C.1.1 P. James

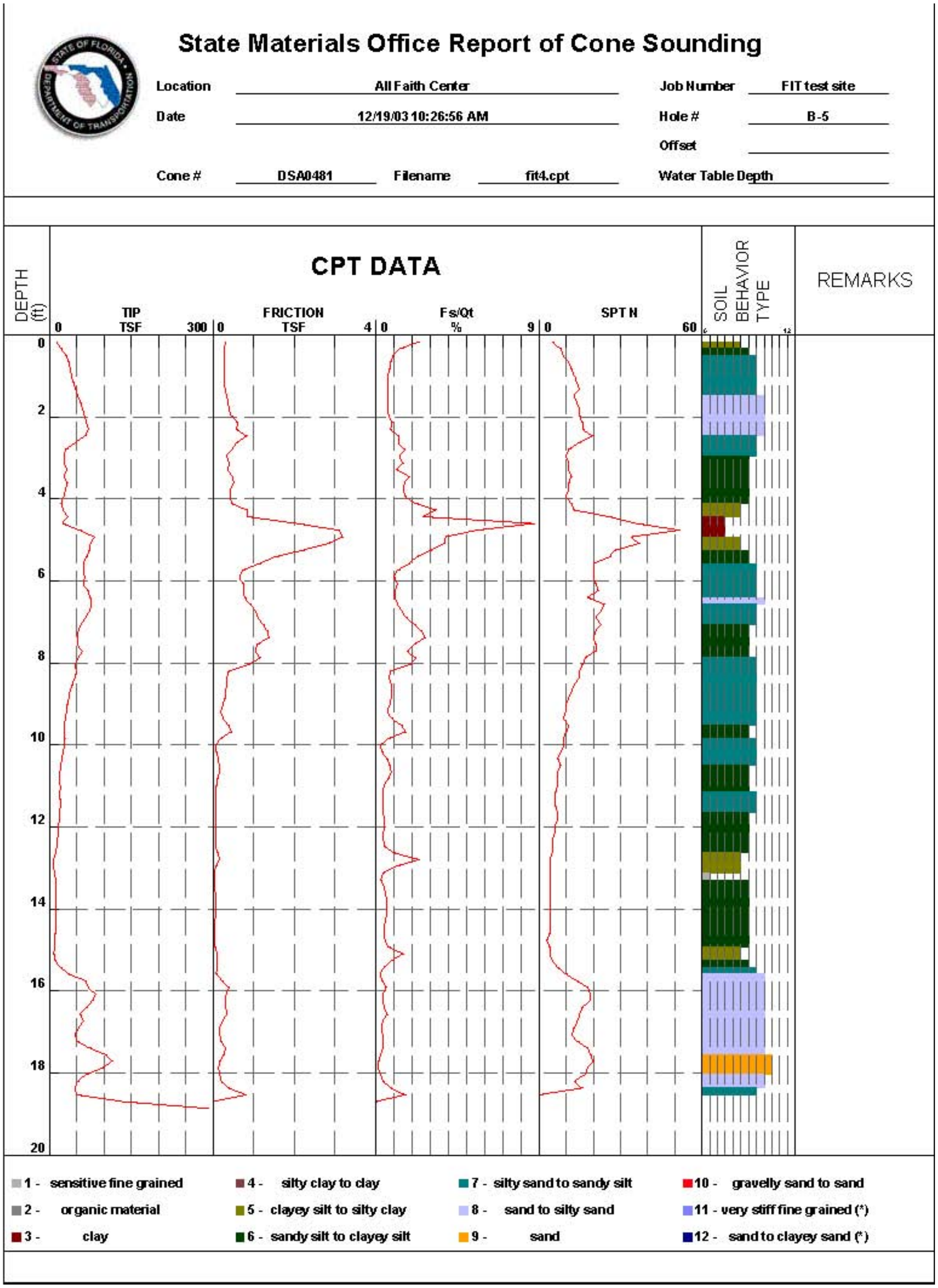
C.1.1.1 Sounding A1



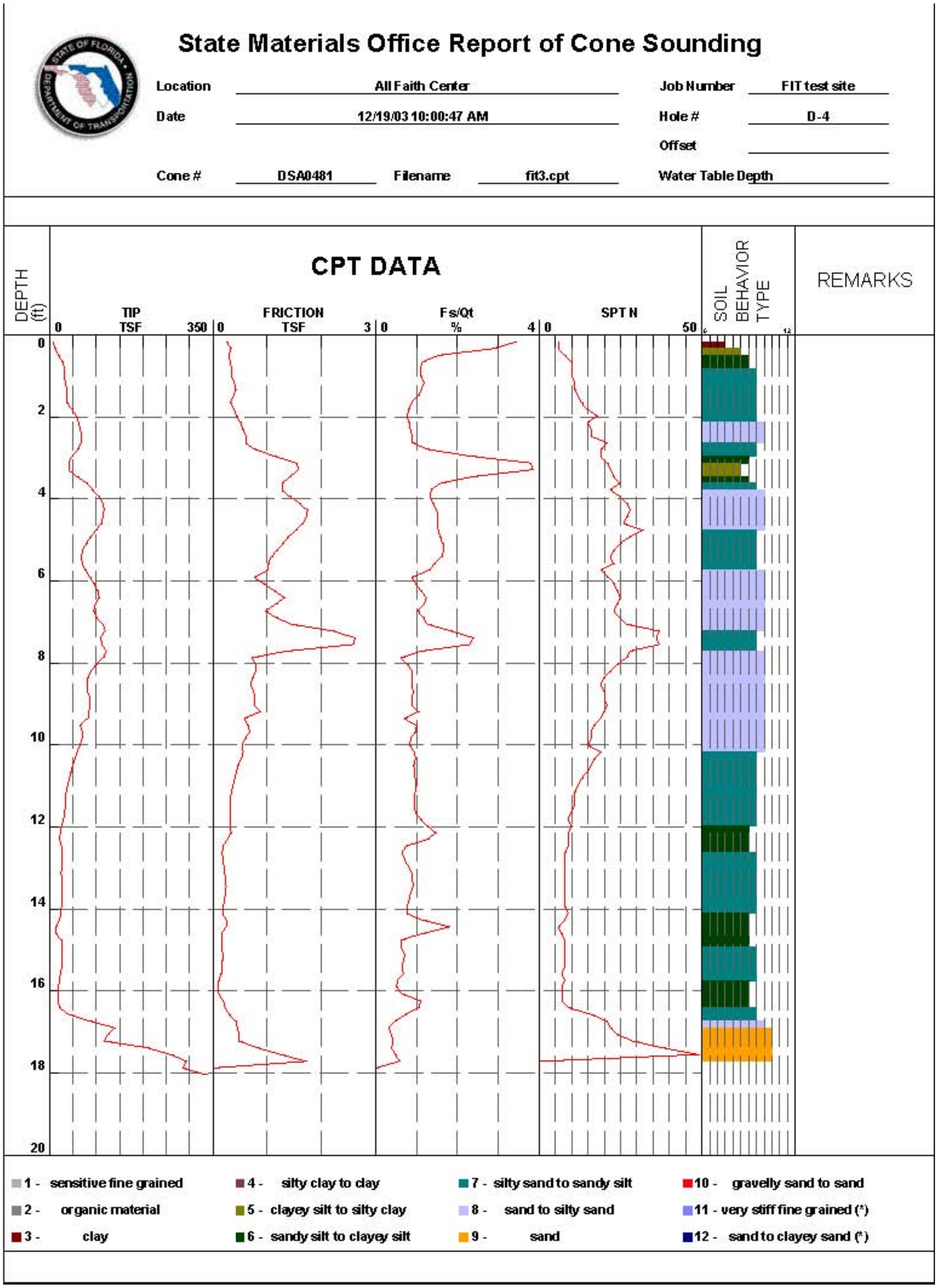
C.1.1.2 Sounding A3



C.1.1.3 Sounding B5

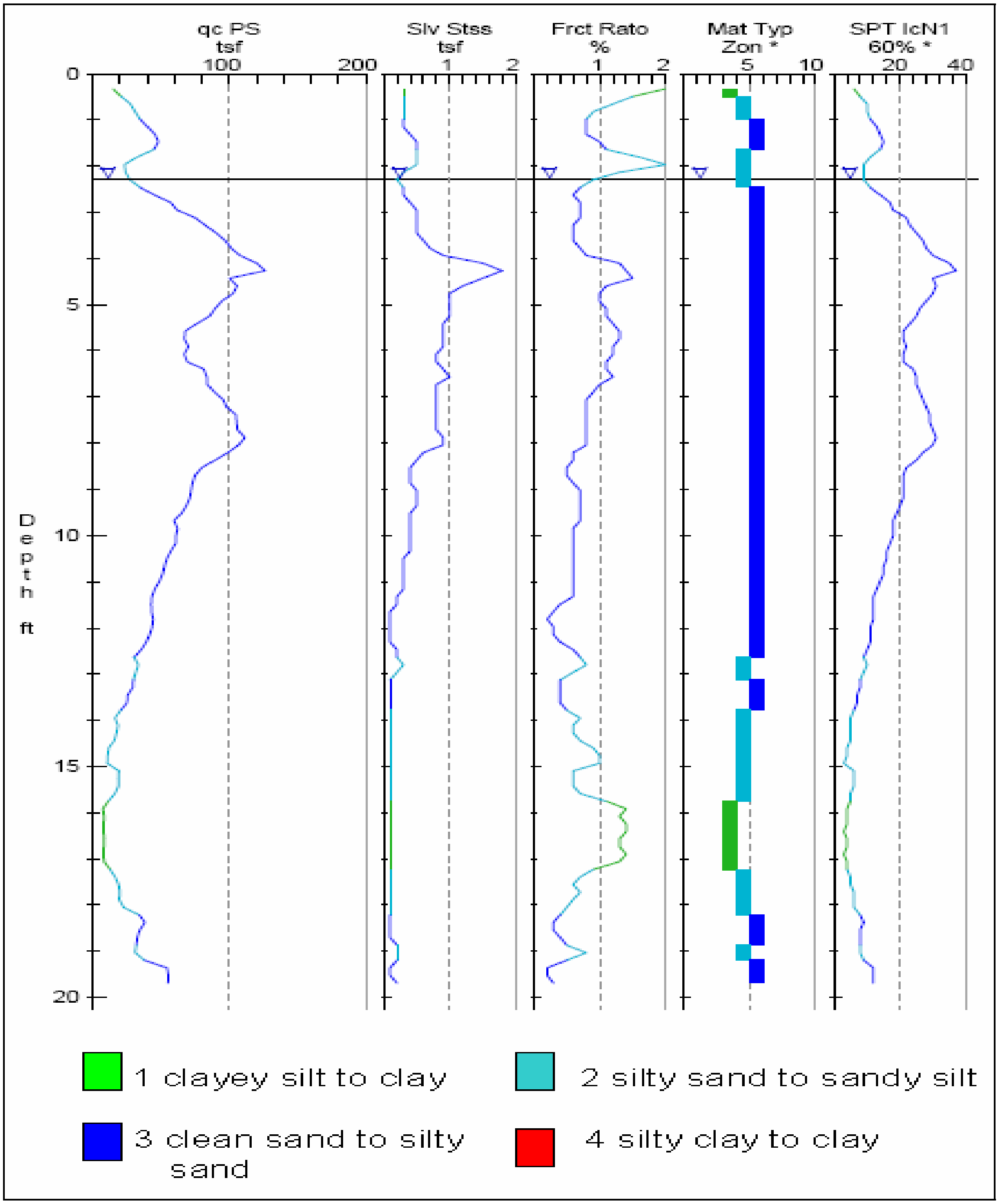


C.1.1.4 Sounding D4

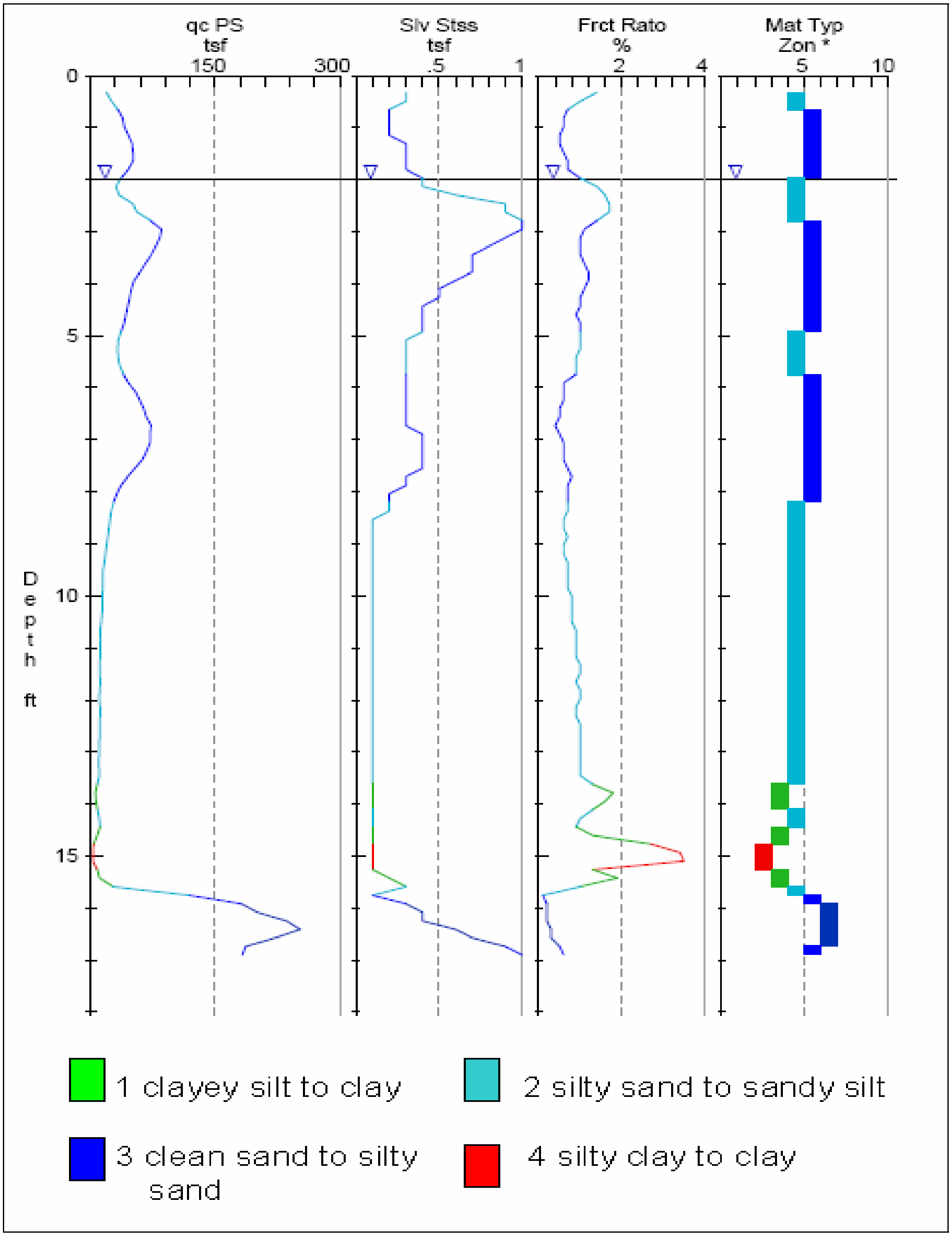


C.1.2 S. Sundaram

C.1.2.1 CPT 1

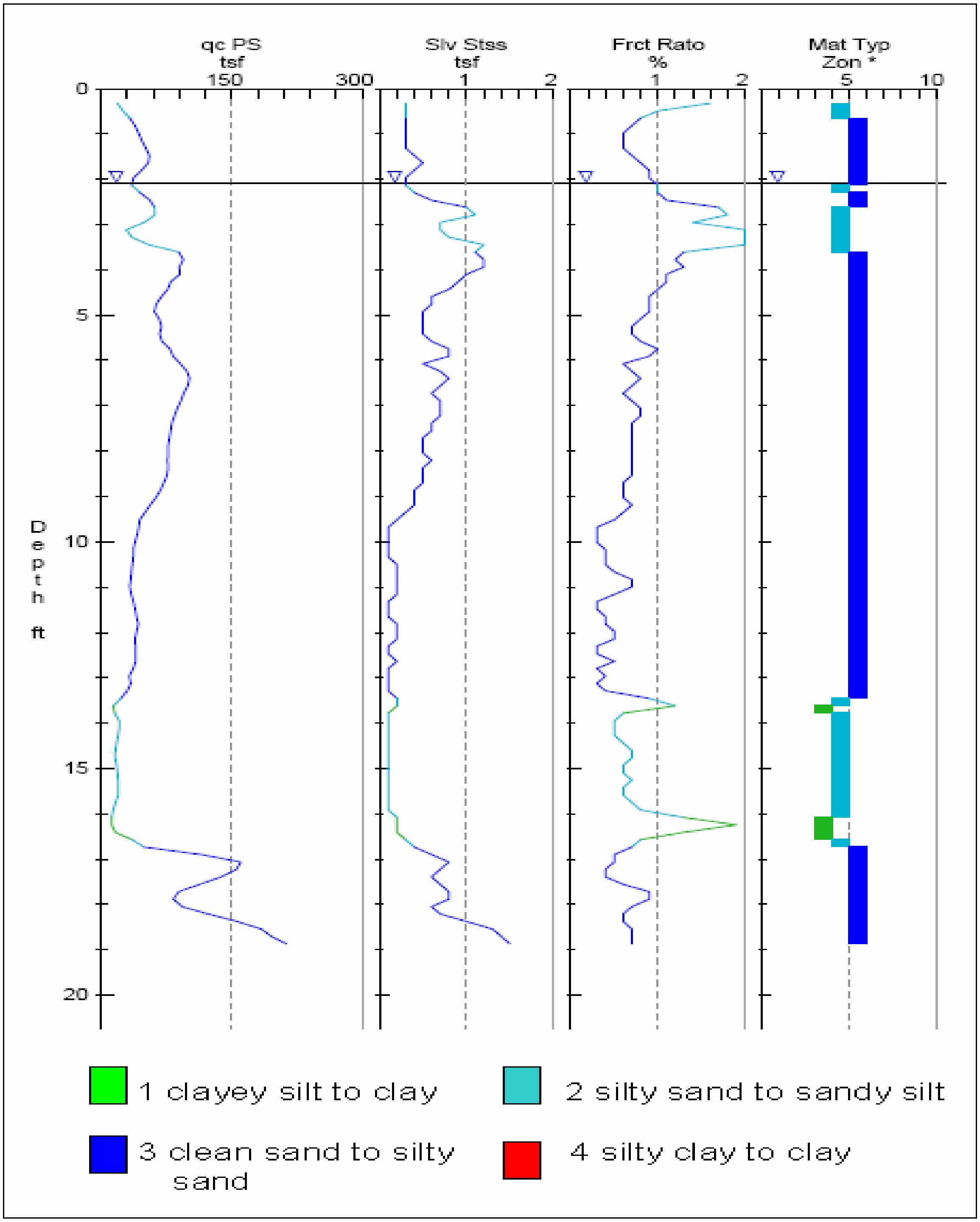


C.1.2.2 CPT 2

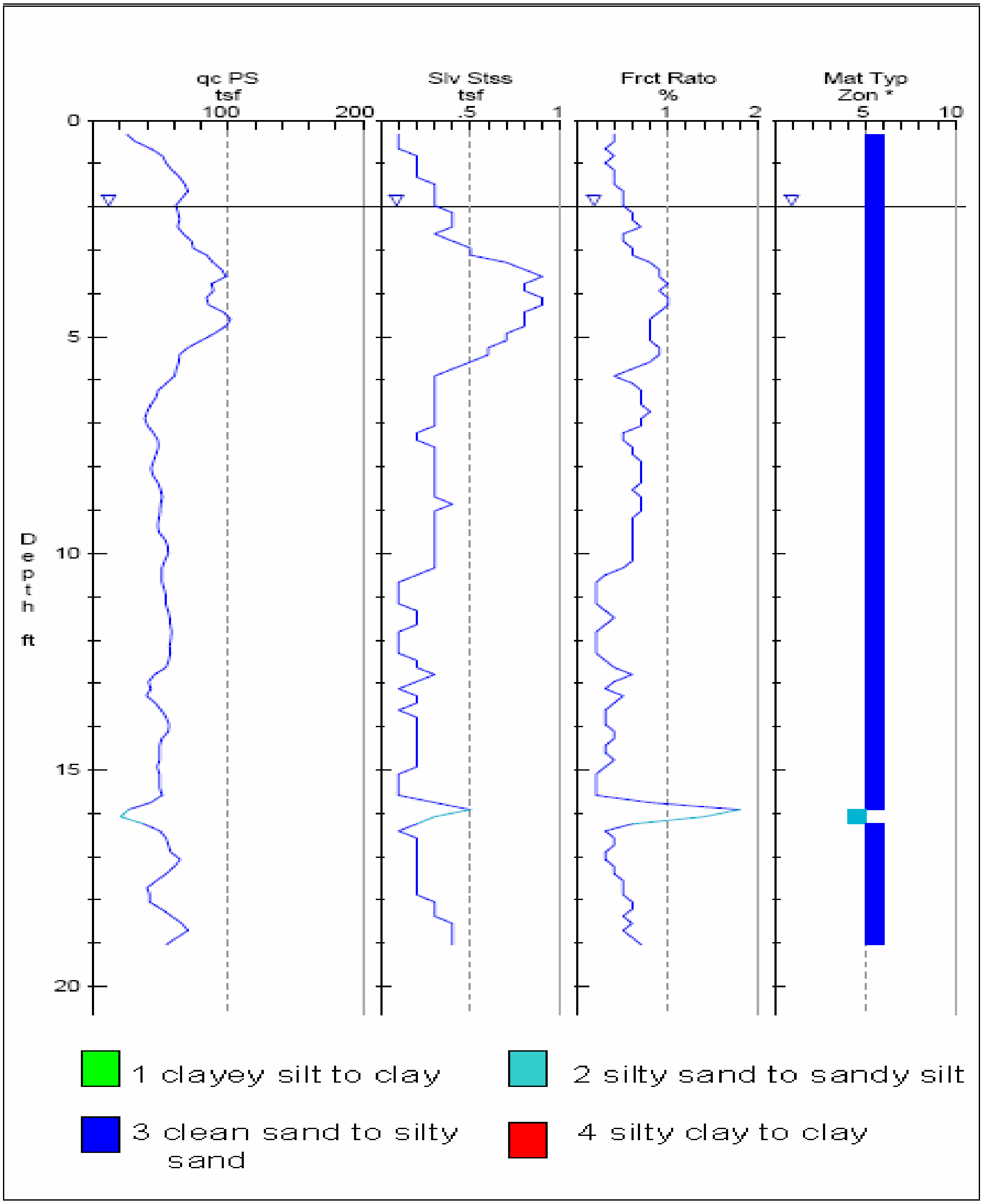


qc PS
tsf
150
300
Slv Stss
tsf
.5
1
Frct Rato
%
2
4
Mat Typ
Zon *
5
10
0
5
10
15
D e p t h ft
1 clayey silt to clay
2 silty sand to sandy silt
3 clean sand to silty sand
4 silty clay to clay

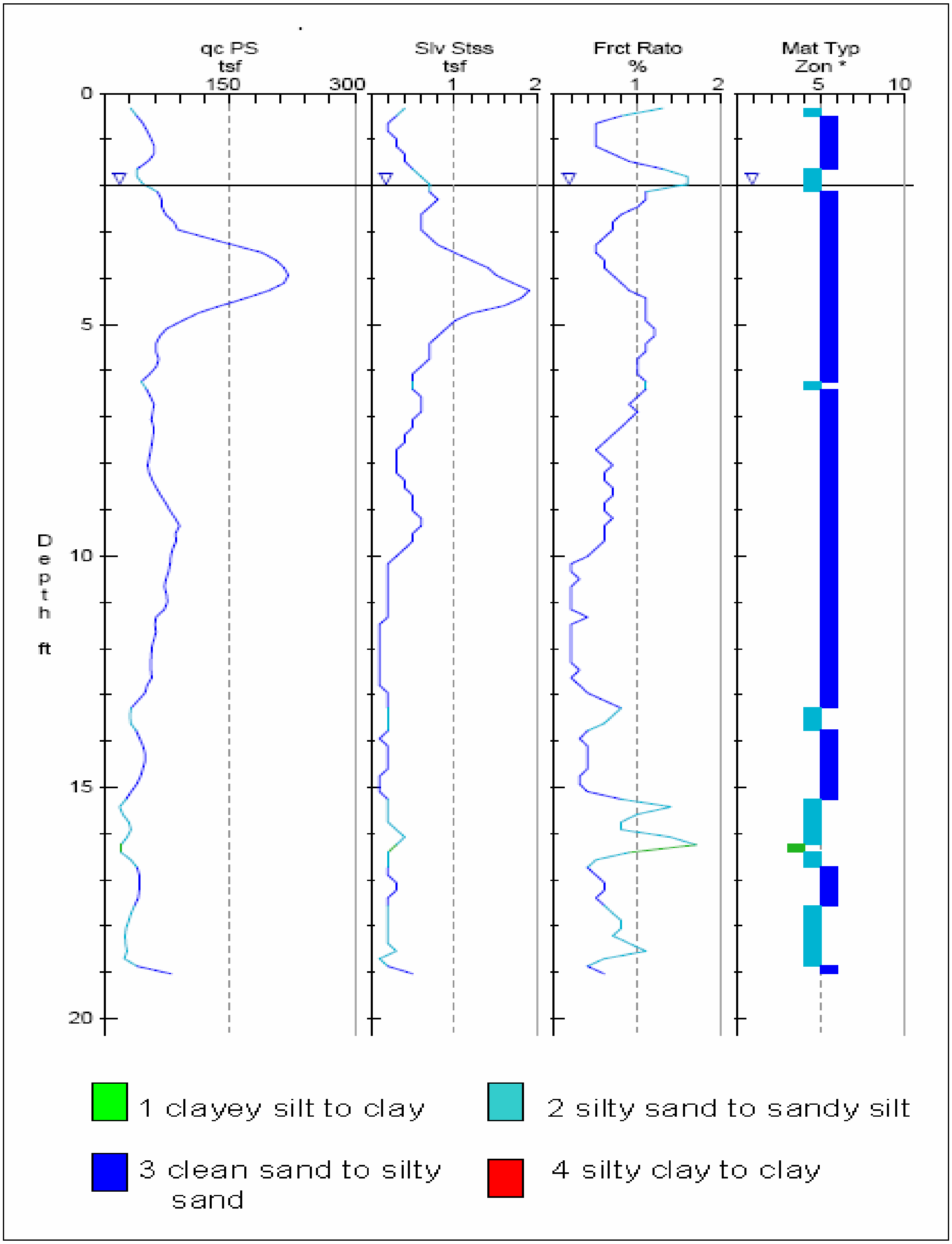
C.1.2.3 CPT 3


qc PS
tsf
150
300
Slv Stss
tsf
1
2
Frct Rato
%
1
2
Mat Typ
Zon *
5
10
0
5
10
15
20
D e p t h
ft
1 clayey silt to clay
2 silty sand to sandy silt
3 clean sand to silty sand
4 silty clay to clay

C.1.2.4 CPT 4

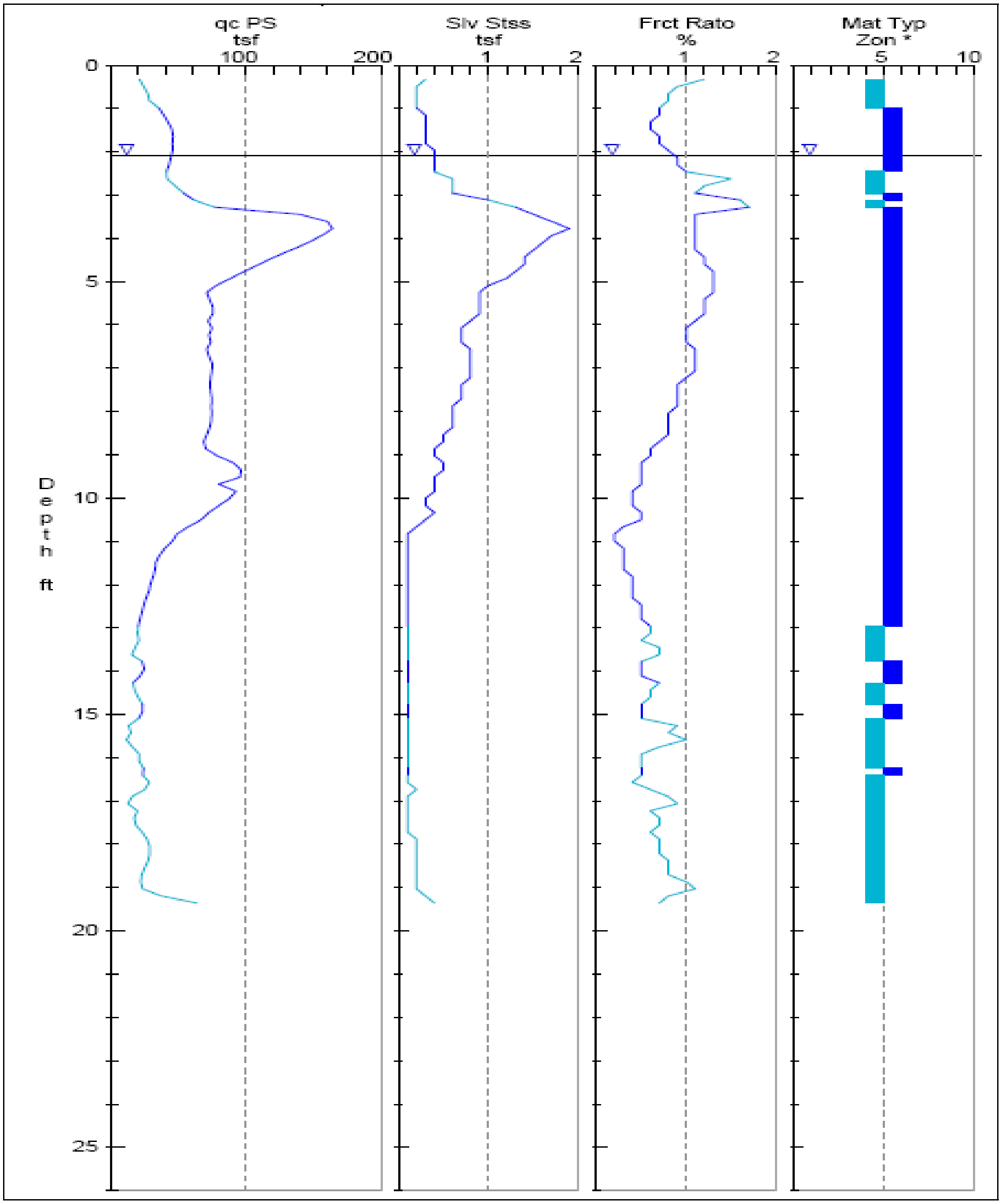

qc PS
tsf
100
200
Slv Stss
tsf
.5
1
Frct Rato
%
1
2
Mat Typ
Zon *
5
10
0
5
10
15
20
Depth
ft
1 clayey silt to clay
2 silty sand to sandy silt
3 clean sand to silty sand
4 silty clay to clay

C.1.2.5 CPT 5



qc PS
tsf
150
300
Slv Stss
tsf
1
2
Frct Rato
%
1
2
Mat Typ
Zon *
5
10
0
5
10
15
20
Depth
ft
1 clayey silt to clay
2 silty sand to sandy silt
3 clean sand to silty sand
4 silty clay to clay

C.1.2.6 CPT 6

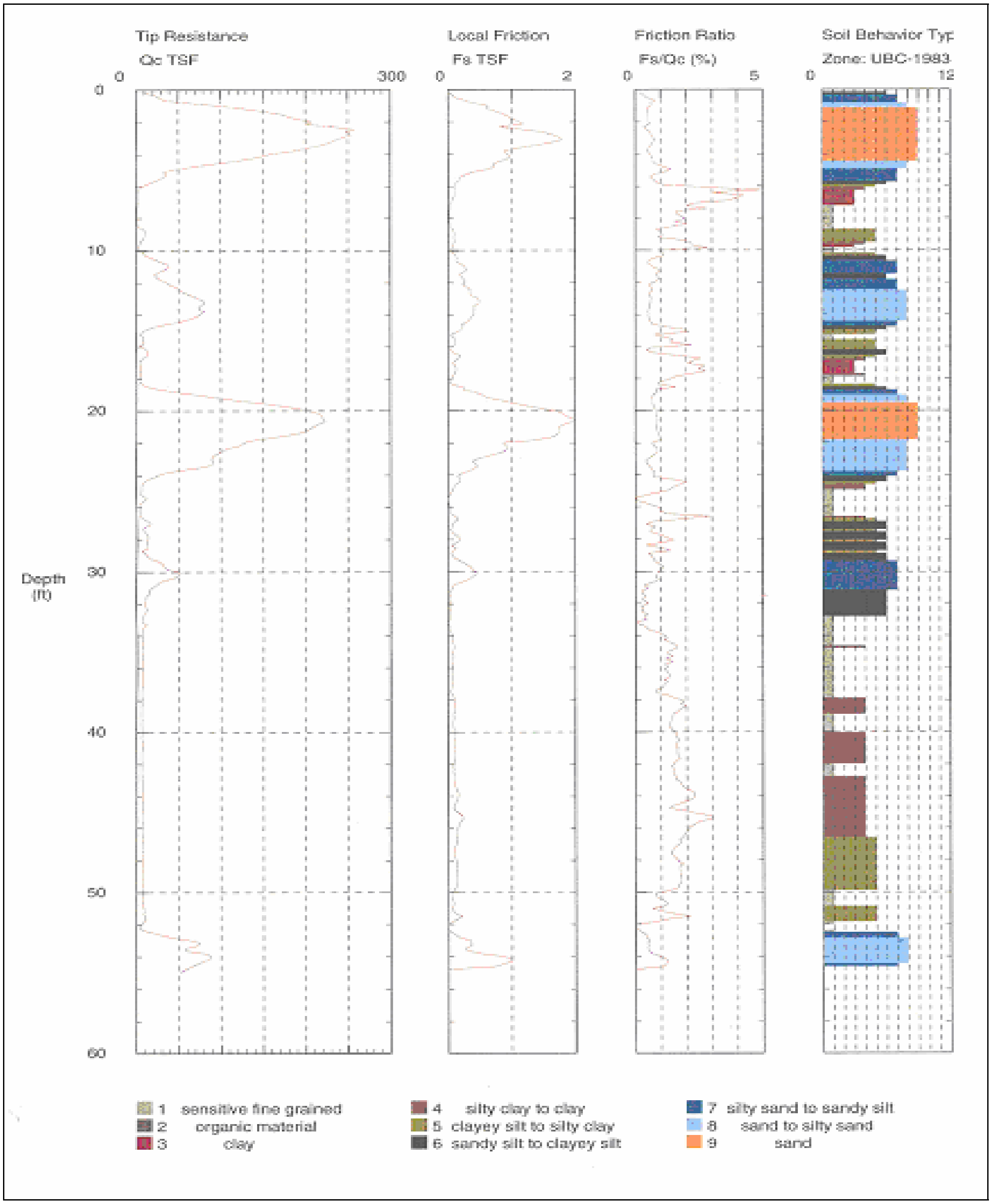


qc PS
tsf
100
200
Slv Stss
tsf
1
2
Frct Rato
%
1
2
Mat Typ
Zon *
5
10
0
5
10
15
20
25
D e p t h
ft

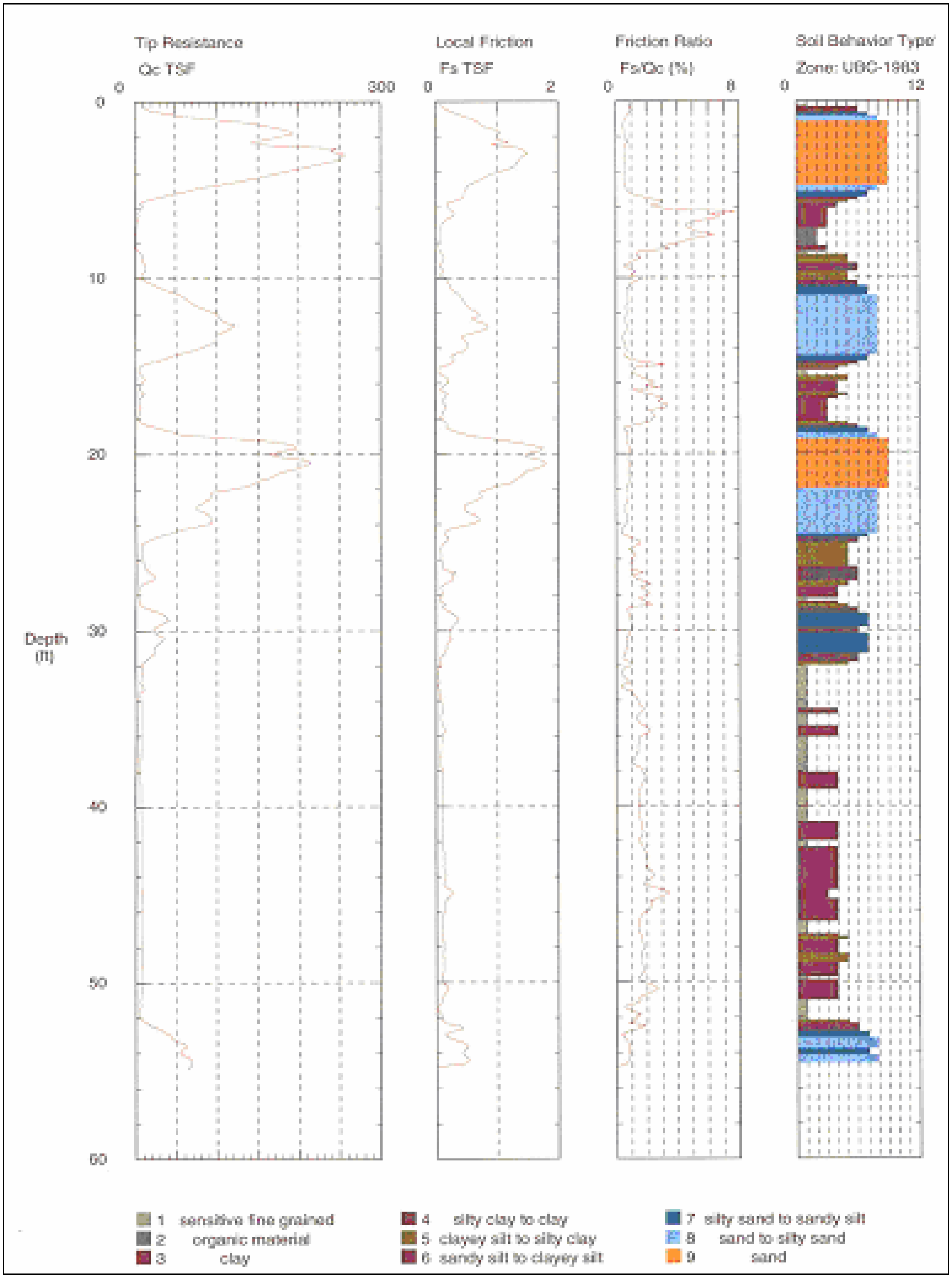
C.2 Puerto Del Rio Test Site

C.2.1 S. Sundaram

C.2.1.1 CPT 1

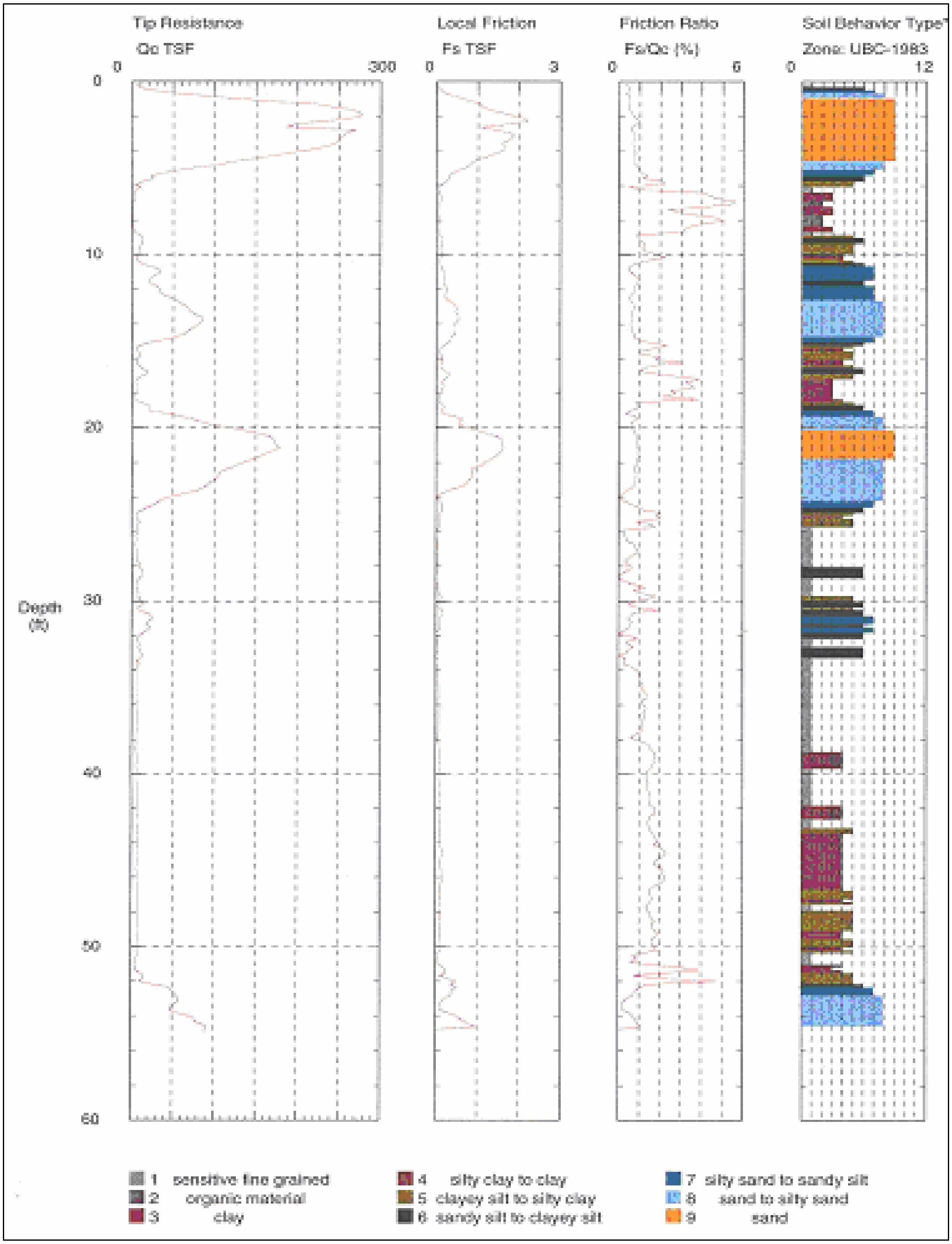


C.2.1.2 CPT 2



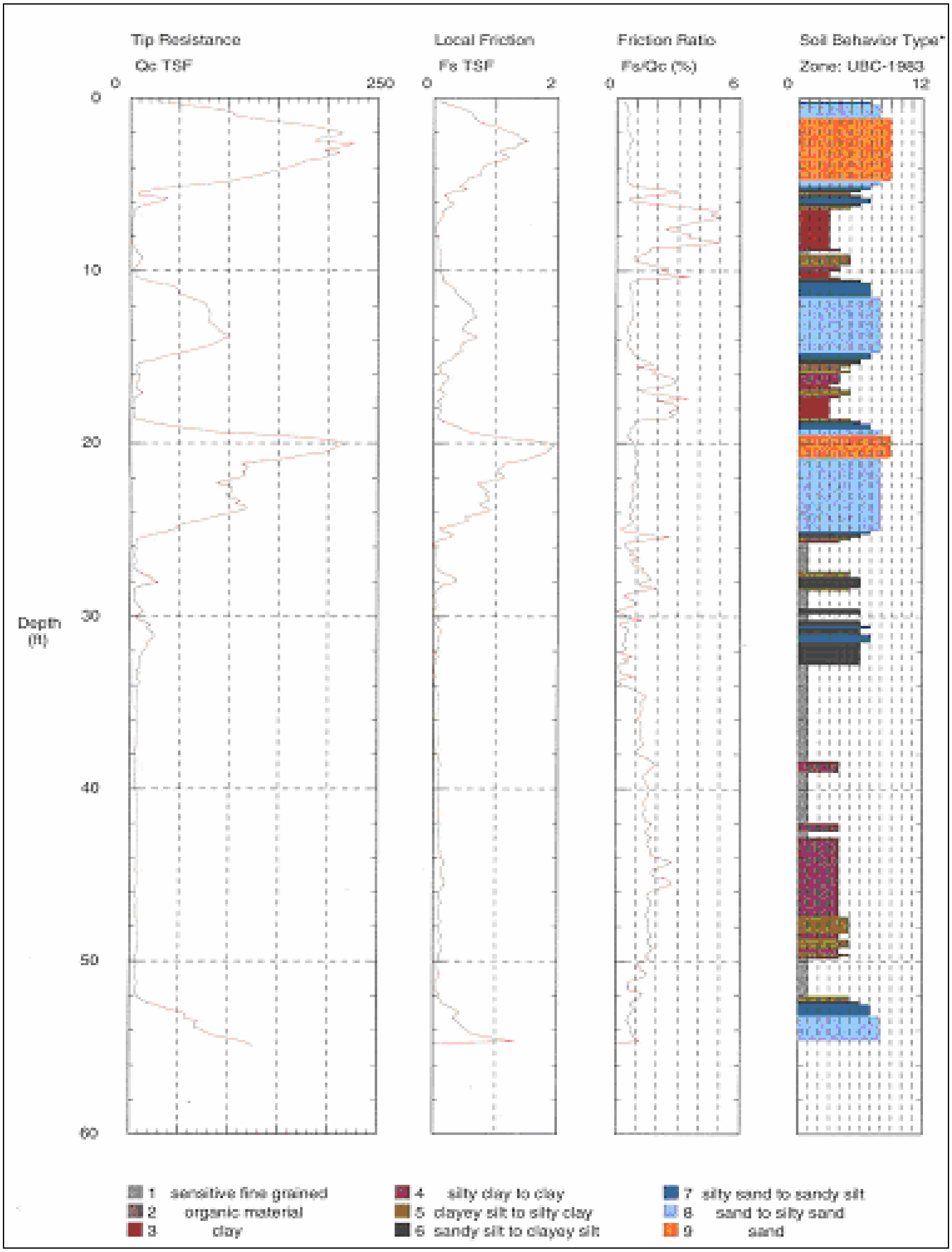
Tip Resistance
Qc TSF
0
300
Local Friction
Fs TSF
0
2
Friction Ratio
Fs/Qc (%)
0
8
Soil Behavior Type
Zone: UBC-1983
0
12
0
10
20
30
40
50
60
Depth
(ft)
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand

C.2.1.3 CPT 3



Tip Resistance
Qc TSF
Local Friction
Fs TSF
Friction Ratio
Fs/Qc (%)
Soil Behavior Type*
Zone: UBC-1983
Depth
(ft)
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand

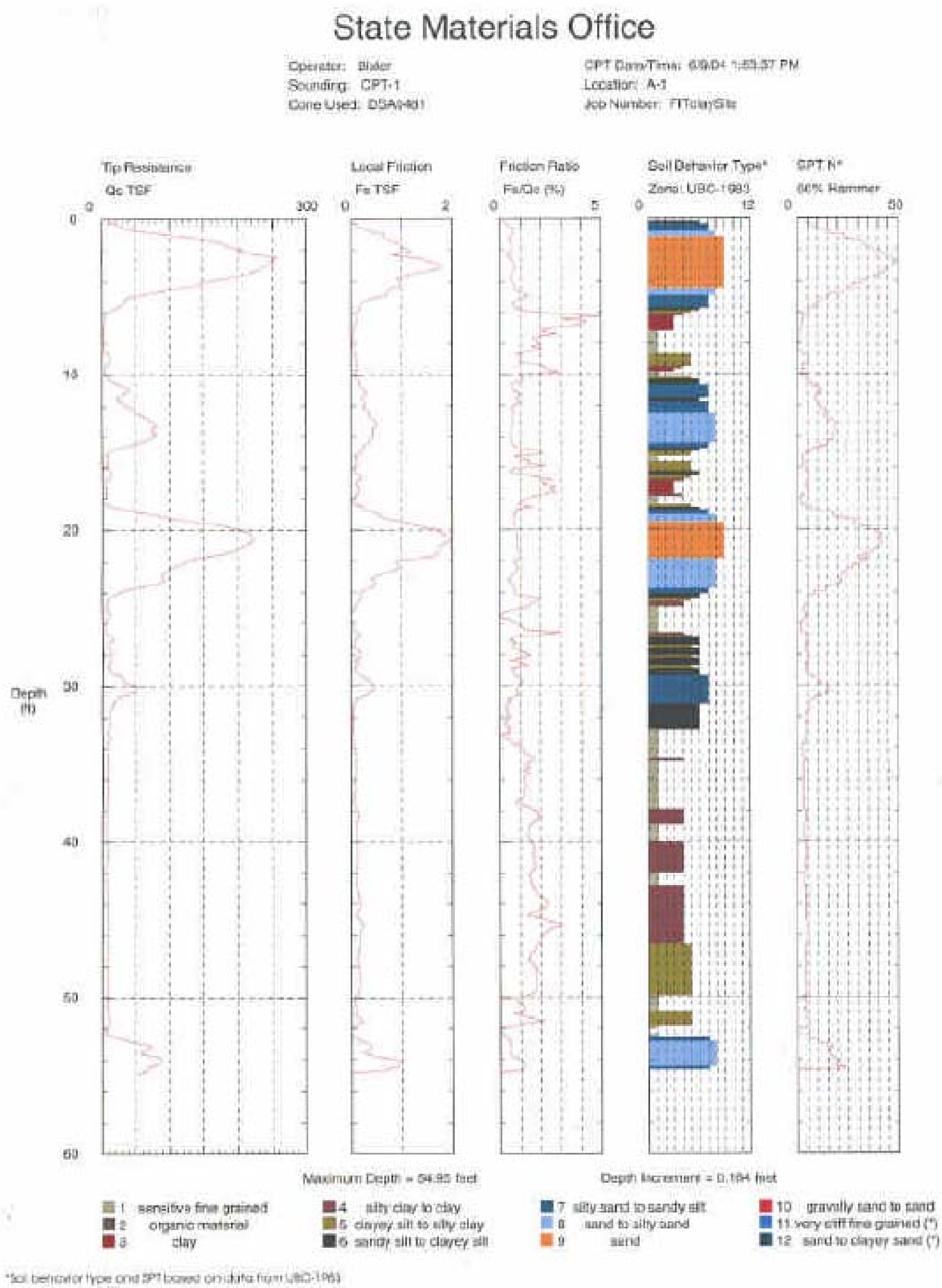
C.2.1.4 CPT 4



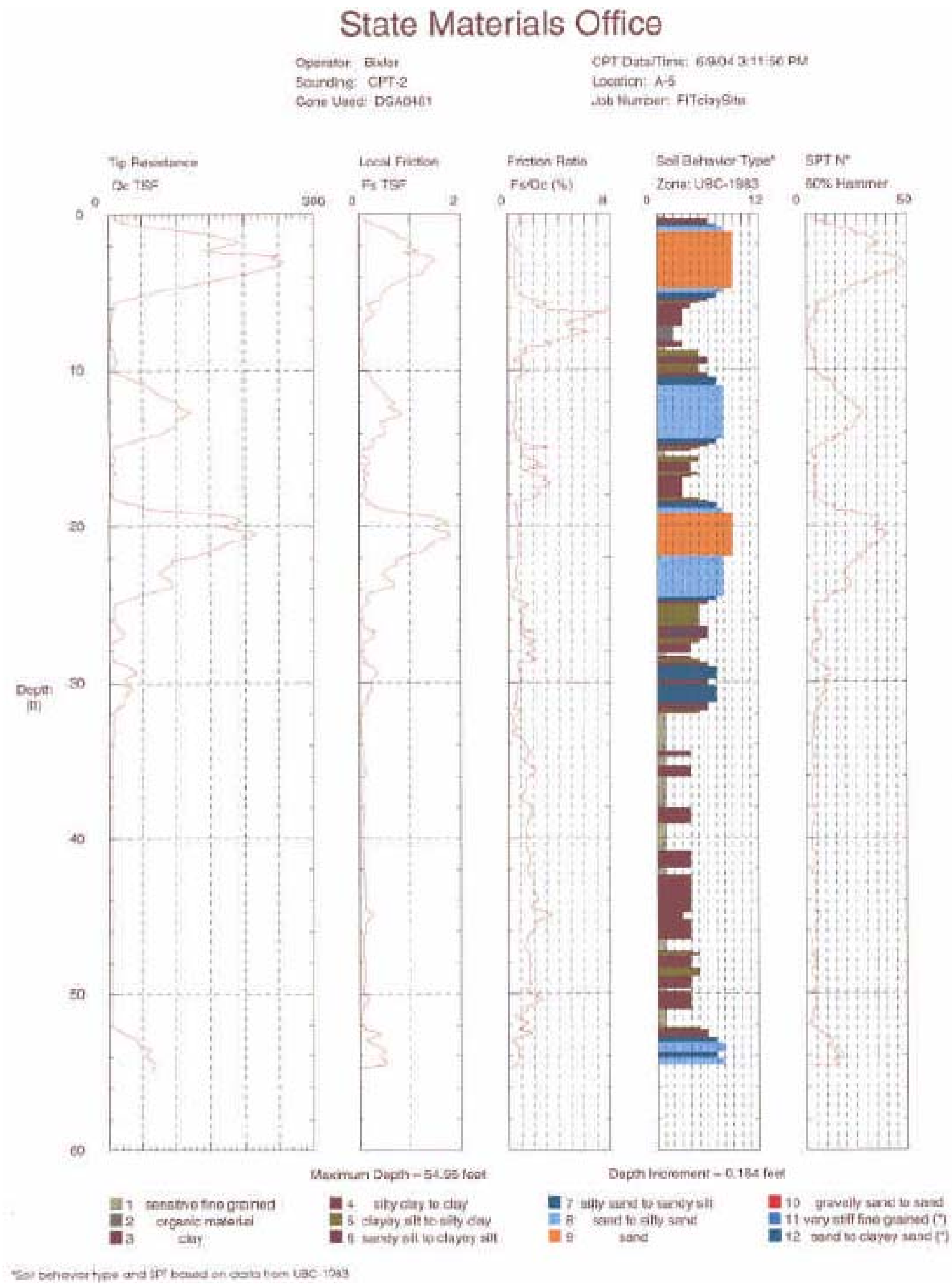
Tip Resistance
Qc TSF
0
250
Local Friction
Fs TSF
0
2
Friction Ratio
Fs/Qc (%)
0
6
Soil Behavior Type*
Zone: UBC-1983
0
12
Depth (ft)
0
10
20
30
40
50
60
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand

C.2.2 F. Messaoud

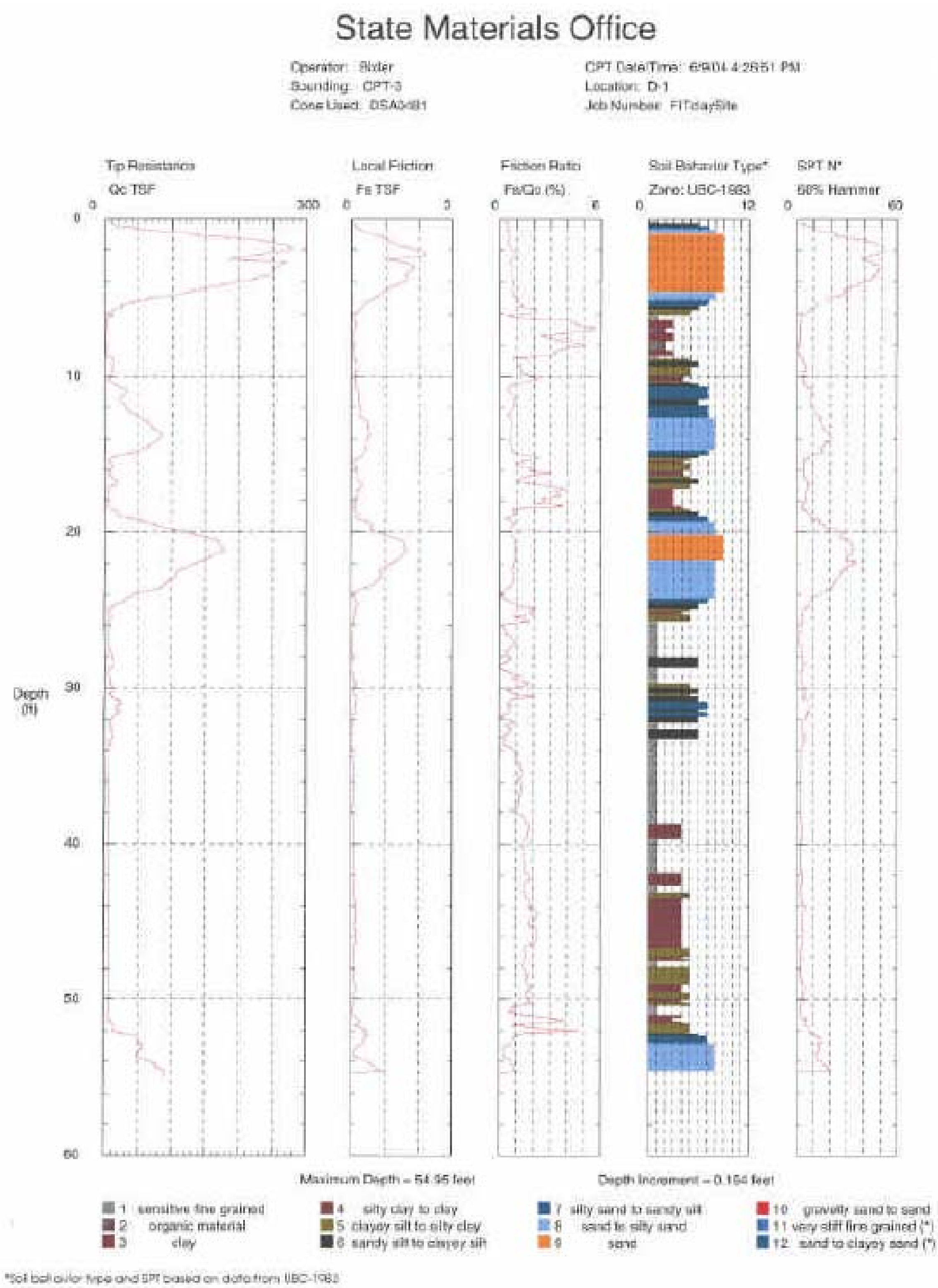
C.2.2.1 CPT A-1



C.2.2.2 CPT A-5

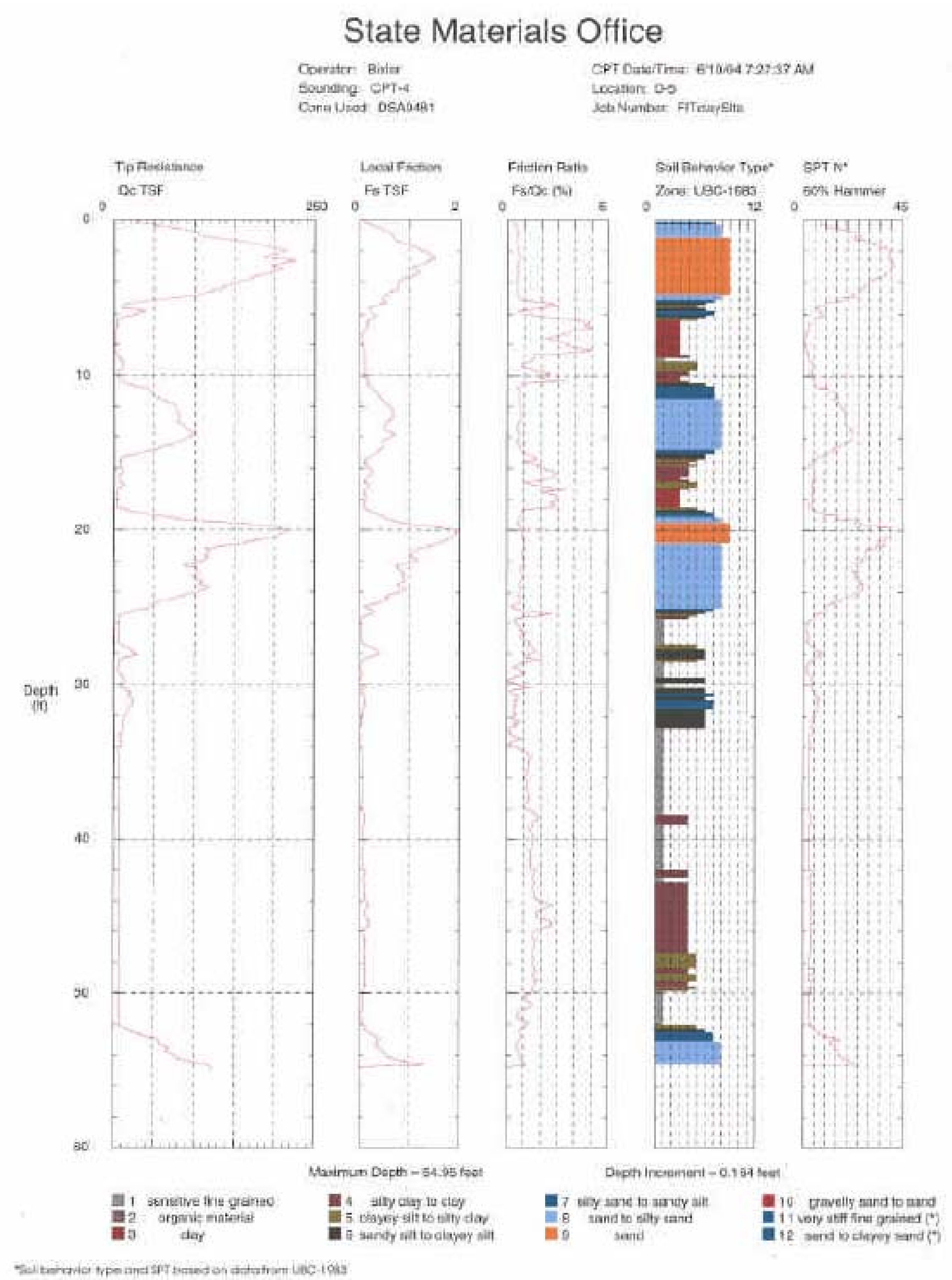

State Materials Office
Operator: Bixler
Sounding: CPT-2
Cone Used: DSA0401
CPT Date/Time: 6/9/04 3:11:56 PM
Location: A-5
Job Number: FITclaySite
Tip Resistance
Qc TSF
Local Friction
Fs TSF
Friction Ratio
Fs/Qc (%)
Soil Behavior Type*
Zone: UBC-1983
SPT N*
60% Hammer
Depth
(ft)
Maximum Depth = 54.95 feet
Depth Increment = 0.164 feet
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)
*Soil behavior type and SPT based on data from UBC-1983

C.2.2.3 CPT D-1



State Materials Office
Operator: Bixler
Sounding: CPT-3
Cone Used: DSA0481
CPT Date/Time: 6/9/04 4:26:51 PM
Location: D-1
Job Number: FITclaySite
Tip Resistance
Qc TSF
Local Friction
Fs TSF
Friction Ratio
Fs/Qc (%)
Soil Behavior Type*
Zone: UBC-1983
SPT N*
60% Hammer
Depth (ft)
Maximum Depth = 54.95 feet
Depth Increment = 0.164 feet
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)
*Soil behavior type and SPT based on data from UBC-1983

C.2.2.4 CPT D-5

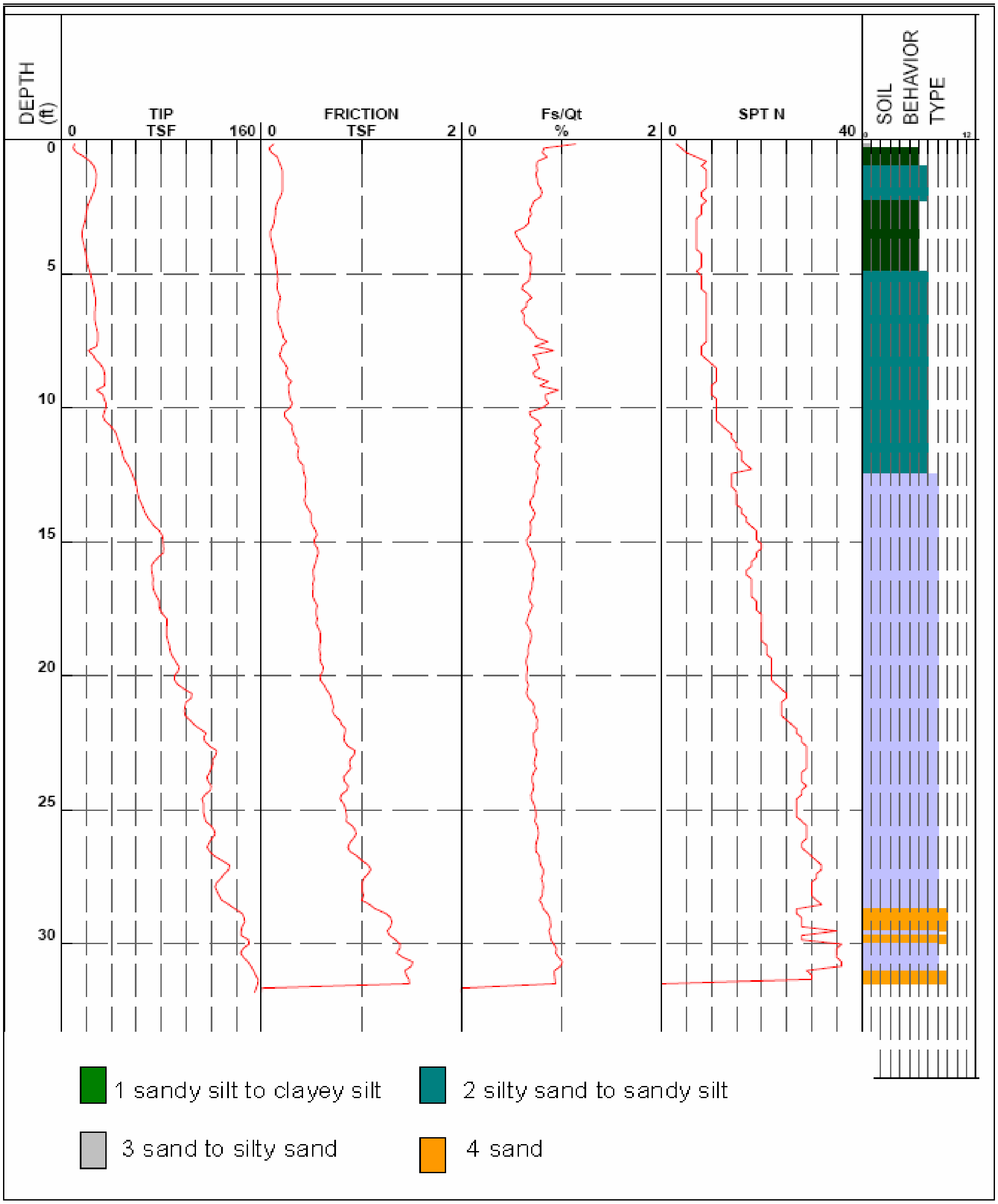


State Materials Office
Operator: Bixler
Sounding: CPT-4
Cone Used: DSA0481
CPT Date/Time: 6/10/04 7:27:37 AM
Location: D-5
Job Number: FITclaySilts
Tip Resistance
Qc TSF
Local Friction
Fs TSF
Friction Ratio
Fs/Qc (%)
Soil Behavior Type*
Zone: UBC-1983
SPT N*
60% Hammer
Depth (ft)
Maximum Depth = 54.95 feet
Depth Increment = 0.164 feet
1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)
*Soil behavior type and SPT based on data from UBC-1983

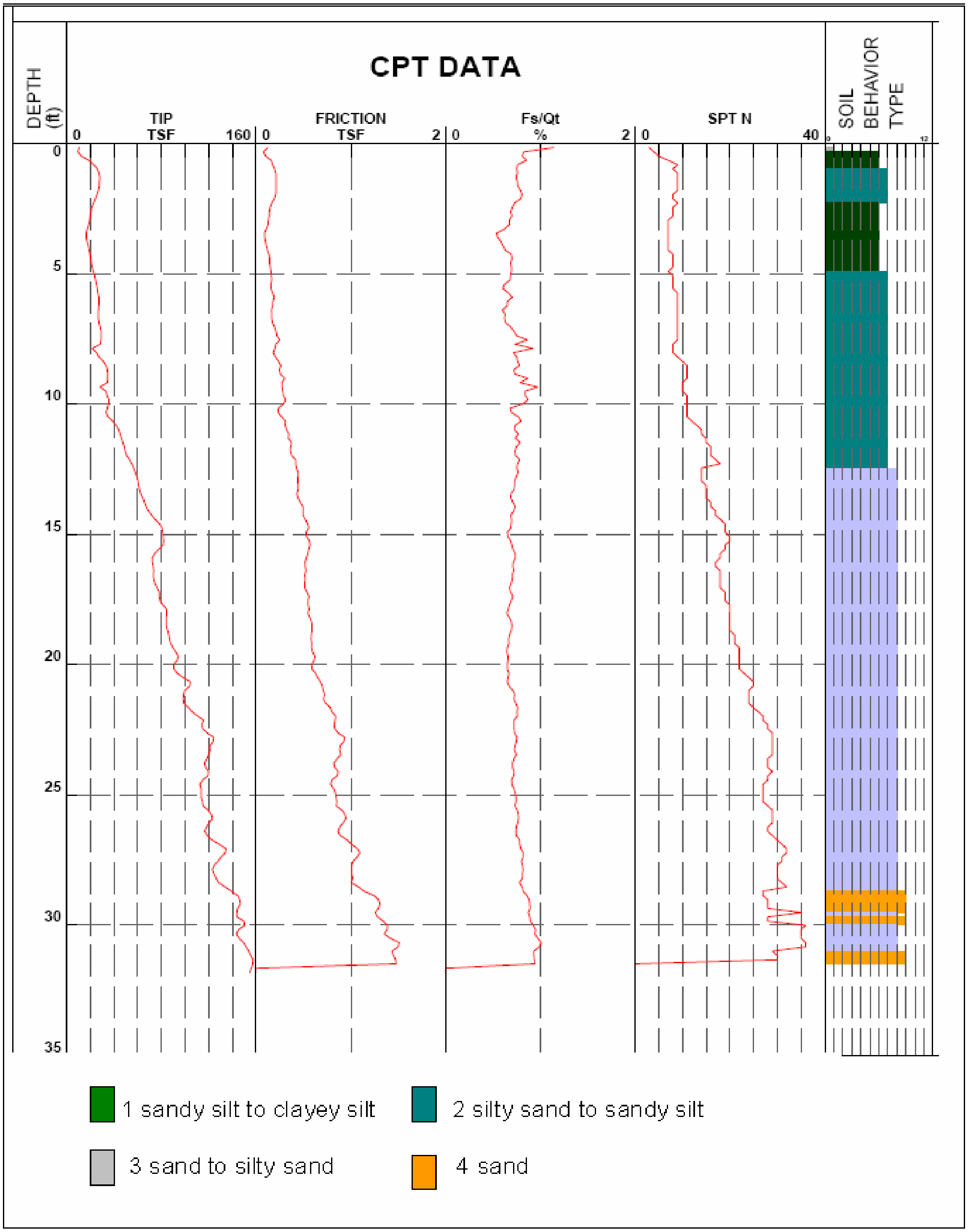
C.3 Archer Test Site

C.3.1 S. Sundaram

C.3.1.1 CPT 1



C.3.1.2 CPT 2



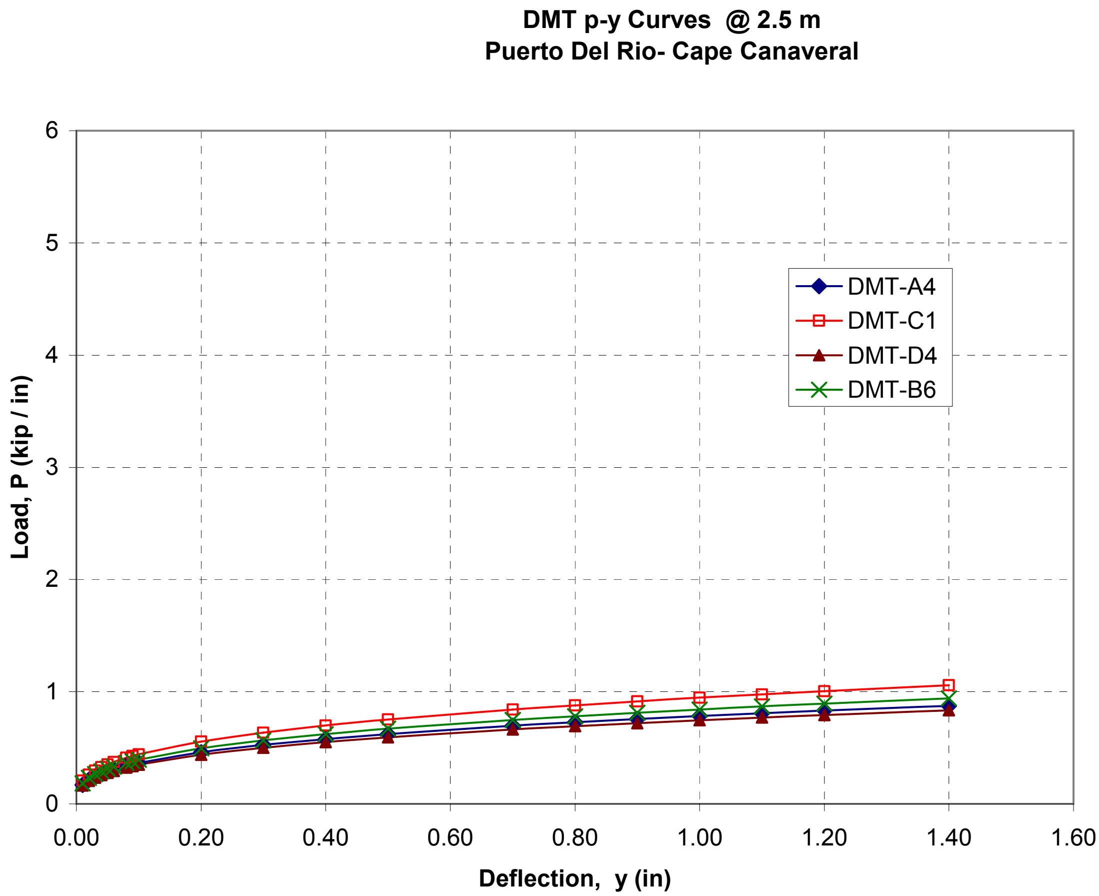
CPT DATA
DEPTH (ft)
TIP TSF
0
160
FRICTION TSF
0
2
Fs/Qt %
0
2
SPT N
0
40
SOIL BEHAVIOR TYPE
0
5
10
15
20
25
30
35
1 sandy silt to clayey silt
2 silty sand to sandy silt
3 sand to silty sand
4 sand

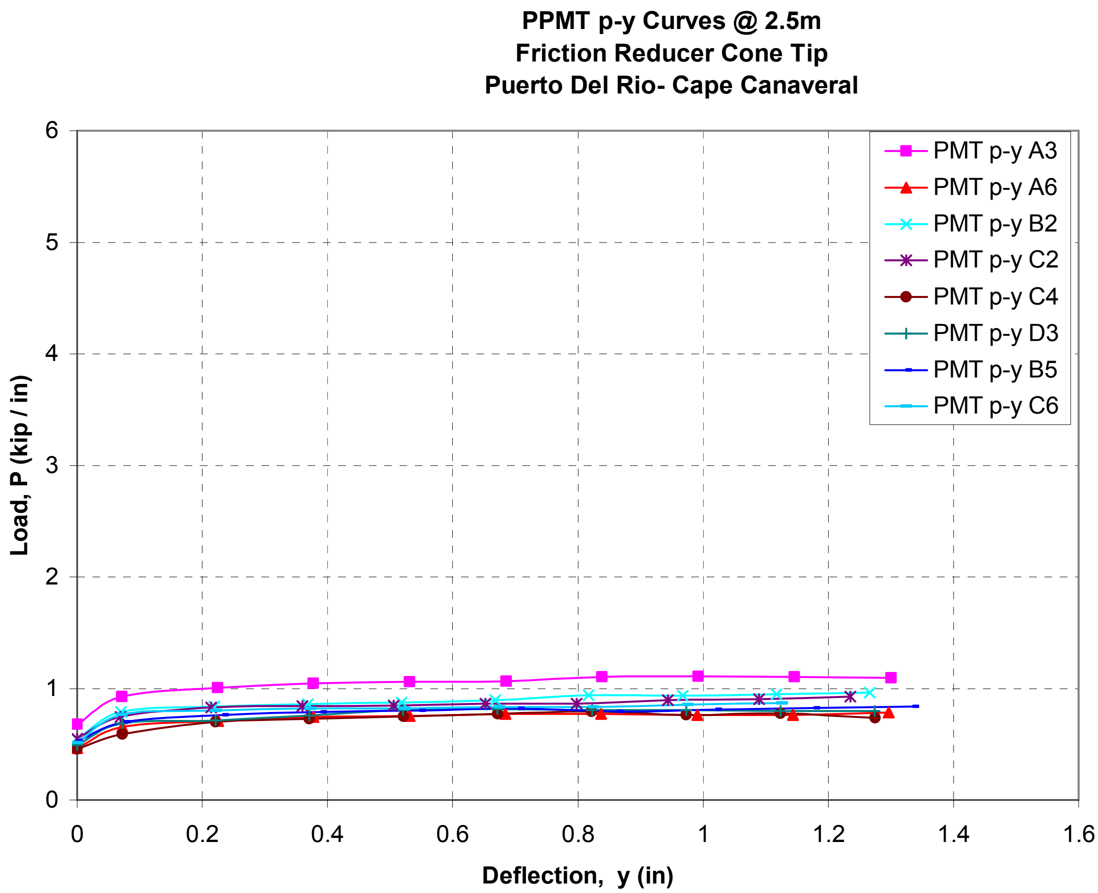
D Appendix D P–Y CURVES

D.1 PPMT and DMT p-y Curves from Puerto Del Rio Field Site

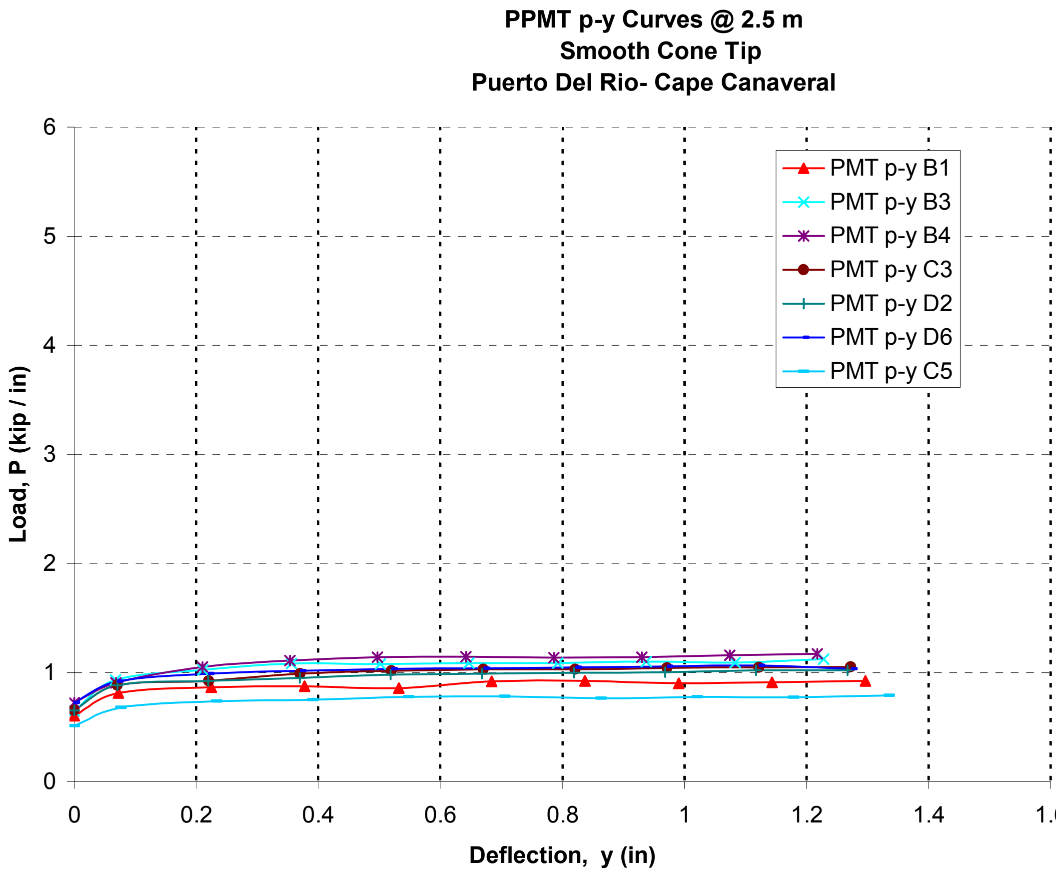
D.1.1 F. Messaoud

D.1.1.1 2.5 meters

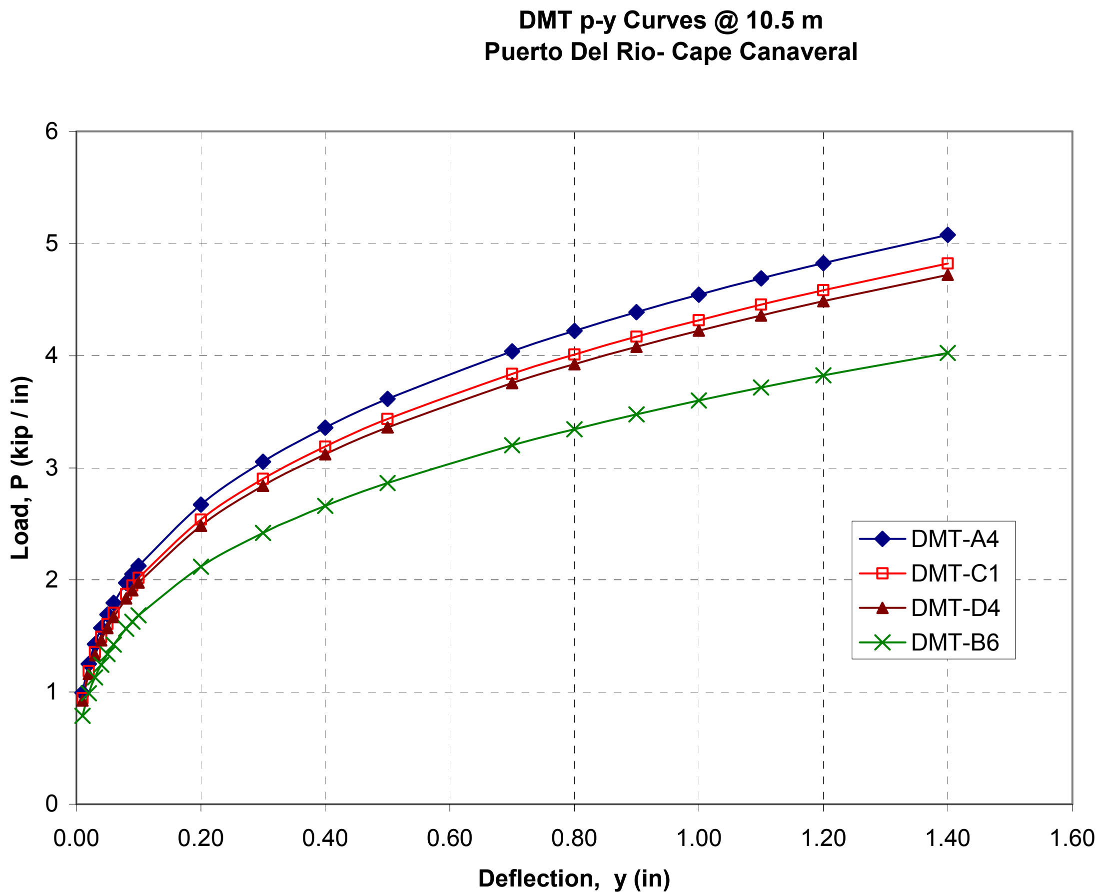


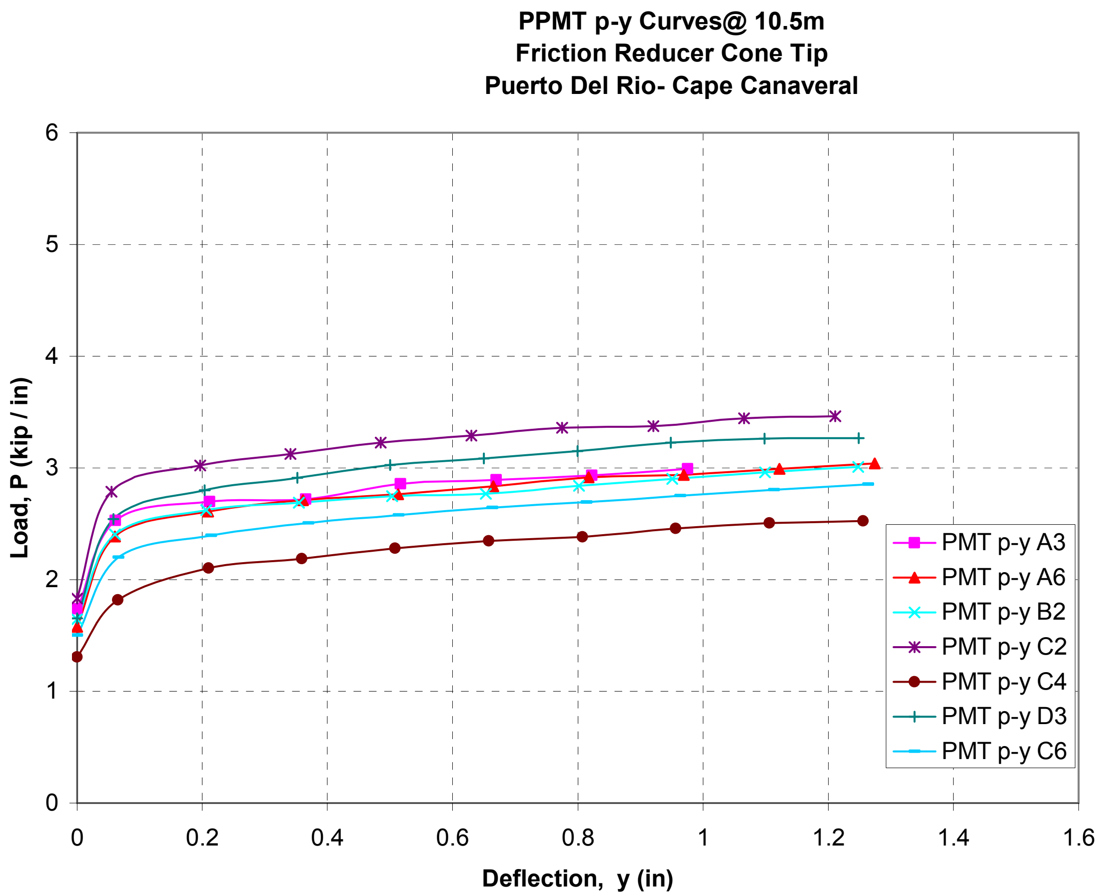


PPMT p-y Curves @ 2.5m
Friction Reducer Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y A3
PMT p-y A6
PMT p-y B2
PMT p-y C2
PMT p-y C4
PMT p-y D3
PMT p-y B5
PMT p-y C6

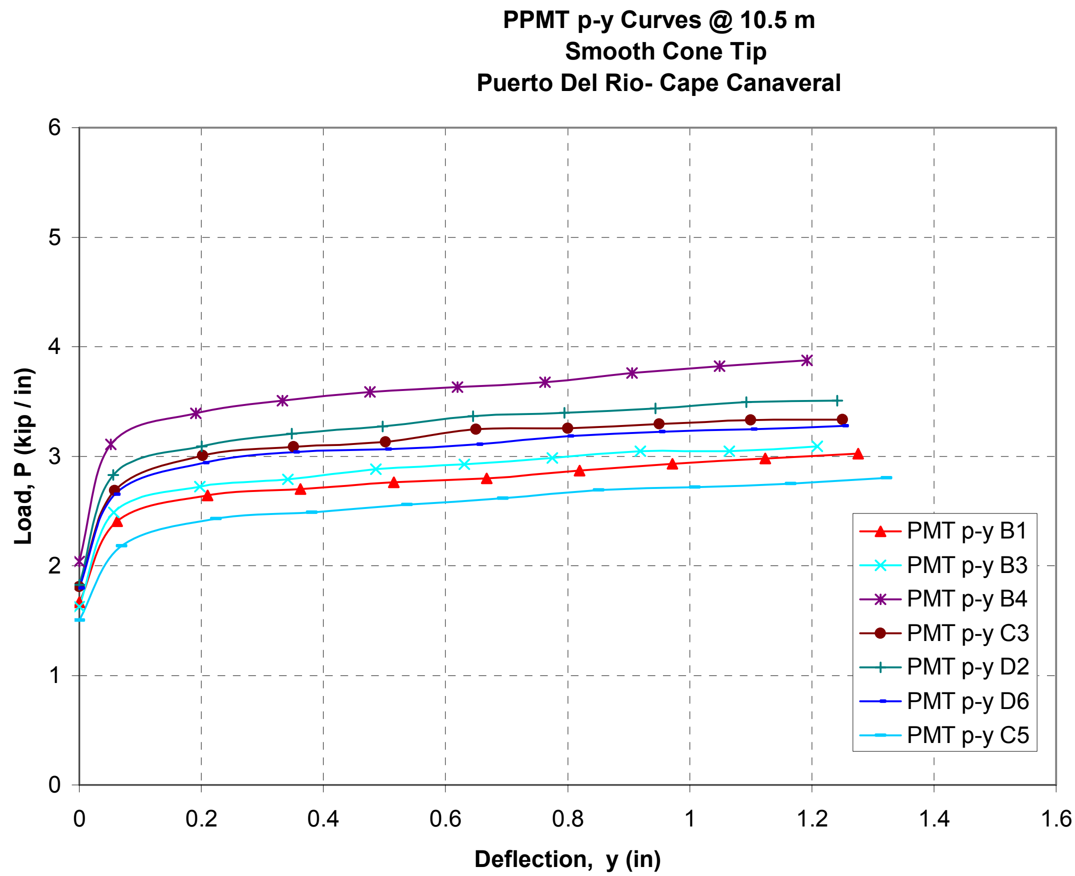

PPMT p-y Curves @ 2.5 m
Smooth Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
PMT p-y B1
PMT p-y B3
PMT p-y B4
PMT p-y C3
PMT p-y D2
PMT p-y D6
PMT p-y C5
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

D.1.1.2 10.5 meters

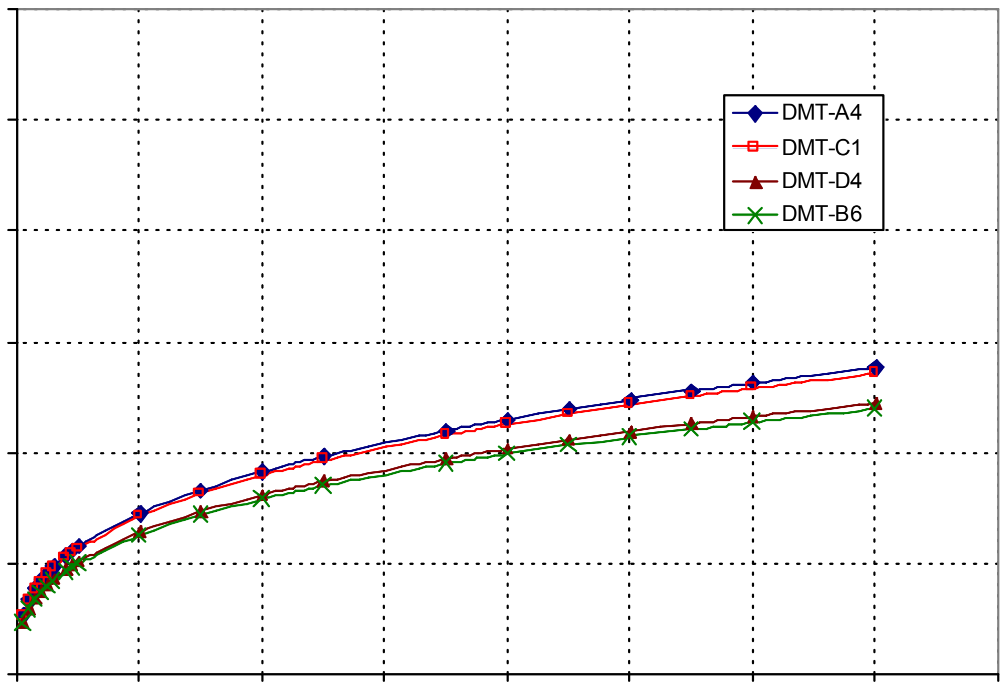


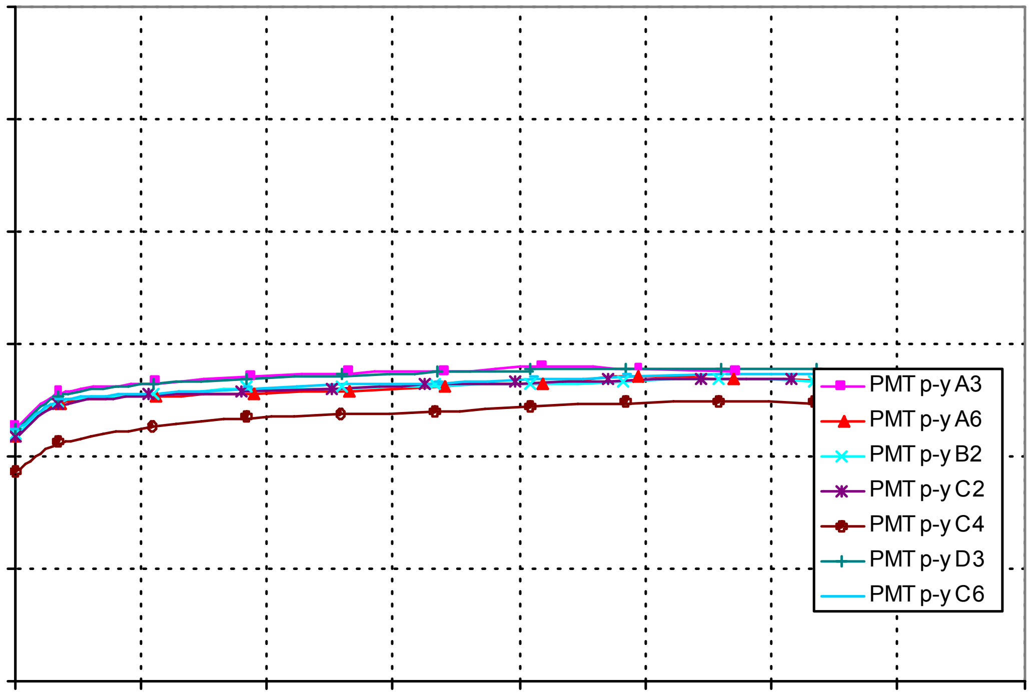


PPMT p-y Curves@ 10.5m
Friction Reducer Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y A3
PMT p-y A6
PMT p-y B2
PMT p-y C2
PMT p-y C4
PMT p-y D3
PMT p-y C6

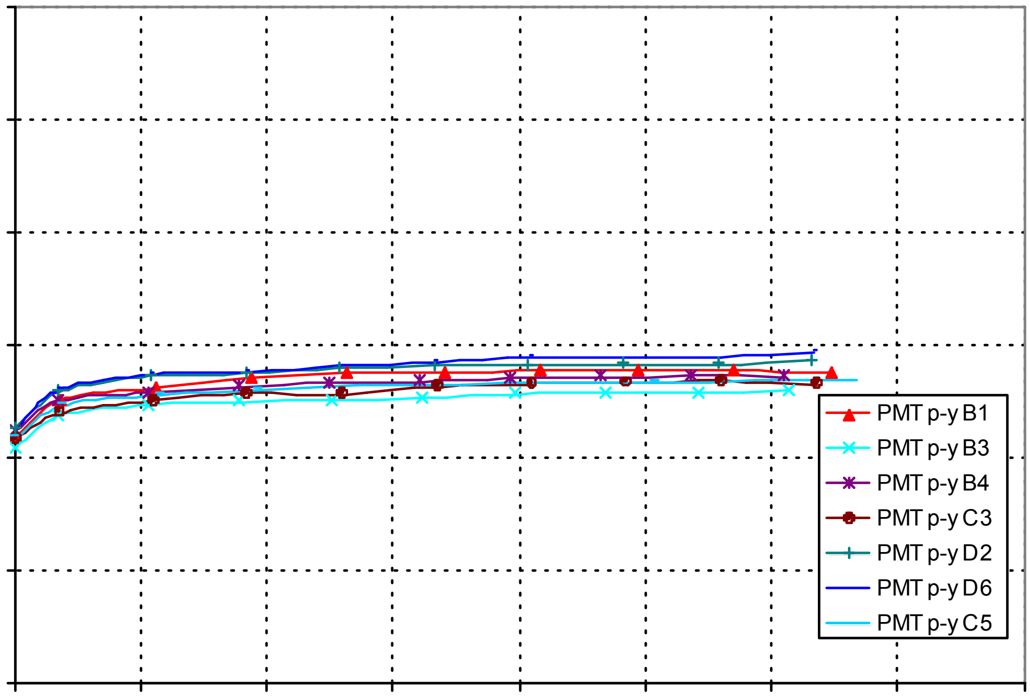

PPMT p-y Curves @ 10.5 m
Smooth Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y B1
PMT p-y B3
PMT p-y B4
PMT p-y C3
PMT p-y D2
PMT p-y D6
PMT p-y C5

D.1.1.3 12 meters



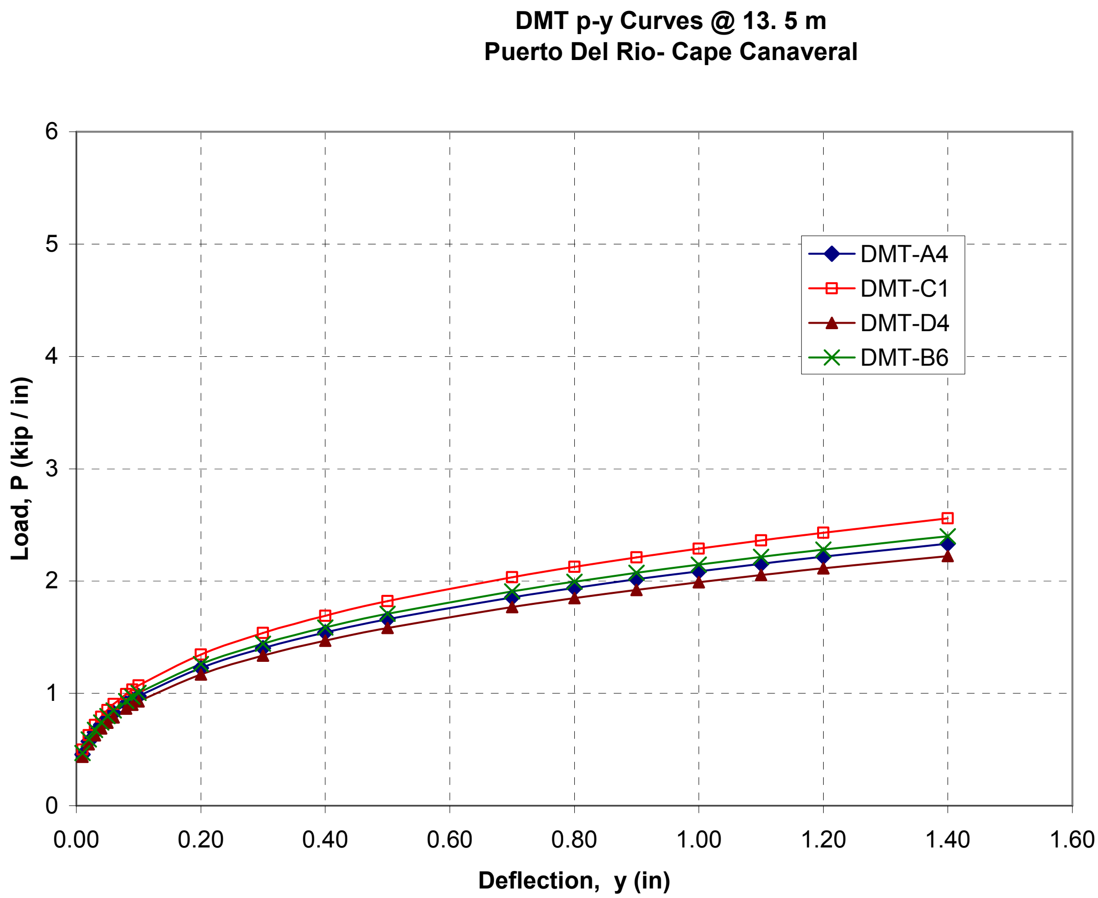


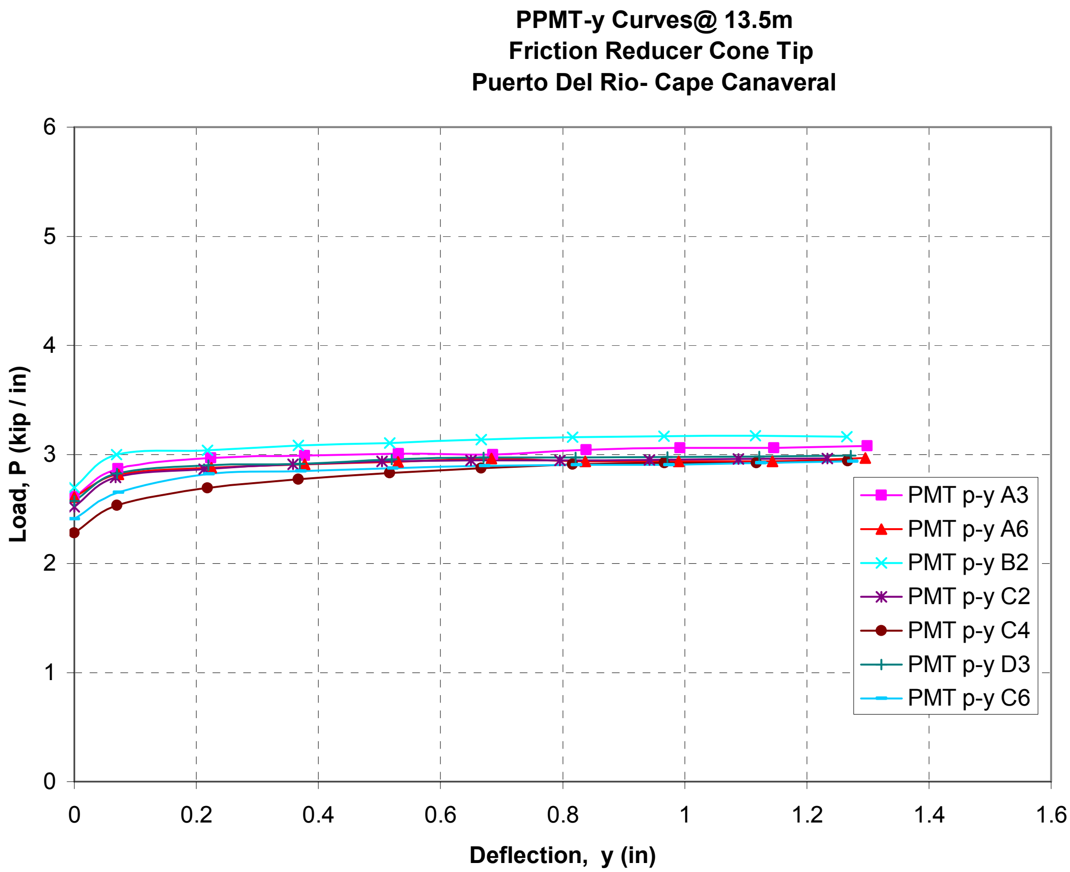
PMT p-y A3
PMT p-y A6
PMT p-y B2
PMT p-y C2
PMT p-y C4
PMT p-y D3
PMT p-y C6

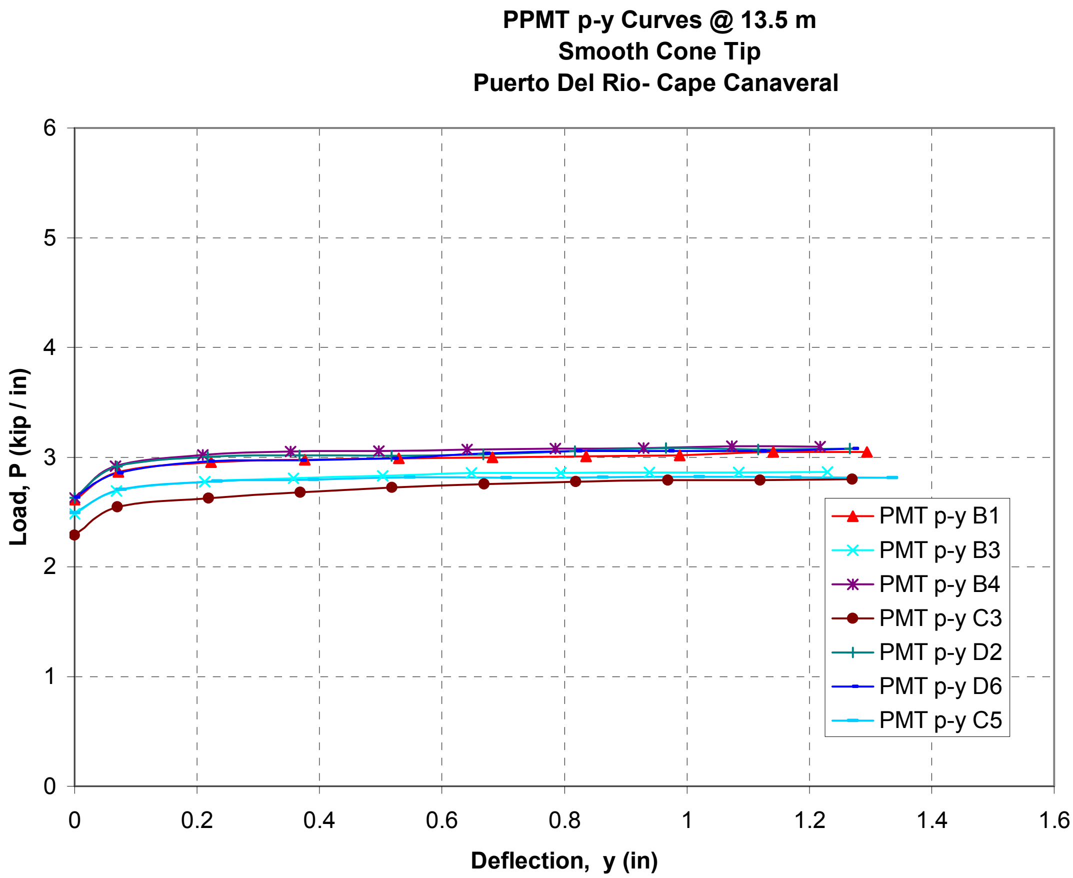


PMT p-y B1
PMT p-y B3
PMT p-y B4
PMT p-y C3
PMT p-y D2
PMT p-y D6
PMT p-y C5

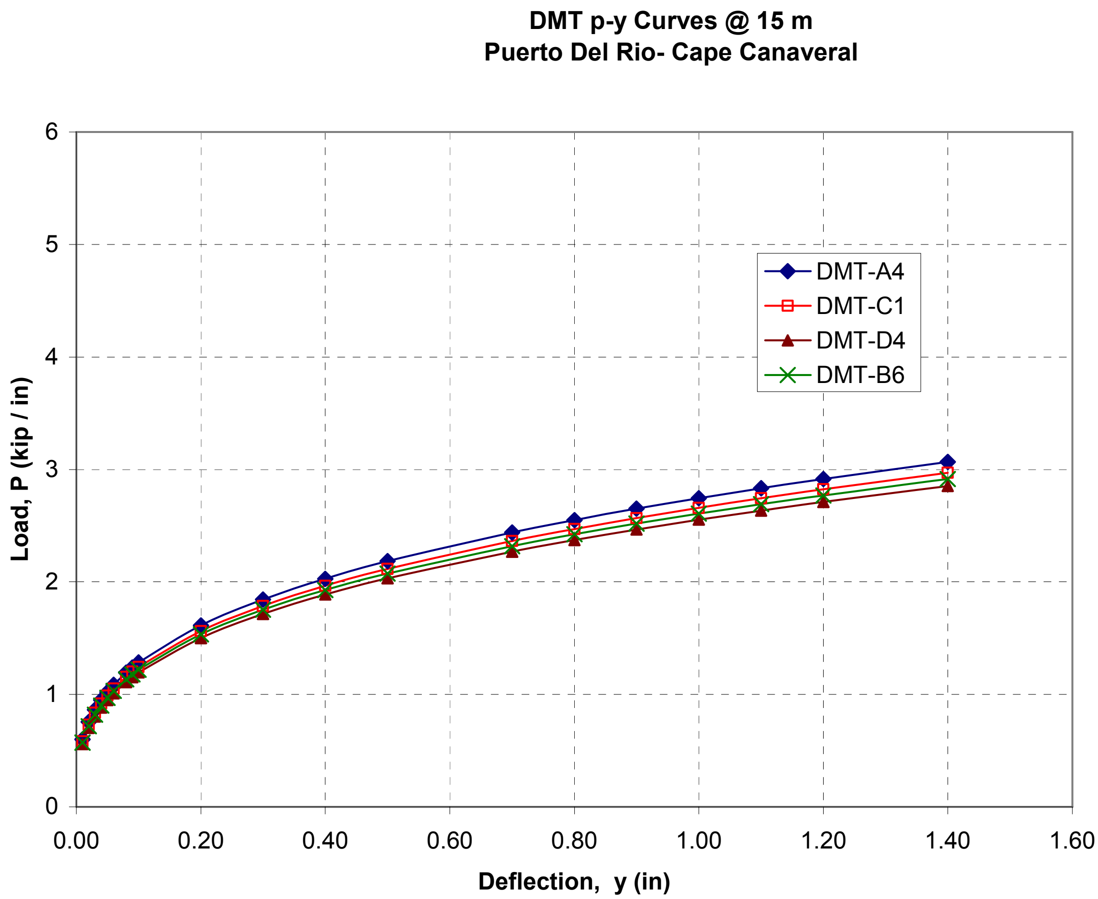
D.1.1.4 13.5 meters

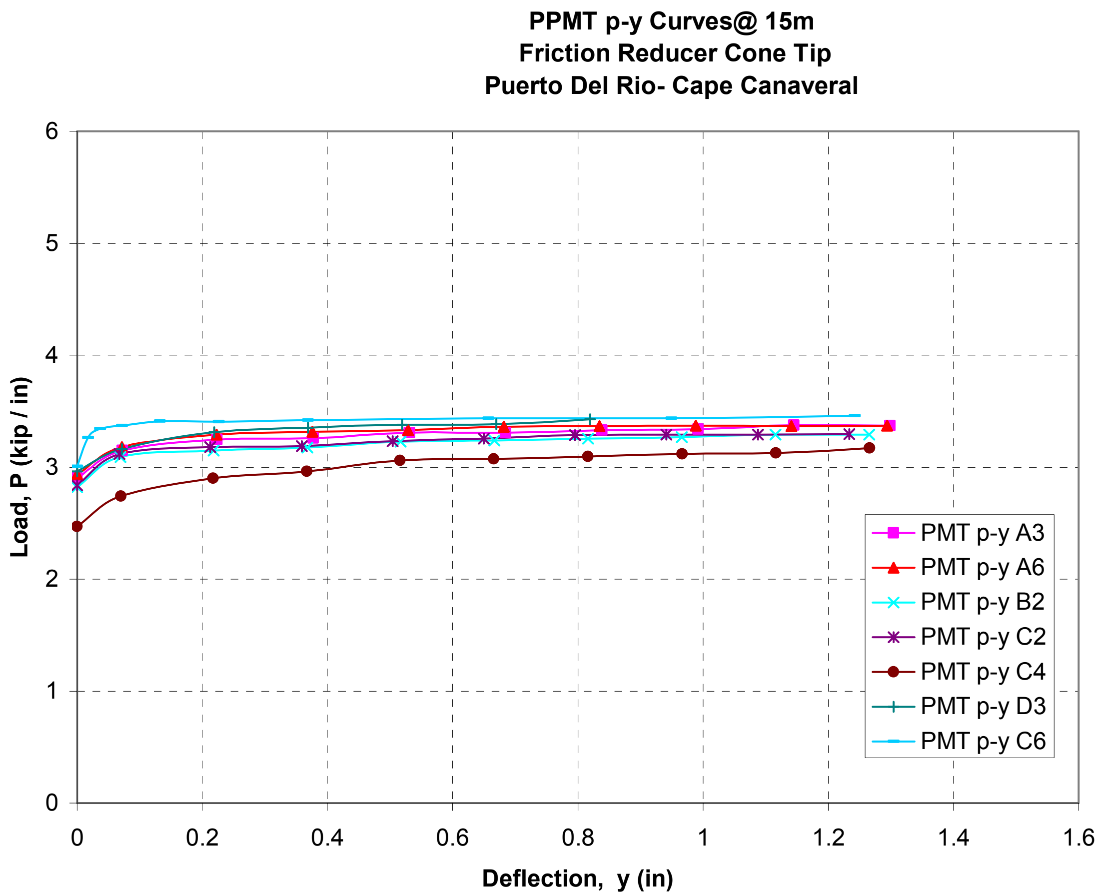


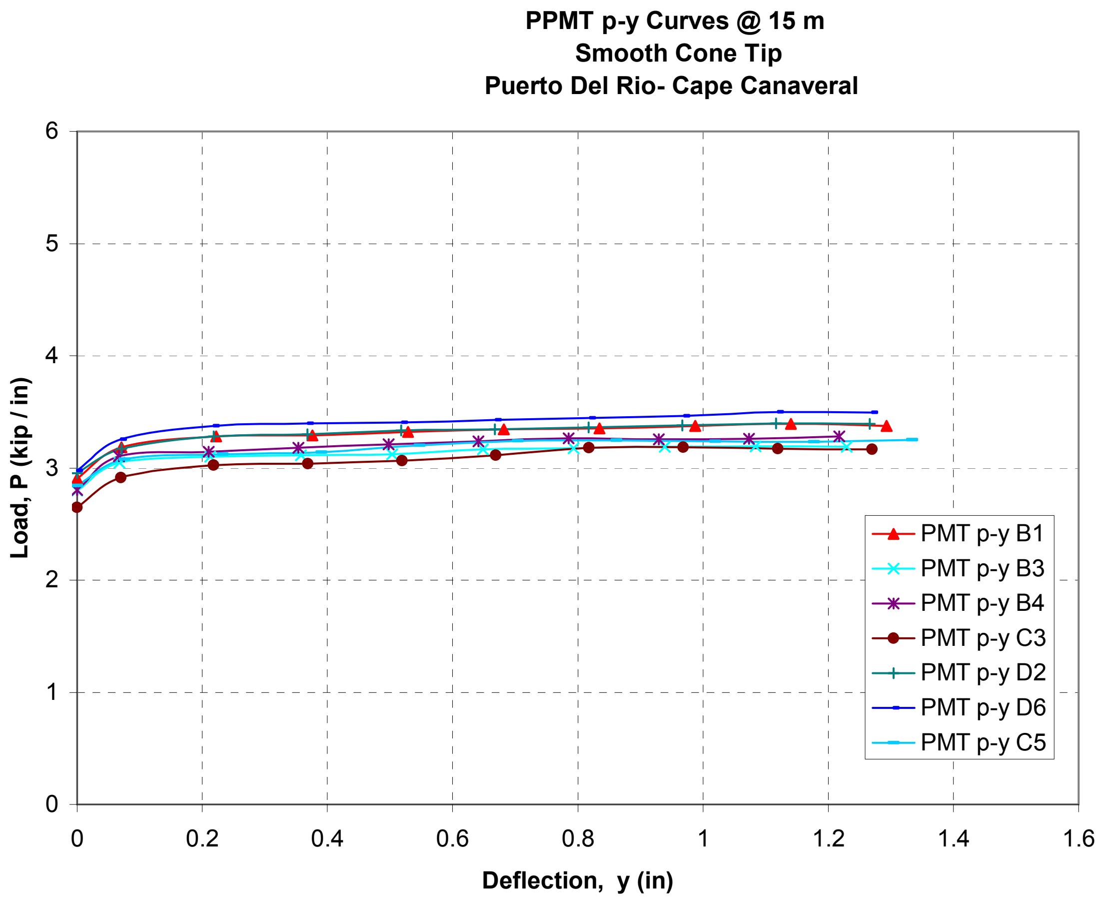

PPMT-y Curves@ 13.5m
Friction Reducer Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y A3
PMT p-y A6
PMT p-y B2
PMT p-y C2
PMT p-y C4
PMT p-y D3
PMT p-y C6


PPMT p-y Curves @ 13.5 m
Smooth Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y B1
PMT p-y B3
PMT p-y B4
PMT p-y C3
PMT p-y D2
PMT p-y D6
PMT p-y C5

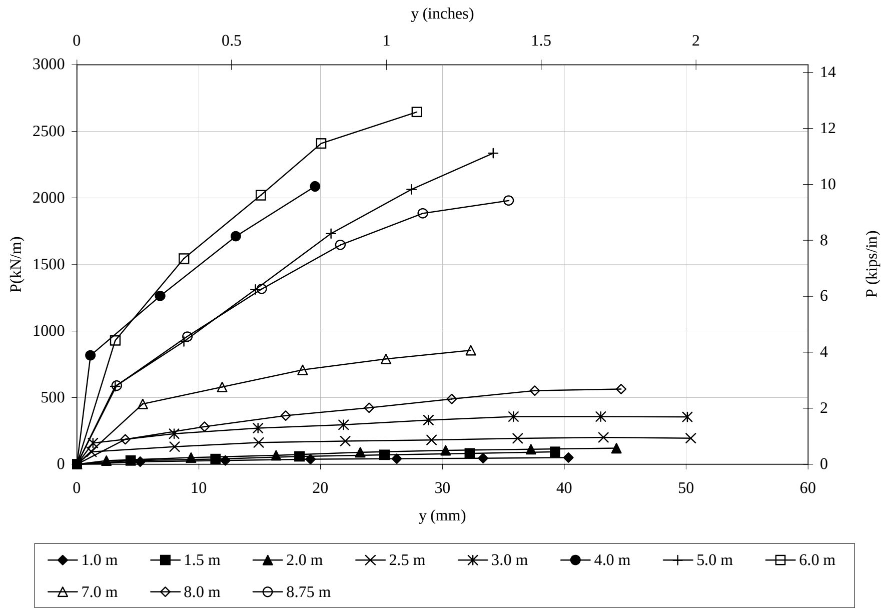
D.1.1.5 15 meters



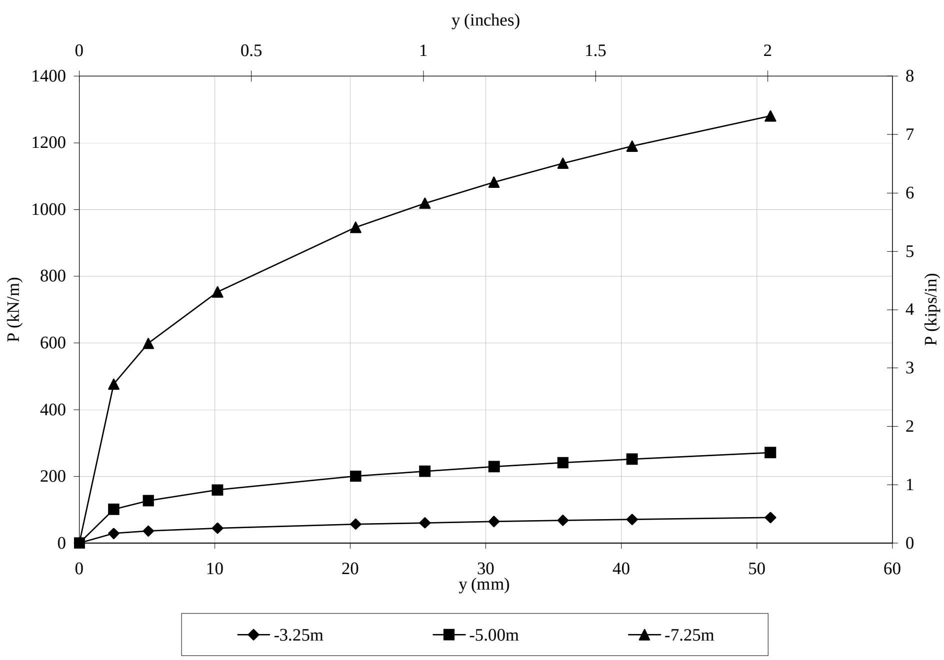

PPMT p-y Curves@ 15m
Friction Reducer Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y A3
PMT p-y A6
PMT p-y B2
PMT p-y C2
PMT p-y C4
PMT p-y D3
PMT p-y C6


PPMT p-y Curves @ 15 m
Smooth Cone Tip
Puerto Del Rio- Cape Canaveral
Load, P (kip / in)
Deflection, y (in)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PMT p-y B1
PMT p-y B3
PMT p-y B4
PMT p-y C3
PMT p-y D2
PMT p-y D6
PMT p-y C5

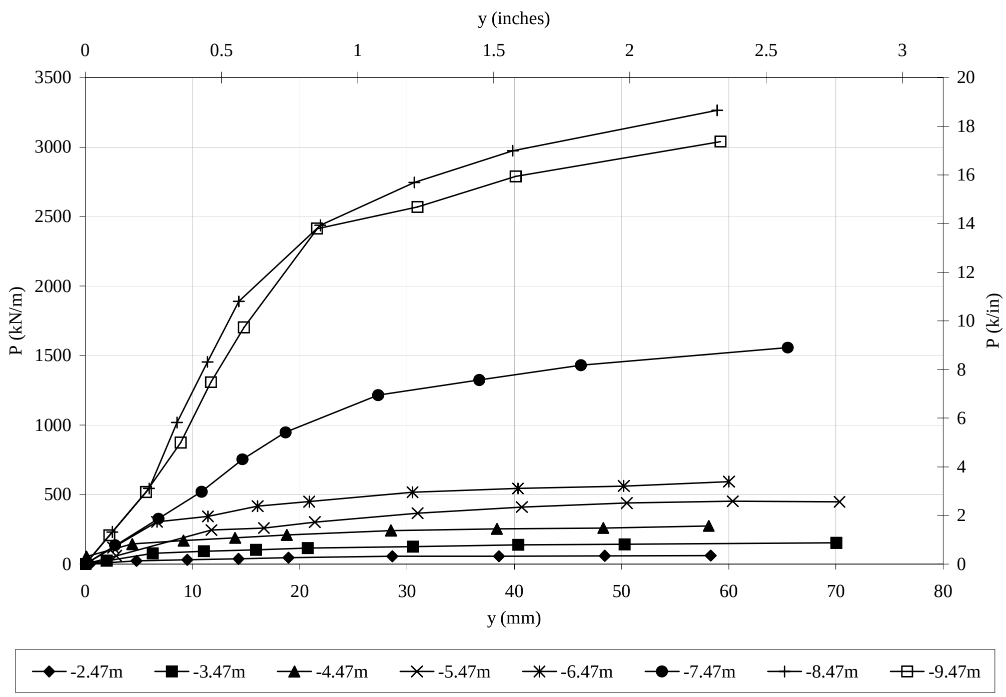
D.2 University of North Carolina Charlotte Case Histories



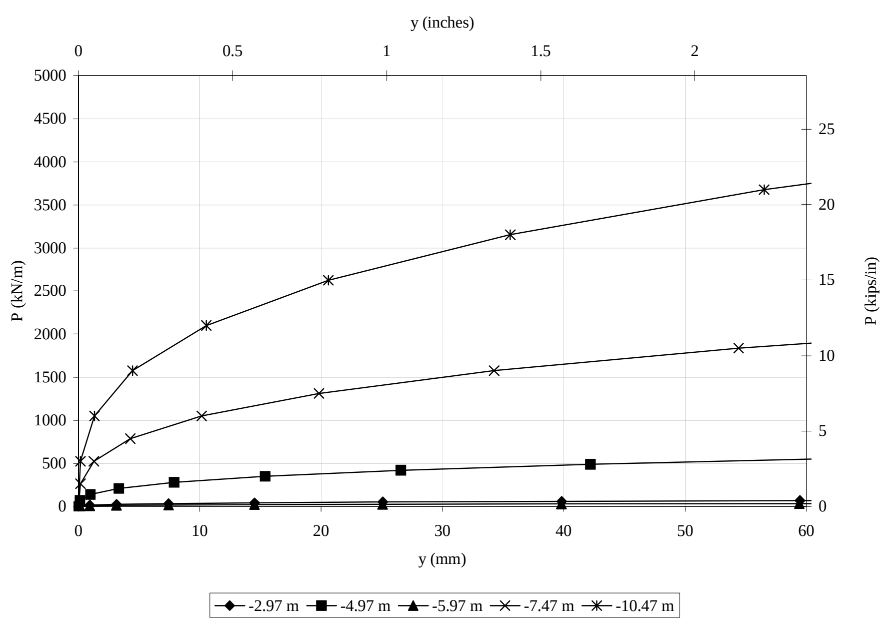
D.2.1 Roosevelt Bridge p-y curves from PPMT data



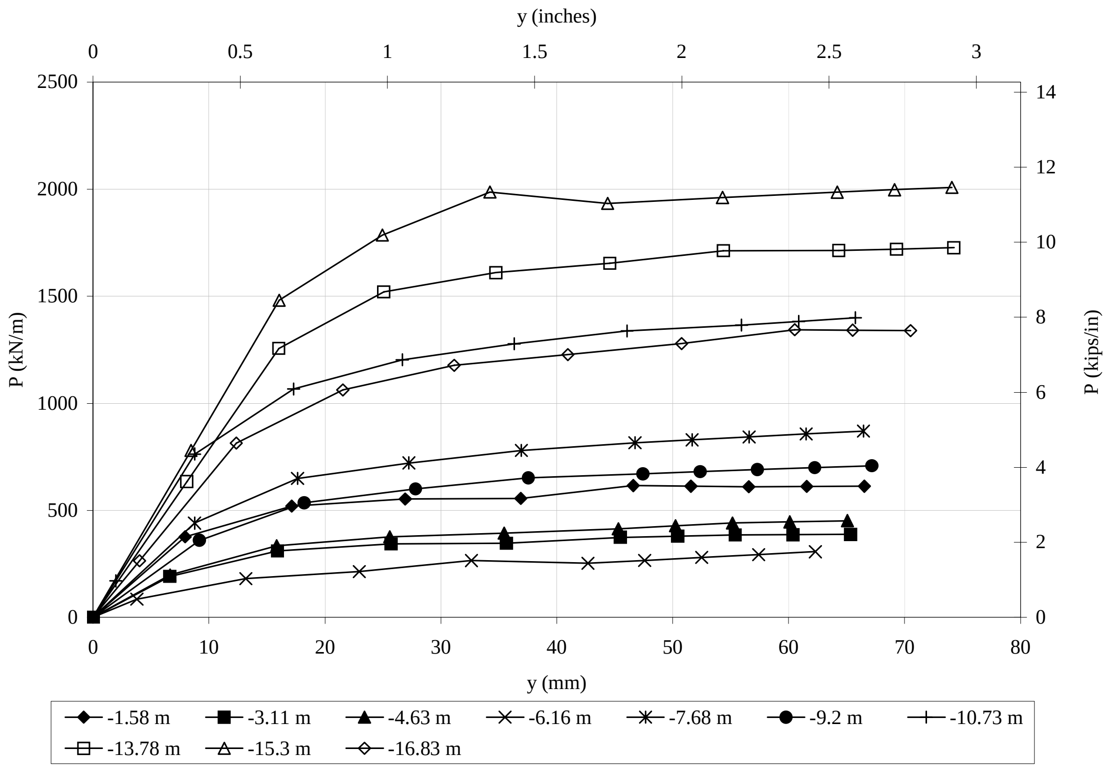
D.2.2 Roosevelt Bridge p-y curves from DMT data



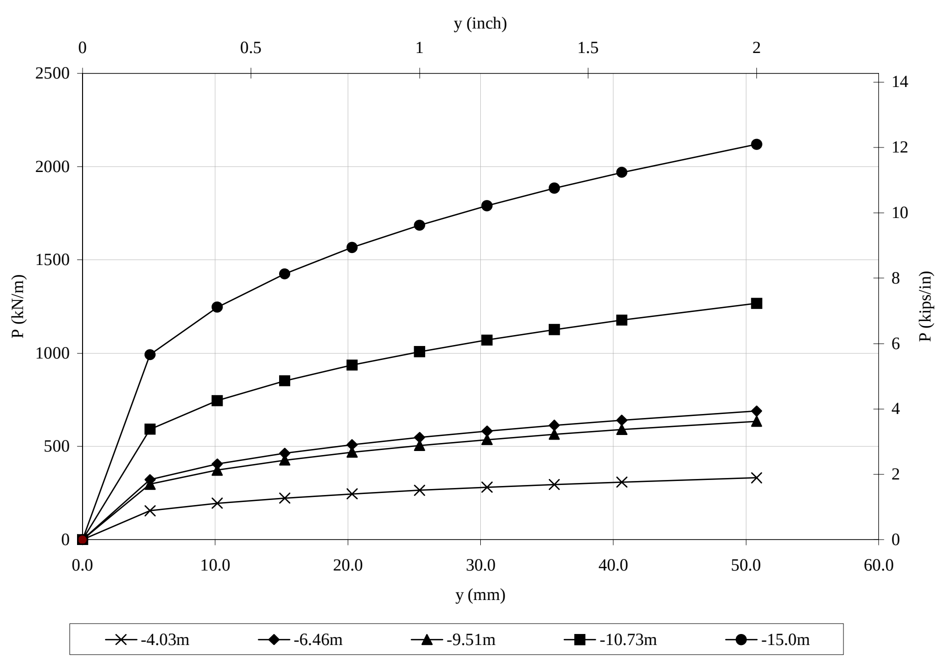
D.2.3 US 17 Wilmington Bypass p-y data from PPMT testing



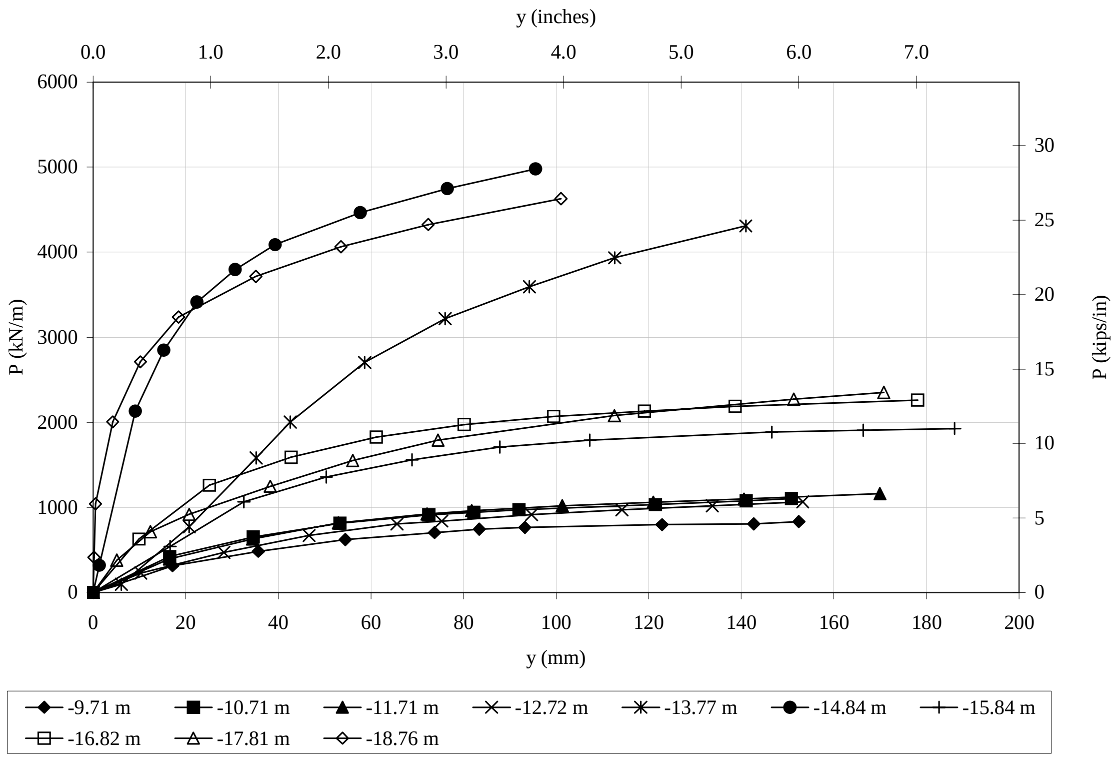
D.2.4 US 17 Wilmington Bypass p-y data from PPMT testing



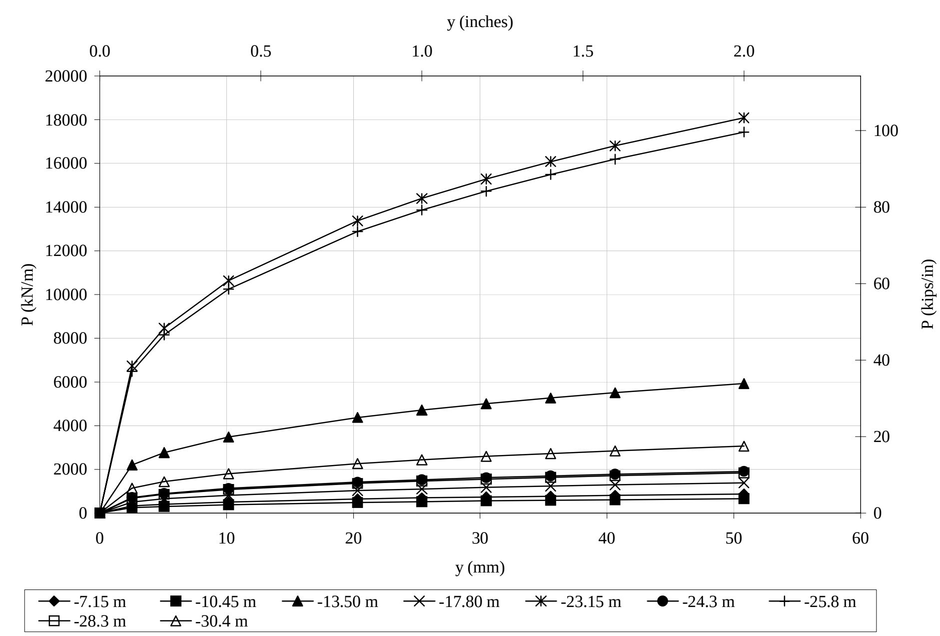
D.2.5 Rio Puerto Nuevo p-y data from PPMT testing



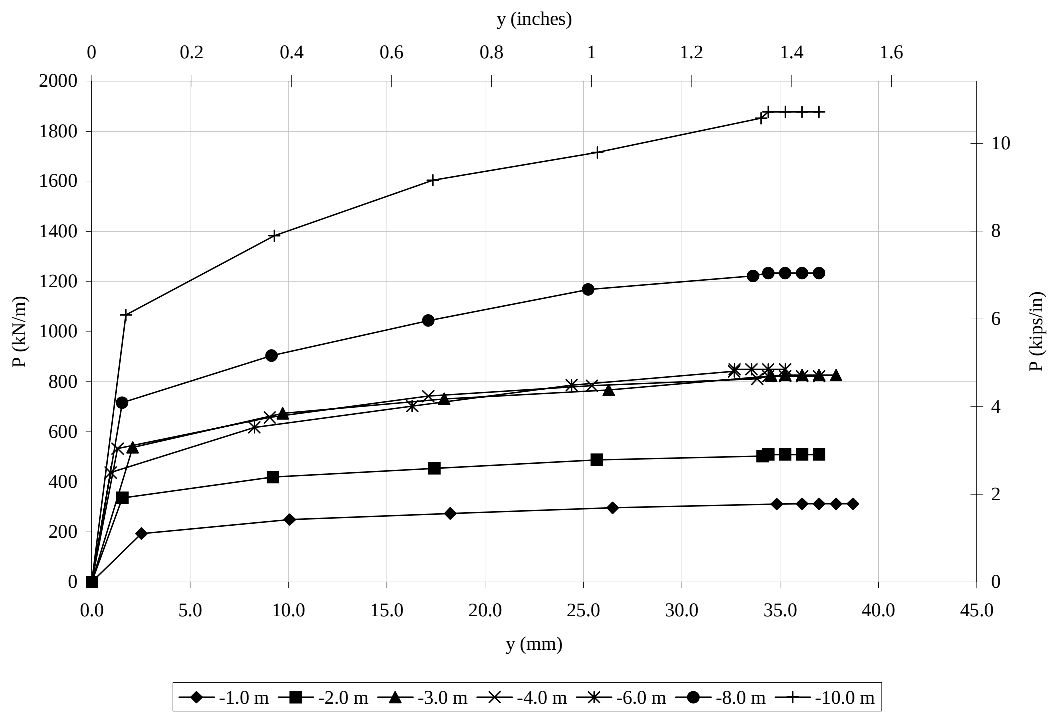
D.2.6 Rio Puerto Nuevo p-y data from DMT testing



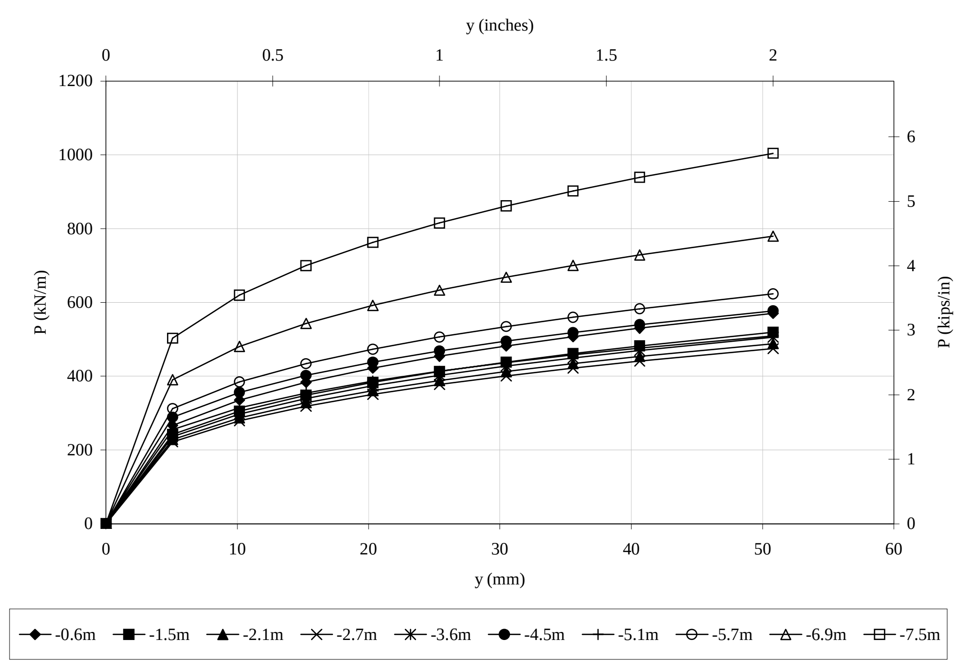
D.2.7 East Pascagoula River Bridge p-y data from PPMT testing



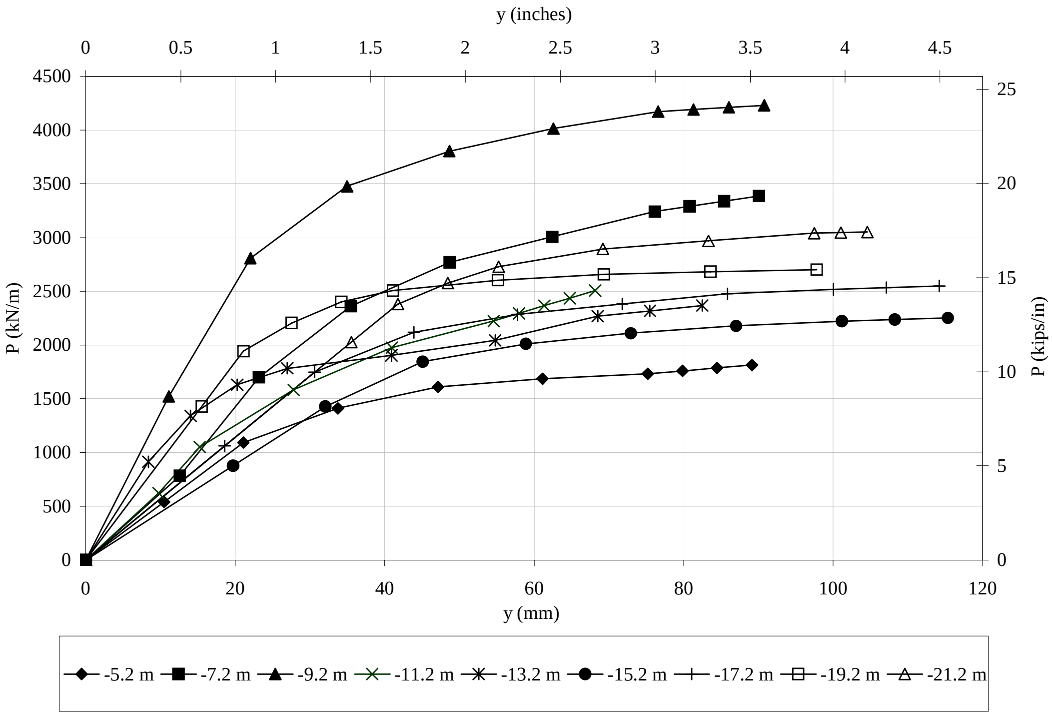
D.2.8 East Pascagoula River Bridge p-y data from PPMT testing



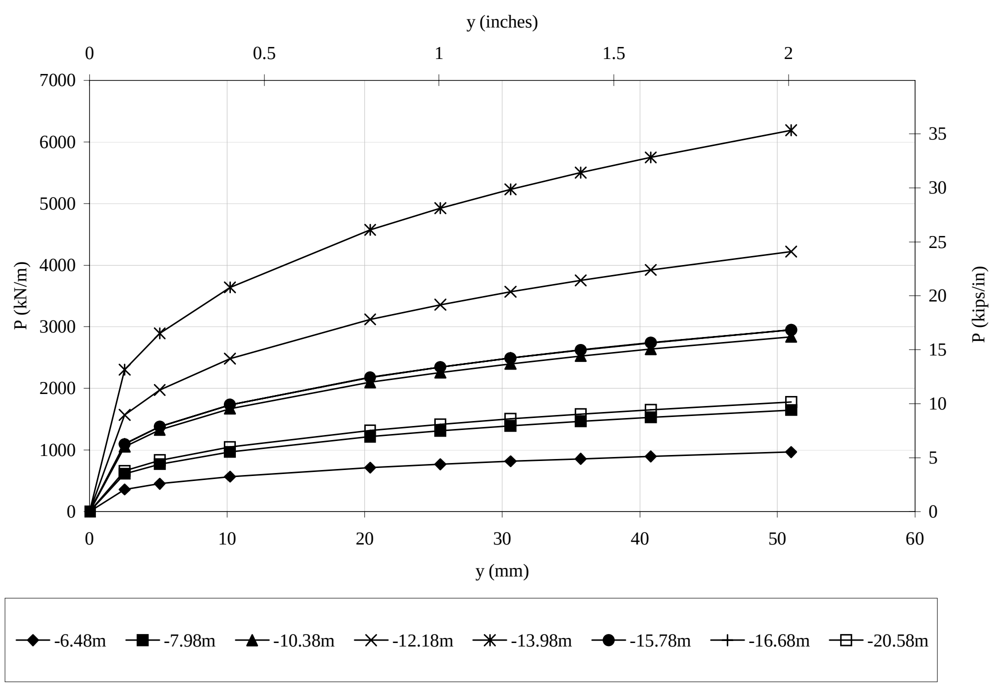
D.2.9 Auburn University Test Site p-y curves from PPMT tests



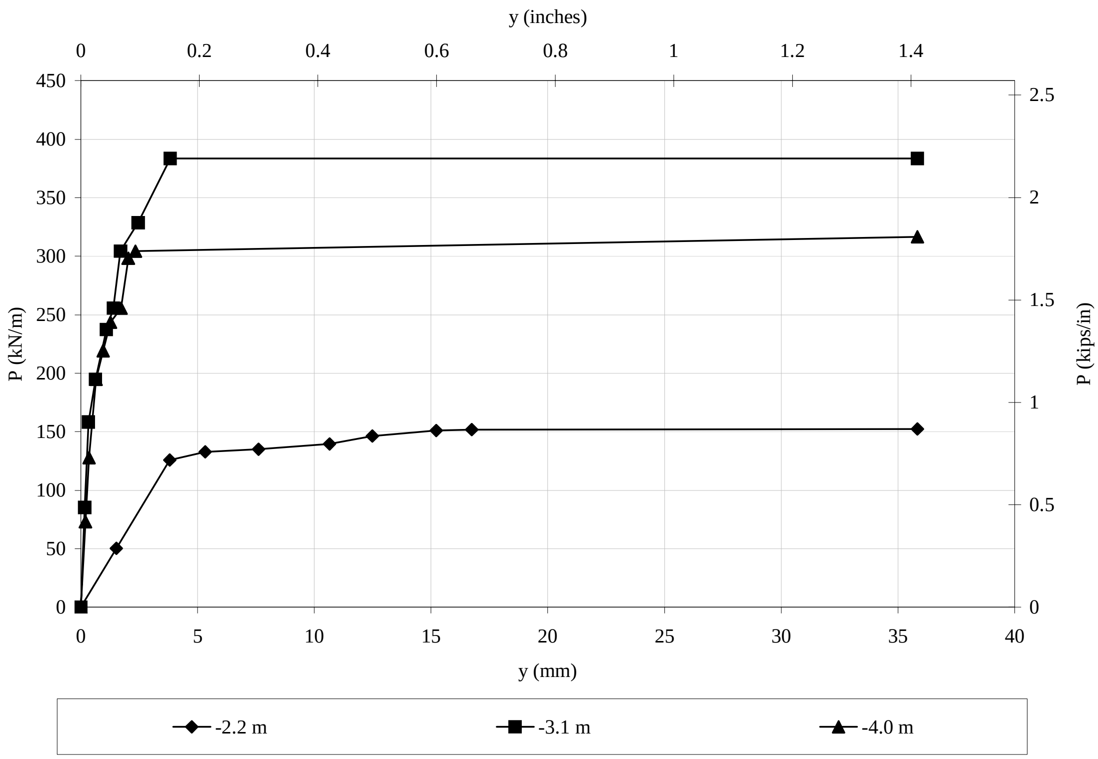
D.2.10 Auburn University Test Site p-y curves from DMT tests



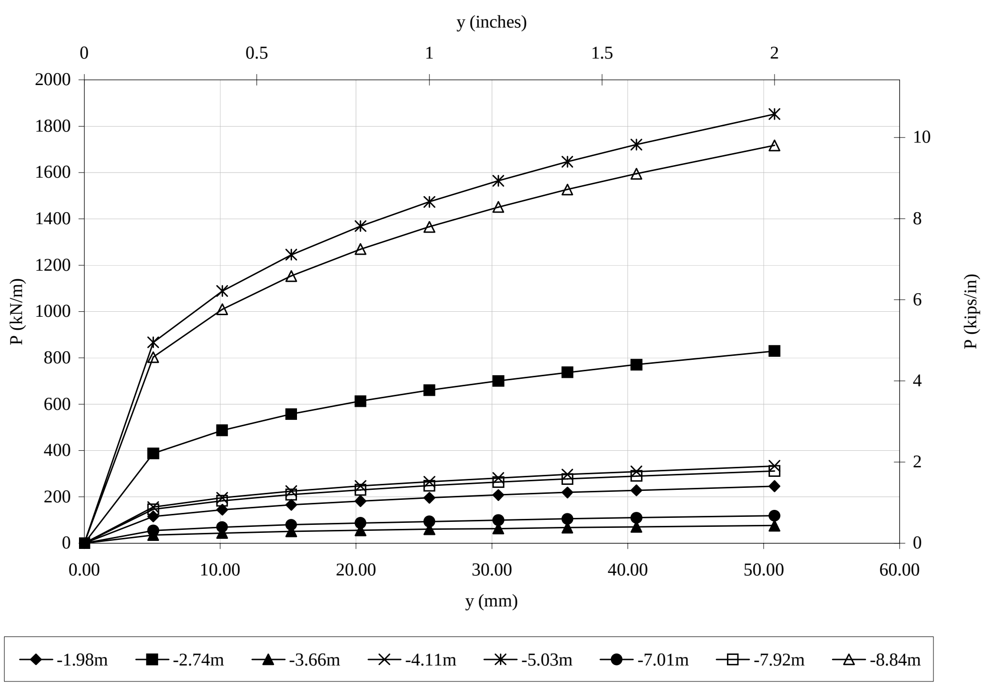
D.2.11 Broadway Bridge Daytona Beach Florida p-y data from PPMT test



D.2.12 Broadway Bridge Daytona Beach Florida p-y data from DMT test



D.2.13Salt lake City Airport p-y curves from PPMT tests



D.2.14Salt lake City Airport p-y curves from PPMT tests

E Appendix E

Volume

1

ProvaFIT2005 User Guide

FLORIDA INSTITUTE OF TECHNOLOGY

ProvaFIT 2005 User Guide

Funded by FDOT

Table of Contents

Section 1
Install and Uninstall

The software is designed for Windows based computer systems. Below are the minimum system requirements to setup install and run the software.

Windows PC or Laptop with windows XP or 2000

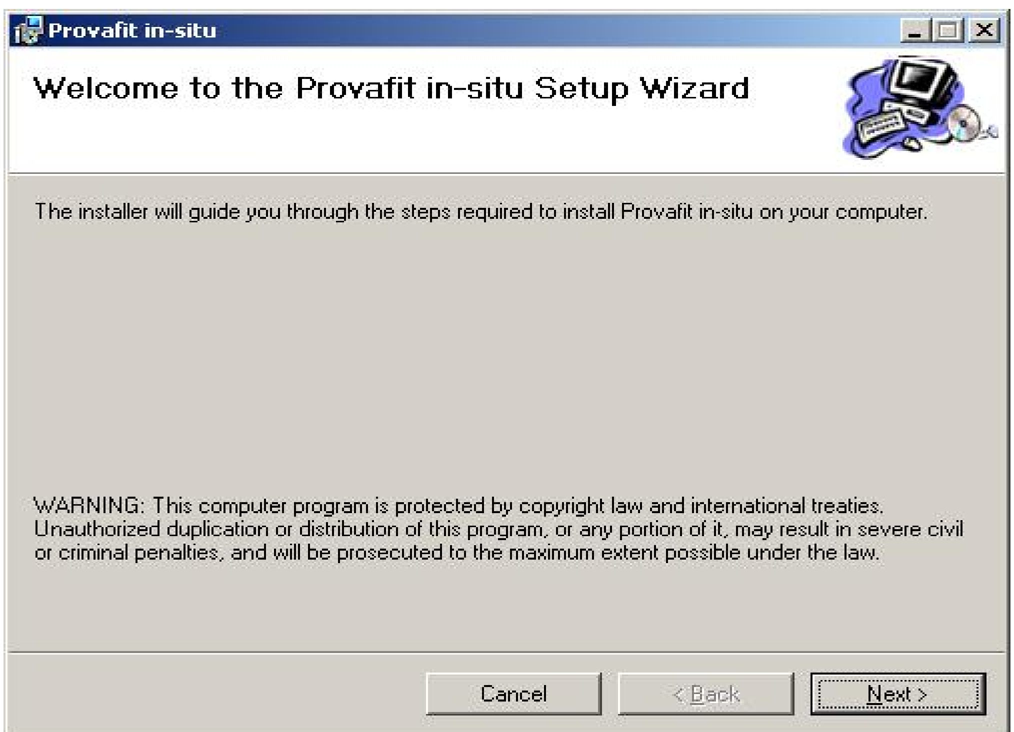
512 MB Ram

20 MB hard drive Space

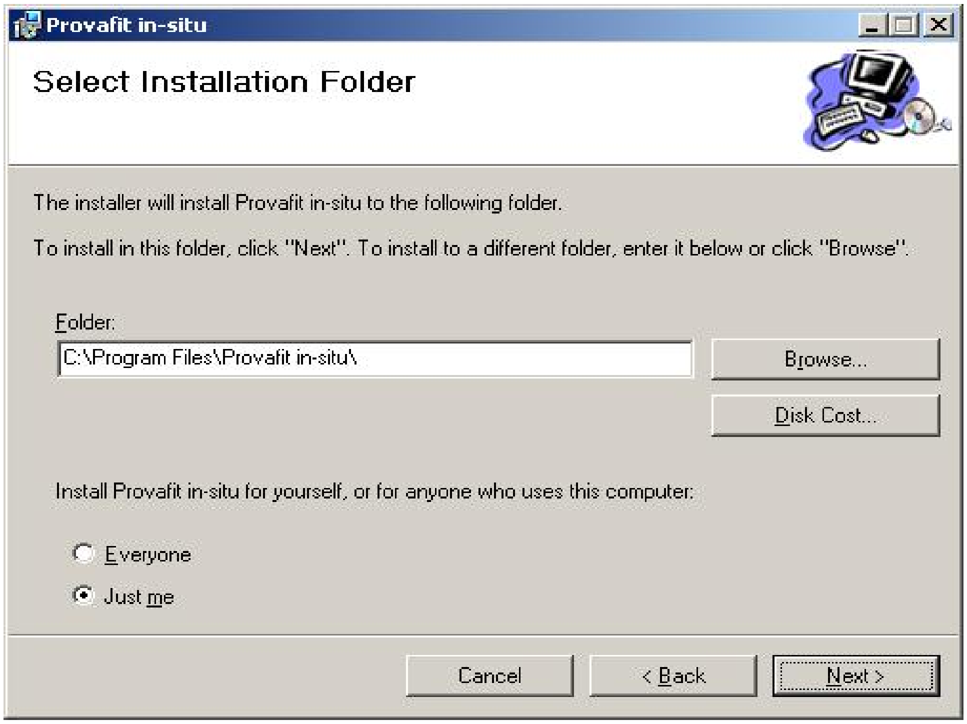
Steps for Software Installation:

Following are the steps for the software installation. The installation program can be found on the supplied installation CD in the ProvaFIT 2005 directory.

- Double click "setup.exe" existing in the INSTALL directory of the CD ROM.
- The installation starts.
    - Note: If the system on which the installation is being done has an older version of the .Net framework or has no .Net framework then the framework is installed automatically before ProvaFIT 2005.
- Once the installation of the .NET framework is completed, the ProvaFIT 2005 software installation starts.

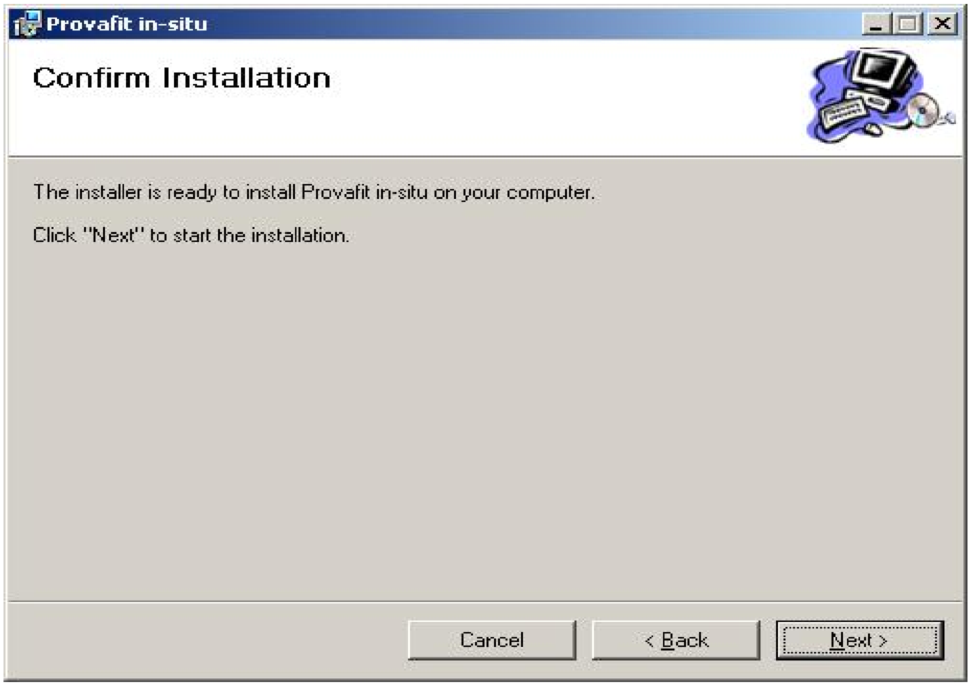


- Here the user can choose a directory to install the software. A default directory is given at first. The user can change it to the desired configuration. When done, click on Next.

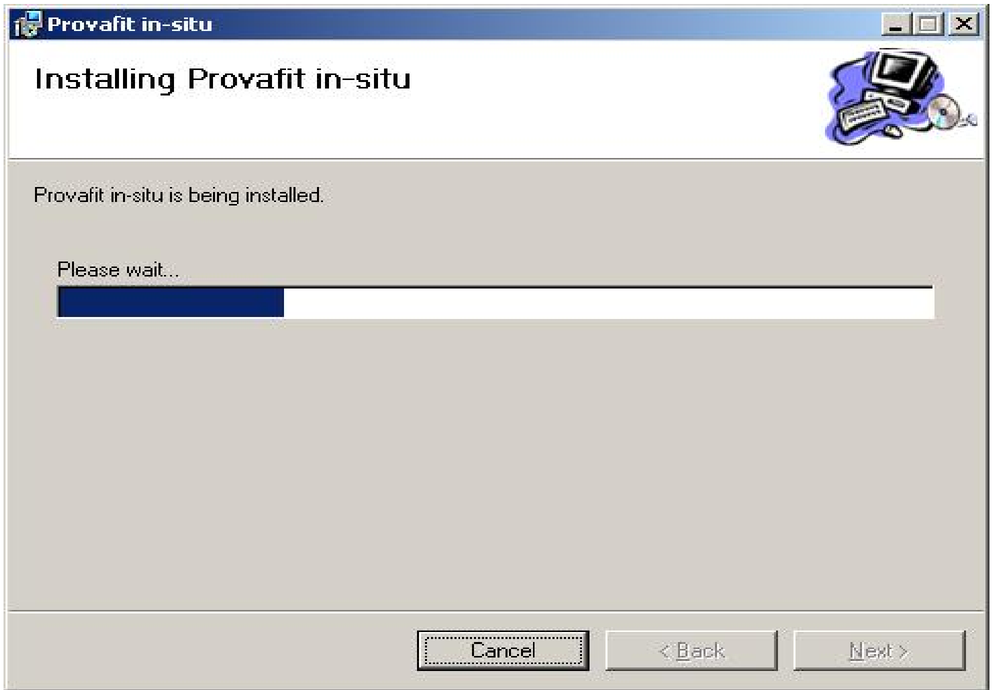


  - Note: Clicking on Disk cost will show you how much space is required and what is available. Depending on this information you can select a better drive to install this software.

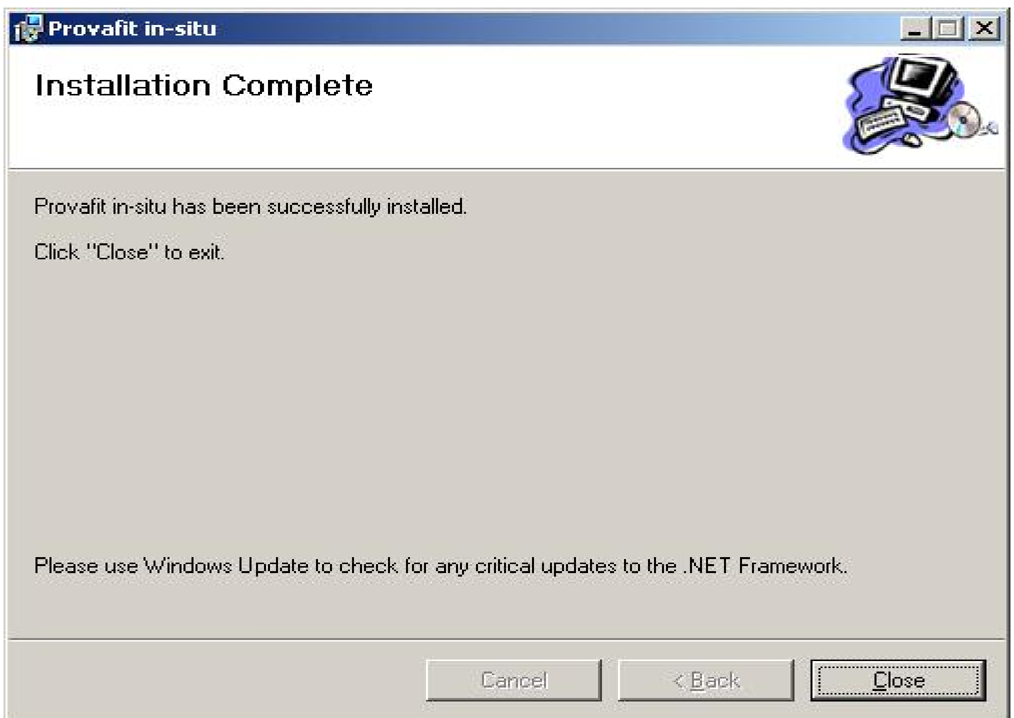
- If satisfied with all the parameters selected in the previous steps click on Next to continue the installation. If not, click on Back to change the parameters.



- When clicking on Next in the previous window the installation starts. The next and back buttons are not available during the process. You may cancel the installation at any time if you choose to.



- If the installation is successful, the following window is displayed where the user can select "Close" to complete the installation.



- Once the software is installed the user can access it from the START menu or, click on PROGRAMS and then select ProvaFIT 2005.

Steps to Uninstall the Software

Follow these steps to uninstall either the .Net or ProvaFIT 2005 software.

- **.Net framework**
  - Double Click "Add Remove Programs" in the control panel
  - Scroll the list to find ".Net framework Ver x.x"
  - Click on Remove to uninstall the framework
  - Please restart your computer to allow better functioning.

- **ProvaFIT 2005**
  - Double Click "Add Remove Programs" in the control panel
  - Scroll the list to find "Provafit in situ 2005"
  - Click on Remove to uninstall the software
  - Please restart your computer to allow better functioning.

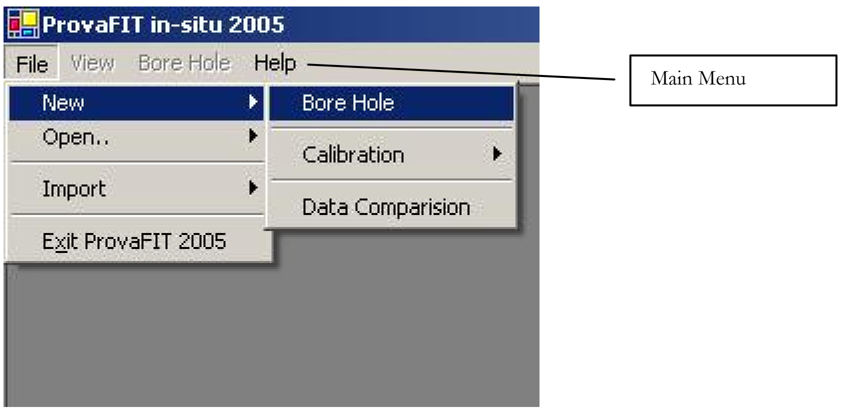
Section 2
Using the Software

The following sections will help the user in understanding how to utilize the software. Following sections are task based. The person using this software should have sufficient Geotechnical Engineering knowledge of the pressuremeter to perform the following calculations manually. This manual presents a simple approach for creating a calibration file and then reducing test data based on it.

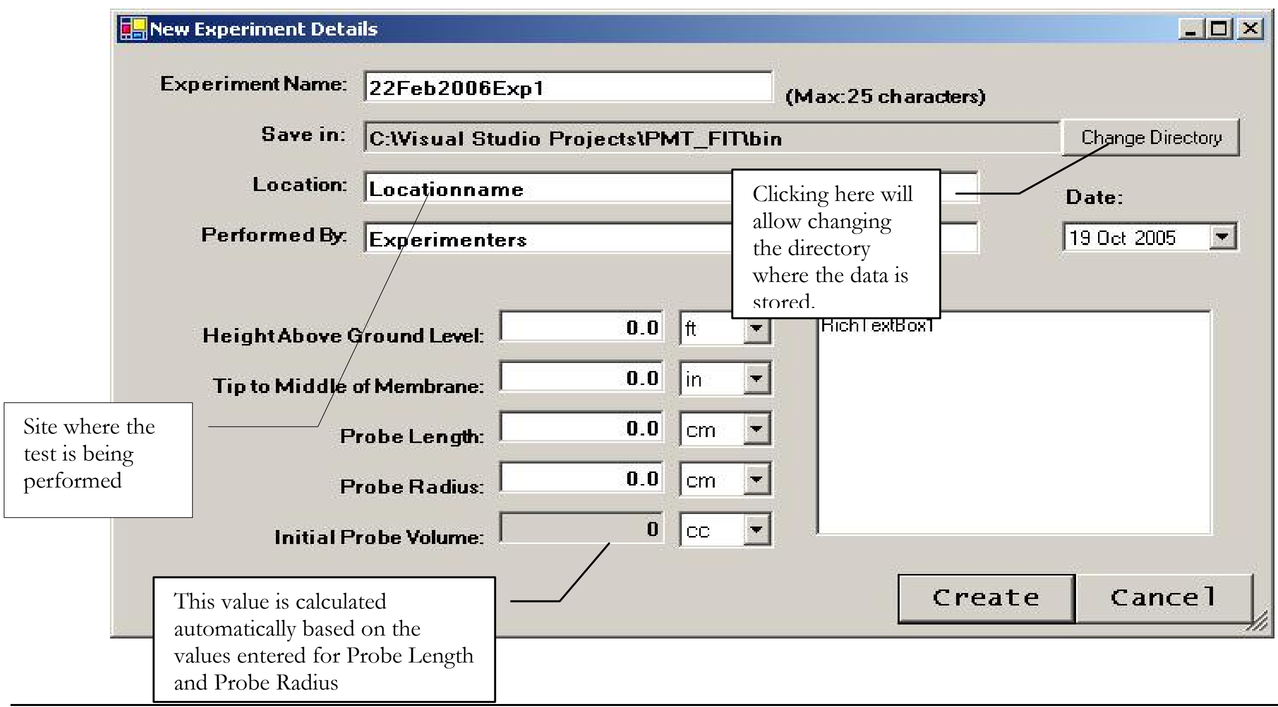
For the following sections the ProvaFIT 2005 program should be running.

2.1 New Bore Hole (or sounding)/Experiment

Click on File from the Main Menu and then click on New → Bore Hole as shown below.



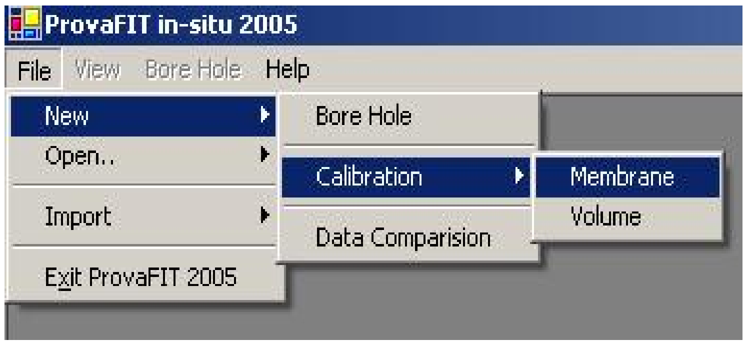
This will bring up the following screen. Please enter the information shown on the screen



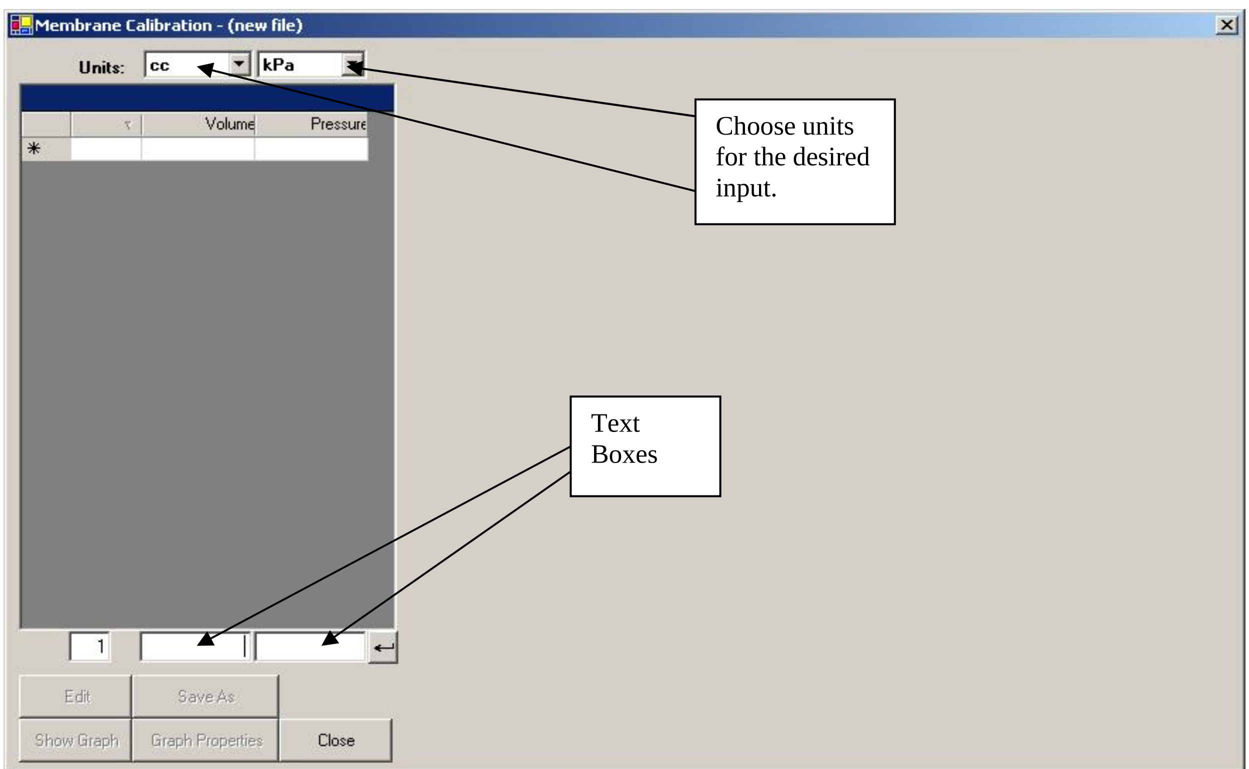
Enter the details and click on “Create”. This step will create an experiment file and the data entered is stored in that file. The software is now ready to work on the new details. The software assumes that the current membrane calibration and/or volume calibration to be valid and is/are used for the test. You can also reenter the calibration data if you wish so. However you need to enter it before you start doing the test.

2.2 Membrane Calibration

If there is no calibration data available for the membrane or the user wants to enter new calibration data, then choose File → New → Calibration → Membrane

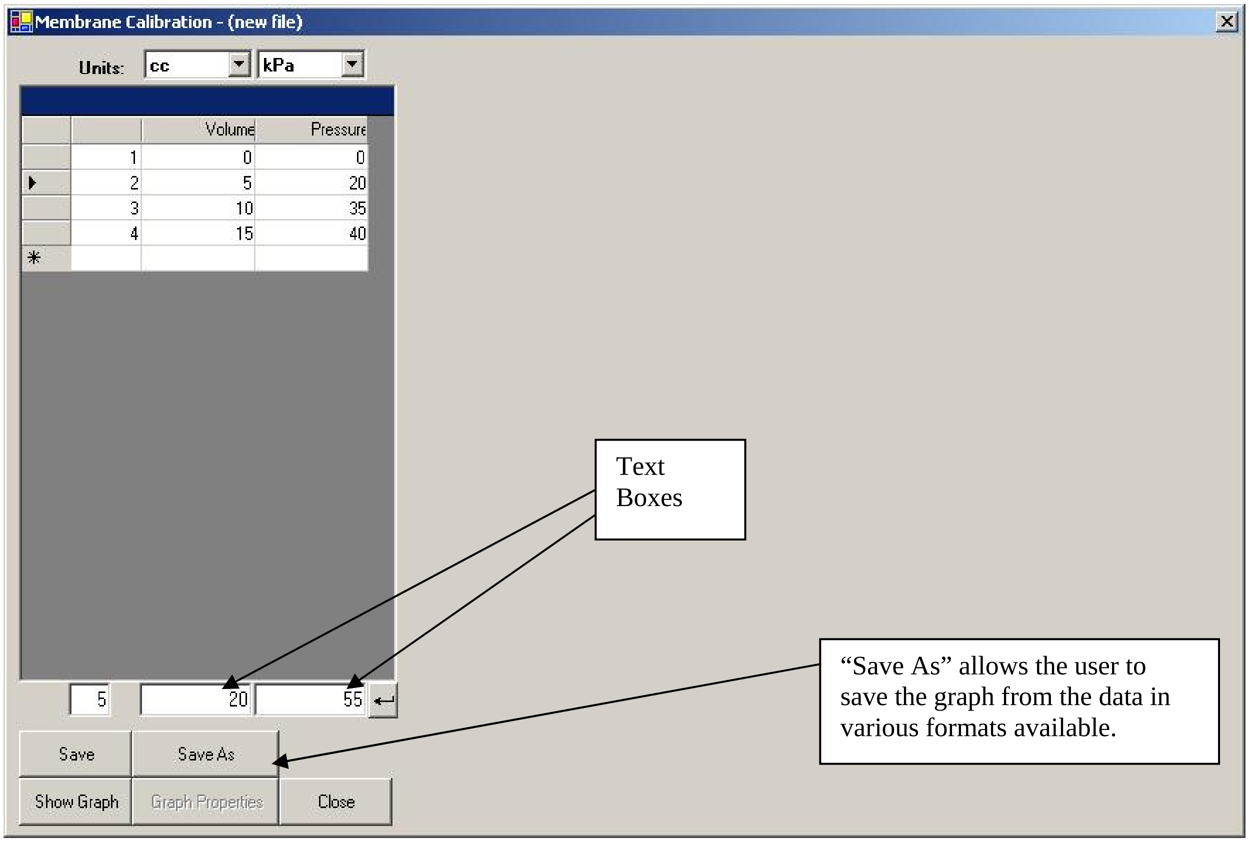


The following screen is shown.



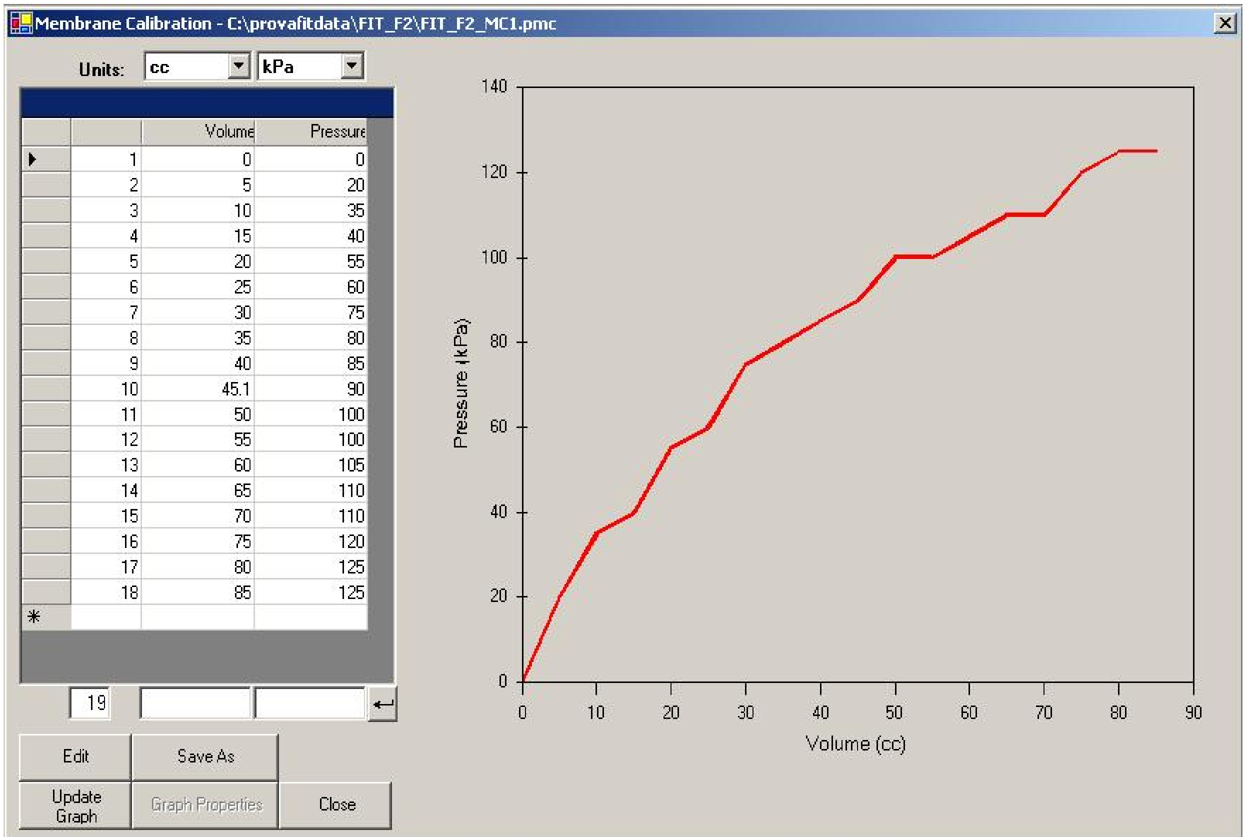
Start entering data in the 2 text boxes at the bottom of the screen. The user can either press enter key when finished with the entering pressure value or click on the ↵ button.

The following is a typical data entry form.



After entering all the data, click on "Save" to save the file. In the dialog box, as shown below, enter the name of the file and click on "Save". The dialog box gives the user the opportunity to save it to a different location.

If the user wishes to see a graph of the data entered, click on the “Show Graph” button. This option is available while entering the data, and will show the plot up to the current data point.



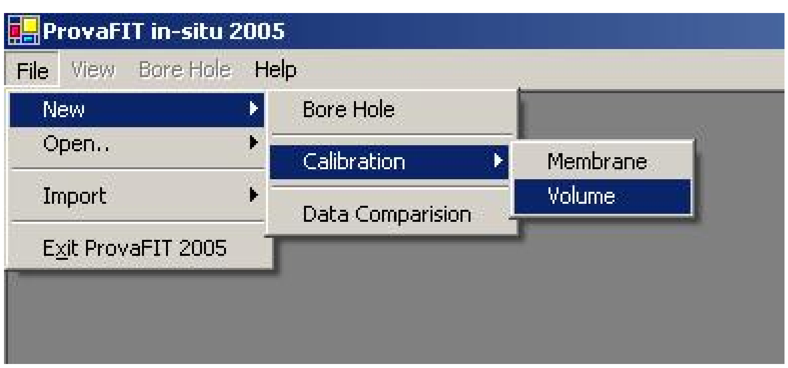
Apart from saving the data, it is also possible to save the graph as an image. To save the graph click on the “Save As” button, and in the dialog box choose the desired file type and click on “Save”.

The user can click on the “Graph Properties” button to set the various properties of the graph. However, please note that these settings are not saved. They are lost once you close the form.

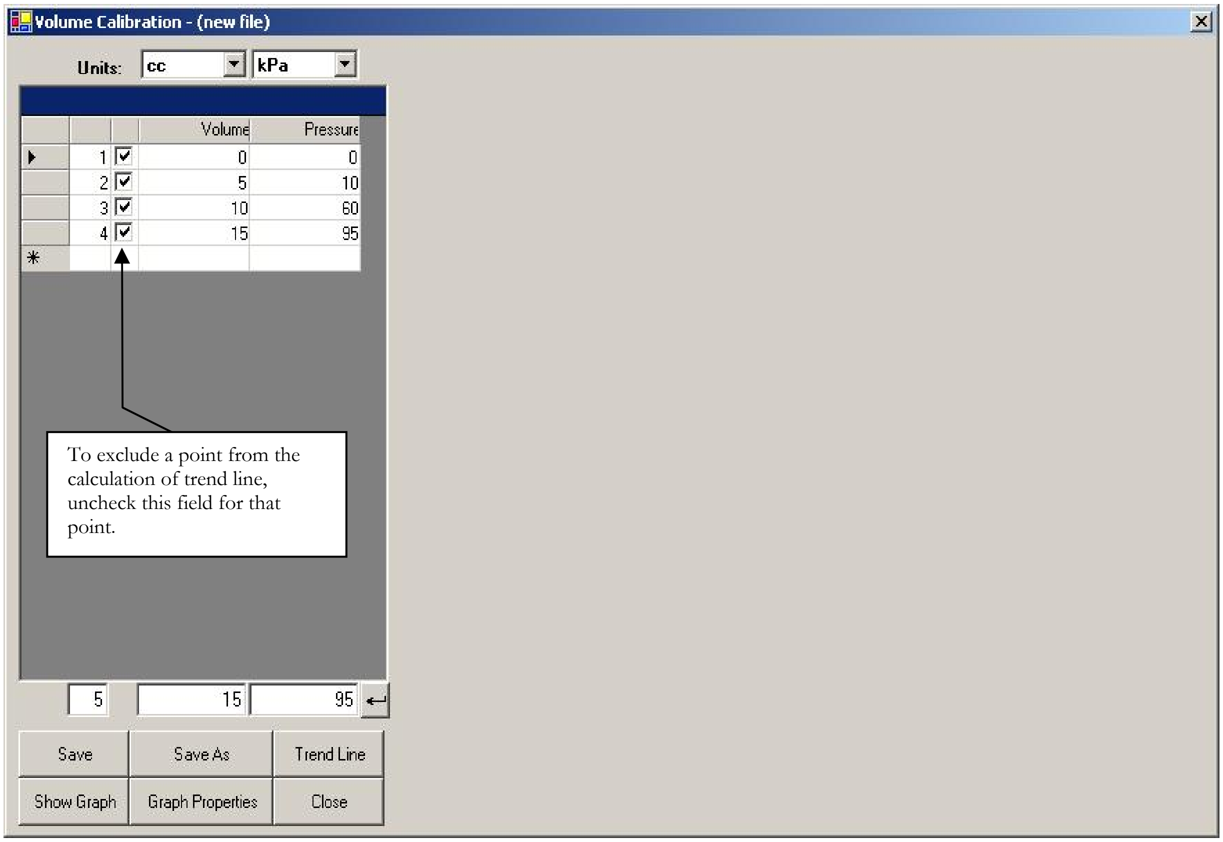
Click on “Close” to close the form. Please work only on one form at a time.

2.3 Volume Calibration

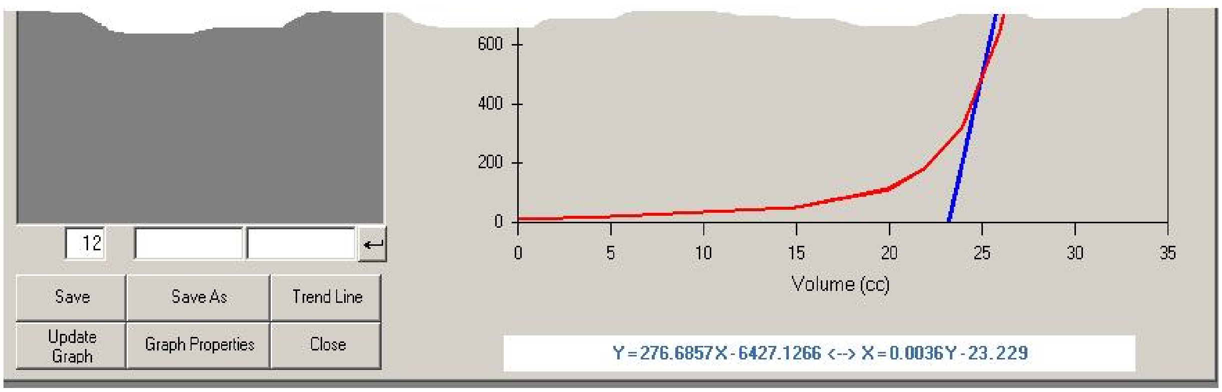
If there is no calibration data available for volumetric expansion or the user wants to enter new calibration data, then choose File → New → Calibration → Volume from the main menu.



The following form appears. All the functionality of this form is similar to the functionality of the membrane calibration form, except for a new field which is used to include or exclude points in the calculation of the trend line.

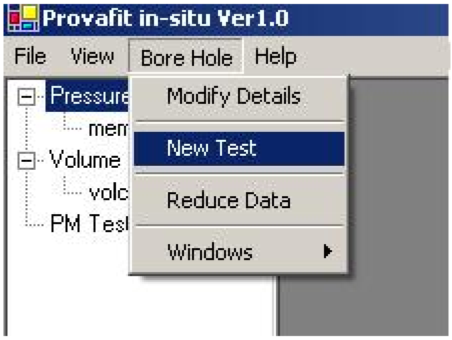


After entering the calibration data, then click on the "Trend Line" button and the trend line is fitted to the data and displayed on the graph. The points that have a checkmark are included in the calculation and the trend line equation is shown in the bottom of the form as shown below. To remove a point from the calculation of the trend line, uncheck the point. The trend line is automatically updated.



2.4 Input Test Data

To create a new test, click on Borehole→ New Test from the main menu.



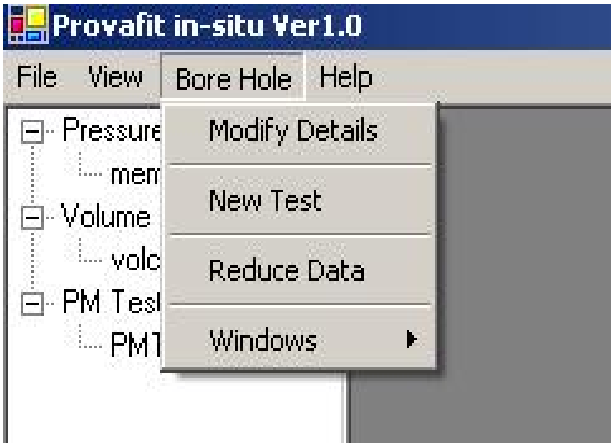
In the following popup enter the Depth of the borehole being tested and click ok.

The "New Test" form has the same functionality as the membrane calibration form. Enter the data and click on the "Save" button to save the data in a file.

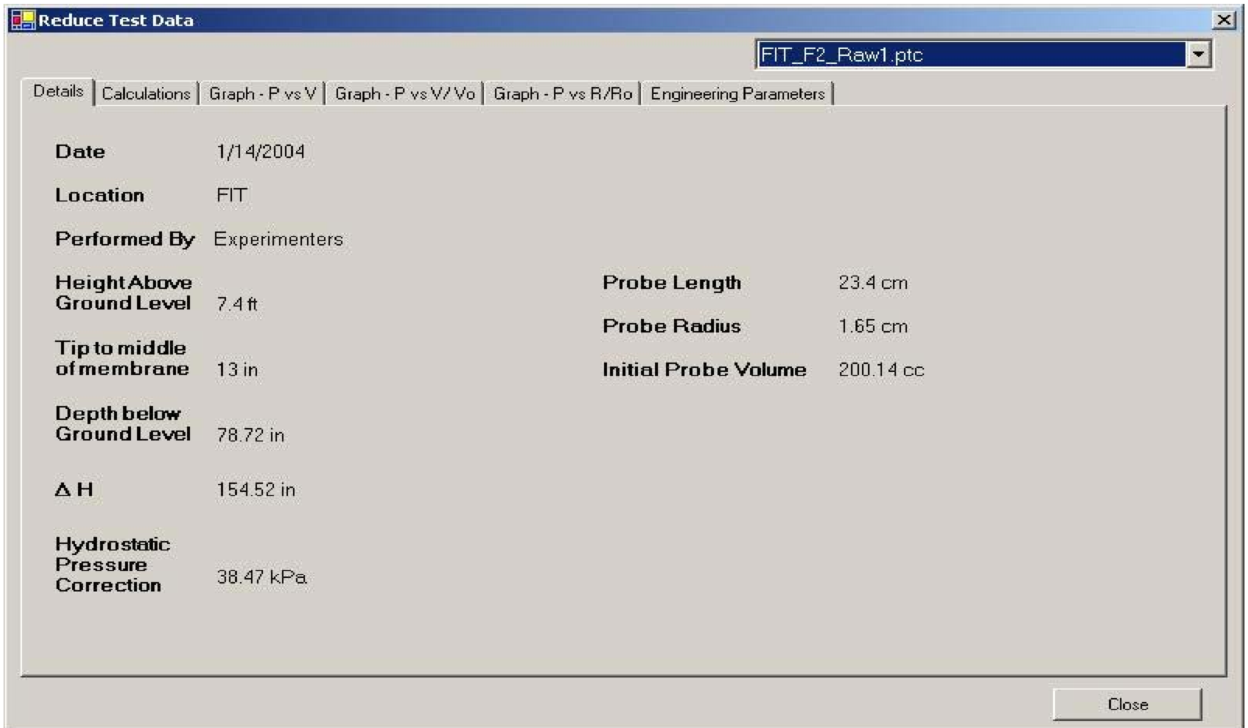
To create another test, follow the above steps. When the user has entered all the data required for various depths, proceed to the next step which is reducing the data.

2.5 Reduce Test Data

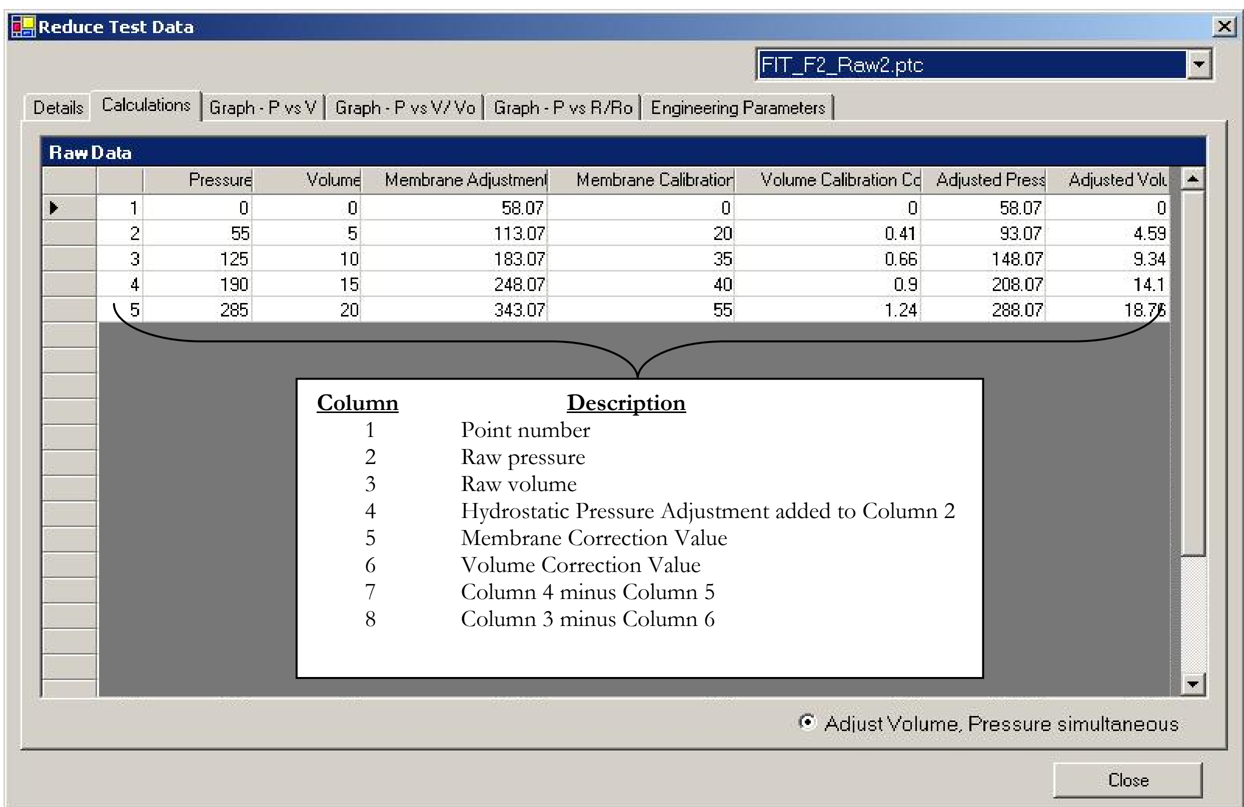
To generate reduced data, select Borehole → Reduce Data from the main menu.



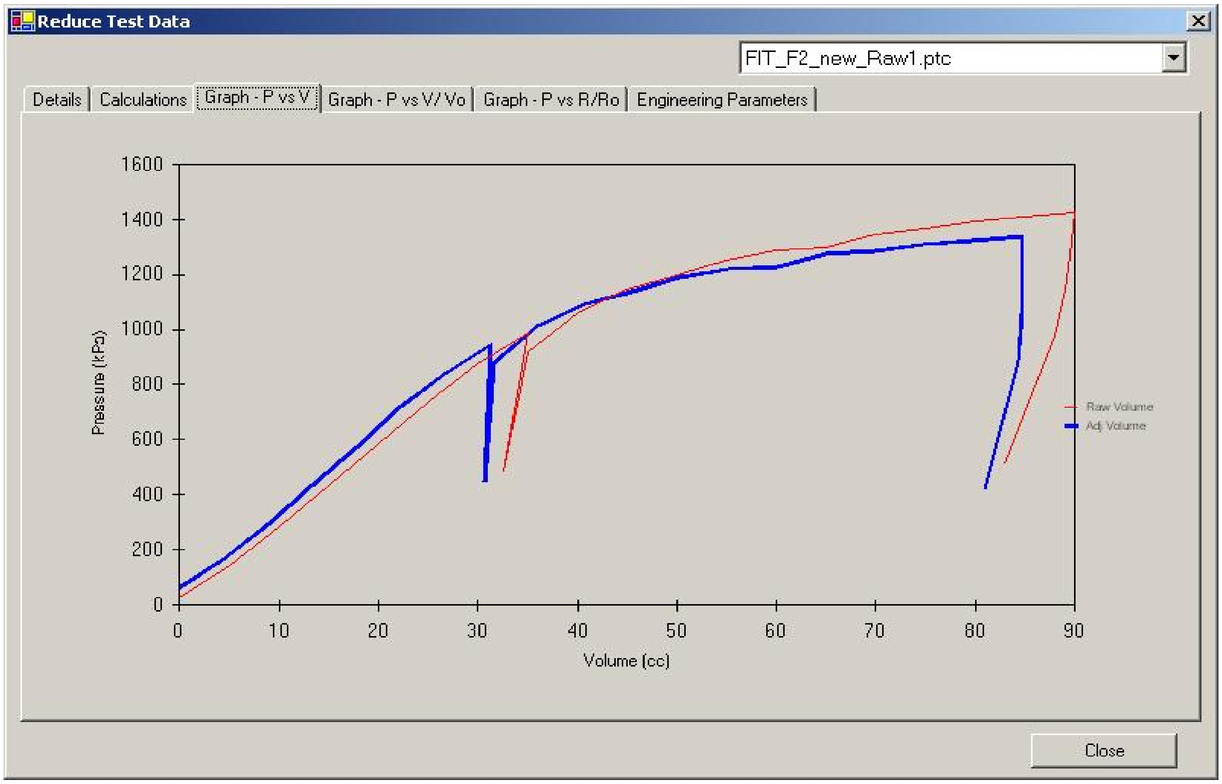
The following form is displayed which handles all the tests performed in a particular bore hole. In this form the user can reduce and compare the data. The “Details” tab displays all the parameters that were used during the test.



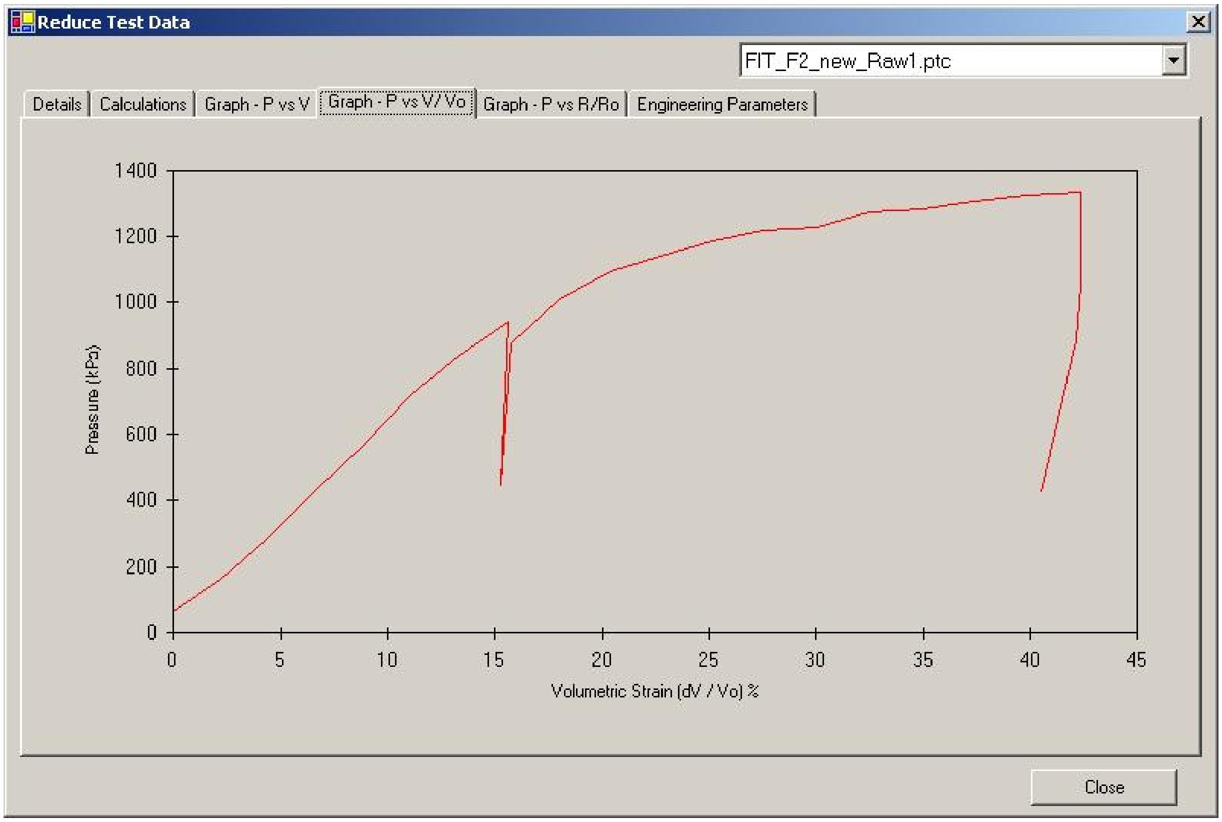
The Calculations tab will display the different steps involved in calculating the reduced data.



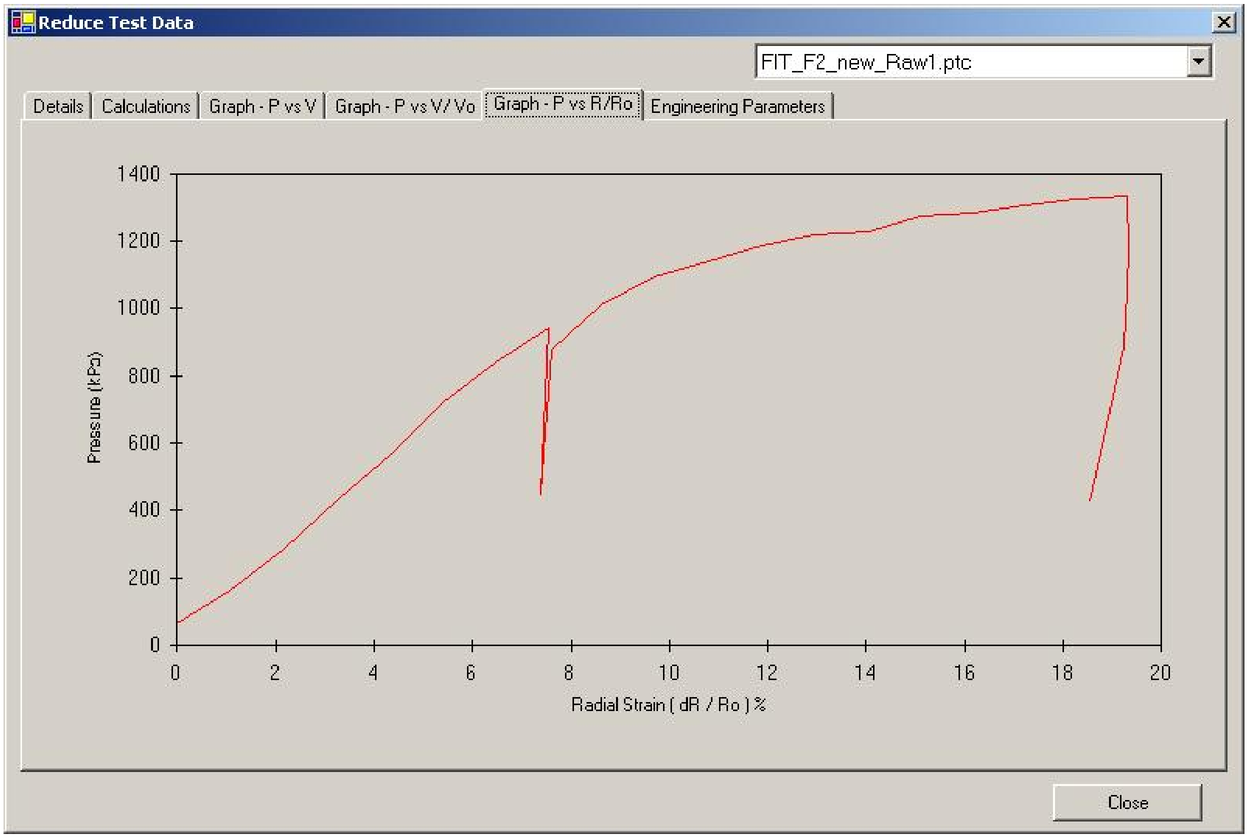
The Graph – P vs V tab displays the graph of pressure plotted against the Volume



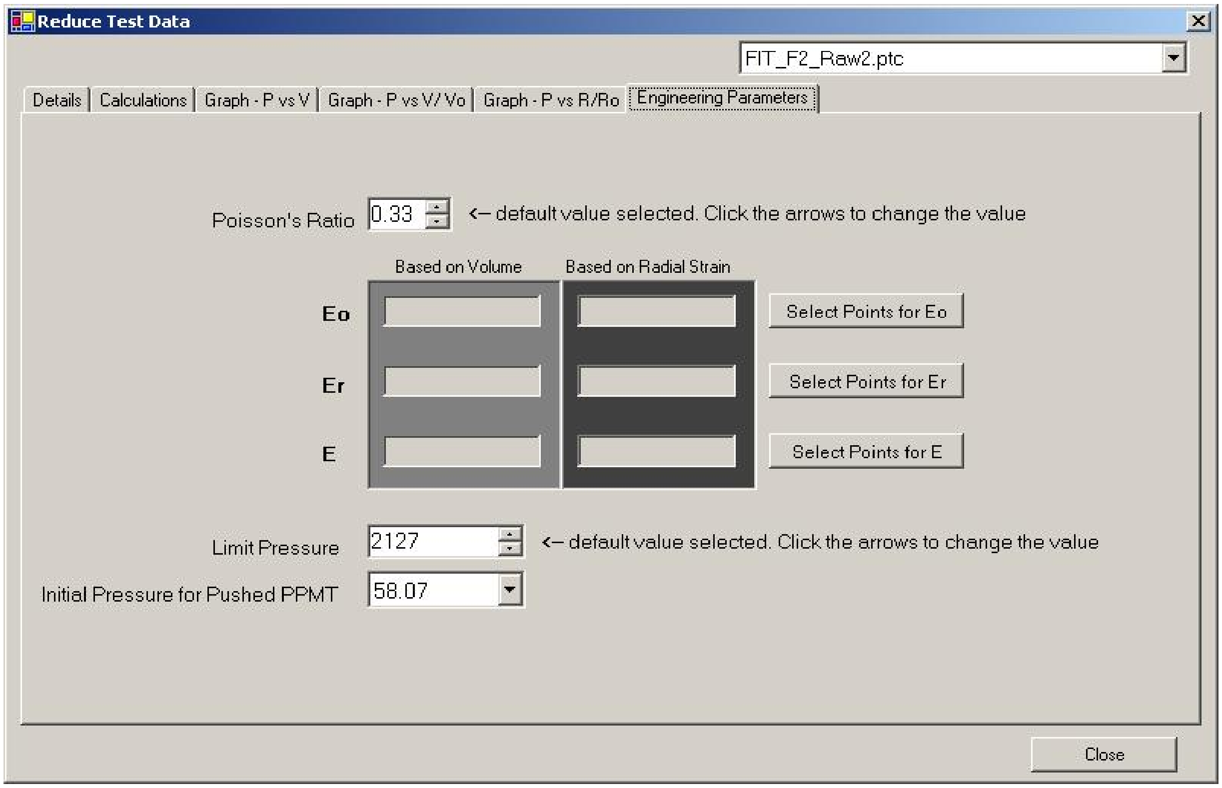
The Graph – P vs V/Vo tab displays the graph of pressure plotted against the Volumetric Strain



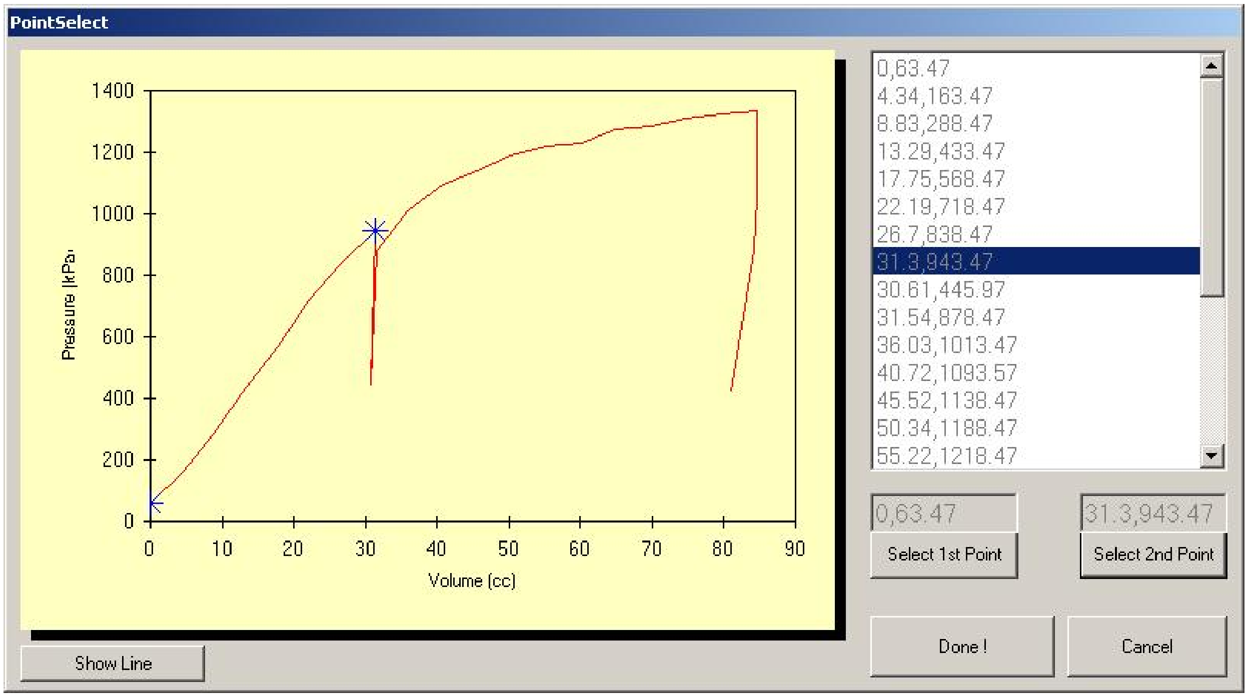
The Graph – P vs R/Ro tab displays the graph of pressure plotted against the Radial Strain



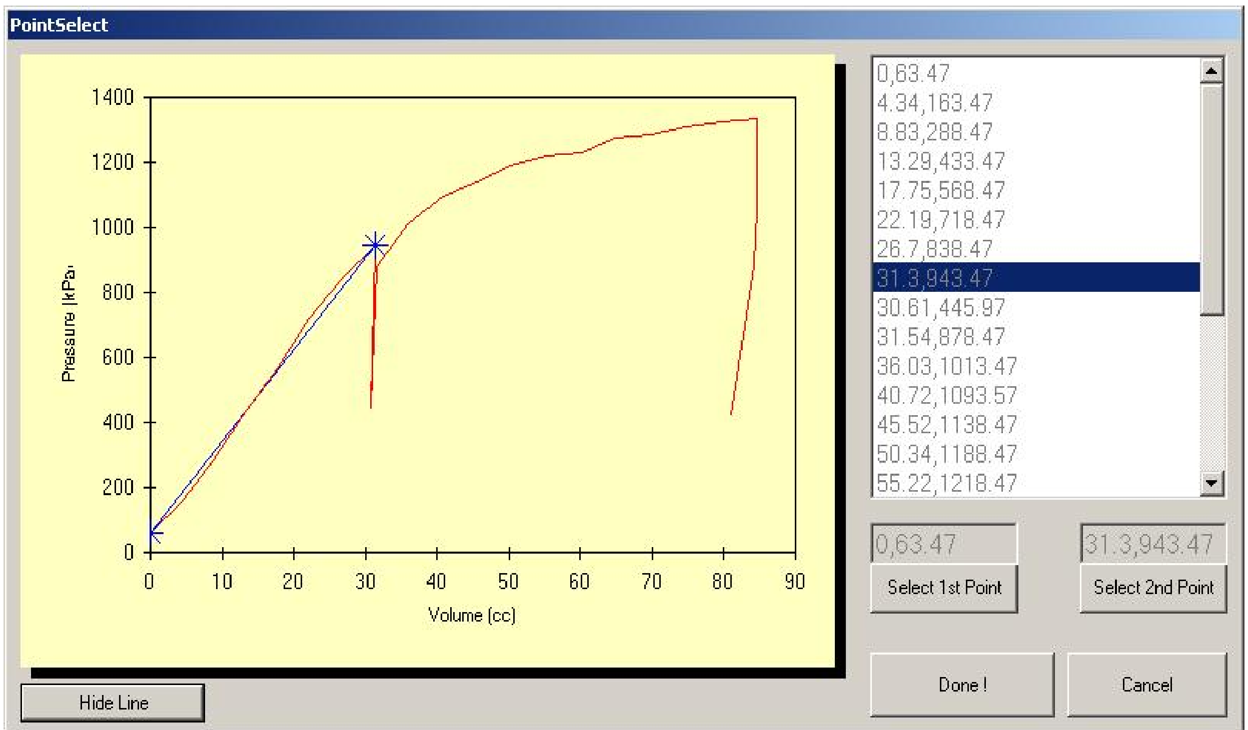
The Engineering parameters tab will allow users to calculate values of E_o, E_r and E and Limit Pressure.



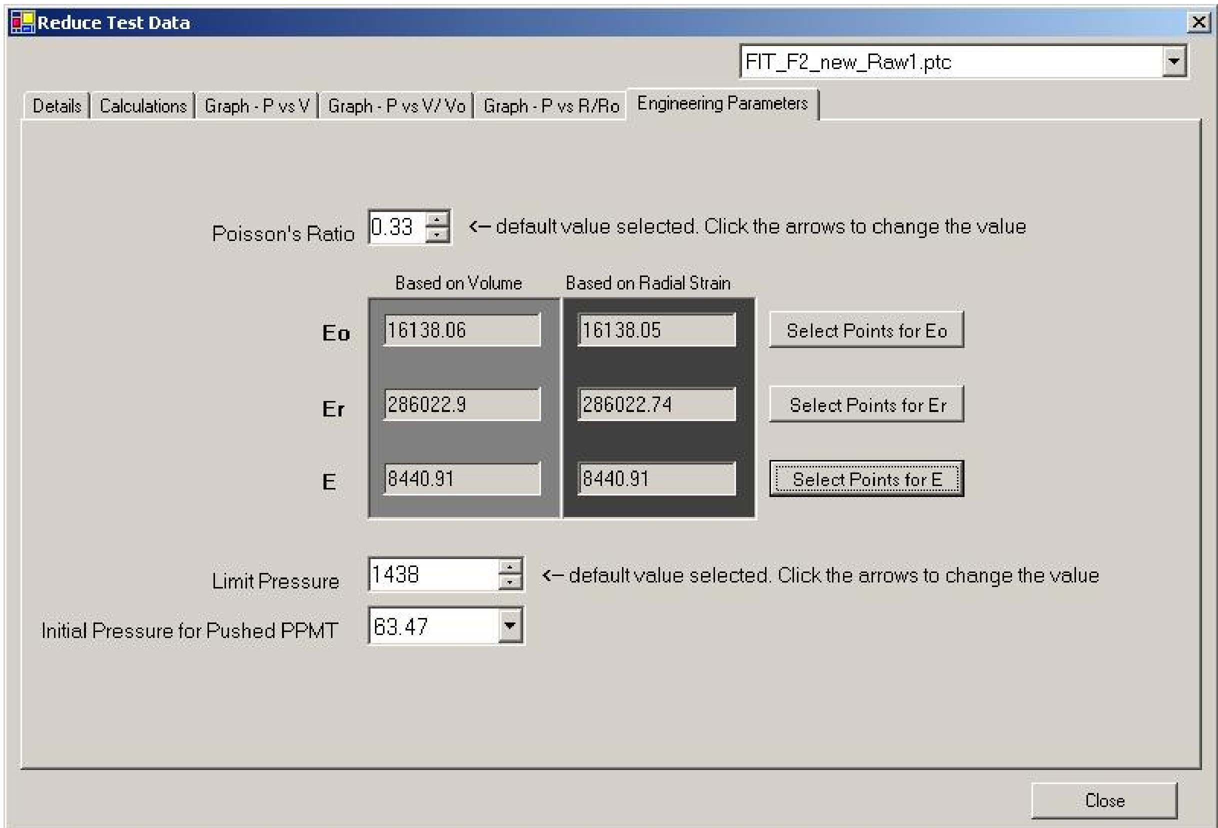
For calculating E_0, click on "Select Points for E_0". The following window is shown where users can select the points desired for calculating E_0.



Users can choose to display a line connecting the selected points by clicking on "Show Line".



Similarly Er and E (for any user selected points) can be calculated. At each step the Engineering Parameters are updated with the calculated values. The following screen shot shows an updated Engineering Parameters tab of a Reduce Data Window.

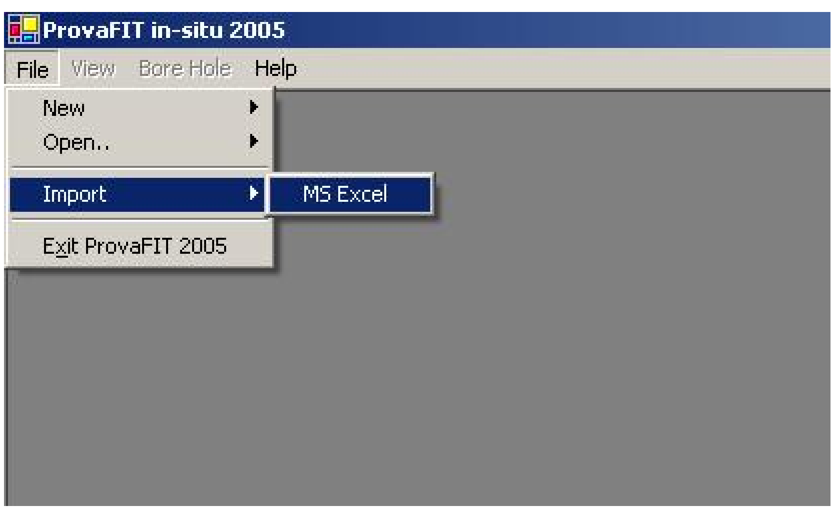


The formulae used for various calculations have been discussed in detail in Section 3.

2.6 Import Data

The data can also be imported from Excel files as shown on the following pages. This applies only to the special Excel format that has been in use by the FDOT. Use the import option of the ProvaFIT and the desired data will be imported in a step wise wizard mode.

To import data from Excel click on File → Import → MS Excel as shown below



The following window is displayed.

FDOT PPMT Excel Format for Main Data Page

Date	6/11/04	**Height above GL**	7.333 ft	**1 in (h_20) =**	0.248976 Kpa
Location	Puerto Del Rio Complex - FDOT truck		88 in		
Performed by	Farid Messaoud	**Tip to middle of membrane**	13 in	**Probe length**	23.4 cm
Depth below GL	2 m			**Probe radius**	1.6 cm
	78.74 in	**ΔH**	153.74 in	**Ini. Probe Vol.**	188.19 cm^3
			38.3 KPa		

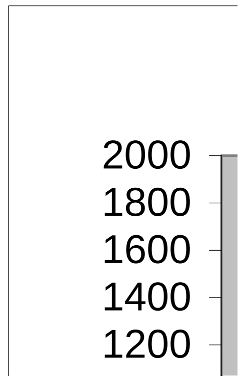
Borehole A2

Raw data		Hydrostatic Pressure Adjustments	Volume Calibration Correction	Pressure Calibration Correction	Adjusted Volume	Adjusted Pressure
Volume (cm^3)	Pressure (kPa)	Pressure (kPa)	Volume (cm^3)	Pressure (kPa)	Volume (cm^3)	Pressure (kPa)
0	20	58	0.34	-1	-0.34	60
5	58	96	0.57	16	4.43	80
10	125	163	0.96	30	9.04	133
15	182	220	1.30	43	13.70	177
20	238	276	1.63	54	18.37	222
25	285	323	1.91	64	23.09	259
30	340	378	2.23	72	27.77	306
35	370	408	2.41	80	32.59	329
40	398	436	2.58	86	37.42	350
45	425	463	2.74	91	42.26	372
50	462	500	2.96	96	47.04	405
55	475	513	3.03	100	51.97	414
53	460	498	2.94	98	50.06	400
55	477	515	3.04	100	51.96	416
60	490	528	3.12	103	56.88	425
65	512	550	3.25	107	61.75	443
70	530	568	3.36	110	66.64	458
75	537	575	3.40	114	71.60	461
80	555	593	3.50	118	76.50	475
85	576	614	3.63	123	81.37	492
90	595	633	3.74	128	86.26	505
87.5	540	578	3.42	126	84.08	453
85	518	556	3.29	123	81.71	433
82.5	503	541	3.20	121	79.30	421

Volume Calibration

Date 6/11/04
Location Puerto Del Rio Complex - FDOT truck
Performed by Farid Messaoud
Membrane A1

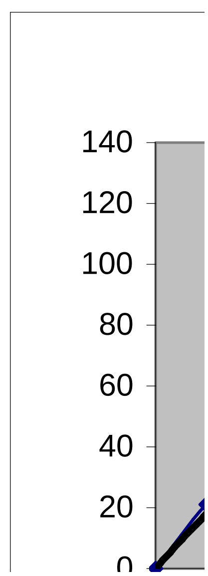
Volume (cm^3)	Pressure (kPa)
0	0
5	50
10	166
15	460
20	1152
23.4	1903



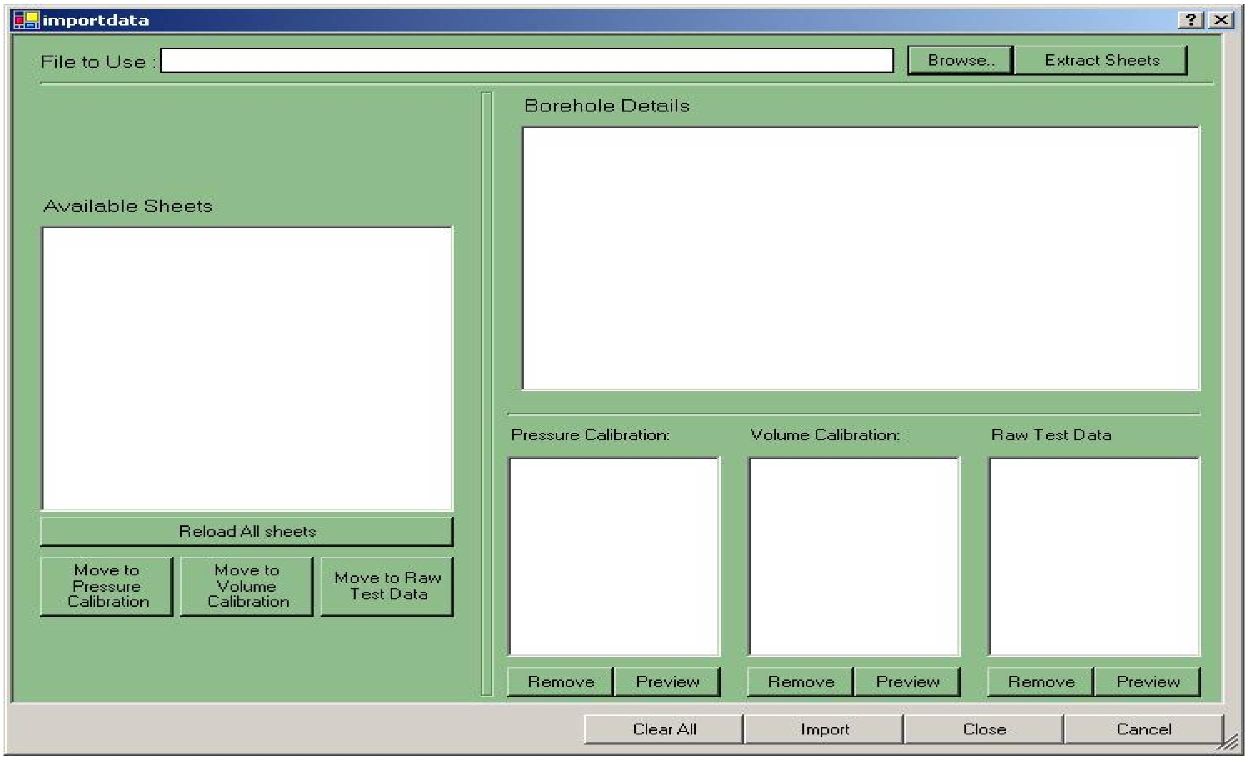
Pressure Calibration

Date 6/11/04
Location Puerto Del Rio Complex - FDOT truck
Performed by Farid Messaoud
Membrane A1

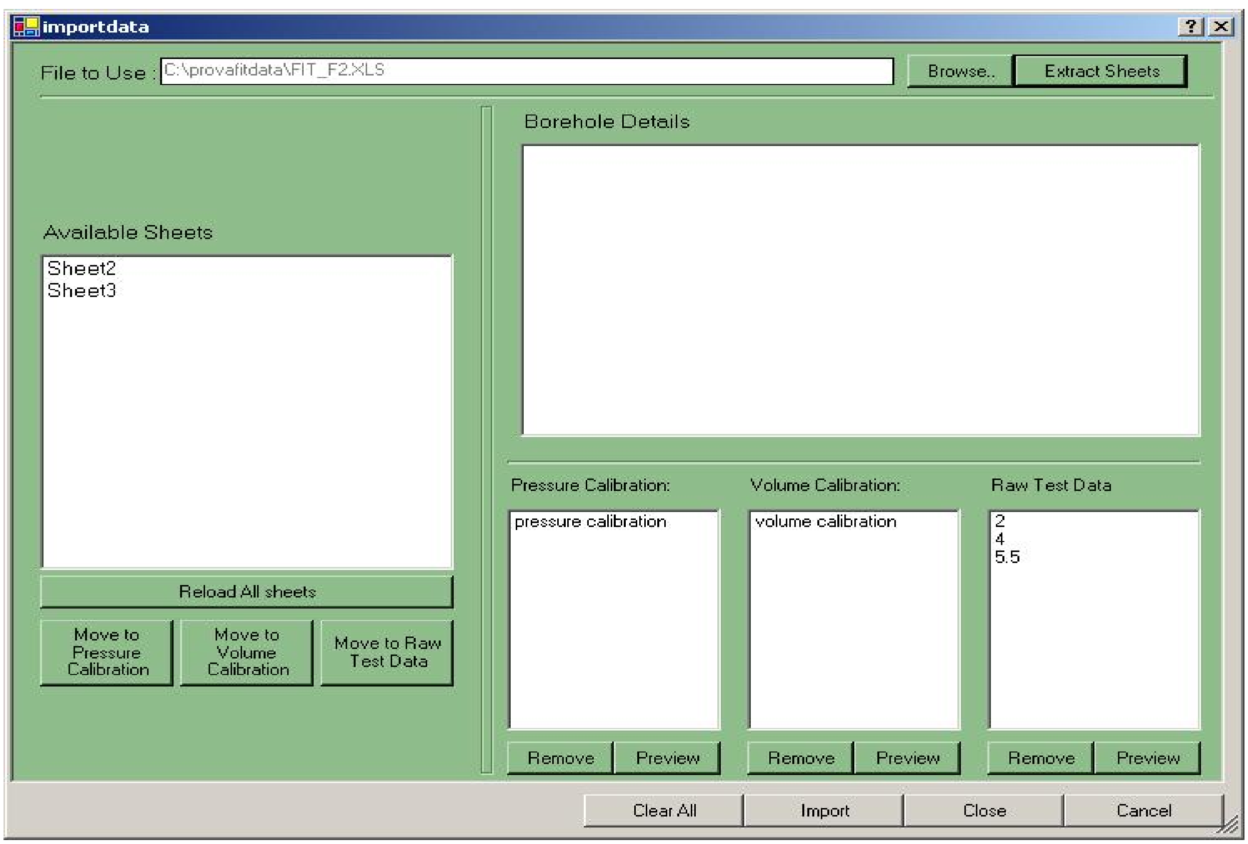
Volume (cm^3)	Pressure (kPa)	Pressure (psi)	Pressure (kPa)
0	0	0	0
5	21	3	20.685
10	35	5	34.475
15	48	7	48.265
20	55	8	55.16
25	69	10	68.95
30	76	11	75.845
35	83	12	82.74
40	90	13	89.635
45	90	13	89.635
50	96	14	96.53
60	103	15	103.425
70	117	17	117.215
80	124	18	124.11
90	130	19	131.005



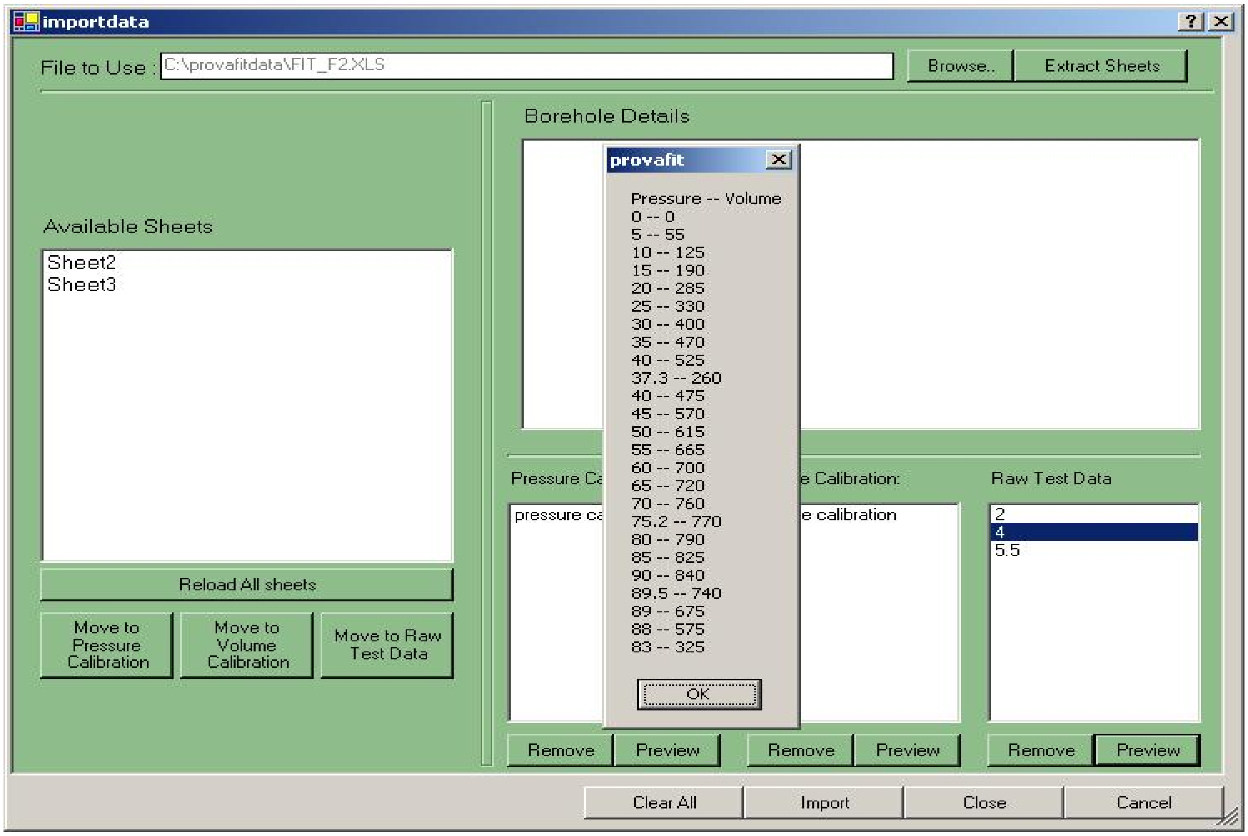
FDOT PPMT Excel Format for Volume and Membrane Calibrations



Click on Browse for searching and selecting the file desired for import. Once user selects the file, click on "Extract Sheets". ProvaFIT reads the Excel file and appropriately places the calibration and the Test Data files. Other sheets are shown under "Available Sheets".



Users can click on the Preview button under each section to review the data for the selected file in that section. For instance, if a user wants to preview Raw Test Data “4”, Select 4 from the Raw Test Data section and click on the corresponding “Preview” button. The data in it is shown as follows.



Once the user is satisfied with all the details, click on “Import”. This will prompt the user where to store the project. The project is named the same as that of the Excel file to avoid confusion from the importing of data.

Once the users are done with importing click on “Close” to close the import form.

If a user wants to import more Excel files, first click on “Clear All”. Then click on browse and select another file. Follow the remaining steps to complete the import.

Section 3
Calculations

There are several calculations that are performed in this software. This section explains what information the program uses to make the calculations.

3.1 Calibration

a. Volume Calibration Slope

The Volume Calibration Slope is used to adjust reading taken from the pressuremeter. This calibration is used to adjust for the system expansion due to the pressure exerted on the system during a test. The equation that is used to determine the slope is:

$$m_v = \frac{\sum_{j=0}^{n-1}(V_j) \times \sum_{j=0}^{n-1}(P_j) - i \times \sum_{j=0}^{n-1}(V_j \times P_j)}{\left(\sum_{j=0}^{i-1}(V_j)\right)^2 - n \times \left(\sum_{j=0}^{i-1}(V_j)\right)}$$

The following table explains the variables that are used in this equation.

m_v	=	Volume Calibration Slope
n	=	Number of points used to calculate slope
V	=	Set of the n most recently recorded volume points
P	=	Set of the n most recently recorded pressure points

b. Hydrostatic Correction Calculation

The hydrostatic correction, which is the correction for the head of water at the center of the probe at depth, is calculated using the following formula:

$$P_{Hydrostatic} = P_{Raw} + H_{Total} \times \left(\frac{1g}{1ml}\right) \times \left(\frac{9.81m}{1s^2}\right)$$

H_{Total}	=	*Depth of Sounding + Unit Height – Tip to Center of Probe*
$P_{hydrostatic}$	=	Hydrostatic pressure in kPa
P_{Raw}	=	Raw pressure in kPa
H_{Total}	=	Depth from control unit to center of Probe

3.2 Data Reduction Calculations

a. Volume Reduction

To reduce the volume from the Raw Data Collected from the Unit to the actual corrected volume, the software uses the following formula.

$$V_{Reduced} = V_{Raw} - \frac{(2 \times P_{Raw}) + \rho \times g \times (H_{Total})}{2 \times Volume\,Calibration\,Slope}$$

b. Pressure Reduction

The following equation is used to reduce the pressure recorded from the pressuremeter unit to the actual pressure applied at the probe.

$$P_{Reduced} = \rho \times g \times (H_{Total}) \text{ - Pressure Calibration Adjustment}$$

3.3 Strain Calculations

a. Volumetric Strain

The equation used to determine the Volumetric Strain is:

$$\varepsilon_{Volumetric} = \frac{\Delta V}{V_0}$$

V_0 = Initial Probe Volume

ΔV = (Current Injected Volume - V_0)

b. Radial Strain

The Equation for calculating Radial Strain is:

$$\varepsilon_{Radial} = \frac{\Delta r}{r_0} = \sqrt{\frac{\Delta V}{\pi \times l \times r_0^2} + 1} - 1$$

r_0 = Initial Probe Radius

Δr = Current Radius – r_0

l = Length of exposed membrane

3.4 Elastic Modulus Calculations

a. Pressure vs. Volume

The formula for calculating the elastic modulus between two points from pressure and volume data is:

$$E = 2 \times (1 + \nu) \times \left(\frac{P_2 - P_1}{V_2 - V_1} \right) \times \left(\frac{V_2 - V_1}{2} + V_1 + V_0 \right)$$

E = Elastic Modulus

ν = Poisson's Ratio

P_1 = Pressure at Point 1

P_2 = Pressure at Point 2

V_1 = Volume at Point 1

V_2 = Volume at Point 2

V_0 = Probes Initial Volume

b. Pressure vs. Radial Strain

The equation for calculating radial strain is as follows:

$$E = (1+\nu)\times\left[(1+R_1)^2+(1+R_2)^2\right]\times\left(\frac{P_2+P_1}{(1+R_2)^2-(1+R_1)^2}\right)$$

R_1	=	Radial Strain at Point 1
R_2	=	Radial Strain at Point 2
P_1	=	Pressure at Point 1
P_2	=	Pressure at Point 2
ν	=	Poisson's Ratio

c. Limit Pressure

The Software uses the last two points to create a straight line approximation of elastic range to determine where the limit pressure will be. The limit pressure is obtained at the pressure corresponding to approximately twice the initial volume of the probe. Using the following formula the estimated limit pressure is calculated:

$$m = \frac{P_2-P_1}{\left(\frac{1}{V_2}\right)-\left(\frac{1}{V_1}\right)}$$

$$b = P_1 - m\times\left(\frac{1}{V_1}\right)$$

$$p_L = \frac{1}{(2\times V_0)}\times m + b$$

$$p_L = \frac{1}{2\times V_0}\times\frac{P_2-P_1}{\left(\frac{1}{V_2}\right)-\left(\frac{1}{V_1}\right)}+\left(P_1-\frac{P_2-P_1}{\left(\frac{1}{V_2}\right)-\left(\frac{1}{V_1}\right)}\times\frac{1}{V_1}\right)$$

p_L	=	Limit Pressure
V_0	=	Initial Probe Volume
V_1	=	Probe Volume at Point 1
P_1	=	Probe Pressure at Point 1
V_2	=	Probe Volume at Point2
P_2	=	Probe Pressure at Point 2

Appendix F APMT 2005

Automated Pressuremeter and Data Acquisition System

Instruction Manual

12 January 2006
Revision V. 0.95

Florida Institute of Technology
Civil Engineering
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Melbourne, Florida 32901
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Table of Contents

1. Introduction

The purpose of the Automated Pressuremeter (APMT) Software is to allow the connection of the Florida Institute of Technology automated Pencel Pressuremeter to a computer to record and analyze test data in a timely fashion. This manual explains how to install APMT software package, to run an automated test, and to use the analysis software.

1.1. General Function of the APMT System

The APMT system is a data acquisition and analysis system designed specifically for Automated Pressuremeter testing. This system can be used with Roctest Inc., PENCEL Pressuremeter that has been digitally instrumented by Florida Tech. This system gives the user the ability to record data in the field and have the reduced data available for engineering decisions within minutes of completing the test.

1.2. The APMT Data Acquisition and Analysis Software

APMT software functions as an interface between the user and the data acquisition hardware. This includes recording analyzing and presenting data to the user, and storage of the recorded data. The APMT system is a graphically driven software system. This means that user interaction is preformed using buttons and controls presented on organized screens.

The APMT system is designed around the concept of performing a series of tests in one sounding at a time. The operator enters parameters for a given sounding and then enters a test; the operator can change the depth within a same sounding without leaving the test window.

1.3. Florida Tech Data Acquisition Module

The data acquisition module that is fitted into the Pencel Pressuremeter performs the signal capture of the two parameters that are needed for the pressuremeter test (PMT) and sends it to the APMT software for analysis. The data acquisition module includes a Setra Model 209 XDUC pressure transducer capable of reading pressures from -14.7psi to 500psi (-101kPa 3447kPa). This ranges exceeds the -14.7 to 360 psi (-100 to 2500 kPa) range supplied with the standard Pencel Pressuremeter to avoid possible damage to the electronics because of over range pressures. The data acquisition module uses a linear potentiometer to determine the current volume of fluid injected into the PMT probe. The digital signals from these two devices are routed through an electronic interface board that consists of a Programmable Interrupt Controller (PIC) microprocessor and a serial interface chip. An 8 volt regulator is used as the power source for the pressure transducer and a 5 volt regulator is used to supply power for the potentiometer. A data transfer cable is connected to the serial port of the laptop computer, to run the APMT software.

2. System Installation

APMT can interface with Windows based computer systems. Below are the minimum system requirements to setup install and run the APMT system.

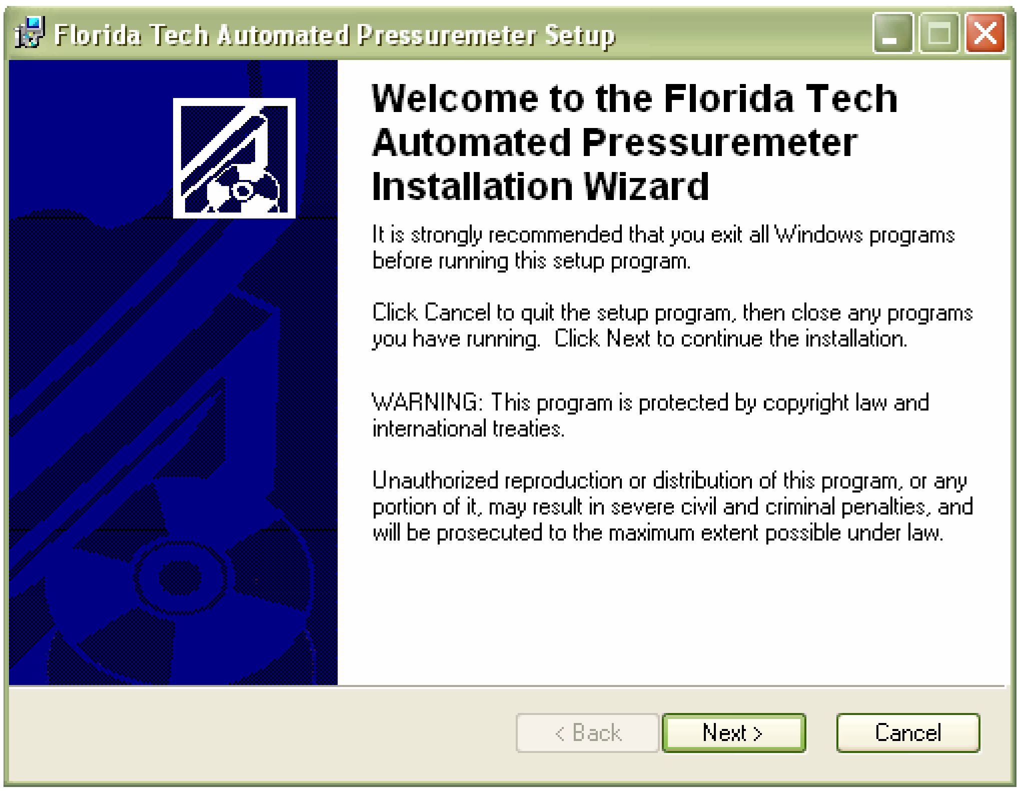
2.1. Minimum APMT Requirements

- Florida Tech Automated Pencel Pressuremeter
- Windows PC or Laptop with Windows XP or 2000
  - 32 MB Ram
  - 20 MB hard drive Space
  - Serial Port (Built-in or USB)
  - Soundcard and speakers

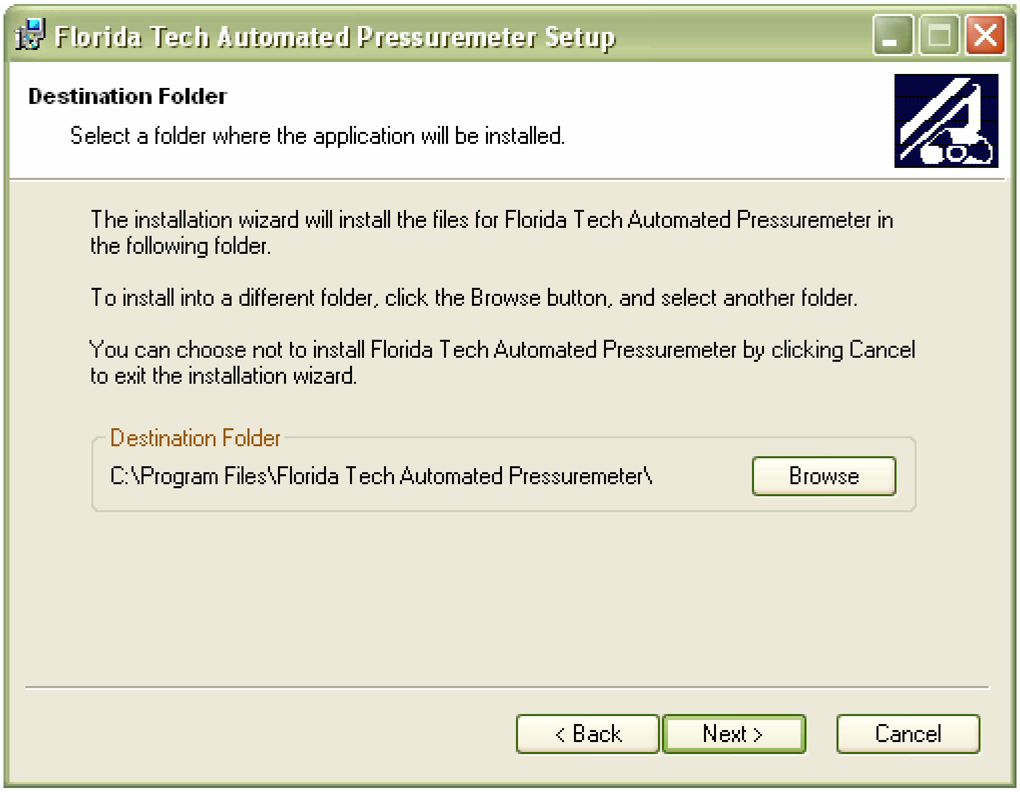
2.2. Software Installation

The instructions in this section are to guide you through the software installation of the APMT system. The installation program can be found on the supplied installation CD along with ProvaFIT 2005. APMT software is located in the APMT Directory.

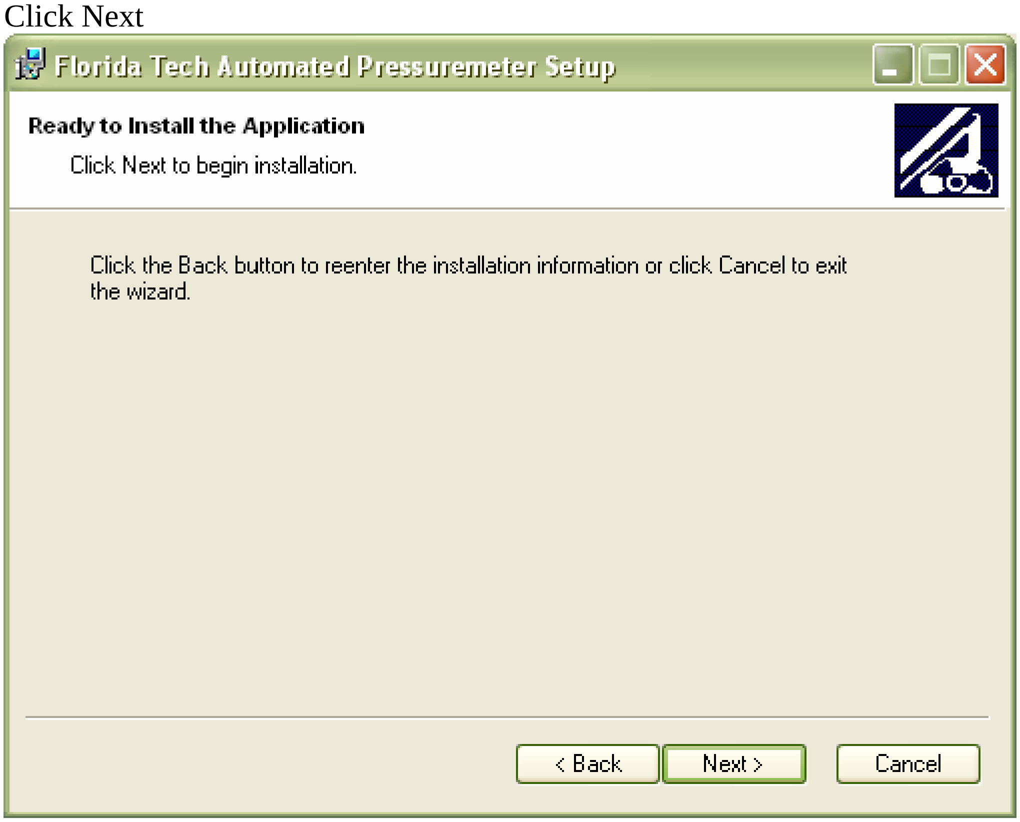
1) Run **<CDDrive Letter>:\APMT\install.exe**



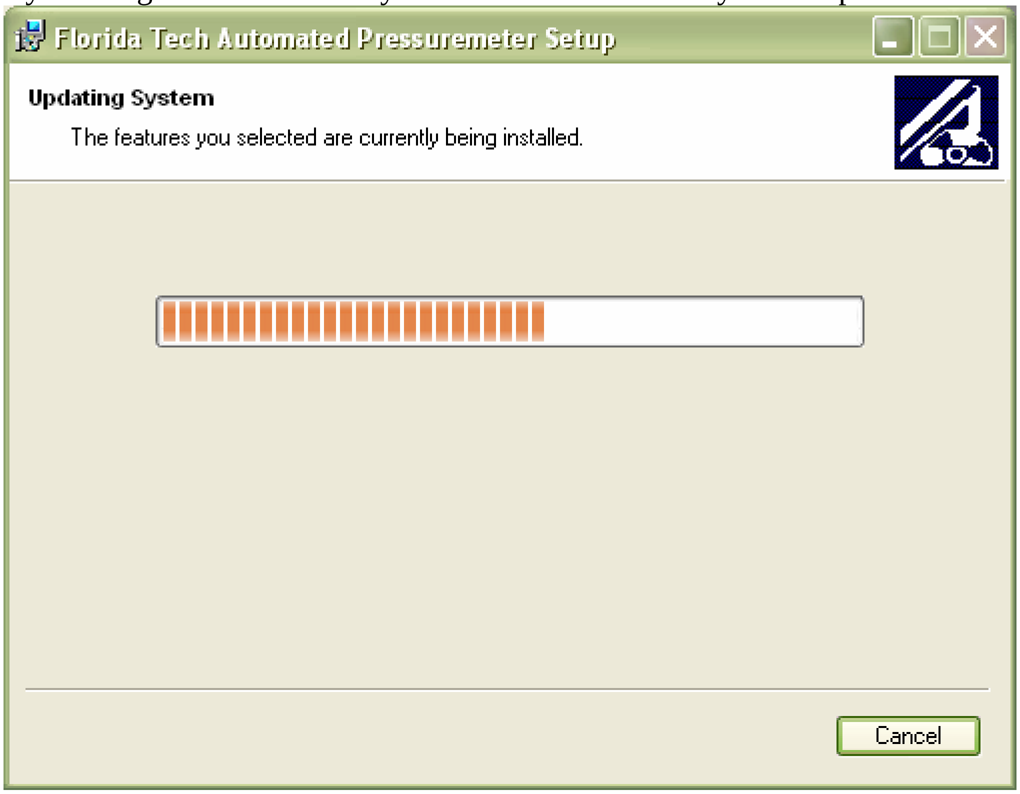
2) Click **Next**



3) Click Next



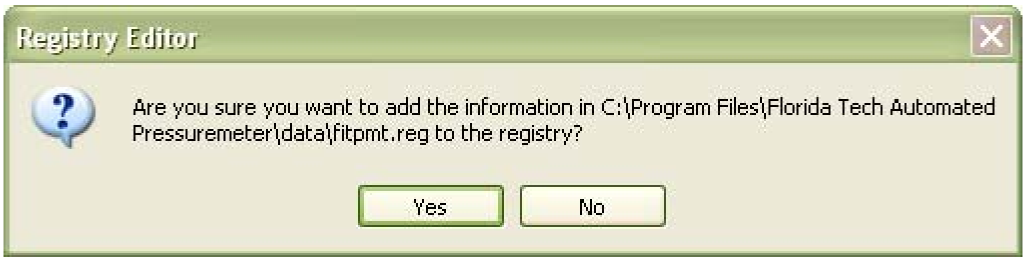
4) By clicking next the APMT system will be installed on your computer.



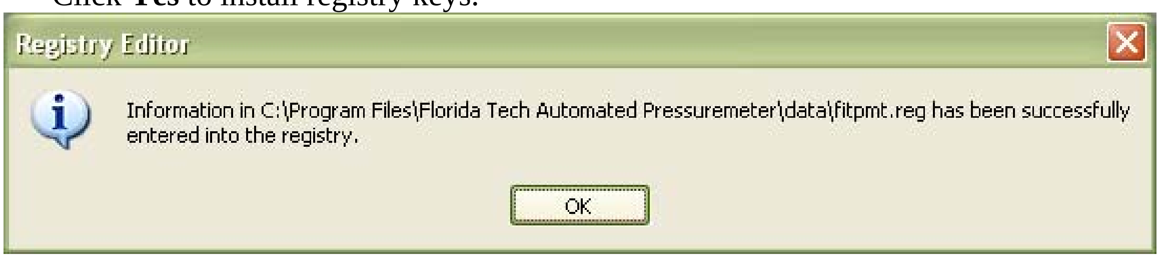
5) Once the installation has completed the following screen will be displayed. Click Finish to Complete Installation.

IMPORTANT: To ensure that the APMT system functions properly you **must** install the registry settings. These can be found from the start menu.

Under the Windows XP operating system follow this menu sequence:
Start -> All Programs -> Florida Tech Automated Pressuremeter -> Install Registry Keys
Under the Windows 2000 operating system follow this menu sequence:
Start -> Program Files -> Tech Automated Pressuremeter -> Install Registry Keys



Click **Yes** to install registry keys.



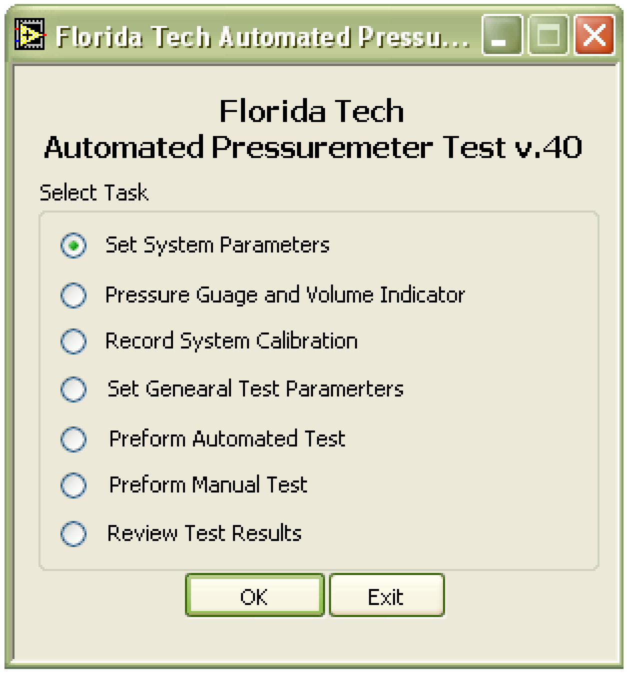
The preceding message will be displayed after the registry keys are installed.

6) Congratulations, the Florida Tech Automated Pressuremeter software has been successfully installed, on your system. You can now run the software from the following sequence:
Start -> All Programs -> Florida Tech Automated Pressuremeter -> Florida Tech Automated Pressuremeter.

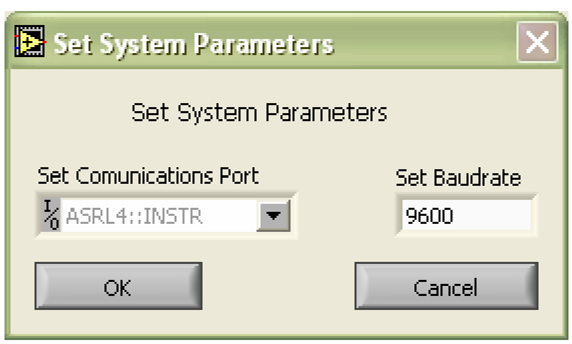
3. Using the APMT Software

3.1. Software Configuration

The Florida Tech Automated Pressuremeter Software needs to be configured before it can be used to retrieve data from the data acquisition software. When the APMT software is launched this screen is displayed:



Before the operator uses this program the System Parameters must be set. To do this click on the radio button located to the left of "Set System Parameters" then click OK, the following screen will be presented:



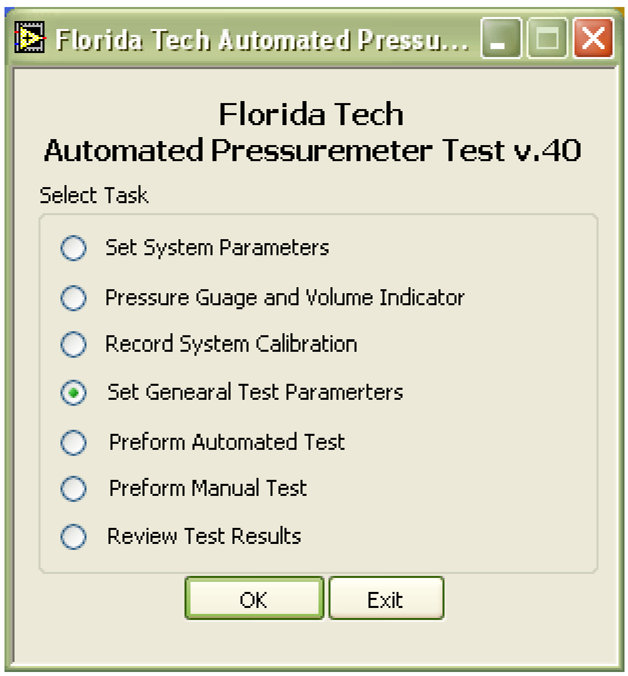
The first item that must be configured is the "Set Communications Port" Drop down box that specifies which Com port the APMT is connected to. The Com ports can be displayed in 2 ways. The table below illustrates the standard choices and their alternates, which may be displayed by the software.

COM1	ASRL1::INSTR
COM2	ASLR2::INSTR
COM3	ASLR3::INSTR
COM4	ASLR4::INSTR

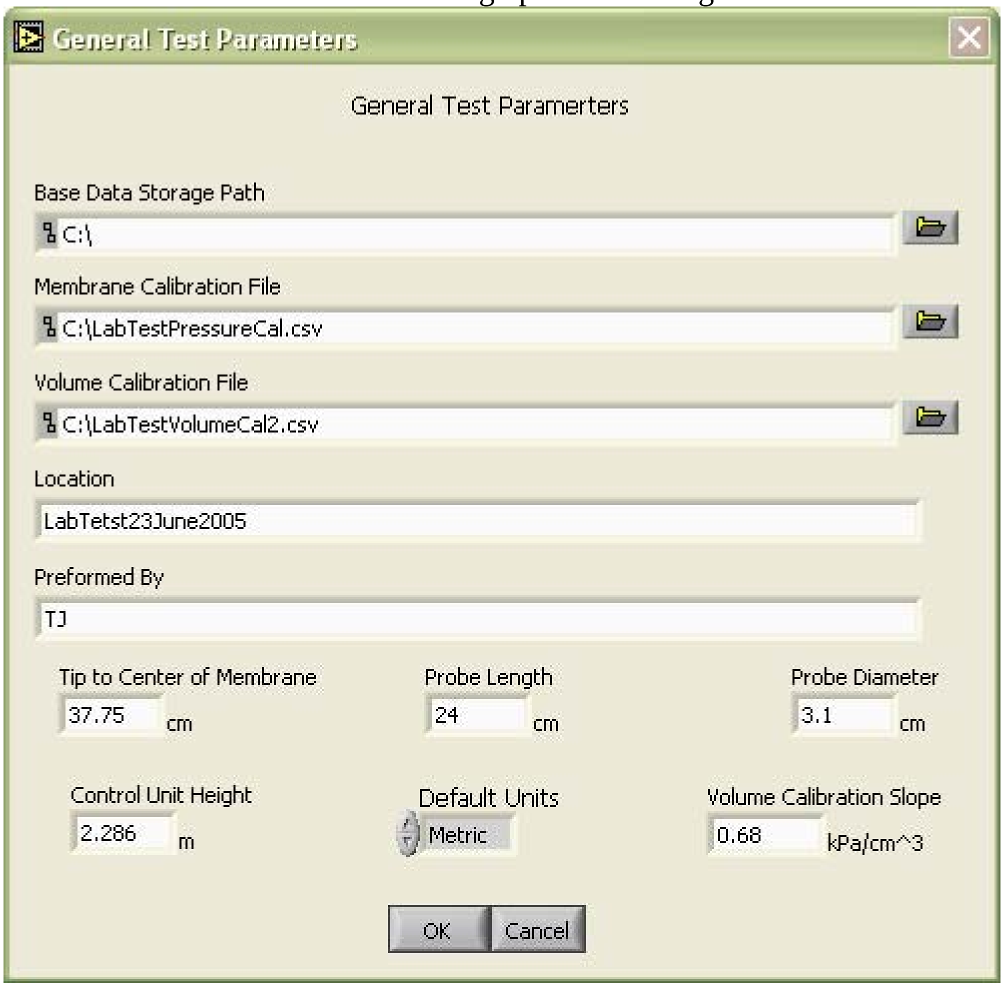
By default the system is configured for a baud rate of 9600, this is a hardware setting and should not need to be changed. Only change this value if instructed to by "Florida Tech." Once any necessary adjustments have been made to the settings click OK to save your changes and return to the Main Screen or Cancel to discard and return to the Main Screen without saving.

3.2. Preparing to Run an Automated Test

Before start starting an automated test you will first need to enter some general test parameters. To set these values click on the "Set General Test Parameters" from the main menu.



Then click OK. This action will bring up the following screen



3.2.1. Explanation of Input Fields

1) **Base Data Storage Path:** This field is used specify where the test data is stored, and the default location for saving the Calibration Files.
2) **Membrane Calibration File:** This is the path to the membrane calibration file used for reducing recorded data to adjust for the membranes resistance. This field is automatically set when the record calibration feature is used.
3) **Volume Calibration File:** This path to the volume calibration file includes the pressure and volume data taken during the volume calibration procedure. This field is automatically set when the record calibration feature is used.
4) **Location:** The data entered is the location of the test site (E.g. Proposed Administration Building, Anytown, U.S.A). The APMT software will use this information to create a subfolder to store all the sounding information for the test site.
5) **Preformed By:** In this field enter the operator responsible for conducting this test. This name will be included on the reports generated by the software.

6) **Tip to Center of Membrane:** The operator will need to measure the distance from the tip of the probe to the center of the membrane and enter that value. This information is used in calculating the hydrostatic head that is present on the probe.

7) **Probe Length:** This is the length of the exposed membrane and this **must** be entered by the operator before the test is preformed.

8) **Probe Diameter:** This dimension is the Probe diameter at the midpoint of the exposed membrane. This value is used for calculating the initial volume and radius of the probe for the volumetric and radial strain calculations, and it must be entered before a test is preformed.

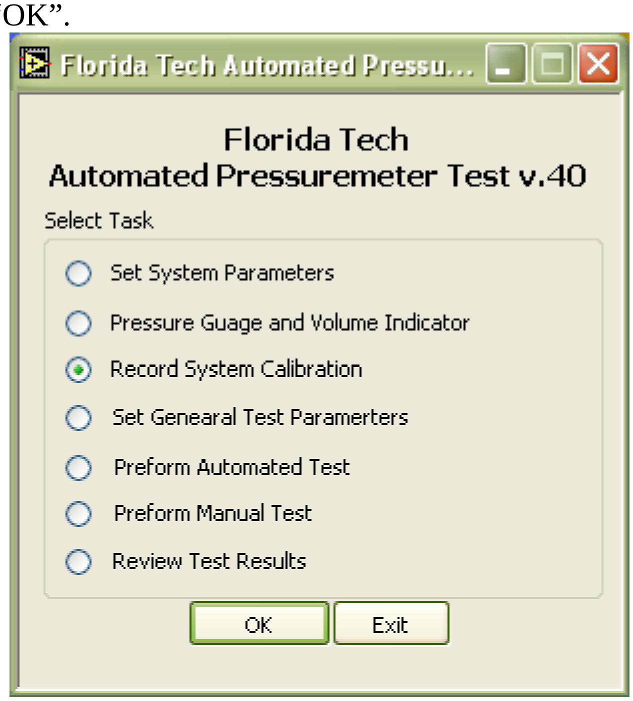
9) **Control Unit Height:** The height above ground level that the PMT control unit is located is entered and used in the calculation of the hydrostatic head.

10) **Default Units:** This control allows the operator to select units to be displayed and recorded in the data files.

11) **Volume Calibration Slope:** This value is the straight line approximation of the system volume expansion that is recorded during the volume calibration. This is used for the system expansion correction that is applied when data is reduced during a test.

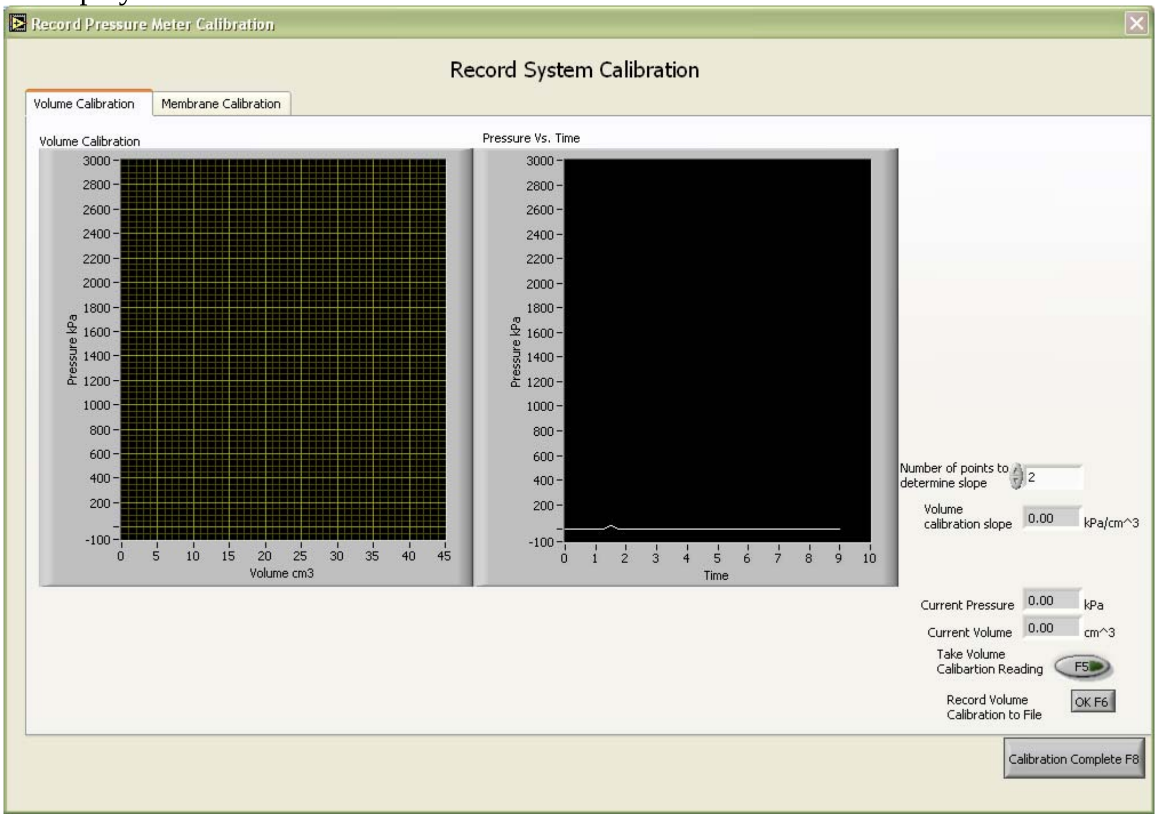
3.3. Recording Calibration for Test

To perform the pressuremeter system calibration, run the “Record System Calibration” module in the APMT software. This module can be found from the main menu. To run the “Record System Calibration” module select the option from the main menu and then click “OK”.



3.3.1. Volume Calibration

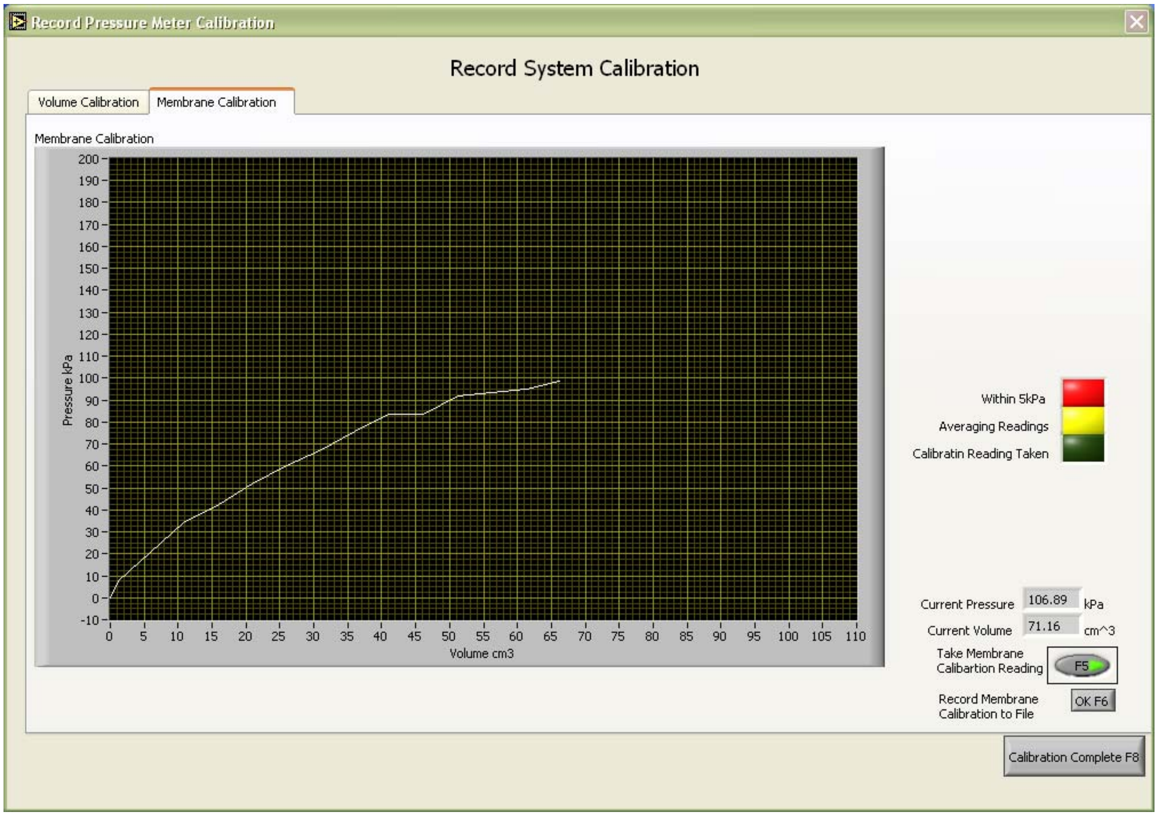
Once the "Record System Calibration" module has loaded following screen will be displayed.



This screen is used for recording the volume calibration and setting the volume calibration slope. The graph on the left will show the recorded points from the calibration. The graph on the right shows pressure verses time to allow the operator to record a data point after the pressure has stabilized. To take a reading the operator clicks on the button labeled "Take Volume Calibration Reading," this will capture the current pressure and volume reading into memory and also shows this point on the left graph. After three points have been recorded the system will begin to calculate the "Volume Calibration Slope." The software selects either the last 2 or 3 recorded points to determine the straight line slope; the number of recorded points used is controlled by the "Number of points to determine slope" box. Once the calibration has been completed the operator should now click on the "Record Volume Calibration File" button. The system will then display a dialog box to specify the location where to save the data, and this will also set the volume calibration slope in the "General Test Parameters" module, which is used later for reducing test data.

3.3.2. Membrane Calibration

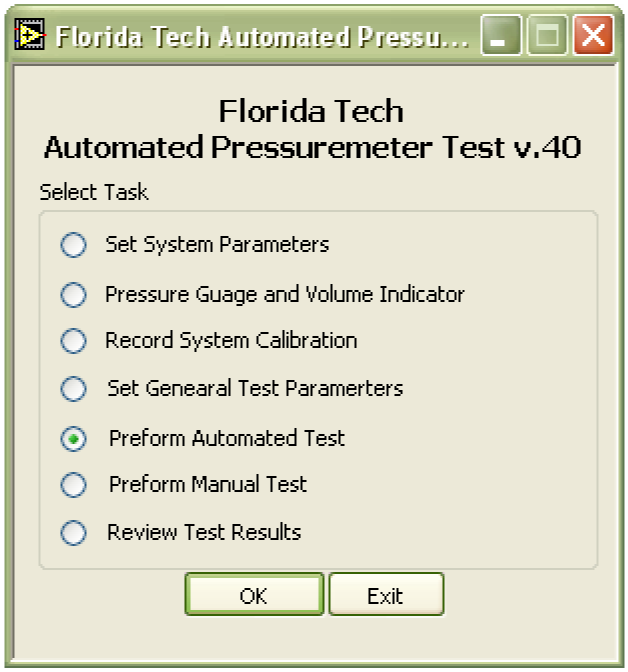
The next step is to perform the Membrane Calibration located in the "Record System Calibration" module. When this module is opened the operator will need to click on the "Membrane Calibration" tab located near the top of the screen. The Membrane Calibration screen is shown below; this image also shows typical data collected during a membrane calibration.



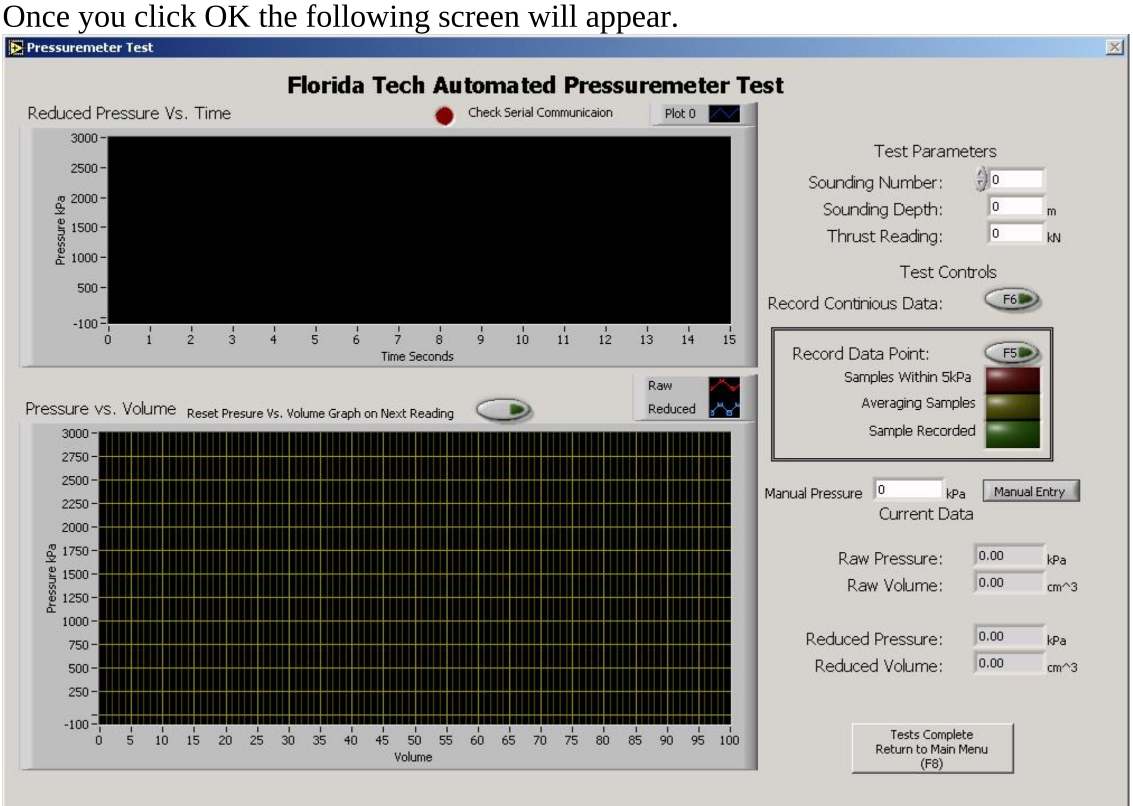
This calibration has been automated to a greater degree than the volume calibration. When performing the Membrane Calibration the operator will click on the "Take Membrane Calibration Reading" button. When the take membrane calibration reading button is clicked the software starts an automated process that checks each reading, first to insure that each consecutive reading is within 5 kPa, and a second check that consecutive readings are within 1 bit of change to compensate for the search methods of the digital to analog converters. If a reading falls outside the 1 bit limit of change the system will continue collecting samples of data until the previous three readings are all within 1 bit change of each other. As long as the samples are within 5 kPa the red light on the panel will illuminate, the yellow light will illuminate as long as the samples are within 1 bit of each other, and when the sample has been taken the green light will turn on and a system bell will be played through the system speakers. When determining the pressure and volume for the recorded point, the software will take the average of the three previous readings and that will become the recorded reading. Once a reading is recorded into memory the system will add this point to the graph to show the operator the progression of calibration. To ensure the proper test results one calibration reading 5 cm^3 past the final volume to be reached during the test should be recorded. For example, if the soil is to be tested by injecting 90 cm^3 into the probe, then the membrane calibration should be recorded up to 95 cm^3. After collecting all necessary calibration readings the operator needs to click on the "Record Membrane Calibration to File" button, this will display a dialog box requesting the name of the file to save the calibration to and also set the path for where the calibration file is stored in the "General Test Parameters" module. To exit this module when the calibration is completed calibration and the data has been saved click on the "Calibration Complete" button to return to the main menu.

3.3. *Performing an Automated Test*

After completing specifying the probe dimensions and recording the volume and membrane calibrations the program is ready to record data from an automated test. From the main menu select "Perform an Automated Test" then click OK.



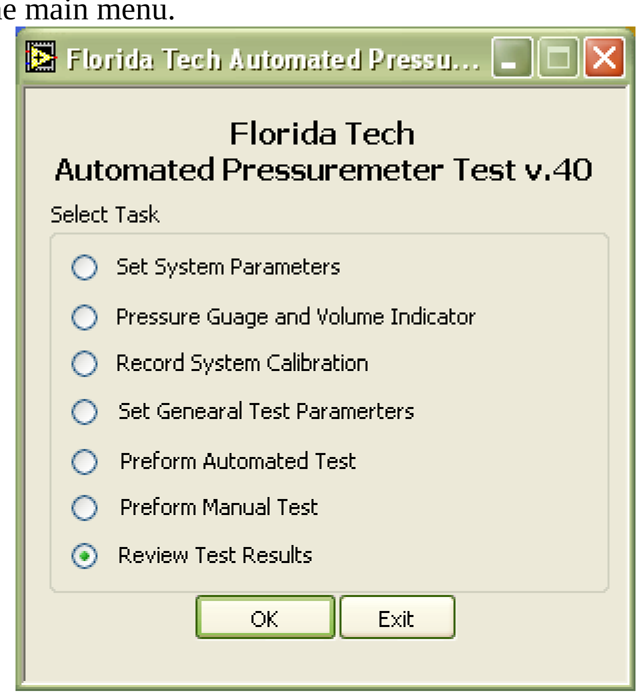
Once you click OK the following screen will appear.



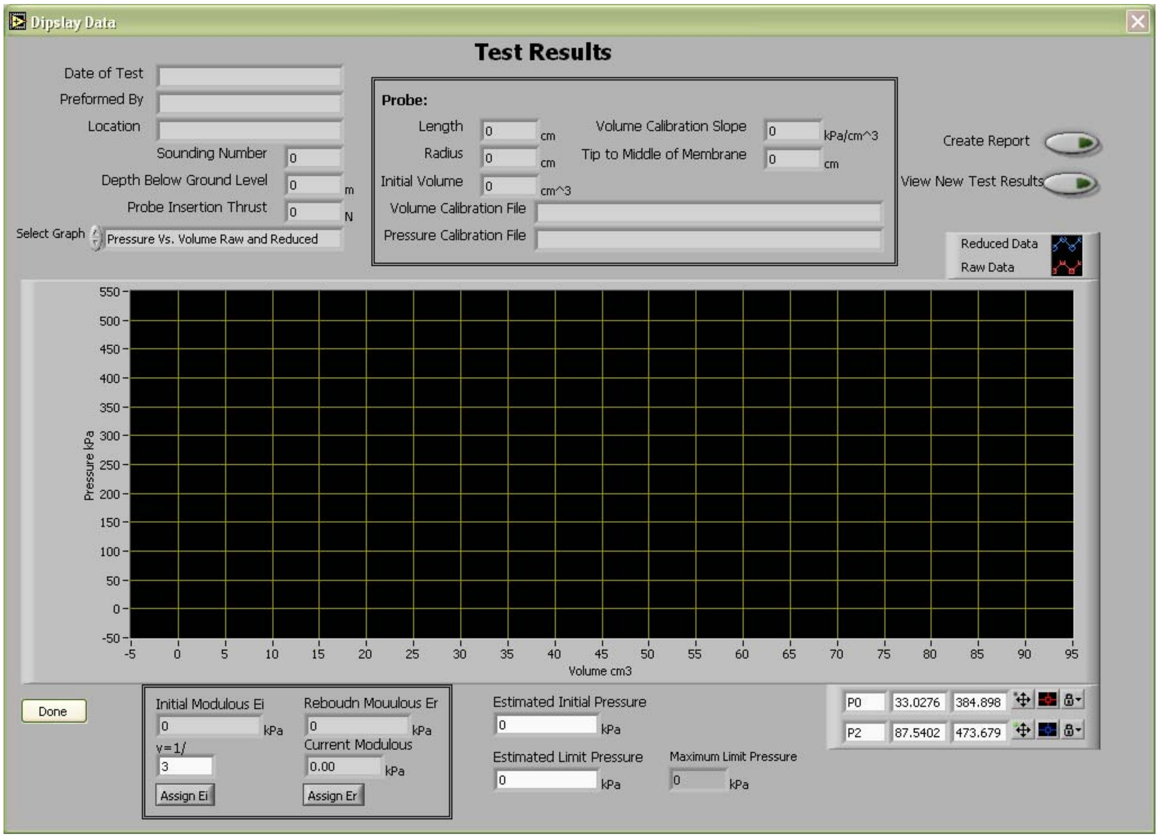
The automated test screen is divided in three main areas 1) the pressure vs time and pressure vs volume graphs, 2) the test parameters, and 3) data termed test controls. The pressure vs time graph displays continuous pressure readings during for monitoring purposes during each volume increment. The pressure vs volume graph, displayed on the left side of the panel, displays each point as it is recorded. The red points and lines are the Raw Data points, while the blue points and lines are the Reduced Data points. In the upper right corner of the screen is the test parameters are specific to this test. The sounding number is used for data organization and the reports. The Sounding depth control is used to set the depth that the bottom tip of the probe has been inserted to. The thrust reading can be used to store the thrust needed to insert the probe to the given depth, if available. The remainder of the right side of the panel is used for controlling the test. The Record Data Point works similar to the "Take Membrane Calibration Reading" button, except that when a data point is recorded it is automatically saved, no additional user interaction is required to save the data. As equal 5 cm^3volumes of water are injected, continue to press the Take Reading button and wait for the green light prior to injecting the next volume; this process is repeated until the test is complete. When a subsequent test is going to be preformed in the same sounding, but at a different depth, you can click on the "Reset Pressure verses Volume Graph" and the graph will clear when the next reading taken. To exit and return to the main menu click on the "Tests Complete Return to Main Menu" button.

3.4. Reviewing Test Results

After a test has been preformed the collected data can now be analyzed to determine several engineering parameters. To start to analyze the data select "Review Test Results" from the main menu.



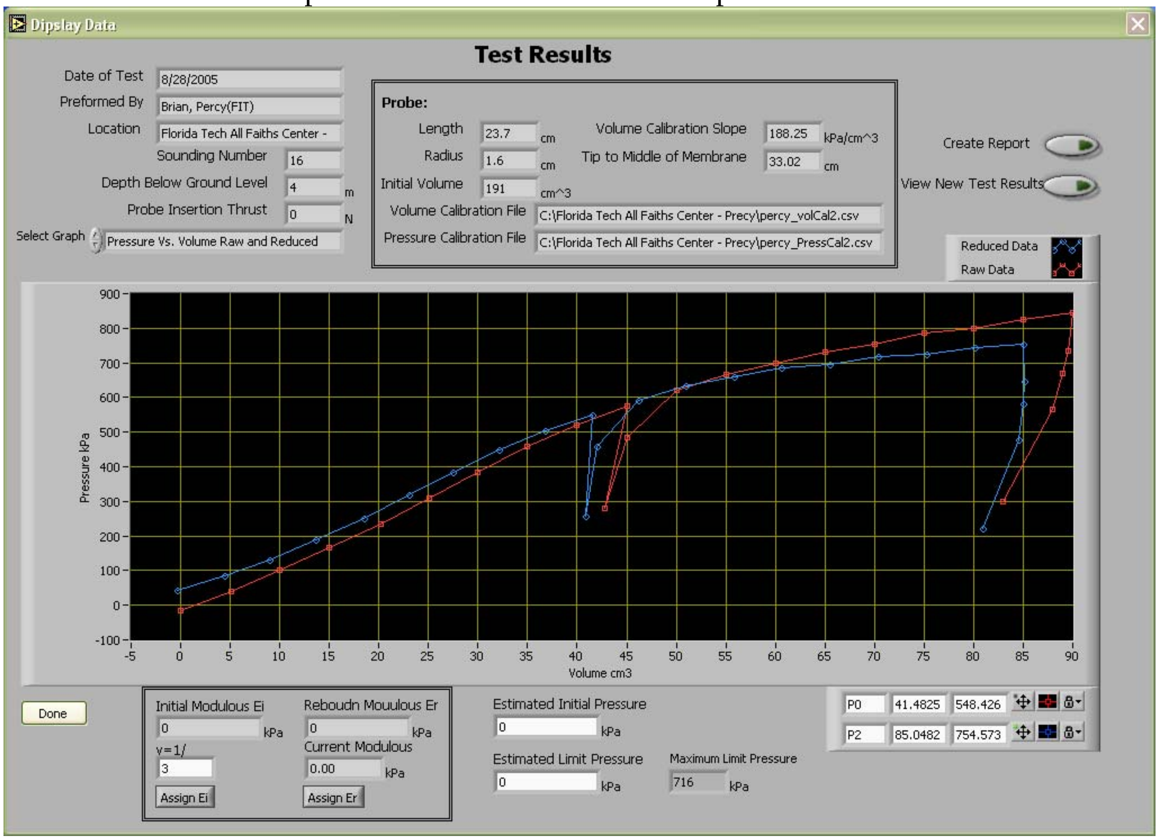
After clicking OK the Review Test Results module will appear, as shown below.



This is the screen used to perform all analysis of your data in APMT. To load a set of data click on the "View New Test Results" button, this will prompt the user for the reduced data file to view, by default the name of the file is Reduced_Data.csv. APMT stores data from tests in a predictable pattern. Reduced Data is stored in the following generalized location:

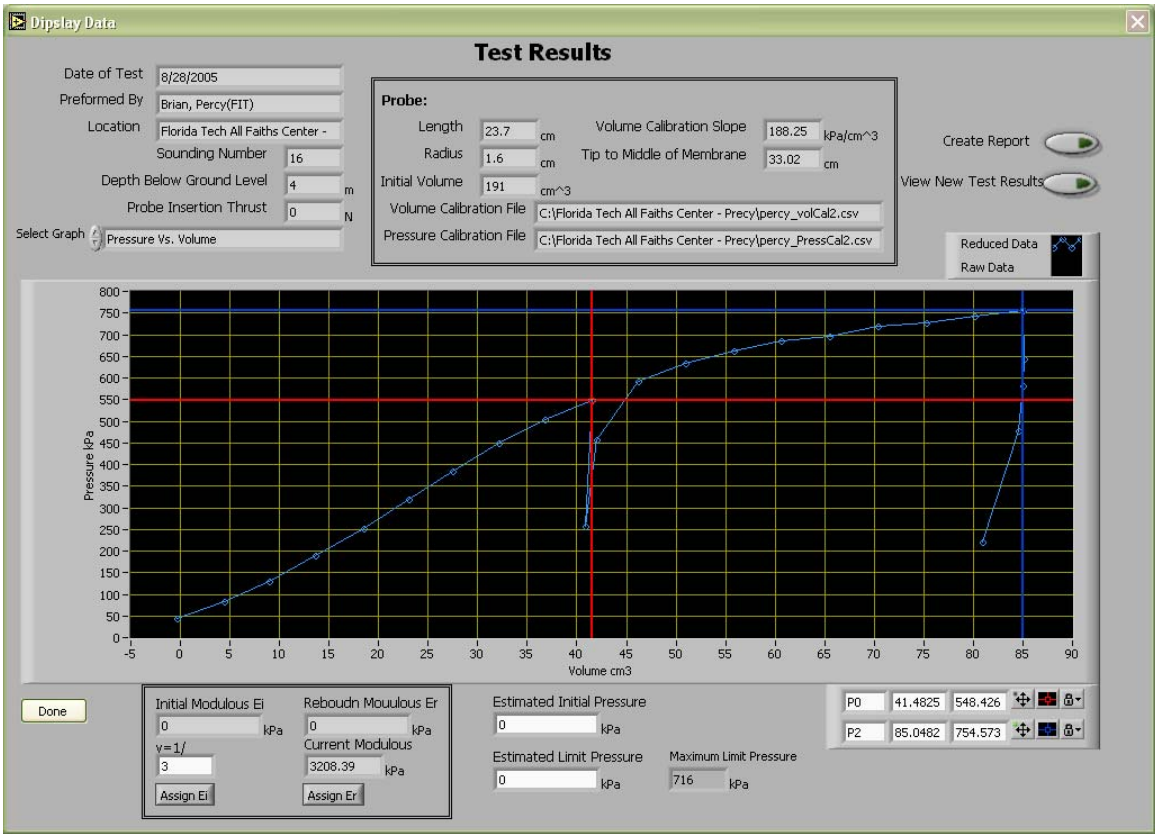
Base Path\Location of Test\Sounding_NNN\Depth\Reduced_Data.csv

When a test is open a screen similar to below is presented:

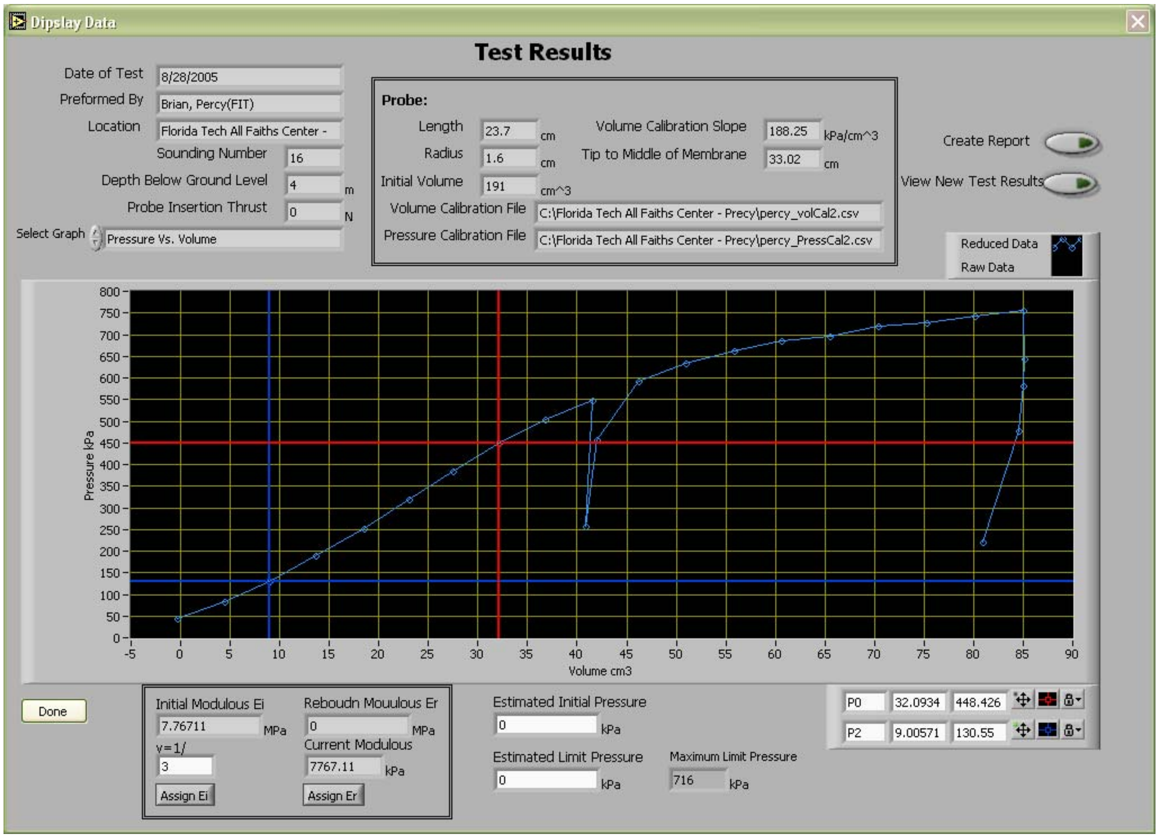


The upper portion of the screen includes the parameters that were set before performing the test, and the calibration files used to reduce the data. The center of the screen shows the raw and reduced pressure vs. volume data that was collected during the test. The "Select Graph" control, just above the graph, changes the view of the data that that is presented; the choices are "Pressure Vs. Volume Raw and Reduced," "Pressure Vs. Radial Strain," Pressure Vs. Volumetric Strain," "Pressure Vs. Volume" (reduced data only). You can choose which representation of data you want by clicking on the arrows on the left side of the "Select Graph" box.

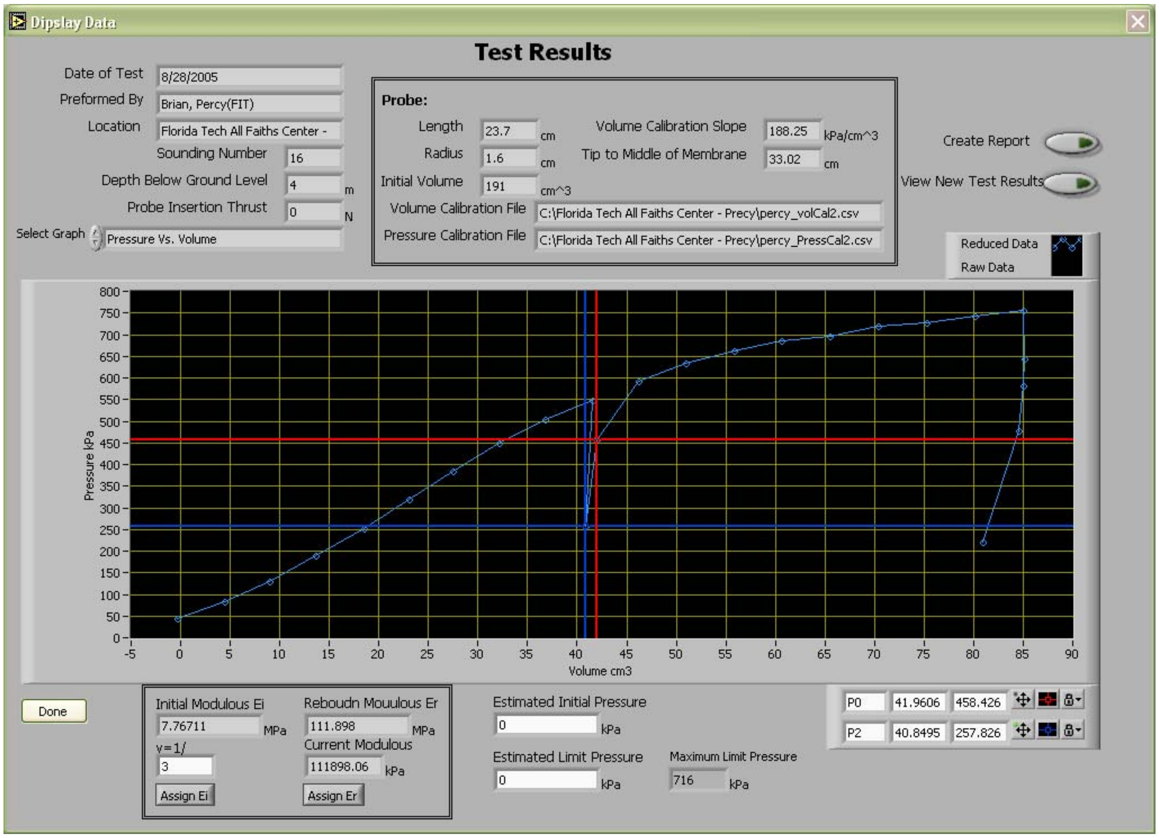
For assigning the initial modules (E_i) and Rebound Modulus (E_r) either the "Pressure Vs. Volume," or "Pressure Vs. Radial Strain" view must be selected. In both of these views a set of crosshairs will be turned on to allow the selection of two points to use in calculating the moduli. The screen shows the how the cross hairs can be used to select the rebound modulus



A modulus is calculated based on the position of each crosshair, and each time a new value is selected it updates the “Current Modulus” indicator. When the data points are selected to determine the Initial Modulus then click on the “Assign Ei” button, as shown below, and that modulus will be placed in the Initial Modulus box.



The same process is then used to select the rebound modulus, and to assign the rebound modulus click on the “Assign Er” button.



When a test is loaded into APMT to analyze, the software selects the last six (6) readings where there is an increase in volume and determines a predicted limit pressure for that test, and is shown in the Maximum Limit Pressure.

When the analysis has been completed the user can click on the “Create Report” button to generate a report saving the analysis that has just been completed. If the user wants to look at another set of data all that is needed to be done is to click on the “View New Test Results” button and select the new set of data. To exit and return to the main menu then click on the “Done” button.

3.5. Test Reports

The APMT software has a built in feature to develop a report to summarize the data collected and analyzed. This report creates a standard format for presenting data. The report when generated is saved in the directory that the test data is stored in. The report is grouped into 5 sections; Test Summary, Probe Parameters, Graphs, Recorded Data, and Membrane Calibration.

The first section of the report is the Test Summary, gives you a overview of the data found in the report. The summary section includes:

- Location of Test
- Date of Test
- Test Operators
- Sounding Number
- Probe Insertion Thrust
- Depth of Probe Below ground level

- Unit Height above ground level
- Initial Elastic Modulus (E_0)
- Rebound Elastic Modulus (E_r)
- Estimated Initial Pressure (P_0)
- Estimated Limit Pressure (P_l)

The next section of the report produces a record of the probe parameters taken during the test. These parameters include:

- Probe Length
- Probe Radius
- Probes Initial Volume
- Distance from Tip of Probe to Middle of Membrane
- Volume Calibration Slope used for data reduction
- Volume Calibration Filename
- Pressure Calibration Filename

The report also produces three graphs that represent the results that were recorded. The first graph is the Pressure vs. Volume graph, this graph shows the raw and reduced curves for pressure vs. volume and it also has the membrane calibration curve superimposed on to it. The second and third graphs, Pressure s. Volumetric Strain and Pressure vs. Radial Strain, only depict the reduced data points.

The next section of the report is the Recorded Data. This section prepares a table with the following information:

- Raw Volume
- Raw Pressure
- Reduced Volume
- Reduced Pressure
- Volumetric Strain, in %Strain
- Radial Strain, in %Strain

The final section of the report is a table that includes the volume and pressure data that were recorded during the membrane calibration.

4. Calculations

There are several calculations that are performed in this software. This section explains what information the program uses to make the calculations.

4.1. Calibration

4.1.1. Volume Calibration Slope

The Volume Calibration Slope is used to adjust reading taken from the pressuremeter. This calibration is used to adjust for the system expansion due to the pressure exerted on the system during a test. This slope is determined during the Volume Calibration Section of the System Calibration Procedure. The slope is determined by either the last two or three points recorded, which is supposed to be the straight line of the graph. The equation used to determine the slope is:

m_v $$= \frac{\sum_{j=0}^{n-1}(V_j) \times \sum_{j=0}^{n-1}(P_j) - i \times \sum_{j=0}^{n-1}(V_j \times P_j)}{\left(\sum_{j=0}^{i-1}(V_j)\right)^2 - n \times \left(\sum_{j=0}^{i-1}(V_j)\right)}$$

The following table explains the variables that are used in this equation.

m_v	=	Volume Calibration Slope
n	=	Number of points used to calculate slope
V	=	Set of the n most recently recorded volume points
P	=	Set of the n most recently recorded pressure points

4.1.2. Hydrostatic Correction Calculation

The hydrostatic correction, which is the correction for the head of water at the center of the probe at depth, is calculated using the following formula:

$$P_{Hydrostatic} = P_{Raw} + H_{Total} \times \left(\frac{1g}{1ml}\right) \times \left(\frac{9.81m}{1s^2}\right)$$

H_{Total}	=	*Depth of Sounding + Unit Height – Tip to Center of Probe*
$P_{hydrostatic}$	=	Hydrostatic pressure in KPa
P_{Raw}	=	Raw pressure in KPa
H_{Total}	=	Depth from control unit to center of Probe

4.2. Data Reduction Calculations

4.2.1. Volume Reduction

To reduce the volume from the Raw Data Collected from the Unit to the actual corrected volume, the software uses the following formula.

$$V_{Reduced} = V_{Raw} - \frac{(2 \times P_{Raw}) + \rho \times g \times (H_{Total})}{2 \times Volume\, Calibration\, Slope}$$

4.2.2. Pressure Reduction

The following equation is used to reduce the pressure recorded from the pressuremeter unit to the actual pressure applied at the probe.

$$P_{Reduced} = \rho \times g \times (H_{Total}) - \text{Pressure Calibration Adjustment}$$

4.3. Strain Calculations

4.3.1. Volumetric Strain

The equation used to determine the Volumetric Strain is:

$$\varepsilon_{Volumetric} = \frac{\Delta V}{V_0}$$

V_0	=	Initial Probe Volume
ΔV	=	(Current Injected Volume - V_0)

4.3.2. Radial Strain

The Equation for calculating Radial Strain is:

$$\varepsilon_{Radial} = \frac{\Delta r}{r_0} = \sqrt{\frac{\Delta V}{\pi \times l \times r_0^2} + 1} - 1$$

r_0 = Initial Probe Radius

Δr = Current Radius – r_0

l = Length of exposed membrane

4.4. *Elastic Modulus Calculations*

4.4.1. Pressure vs. Volume

The formula for calculating the elastic modulus between two points from pressure and volume data is:

$$E = 2 \times (1 + \nu) \times \left(\frac{P_2 - P_1}{V_2 - V_1} \right) \times \left(\frac{V_2 - V_1}{2} + V_1 + V_0 \right)$$

E = Elastic Modulus

ν = Poisson's Ratio

P_1 = Pressure at Point 1

P_2 = Pressure at Point 2

V_1 = Volume at Point 1

V_2 = Volume at Point 2

V_0 = Probes Initial Volume

4.4.2. Pressure vs. Radial Strain

The equation for calculating radial strain is as follows:

$$E = (1 + \nu) \times \left[(1 + R_1)^2 + (1 + R_2)^2 \right] \times \left(\frac{P_2 + P_1}{(1 + R_2)^2 - (1 + R_1)^2} \right)$$

R_1 = Radial Strain at Point 1

R_2 = Radial Strain at Point 2

P_1 = Pressure at Point 1

P_2 = Pressure at Point 2

ν = Poisson's Ratio

4.4.3. Limit Pressure

The APMT Software uses two points selected by the user to create a straight line approximation of elastic range to determine where the limit pressure will be. The limit pressure is defined as the pressure associated with doubling the initial volume of the probe. Using the following formula the estimated limit pressure is calculated:

$$m = \frac{P_2 - P_1}{\left(\frac{1}{V_2} \right) - \left(\frac{1}{V_1} \right)}$$

$$b = P_1 - m \times \left(\frac{1}{V_1} \right)$$

$$p_L = \frac{1}{(2 \times V_0)} \times m + b$$

$$p_L = \frac{1}{2 \times V_0} \times \frac{P_2 - P_1}{\left(\frac{1}{V_2} \right) - \left(\frac{1}{V_1} \right)} + \left(P_1 - \frac{P_2 - P_1}{\left(\frac{1}{V_2} \right) - \left(\frac{1}{V_1} \right)} \times \frac{1}{V_1} \right)$$

p_L = Limit Pressure
V_0 = Initial Probe Volume
V_1 = Probe Volume at Point 1
P_1 = Probe Pressure at Point 1
V_2 = Probe Volume at Point2
P_2 = Probe Pressure at Point 2

Appendix G— Subsurface Data for 7 Instrumented Case Histories

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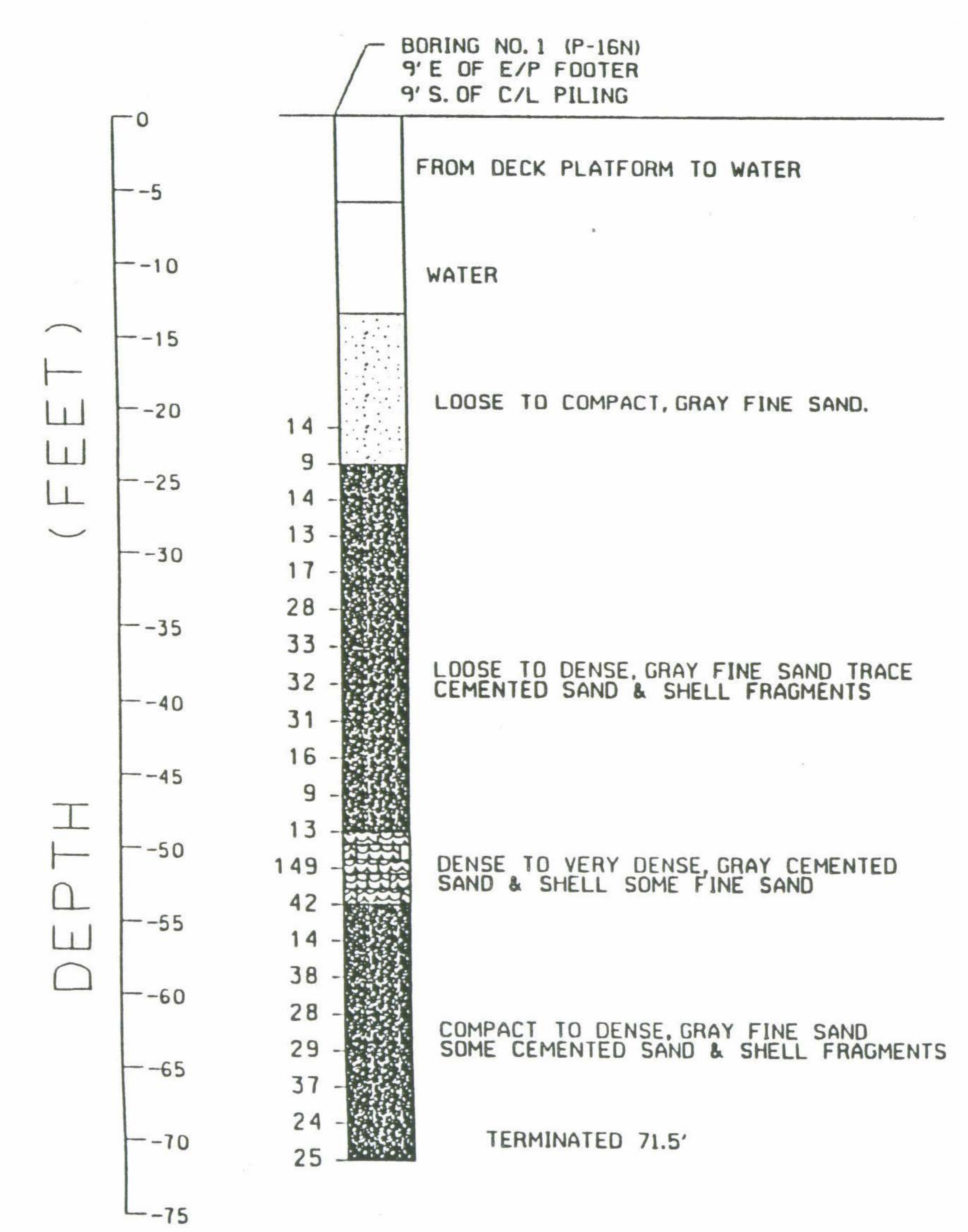
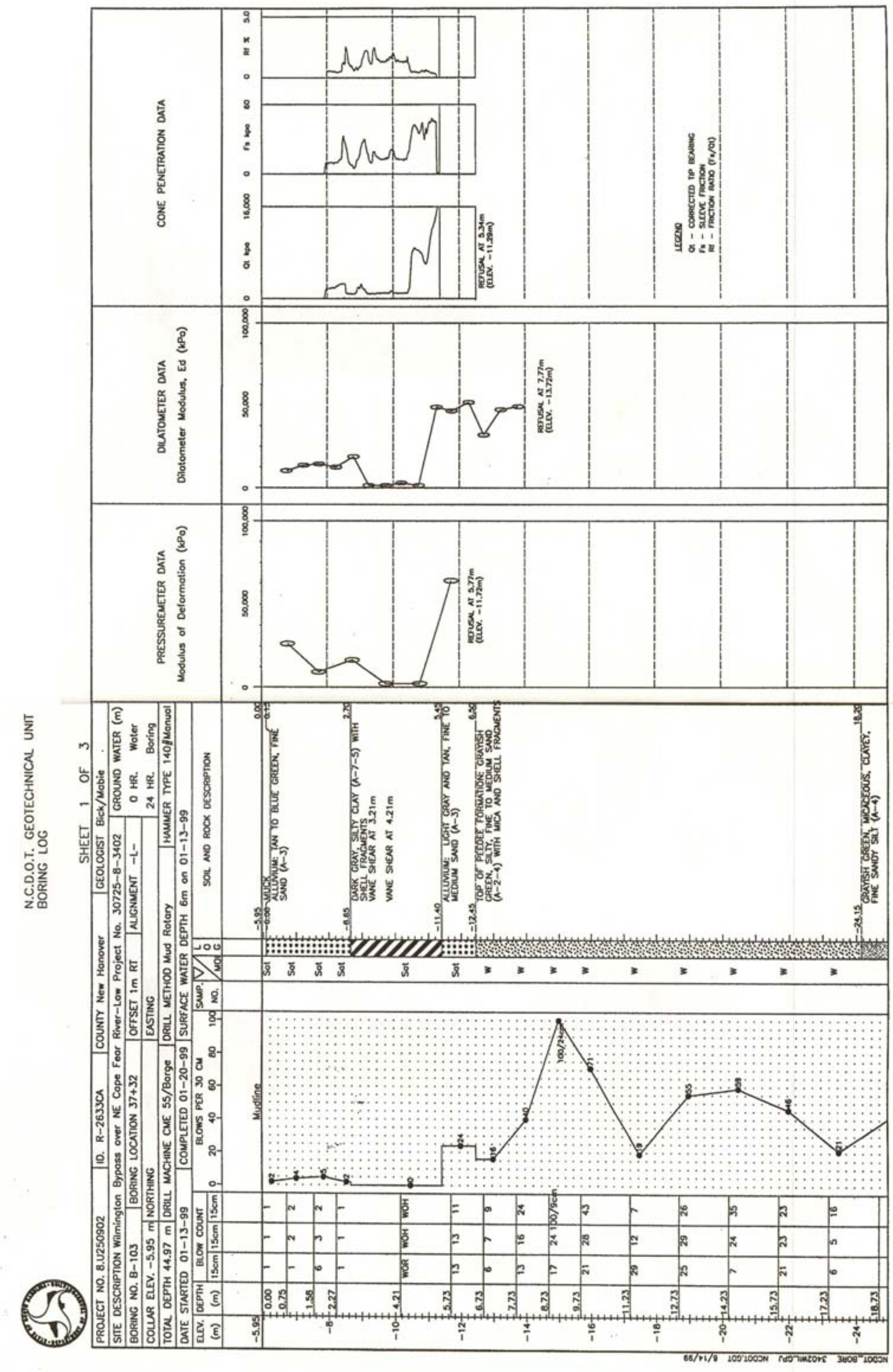
Appendix G. Subsurface Data for 7 Instrumented Case Histories

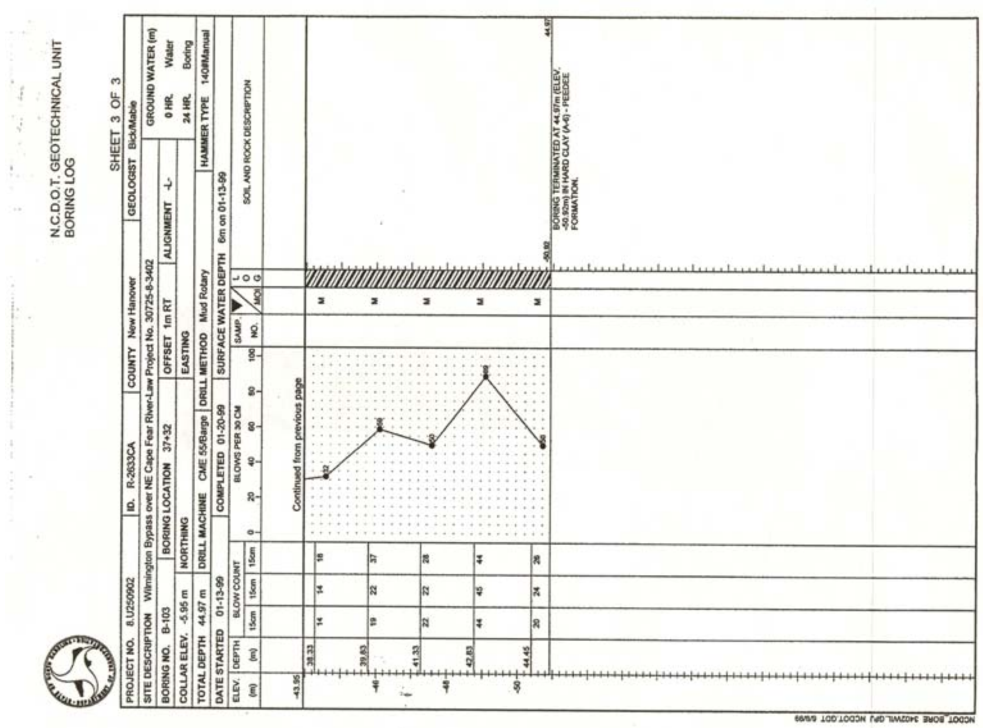
G.1. Generalized Subsurface Profile for the Roosevelt Bridge Site

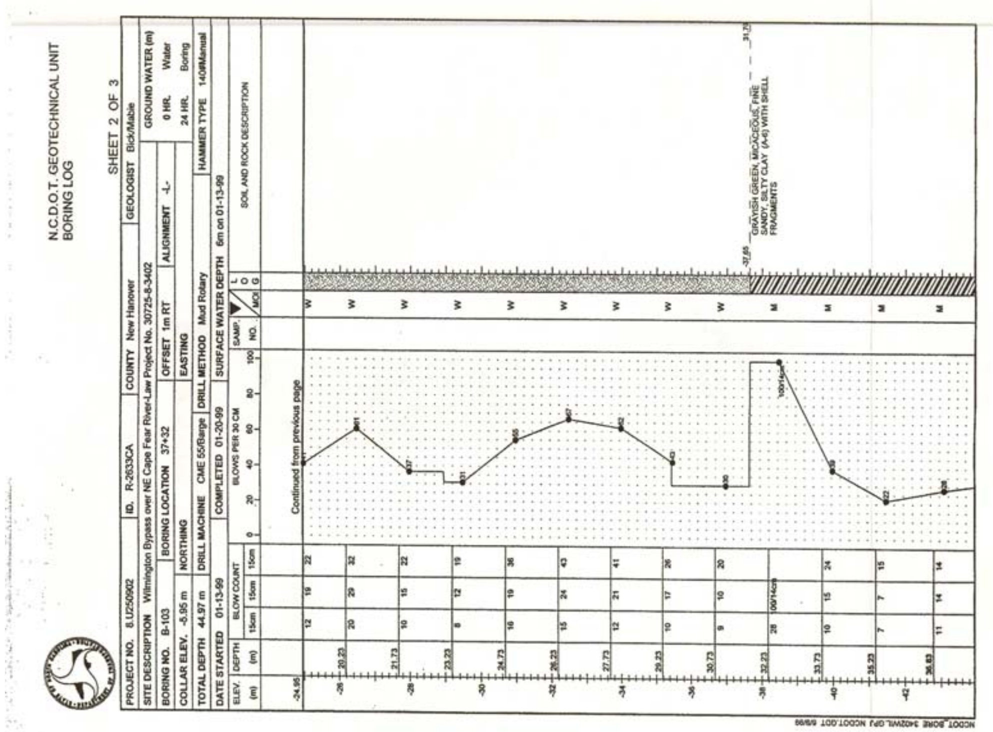


G.2. Generalized Subsurface Profile Wilmington Pipe Pile,US17 Bypass Part 1

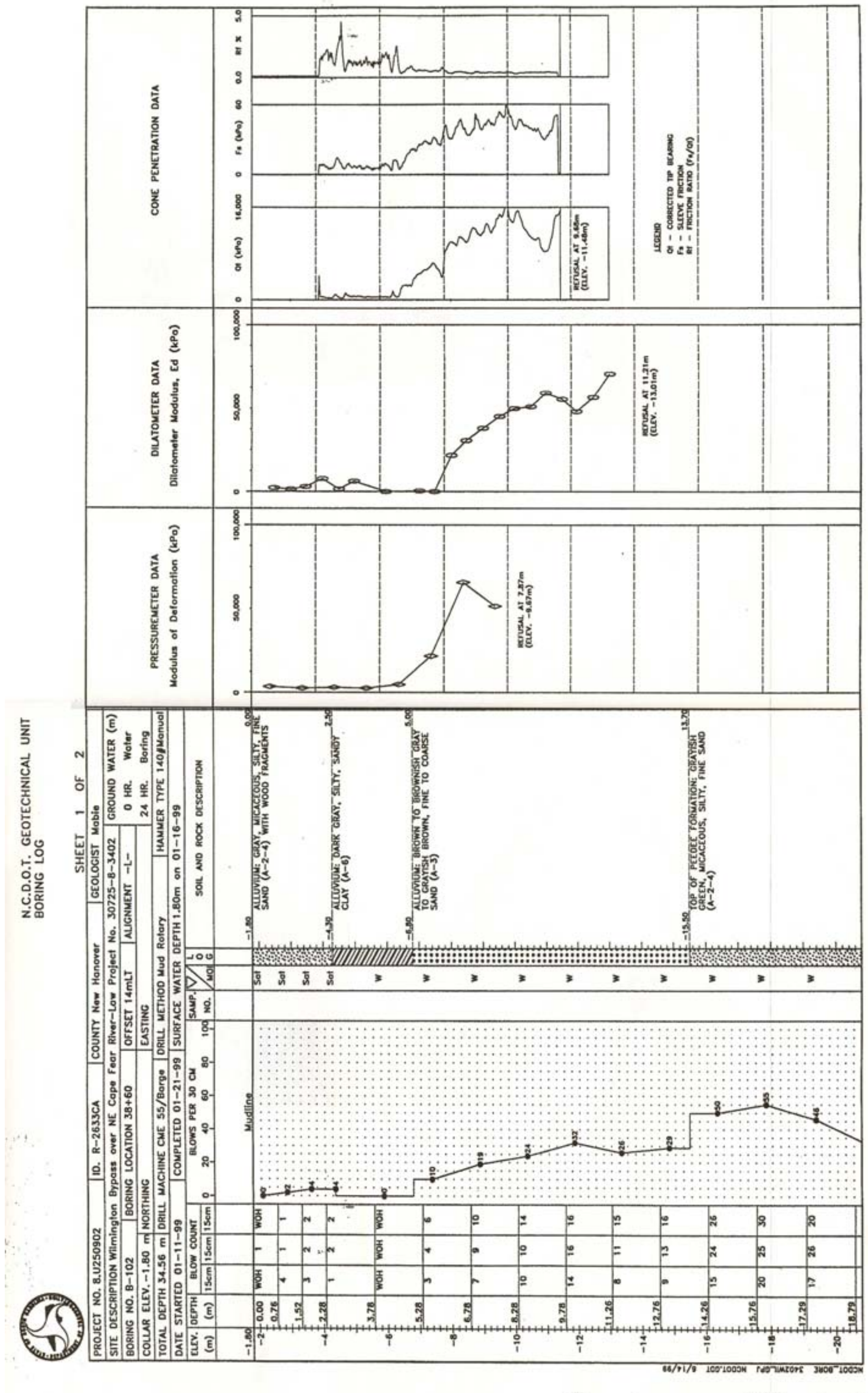


G.3. Generalized Subsurface Profile Wilmington Pipe Pile, US17 Bypass Part 2 & 3

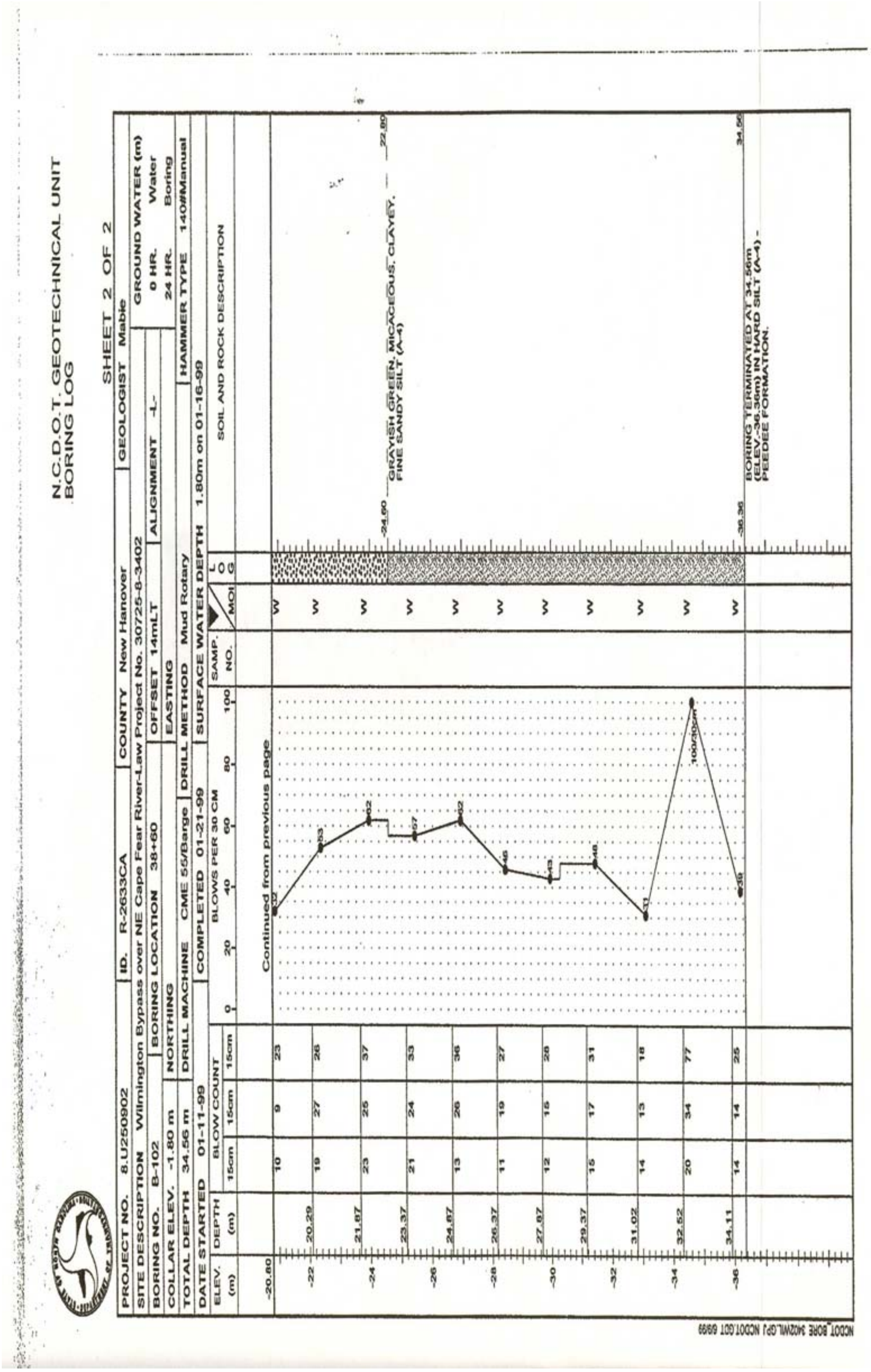




G.4. Generalized Subsurface Profile Wilmington Square Pile, US17 Bypass Part 1



G.5. Generalized Subsurface Profile Wilmington Square Pile; US 17 Bypass Part 2



G.6. Generalized Subsurface Profile for Rio Puerto Nuevo Part 1

Hole No. CB-PNL-59

DRILLING LOG	DIVISION: ATLANTIC DIVISION
INSTALLATION: JACKSONVILLE DISTRICT CORPS OF ENGINEERS	SHEET 1 OF 4 SHEETS
1. PROJECT: PUERTO NUEVO CHANNEL, PUERTO NUEVO CHANNELS PROJECT, SAN JUAN, P.R.	10. SIZE AND TYPE OF BIT: SEE REMARKS
2. LOCATION (Coordinates or Station): X=623,084.90FT Y=216,375.86FT	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: GEO CIM, INC.	12. MANUFACTURER'S DESIGNATION OF DRILL: CME-450
4. HOLE NO. (As shown on drawing title and file number): CB-PNL-59	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 47; UNDISTURBED -
5. NAME OF DRILLER: SANTOS RODRIGUEZ	14. TOTAL NUMBER CORE BOXES: 2
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ___ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 1.14FT
7. THICKNESS OF OVERBURDEN: 70.5'	16. DATE HOLE: STARTED 7/20/88; COMPLETED 7/20/88
8. DEPTH DRILLED INTO ROCK: -	17. ELEVATION TOP OF HOLE: 4.56FT
9. TOTAL DEPTH OF HOLE: 70.5'	18. TOTAL CORE RECOVERY FOR BORING: 93.4
	19. SIGNATURE OF INSPECTOR: ALBERTO R. BARRERA

ELEVATION FT	DEPTH FT	LEGEND	CLASSIFICATION OF MATERIALS (Description)	% CORE RECOVERY	SAMPLE NO.	BLOWS	N	W%	REMARKS
4.56	0		Clay, trace sand, trace roots, trace gravel, soft, yellowish brown. (CL)	33	1	2, 2, 2	4		
3.06	1.5		Clay, soft to medium yellowish brown to olive gray. (CH)	39	2	1, 2, 2	4		
				100	3	2, 1, 2	3		
			- medium stiff.	100	4	2, 3, 3	6		
				100	5	1, 2, 2	4		
				100	6	4, 5, 5	10	51.2	
				100	7	1, 1, 2	3		
			- gray.	100	8	2, 2, 3	5		
				100	9	2, 1, 2	3		
				100	10	2, 3, 3	6		
				100	11	WH, WH, WH	WH		
				100	12	1, 2, 2	4		
			- trace organic matter.	100	13	1, 1, 2	3		
-15.44	20					1			

REMARKS (Drilling time, water loss, depth of weathering, etc., if significant):

"N" VALUE - BLOWS IN LAST 12" OF PENETRATION OF 1-3/8" I.D. x 2' LONG SPLIT-SPOON SAMPLER FROM BLOWS OF 140 LBS. HAMMER DROPPING 30 INCHES.

W% - NATURAL WATER CONTENT (%)

WH - SAMPLER PENETRATED WITH WEIGHT OF HAMMER.

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

PROJECT: PUERTO NUEVO CHANNEL | HOLE NO. CB-PNL-59

01000-J11

G.7. Generalized Subsurface Profile for Rio Puerto Nuevo Part 2

DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE 4.56FT | Hole No. CB-PNL-59

PROJECT PUERTO NUEVO CHANNEL, PUERTO NUEVO CHANNELS PROJECT, SAN JUAN, P.R. | INSTALLATION JACKSONVILLE DISTRICT CORPS OF ENGINEERS | SHEET 2 OF 4 SHEETS

ELEVATION FT.	DEPTH FT.	LEGEND	CLASSIFICATION OF MATERIALS (Description)	% CORE RECOVERY	SAMPLE NO.	BLOWS	N	W%	REMARKS
-15.44	20		As Above.	100	14	2, 3	5		AS ABOVE.
				100	15	1, 1, 2	3		
				100	16	2, 2, 3	5		
			- olive stains.	39	17	2, 2, 3	5		
				94	18	2, 1, 2	3		
				56	19	2, 3, 3	6		
				67	20	2, 2, 3	5		
				100	21	1, 2, 3	5		
-26.94	31.5		Clay, trace fine sand, medium to stiff, olive gray to yellowish brown. (CH)	100	22	2, 2, 3	5		
				78	23	2, 4, 5	9		
				83	24	2, 4, 5	9		
				100	25	4, 4, 5	9	45.6	
				100	26	4, 5, 6	11		
				100	27	5, 5, 9	14		
				100	28	3, 4, 7	11		
-37.44	42		Clay, trace fine sand, very stiff, olive yellowish brown. (CH)	100	29	5, 10, 11	21		
-39.44	44					12			

ENG FORM 1836-A (ER 1110-1-1801) | PROJECT PUERTO NUEVO CHANNEL | HOLE NO. CB-PNL-59

01000-J12

G.8. Generalized Subsurface Profile for Puerto Nuevo Part 3

DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE: 4.56FT | Hole No. CB-PNL-59

PROJECT: PUERTO NUEVO CHANNEL, PUERTO NUEVO CHANNELS PROJECT, SAN JUAN, P.R. | INSTALLATION: JACKSONVILLE DISTRICT CORPS OF ENGINEERS | SHEET 3 OF 4 SHEETS

ELEVATION FT a	DEPTH FT b	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	SAMPLE NO f	BLOWS	N	W%	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
-39.44	44	As Above, hard.	100	30	13 20	33		AS ABOVE.
-40.44	45	Clay, trace fine sand, yellowish brown, very stiff to hard. (CH)	100	31	3 6 9	15		
			100	32	7 9 15	24		
			100	33	7 8 10	18		
			100	34	7 10 14	24		
			100	35	5 9 12	21		
		- red stains.	100	36	17 18 18	36		
			100	37	4 8 11	19		
			100	38	8 16 17	33		
			100	39	6 8 9	17		
			100	40	7 8 10	18		
-55.44	60	Clay, very stiff, yellowish to reddish brown. (CH)	100	41	4 8 10	18		
			100	42	5 10 12	22		
			100	43	6 8 10	18	42.5	
			100	44	6 9 14	23		
			100	45	7 10 10	20		
-63.44	68				6			

ENG FORM 1836-A 01000-J13 | PROJECT: PUERTO NUEVO CHANNEL | HOLE NO: CB-PNL-59

G.9. Generalized Subsurface Profile for Puerto Nuevo Part 4

DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE 4.56FT | Hole No. CB-PNL-59

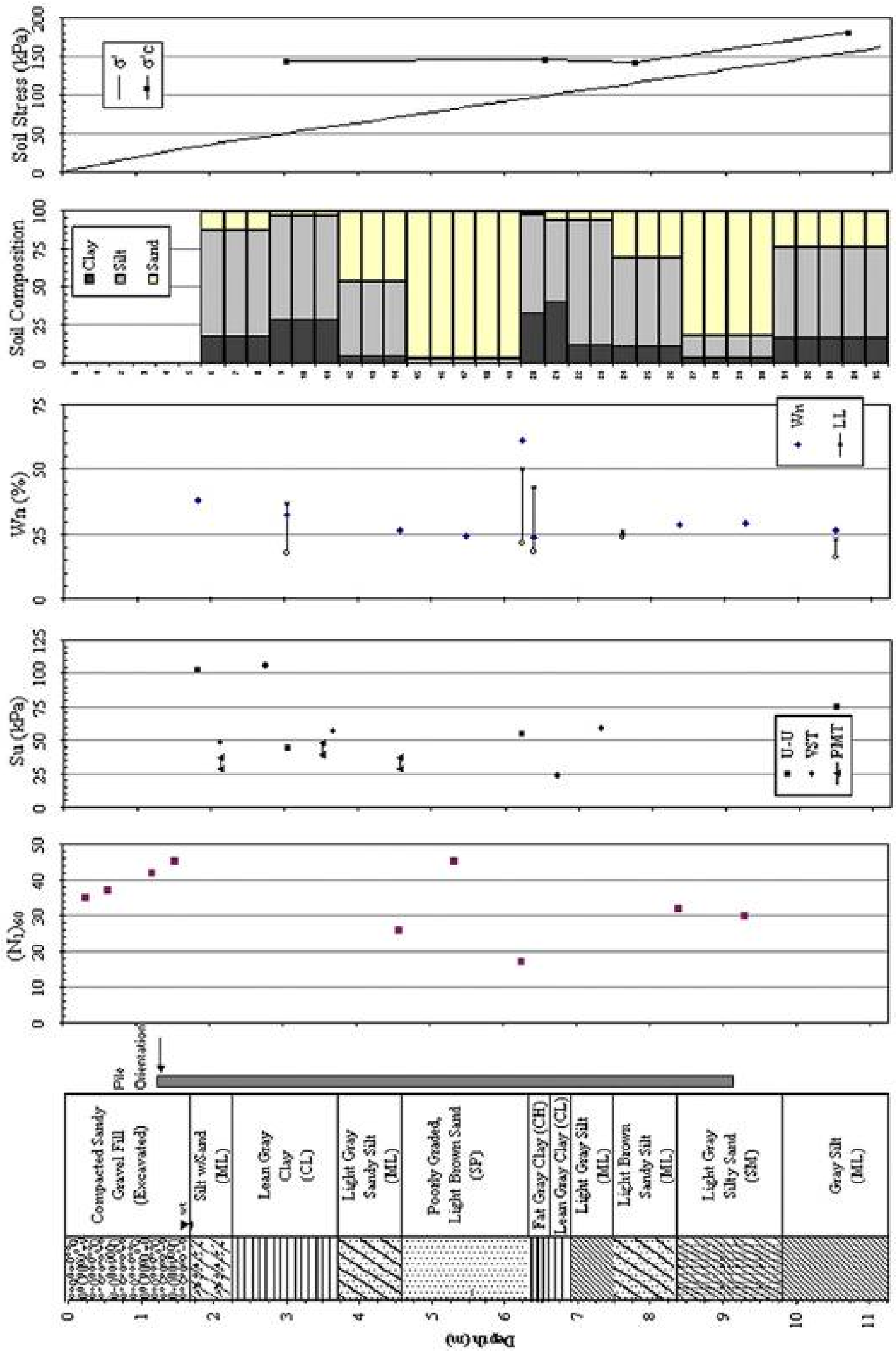
PROJECT PUERTO NUEVO CHANNEL, PUERTO NUEVO CHANNELS PROJECT, SAN JUAN, P.R. | INSTALLATION JACKSONVILLE DISTRICT CORPS OF ENGINEERS | SHEET 4 OF 4 SHEETS

ELEVATION FT a	DEPTH FT b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	SAMPLE NO. f	BLOWS	N	W	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
-63.44	68		As Above; gray streaks.	100	46	8 14	22		AS ABOVE.
				100	47	6 10 12	22		
-65.94	70.5		END OF BORING NO. CB-PNL-59 AT 70'6" DEPTH; -65.94FT ELEVATION.						

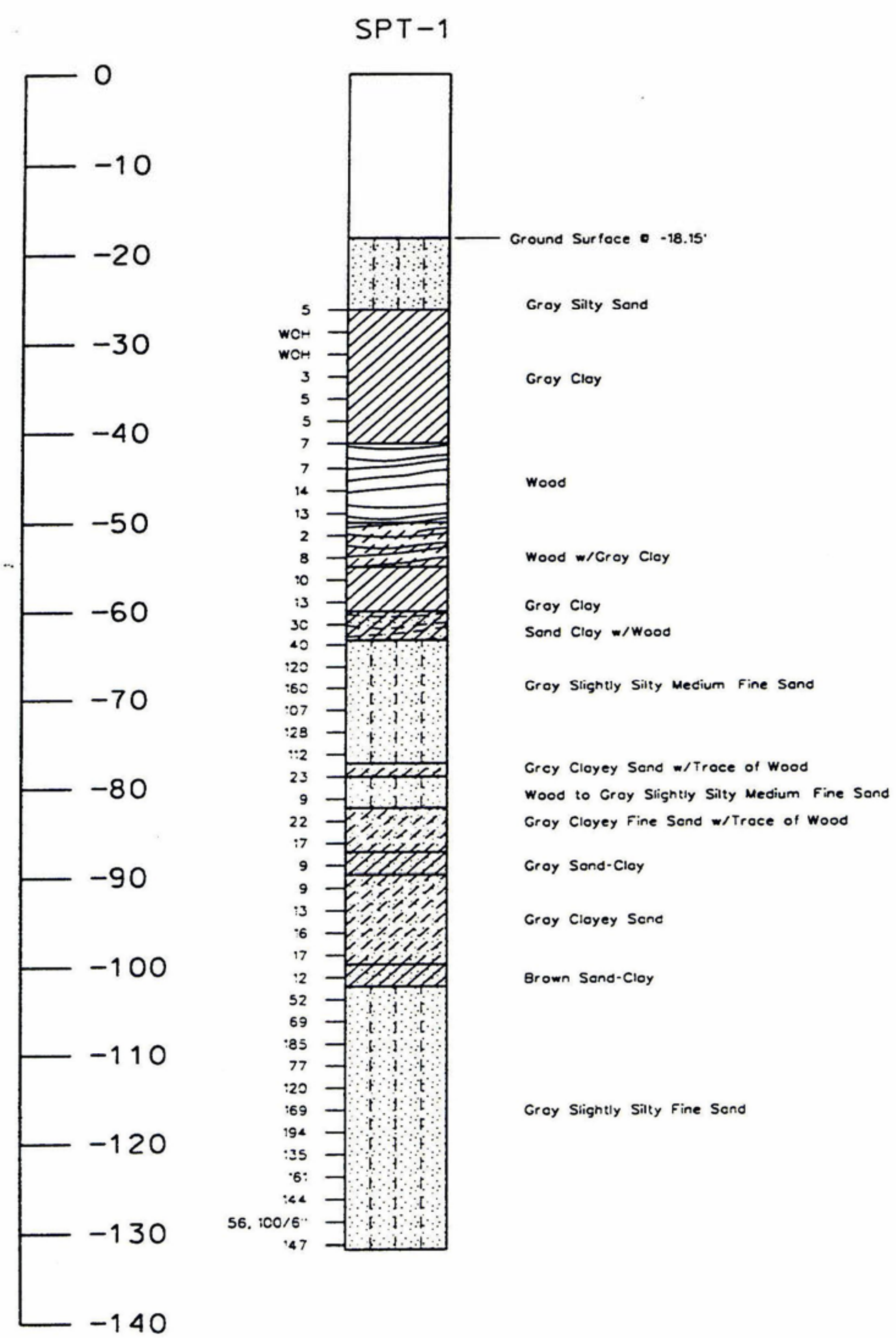
ENG FORM 1836-A (ER 1110-1-1801) | PROJECT PUERTO NUEVO CHANNEL | HOLE NO. CB-PNL-59

01000-J14

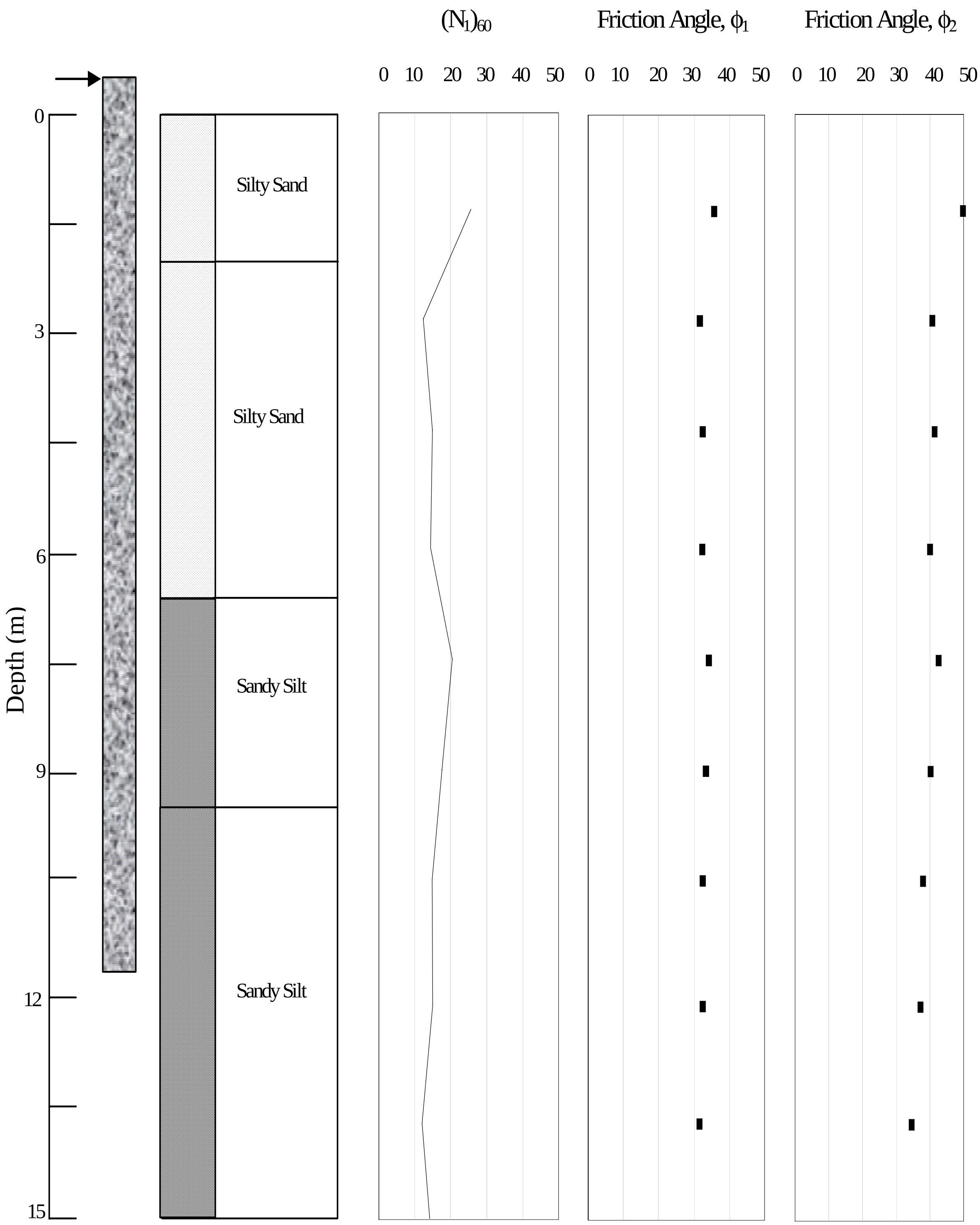
G.10. *Generalized Soil Profile for Salt Lake City International Airport*



G.11. Generalized Subsurface Profile for East Pascagoula River Bridge MS



G.12. *Subsurface Profiles for Auburn NGES*



Subsurface Profiles for Broadway Bridge Daytona