TECHNICAL REPORT STANDARD PAGE

1. Report No. FHWA/LA.88/311	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Continuous Intrusion Miniature Cone Penetration Test System for Transportation Applications	5. Report Date January 1999 6. Performing Organization Code	
7. Author(s) Mehmet T. Tumay, Ph.D., P.E. Pradeep U. Kurup, Ph.D., P.E.	8. Performing Organization Report No. 311	
9. Performing Organization Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	10. Work Unit No. 11. Contract or Grant No. LTRC Research Project No. 96-3GTX State Project No. 736-99-0355	
12. Sponsoring Agency Name and Address FHWA/Priority Technologies Program Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	13. Type of Report and Period Covered Final Report 02/01/96 - 06/30/98 14. Sponsoring Agency Code	

15. Supplementary Notes

Conducted in Cooperation with the U.S. Department of Transportation, Priority Technologies Program, Federal Highway Administration

16. Abstract

The electronic cone penetrometer is a popular in situ investigation tool for site characterization. This research report describes the application of this proven concept of the cone penetration test (CPT) to highway design and construction control by miniaturization. A miniature cone penetrometer with a projected cone area of 2 cm^2 has been developed and implemented in a Continuous Intrusion Miniature Cone Penetration Test system (CIMCPT). This novel device may be used for rapid, accurate and economical characterization of sites and to determine engineering soil parameters needed in the design of pavements, embankments, and earth structures. The miniature cone penetration test (MCPT) and the miniature piezocone penetration test (MPCPT) give finer details compared to the standard 10 cm^2 cross-sectional area "reference" cone penetrometer. This makes CIMCPT attractive for subgrade characterization, quality control assessment, compaction control of embankments, and assessment of ground improvement effectiveness for transportation infrastructure. In situ calibration of the CIMCPT system was conducted at Highland Road site in Baton Rouge, Louisiana; and also at two of the National Geotechnical Experimentation Sites (NGES): University of Houston, and the Texas A & M University. CIMCPT penetration profiles were compared with those obtained using the standard cone penetrometer. The average tip resistance of the CIMCPT was 11 percent higher than that of the reference CPT. The average CIMCPT sleeve friction was lower than that of the reference CPT by 11 percent. These results compare well with previous research.

17. Key Words cone penetration test, continuous intrusion, miniature cone penetrometer, National Geotechnical Experimentation Sites (NGES), laboratory/field calibration, standard/miniature cone test correlation		18. Distribution Statement **Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.**	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 61	22. Price

A CONTINUOUS INTRUSION MINIATURE CONE PENETRATION TEST SYSTEM FOR TRANSPORTATION APPLICATIONS

FINAL REPORT

By

Mehmet T. Tumay, Ph.D., P.E.
Associate Dean for Research and Professor,
Department of Civil and Environmental Engineering
Louisiana State University

and

Pradeep U. Kurup, Ph.D., P.E.
Assistant Professor,
Department of Civil and Environmental Engineering
University of Massachusetts Lowell
(formerly, Research Associate V, Louisiana Transportation Research Center)

State Project No. 736-99-0355
LTRC Research Project No. 96-3GTX

JANUARY 1999

ABSTRACT

The electronic cone penetrometer is a popular in situ investigation tool for site characterization. This research report describes the application of this proven concept of the cone penetration test (CPT) to highway design and construction control by miniaturization. A miniature cone penetrometer with a projected cone area of 2 cm^2 has been developed and implemented in a Continuous Intrusion Miniature Cone Penetration Test system (CIMCPT). This novel device may be used for rapid, accurate and economical characterization of sites and to determine engineering soil parameters needed in the design of pavements, embankments and earth structures. The miniature friction cone penetration test (MCPT) and the miniature piezocone penetration test (MPCPT) give finer details compared to the standard 10 cm^2 cross-sectional area "reference" cone penetrometer. This makes CIMCPT attractive for subgrade characterization, quality control assessment, compaction control of embankments, and assessment of ground improvement effectiveness for transportation infrastructure. In situ calibration of the CIMCPT system was conducted at a Highland Road site in Baton Rouge, Louisiana, and also at two National Geotechnical Experimentation Sites (NGES): University of Houston and Texas A & M University. CIMCPT penetration profiles were compared with those obtained using the standard 10 cm^2 cone penetrometer. The average tip resistance of the CIMCPT was 11 percent *higher* than that of the reference CPT. The average CIMCPT sleeve friction was *lower* than that of the reference CPT by 11 percent. These results compare well with previous research.

ACKNOWLEDGMENTS

This research was funded by the Priority Technologies Program of the Federal Highway Administration (FHWA) and their support is gratefully acknowledged. The support and facilities provided by Louisiana Transportation Research Center (LTRC) is also acknowledged. The CIMCPT system was fabricated by SAGE Engineering, Inc., Houston, Texas.

The additional financial support of LTRC, the Department of Transportation and Development (DOTD), and also the technical assistance provided by SAGE Engineering, Inc. are recognized. William T. Tierney and Yigal Bynoe (research associates), contributed boundless physical and mental energy for the successful implementation phase of the project. The development of the data acquisition system and the implementation of the global positioning system could not have been completed without the dedicated meticulous efforts of many graduate students, Swaroop Dutta, Rama Sarma, and Balaji Muthuvarantan, who were the primary contributors to the project. Dan Brock, Instructional Support and Development, LSU and Nick Champion, Video Specialist, LTRC are acknowledged for the production of the videos and the CD-ROM.

The authors also express their appreciation to Dr. Hani Titi and Dr. Murad Abu-Farsakh for plotting the MCPT and CPT soil profiles, and for performing the soil classification graphics for the test sites.

IMPLEMENTATION STATEMENT

A continuous intrusion miniature cone penetration test system (CIMCPT) has been developed for site characterization for transportation applications. It is portable, fast, reliable and ideally suited for shallow to semi-deep (c. 15 m) subsurface investigations/evaluation, especially in locations were accessibility presents a problem. The CIMCPT system will provide engineers and the technical personnel of the Department of Transportation and Development (DOTD) with a wide range of testing capability for use in soil identification and behavior prediction. It is expected that the reduction of disturbed/undisturbed sampling, strength/deformation tests, and shelf/testing time will result in great savings for the DOTD. The CIMCPT system will improve real time subgrade and base characterization for pavement data analysis. It can be used to assess and evaluate the effectiveness of ground improvement techniques for highway construction and compaction control, the design of short piles, piers, and abutments supporting bridges, the design of shallow and semi-deep foundations, and in determining other data pertaining to the performance and environmental impact of highway construction projects.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The Louisiana Department of Transportation and Development (DOTD) has for years maintained a large fleet of sophisticated drilling equipment and staffed a number of personnel for exploratory drilling and laboratory analysis to gather soil data for engineering design. Budget cutbacks have forced reduction in personnel and equipment causing exploratory work to fall behind. Conventional boring of soil samples for laboratory testing and analysis is an expensive, time consuming process. Delays in starting critical projects are often the result of long periods of laboratory testing. Hence, there is need for more rapid and accurate site characterization techniques for analysis and design related to transportation applications.

Among the various in situ test methods currently available, the cone penetration test (CPT) is becoming increasingly popular because it is reliable, fast, economical, and gives continuous detailed soil profiles. CPT essentially consists of pushing an electronic probe known as the cone penetrometer into the soil at a rate of two cm/s. The probe is typically pushed into the soil using a string of one-meter-long push rods advanced by a hydraulically-operated thrust system. The cylindrical probe has a conical tip of apex angle equal to 60 degrees. The device is equipped with a load cell at the tip to measure the cone or tip resistance (q_c), which is the force offered by the soil to the tip during intrusion divided by the projected cone area. The projected cone area of the standard cone penetrometer is 10 cm^2. It is also equipped with a friction sleeve (150 cm^2 surface area) and a load cell to measure the sleeve friction (f_s), which is the local friction between the surrounding soil and the shaft of the probe. In addition to the standard (reference) cone penetrometer, 15 cm^2 cone penetrometers with a 200 cm^2 surface area friction sleeve are also extensively used. Previous studies have demonstrated 10 cm^2 and 15 cm^2 cone penetrometers to give undifferentiable test results. The term friction ratio (R_f), often used in CPT data interpretation, is the ratio of the sleeve friction to the cone resistance expressed as a percentage.

The CPT data (i.e. the tip resistance and friction ratio) are used to determine the soil type for classification and for profiling subsurface soil stratigraphy. Coarse grained soils such as sands are characterized by high cone resistance and low friction ratios whereas fine grained soils such as clays are characterized by low cone resistance and high friction ratios. The CPT data is also used to estimate various engineering soil properties needed for analysis, design and construction.

Cone Penetration Testing For Highway Applications

The Research Vehicle for Geotechnical In Situ Testing and Support (REVEGITS, figure 1) and its sister vehicle the Louisiana Electric Cone Penetrometer System (LECOPS) represent state-of-the-art equipment in the area of site exploration for transportation applications [*1*]. REVEGITS is a 20-ton all wheel drive vehicle which incorporates modern technology for in situ subsurface soil exploration for civil and geo-environmental engineering purposes. The CPT system is housed in a specially fabricated, environmentally controlled van body mounted vehicle with sufficient reaction weight and off-road maneuverability to carry out in situ geotechnical investigations. This vehicle is capable of performing standard cone penetration tests, piezocone penetration tests (PCPT) using 10 cm^2 and 15 cm^2 cones, seismic cone penetration tests (SCPT), conductivity cone penetration tests (CCPT), self boring pressuremeter tests (SBPT), and dilatometer tests (DMT).

The friction cone penetrometer was miniaturized, and a prototype miniature cone penetration test (MCPT) system was implemented for highway design and construction control in a previous study by Tumay and Kurup *[2]*. This prototype system with a 1.27cm^2 projected cone area mounted in front of REVEGITS (figure 2) consists of a reaction/leveling plate that is lowered and raised by two hydraulic cylinders. The hydraulic thrust system consists of a hollow cylinder fixed to the center of the reaction plate that is used for pushing and pulling the cone penetrometer by segmental rods. The second generation miniature friction cone penetrometer fabricated by SAGE Engineering Inc., of Houston, Texas, on contract to LTRC has a projected cone area of 2 cm^2, a friction sleeve area of 40 cm^2, and a cone apex angle of 60^0. Miniature cone penetration tests provide continuous soil profiles and are capable of detecting thin layers making them more attractive than the large size cones for characterizing subgrade soils and construction control of embankments. In addition, they are reliable, fast, and economical and may be used in conjunction with conventional laboratory tests. The MCPT profiles indicate larger variation in the cone resistance, sleeve friction, and friction ratio values because of its capability to capture local soil characteristics and thin layer properties in comparison to large size penetrometers which globalize the soil properties. Statistical analysis of previous test data *[3, 4, 5]* obtained using 1.27 cm^2 (first generation minicone), versus the 10 cm^2, and 15 cm^2 cone penetrometers developed by Fugro have indicated that mean cone resistance value decreases with increase in cone size. The test results between 10 cm^2, and 15 cm^2 cone penetrometers were undifferentiable. It was also recommended that a multiplication factor of 0.85 can be used effectively to correct the 1.27 cm^2 cone resistance, ($q_{c(1.27)}$) in order to obtain the reference penetrometer cone resistance (i.e., $q_{c(10)} = 0.85 * q_{c(1.27)}$).

Figure 1
The Research Vehicle for Geotechnical In Situ Testing and Support (REVEGITS)

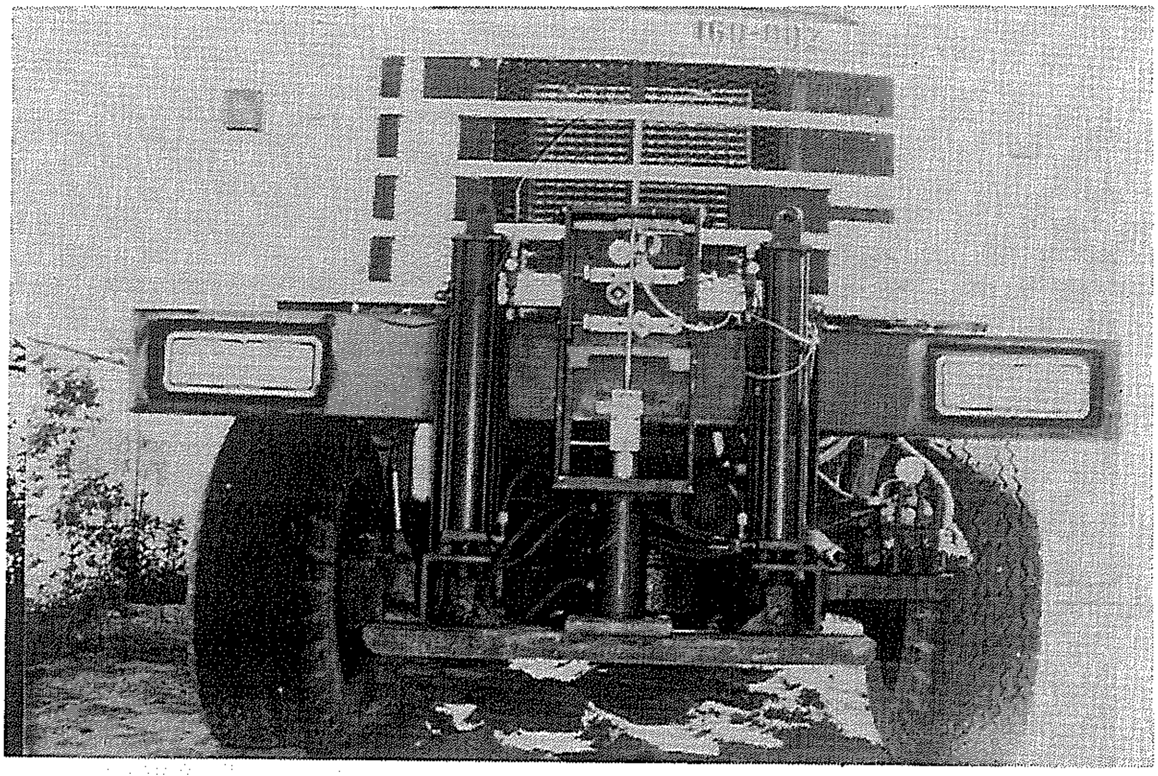


Figure 2
Prototype miniature cone penetrometer system

The local side friction resistance and friction ratio of the 1.27 cm^2 cone penetrometer may be corrected via linear regression equations considering two ranges of cone resistance: (1) soils with q_c equal or smaller than 80 kg/cm^2 and (2) soil with q_c higher than 80 kg/cm^2 *[3], [4], [5]*. No significant correction is necessary for cross-correlating cone resistance of the reference and the 15 cm^2 cross-sectional area penetrometer *[3], [4], [5]*.

The implementation of the prototype second generation 2 cm^2 miniature cone penetrometer was tested and verified by comparing the transformed penetration profiles (using equations 1-3) with those obtained using the 15 cm^2 cross-sectional area friction cone penetrometer at a site near the intersection of Highland Road and Interstate 10 (LA SR-42) in Baton Rouge, Louisiana *[6]*.

$$q_{c(15\ cm2)} = 1.032 + 0.816 * q_{c(MCPT)} \quad (1)$$

$$f_{s1(15\ cm2)} = 0.186 + 0.727 * f_{s1(MCPT)} \quad (2)$$

$$R_{f1(15\ cm2)} = 2.560 + 0.549 * R_{f1(MCPT)} \quad (3)$$

Equations 1-3 have been derived from the regression equations correlating the 1.27 cm^2 MCPT profile and the 15 cm^2 CPT profile to the 10 cm^2 CPT profile (for q_c smaller or equal to 80 kg/cm^2) *[3] -[6]*. During testing, the joints of the one meter long MCPT push rods represented a source of weakness with the rods frequently breaking at the connection. There was also the additional problem of water seeping through the joints into the cone and damaging the electronics. The cone advance was not continuous since the hydraulic thrust system had a stroke of only 15 cm. Normal stress release and excess pore pressure dissipation occurred during the pauses in between strokes.

OBJECTIVES

The following were the objectives of this research:

1. Acquire and modify a four-wheel drive, all-terrain vehicle (GMC Sierra extra cab pickup, 1 ton) with capability of leveling and providing reaction needed during cone penetration.

2. Design, fabricate, and implement a continuous intrusion miniature cone penetrometer test (CIMCPT) system for transportation applications.

3. Implement a new state-of-the-art data acquisition system using DGH interface modules and a Global Positioning System (GPS) for real-time monitoring, acquiring, storing on magnetic media, and displaying data in real time on a computer screen in graphic form.

4. Test and evaluate the CIMCPT system in well-characterized and well-documented sites, including the National Geotechnical Experimentation Sites (NGES). Compare the MCPT and MPCPT penetration profiles with CPT profiles obtained using a standard 10 cm^2 Fugro-cone penetrometer to evaluate scale effects and to assess the accuracy of MCPT results.

SCOPE

A four-wheel drive, all-terrain vehicle (GMC Sierra extra cab pickup, 1 ton) was acquired. The vehicle was modified to provide capabilities for leveling and reaction needed during cone penetration. An environmentally controlled van body was added to house the continuous intrusion device and the data acquisition system. A continuous feed miniature cone penetrometer thrust device was designed, fabricated, and mounted on the pickup chassis. A new state-of-the-art data acquisition system using DGH interface modules and a Global Positioning System (GPS), for real-time monitoring, acquiring, storing on magnetic media, and displaying data in real time on a computer screen in graphic form was developed. The CIMCPT system was tested in well-characterized and well-documented sites, including the National Geotechnical Experimentation Sites.

METHODOLOGY

Continuous Intrusion Miniature Cone Penetration Test System (CIMCPT)

The authors have recently developed and implemented a field-rugged continuous intrusion miniature cone penetration test system for transportation applications. This system is mounted in a four-wheel drive, one ton, all terrain vehicle (figure 3). A novel feature of this new in situ testing vehicle is the chain driven caterpillar-type continuous intrusion device powered by a hydraulic motor to advance the cone penetrometer, which greatly increases productivity and serviceability (figure 4). Hydraulic power is provided by the vehicle's transmission. Penetration speed is controlled by a pressure compensated flow control valve. The reversible hydraulic motor is capable of continuously inserting and retracting the single, continuous, coiled penetration rod, a single continuous coiled tube. The penetration rod is a 12.7 mm diameter 15 m long stainless steel tube. It has a 2 cm^2 cone penetrometer attached to one end and a connector at the other. The ability to coil and uncoil the thrust rod is one unique feature of this miniature cone system. Coiling eliminates threaded connections and simplifies water proofing. The coiling mechanism also straightens the rod prior to insertion into the soil. The plastic deformation of the rod as it is coiled and straightened might eventually result in failure after a number of cycles. The rods have shown to withstand more than 200 cycles of coiling and uncoiling. The maximum depth of penetration that can be achieved by the CIMCPT system is 12 m.

The CIMCPT provides a reliable, economical, and time-saving tool for site characterization compared to the conventional boring, sampling, and laboratory testing methods. The novel continuous feed device implemented in the CIMCPT system minimizes the normal stress release and consolidation effects on cone data often observed during intermittent pushing. The system can be operated by one person. The miniature cone penetrometer gives finer details compared to the standard size cone penetrometer, making it more attractive for pavement subgrade characterization, compaction control, and assessment for ground improvement effectiveness for transportation infrastructure. The soil data obtained can also be used in the design of short piles, piers, and abutments supporting bridges. The system may be used to test beneath existing pavement via a one inch diameter access hole and is, therefore, less intrusive than the larger diameter borings. The system can be mounted in small all-terrain vehicles due to smaller reaction forces needed to push the miniature cone as compared to large size cones. Installation in a smaller vehicle provides greater mobility and site accessibility. The problem of ground water seeping in through joints (as in the conventional one meter long jointed push rods) and damaging the electronics is minimized since the push rod is one single continuous coiled piece. The outcome of this research development has

Figure 3
The CIMCPT vehicle

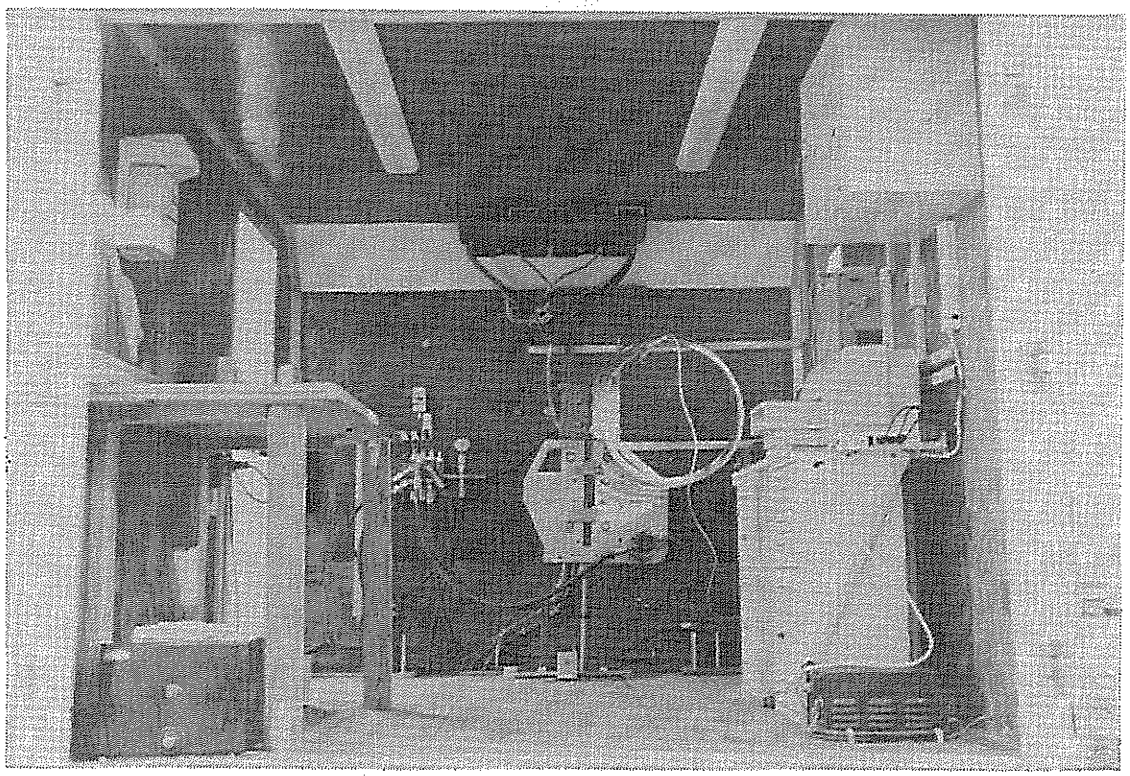


Figure 4a
The continuous intrusion device

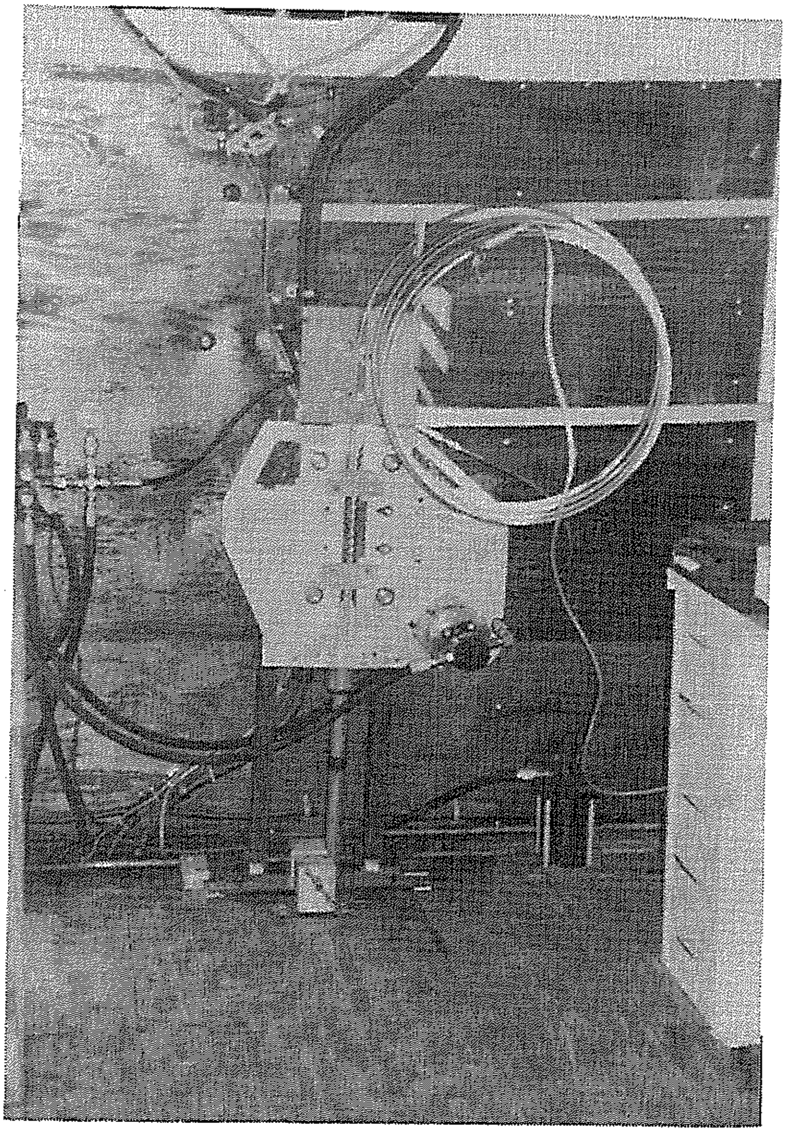


Figure 4b
Detail of continuous intrusion device

immediate practical applications in transportation systems and is envisioned to significantly advance transportation design, analysis, and construction practice.

Cone Penetrometers

The 2 cm^2 miniature friction cone penetrometers, MCPT, (Cone no. X01 and Cone no. X02) and the miniature piezocone penetrometer, MPCPT, have a projected cone area of 2 cm^2, a friction sleeve area of 40 cm^2, and a cone apex angle of 60^0 (figure 5). The miniature cone penetrometer has the same frame size and geometric configuration, and in addition accommodates a miniature Entran pressure transducer (to measure generated pore pressures) and Entran minature accelerometer (to measure inclination during intrusion). They both are of the subtraction type (i.e. they measure cone resistance, combined cone resistance and local sleeve friction resistance). The new cone penetrometers are an integral part of the coiled push rod and are more robust. The probes are also temperature compensated thereby reducing drift and increasing accuracy. The penetration depth is measured by a displacement transducer that works via an optical increment shaft encoder which is friction coupled to the rod.

The tip and sleeve load cells are of the strain gauge type, and changes in electrical resistance due to strains during load application are monitored by a Wheatstone full bridge configuration. To determine the calibration factors, the tip and sleeve load cells are loaded in increments, and the output voltage (from the Wheatstone bridge) is measured for each increment. Figure 6 shows the load versus gauge output voltage for the tip and sleeve load cells. The output voltage is in millivolts/volt of excitation to the bridge circuit. The excitation voltage used for calibration (4.98 volts) is the same as that supplied by the power module of the CIMCPT system during field testing. Both the tip and sleeve load cell calibration showed zero return, excellent linearity, practically no hysteresis, and high repeatability. The temperature sensitivity for the tip and sleeve were 0.063mV/V/°F and 0.032mV/V/°F, respectively. Linear regression analyses were used to obtain the best fit lines through the tip and sleeve calibration data points (figure 6). The coefficients of determination (R^2) for both the tip and sleeve were 0.9999. Both the tip and sleeve load cells show similar slope. The tip slope is 838 kg/mV/V and the sleeve slope is 842 kg/mV/V.

Data acquisition system

The data acquisition system depicted in figure 7 is an enhanced version designed for a 2 cm^2 miniature piezocone penetrometer (the latest addition planned for the CIMCPT system), which is capable of acquiring pore water pressure and cone angle tilt, in addition to the tip resistance and

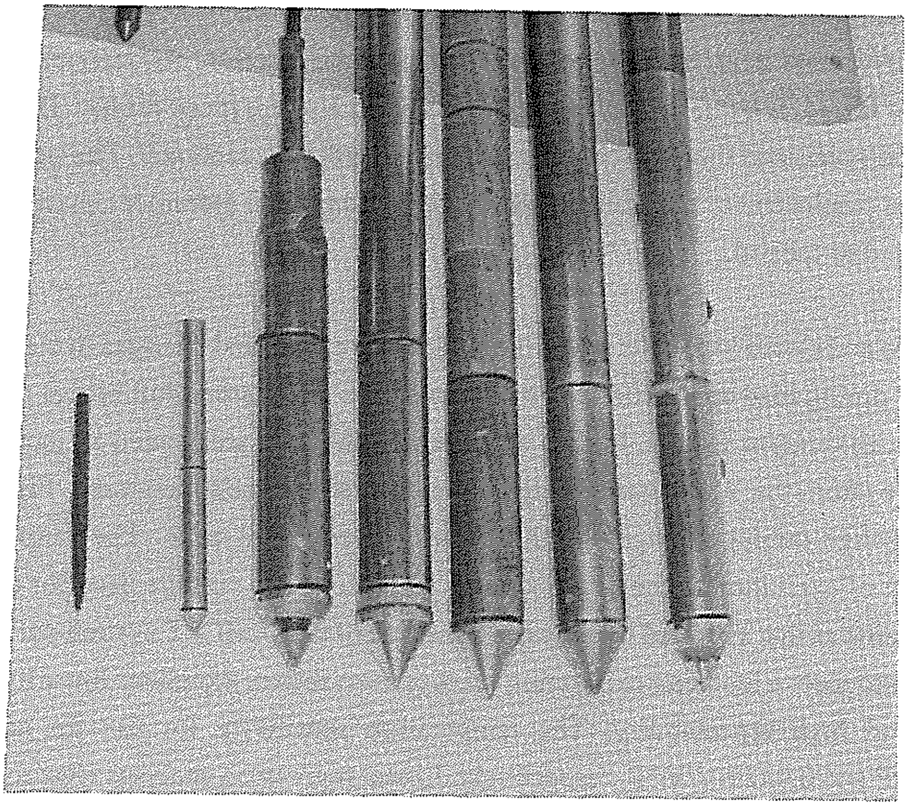


Figure 5a
Miniature versus 15 cm^2 cone penetrometers

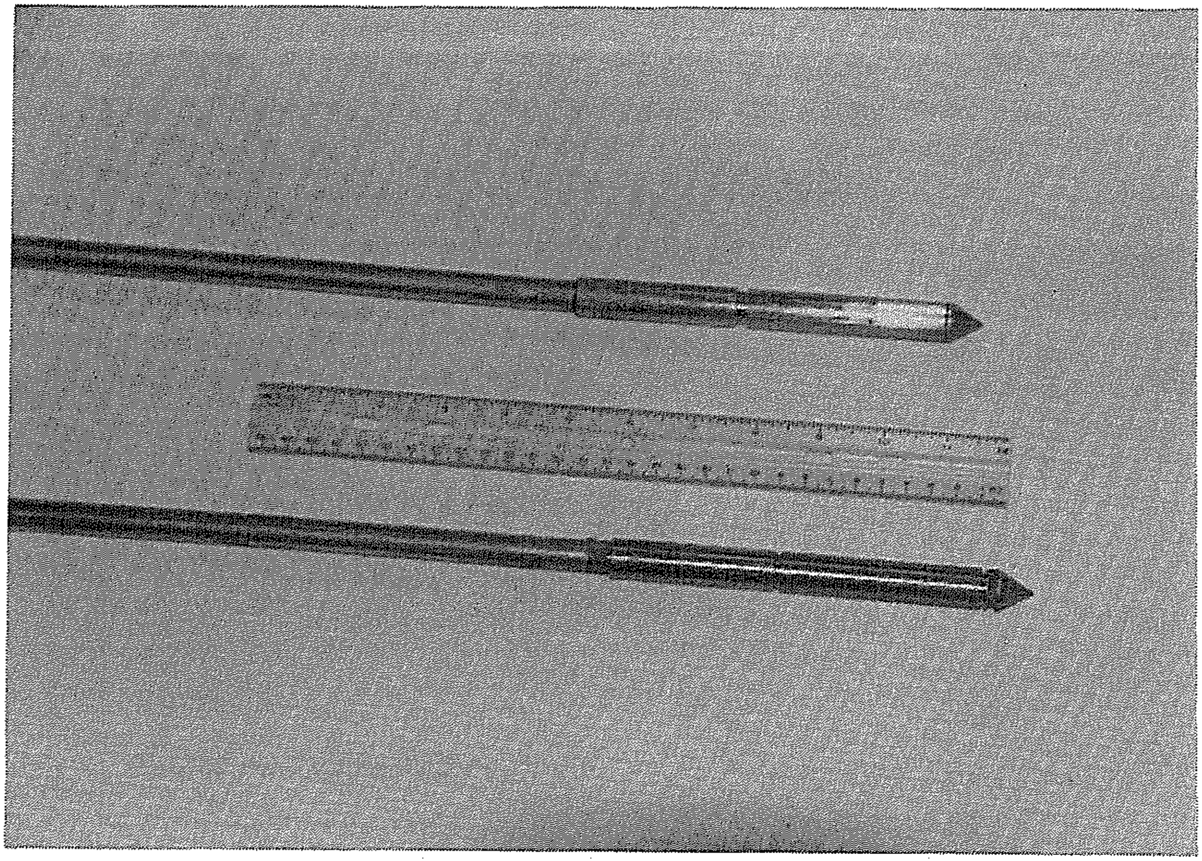


Figure 5b
The miniature cone penetrometer

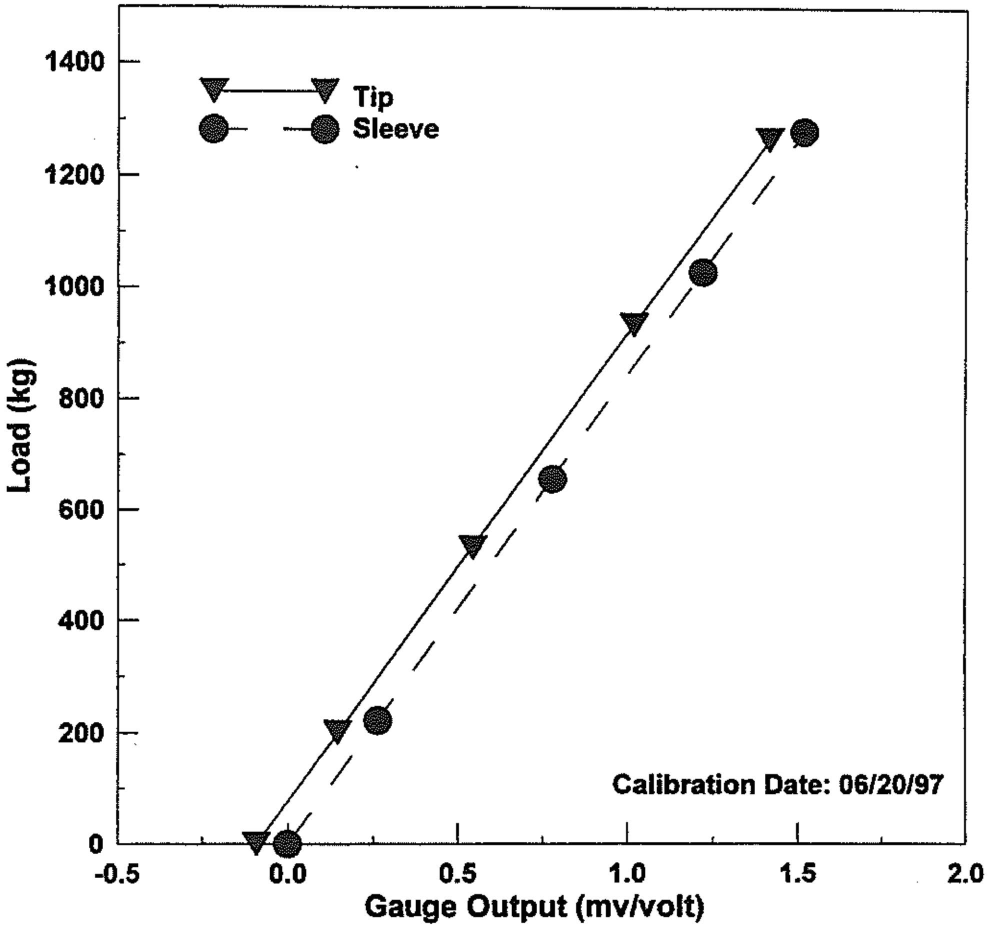


Figure 6
Load calibration of the miniature cone penetrometer

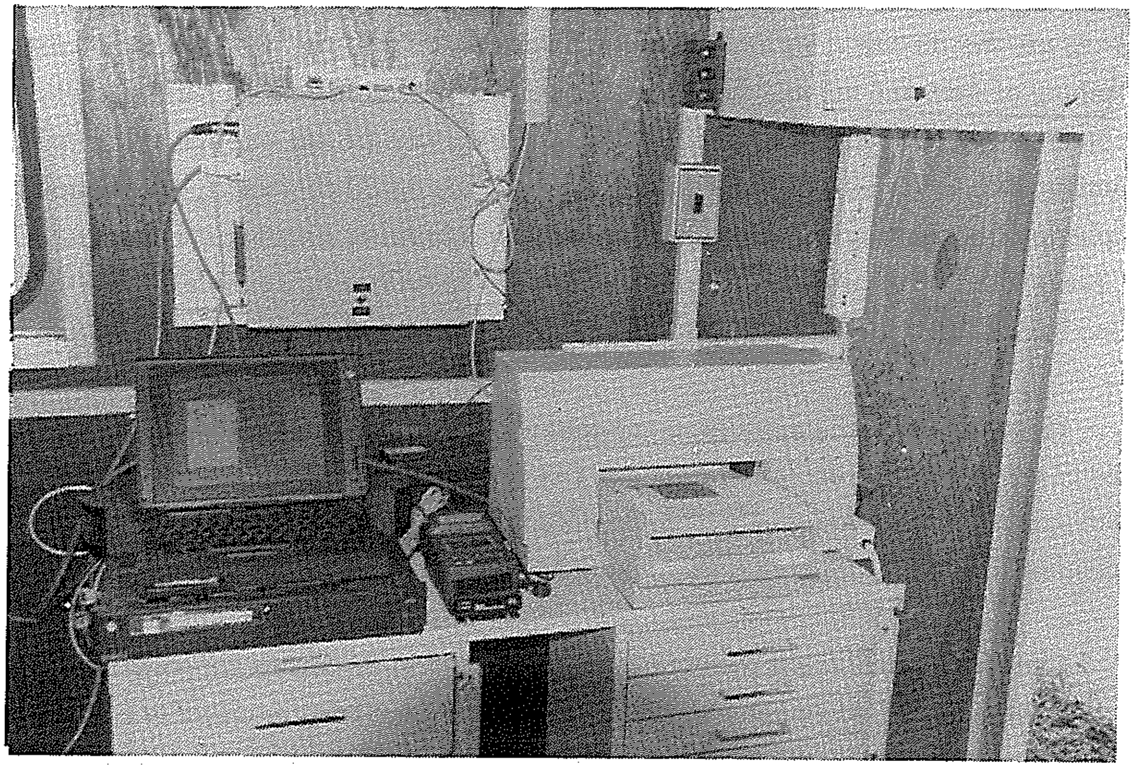


Figure 7
The complete data acquisition system

sleeve friction. For the data collection of five measurements (penetration depth, tip resistance, sleeve friction, pore pressure, and inclination), a system of dedicated smart-digital-sensors modules are used to collect, hold, and communicate to a personal computer the measured data from each sensor. The schematics of the DGH modules are given in figure 8. These modules along with a power supply housed in a metal box comprise the data acquisition hardware (figure 9).

The dedicated smart-digital-sensors modules, manufactured by DGH corporation, are sensor to computer interfaces, designed primarily for data acquisition based on personal computers with standard serial I/O ports. These modules collect analog or digital output signals from sensors, within and/or out of the cone, convert them into digital signals, and send them to a computer's standard RS-485 or RS-232C serial port. The computer itself can be used to communicate to the DGH module to program the module's various data conditioning features, such as scaling of data output, smoothing of data, and noise filtration. Also, interfacing communication parameters between the computer and module, such as baud rates and parity, can be set through the serial port. All communications to and from the modules are in printable ASCII characters, which allows for easy deciphering of output signals. This means a high level computer language such as BASIC, Pascal, or C can be used for programing a data acquisition system by issuing a simple ASCII command and getting back a result in an ASCII string.

Physically, each DGH module is enclosed in a plastic case measuring 7.7 x 3.6 x 1.1 cm, with a labeled screw terminal on one of its edges. DGH modules are selected by model number for the type of sensor to be monitored. A total of five DGH modules are used for a miniature piezocone data acquisition system, one for each sensor. The following is a list of the different DGH modules used.

- One DGH D1622 event counter module is used as a pulse counter for counting digital pulses from a optical incremental encoder. The encoder is axially mounted to a wheel, which is located within the cone pushing device, that rotates as the cone rod is unwound and pushed into the soil.
- Two DGH D1102 voltage modules are used to capture millivolt readings from the tip and sleeve strain gauges.
- One DGH D1512 bridge input module is connected to an Entran miniature accelerometer, located within the cone, to measure the inclination during intrusion.
- One DGH D1532 bridge input is use to measure the millivolt readings from the an Entran miniature pressure transducer.

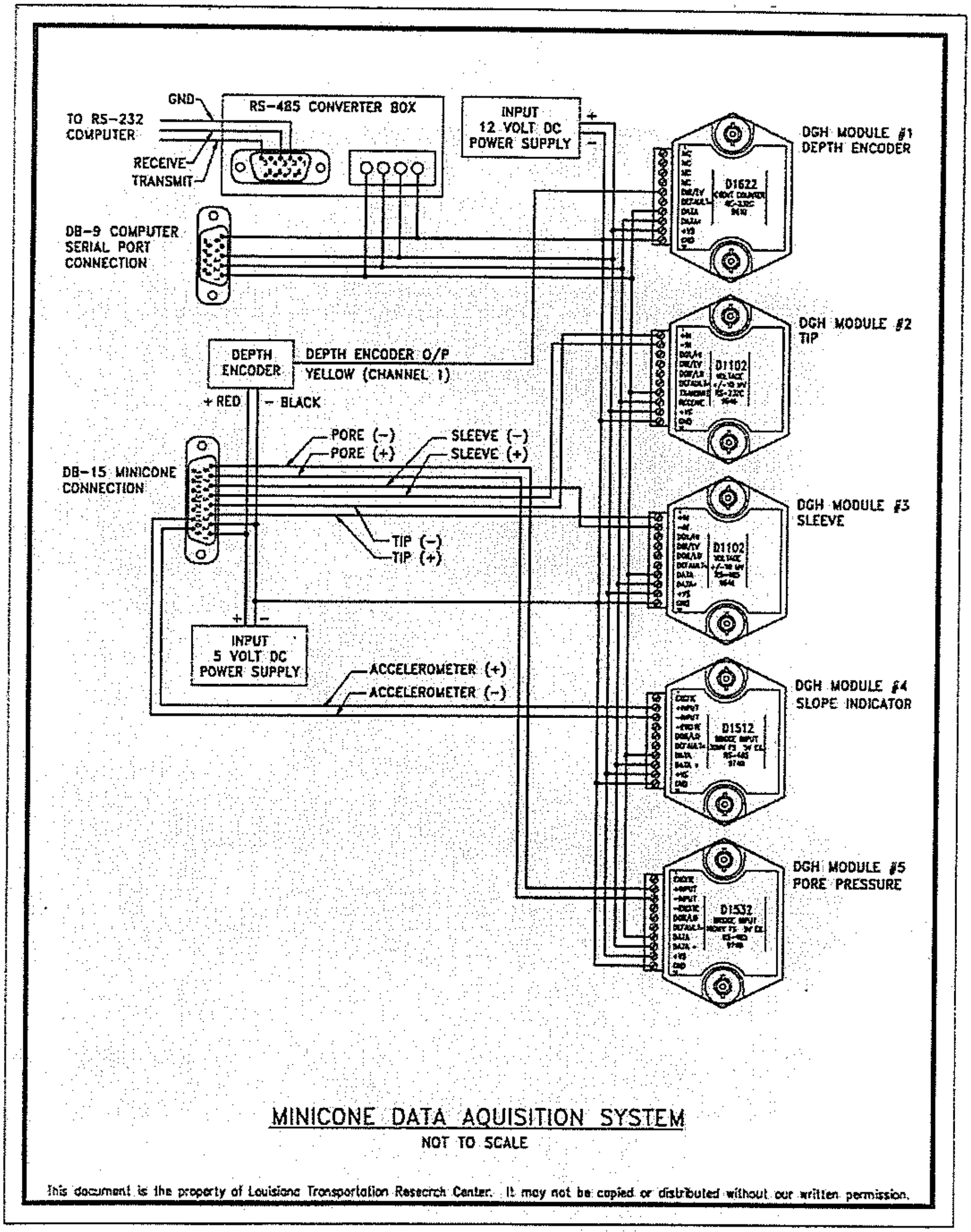


Figure 8
The DGH data acquisition modules (wiring diagram)

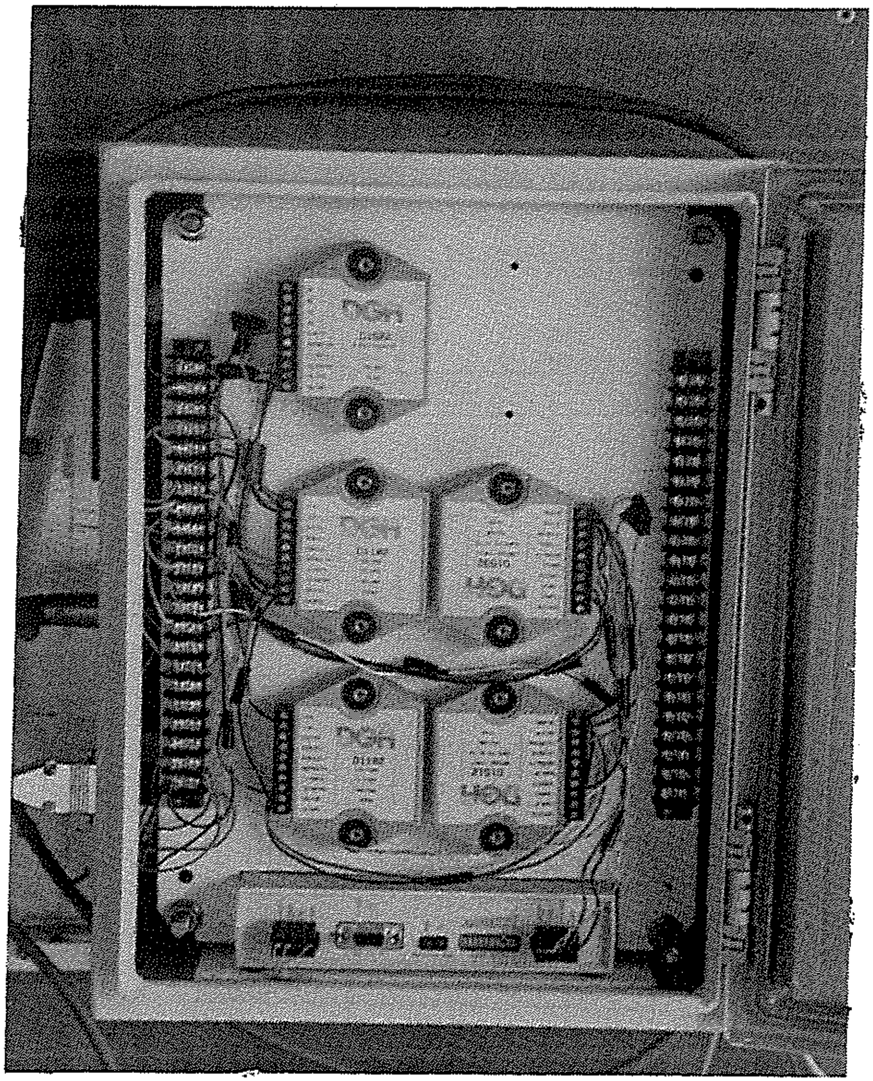


Figure 9
General view of housing for the DGH data acquisition modules

All modules are mounted on a panel within a weather-resistant 30 x 43 x 18 cm metal box. The metal box also houses a 5 and 12 volt power supply to supply power to the DGH modules and excitation voltage to the cone's sensors. To exhaust the heat generated by the modules and the power supply, an electric fan, rated at 32 CFM, is used to vent air though two 3-inch diameter holes fitted with air filters and finger guards. Also housed within the box is a serial signal converter for converting RS485 to RS232C, which is compatible to the standard serial ports of almost any personal computer. Converting the serial signal before it comes out of the box allows for any personal computer to be hooked up to the minicone data acquisition system without the need to install special equipment in the computer itself.

A data acquisition, processing, and display software has been developed in Turbo C ++ to acquire and display data on screen in real time. The software part of the data acquisition system consists of two main parts; the communications part and the graphic part. The communications part consists of the software interacting with hardware to get data. Once the data from the modules are acquired, the software converts the data into engineering units and plots them onto a computer screen in a graphic form in real time. Simultaneously, the data is written to a data file. The graphical user interface is designed to be user-friendly. A pentium notebook computer running at 100 MHz with 16 MB RAM and 810 MB hard drive capacity is used for data acquisition, processing, and analysis. A printer is also available to obtain hard copy output and plots of the cone penetration profiles.

Global Positioning System (GPS)

A Global Positioning System (GPS) installed in the vehicle outputs test locations directly to the computer via an RS-232 port. This is accomplished by a MARCH I unit, an all purpose Global Positioning System (GPS) Data Recorder and navigator, developed by Corvallis Microtechnology, Inc. (figure 10). The unit is practically a handheld computer. It uses a ten MHz CMOS 80c88 CPU with one megabyte internal RAM disk as its main operating platform to run an eight channel Motorola GPS module. Its physical dimensions are 7.9 x 4.9 x 3.0 and weighs 33 ounces. For corrections a Leica differential receiver, tuned to marine Coast Guard frequency is used. With Coast Guard RTCM corrections and a dilution of precision (DOP) less than four (DOP < 4) it has an accuracy of 2 meters under CEP (50 percent), 2.5 meters under RMS (63 percent), and 5 meters under 2DRMS (95 percent). Without any corrections the unit on its own has an accuracy anywhere from 40 to 100 meters. The MARCH GPS unit essentially consists of a MARCH Field Data Recorder, a built-in GPS antenna, and a GPS receiver for satellite signals. The unit is used to collect accurate position data. When the GPS unit is turned on, the tracking status indicator on the screen indicates the quality of the constellation of satellites being tracked by the unit.

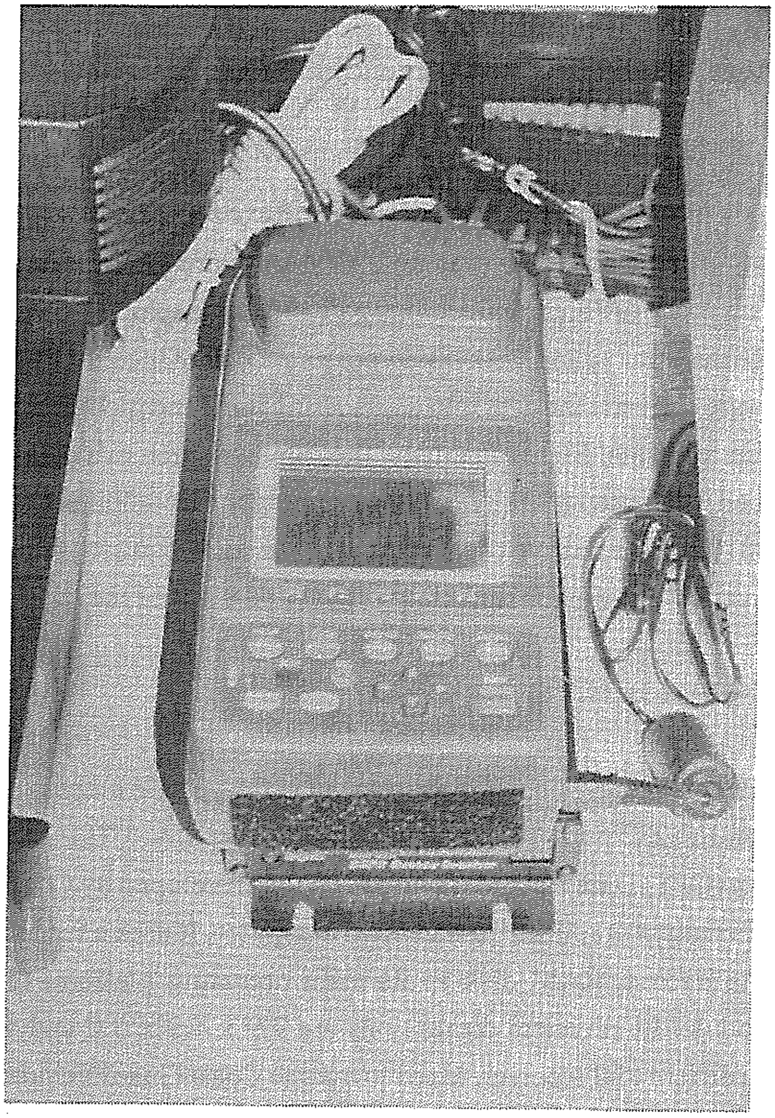


Figure 10
MARCH I - Global Positioning System (GPS)

The appropriate status is "N3D4" which means MARCH GPS is navigating in 3-D and tracking four or more satellites. If differential correction is being used with the RTCM_104 function, the "D" in the indicator will become a "C" indicating correction. The differential correction is received from the Coast Guard radio beacon receiver.

A program module written in Turbo C receives data from the COM port and extracts the latitude and longitude from the reading. The program receives ten corrected readings and computes the average of the latitude and longitude. A listing of the program code is given in appendix 1a. The MARCH GPS unit is provided with two RS-232 interface ports (COM ports) for communication with the external PC. The NMEA function enables the MARCH GPS to output its current calculated coordinates through a COM port for use by the external device. The RTCM_104 function is used to apply the differential correction to the data collected by the GPS unit. These two functions are used in conjunction with each other to produce corrected data and output it to the computer port. The RTCM_104 message is received on COM1, and the NMEA message with the corrected GPS position is sent from COM2 to the PC. It is essential to maintain the same baud rate and other communication parameters between the device providing the correction (LEICA beacon receiver) and the GPS for the RTCM_104 function. Similarly the same parameters are set between the NMEA function and the PC. In this project, the following communication parameters have been set:

Baud Rate	9600
Data bits	8
Parity	None
Stop Bit	1
RTCM_104	Auto (This indicates that the March GPS will use the RTCM_104 message whenever it is received.)
Output Frequency	3 (This indicates how often the NMEA messages will be outputted in this case it is 3 seconds)

A typical output from the GPS is shown in appendix 1b.

DISCUSSION OF RESULTS

Field testing and calibration of the CIMCPT system

The implementation of the miniature cone penetrometer was tested and verified by comparing the penetration profiles with those obtained using a standard 10 cm^2 cross-sectional area reference cone penetrometer developed by Fugro. The 10 cm^2 electronic cone penetrometer has a friction sleeve area of 150 cm^2 and a 60^0 cone apex angle. For field calibration, it is essential to conduct tests at well-documented sites with homogeneous soil deposits to minimize the effect of soil variability on the measured data. The miniature cone is capable of detecting thin layers compared to the large size cones and this feature must be taken into account while interpreting MCPT data. Penetrations by the 10 cm^2 reference cone penetrometer and the 15 cm^2 cone penetrometer have greater radial influence, than the MCPT's. Hence the MCPT's were conducted first before conducting the reference CPT's to minimize interaction and influence of soil disturbance on the tests results. In situ calibration of the CIMCPT system was conducted at a highway embankment site in Baton Rouge, Louisiana; and also at two of the National Geotechnical Experimentation Sites (NGES): University of Houston, and the Texas A & M University. A description of the soil properties at the sites followed by the in situ test results are given below.

Site description and results of in situ tests

Highland Road Site in Baton Rouge, Louisiana. The CIMCPT was field tested and calibrated near the intersection of Highland Road and Interstate 10 (LA SR-42) in Baton Rouge, Louisiana *[6], [7]*. The soil at the test site was overconsolidated, desiccated silty clay/clayey silt formed during the Pleistocene period and deposited in a deltaic environment. The soil is of stiff consistency, low moisture content, and fissured with slickensides and occasional sand pockets *[8]*. The ground water table was located at a depth of 4.5 m. Detailed piezocone penetration tests, soil sampling, and laboratory tests have been performed by Chen and Mayne *[9]* to a depth of 34 meters. Since the CIMCPT system was used to test only the top eight meters, the description of soil properties were limited up to this depth. The liquid limit ranges from 52 to 76 percent with an average of 64 ± 12 percent. The plasticity index ranges from 26 to 40 percent with an average of 33 ± 7 percent. The soil is classified as CH material in the Unified Soil Classification System (USCS). The natural water content varies from 30 to 42 percent (36 ± 6 percent) and is very close to the plastic limit, indicating a stiff deposit. The liquidity index ranges from 0.142 to 0.154. Consolidation test results indicated an overconsolidated deposit with OCR decreasing from 15.6 at a depth of 5.5 meters to an OCR of 11.9 at a depth of 7.9 meters. The compression index (C_c) varies from 0.47 to

0.62, and the swelling index (C_s) ranges from 0.14 to 0.22 ($C_s = 0.18 \pm 0.04$). Isotropically consolidated undrained triaxial compression tests (CIUC) show that the undrained shear strengths range from 60 kN/m^2 to 120 kN/m^2 *[9]*.

Figure 11 shows the location and test plan at the calibration site. Five MCPT's (MCPT1, MCPT2, MCPT3, MCPT4, and MCPT5) were performed at the corners of two equilateral (2.22 m each side) triangular grids. Two 10 cm^2 reference cone penetration tests (CPT1 and CPT2) were conducted at the centroid of each triangles. The distance between two adjacent MCPT's was 2.22 m, and that between the two reference CPT's was 2.56 m (144 times the radius of the reference cone). Hence the influence of soil disturbance and effects of consolidation (due to the proximity of tests) on the data was minimal. At this site it was possible to conduct MCPT's to maximum depths ranging from 7.75 m to 8.75 m. Beyond this depth the total resistance due to friction and tip load exceeded the thrust capacity of the continuous push device. The homogeneity at this site can be easily seen in figure 12 that compares the CPT1 and CPT2 profiles. Figure 13 shows CPT1 profiles compared with those of MCPT1, MCPT2, and MCPT3. Figure 14 shows CPT2 profiles compared with those of MCPT3, MCPT4, and MCPT5. Very good comparison is seen between the 2 cm^2 MCPT profiles and the standard 10 cm^2 CPT profiles. Soil classification by the computerized probabilistic method by Zhang and Tumay, 1999 *[10]* using the mean CPT profiles and the mean MCPT profile are shown in figures 15 and 16.

National Geotechnical Experimentation Sites. A system of test sites is now available in the United States through the National Geotechnical Experimentation Sites (NGES) program funded by the National Science Foundation (NSF) and the Federal Highway Administration (FHWA)[*11*],[*12*]. The NGES system of multiple user test sites provides easy access to well-documented field sites, allowing geotechnical researchers to select the most appropriate site for their needs on the basis of soil type, site location, and available geotechnical data. These well-documented field, well-referenced test sites greatly facilitate the development and validation of new techniques for soil characterization. Associated with the NGES program is a central data repository which provides a database designed to promote exchange of information, resulting in a more cost effective use of available research funds.

Five of the forty-two sites have been selected at an NSF/FHWA workshop and classified as level I or level II sites. The remaining sites are classified as level III. level I sites are those sites which most closely fit the combined criteria of research areas identified through several workshops as being of significant national importance and possessing favorable site characteristics. Theme research areas are geotechnical earthquake engineering (liquefaction, site amplification,

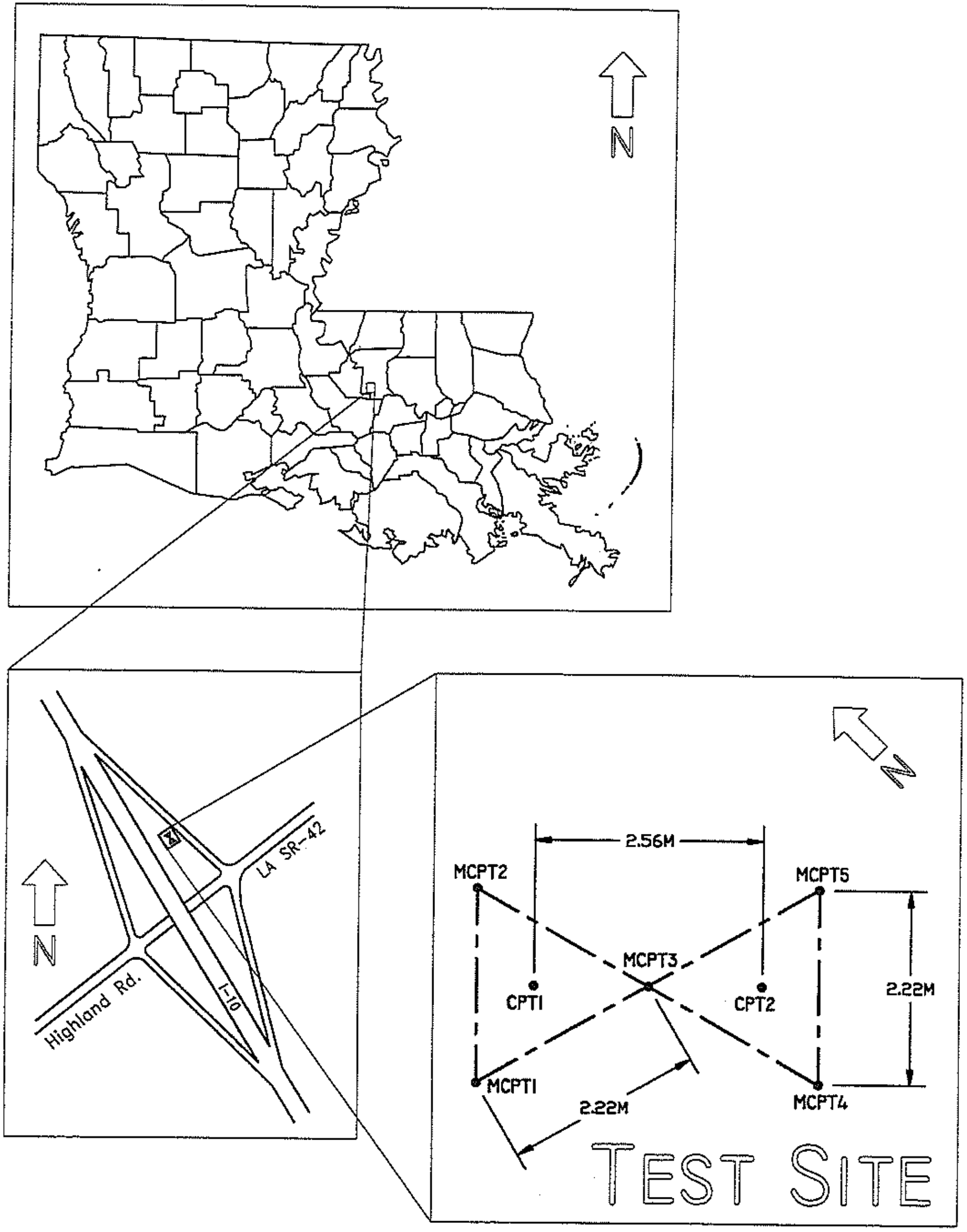


Figure 11
Location and test plan at the Highland Road site in Louisiana

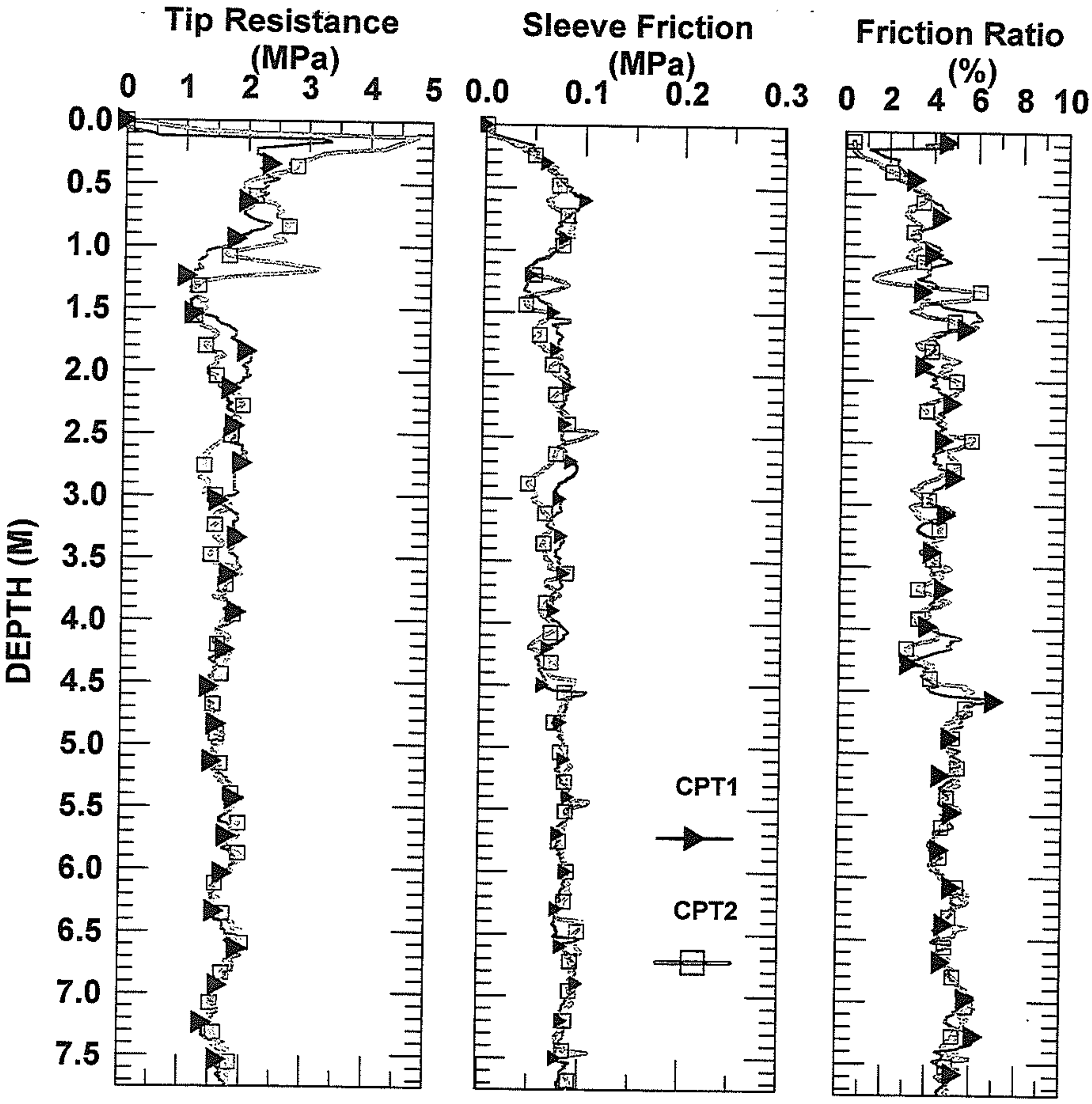


Figure 12
Comparison of penetration profiles of CPT1 and CPT2 at the Highland Road site in Louisiana

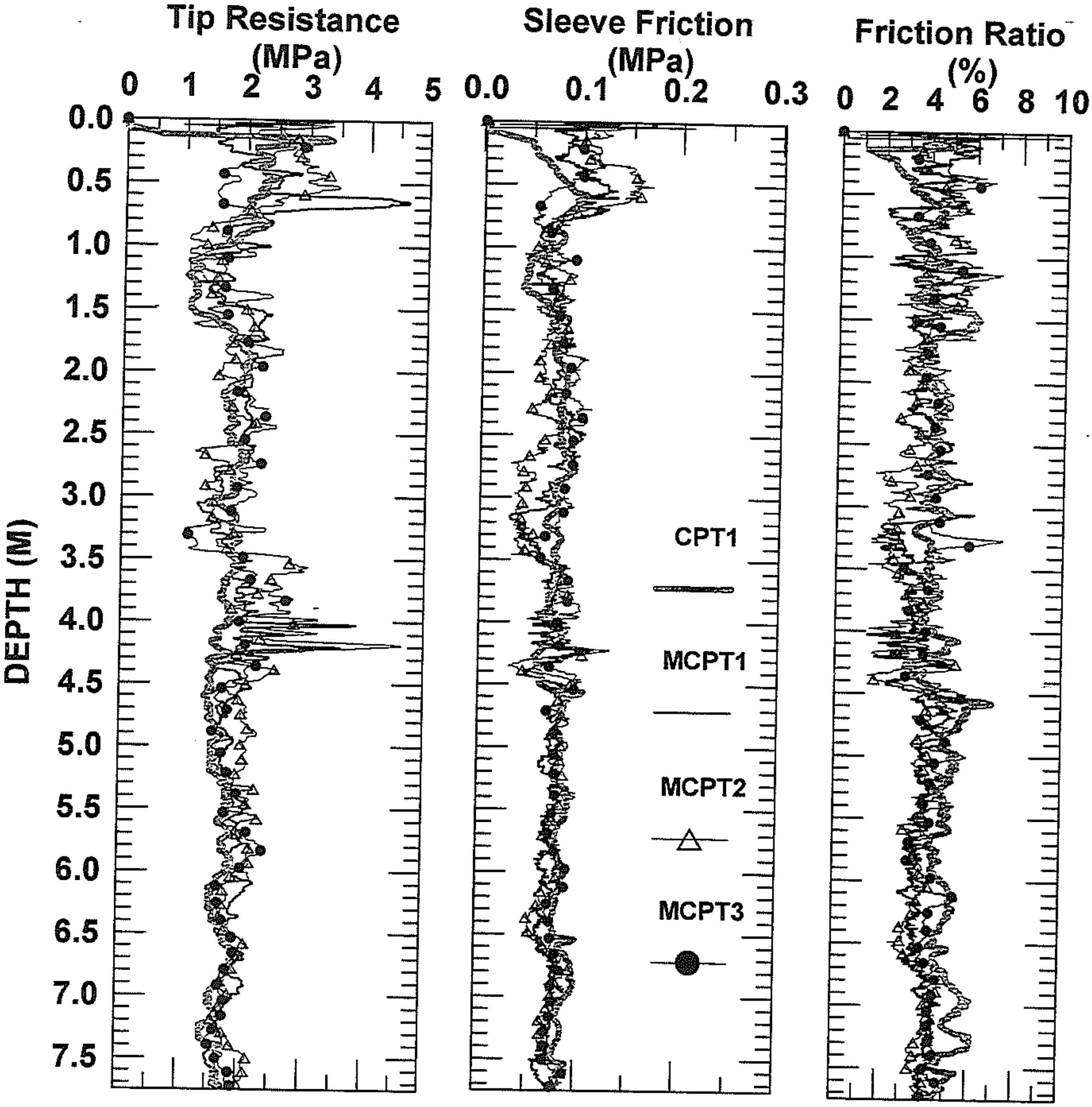


Figure 13
Comparison of penetration profiles of MCPT1, MCPT2 MCPT3 and CPT1 at the Highland Road site in Louisiana

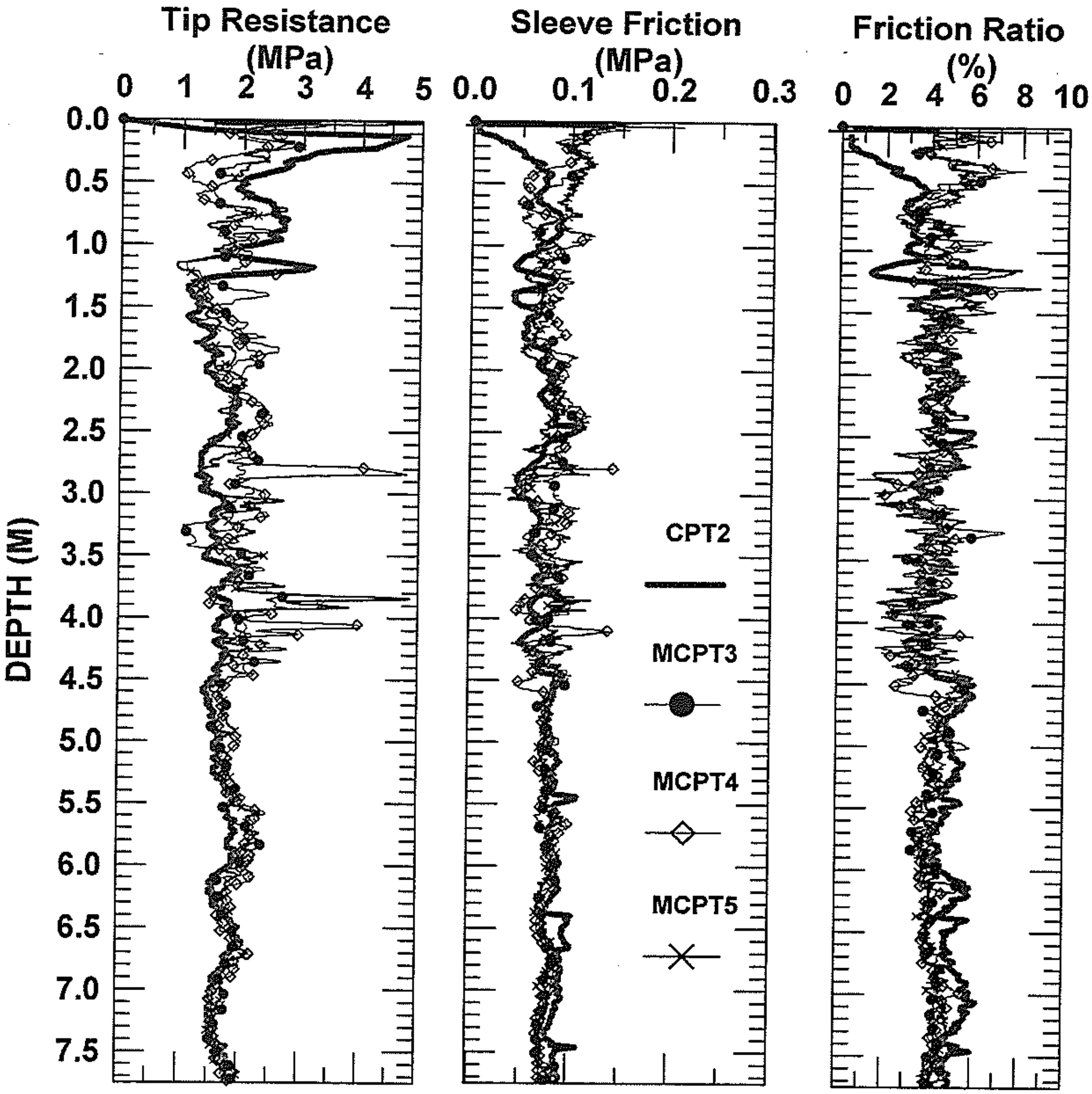


Figure 14
Comparison of penetration profiles of MCPT3, MCPT4, MCPT5 and CPT2 at the Highland Road site in Louisiana.

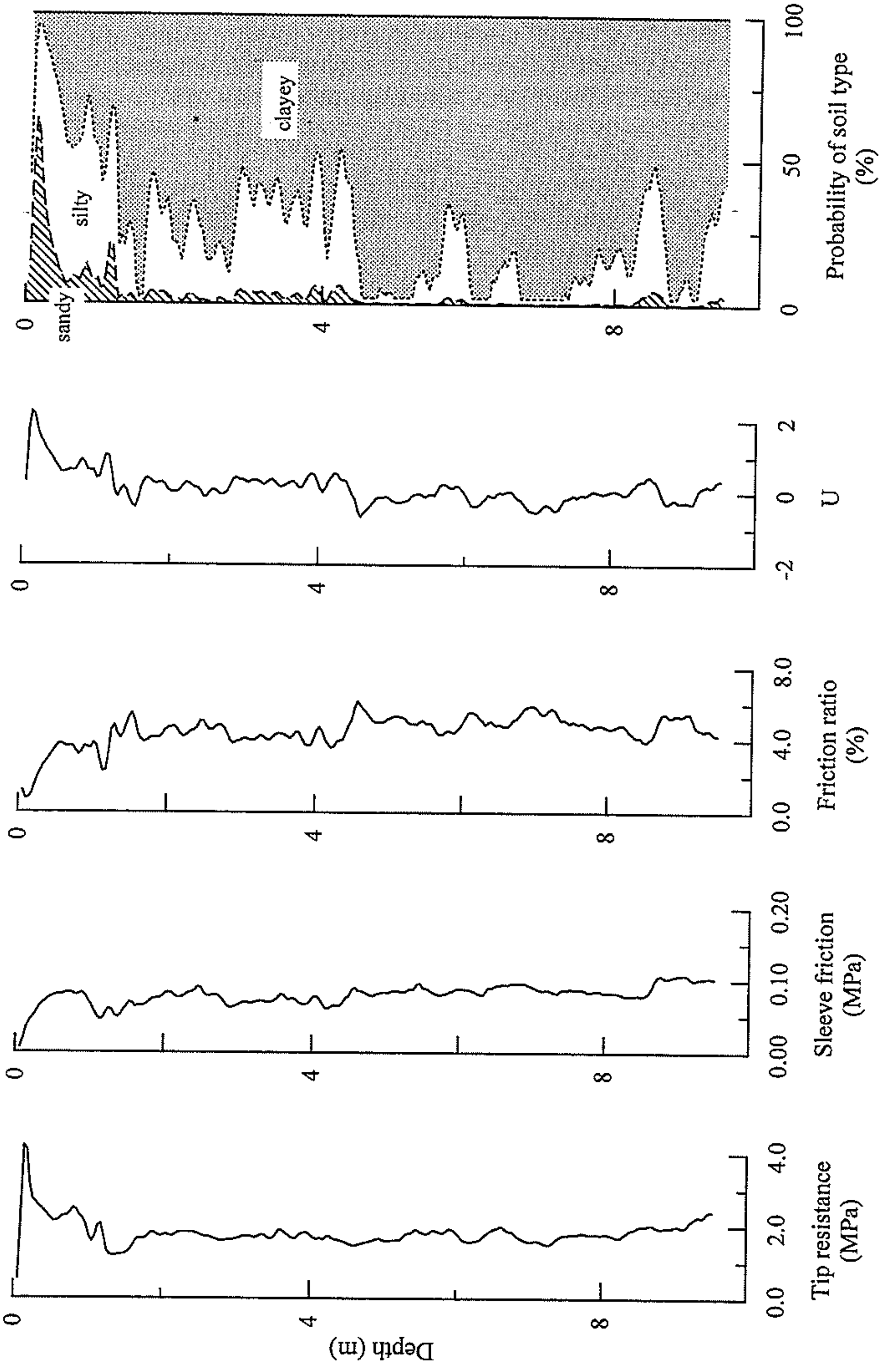


Figure 15
CPT soil classification at the Highland Road site

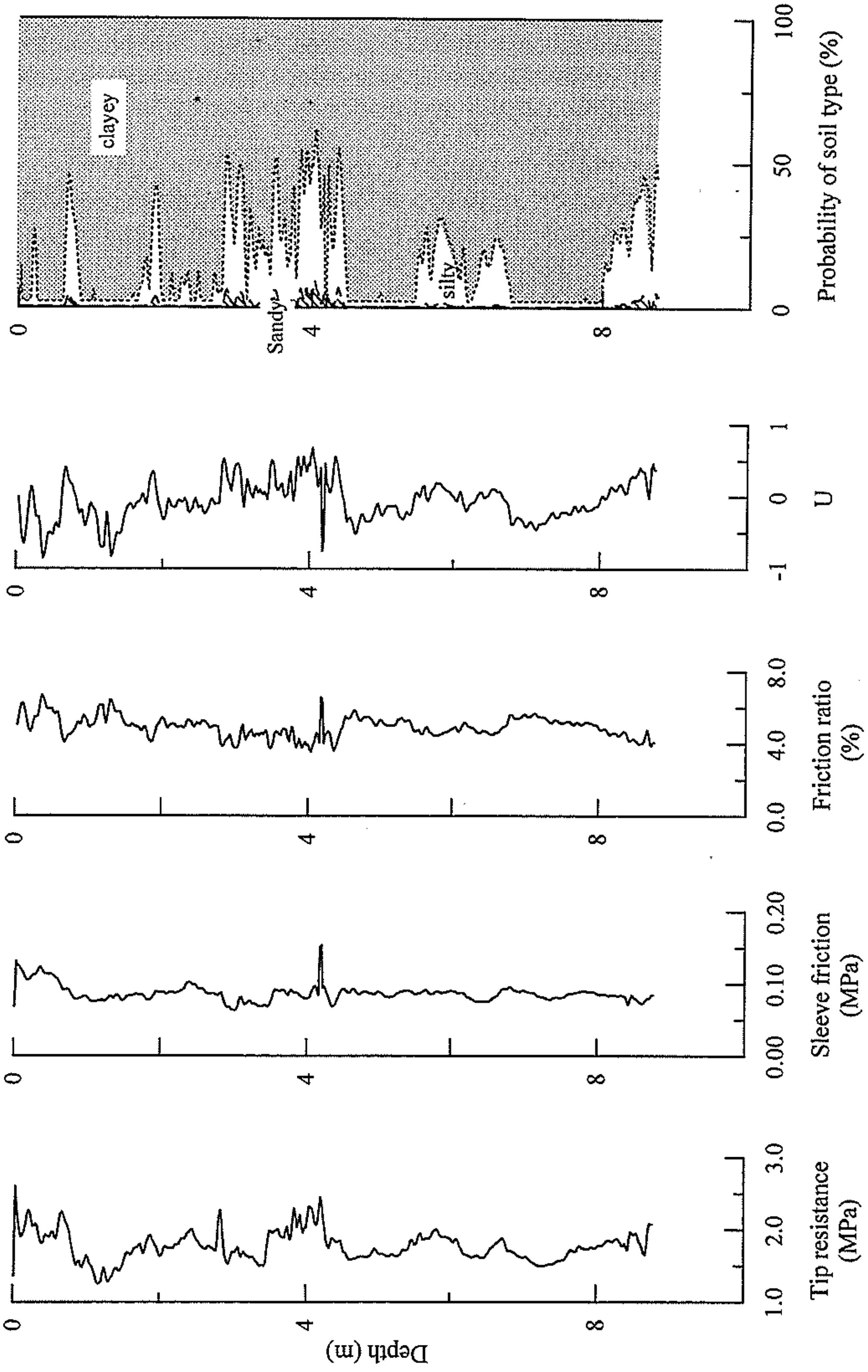


Figure 16
MCPT soil classification at the Highland Road site

and permanent deformations), calibration of new equipment, proof-testing site improvement techniques, geo-environmental problems, expansive clay problems, and foundation prototype testing. Sites qualifying in the theme areas were also screened based on a short list of site characteristics consisting of soil types, stratification, site size, interest and energy of site proponents, security, and long-term accessibility. For level I and II sites, detailed individual field and laboratory test results are accessible on the Internet to potential users and researchers, allowing them to review the quality and numerical details of the results.

The CIMCPT testing at the National Geotechnical Experimentation sites was conducted using the newly developed MPCPT. The MPCPT has the same frame size and geometric configuration of the MCPT, however, in order to accommodate the pressure transducer for pore pressure measurment, a circular cavity in the load cell component of the probe had to be created. CIMCPT results have indicated that this configuration tends to increase the moment sensitivity of the probe which leads to lower friction sleeve readings when tip resistance is higher than two MPa, especially in sandy soils. The sleeve resistance correction due to moment sensitivity was investigated by subjecting the minicone to a simple four-point bending test in the laboratory which resulted in the following empirical relationship based on statistical analysis:

$$f_s \text{ (corrected, MPa)} = f_s \text{ (measured, MPa)} + 0.015*[q_c \text{ (measured, MPa)}]^{1/2}$$

This correction is reflected in the MPCPT data presented for CIMCPT investigations performed at the National Geotechnical Experimentation Sites of Texas A&M University and University of Houston, Texas.

National Geotechnical Experimentation Site at Texas A&M University. The CIMCPT system was tested in the clay site, at Texas A&M University, Riverside Campus, College Station, Texas*[12], [13]*. This Level I site (with Site I.D.: TXAMCLAY) essentially consists of highly plastic, stiff clay (CH) up to a depth of 6.5 meters. Below this is a hard clay deposit 5.7 m thick, with high shrink-swell potential, over hard clay/clay shale 23 m thick. The ground water table is normally located between 7 and 7.3 m. The site has been used in the past by various investigators for a variety of tests on full-scale deep and shallow foundations, as well as for extensive in situ testing.

Figure 17 shows the test plan layout for the in situ tests performed at this site. In figure 17 the test numbers with prefix MPCPT are the miniature piezocone penetration tests, those beginning with letters CPT are the 10 cm^2 standard friction cone penetration tests. MPCPT profiles MPCPT-TXAM1, MPCPT-TXAM3 and MPCPT-TXAM4 are compared with the mean of CPT18 and CPT22

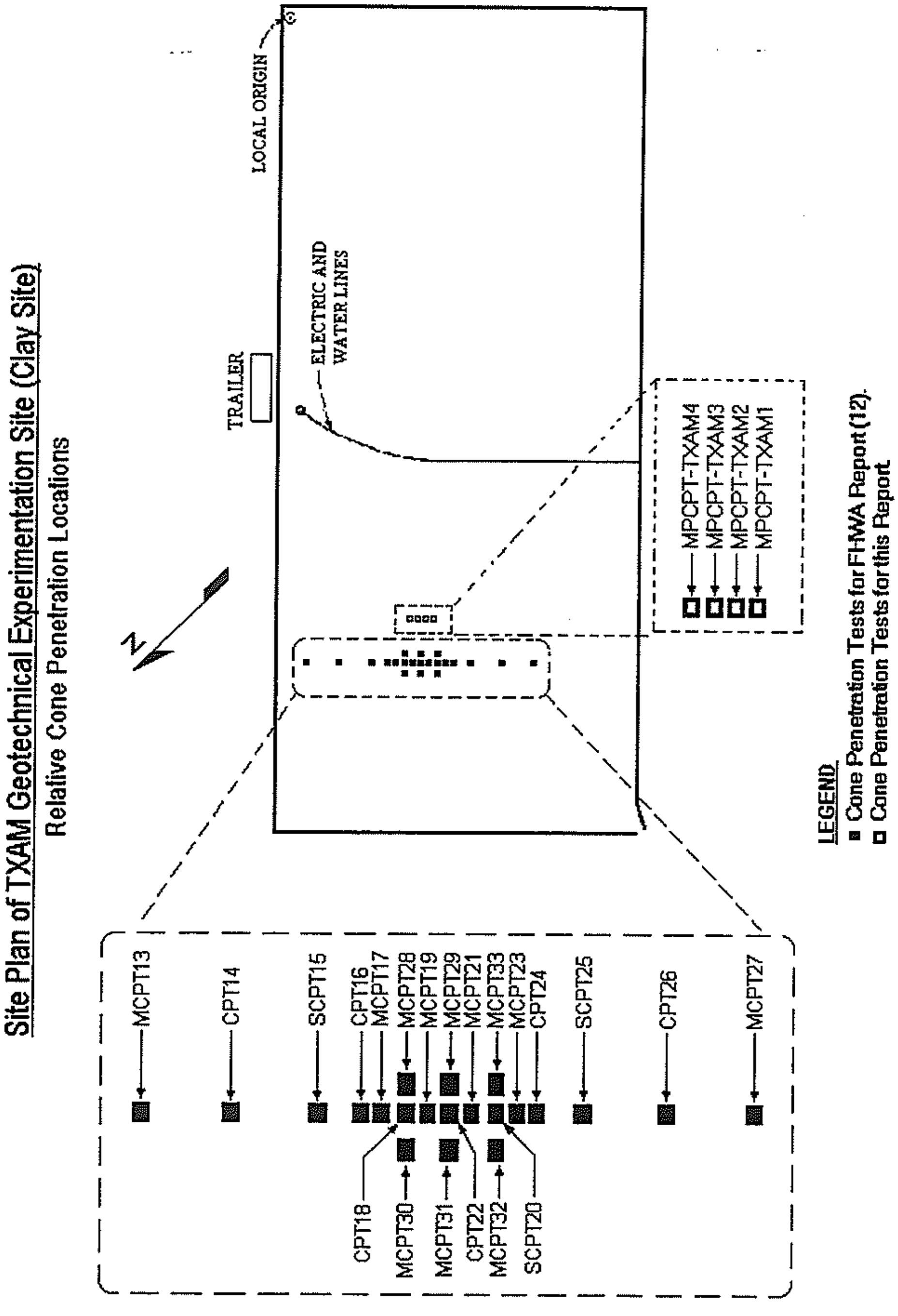


Figure 17
Location and test plan at the NGES in Texas A&M University

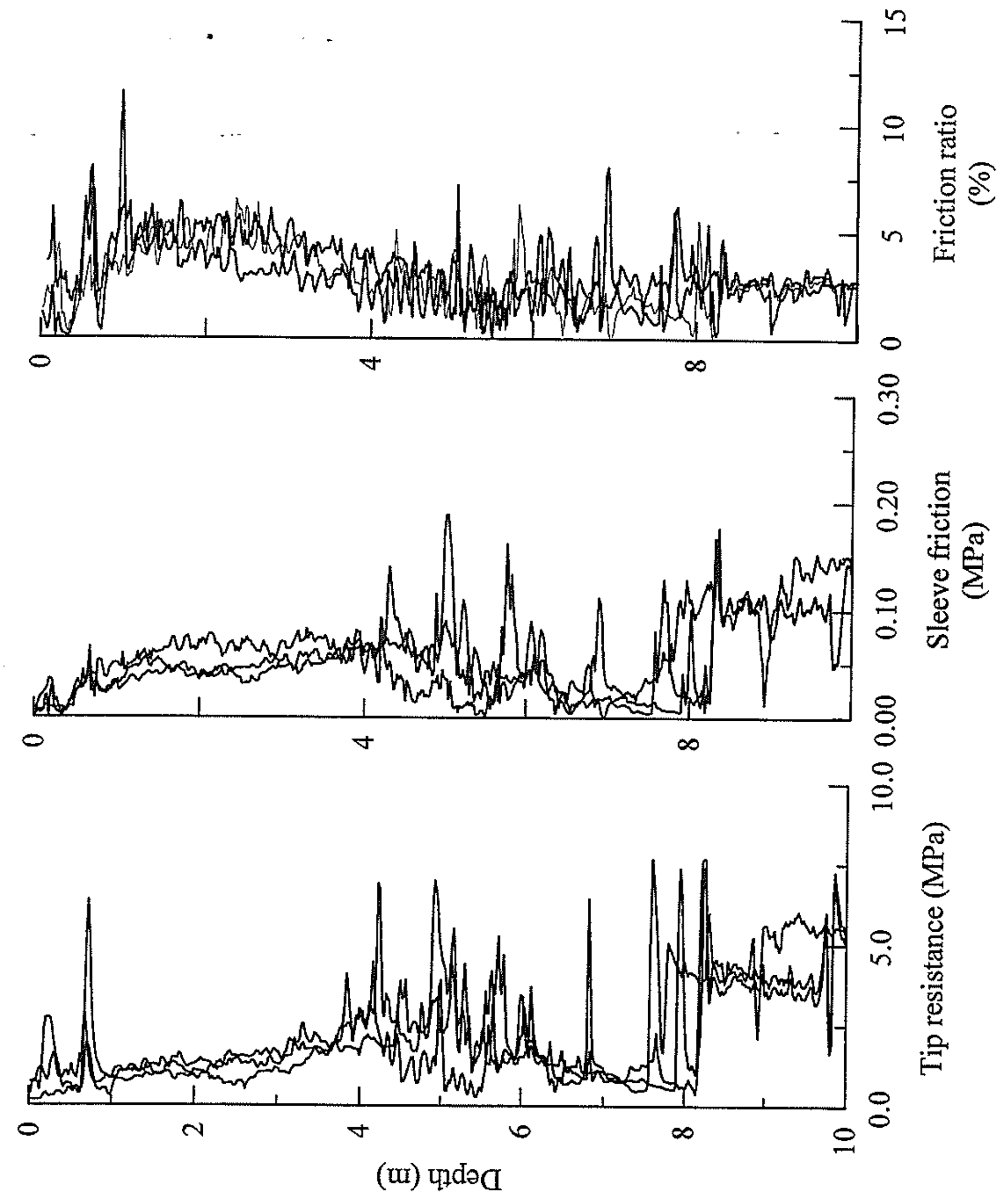


Figure 18
Comparison of penetration profiles of MPCPT-TXAM1, MPCPT-TXAM3, MPCPT-TXAM4 with the means of CPT18 and CPT22 at the NGES in Texas A&M University

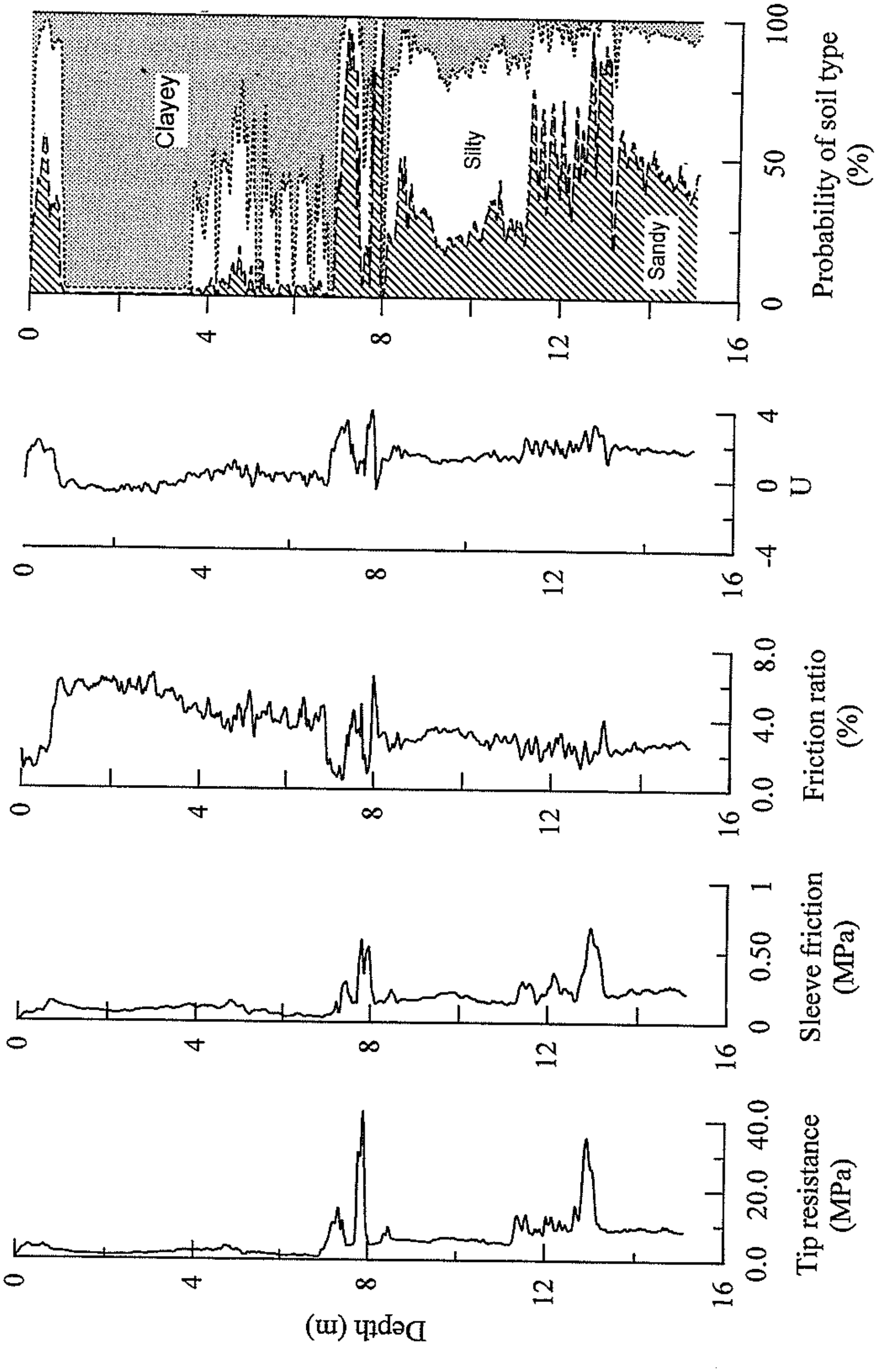


Figure 19
CPT Soil classification at the NGES at Texas A&M University

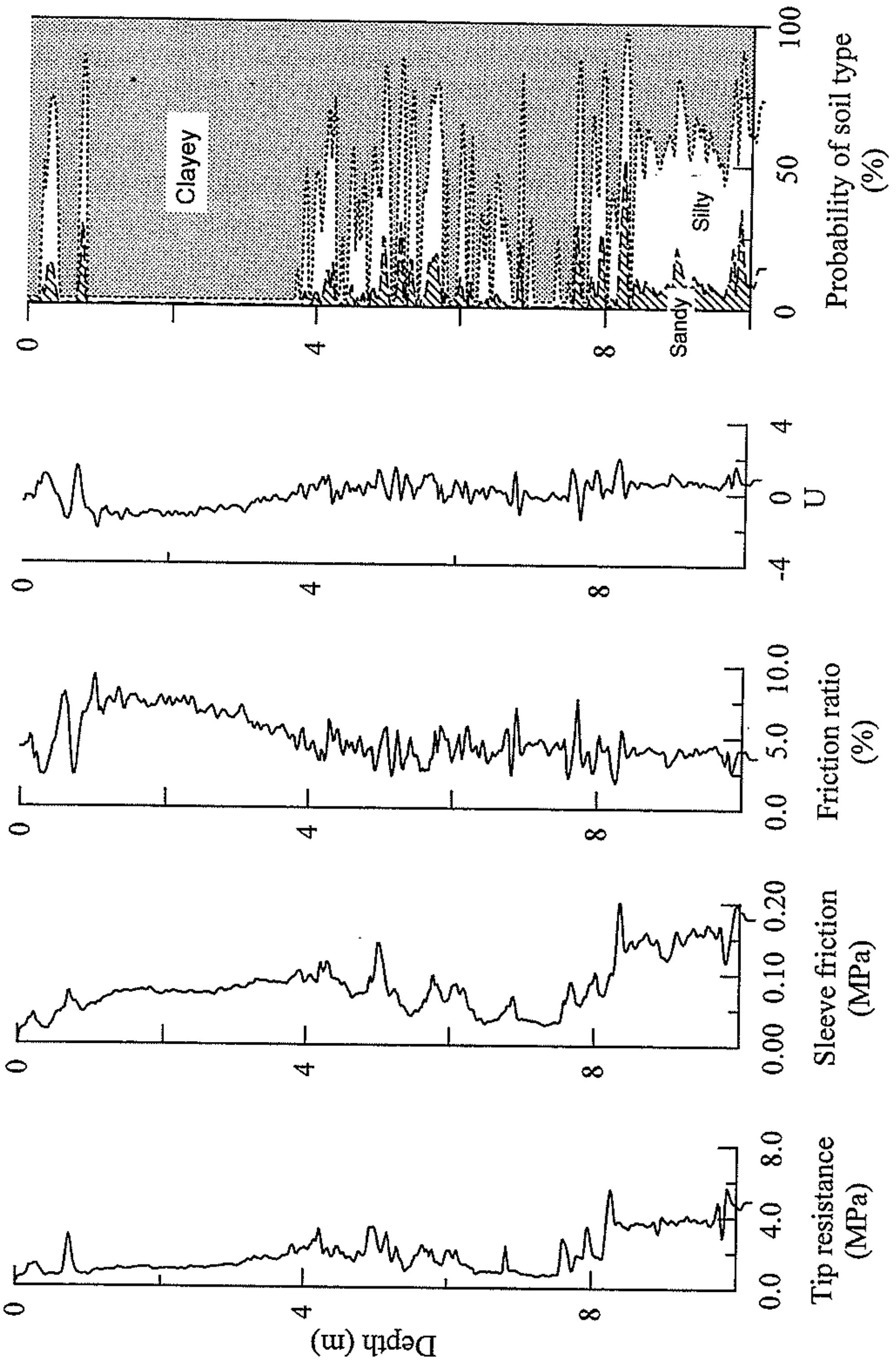


Figure 20
MCPT classification at the NGES in Texas A&M University

profiles in figure 18. Soil classification by the computerized probabilistic method [*10*] using the mean CPT profile and the mean MPCPT profile are shown in figures 19 and 20.

National Geotechnical Experimentation Site at University of Houston, Texas. The CIMCPT system was tested in the level II site at the University of Houston (figure 21). This site (with Site I.D.: TXHOUSTO) essentially consists of overconsolidated stiff to hard clay (CH to CL) up to a depth of 30 meters [*12*], [*14*]. The ground water table is located at 2.1 m. The site has been used in the past by various investigators for individual and group behavior of deep foundations. Extensive in situ and laboratory testing data are available.

Figure 22 shows the test plan layout for the in situ tests performed at this site. MPCPT profiles MPCPT-UH1, MPCPT-UH2, MPCPT-UH3 and MCPT-UH4 are compared with the mean CPT profile in figure 23. The mean CPT profile is the mean of C3, C4, C4A, and C5 (figure 22). Soil classification by the computerized probabilistic method *[10]* using the mean CPT profile and the mean MPCPT profile are shown in figures 24 and 25.

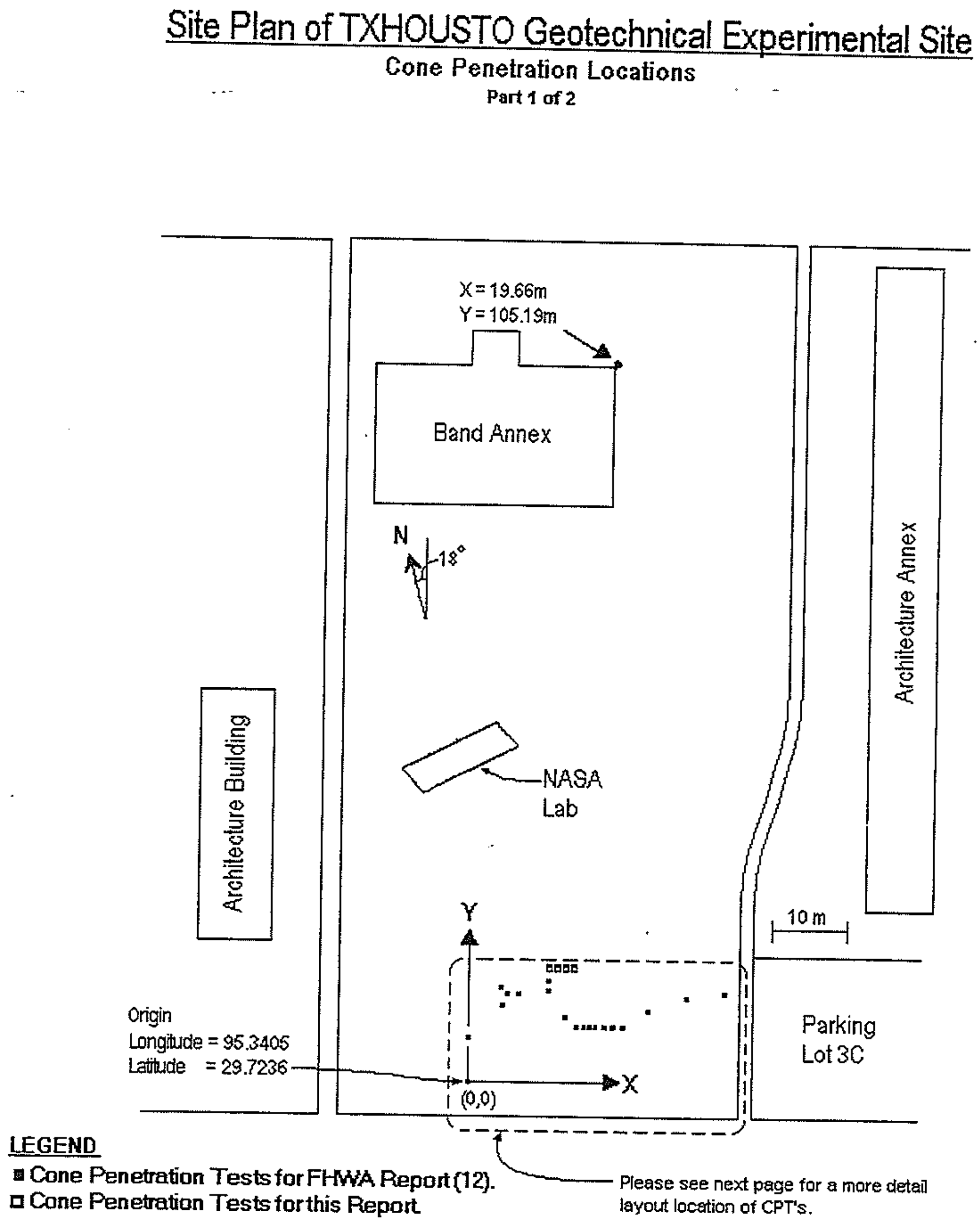


Figure 21
Location of the NGES in the University of Houston

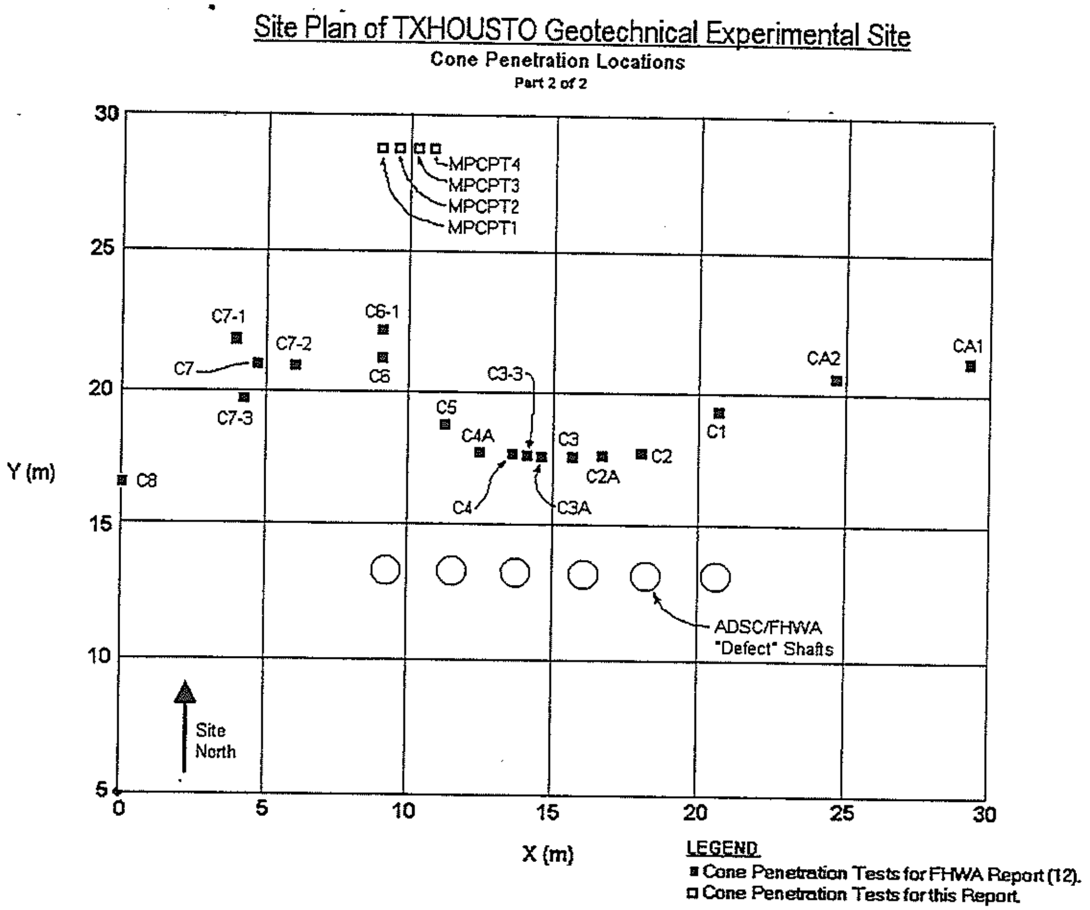


Figure 22
Test plan at the NGES in the University of Houston

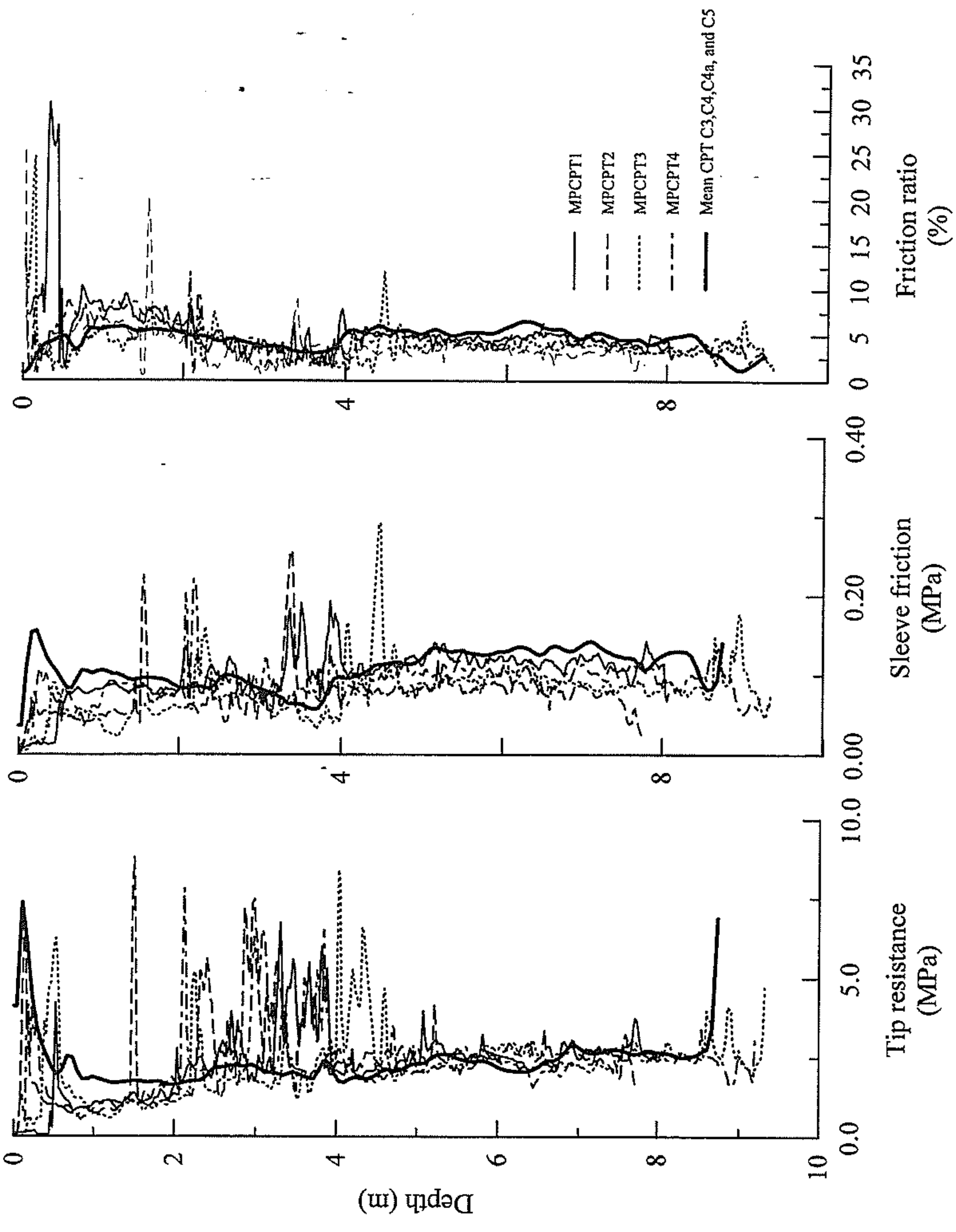


Figure 23
Comparison of the penetration profiles MPCPT-UH1, MPCPT-UH2, MPCPT-UH3 and MPCPT-UH4 with the mean of CPT profiles C3, C4, C4a, and C5 at the NGES in the University of Houston

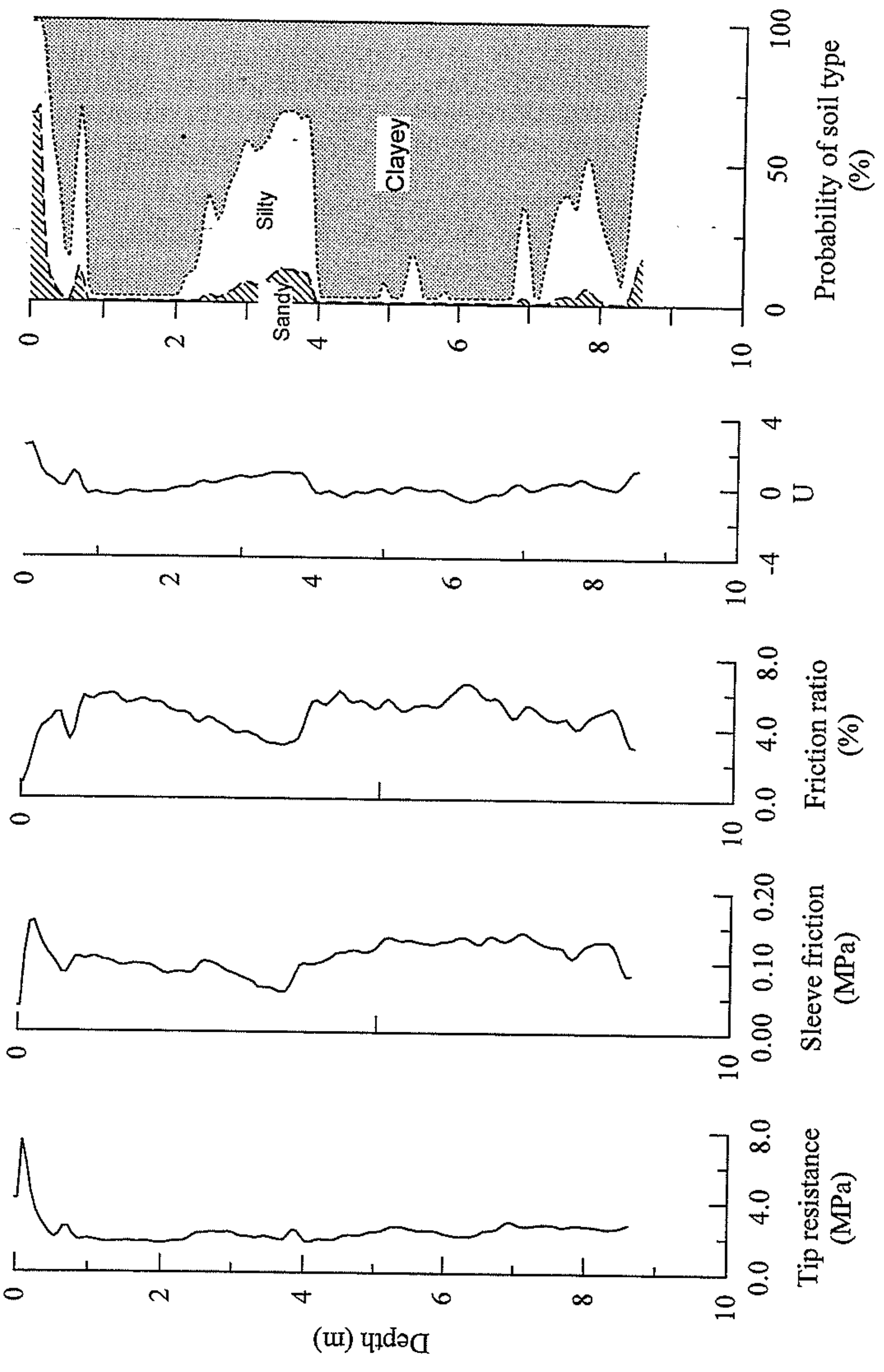


Figure 24
CPT soil classification at the NGES in the University of Houston

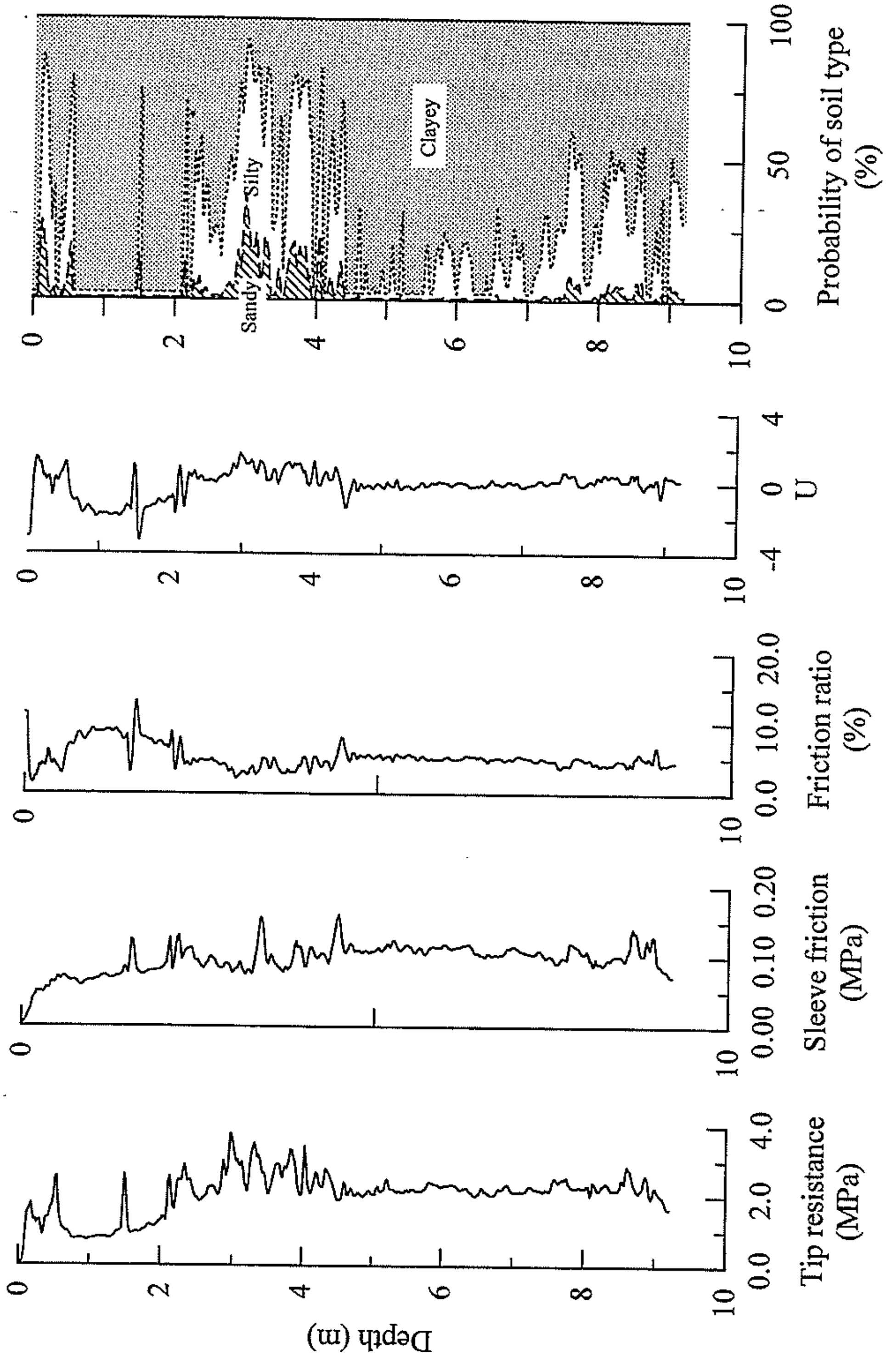


Figure 25
MPCPT soil classification at the NGES in the University of Houston

CONCLUSIONS

The validity of the CIMCPT system is readily verified by comparing the 2 cm^2 MCPT and MPCPT profiles with the 10 cm^2 CPT profiles performed at the Highland Road site in Baton Rouge, Louisiana, and at the National Geotechnical Experimentation Sites at Texas A&M University and the University of Houston (figures 13, 14, 18 and 23).

At each of these sites, comparison between the MCPT, MPCPT and CPT test profiles indicate "scale" (size and rate) effects. Table 1. summarizes the scale effects at the three test sites.

TABLE 1
Scale effects at the test sites

TEST SITE (Minicone Type)	Depths	$q_{c(2\ cm2)} / q_{c(10\ cm2)}$	$f_{s(2\ cm2)} / f_{s(10\ cm2)}$
Highland Road(1) Baton Rouge, LA	4.5 m - 7.5 m	1.10	0.89
NGES (2) Texas A&M Univ.	1.5 m - 7.0 m	1.13	0.91
NGES (2) Univ. of Houston	1.0 m - 8.5 m	1.11	0.87

(1) MCPT
(2) MPCPT (Sleeve resistance corrected for moment sensitivity)

The CIMCPT was field-tested at sites where the tip resistance of the sediments were less than eight MPa. The range of depths chosen for analyses at these sites are such that the probability of clay is about 75 percent, using the computerized probabilistic method for soil classification *[10]*. The scale effects are valid provided the probability of sand is less than ten percent.

A continuous intrusion miniature cone penetration test system (CIMCPT) was developed for transportation applications. CIMCPT was validated by testing at a Highland Road test site in Baton Rouge, Louisiana and also at two well documented, well referenced, National Geotechnical Experimentation Sites (University of Houston, and at the clay site, at Texas A&M University). Penetration profiles obtained using the 2 cm^2 cross-sectional area miniature cone penetrometers showed the existence of "scale effects" when compared to penetration profiles obtained using a 10

cm^2 cross-sectional area reference cone penetrometer. The average CIMCPT (MCPT and MPCPT) tip resistance was found to be 11 percent higher than that of the reference CPT. The average CIMCPT (MCPT and MPCPT) sleeve friction was found to be 11 percent lower than the reference CPT sleeve friction. These correction factors can be easily implemented into the computer programs for calculation of the tip resistance q_c and sleeve resistance, f_s. These trends in the results compare very well with previous research.

Penetration records of CIMCPT generally render much more detailed soil identification/classification profiles than penetration records obtained by CPT.

RECOMMENDATIONS

The CIMCPT system may be used for shallow and semi-deep subsurface investigations for highway subgrade characterization, embankment construction control, and for the assessment of ground improvement effectiveness for transportation applications.

The following recommendations are proposed for future enhancement of the equipment and for field testing:

1. The 2 cm^2 miniature cone penetrometer that has been implemented and tested in this project is a basic friction cone penetrometer, MCPT, which gives cone resistance and sleeve friction profiles with depth. With the inclusion of a pressure transducer and an inclinometer, the capabilities of MCPT were modified to measure pore pressures generated during cone penetration and the inclination during intrusion. It is recommended that the 2 cm^2 miniature "piezocone" penetrometer test (MPCPT) capability of the CIMCPT system be further developed for locating the depth of the ground water table, detailed profiling of soil stratigraphy, and for estimating flow and consolidation characteristics of fine grained soils from the dissipation of excess pore pressure data.

2. The inclusion of the pore pressure transducer and the inclinometer in the limited space of the MPCPT probe requires a hole in the load cell configuration thus increasing the moment sensitivity. This sensitivity tends to decrease friction sleeve readings in stiffer layers where tip resistance in excess of 2 MPa are encountered (i.e. sandy soils). It is recommended to modify the sleeve friction load cell design to strengthen the structural integrity of the probe to remedy this hardware problem.

3. More in situ calibration tests in well-characterized and well-documented sites should be conducted to further refine and correlate MCPT and MPCPT data with engineering soil properties (such as resilient modulus, shear strength, deformation, consolidation, and flow characteristics) needed for highway design and construction control.

REFERENCES

1. Tumay, M.T., *Implementation of Louisiana Electronic Cone Penetrometer System (LECOPS) for Design of Transportation Facilities*, Executive Summary, FHWA/LA Report No. LA - 94/280 A&B, 1994, p.118.

2. Tumay, M. T., and Kurup, P. U., *Calibration and Implementation of Miniature Electronic Cone Penetrometers for Road and Highway Design and Construction Control*, LTRC State Project No. 736-13-0036,1997, p.71.

3. de Lima, D. C., *Development, Fabrication and Verification of the LSU In Situ Testing Calibration Chamber*. Ph.D. Dissertation, Louisiana State University, Baton Rouge, LA, 1990.

4. de Lima, D. C., and Tumay, M. T., "Scale Effects in Cone Penetration Tests." *Proc., Geotechnical Engineering Congress*, GT Div/ASCE, Special Publication No. 27, Boulder, CO, 1991, pp. 38-51.

5. Tumay, M. T., and de Lima, D. C., *Calibration and Implementation of Miniature Electronic Cone Penetrometer and Development, Fabrication and Verification of the LSU In-situ Testing Calibration Chamber (LSU/CALCHAS)*, LTRC/FHWA Report No. GE-92/08, 1992, 240 p.

6. Kurup, P.U., and Tumay, M.T., "Calibration of a Miniature Cone Penetrometer for Highway Applications" Transportation Research Record No. 1614: In Situ Testing Devices and Strain Measurements, 1998, pp. 8-14.

7. Tumay, M.T., Kurup, P.U. and Boggess, R.L., "A Continuous Feed Electronic Miniature Cone Penetrometer System for Site Characterization," Geotechnical Site Characterization, (eds. Robertson, P.K. and Mayne, P.W.), A.A. Balkema, Rotterdam, Proceedings of the First International Conference on Site Characterization (ISC'98), Atlanta, April 19-22, 1998, Vol. 2, pp. 1183-1188.

8. Arman, A., and McManis, K. L., "The Effect of Conventional Soil Sampling Methods on the Engineering Properties of Cohesive Soils in Louisiana." *Engineering Research Bulletin No. 117*, Louisiana State University, Baton Rouge, Louisiana, 1977, 294 p.

9. Chen, B. S., and Mayne, P. W., *Profiling the Overconsolidation Ratio of Clays by Piezocone Tests*. Report No. GIT-CEEGEO-94-1, Georgia Tech Research Corporation, Georgia Institute of Technology, Atlanta, Georgia, 1994, p. 279.

10. Zhang, Z., and Tumay, M. T., "Statistical to Fuzzy Approach Toward CPT Soil Classification, "*Journal of Geotechnical & Geoenvironmental Engineering*, ASCE, Vol. 125, No. 3, 1999, pp. 179-186.

11. DiMillio, A.F., and Prince, G., "National Geotechnical Experimentation Sites," *Public Roads*, FHWA, U.S. DOT, Vol. 57, No. 2, pp 17-22.

12. Tumay, M. T., "In Situ Testing at National Geotechnical Experimentation Sites - Phase 2," Contract DTFH61-97-P-00161, Final Report, U.S. Department of Transportation, Federal Highway Administration, February 1998, 154 pp + CD-ROM.

13. Simon, P.A., and Briaud, J-L., " The National Geotechnical Experimentation Sites at the Texas A & M University: Clay and Sand," NGES-TA&M-006, December 1996, Texas A & M University, College Station, Texas.

14. O'Neill, M.W., Professor of Civil Engineering, University of Houston, Personal Communication, 1998.

APPENDIX 1

1a. Listing of the GPS program code

1b. Typical output from the Global Positioning System

1a. Listing of the GPS program code:

```
/* GPS MODULE ********************************************************/
/*                                                                   */
/* by Ramya Sarma                                                    */
/*                                                                   */
/* This module uses Borland C++ function bioscom to initialize com   */
/* port and collect data from GPS on COM 2.  Ten latitude and        */
/* longitude values are collected and averaged.  GPS correction      */
/* reception is verified.  If corrections are not present, the       */
/* module notifies operator and asks if another collection should    */
/* occur.                                                            */
/*********************************************************************/

/* The following variables and functions are responsible for receiving
   GPS data and convert them into suitable form to be displayed in
   th computer screen */
#define COM2 1
#define COM1 0
#define DATA_READY 0x100
#define TRUE 1
#define FALSE 0
#define SETTINGS (0xE0|0x00|0x00|0x03)
struct gpsreading {
        char reading[100];
        char slatitude[30];
        char slongitude[30];
        float flatitude;
        float flongitude;
        char fix;
        } gpsdata[10];
char latitudedirection,longitudedirection;
int gpsnumber=0;
int uncorrected=FALSE;
void gps(void)
{
        int count = 0;
        char ch;
        /*Declare variables*/
        int in, out, status, DONE=FALSE;
        int gpscount=0;
        char format[7];
        char c;
        /*set the communications parameters*/
        bioscom(0,SETTINGS,COM2);
        gpsnumber=0;
        printf("\n\n");
        printf("                                GPS Readings");
        printf("\n");
        while(!DONE) {
                status=bioscom(3,0,COM2);
                if ((status & DATA_READY))
                {
                        if(((out=bioscom(2, 0, COM2) & 0x7F) != 0) && (out!='\n') ){
```

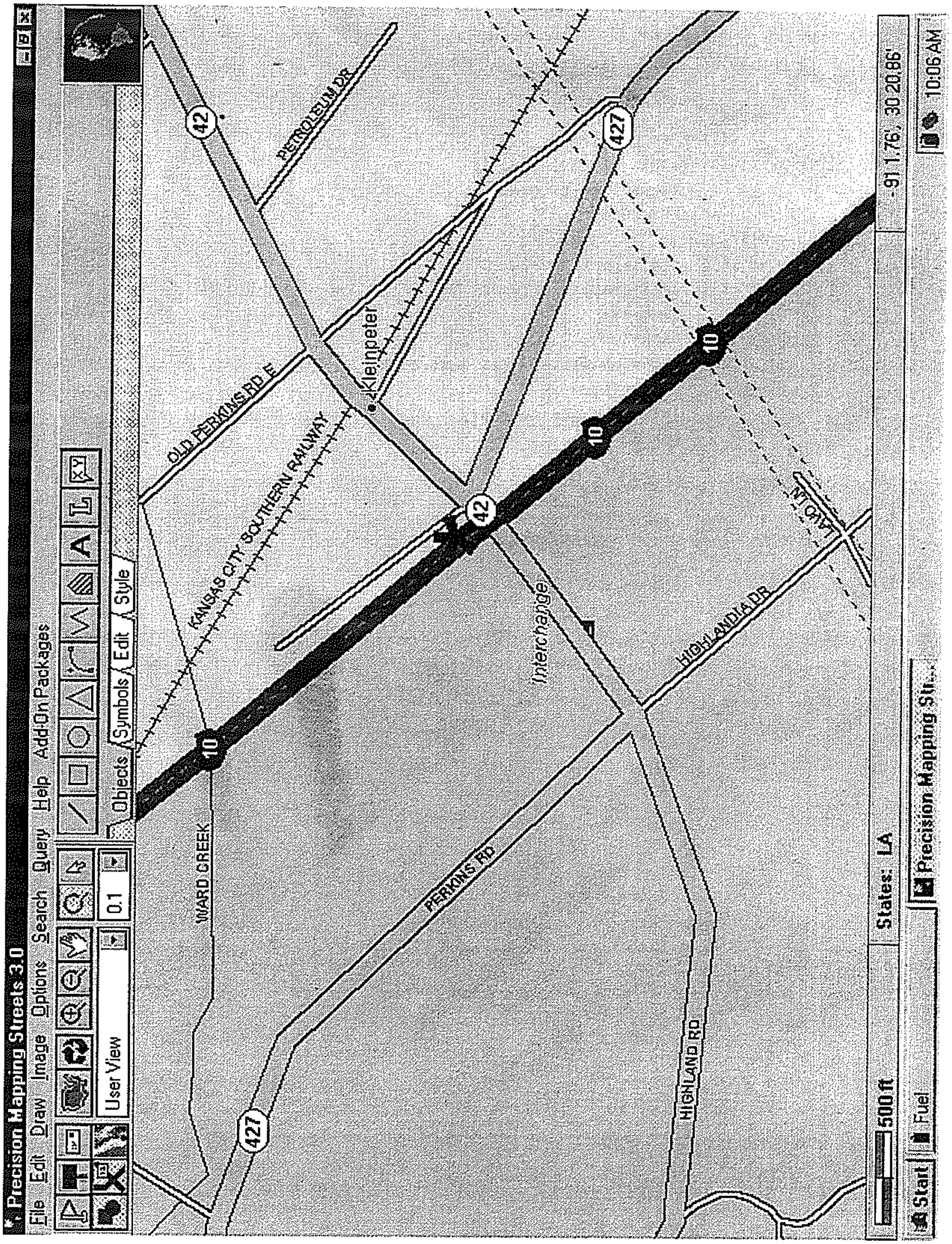
```
                                gpsdata[gpscount].reading[count]=out;
                                count++;
                                if (count==71) {
                                        if ((strncmp("$GPGGA",gpsdata[gpscount].reading,6)==0)) {
                                                gpsdata[gpscount].reading[count]='\0';
                                                gpsnumber++;
                                                printf("\n#%d:
%s",gpsnumber,gpsdata[gpscount].reading);

                                                count=0;
                                                gpscount=gpsnumber;
                                                delay(2000);
                                                DONE=FALSE;
                                                if (gpsnumber==10) {
                                                        DONE=TRUE;
                                                        getlatlong();
                                                        getaverage();
                                                        return(1);
                                                }
                                        }
                                }
                        }
                }
        }
}
/* Subroutine to display latitude and longitude*/
getlatlong()
{
 int i=0;
 char *promptstring;
 char degrees[3],minutes[7];
 int count=0;
 int gpscount=0;
        for (gpscount=0; gpscount<=gpsnumber-1; gpscount++) {
                count=0;
                /*get the latitude reading*/
                for (i=14;i<=21;i++) {
                        gpsdata[gpscount].slatitude[count]=gpsdata[gpscount].reading[i];
                        count++;
                }
                latitudedirection=gpsdata[gpscount].reading[23];
                /*make it a string*/
                gpsdata[gpscount].slatitude[count]='\0';
                /*convert slatitude into a float and fill the array element*/
                gpsdata[gpscount].flatitude=atof(gpsdata[gpscount].slatitude);
                /*reinitialize count to get the longitude reading*/
                count=0;
                /*get the longitude string*/
                for (i=26;i<=33;i++) {
                        gpsdata[gpscount].slongitude[count]=gpsdata[gpscount].reading[i];
                        count++;                }
                longitudedirection=gpsdata[gpscount].reading[35];
                /*make it a string*/
                gpsdata[gpscount].slongitude[count]='\0';
                /*convert slongitude into a float and fill the array element*/
```

```
                gpsdata[gpscount].flongitude=atof(gpsdata[gpscount].slongitude);
                /*store the fix*/
                gpsdata[gpscount].fix=gpsdata[gpscount].reading[39];
                /*check for corrected fix*/
                if (gpsdata[gpscount].reading[37] != '2')
                        uncorrected=TRUE;
                else uncorrected=FALSE;
        }
        /* get the latitude and lonitude direction*/
        return;
}

getaverage()
{
float avglatitude=0.0, avglongitude=0.0;
char *stemplatitude, *stemplongitude;
int ilatdigits=7;
int ilongdigits=8;
int idec,isign;
int count=0;
int gpscount=0;
char c;
        /*get the average of the ten latitude readings obtained in flatitude*/
        for (gpscount=0;gpscount<=gpsnumber-1;gpscount++) {
                avglatitude=avglatitude+gpsdata[gpscount].flatitude;
        }
        avglatitude=avglatitude/gpscount;
        /*convert the latitude into a string*/
        stemplatitude= fcvt(avglatitude, ilatdigits, &idec, &isign);
        /*get the degree component - the first two characters*/
        count=idec-2;
        strncpy(sfinallatitude,stemplatitude,count);
        sfinallatitude[count]='\0';
        /*attach "deg" string to it*/
        strcat(sfinallatitude," deg ");
        count=strlen(sfinallatitude);
        /* get the minute component*/
        sfinallatitude[count]= stemplatitude[2];
        count++;
        sfinallatitude[count]=stemplatitude[3];
        count++;
        sfinallatitude[count]='.';
        count++;
        sfinallatitude[count]= stemplatitude[4];
        count++;
        sfinallatitude[count]=stemplatitude[5];
        count++;
        sfinallatitude[count]= stemplatitude[6];
        count++;
        sfinallatitude[count]='\'';
        count++;
        /*get the direction*/
        sfinallatitude[count]=latitudedirection;
        count++;
```

```
        sfinallatitude[count]='\0';
        /*get the average of the ten longitude readings obtained in flongitude*/
        for (gpscount=0;gpscount<=gpsnumber-1;gpscount++) {
                avglongitude=avglongitude+gpsdata[gpscount].flongitude;
        }
        avglongitude=avglongitude/gpscount;
        /*convert the longitude into a string*/
        stemplongitude= fcvt(avglongitude, ilongdigits, &idec, &isign);
        /*get the degree component - the first two characters*/
        count=idec-2;
        strncpy(sfinallongitude,stemplongitude,count);
        sfinallongitude[count]='\0';
        /*attach "deg" string to it*/
        strcat(sfinallongitude," deg ");
        count=strlen(sfinallongitude);
        /* get the minute component*/
        sfinallongitude[count]= stemplongitude[2];
        count++;
        sfinallongitude[count]=stemplongitude[3];
        count++;
        sfinallongitude[count]='.';
        count++;
        sfinallongitude[count]= stemplongitude[4];
        count++;
        sfinallongitude[count]=stemplongitude[5];
        count++;
        sfinallongitude[count]= stemplongitude[6];
        count++;
        sfinallongitude[count]='\'';
        count++;
        /*get the direction*/
        sfinallongitude[count]=longitudedirection;
        count++;
        sfinallongitude[count]='\0';
        /*print the average latitude and longitude*/
        printf("\n\n");
        printf("\n\n            Average Latitude:       %s",sfinallatitude);
        printf("\n              Average Longititude:    %s",sfinallongitude);

        printf("\n\n\n\n");
        gotoxy(1,24);
        if (uncorrected==FALSE || uncorrected==TRUE)
        {
                if (uncorrected==TRUE)
                {
                        puts("The gps data contains uncorrected values. Proceed to redetermine
the location?");
                        do
                        {
                        gotoxy(80,24);
                        c=getch();
                        if (toupper(c)=='Y') gpsmain();
                        else return;
                        } while(toupper(c)!='Y' || toupper(c)!='N');
```

```
                }
                else
                {
                        puts("The gps data contains corrected values. Proceed to redetermine the
location?");
                        do
                        {
                        gotoxy(78,24);
                        c=getch();
                        if (toupper(c)=='Y') gpsmain();
                        else return;
                        } while(toupper(c)!='Y' || toupper(c)!='N');
                }
        }


}

/*subroutine to create the output window*/
makewindow(left,top,right,bottom,text,back)
int left,top,right,bottom,text,back;
{
        window(left,top,right,bottom);
        textcolor(text);
        textbackground(back);
        return;
}


gpsmain()
{
int c;
int text=15;
int back=4;

        clrscr();

        /*make a window*/
        makewindow(1,1,80,25,text,back);
        clrscr();

        /*prompt the user to get the gps reading*/
        /*gotoxy(5,12);
        puts("Press G to get the GPS reading or Esc to quit.");

        do
        {
                gotoxy(60,12);*/
                /*get a keystroke from the keyboard*/
                /*c=(getch());
                gotoxy(60,12);
                putch(c);
                delay(500);
                if (toascii(c)!=27 || toascii(c)!=71)
```

```
            {
                    gotoxy(60,12);
                    cputs(" ");
            } */
            /*if Esc is pressed*/
            /*if (toascii(c)==27) {*/
                    /*quit the program*/
                    /*return;
            }*/
            /*if G or g is pressed*/
            /*if(toascii(toupper(c))==71) { */
                    text=15;
                    back=1;
                    makewindow(1,1,80,15,text,back);
                    clrscr();
                    /*run the gps module*/
                    gps();
          /*        }

}while (c!='g' || c!='G' || toascii(c)!=27);*/}
```



1b. Typical output from the Global Positioning System

APPENDIX 2 CD-ROM (1)

(a) Continuous Intrusion Miniature Cone Penetration Test (CIMCPT) 9:00 min.
(b) Research Vehicle for Geotechnical In Situ Testing & Support (REVEGITS) 4:30 min.

This public document is published at a total cost of $1741.18. Four hundred copies of this public document were published in this first printing at a cost of $1191.18. The total cost of all printings of this document including reprints is $1741.18. This document was published by Louisiana State University, Graphic Services, 3555 River Road, Baton Rouge, Louisiana 70802, to report and publish research findings of the Louisiana Transportation Research Center as required by R.S.48:105. This material was printed in accordance with standards for printing by state agencies established pursuant to R.S.43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.