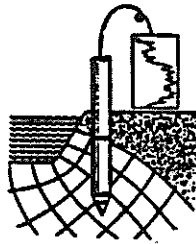


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16. Abstract <p>For several decades, the Louisiana Department of Transportation and Development (LDOTD) has been able to rely on an ample supply of labor with appropriate equipment to provide soil design data. Budget cutbacks have forced reduction in personnel and equipment to the point that the Department forces are no longer able to keep up with the demand for their work.</p> <p>Conventional boring to obtain soil samples for laboratory testing and final design data is an expensive, time consuming process. Some laboratory tests, particularly involved in strength and compressibility, are intrinsically long duration tests. Delays in starting critical projects are often the result of the time duration in testing.</p> <p>In this research, the Louisiana Electric Cone Penetrometer System (LECOPS) and the accompanying data acquisition and reduction codes (TRUCK, CONEDATA & CONEXP) were developed, field tested and implemented to enable the LDOTD to maintain and even advance its soil design expertise. The results of this project will further provide a research vehicle and a desperately needed soils information data base.</p>			
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**IMPLEMENTATION
OF
LOUISIANA ELECTRIC CONE PENETROMETER
SYSTEM
(LECOPS)
FOR DESIGN OF TRANSPORTATION FACILITIES**



EXECUTIVE SUMMARY

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State Project No. 736-13-37

Research Project No. 88-2-GT

The contents of this summary reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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The data acquisition and computational code development phase of this project could not have been completed without the dedicated and meticulous efforts of Mr. Adrian S. Chan and Mrs. Zhou Pei, from conception to final product. The work constitutes a major portion of Mr. Chan's doctoral dissertation. Most of Mrs. Pei's Research Associate duties with the author were dedicated to the complex integration of the computer routines (exceeding 11,000 lines) into a "user friendly" code.

Mr. William T. Tierney (Research Associate), LTRC, contributed boundless physical energy and moral support to the successful field implementation phase of the project.

ABSTRACT

For several decades, the Louisiana Department of Transportation and Development (LDOTD) has been able to rely on an ample supply of labor with appropriate equipment to provide soil design data. Budget cutbacks have forced reduction in personnel and equipment to the point that the Department forces are no longer able to keep up with the demand for their work.

Conventional boring to obtain soil samples for laboratory testing and finally design data is an expensive, time consuming process. Some laboratory tests, particularly involved with soil strength and compressibility, are intrinsically long duration tests. Delays in starting critical projects are often the result of the time duration in testing.

In this research the Louisiana Electric Cone Penetrometer System (LECOPS) and the accompanying data acquisition and reduction codes (TRUCK, CONEDATA & CONEXP) were developed, field tested and implemented to enable the LDOTD to maintain and even advance its soils design expertise. The results of this project will further provide a research vehicle and a desperately needed soils information data base.

The referenced appendices are available from the Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808. Also available are microcomputer versions of TRUCK, CONEDATA & CONEXP programs on three 3.5" DS, HD micro floppy disks.

**IMPLEMENTATION OF
LOUISIANA ELECTRIC CONE PENETROMETER SYSTEM
(LECOPS)
FOR DESIGN OF TRANSPORTATION FACILITIES**

EXECUTIVE SUMMARY

A. BACKGROUND

The Louisiana Department of Transportation and Development (LDOTD) has for years relied on a combination of exploratory drilling and laboratory analyses for gathering soil design data upon which to base engineering decisions. To do so, LDOTD has maintained a large fleet of sophisticated drilling equipment and staffed a number of teams of drilling personnel and laboratory staff. Under tight budgetary constraints, the drilling crews' and laboratory personnel's numbers have fallen through attrition and have not been allowed to restaff. Exploratory work has fallen behind, which forces the LDOTD to rely increasingly on consulting engineering firms for soils data. This problem of excessive work for available staff will continue into the foreseeable future.

There is a need for an in situ device and an accompanying procedure that will offset these field and laboratory losses and still remain economically feasible. The electronic cone penetrometer is such a device. The Louisiana Electric Cone Penetrometer System (LECOPS) will provide this state-of-the-art methodology to acquire and reduce data for soil engineering investigations for design of transportation facilities. The Quasi-static Cone Penetration Test (QCPT or CPT) has been used for years in Europe and some other states in lieu of conventional exploration methods. It has also been used by LDOTD on several occasions, most of which were research oriented. Summary of details and history of previous work in Louisiana can be found elsewhere (see Executive Summary, "Field Calibration of Electric Cone Penetrometers in Soft Soil," FHWA/LA/LSU-GE-85/2, 1985).

B. INTRODUCTION

In situ soil testing methods such as the electronic Quasi-static Cone Penetration Test (CPT) that works on the principle of measuring the tip resistance and frictional resistance around a penetrating probe has become increasingly acceptable as a subsurface investigation method for geotechnical engineering applications in the United States during the last two decades. This is mainly attributed to the error free operation of the CPT with an automatic data acquisition system and the abundance of information and experience readily available on the CPT method and interpretation worldwide.

CPT originally found its main application in the testing of uniform and homogeneous deposits for the determination of bearing capacity of piles. Currently, the usage of CPT is being expanded to perform functions such as subsurface characterization in profiling, soil classification, determination of undrained shear strength and compressibility of clays, determination of settlement in sand, determination of pile capacity, and site construction control for trafficability.

With the advent of new advances in the functionality and reliability of transducer technology, there have been new additions to the capabilities of the cone penetrometer, such as measuring pore pressures generated during penetration, evaluating soil/groundwater conductivity, and assessing seismic properties of soil strata. Among these developments, the addition of pore pressure sensing elements into the electronic cone penetrometer design has led to the popular acceptance of the Piezocone Penetrometer Test, PCPT. The pore pressure measurement in PCPT gives more insight into the phenomena associated with the cone penetration mechanism than CPT, and helps better identify the strength and deformability characteristics of the soil media being penetrated. Likewise, the probes that measure the soil/groundwater conductivity and dynamic properties of the soil are called "conductivity cone" and "seismic cone" penetrometers, respectively, and have other site specific capabilities. *Hereafter in this report "CPT" will be used as a collective term implying various kinds of electronic cone penetrometers. A*

scaled down version of the electronic CPT probe has also been developed. Due to its smaller size, this CPT probe is commonly referred as the Miniature Cone Penetrometer (MQCPT or M-CPT). There is currently an active LDOTD research project on M-CPT ("Calibration and Implementation of Miniature Electric Cone Penetrometers for Road and Highway Design and Construction Control," State Project No. 736-13-36). The computer codes developed for LECOPS have commonality with M-CPT.

In practice, theoretical solutions cannot be used for the "direct" analysis of the cone penetration mechanism, so interpretation of CPT results will only be semi-empirical in nature. This implies that correlations are needed for the interpretation of cone data. Thus, side by side conventional soil testing information will be needed to further improve the reliability of the empirical correlations. Reviews of past CPT research confirmed that most of the available data and information are reported in the form of goal-specific non computer-based record keeping systems. This kind of ad hoc system will serve well only when data are needed for local correlations, and cannot be effectively used in a global sense.

It is the mission of this study to develop state-of-the-art equipment, hardware and software, for an environmentally contained cone penetrometer system mounted on a self-sufficient vehicle. The goal is to improve the CPT testing procedures as well as keeping both the hard earned conventional soil testing and in situ field testing data available for future reference. A well organized computer-based data and information maintenance system allows for acquisition, reduction, storage and retrieval of both laboratory and field data. Data can be searched and used in flexible ways with different access paths fully explained in a Reference and Operation Manual, to be printed or plotted (see TRUCK and CONEDATA computer codes in Appendix).

To achieve the above mentioned objectives an abstract data modeling in data base implementation was utilized. Most data models used in database management systems are business oriented in nature, thus application of these models to engineering data is less efficient. A semantic model is introduced in this study that

takes into consideration the general aspects of engineering data. The goal of semantic modeling is to provide abstractions that naturally adapt to the way the users describe the enterprise. An expert data base system is implemented using this semantic data model geared towards engineering oriented data. The resulting system can be viewed as a knowledge or intelligent data base system that contains the knowledge of the conceptual level and physical level of the data base system (see CONEXP computer code in Appendix).

The Reference and Operation Manual given in the Appendix for TRUCK, CONEDATA and CONEXP computer codes are self explanatory and have been prepared as stand alone documents. The source codes exceed 11,000 lines of computer programming. Microcomputer executable versions of these programs on three 3.5" DS, HD micro floppy disks are available from Louisiana Transportation Research Center, P.O. Box 94245, Baton Rouge, LA 70804-9245.

C. EQUIPMENT

A dedicated heavy vehicle is generally required to perform efficient CPT soundings. The four major components of such a vehicle are the specialized chassis and the hydraulic system, the penetrometer probes, the depth encoder, and the data acquisition hardware and software. The Louisiana Electric Cone Penetrometer System (LECOPS) which was developed in this project is shown in Figure 1.

LECOPS is a 20-ton truck powered by a caterpillar 210 HP diesel engine on a model G-744 6x6 chassis, modified by Zeligson Company of Tulsa, Oklahoma. The van body (subframe and cabin) and the hydraulic pump (maximum pressure of 300 bar at 1000 rpm) which is driven by the power take-off (PTO) of the truck were fabricated to the specifications set by the author at A.P. van den Berg, b.v. of the Netherlands, and attached to the chassis in the U.S.

The hydraulic system serves two functions: leveling the vehicle and penetrating the probes. The horizontal leveling of the vehicle is provided by three hydraulic jacks that



Figure 1a. General Exterior View of Louisiana Electric Cone Penetrometer System (LECOPS)

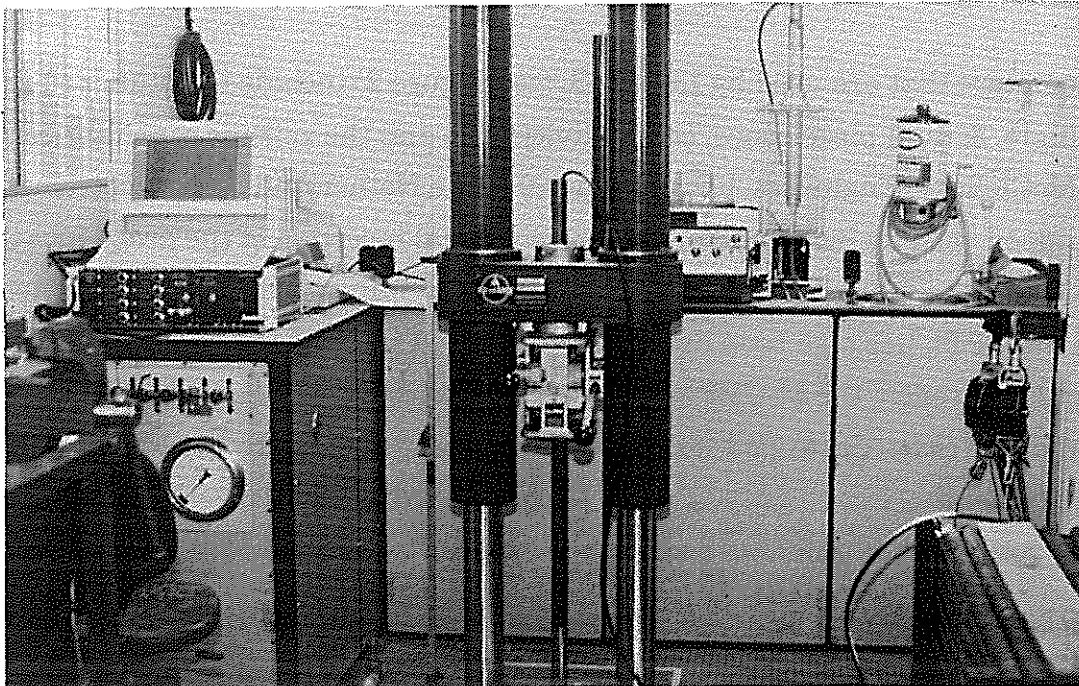


Figure 1b. General Interior View of Louisiana Electric Cone Penetrometer System (LECOPS)

are mounted on the subframe. The hydraulic jacks are equipped with heading-plates (pads) with dimensions of 500mm x 500 mm. The pads are mounted at the hydraulic jacks by means of a ball knob. The horizontal levelling is achieved by intermittently jacking the pads until verticality of penetrometer rods is realized. The penetration thrust system is Hyson 200 KN Type III. The system consists of two hydraulic cylinders connected to each other by an upper arm and a lower beam. The cylinders have a continuous stroke of 1250 mm. The hydraulic oil is supplied through the piston rod to the cylinders at an engine speed of 1200 rpm. A unique chuck-in system can push or pull the rods during the sounding operation.

In order to obtain an accurate depth measurement of the sounding profile during CPT operation, a displacement transducer (depth encoder) manufactured by Fugro-McClelland, b.v. of the Netherlands is installed. The displacement transducer consists of a bi-directional optical incremental shaft encoder which is driven by a pulley connected to the slide on the sounding rods. For every meter of displacement, 1000 output pulses are generated (for the standard penetration rate of 2 cm/sec, only 50 pulses are required). These pulses are 90 degrees phase shifted and have a square waveform on TTL levels which are polled by the computer through the digital I/O channel. A data conversion on all incoming signals will be performed every time the TTL level is high.

Penetrometers that are used by LECOPS (see Figure 2) include the standard friction cone, single & dual piezo cones, conductivity cone and the seismic cone fabricated by Fugro-McClelland Engineers, b.v. (i.e. Fugro) of the Netherlands. All penetrometers are equipped with an inclinometer to ensure vertical insertion of the probe into the ground during sounding operations. A self sufficient Miniature Cone Penetrometer system (M-CPT), has also been developed to be used with smaller vehicles (i.e. pick-up truck). Currently the M-CPT system is mounted on a vehicle similar to LECOPS. The computer codes developed for LECOPS are compatible with the M-CPT.

The electronic data acquisition hardware consists of a signal conditioning unit (PCU-M) manufactured by Fugro-McClelland b.v. of the Netherlands to the author's

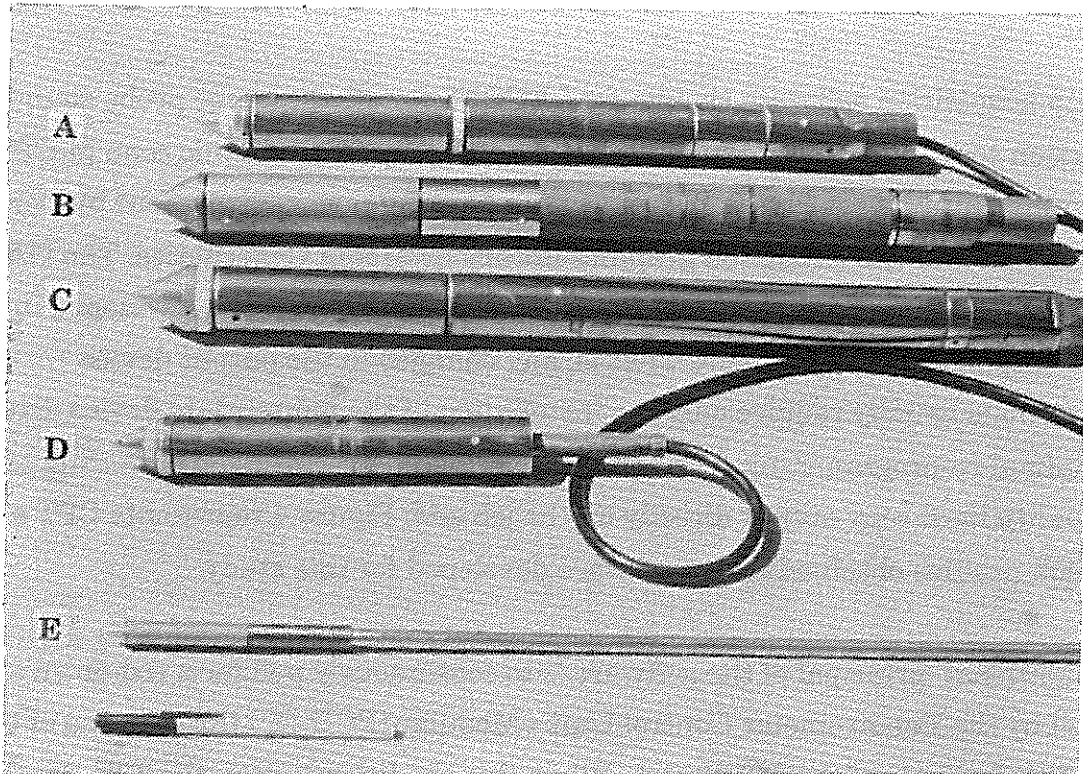


Figure 2. Cone Penetrometers Used
a. Dual Piezo Cone
b. Conductivity Cone
c. Seismic Cone
d. Friction Cone
e. Miniature Cone

specifications, a Compaq Portable III micro computer with a 640x400 high resolution screen (for real time graphics processing), a forty megabyte internal hard disk drive for storage, and a Data Translation DT-2801 A analog to digital conversion and digital I/O board. Signals coming from the cone penetrometer are amplified and scaled by the PCU-M unit before they are transmitted to the DT-2801 A for conversion. Figure 3 depicts the flow path of the data acquisition system on capturing, processing, presenting and storing the CPT sounding data for interpretation. A plotter or a printer can be connected to the system to produce off-line high quality output.

The data acquisition software system for LECOPS for all electronic probe soundings (i.e. friction cone, piezo or dual piezo cone, conductivity cone, seismic cone M-CPT) is programmed around the Turbo Pascal version 4.0 language environment by Borland International and the HALO '88 graphics library by Media Cybernetics. The HALO '88 graphics library allows the graphic portion of the program to be developed in the device-independent environment. That is, any changes in the output device configurations usually require only the installation of the appropriate device driver and minimal re-programming. The software is capable of printing and plotting off-line high quality hard copy output directly on the job site. Figure 4 represents CPT and PCPT soil profiles obtained using software developed for this study.

The operational principal of the software is to continuously poll for a rod-down signal supplied by the Penetrometer Control Unit - Modular (PCU-M) through one of the digital I/O channels of the DT-2801 A. When this condition is met, the TTL depth pulse will be polled from another digital I/O channel. When the TTL logic is true, the program will trigger an analog to digital conversion on all the corresponding channels of the penetrometer. After each set of analog to digital conversions, the measured voltages are scaled to their physical representations and plotted in real time onto the gas plasma display of the computer. This allows the operator to obtain the reading at the actual unit of measurement of choice. The program operation for the friction cone, seismic cone and conductivity cone is straightforward. However, operation intervention is required in Piezo & Dual Piezo Cone Penetration Testing (PCPT & DPCPT) when dissipation of pore pressure is performed after penetration is stopped.

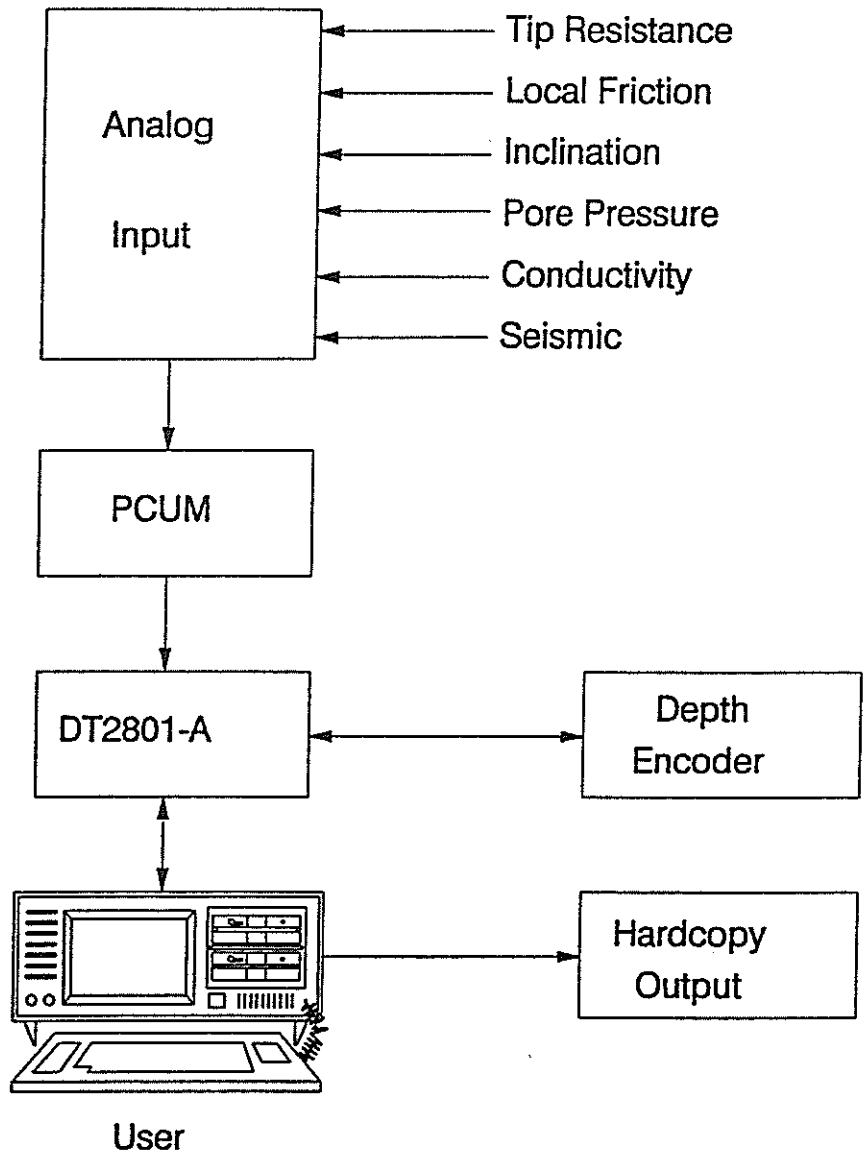
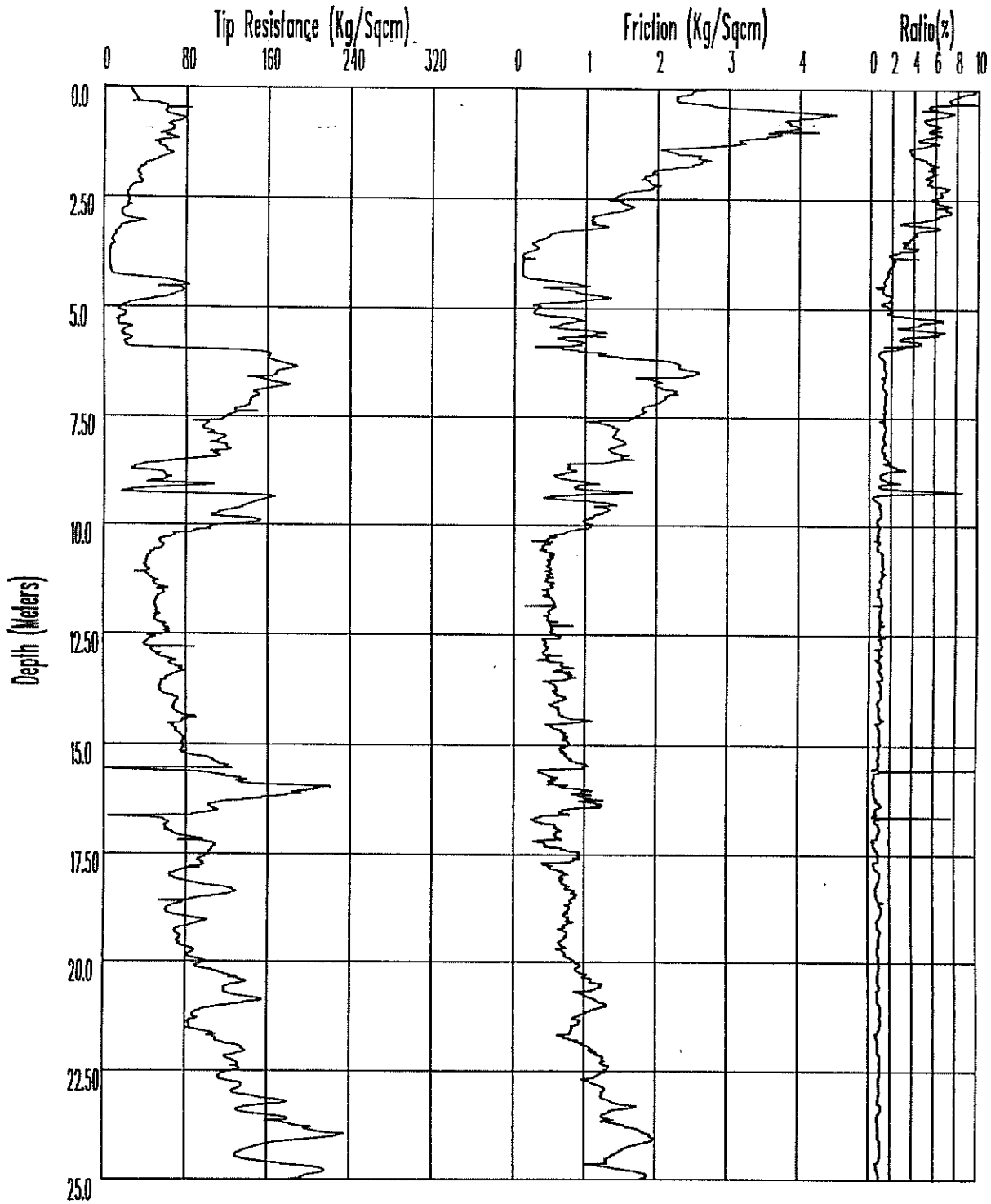


Figure 3. Data Acquisition Flow Diagram for Penetrometer Testing

In-Situ Cone Penetration Test Result



Job Description : Bridge replacement Chemin A Haute Bayou Parish Road 9202

Job Location/No: Parish Road 9202 at 9+70 3ft. ft d/ 713-53-4

Probe ID : F7.5cke/v 318

Remarks : Soil exploration centerline gravel road west end

Date/Time : 04-05-1989/ 8:35pm

Elevation/GWT : 97.5 ft. msl/ 8 ft. below g

File Name : A:CHE1

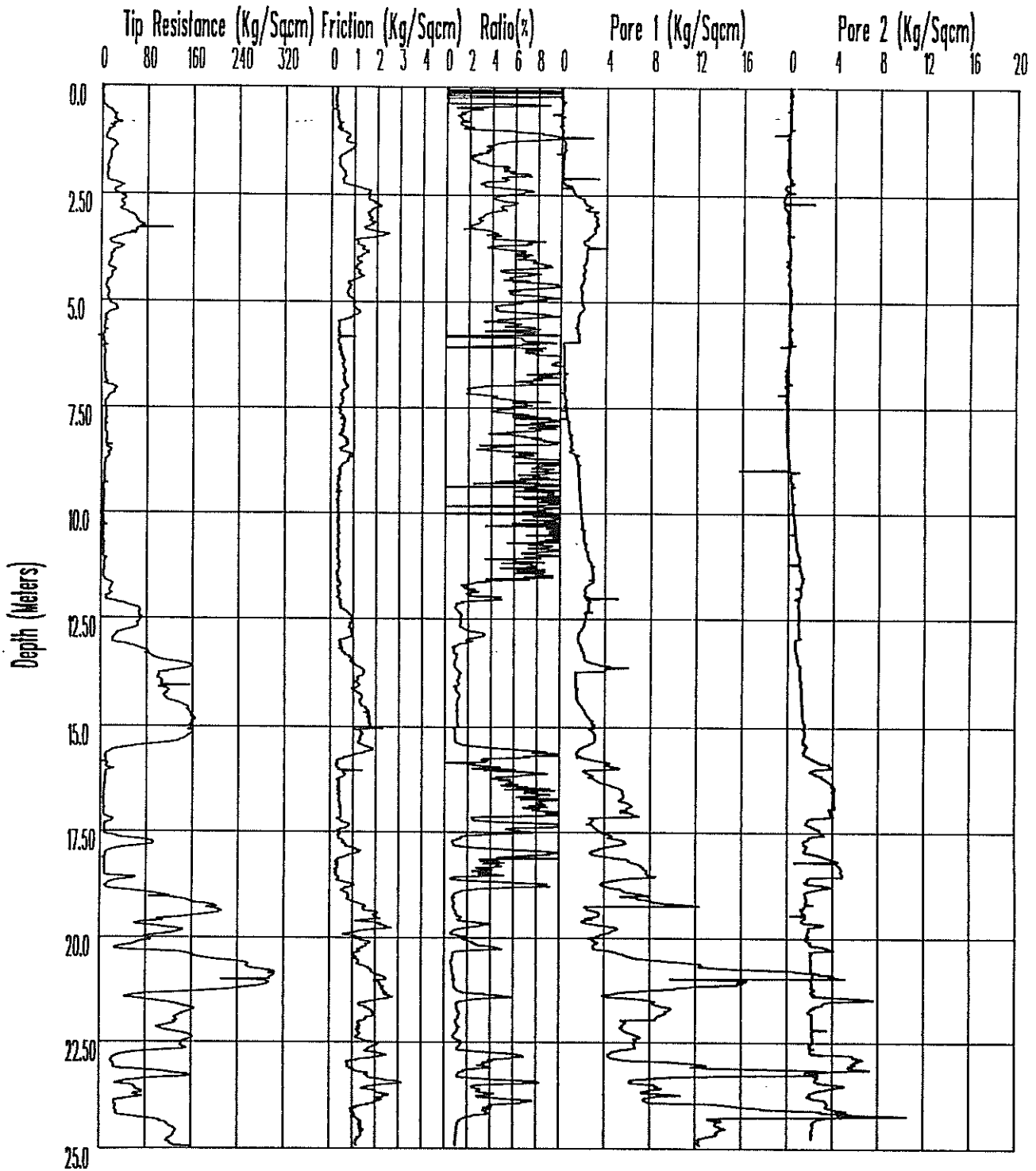
ac/mjs

LTRC Geotechnical Research

Leopold

Figure 4a. Sample Output for Friction Cone Test, QCPT

In-Situ Cone Penetration Test Result



Job Description : i-49 sb approach slab offgoing
 Job Location/No: 840+40/ 455-05-2
 Probe ID : 17.5cke2w/v207
 Remarks :

Date/Time : 02-05-1991/12:37am
 Elevation/CWT : 6" higher app/ unk.
 File Name : AKEEB

me/mj

LTC Geotechnical Research

Scops

Figure 4b. Sample Output for Friction Cone Test, PCPT

Two soil samplers (MOSTAP) are also available on LECOPS. These are 35mm and 65mm diameter samplers with a length of about 1 meter to allow recovery of "undisturbed" samples at predetermined depths for comparative study of laboratory tests. Insertion of these samplers operate with the same principle as the cone penetrometers. That is, the sampler, connected to a sounding rod, is hydraulically penetrated by the push head into the formation at the desired depth. In MOSTAP sampling the only electronic measurement made is by the depth encoder.

During the course of this study LDOTD "Water Well Rules, Regulations and Standards (1985)" were put into effect. Thus the CPT holes were deemed not exempt from the environmental requirement that "geotechnical boreholes be sealed to protect groundwater from preferential pathway contamination." A sister study was conducted on "Sealing of Cone Penetrometer Testing Holes for Groundwater Protection (Collette, A. Donald & Tumay, M.T., Report No. GE-92/09, 1992)." Three aspects of "sealing" were investigated in this study: a. reentering CPT holes for sealing; b. the characteristics of specified bentonite slurry as a sealant; c. the sealing behavior of the displacement-type CPT holes under confining stress. Observations and data from in situ and laboratory case histories were studied. The in situ investigation included reentry into CPT soundings at three sites in southern Louisiana. Each attempt involved thrusting one-half inch outer diameter stainless steel tubing (inserted as a miniature cone penetrometer, M-CPT) into the location of the 10 cm² or 15 cm² CPT soundings or 80 cm² MOSTAP sampling tube sounding. Sealing entailed retrieving the tubing while pumping bentonite slurry at depths below 25 feet, and then pumping cement-bentonite slurry at depths shallower than 25 feet. The laboratory investigation of the effectiveness of bentonite slurry was conducted in compacted soil samples of two low hydraulic conductivity soils, a silt and a clay. In the initial model study phase, evaluation of the bentonite slurry included coring, sealing and measurement of the hydraulic conductivity of the cored/sealed sample. The hydraulic conductivity of the cored/sealed sample was compared to that of the original compacted sample. The effects of the confining stress and local strains/fractures due to soil displacement during full-size CPT sounding were

simulated in the 20.7 inch diameter LSU-LTRC/Calibration Chamber System (LSU-LTRC/CALCHAS) developed for another LDOTD research project (deLima, D.C. & Tumay, M.T., Report GE-92/08, 1992). The results indicate that reentry and grout introduction into CPT soundings is a satisfactory alternate method by which CPT ground disturbances can be sealed in accordance with the Water Well Rules, Regulations and Standards of the State of Louisiana.

D. COMPUTER PROGRAM INTEGRATION

A computer-based data management system for LECOPS was developed. The system involves three parts: a. TRUCK program is the basic data acquisition routine for CPT soundings; b. CONEDATA program serves as the data repository and handling tool for the CPT and conventional testing information database; c. CONEXP program “expertly” manages the Cone Penetrometer Database System (CPDS).

Figure 5 illustrates the flow chart for the computer program integration for LECOPS. Detailed information about the definitions of terms and operating instructions of the individual programs are given in the Appendix.

E. COMPUTER PENETROMETER DATABASE SYSTEM (CPDS)

Database Management Systems (DBMS) are widely accepted as tools for reducing the problem of managing a large collection of shared data for application programmers and end users. The users interact with the database of the DBMS by submitting requests for data selection (queries) or manipulation (updates). A data model is normally used to represent the actual database during implementation. Classic data models such as the relational model, the network model or the hierarchical model do not provide sufficient tools for representing engineering data, especially CPT data. In geotechnical testing, no two borings are identical, thus, the only linkage on two sets of data from different test types for use in database implementation will be on samples collected from a close proximity three dimensional space. CPT data and geotechnical laboratory testing data from neighboring borings

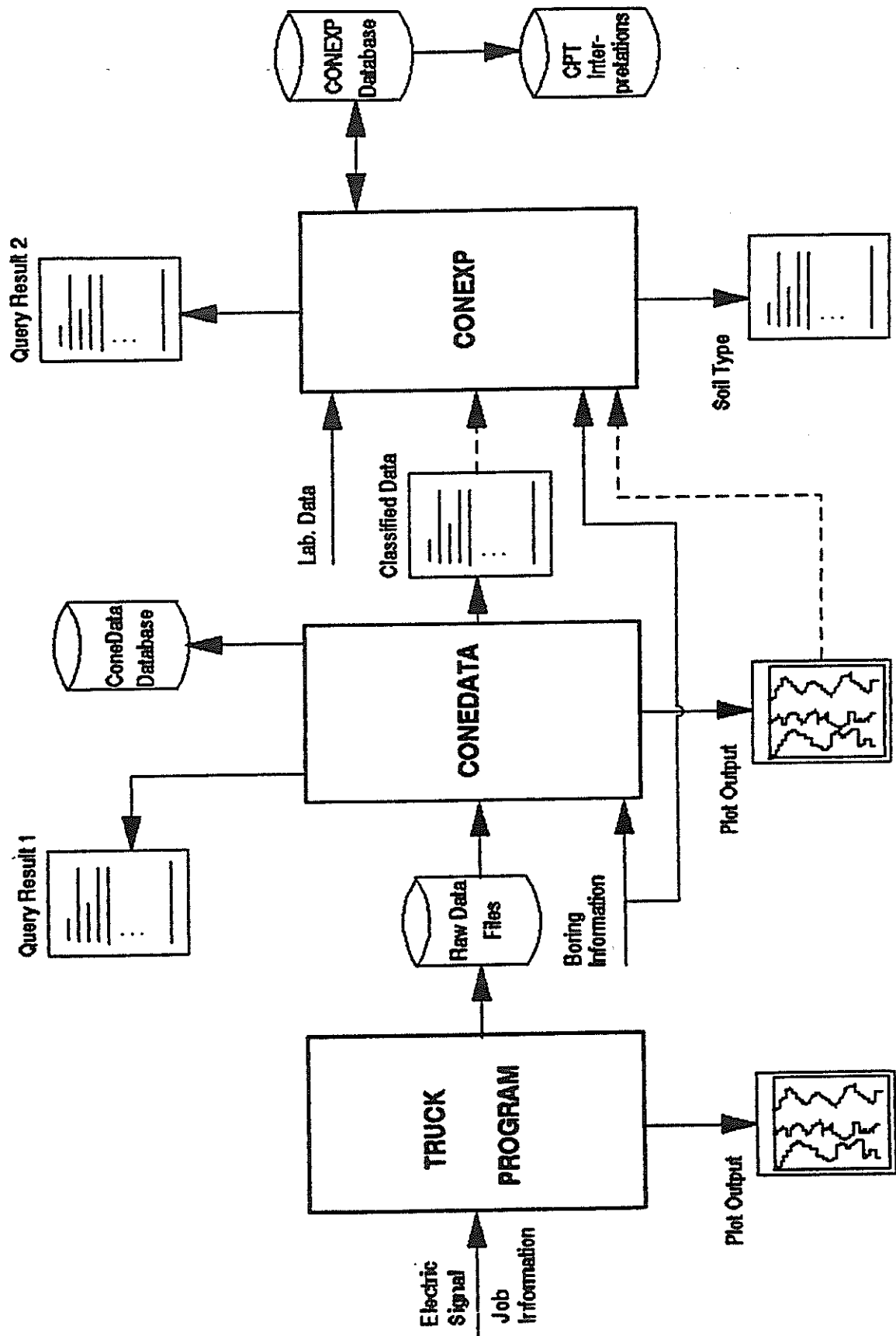


Figure 5. Overview of Computer Program Integration for LECOPS

can be incorporated into a database using the Geotechnical Engineering Database Model (GEDM) (Chan, A.S. , Report in press, 1994).

CPDS is an expert database management system that combines the explicit CPT data based on GEDM and the implicit CPT information into a database management system. Explicit CPT information is data from direct comparison of laboratory and field results on the same sounding location. Implicit CPT data are generalized implied data that are presented in chart format from culmination of past experiences. The system primarily stresses the storage and retrieval of explicit data that is generated from the CPT sounding program. That is, the most vital information from a CPT database should still be the direct data obtained from side by side borings. These data will be used for updating information contained in the implicit database. Secondly, implicit data is used for the decision making process under the option of the user when explicit data are not available or when the user deems necessary to check on previous experience. Implicit data can also be updated and retained in the system to ensure refinement of localized correlation for soil characterization.

The computer code CONEXP, which is the expert data base management segment of the LECOPS' GEDM , is detailed in the Appendix.

F. SYNOPSIS AND DELIVERABLES

In a previous study by the author, it was recommended that "it would be advisable for state transportation departments to develop their own penetrometer systems befitting the special characteristics of the soil deposits of their region, using the correlations developed to modify the general theories of penetration."

In this study, state-of-the-art equipment, hardware and software for an environmentally contained cone penetrometer system mounted on a self-sufficient vehicle, namely Louisiana Electric Cone Penetrometer System (LECOPS) have been developed, implemented, field-tested, and initial LDOTD crews have been trained.

The deliverables included:

1. An operational CPT vehicle which is currently fully utilized by the Materials Section of LDOTD.
2. Software to operate LECOPS's data gathering and dissemination system.
3. A "user friendly" database management system for installing, keeping, and providing CPT and other geotechnical data for analysis.

The Louisiana Electric Cone Penetrometer System (LECOPS) has successfully been implemented in the field by the LDOTD for the last two years in connection with projects generally dealing with site investigation and pile capacity design and prediction. The acceptance of LECOPS by the field and office crews were very positive. It is anticipated that the current limited utilization of LECOPS in embankment control, geo-environmental engineering aspects of transportation facilities, creation of state wide data bases for soil profiling/characterization, and performance evaluation of bridge and retaining wall foundations will be expanded in the very near future. Although the system requires substantial initial capital investment, the operational costs are lower than conventional soil boring methods. Considering the reliability of operation, speed of data acquisition and reduction, and reliability of results, LECOPS has proven to be more economical in the long run.

☆☆☆☆☆☆☆☆

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