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To: Distribution

Subj: FIELD PROCEDURES FOR CONE PENETROMETER TESTING AND HYDROPUNCH GROUNDWATER SAMPLING AT NAVAL AIR STATION, MOFFETT FIELD

Encl : (1) Field Procedures for Cone Penetrometer Testing and Hydropunch Groundwater Sampling at NAS Moffett Field

1. Please review enclosure (1) and be prepared to comment on the report at the December 18th presentation at Camp Dresser McKee's offices located at 301 Howard St. in downtown SanFrancisco

2. Should you have any questions regarding this matter, the point of contact is Commander, Western Division, Naval Facilities Engineering Command (Attn: Mr. Stephen Chao, Code 1813SC, (415) 877-7512).

RICHARD SERAYDARIAN
By direction

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FIELD PROCEDURES FOR
CONE PENETROMETER TESTING AND
HYDROPUNCH™ GROUND WATER SAMPLING
NAVAL AIR STATION MOFFETT FIELD

December 1989

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ENCLOSURE (1)

CONTENTS

<u>FIGURES</u>

1.0 INTRODUCTION

This document describes the field procedures (FP) to be used for the performance of the "Cone Penetrometer Test" (CPT) and the Hydropunch™ (or similar equipment) sampling at Naval Air Station (NAS) Moffett Field. It includes the calibration and data reporting requirements, and some operational constraints. Standardization of the design and practices of the CPT is by the American Society of Testing Materials (ASTM) Designation: D3441-86, which governs the testing, calibration and reporting of the procedure.

2.0 PROJECT OBJECTIVE

The CPT and Hydropunch™ are methods to determine if subsurface aquifer material exists and if it is capable of producing water to a well. The methods are less expensive than drilling wells and can be a preliminary method for the selection of the locations for test-hole drilling. Therefore, the CPT and Hydropunch™ will be used in the initial Phase II field activities of NAS Moffett Field.

These tests will be used to acquire physical data for soils classification, and to collect ground water samples from the A aquifer. CPT surveys will be made to locate the more sandy (and more permeable) A aquifer locations. Based on this information, the Hydropunch™ is used to collect a ground water sample. Chemical analysis of the Hydropunch™ water samples is intended to provide preliminary information about the distribution of contaminantion in the A aquifer and will aid in the placement of Phase II wells within each site. The water samples will be analyzed for volatile organic compounds (VOC) and total petroleum hydrocarbons (TPHC) on a 48-hour turnaround time. One hundred and thirty CPT/Hyrdopunch™ locations are proposed at Sites 3-9. These locations are tentative and are intended to provide the following data:

- Detailed lithologic and chemical information relevant to potentially contaminated areas identified during the Phase I activity.
- Lithologic and chemical information upgradient and downgradient of suspected contaminant sources. Chemical analysis of Hydropunch™ ground water samples will assist in determining the need for upgradient and downgradient monitoring wells at these suspected contaminant sources.
- Lithologic and chemical information in areas not covered during Phase I.
- CPT/Hydropunch™ data will be used to evaluate the placement and need for additional Phase II monitored wells at all sites. Chemical and geologic information obtained from these may indicate some wells are improperly located or unnecessary. Wells will be relocated or eliminated on the basis of these tests.

3.0 EQUIPMENT

CONE PENETROMETER TEST

The CPT is conducted by hydraulically driving a cone penetrometer into the soil (Figure 1). The cone penetrometer measures tip resistance (Q_c), sleeve friction (F_s), pore pressure (U) of the soils and inclination as it is driven. The standard cone penetrometer has a 60-degree apex cone tip with a projected cross section area of 1.55 in.^{2} (10 cm^2), and a friction sleeve with surface area of 23.2 in.^{2} (150 cm^2) +/- 2% and a length of 5.24 inches (13.3 cm). However, these standards are not always strictly adhered to, with the friction sleeve area and length varying between manufacturers. Many companies use a 2.32 in.^{2} (15 cm^2) cone because it is more rugged and can withstand penetrating hard or gravelly soils.

The conical tip and cylindrical friction sleeve are attached to strain gauged load cells which measure the soil resistance to penetration. The CPT tip also contains a porous stone filter which is built into the cone tip and is connected to a pressure transducer, which measures pore pressure. An inclinometer in the penetrometer provides a check on the plumbness of the penetrometer. Electronic signals from the pressure transducer, the strain gages and the inclinometer are transmitted through a cable in the hollow push rods to analog and digital data recorders, which comprise the data acquisition system. The system is generally housed in the cabin of a 4-wheel drive 20 (18 metric) ton truck. The data acquisition system for the CPT has a total of eight recording channels. Data on cone tip resistance, sleeve friction resistance, friction ratio, depth, inclination, pore pressures and differential pore pressure ratio are usually recorded. In addition, penetration can be stopped at any depth and pore pressure dissipation can be measured. Dissipation is recorded at set time intervals or depths and can be recorded as long as required.

The truck is rigged with a hydraulic jacking system used to drive the penetrometer, the load of the hydraulic ram is transferred to the push rods either by a thrust head on top of the push rods or by a hydraulic clamping system. Each push rod is one meter in length. An electric cable has been inserted through all the push rods connecting the penetrometer with the automatic data recording system. The maximum thrust the push rods can withstand is 45,000 pound force (lb_f) (200 kiloNewton (kN)). A 45,000 lb_f (200 kN) thrust will penetrate depths up to 100 feet (30 meters) in dense or stiff materials and up to 260 feet (80 meters) in looser soils. Power is supplied by the power-takeoffs of the truck.

HYDROPUNCH™

The Hydropunch™ ground water sampling tool (Figure 2) can be used with either cone penetrometer equipment or conventional drilling equipment to push or drive the sampler to the desired sampling depth. The sampler is approximately 5 feet (152 cm) long and 1.5 inches (3.8 cm) in diameter and is constructed entirely of stainless steel and Teflon®. The Hydropunch™ has a stainless steel drive point, a perforated section of stainless steel pipe for sample intake, a stainless steel and Teflon® sample chamber which is capable of collecting 0.53 quarts (500 milliliters) of ground water, and an adapter to attach the unit to either penetrometer push rods or standard soil sampling drill rods.

As the unit is pushed or driven through the soil, the sample intake pipe is shielded in watertight housing that prevents contaminated soil or ground water from entering the unit. The shape of the sampler and its smooth exterior surface prevents the downward transport of the surrounding soil and liquid as the tool is advanced. When the desired sampling interval is reached, the sampler is "jerked" (retracted) upwards 12 to 18 inches, exposing the sampling port to the water-bearing zone, permitting ground water to flow through the screen into the sample chamber. A disposable, polypropylene screen covers the sampling port to filter out sand particles.

As a ground water sample is collected, the drive cone and the sample chamber are flush against the borehole walls, serving as packers which isolate the intake screen from ground water above and below the zone being sampled. The sample is collected under in-situ hydrostatic pressure with no aeration. In addition to the sample being collected, the potentiometric surface of the aquifer being sampled can be measured from the stabilized water level inside the push rods. After the sample chamber is filled, the Hydropunch™ is pulled upwards. This increases the hydrostatic pressure in the unit compared to the aquifer which closes the two Teflon® check valves and retains the sample within the sample chamber. Upon retrieval, the upper check valve is replaced with a Teflon® stop cock valve and a disposable tube. The ground water sample is decanted out of the top of the sampler, in much the same way as decanting a bailer. The sampler is turned upside down, the cock valve opened and the sample decanted into a sample container through the Teflon® stopcock and tubing.

4.0 SCOPE

The CPT soundings and Hydropunch™ sampling will be conducted up to the maximum probable depth of the A aquifer, should it exist. It is anticipated that soundings and sampling will not exceed a depth of 50 feet (15 meters), depending on subsurface conditions encountered. Stratigraphic and related geotechnical data will be obtained. CPT soundings will be performed at up to 172 locations. The initial planned locations are based on data from Phase I activities and the objectives of Phase II and are shown in the Phase II plans for each site. The final 25 percent of the CPT soundings, if needed, will be located based on the initial CPT data, to locate sufficient aquifer material for Hydropunch™ sampling. The Hydropunch™ will be employed at 130 locations. Locations of the Hydropunch™ will be determined based on known data and on data collected from the adjacent CPT location. The Hydropunch™ will be used to collect ground water samples and water levels at depths to be determined in the field.

Hydropunch™ equipment will be disassembled and steam-cleaned before use and between holes. All water during steam cleaning operations will be drummed and temporarily stored on site. Decontamination procedures will be at least as stringent as those outlined in Section 5.7.8 of the Sampling and Analysis Plan. The cone penetrometer will be cleaned as necessary to remove soil and other particulates from the tip and friction sleeve. Rinse water will be drummed and disposed of with the Hydropunch™ decon water.

All CPT and Hydropunch™ holes will be backfilled with bentonite-cement grout when possible though some holes may cave in upon removal of the tools. The holes will be grouted from total depth to surface using tremie pipe. If the holes do not remain open, an expendable cone will be inserted on the end of the Hydropunch™ push rods or tremie pipe and advanced in the same hole to the total depth. The expendable cone will be dislodged and cemented in place, and the hole will be grouted from bottom to surface using this tremie method.

5.0 INTERFERENCES AND LIMITATIONS

There are certain factors which have a marked effect upon the performance, measurements and interpretation of the cone penetrometer data, especially pore pressure and friction sleeve measurements. These factors are discussed below.

- The rate at which the penetrometer is driven into the ground. The rate of penetration may be affected by particle creep, particle crushing, and pore pressure effects. Anything below the standard rate of penetration could affect undrained soil conditions allowing time for the system to drain, causing smaller excess pore pressures. However, as long as the rate of penetration is the same for all soundings, all the parameters will be measured relative to one another. In other words, the rate of penetration must remain constant for all soundings done at NAS Moffett Field. (Ref. Smythe, et al, 1988)

- Placement of the piezoelement. The measured pore pressures during cone penetrometer testing depends on the location of the piezometer element. This must be taken into account during interpretation. (Ref. Smythe, et al, 1988)

- Choice of material for the piezocone. Sintered steel, ceramic, stone and polyethylene are some of the filter materials being used. The type of material used does not seem to affect the pore pressure readings, but ceramic and stone elements are most widely used. (Ref. Smythe, et al, 1988)

- Saturation of the piezocone has the greatest effect on the pore pressure reading. It is absolutely essential that the element is saturated at all times during the penetration test, since entrapped air could cause pore pressures to continue to build even after penetration has stopped. In this situation, trapped air will allow the pore water to continue to flow for a period of time. (Ref. Smythe, et al, 1988)

- Temperature effects on the load cells (most commonly strain gauges). The load cells and pressure transducers within the cone are often temperature dependent and are almost always calibrated at room or air temperature. Soil and ground water are often cooler than the calibration temperature, and a shift in the zero can occur for both load cells and pressure transducers during penetration. For cone testing in dry sand, considerable heat can be generated during penetration. These changes in temperature may have little consequence for cone testing in sand where measurements are usually large. However, the zero shift can be significant in very soft or loose soils. Temperature corrections can be made if the temperature of the cone tip is monitored. (Ref. Smythe, et al, 1988)

- The tip is often deflected or drifted from the vertical. Once a cone tip has been deflected or has drifted, it continues along a path with a relatively consistent radius of curvature. In general, the equipment accepts one degree of deflection per meter length without noticeable damage. A sudden deflection in excess of one or two degrees may cause damage to the push rods and penetration should cease. If cemented gravel is encountered during CPT, it may be a limiting factor to possible sounding depth.

- Wear of tip. Penetration into abrasive soils eventually wears down or scours the penetrometer tip. Discard tips or parts of, whose wear changes their geometry or surface roughness. (Ref. ASTM, 1988)

- Friction sleeves with unequal end areas require a correction for a shift in the zero for both the friction and tip measurements. The zero shift is because of unequal end areas of the friction sleeve and is especially significant in deep profiles beneath the water table and in low permeability saturated soils where very large dynamic pore pressures are generated during penetration. The best solution is to use a friction sleeve with equal end areas. If not, a correction needs to be applied to the measured bearing. (Ref. Smythe, et al, 1988)

- Soils' stress (geologic) history is important in CPT interpretation because the in situ radial stress has a significant effect on the cone resistance. For this reason, CPT soundings shall not be performed any closer than 25 boring diameters from an existing, unbackfilled, or uncased boring hole. (Ref. ASTM, 1988)

- Variations of sound compressibility will have a significant influence on correlations with relative density but a smaller influence on correlations with friction angle.

- Layering in geologic systems (i.e., a thin sand layer located in soft clay deposits) can cause scale effects when using cones of a large diameter.

The Hydropunch™ is a ruggedly constructed sampling tool designed to be pushed or driven into position. Although designed for durability, some basic guidelines should be followed.

- As a general rule, the Hydropunch™ can be driven into formations where a standard 2-inch split spoon sampler or a CPT can be driven. Suitable geologic material include unconsolidated clays, silts, sands and fine gravels.

- Blow counts of over thirty blows per six inches may indicate that damage might occur while driving the Hydropunch™ sampler.

- Do not push the Hydropunch™ from the surface into the soil with the entire barrel unsupported. If the applied force to the unit is not in a vertical plane or an obstruction is encountered while driving the unit, the unit may be damaged by bending.

- The Hydropunch™ sample chamber is designed to be filled using the aquifer's hydrostatic pressure. The sample chamber will fill only as fast as the formation will yield water. In addition, the cone and sample chamber must isolate the sampling intake port from fluids above and below the zone being sampled. To collect the desired ground water sample, the sampling intake port must be in hydraulic contact with only the selected aquifer zone.

- The location of the sample chamber above the intake requires that the Hydropunch™ be driven a minimum of five feet below the static water level for a sample to be collected.

6.0 PROCEDURES

The Field Coordinator will perform and document a quality check to determine that the subcontractor has provided all the stipulated equipment and is prepared to do the survey as planned. The CPT subcontractor will provide data on the type and dimensions of the probes and equipment, type and location of the piezoelement along with the results of previous periodic calibrations.

- CPT cones will be calibrated at zero load reading in air and water and shielded away from direct sunlight before the sounding at each location. Upon completion of the test, the piezocone will again be calibrated to zero load reading and compared to the initial reading.
- The CPT will be advanced into the subsurface at a consistent controlled rate of 0.03 to 0.07 ft/second (1 to 2 cm/second). Field plots can consist of cone tip resistance, sleeve friction resistance, friction ratio, depth, inclination, pore pressures and differential pore pressure ratio.
- Pore pressure dissipation tests may be conducted when the CPT probe is stationary at pre-chosen horizons and recorded for a set time interval. The time interval is dependent on the lithology of the zone being tested.
- The CPT will be retracted from the hole and the hole grouted before setting up over the adjacent Hydropunch™ location.
- The Hydropunch™ sample locations will be set approximately 3 to 4 feet (1 to 1.2 meters) from a previous CPT location. The probe will be advanced to the specified depth, which will be a permeable layer as defined from the adjacent CPT. Once at the specified depth, the outer jacket of the Hydropunch™ probe will be "jerked" (retracted) upwards to allow ground water inflow into the sample chamber. After the sample chamber has filled, the probe will be retracted from the hole and the sample transferred to the sample containers. To detect when the sample chamber is full, place a surgical glove over the end of the push rod (before the sampler is retracted). When the glove inflates, a sample has been collected (an optional technique to use if unsure whether the chamber is full). The probe and push/drive rods will be decontaminated before reuse as described in Section 4.0 of this document and 5.7.8 of the Sampling and Analysis Plan.
- For water level measurements using the Hydropunch™, allow enough time for ground water to fill the sample chamber and the push rods. After static water level conditions are achieved, a thoroughly decontaminated electric tape is lowered through the push rods and the water level is measured and recorded. The measurement is repeated three times. Measurement is referenced to ground surface.
- The CPT soundings and the Hydropunch™ ground water sample collection will be performed by an experienced subcontractor under the direction of the IT Field Supervisor.

7.0 MEASUREMENTS, SAMPLING, CALIBRATION, AND CORRELATION OF DATA

CPT MEASUREMENTS

The CPT measures tip resistance, sleeve friction, and pore pressure. All other output are variations on these three parameters except depth and inclination. Typical continuous printout of the field log is tip resistance (Q_c), sleeve friction (F_s), friction ratio (FR), pore pressure (U), and differential pore pressure ratio ($\delta U/Qt$) (Figures 3 and 4). (Q_t is the tip resistance corrected for pore pressure effects.) The friction ratio is equal to the corrected tip resistance divided by the sleeve friction (Q_t/F_s). Electronic sensors at the tip and sides of the probe measure penetration (tip) resistance and side (sleeve) friction of the soil, respectively. These two parameters are typically different for granular soils and clayey soils, thus identifying the occurrence of sands and gravels versus clays and silts. Values for both of these parameters are low with a high friction ratio as the probe is driven through clays and silts and relatively high with a low friction ratio for sands and gravels. The value of the friction ratio and the tip resistance at a certain depth is plotted on a soil behavior type classification chart and the type of soil at that point is determined. The use of the differential pore pressure ratio will differentiate soil types and allow for more accurate stratigraphic interpretations. Dynamic pore pressure measurements from the dissipation tests can be used to estimate hydraulic conductivity of the fine grained soil layers. Pore pressure dissipation measurements may also be used to identify the potentiometric level. (Ref. Smythe, et al, 1988)

Depth control is maintained by the data acquisition system. The system counts the number of whole and partial push rods used. The cone penetrometer is measured at the tip of the tool and zeroed at the ground surface.

HYDROPUNCH™ SAMPLING

A ground water sample is retrieved when the Hydropunch™ sample chamber is filled. Similar to a bailer, the upward movement of the sampler increases the hydrostatic pressure in the unit, which closes the two check valves and retains the sample within the sample chamber. Upon retrieval, the push rods are disconnected from the Hydropunch™ and the upper valve is removed. The ground water sample is decanted out of the top of the sampler, in much the same way as decanting a bailer. The upper check valve is replaced with a Teflon® stop cock valve and a disposable tube. The sampler is turned upside down, the cock valve opened and the sample decanted into a sample container through the Teflon® stopcock and tubing. The sample is then sent to the laboratory for analysis. Samples will be analyzed for VOCs (EPA Method 324), and for high boiling TPHC (EPA Modified Method 8015) and confirmed results reported within 48 hours. The sample collection procedures are further described in Section 5.9.1 of the Sampling and Analysis Plan.

Depth control is maintained by counting the number of whole and partial push or drive rods used. The Hydropunch™ is measured at the tip of the tool and zeroed at the ground surface.

CALIBRATION AND CORRELATION

CPT

The CPT subcontractor will provide data on the type and dimensions of the probes and equipment, along with the results of current shop calibrations.

CPT cones will be calibrated at zero load reading in air and water and shielded away from direct sunlight before the sounding at each location. Upon completion of the test, the piezocone will again be calibrated to zero load reading and compared to the initial reading.

Initial correlation of the CPT data with Moffitt lithology for the site will be accomplished by comparing the CPT data with data from an adjacent continuously sampled and geophysically logged soil boring.

HYDROPUNCH™

To correlate the Hydropunch™ sample data, analytical results from the Hydropunch™ ground water samples will be compared to monitoring well sample data. Samples will be collected with the Hydropunch™ from several test locations adjacent to existing A aquifer wells. The test locations (wells) will be selected to test the accuracy of the Hydropunch™ samples (relative to the wells) for high, low, and mid-range contaminant levels.

8.0 REPORTING

The CPT subcontractor will provide a field survey report of the test data prior to moving off each location. The CPT subcontractor will record on the survey report the operator's name, date of the survey, and the CPT location number. The report will include descriptions of the various probes and equipment and the results of calibrations performed as well as interpretation of the survey data.

Profiles of cone tip resistance, sleeve friction resistance, friction ratio, inclination, pore pressures and differential pore pressure ratio versus depth will be included in the report (Figures 3 and 4). Graphs of pore pressure dissipation versus time will be provided for each of the relevant test locations. In addition, the report will list the derived geotechnical parameters related to the subsurface conditions, including soil types, standard penetration test blow counts, relative density, and shear strengths.

All data is to be stored on a magnetic medium for future processing and so that a printout (graphical presentation) of the data is immediately available for in-field stratigraphic correlation and evaluation. The interpretative data will be copied to floppy disks in ASCII format for further data reduction purposes.

9.0 REFERENCES

ASTM, 1988, "Standard Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soil," Designation D3441-86, Vol. 4.08 Soil and Rock, Building Stones: Geotextiles, pp. 409-414 (Appendix A).

Cordry, K.E., 1986, "Groundwater Sampling Without Wells," Sixth National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring, Columbus, Ohio.

Edge, R.W. and Cordry, K., 1989, "The HydroPunch: An In Situ Sampling Tool for Collecting Ground Water from Unconsolidated Sediments," Ground Water Monitoring Review, Dublin, Ohio.

Klopp, R.A., and Walker, J.M, 1987, "The Use of Cone Penetration Testing for Evaluation of Waste Disposal Alternatives," ASCE Conference on Geotechnical Practices for Waste Disposal, Univ. Of Michigan, Ann Arbor.

Smolley, M. and Kappmeyer, J.C., 1989, Cone Penetrometer Tests and HydroPunch Sampling an Alternative to Monitoring Wells for Plume Definition," HAZMACON 89, Santa Clara, California.

Smythe, J.M., Bedient, P.B., and Klopp, R.A., 1988, "Cone Penetrometer Technology for Hazardous Waste Site Investigations," Proceedings of the Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, Water Well Journal Publishing Co., Dublin, Ohio.

Date: 12/06/89

SOUNDING DATA IN FILE #

ENGINEER:
CONE ID:

LOCATION:
JOB #:

Terra Technologies

DEPTH (feet)	TIP RESISTANCE (Ton/ft2)	LOCAL FRICTION (Ton/ft2)	FRICTION RATIO (Percent)	PORE PRESSURE (PSI Gauge)	PORE PRESSURE DIFFERENTIAL RATIO (Percent)	INCLINATION (Degrees)
1	0.2	-0.05	31.25	0.0	0.2	0.0
2	0.2	-0.05	34.75	0.0	1.2	0.0
3	0.3	-0.05	15.63	0.0	0.9	0.0
4	0.0	-0.05	66.51	-0.0	-0.0	-0.0
5	0.0	-0.06	144.99	0.0	4.0	-0.0
6	0.3	-0.06	18.37	0.0	1.4	0.0
7	0.4	-0.07	16.69	0.0	0.2	-0.0
8	1.9	-0.07	3.80	-0.0	-0.02	0.0
9	0.0	-0.07	163.98	0.2	39.0	0.0
10	0.7	-0.05	7.99	0.3	2.40	0.0

APPENDIX A

ASTM DESIGNATION: D3441-86

Standard Test Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soil[1]

This standard is issued under the fixed designation D 3441; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of end bearing and side friction, the components of penetration resistance which are developed during the steady slow penetration of a pointed rod into soil. This method is sometimes referred to as the "Dutch Cone Test," or "Cone Penetration Test" and is often abbreviated as the "CPT."

1.2 This test method includes the use of both cone and friction-cone penetrometers, of both the mechanical and electric types. It does not include data interpretation. It also includes the penetrometer aspects of piezocone soundings, but does not include the details of piezometer construction, location, measurement, or data interpretation.

NOTE 1—The European Standard for the CPT uses a tip of right cylindrical shape as shown in Fig. 3, as their reference test against which other CPTs may be compared.

1.3 Mechanical penetrometers of the type described in this method operate incrementally, using a telescoping penetrometer tip, resulting in no movement of the push rods during the measurement of the resistance components. Design constraints for mechanical penetrometers preclude a complete separation of the end-bearing and side-friction components. Electric penetrometers are advanced continuously and permit separate measurement of both components. Differences in shape and method of advance between cone penetrometer tips may result in significant differences in one or both resistance components.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Definitions

2.1 *cone*—the cone-shaped point of the penetrometer tip, upon which the end-bearing resistance develops.

2.2 *cone penetrometer*—an instrument in the form of a cylindrical rod with a conical point designed for penetrating soil and soft rock and for measuring the end-bearing component of penetration resistance.

2.3 *cone resistance or end-bearing resistance, q_c*—the resistance to penetration developed by the cone, equal to the vertical force applied to the cone divided by its horizontally projected area.

2.4 *cone sounding*—the entire series of penetration tests performed at one location when using a cone penetrometer.

2.5 *electric penetrometer*—a penetrometer that uses electric-force transducers built into a nontelescoping penetrometer tip for measuring, within the tip, the component(s) of penetration resistance.

2.6 *friction-cone penetrometer*—a cone penetrometer with the additional capability of measuring the local side friction component of penetration resistance.

2.7 *friction-cone sounding*—the entire series of penetration tests performed at one location when using a friction-cone penetrometer.

2.8 *friction ratio, R_f*—the ratio of friction resistance to cone resistance, f_s/q_c, expressed in percent.

2.9 *friction resistance, f_s*—the resistance to penetration developed by the friction sleeve, equal to the vertical force applied to the sleeve divided by its surface area. This resistance consists of the sum of friction and adhesion.

2.10 *friction sleeve*—a section of the penetrometer tip upon which the local side-friction resistance develops.

2.11 *inner rods*—rods that slide inside the push rods to extend the tip of a mechanical penetrometer.

2.12 *mechanical penetrometer*—a penetrometer that uses a set of inner rods to operate a telescoping penetrometer tip and to transmit the component(s) of penetration resistance to the surface for measurement.

2.13 *penetrometer tip*—the end section of the penetrometer, which comprises the active elements that sense the soil resistance, the cone, and in the case of the friction-cone penetrometer, the friction sleeve.

2.13.1 *Discussion*—The addition of a piezometer to the electric penetrometer tip permits the measurement of pore water pressure during and after stopping tip penetration. A penetrometer including a piezometer is known as a piezocone penetrometer, or just piezocone.

2.14 *piezocone sounding*—the entire series of penetration tests performed at one location when using a piezocone penetrometer.

2.15 *push rods*—the thick-walled tubes, or other suitable rods, used for advancing the penetrometer tip to the required test depth.

3. Significance and Use

3.1 This test method supplies data on the engineering properties of soil intended to help with the design and con-

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

Current edition approved Oct. 31, 1986. Published December 1986. Originally published as D 3441 – 75 T. Last previous edition D 3441 – 79.

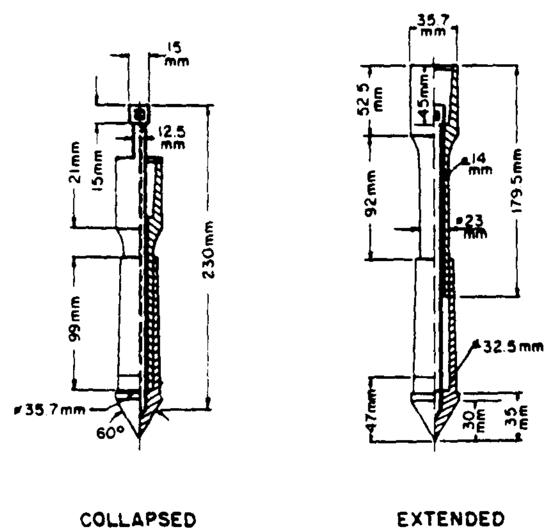

FIG. 1 Example of a Mechanical Cone Penetrometer Tip (Dutch Mantle Cone)

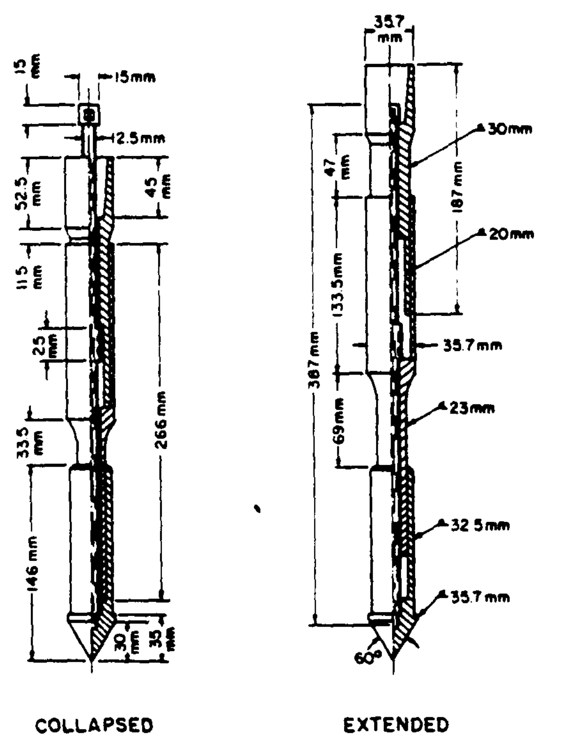

FIG. 2 Example of a Mechanical Friction-Cone Penetrometer Tip (Begemann Friction-Cone)

struction of earthworks and the foundations for structures.

3.2 This test method tests the soil in place and does not obtain soil samples. The interpretation of the results from this method requires knowledge of the types of soil penetrated. Engineers usually obtain this soil information from parallel borings and soil sampling methods, but prior information or experience may preclude the need for borings.

3.3 Engineers often correlate the results of tests by this test method with laboratory or other types of field tests, or directly with performance. The accuracy of such correlations will vary with the type of soil involved. Engineers usually rely on local experience to judge this accuracy.

3.4 Most engineers with offshore experience have also found this test method suitable for offshore use.

4. Apparatus

4.1 *General:*

4.1.1 *Cone*—The cone shall have a 60° (±5°) point angle and a base diameter of 1.406 ± 0.016 in. (35.7 ± 0.4 mm), resulting in a projected area of 1.55 in.^{2} (10 cm^2). The point of the cone shall have a radius less than ⅛ in. (3 mm).

NOTE 2—Cone tips with larger end areas may be used to increase measurement sensitivity in weak soils. Experience with electrical tips with end area between 0.78 in.^{2} (5 cm^2) and 3.10 in.^{2} (20 cm^2) has shown that they produce data similar to the 1.55 in.^{2} (10 cm^2) standard provided they maintain the same tip geometry. Cone tip sizes in this range may be used for special circumstances provided the cone tip and friction sleeve (if any) area is noted.

4.1.2 *Friction Sleeve*, having the same outside diameter +0.024 to −0.000 in. (+0.5 to −0.0 mm) as the base diameter of the cone (see 4.1.1). No other part of the penetrometer tip shall project outside the sleeve diameter. The surface area of the sleeve shall be 23.2 in.^{2} (150 cm^2) ±2 %.

4.1.3 *Steel*—The cone and friction sleeve shall be made from steel of a type and hardness suitable to resist wear due to abrasion by soil. The friction sleeve shall have and maintain with use a roughness of 20 µin. (0.5 µm) AA, ±50 %.

4.1.4 *Push Rods*—Made of suitable steel, these rods must have a section adequate to sustain, without buckling, the thrust required to advance the penetrometer tip. They must have an outside diameter not greater than the diameter of the base of the cone for a length of at least 1.3 ft (0.4 m) above the base, or, in the case of the friction-cone penetrometer, at least 1.0 ft (0.3 m) above the top of the friction sleeve. Each push rod must have the same, constant inside diameter. They must screw or attach together to bear against each other and form a rigid-jointed string of rods with a continuous, straight axis.

4.1.5 *Inner Rods*—Mechanical penetrometers require a separate set of steel, or other metal alloy, inner rods within the steel push rods. The inner rods must have a constant outside diameter with a roughness, excluding waviness, less than 10 µin. (0.25 µm) AA. They must have the same length as the push rods (±0.004 in. or ±0.1 mm) and a cross section adequate to transmit the cone resistance without buckling or other damage. Clearance between inner rods and push rods shall be between 0.020 and 0.040 in. (0.5 and 1.0 mm). See 6.8.1.

4.1.6 *Measurement Accuracy*—Maintain the thrust-measuring instrumentation to obtain thrust measurements within ±5 % of the correct values.

NOTE 3—Special, and preferably redundant, instrumentation may be required in the offshore environment to assure this accuracy and the proper operation of all the remote systems involved.

4.2 *Mechanical Penetrometers:*

4.2.1 The sliding mechanism necessary in a mechanical penetrometer tip must allow a downward movement of the

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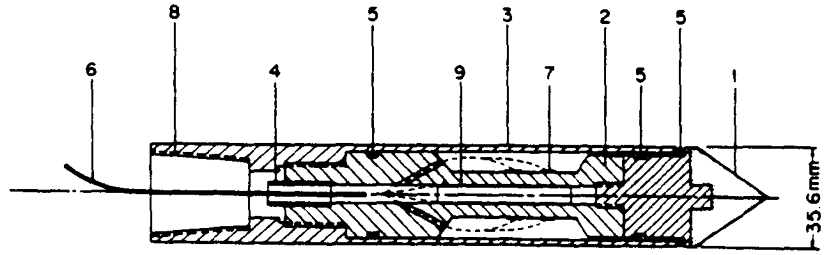
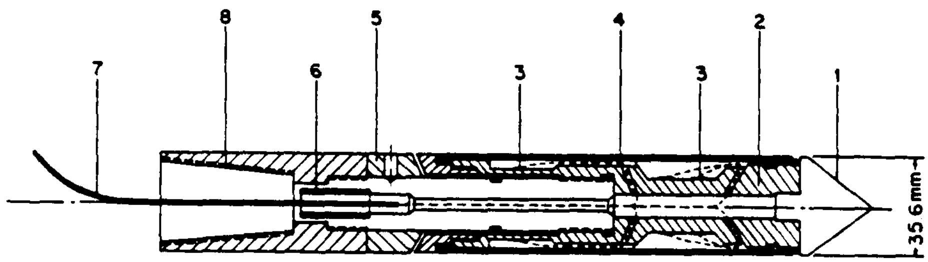


1 Conical point (10 cm^2)
2 Load cell
3 Protective mantle
4 Waterproof bushing
5 O-rings
6 Cable
7 Strain gages
8 Connection with rods
9 Inclinometer

FIG. 3 Electric-Cone Penetrometer Tip



1 Conical point (10 cm^2)
2 Load cell
3 Strain gages
4 Friction sleeve (150 cm^2)
5 Adjustment ring
6 Waterproof bushing
7 Cable
8 Connection with rods

FIG. 4 Electric Friction-Cone Penetrometer Tip

cone in relation to the push rods of at least 1.2 in. (30.5 mm).

NOTE 4—At certain combinations of depth and tip resistance(s), the elastic compression of the inner rods may exceed the downward stroke that the thrust machine can apply to the inner rods relative to the push rods. In this case, the tip will not extend and the thrust readings will rise elastically to the end of the machine stroke and then jump abruptly when the thrust machine makes contact with the push rods.

4.2.2 Mechanical penetrometer tip design shall include protection against soil entering the sliding mechanism and affecting the resistance component(s) (see 4.2.3 and Note 5).

4.2.3 *Cone Penetrometer*—Figure 1 shows the design and action of one mechanical cone penetrometer tip. A mantle of reduced diameter is attached above the cone to minimize possible soil contamination of the sliding mechanism.

NOTE 5—An unknown amount of side friction may develop along this mantle and be included in the cone resistance.

4.2.4 *Friction-Cone Penetrometer*—Figure 2 shows the design and action of one telescoping mechanical friction-cone penetrometer tip. The lower part of the tip, including a mantle to which the cone attaches, advances first until the flange engages the friction sleeve and then both advance.

NOTE 6—The shoulder at the lower end of the friction sleeve encounters end-bearing resistance. In sands as much as two thirds of the sleeve resistance may consist of bearing on this shoulder. Ignore this effect in soft to medium clays.

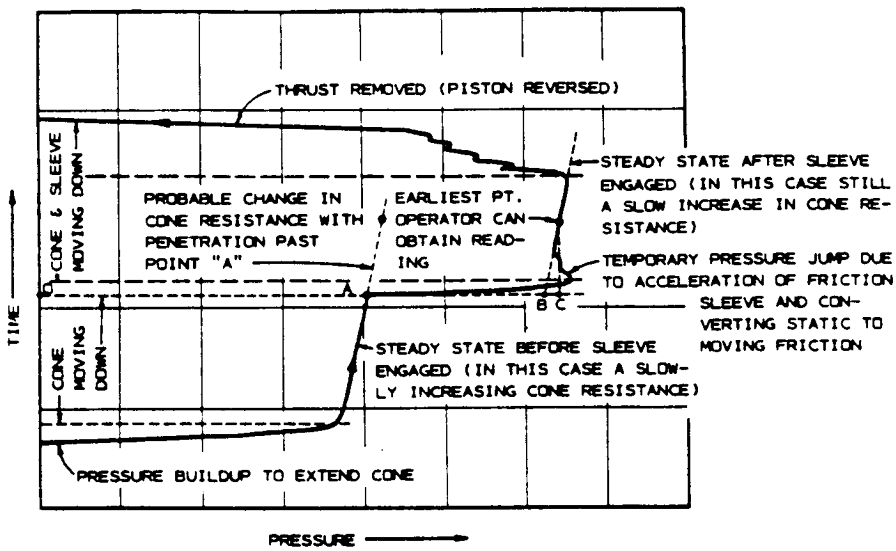
4.2.5 *Measuring Equipment*—Measure the penetration resistance(s) at the surface by a suitable device such as a hydraulic or electric load cell or proving ring.

4.3 *Electric Penetrometers:*

4.3.1 *Cone Penetrometer*—Figure 3 shows one design for an electric-cone penetrometer tip. The cone resistance is measured by means of a force transducer attached to the cone. An electric cable or other suitable system transmits the transducer signals to a data recording system. Electric-cone penetrometers shall permit continuous advance and recording over each push rod-length interval.

4.3.2 *Friction-Cone Penetrometer*—The bottom of the friction sleeve shall not be more than 0.4 in. (10 mm) above the base of the cone. The same requirements as 4.3.1 apply. Figure 4 shows one design for an electric friction-cone penetrometer tip.

4.3.3 *Other Penetrometers*—Electric penetrometers may include other transducer measurements as well as, or instead of, the friction sleeve measurement. Common ones are inclinometers to assist with the alignment control of the tip (see



NOTE—"o-a" represents the correct cone resistance reading just before the pressure jump associated with engaging the friction sleeve during the continuing downward extension of the tip. "a-b" is the correct friction resistance if the friction sleeve could be engaged instantaneously and the cone plus friction resistance read instantaneously. However, the operator cannot read a pressure gage dial until it steadies, such as at point "c." By this forced wait, the operator has introduced a friction resistance error of "b-c." The operator must read the gage as soon as possible after the jump to minimize this error. Erratic or abrupt changes in cone resistance may make this error unacceptable.

FIG. 5 Annotated Chart Record of the Pressure Changes in the Hydraulic Load Cell Measuring Thrust on Top of the Inner Rods During an Example Extension of the Mechanical Friction-Cone Penetrometer Tip

6.3) and piezometers to provide additional data on soil stratigraphy and behavior.

4.4 *Thrust Machine*—This machine shall provide a continuous stroke, preferably over a distance greater than one push rod length. The machine must advance the penetrometer tip at a constant rate while the magnitude of the thrust required fluctuates (see 5.1.2).

NOTE 7—Deep penetration soundings usually require a thrust capability of at least 5 tons (45 kN). Most modern machines use hydraulic pistons with 10 to 20-ton (90 to 180-kN) thrust capability.

4.5 *Reaction Equipment*—The proper performance of the static-thrust machine requires a stable, static reaction.

NOTE 8—The type of reaction provided may affect the penetrometer resistance(s) measured, particularly in the surface or near-surface layers.

5. Procedure

5.1 *General:*

5.1.1 Set up the thrust machine for a thrust direction as near vertical as practical.

5.1.2 *Rate of Penetration*—Maintain a rate of depth penetration of 2 to 4 ft/min (10 to 20 mm/s) ±25 % when obtaining resistance data. Other rates of penetration may be used between tests.

NOTE 9—The rate of 2 ft/min (10 mm/s) provides the time the operator needs to read properly the resistance values when using the mechanical friction-cone penetrometer. The rate of 4 ft/min (20 mm/s) is suitable for the single resistance reading required when using the mechanical cone penetrometer and provides for the efficient operation of electric penetrometers. The European standard requires 4 ft/min (20 mm/s).

NOTE 10—Rates of penetration either slower or faster than the standard rate may be used for special circumstances, such as pore pressure measurements. This is permissible provided the rate actually used and the reason for the deviation is noted on the test record.

NOTE 11—Pore pressures generated ahead of and around the penetrating cone or friction cone penetrometer tip can have an important effect on the q_c and f_s values measured. Piezocone tips with simultaneous pore pressure measurement capability have proven useful to help evaluate such effects and to provide additional data about the stratigraphy and engineering properties of the soils penetrated.

5.2 *Mechanical Penetrometers:*

5.2.1 *Cone Penetrometer*—(*1*) Advance penetrometer tip to the required test depth by applying sufficient thrust on the push rods; and (*2*) Apply sufficient thrust on the inner rods to extend the penetrometer tip (see Fig. 1). Obtain the cone resistance at a specific point (see 5.2.3) during the downward movement of the inner rods relative to the stationary push rods. Repeat step (*1*). Apply sufficient thrust on the push rods to collapse the extended tip and advance it to a new test depth. By continually repeating this two-step cycle, obtain cone resistance data at increments of depth. This increment shall not ordinarily exceed 8 in. (203 mm).

5.2.2 *Friction-Cone Penetrometer*—Use this penetrometer as described in 5.2.1 but obtain two resistances during the step (*2*) extension of the tip (see Figs. 2 and 5). First obtain the cone resistance during the initial phase of the extension. When the lower part of the tip engages and pulls down the friction sleeve, obtain a second measurement of the total resistance of the cone plus the sleeve. Subtraction gives the sleeve resistance.

NOTE 12—Because of soil layering, the cone resistance may change during the additional downward movement of the tip required to obtain the friction measurement.

NOTE 13—The soil friction along the sleeve puts an additional overburden load on the soil above the cone and may increase cone resistance above that measured during the initial phase of the tip extension by an unknown, but probably small amount. Ignore this effect.

5.2.3 *Recording Data*—To obtain reproducible cone-resistance test data, or cone and friction-resistance test data when using a friction-cone tip, record only those thrust readings that occur at a well-defined point during the downward movement of the top of the inner rods in relation to the top of the push rods. Because of the elastic compression of inner rods (see Note 4), this point ordinarily should be at not less than 1.0 in. (25 mm) apparent relative movement of the inner rods. When using the friction-cone penetrometer, this point shall be just before the cone engages the friction sleeve.

NOTE 14—Figure 5 shows one example of how the thrust in the hydraulic load cell can vary during the extension of the friction-cone tip. Note the jump in gage pressure when the cone engages the sleeve.

5.2.3.1 Obtain the cone plus friction-resistance reading as soon as possible after the jump so as to minimize the error described in Fig. 5. Unless using continuous recording as in Fig. 5, the operator should not record a cone plus friction resistance if he suspects the cone resistance is changing abruptly or erratically.

5.3 *Electric Penetrometers:*

5.3.1 If using continuous electric cable, prethread it through the push rods.

5.3.2 Record the initial reading(s) with the penetrometer tip hanging freely in air or in water, out of direct sunlight, and after an initial, short penetration, test hole so that the tip temperature is at soil temperature.

5.3.3 Record the cone resistance, or cone resistance and friction resistance, continuously with depth or note them at intervals of depth not exceeding 8 in. (203 mm).

5.3.4 At the end of a sounding, obtain a final set of readings as in 5.3.2 and check them against the initial set. Discard the sounding, and repair or replace the tip if this check is not satisfactory for the accuracy desired for the resistance component(s).

6. Special Techniques and Precautions

6.1 *Reduction of Friction Along Push Rods*—The purpose of this friction reduction is to increase the penetrometer depth capability, and not to reduce any differences between resistance components determined by mechanical and electric tips as noted in 1.3. To accomplish the friction reduction, introduce a special rod with an enlarged diameter or special projections, called a "friction reducer," into the string of push rods or between the push rods and the tip. Another allowable method to reduce friction is to use push rods with a diameter less than that of the tip. In accordance with 4.1.4, any such projections or changes in diameter must begin no closer than 1.0 ft (0.3 m) from the base of the cone or the top of the friction sleeve when using cones with the standard 4.1.1 diameter. For other cones (see Note 2) use no closer than 8 diameters.

NOTE 15—Non-mechanical techniques to reduce friction, such as the use of drilling mud above the tip, are also allowable.

6.2 *Prevention of Rod Bending Above Surface*—Use a tubular rod guide, at the base of the thrust machine, of sufficient length to prevent significant bending of the push rods between the machine and the ground surface.

NOTE 16—Special situations, such as when working through water, will require a special system of casing support to restrict adequately the buckling of the push rods.

6.3 *Drift of Tip*—For penetration depths exceeding about 40 ft (12 m), the tip will probably drift away from a vertical alignment. Occasionally, serious drifting occurs, even at less depth. Reduce drifting by using push rods that are initially straight and by making sure that the initial cone penetration into soil does not involve unwanted, initial lateral thrust. Passing through or alongside an obstruction such as boulders, soil concretions, thin rock layers, or inclined dense layers may deflect the tip and induce drifting. Note any indications of encountering such obstructions and be alert for possible subsequent improper tip operation as a sign of serious drifting.

NOTE 17—Electric penetrometer tips may also incorporate an inclinometer to monitor drift and provide a warning when it becomes excessive.

6.4 *Wear of Tip*—Penetration into abrasive soils eventually wears down or scours the penetrometer tip. Discard tips, or parts thereof, whose wear changes their geometry or surface roughness so they no longer meet the requirements of 4.1. Permit minor scratches.

6.5 *Distance Between Cone and Friction Sleeve*—The friction resistance of the sleeve applies to the soil at some distance above the soil in which the cone resistance was obtained at the same time. When comparing these resistances for the soil at a specified depth, for example when computing friction ratios or when plotting these data on graphs, take proper account of the vertical distance between the base of the cone and the midheight of the friction sleeve.

6.6 *Interruptions*—The engineer may have to interrupt the normal advance of a static penetration test for purposes such as removing the penetrometer and drilling through layers or obstructions too strong to penetrate statically. If the penetrometer is designed to be driven dynamically without damage to its subsequent static performance (those illustrated herein in Figs. 1 to 4 are not so designed), the engineer may drive past such layers or obstructions. Delays of over 10 min due to personnel or equipment problems shall be considered an interruption. Continuing the static penetration test after an interruption is permitted provided this additional testing remains in conformance with this standard. Obtain further resistance component data only after the tip passes through the engineer's estimate of the disturbed zone resulting from the nature and depth of the interruption. As an alternative, readings may be continued without first making the additional tip penetration and the disturbed zone evaluated from these data. Then disregard data within the disturbed zone.

NOTE 18—Interruption of the piezocone sounding after a push allows the engineer to examine the dissipation of positive or negative excess pore water pressure.

6.7 *Below or Adjacent to Borings*—A cone or friction-cone sounding shall not be performed any closer than 25 boring diameters from an existing, unbackfilled, uncased boring hole. When performed at the bottom of a boring, the engineer should estimate the depth below the boring of the disturbed zone and disregard penetration test data in this zone. The depth may vary from one to five diameters. Where the engineer does not have sufficient experience with this variable a depth of at least three boring diameters should be used.

6.8 *Mechanical Penetrometers:*

6.8.1 *Inner Rod Friction*—Soil particles and corrosion can increase the friction between inner rods and push rods, possibly resulting in significant errors in the measurement of the resistance component(s). Clean and lubricate the inner rods.

6.8.2 *Weight of Inner Rods*—For improved accuracy at low values of cone resistance, correct the thrust data to include the accumulated weight of the inner rods from the tip to the topmost rod.

6.8.3 *Jamming*—Soil particles between sliding surfaces or bending of the tip may jam the mechanism during the many extensions and collapses of the telescoping mechanical tip. Stop the sounding as soon as uncorrectable jamming occurs.

6.9 *Electric Penetrometers:*

6.9.1 *Water Seal*—Provide adequate waterproofing for the electric transducer. Make periodic checks to assure that no water has passed the seals.

Note 19—Some electric tip sleeve designs are not compensated for hydrostatic end area effects and require a calibration correction. Determining the net end area of the cone under hydrostatic pressure also requires a hydrostatic calibration measurement. The tip manufacturer can usually supply these calibration correction constants. Their importance increases as the soil being tested becomes weaker.

7. Report

7.1 *Graph of Cone Resistance, q_c*—Every report of a cone friction-cone sounding shall include a graph of the variation of cone resistance (in units of tons or kPa) with depth (in feet or metres). Successive cone-resistance test values from the mechanical cone and friction-cone penetrometers, usually determined at equal increments of depth and plotted at the depth corresponding to the depth of the measurement, may be connected with straight lines as an approximation for a continuous graph.

7.2 *Friction-Cone Penetrometer:*

7.2.1 *Graph of Friction Resistance, f_s*—In addition to the graph of cone resistance (7.1) the report may include an adjacent or superposed graph of friction resistance or friction ratio, or both, with depth. Use the same depth scale as in 7.1 (see 6.5).

7.2.2 *Graph of Friction Ratio, R_f*—If the report includes soil descriptions estimated from the friction-cone penetrometer data, include a graph of the variation of friction ratio with depth. Place this graph adjacent to the graph for cone resistance, using the same depth scale (see 6.5).

7.3 *Piezocone Penetrometer*—In addition to the 7.1 and 7.2 report requirements, a piezocone sounding shall include a parallel graph, to the same depth scale, of measured pore water pressure during the penetration versus depth. Excess pore water pressure versus time plots may also be constructed at those depths where the piezocone sounding is interrupted (see Note 1).

7.4 *General*—The operator shall record his name, the name and location of the job, date of sounding, sounding number, location coordinates, and soil and water surface elevations (if available). The report shall also include a note as to the type of penetrometer tip used, the type of thrust machine, tip and thrust calibration information, or both, any zero-drift noted, the method used to provide the reaction force, if a friction reducer was used, the method of tip advancement, the method of recording, the condition of the rods and tip after withdrawal, and any special difficulties or other observations concerning the performance of the equipment.

7.5 *Deviations from Standard*—The report shall state that the test procedures were in accordance with this Test Method D 3441. Describe completely any deviations from this test method.

8. Precision and Bias

8.1 Because of the many variables involved and the lack of a superior standard, engineers have no direct data to determine the bias of this method. Judging from its observed reproducibility in approximately uniform soil deposits, plus the q_c and f_s measurement effects of special equipment and operator care, persons familiar with this method estimate its precision as follows:

8.1.1 *Mechanical Tips*—Standard deviation of 10 % in q_c and 20 % in f_s.

8.1.2 *Electric Tips*—Standard deviation of 5 % in q_c and 10 % in f_s.

Note 20—These data may not match similar data from mechanical tips (see 1.3).

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

FIGURES

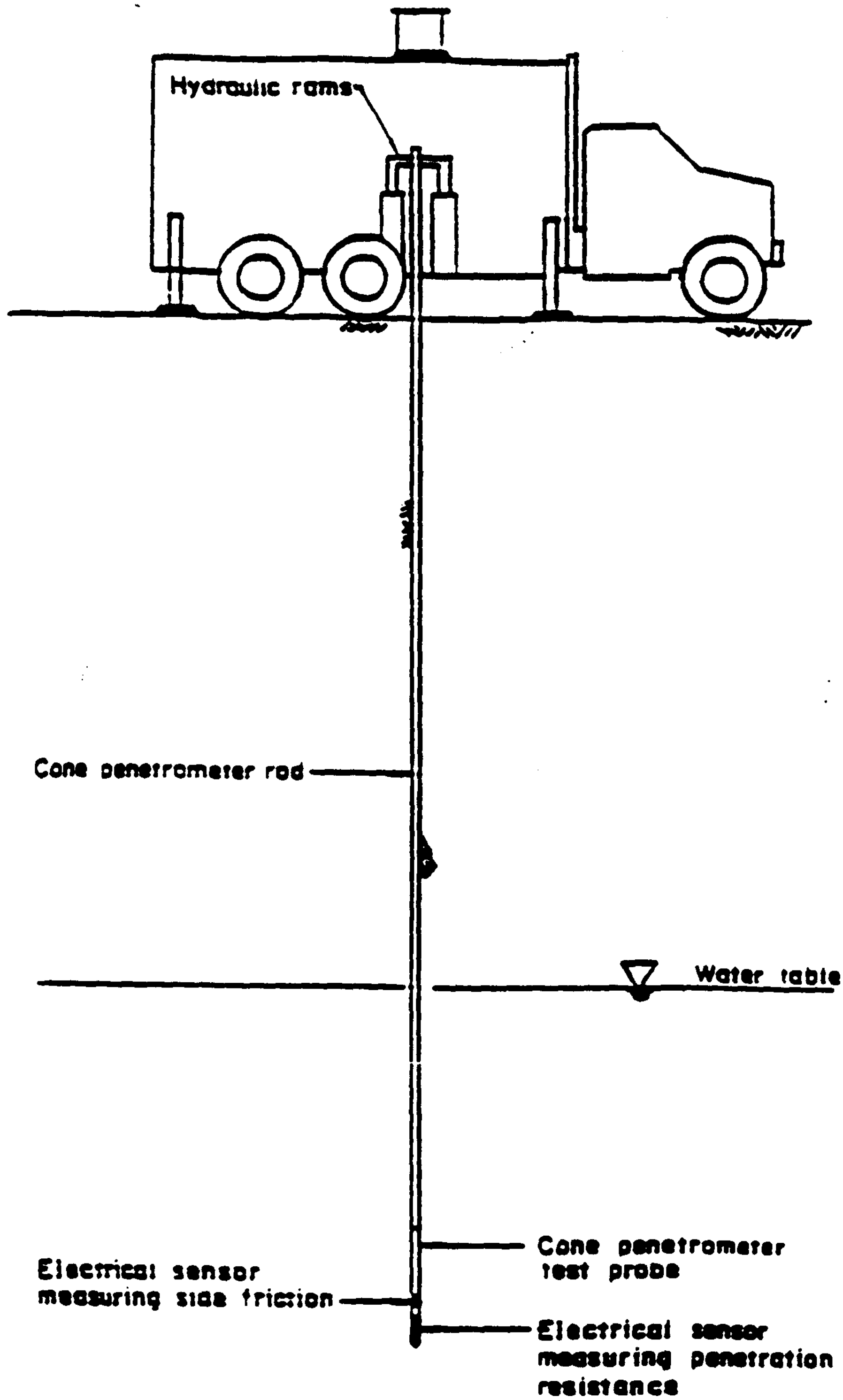


Figure 1

TYPICAL CONE PENETROMETER TEST RIG

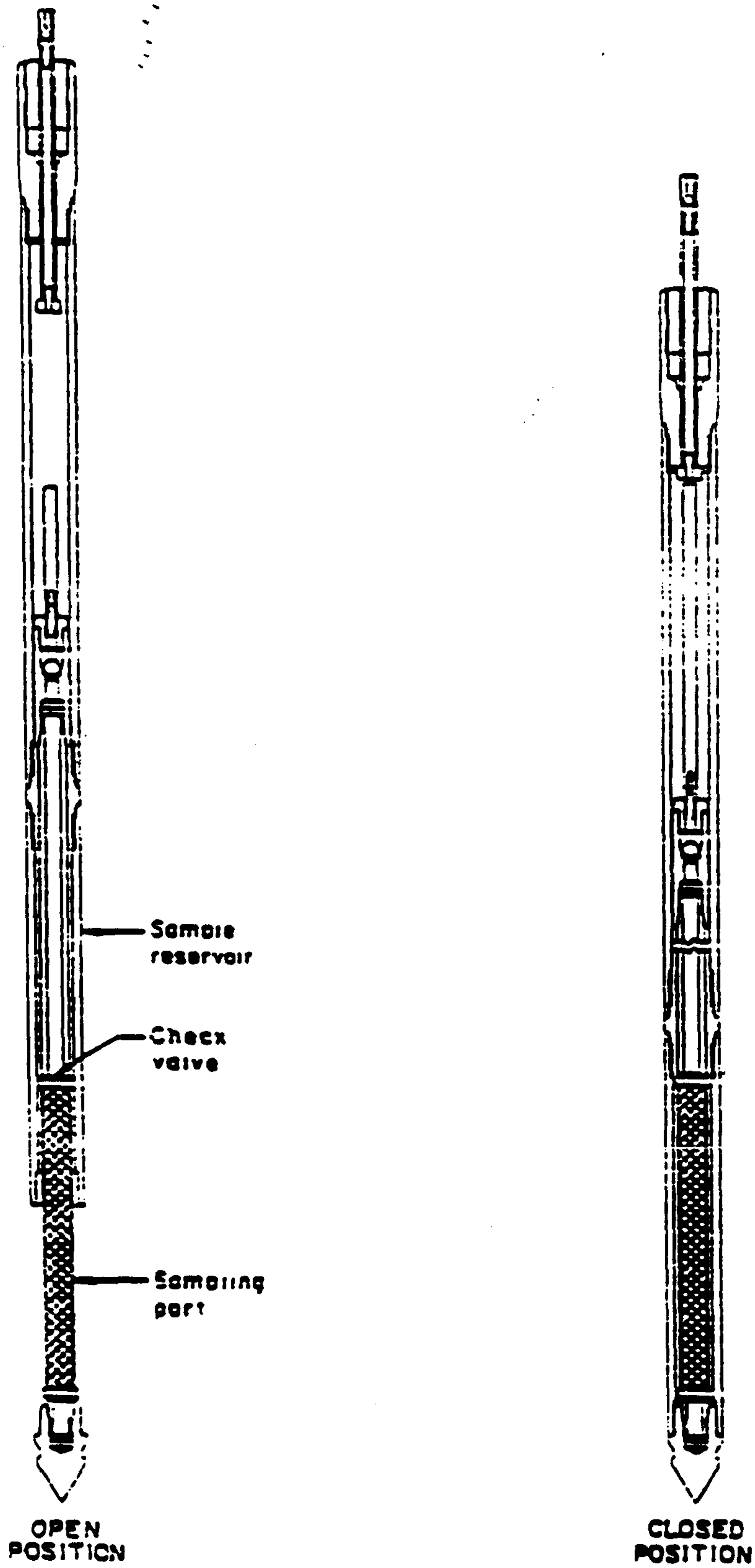


Figure 2.

HYDROPUNCH SCHEMATIC

SOUNDING DATA IN FILE #

ENGINEER : LOCATION :

CONE ID : JOB # :

Terra Technologies

DEPTH (METERS)	TIP RESISTANCE (Ton/ft^2)	LOCAL FRICTION (Ton/ft^2)	FRICTION RATIO (PERCENT)	PORE PRESSURE (PSI GAUGE)	PORE PRESSURE RATIO (PERCENT)	INCLINATION (DEGREES)
0.05	23.5	0.03	0.14	-0.0	-0.00	-0.0
0.10	66.7	0.07	0.10	-0.1	-0.01	0.0
0.15	94.5	0.31	0.32	-0.0	-0.00	0.0
0.20	97.2	0.51	0.52	-0.2	-0.02	0.0
0.25	79.5	0.64	0.80	-0.2	-0.03	0.1
0.30	60.0	0.79	1.31	-0.2	-0.05	0.1
0.35	37.9	0.90	2.35	-0.5	-0.17	0.1
0.40	38.1	0.95	1.16	-1.1	-0.38	0.1
0.45	21.4	0.81	1.80	-2.4	-0.97	0.1
0.50	26.3	0.52	1.96	-1.9	-0.70	0.1
0.55	28.7	0.45	1.55	-1.7	-0.59	0.1
0.60	17.1	0.48	2.80	-0.5	-0.53	0.1
0.65	14.1	0.42	2.98	-0.2	-0.52	0.1
0.70	27.4	0.20	0.74	-0.0	-0.24	0.1
0.75	25.1	0.00	0.00	0.0	-0.26	0.1

Figure 3. CPT digital output

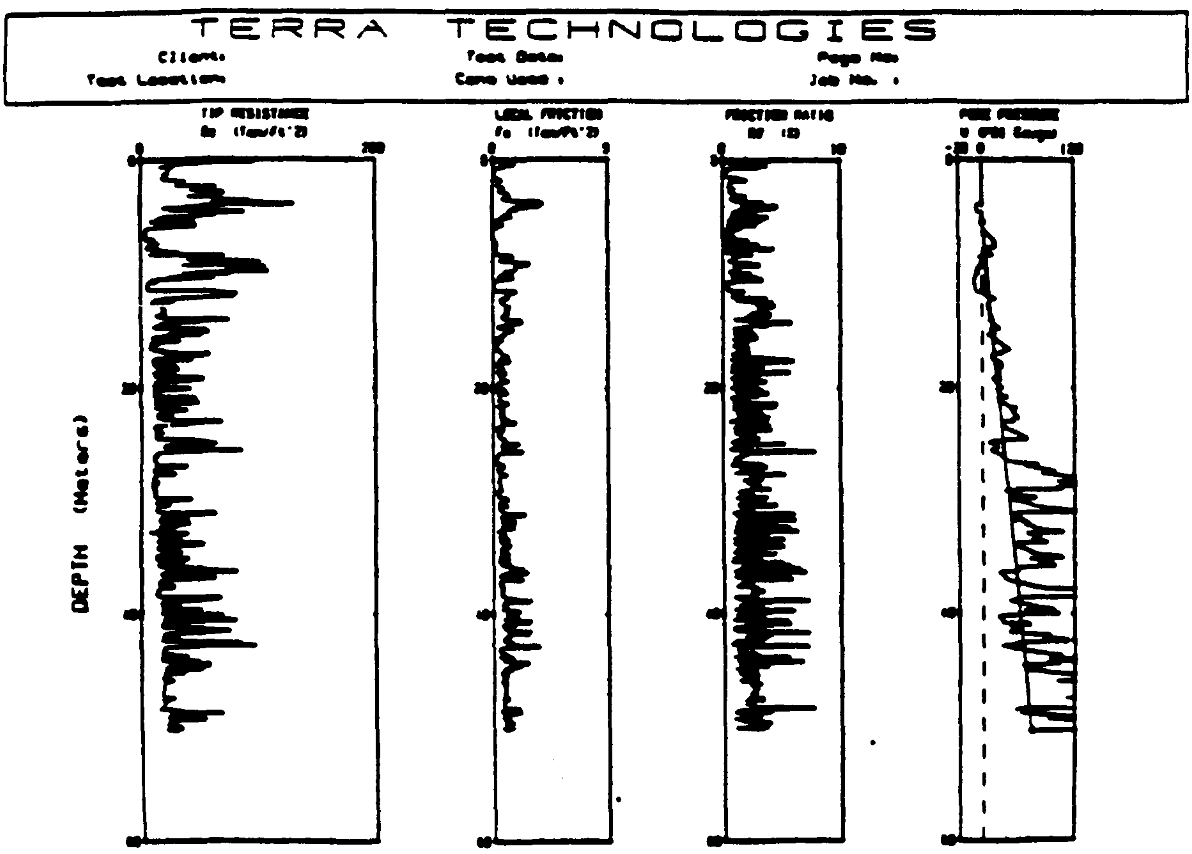


Figure 4. CPT graphical output