0029737

JUL 22 1993 (11)

Station #12

ENGINEERING DATA TRANSMITTAL

Page 1 of 1

1. EDT 136131

2. To: (Receiving Organization) Distribution

3. From: (Originating Organization) Geosciences

4. Related EDT No.: N/A

5. Proj./Prog./Dept./Div.: 200 West Carbon Tetrachloride ERA

6. Cog. Engr.: V. J. Rohay

7. Purchase Order No.: N/A

8. Originator Remarks: Document for release/review.

9. Equip./Component No.: N/A

10. System/Bldg./Facility: N/A

11. Receiver Remarks:

AUG 1993 RECEIVED EDMC

12. Major Assm. Dwg. No.: N/A

13. Permit/Permit Application No.: N/A

14. Required Response Date: N/A

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-EN-TI-171		0	Electronic Cone Penetration Testing at the Hanford Site, 200 West Area	3Q	1/2	1	

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 (see MRP 5.43)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Impact Level for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.
1	1	Cog. Eng. V.J. Rohay	V.J. Rohay	6/4/93	H6-06	Central Files (2)			L8-04	3	
1	1	Cog. Mgr. A. J. Knepp	[signature]	6/4/93	H6-06	B. R. Cassem			N3-05	3	
1	1	QA R. L. Hand	R. L. Hand	7/13/93	H4-16	Information Release Admin. (3)			H4-17	3	
		Safety									
		Env.									
3		EDMC (2) 1			H6-08						
3		ERC			H6-07						

18. Virginia J. Rohay 6/4/93 — Signature of EDT Originator, Date

19. Authorized Representative for Receiving Organization, Date

20. [signature] 6/4/93 — Cognizant Manager, Date

21. DOE APPROVAL (if required)
Ltr No.
- [ ] Approved
- [ ] Approved w/comments
- [ ] Disapproved w/comments

BD-7400-172 (07/91)

SUPPORTING DOCUMENT

1. Total Pages 66

2. Title

Electronic Cone Penetration Testing at the Hanford Site, 200 West Area

3. Number

WHC-SD-EN-TI-171

4. Rev No.

Rev. 0

5. Key Words

Carbon Tetrachloride Expedited Response Action, VOC-Arid ID program

APPROVED FOR PUBLIC RELEASE

6/11/93 D. Sell

6. Author

Name: V. J. Rohay

V J Rohay 6/4/93
Signature

Organization/Charge Code 81231/P12CA

7. Abstract

Rohay, V. J., 1993, *Electronic Cone Penetration Testing at the Hanford Site, 200 West Area*, WHC-SD-EN-TI-171, Rev. 0, prepared by Applied Research Associates, Inc. for Westinghouse Hanford Company, Richland, Washington.

8. P[redacted]SE AND USE OF DOCUMENT - Thi[redacted]ment[redacted]s prepared f[redacted] wi[redacted] the U.S. Department of E[redacted]nd its c[redacted]ractors,[redacted]to be [redacted]d only to perform [redacted]ect, or in[redacted]rate[redacted] under U.S. D[redacted]tment of Energy [redacted]acts. This docum[redacted]t approved for pub[redacted]release unti[redacted]ewed.

PATENT STA[redacted] - [redacted] document copy, sin[redacted] is [redacted]ansmitted in advance of [redacted]earance, is made av[redacted] in co[redacted]dence solely for use i[redacted]formance of work [redacted]r contrac[redacted] with the U.S. Depa[redacted] Energy. This do[redacted]t is not to be [redacted]lished nor its co[redacted]oth[redacted]se dissemina[redacted] used for purpose[redacted]ther than speci[redacted] above be[redacted]re patent [redacted]val for such release or use has be[redacted]cured, upon request, f[redacted]the Patent Counsel, U.S. Department of[redacted]ergy Field Office, Richl[redacted], WA.

9. Impact Level 3Q

10. RELEASE STAMP

OFFICIAL RELEASE (11)
BY WHC
DATE JUL 22 1993
Station #12

INFORMATION RELEASE REQUEST

Date Received: 6/10/93

Reference: WHC-CM-3-4

Complete for all Types of Release

Purpose		ID Number (include revision, volume, etc.)
[] Speech or Presentation (Check only one suffix): [] Full Paper; [] Summary; [] Abstract; [] Visual Aid	[] Reference	WHC-SD-EN-TI-171, Rev. 0
[] Speakers Bureau	[x] Technical Report	List attachments.
[] Poster Session	[] Thesis or Dissertation	
[] Videotape	[] Manual	Date Release Required
	[] Brochure/Flier	June 15, 1993
	[] Software/Database	
	[] Controlled Document	
	[] Other	

Title: Electronic Cone Penetration Testing at the Hanford Site, 200 West Area

Unclassified Category: UC- 630

Impact Level: 3Q

New or novel (patentable) subject matter? [X] No [] Yes
If "Yes", has disclosure been submitted by WHC or other company?
[X] No [] Yes Disclosure No(s).

Information received from others in confidence, such as proprietary data, trade secrets, and/or inventions?
[X] No [] Yes (Identify)

Copyrights? [X] No [] Yes
If "Yes", has written permission been granted?
[] No [] Yes (Attach Permission)

Trademarks?
[X] No [] Yes (Identify)

Complete for Speech or Presentation

Title of Conference or Meeting	Group or Society Sponsoring

Date(s) of Conference or Meeting	City/State	Will proceedings be published?	Will material be handed out?
		[] Yes [] No	[] Yes [] No

Title of Journal

CHECKLIST FOR SIGNATORIES

Review Required per WHC-CM-3-4	Yes	No	Reviewer - Signature Indicates Approval: Name (printed)	Signature	Date
Classification/Unclassified Controlled Nuclear Information	[]	[x]			
Patent - General Counsel	[x]	[]	S. W. Berglin	per DOC memo 2-4-93 MKnight	6-9-93
Legal - General Counsel	[x]	[]	S. W. Berglin		
Applied Technology/Export Controlled Information or International Program	[]	[x]			
WHC Program/Project	[]	[x]			
Communications	[]	[x]			
RL Program/Project	[x]	[]	P. M. Pak	(Review not required per author) MKnight	6-9-93
Publication Services	[x]	[]	M. R. Knight	MKnight	6-9-93
Other Program/Project	[]	[x]			

Information conforms to all applicable requirements. The above information is certified to be correct.

	Yes	No
References Available to Intended Audience	[x]	[]
Transmit to DOE-HQ/Office of Scientific and Technical Information	[x]	[]

Author/Requestor (Printed/Signature) — Date

V. J. Rohay — Virginia J Rohay — 6/4/93

Intended Audience

[] Internal [] Sponsor [X] External

Responsible Manager (Printed/Signature) — Date

A. J. Knepp — AJKnepp — 6/4/93

INFORMATION RELEASE ADMINISTRATION APPROVAL STAMP

Stamp is required before release. Release is contingent upon resolution of mandatory comments.

APPROVED FOR RELEASE — OFFICIAL — NS — DOCUMENT — Date 6/11/93

Date Cancelled	Date Disapproved

ACRONYMS

ANL	Argonne National Laboratory
ARA	Applied Research Associates, Inc.
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CPT	cone penetrometer
DOE	U.S. Department of Energy
ECPT	electronic cone penetration testing
EPA	U.S. Environmental Protection Agency
ERA	Expedited Response Action
ID	inside diameter
OD	outside diameter
R-ECPT	resistivity-ECPT
S-ECPT	seismic-ECPT
SPT	Standard Penetration Test
VOC-Arid ID	Integrated Demonstration for Cleanup of Volatile Organic Compounds at Arid Sites
WHC	Westinghouse Hanford Company

CONTENTS

CONTENTS (continued)

1.0 INTRODUCTION

The 200 West Area Carbon Tetrachloride Expedited Response Action (ERA) is being conducted by the U.S. Department of Energy (DOE) at the direction of the U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology as a provision of both the *Comprehensive Environmental Response Compensation and Liability Act of 1980* (CERCLA) and the Integrated Demonstration for Cleanup of Volatile Organic Compounds at Arid Sites (VOC-Arid ID). The ERA allows expedited response to be taken at waste sites where damage to the environment can be significantly reduced by early action to locate, identify the extent, and remediate imminent hazards. The ERA is focusing specifically on the removal of carbon tetrachloride vapor from the soil column and protection of the groundwater in the 200 West Area. The VOC-Arid ID program allows demonstration of new drilling technologies for environmental characterization monitoring and remediation. Soil vapor vacuum extraction has been proposed to remediate the site. This may require vapor extraction wells to be installed within the plume (Rohay 1991).

Remediation efforts will require a site characterization program to determine the areal extent and concentration of the carbon tetrachloride plume and to determine the level of radiological contamination. Data from the site characterization program will be used to design an optimal network of vapor vacuum extraction wells. One of the key issues for the site characterization program is the health and safety of the personnel conducting the work. The electronic cone penetrometer (CPT) offers many advantages toward protecting the worker and the environment. First, the CPT is minimally invasive and generates minimal drilling wastes. In addition, drilling-type fluids are not injected into the media. Secondly, worker safety is ensured by eliminating worker exposure to hazardous gases or fluids. During the CPT test, the penetration hole is plugged by the push rod. Upon extraction, the push rods are steamed or wiped clean before they enter the truck where the workers are located. Any wastes generated during the cleaning process are minimal and can be disposed of properly by a single worker in appropriate protective gear. For these reasons, the CPT technology is being evaluated by VOC-Arid ID to determine if the cone can penetrate to the depths required, deploy subsurface in-situ sensors, measure physical properties and contaminant concentration, and determine what modifications need to be made to currently available cone penetrometers in order to test for the unique properties at the Hanford Site.

Applied Research Associates, Inc. (ARA) under contract to Argonne National Laboratory (ANL) was funded by both the Westinghouse Hanford Company (WHC) and the VOC-Arid ID program to conduct electronic cone penetration testing (ECPT) at the Hanford Site's 200 West Area. The field tests were conducted to evaluate the potential of the ECPT for characterizing contaminated soils and placing permanent soil-gas monitoring and extraction wells. Testing was conducted at the 200 West Area as part of the Carbon Tetrachloride ERA in a soil that was not radiologically contaminated. The testing was composed of three elements: (1) evaluation of the ability of the cone penetrometer to penetrate the soils in the 200 West Area, (2) determination of the effectiveness of grouting procedures, and (3) placement and grouting of permanent monitoring wells.

This report documents the results obtained from the testing program outlined in Chapter 1.0. Chapter 2.0 discusses the ECPT equipment, testing procedures, and data format. Chapter 3.0 describes the test results, while Chapter 4.0 contains a detailed geologic interpretation of the tests that were performed and the information gained from these tests. Chapter 5.0 contains a summary of the work performed and recommendations for future work.

1.1 PROJECT OBJECTIVES AND FIELD EFFORTS

The ECPT in the 200 West Area was conducted to determine the following:

- The feasibility of using the ECPT to penetrate the soils and sediments in the 200 West Area
- The feasibility of using the ECPT to obtain soil-gas vapor samples
- The correlation of existing geologic data with the data obtained by the ECPT
- The feasibility of using the ECPT to identify and sample dense, non-aqueous phase liquids, if encountered
- The feasibility of using the ECPT resistivity module to measure contaminants in the unsaturated zone
- The feasibility of installing vadose zone monitoring wells with the ECPT
- The effectiveness with which the ECPT can be used to grout penetration holes to prevent cross-contamination.

1.2 ECPT LOCATIONS

Electronic cone penetration tests were conducted in the 200 West Area, which is located near the center of the Hanford Site (Figure 1-1) in the state of Washington. The geology of the site consists of deposits of sands, gravels, and muds, the source of which was the ancestral Columbia River. The upper geology of the site (the Hanford formation) consists of poorly sorted clasts deposited in a high-energy environment, with bedded sequences of graded silt, sand, minor gravel units, and cobbles. In general, this unit is approximately 50% sand and gravel, 45% cobble, and 5% boulder. The unit ranges in thickness from about 20 to 200 ft and is underlain by approximately 5 to 60 ft of silts and fine sands, which in turn are underlain by another gravel unit (Rohay 1991).

Eight locations were tested in the 200 West Area. All testing was completed between September 23 and September 27, 1991. These tests were conducted near established wells and are referenced to these wells as shown in Table 1-1 and in Figure 1-2. The locations of the ECPT with respect to the monitoring wells are shown in more detail in Figure 1-3. Table 1-1 also contains the maximum depth of each penetration and the type of testing that was performed.

Figure 1-1. Hanford Site Map Showing Location of the 200 West Area (Rohay 1991).

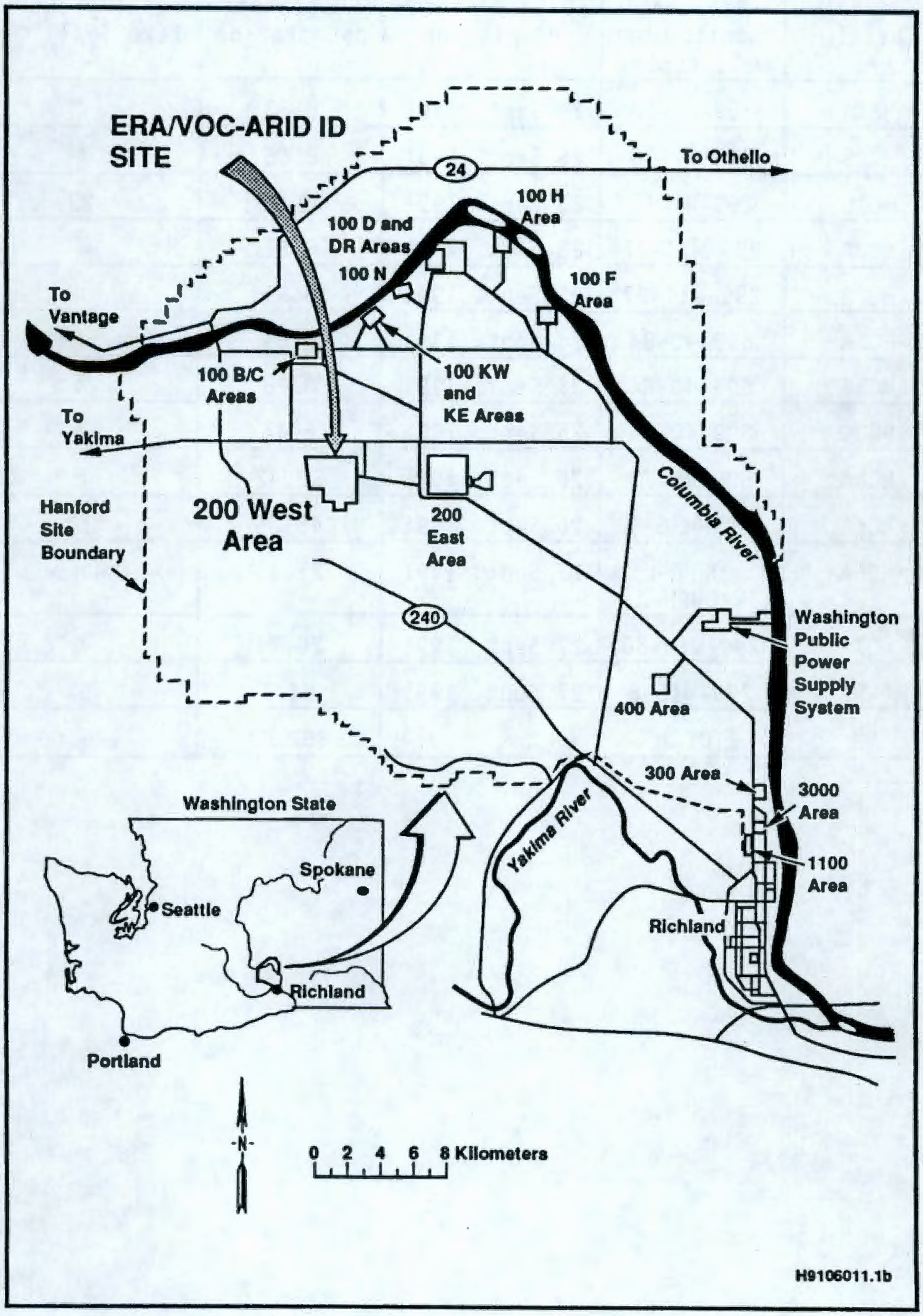


Table 1-1. Summary of Penetration Tests at the 200 West Area.

Test ID	Adjacent monitoring well number	Date of test completion	Depth of penetration	Total grout take (gal)
HC1A	299-W7-10	24 Sept. 1991	8.33	4
HC1B	299-W7-10	25 Sept. 1991	8.06	4
HC1C	299-W7-10	25 Sept. 1991	32.08	23
HC2A	299-W11-27	25 Sept. 1991	6.67	4
HC2B	299-W11-27	25 Sept. 1991	8.91	4
HC3A	699-40-84	26 Sept. 1991	7.61	4
HC3B	699-40-84	26 Sept. 1991	6.26	4
HC3C	699-40-84	26 Sept. 1991	6.44	4
HC4A	699-39-79	26 Sept. 1991	30.42	8
HC5A	299-W26-9	26 Sept. 1991	45.35	10
HC6A	DWPH-V/DWPH-A	27 Sept. 1991	21.13	Unknown
HC7A	299-W19-30	27 Sept. 1991	20.11	8
CPT Well	299-W15-6	27 Sept. 1991	64.7	52
TOTAL			267.07	129.00

Figure 1-2. 200 West Area Site Map Showing Locations of ECPT (Rohay 1991).

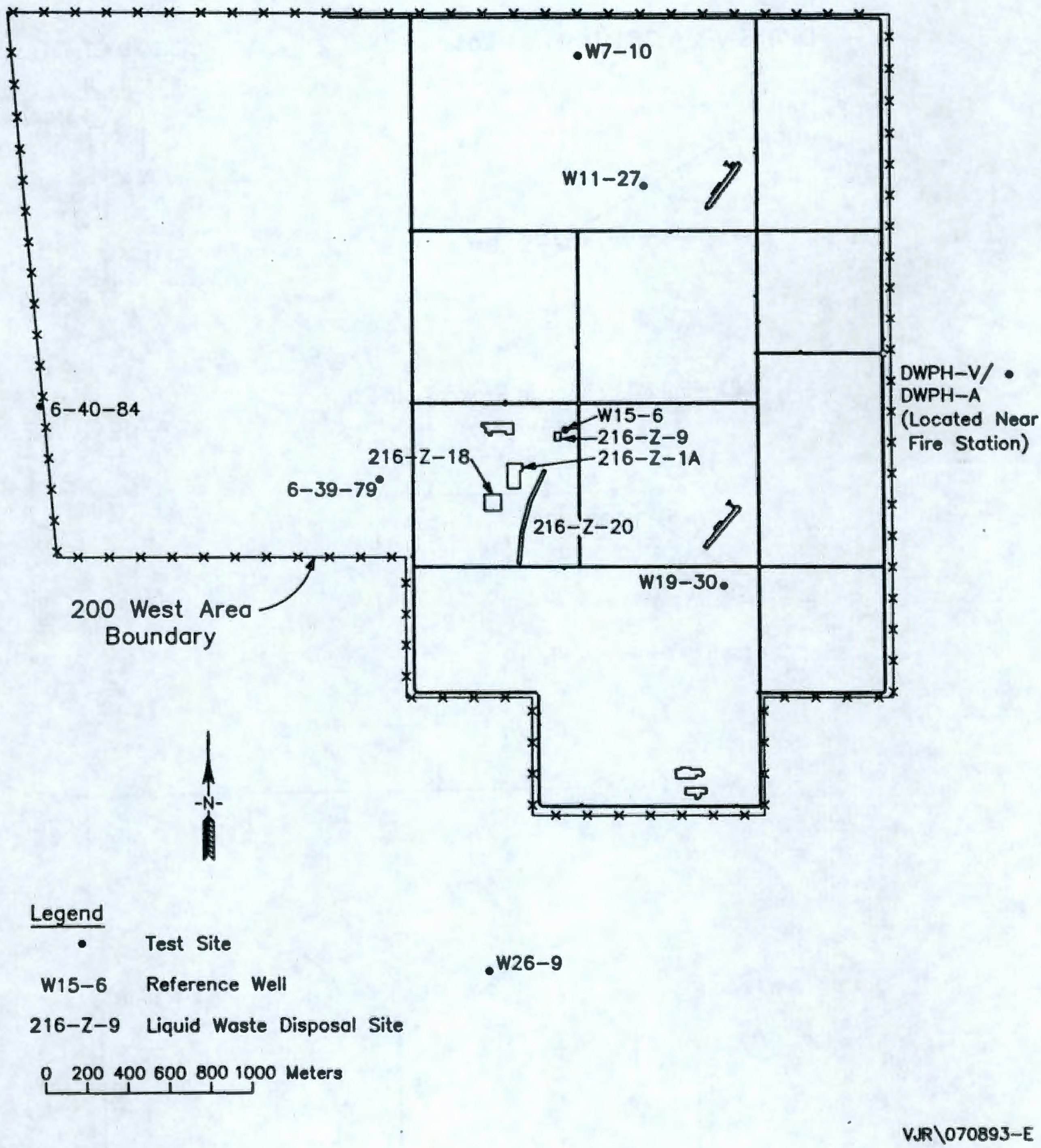
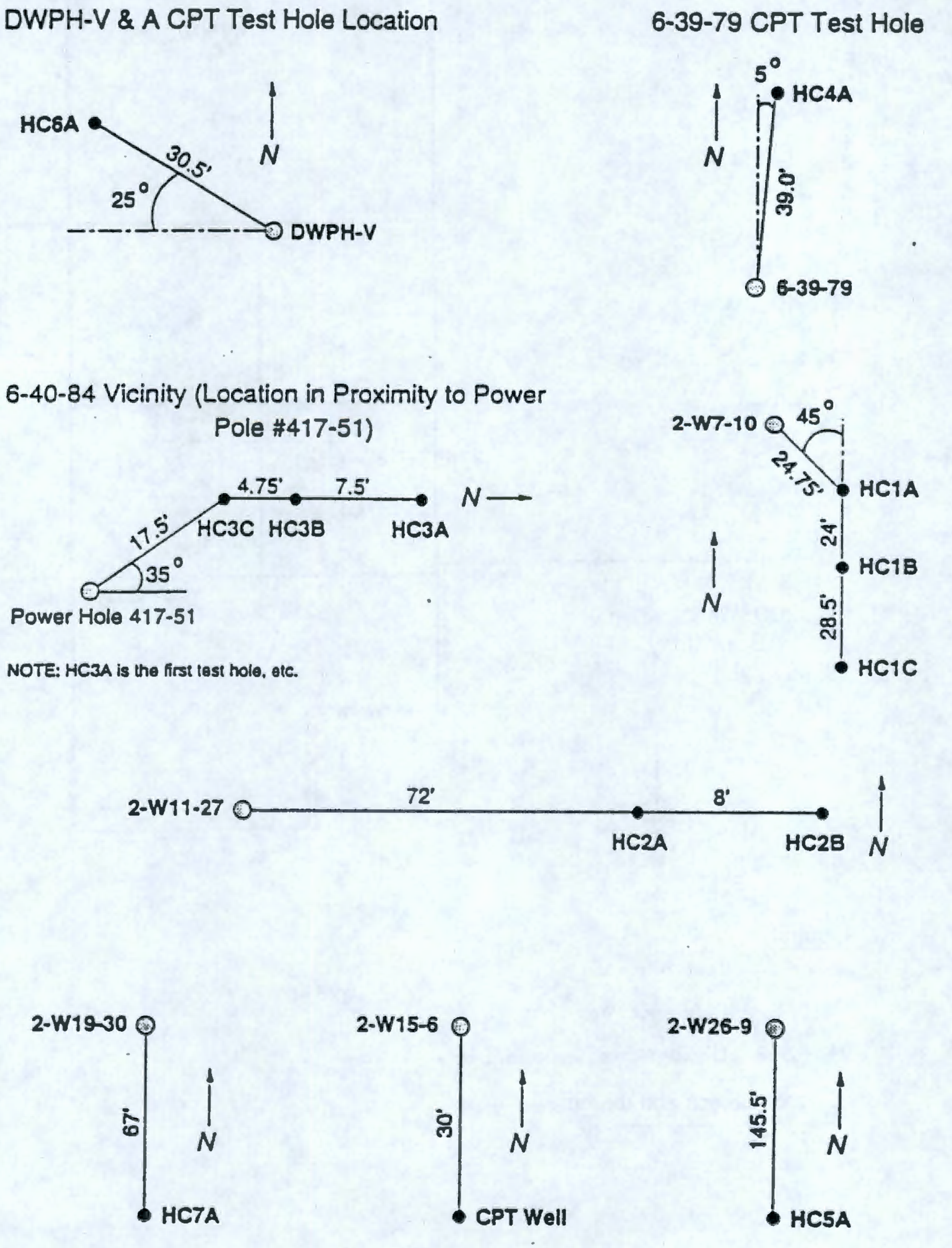


Figure 1-3. Location of CPT Tests Relative to Monitoring Well Locations.



2.0 TESTING EQUIPMENT AND PROCEDURES

The ECPT was originally developed for use in consolidated clay soils. Over the years, cone and push system designs have evolved to the point where they can now be used in strong cemented soils and even soft rock. The most problematic soils for the ECPT to date are soils that contain thick cobble and boulder layers. Because the friction on the push rods is minimal, the ECPT has been successfully used in soils containing thin cobble layers. Boulder layers present problems for current ECPT because of the high probability that the tip will bear directly on a boulder.

The penetrometer developed by ARA consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck. The weight of the truck provides the necessary reaction mass. The probe has a conical tip and a friction sleeve that independently measures vertical resistance beneath the tip as well as frictional resistance on the side of the probe as functions of depth. A schematic view of ARA's penetrometer probe is shown in Figure 2-1. A pressure transducer in the cone is used to measure the pore water pressure as the probe is pushed into the ground (Piezo-ECPT). The probe also includes three seismic transducers that are used to perform downhole seismic surveys. In addition, a resistivity module can be attached to the cone assembly to measure variances in soil conductance, which assists in locating contamination plumes.

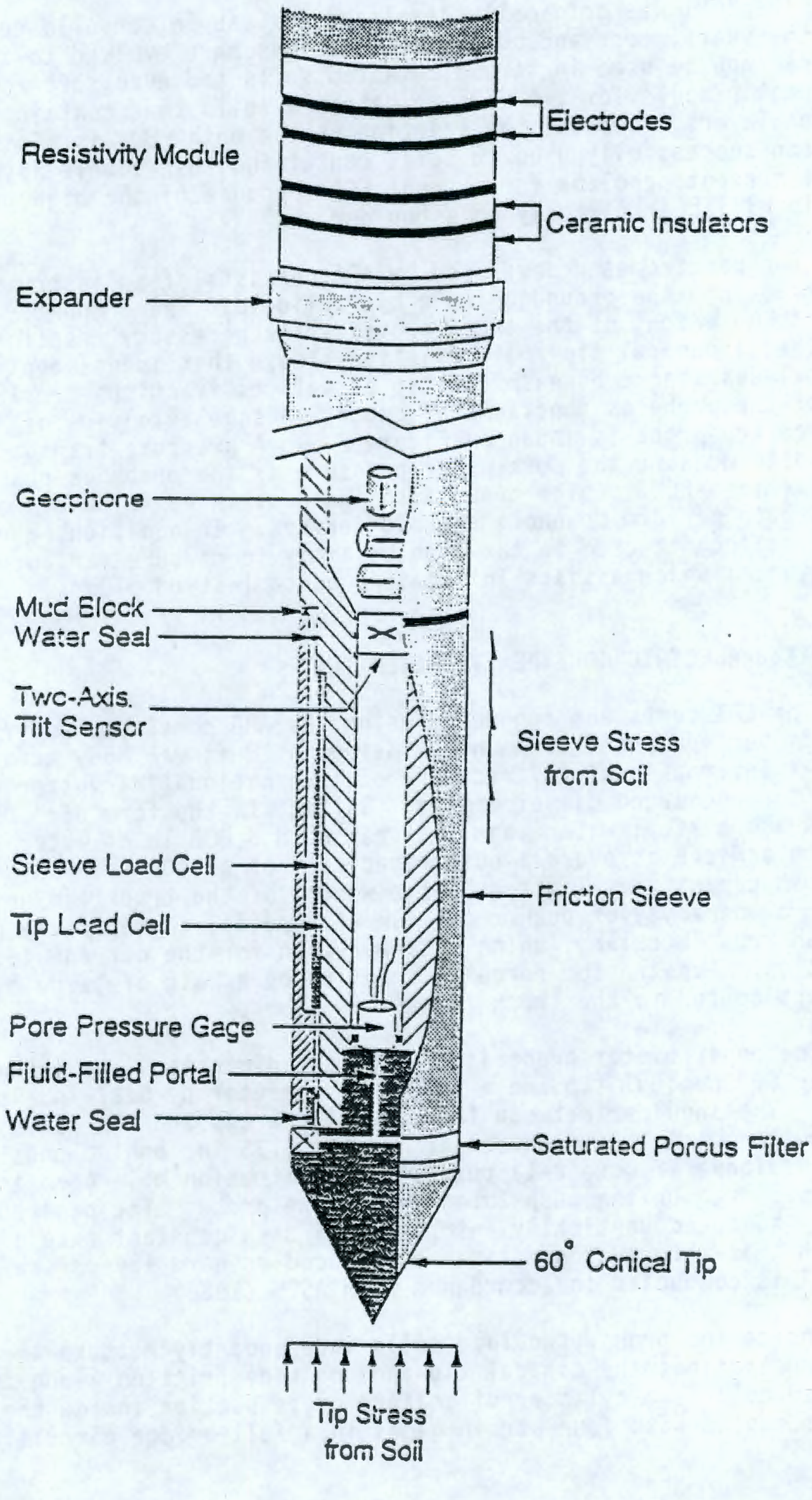
2.1 PIEZO-ELECTRIC CONE PENETROMETER TEST

The CPT tests are conducted using the ARA penetrometer truck. The penetrometer equipment is mounted inside an 18-ft van body attached to a 10-wheel International (a trademark of International Harvester Co.) chassis with a turbo-charged diesel engine. Ballast in the form of 4,000 lb of lead weights and a steel water tank that can hold 5,000 lb of water is added to the truck to achieve an overall push capability of 45,000 lb. In strong soils, this push capacity is limited by the weight of the truck and not by the structural capacity of push rods. In weak soils, there is the possibility of the push rods' buckling, which is the reason for the current 45,000-lb limitation. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

The penetrometer probe is of standard dimensions, having a 1.405-in.-diameter 60° conical tip and a 1.405-in.-diameter by 5.27-in.-long friction sleeve. The shoulder between the base of the tip and the porous filter is 0.08 in. long. A 1.5-in. expander located 5.25 in. behind the top of the friction sleeve (Figure 2-1) pushes the penetration hole open and reduces the frictional drag on the push tubes behind the probe. The penetrometer is normally advanced vertically into the soil at a constant rate of 48 in./min, although this rate must sometimes be reduced as hard layers are encountered. The ECPT is conducted in accordance with ASTM (1986).

Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross section inside the probe, which is instrumented with four strain gages in a full-bridge circuit. Forces are

Figure 2-1. Schematic of ARA's Cone Penetrometer Probe.



sensed by the load cells, and the data are transmitted from the probe assembly through a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometer truck. A set of data is normally recorded each second for a minimum resolution of about one data point every 0.8 in. of cone advance. The depth of penetration is measured using a string potentiometer mounted on the push frame.

As shown in Figure 2-1, the piezo-cone probe senses the pore pressure immediately behind the tip. Currently, there is no accepted standard for the location of the sensing element. Applied Research Associates, Inc. chose to locate the sensing element behind the tip because the filter is protected from the direct thrust of the penetrometer and the measured pore pressure can be used to correct the tip resistance data (discussed in Chapter 3.0) as recommended by Robertson and Campanella (1988). The magnitude of the penetration pore pressure is a function of the soil compressibility and, most important, permeability. In freely draining soil layers, the measured pore pressures will be very close to the hydrostatic pressure computed from the elevation of the water table. When low-permeability solid layers are encountered, excess pore pressures generated by the penetration process cannot dissipate rapidly, resulting in measured pore pressures that are significantly higher than the hydrostatic pressures. Whenever the penetrometer is stopped to add another section of push tube, or when a pore pressure dissipation test is run, the excess pore pressure may begin to dissipate. When the penetration is resumed, the pore pressure quickly rises to the level measured before the penetrometer was stopped. This process causes some of the spikes that may appear in the penetration pore pressure data.

Electronic data acquisition equipment for the CPT consists of an IBM compatible (a trademark of International Business Machines, Inc.) 486 computer (a trademark of NEC Technologies, Inc.) with a graphics monitor and a rack of eight customized signal conditioners. Analog signals are transmitted from the probe to the signal conditioners where the ECPT data are amplified and filtered at 1 Hz. Seismic signals are amplified as required and filtered at 1,000 Hz. Once amplified, the analog signals are transmitted to a high-resonance 16 bit high-speed analog-to-digital converter board, where the signals are digitized, usually at the rate of one sample per second for the penetration data and 5,000 samples per second for the seismic data. The digital data are then read into memory, plotted on a graphics monitor, and written to the internal hard disk for future processing. Data displayed on screen can be used to determine site layering as it is encountered, allowing important decisions to be made in real-time directly in the field. Upon completion of the test, the penetration, dissipation, and seismic data are plotted. Plots can typically be available within 30 minutes of completing the test. Floppy disks containing the data are sent to ARA's New England Division in South Royalton, Vermont, for preparation of final report plots and analysis.

2.1.1 Saturation of the Piezo-Cone

As shown in Figure 2-1, penetration pore pressures are measured with a pressure transducer located behind the tip in the lower end of the probe. Water pressures in the soil are sensed through a 250 μin. porous polyethylene filter that is 0.25 in. high and 0.202 in. thick. The pressure transducer is connected to the porous filter through a pressure port (see Figure 2-1). The pressure port and filter are filled with a high-viscosity silicone oil.

In order for the pressure transducer to respond rapidly and correctly to changing pore pressures upon penetration, the filter and pressure port must be saturated with oil upon assembly of the probe. A vacuum pump is used to de-air the silicone oil before use and also to saturate the porous filters with oil. The probe is assembled with the pressure transducer up and the cavity above the pressure transducer filled with de-aired oil. A previously saturated filter is then placed on a tip and oil is poured over the threads. When the cone tip is screwed into place, excess oil is ejected through the pressure port and filter, thereby forcing out any trapped air.

Saturation of the piezo-cone is verified with field calibrations performed before the probe is inserted into the ground. The high viscosity of the silicone oil, coupled with the small pore space in the filter, prevents the loss of saturation as the cone is punched through dry soils. Saturation of the cone can be verified with a calibration check at the completion of the penetration. Extensive field experience has proven the reliability of this technique with no known case where saturation of the piezo-cone was lost.

2.1.2 Field Calibrations

Many elements can effectively change the calibration factors used to convert the raw instrument readouts, measured in volts, to units of force or pressure. As a quality control measure as well as a check for instrument damage, the load cells and the pressure transducer are routinely calibrated in the field. Calibrations are completed with the probe ready to insert into the ground so that any factor affecting any component of the instrumentation system will be included and detected during the calibration.

The tip and sleeve load cells are calibrated with the conical tip and friction sleeve in place on the probe. For each calibration, the probe is placed in the push frame and loaded onto a precision reference load cell. The reference load cell is periodically calibrated against National Institute of Standards and Technology (NIST) traceable instrument in ARA's laboratory. Additionally, the string potentiometer, used to measure the depth of penetration, is periodically checked against a tape measure.

Each instrument is calibrated using a specially written computer code that displays the output from the reference device and the probe instrument in graphical form. During the calibration procedure, the operator checks for linearity and repeatability in the instrument output. At the completion of each calibration, this code computes the needed calibration factors using a linear regression algorithm. At a minimum, each probe instrument is calibrated at the beginning of each day of field testing. Furthermore, the pressure transducer is recalibrated each time the porous filter is changed and the cone is resaturated. Calibrations are also performed to verify the operation of any instrument if damage is suspected.

2.1.3 Penetration Data Format

A penetration profile from the 200 West Area site is shown in Figure 2-2. Plotted as a function of elevation are the measured tip resistance, sleeve friction, and friction ratio. When the surface elevation of the test location is unknown, the penetration data are plotted against depth.

Tip resistance, q_c (lb/in^2), is obtained by dividing the vertical force on the conical tip by the effective tip area (1.550 in^2). The tip resistance is then corrected for pore pressures acting behind the conical tip as discussed in Chapter 3.0. The corrected tip resistance, q_t (lb/in^2), is plotted in the penetration profile. Sleeve friction, f_s (lb/in^2), is obtained by dividing the total frictional force on the sleeve by the sleeve's surface area (23.26 in^2). The offset between the depth at the tip and the depth at the friction sleeve is corrected by shifting the sleeve friction profile downward so that it corresponds to the depth at the centroid of the tip. In addition to the tip resistance and sleeve friction, a friction ratio profile is plotted for each location. This ratio is simply the sleeve friction expressed as a percentage of the tip resistance at a given depth. In uncemented soils, the friction ratio can be correlated to soil type.

2.2 DATA EDITING

2.2.1 Pore Pressure Correction of Tip Stress

Cone penetrometers, by necessity, must have a joint between the tip and sleeve. Pore pressure acting behind the tip decreases the total tip resistance that would be measured if the penetrometer were without joints. The influence of pore pressure in these joints is compensated for by using the net area concept (Robertson and Campanella 1988). The corrected tip resistance is given by:

$$q_T = q_c + u\left[1 - \frac{A_n}{A_T}\right] \qquad (1)$$

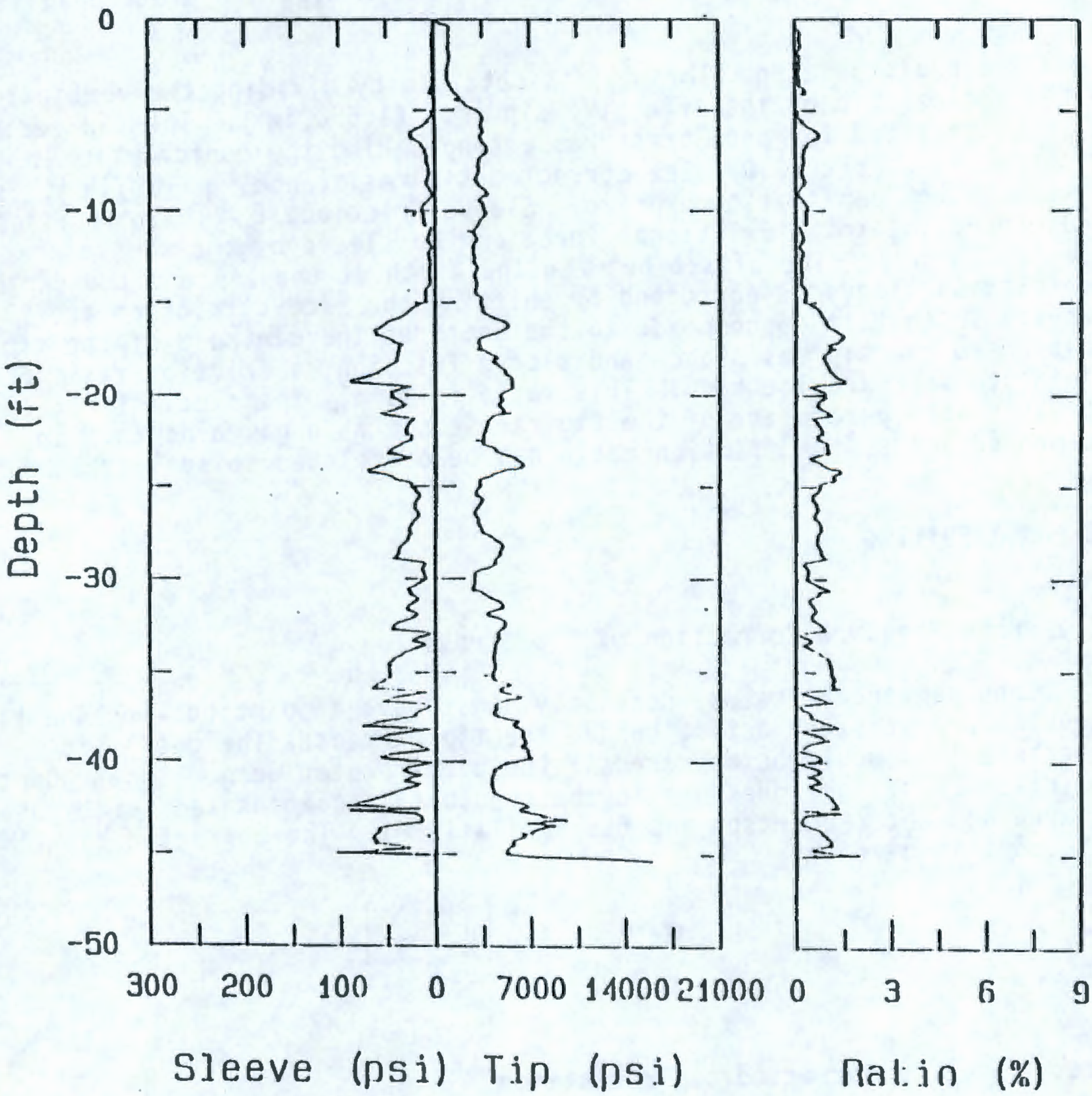
where:
- q_T = corrected tip resistance
- q_c = measured tip resistance
- u = penetration pore pressure measured behind the tip
- A_n = net area behind the tip not subjected to the pore pressure (1.257 in^2)
- A_T = projected area of the tip (1.550 in^2).

Hence, for the ARA cone design, the tip resistance is corrected as:

$$q_T = q_c + u(.1890) \qquad (2)$$

Laboratory calibrations have verified Equation 2 for ARA's piezo-cone design.

Figure 2-2. Cone Penetration Test Results from the 200 West Area.



A joint also exists behind the top of the sleeve (see Figure 2-1). However, because the sleeve is designed to have the same cross-sectional area on both ends, the pore pressures acting on the sleeve cancel out. Laboratory tests have verified that the sleeve is not subjected to unequal end area effects. Thus no correction for pore pressure is needed for the sleeve friction data.

The net effect of applying the pore pressure correction is to increase the tip resistance and to decrease the friction ratio. Generally, this correction is only significant when the pore pressures are high while measured tip resistance is very low.

2.2.2 Numerical Editing of the Penetration Data

Any time that the CPT is stopped or pulled back during a test, misleading data can result. For instance, when the probe is stopped to add the next push tube section or when a pore pressure dissipation test is run, the excess pore pressures will dissipate toward the hydrostatic pore pressure. When the penetration is resumed, the pore pressure generally rises very quickly to the pressures experienced prior to the pause in the test. In addition, the probe is sometimes pulled back and cycled up and down at intervals in deep holes to reduce soil friction on the push tubes. This results in erroneous tip stress data when the cone is advanced in the previously penetrated hole.

To eliminate this misleading data from the penetration profile, the data are numerically edited before being plotted or used in further analysis. Each time the penetrometer stops or backs up, as apparent from the depth data, the penetration data are not plotted. Plotting of successive data is resumed only after the tip is fully re-engaged in the soil by one tip length (1.22 in.) of new penetration. This algorithm also eliminates any data acquired at the ground surface before the tip has been completely inserted into the ground. The sleeve data are similarly treated. The result is that the first data point does not occur at the ground surface, as can be seen in some tip and sleeve profiles. These procedures ensure that all of the penetration data that are plotted and used for analysis were acquired with the probe advancing fully into undisturbed soil.

2.3 RESISTIVITY CONE PENETROMETER TEST

Resistivity, one of the oldest geophysical exploration techniques, was originally developed to locate mineral and oil deposits and groundwater supplies. The measurement principle exploited by resistivity surveying is that an electrical contrast exists between different geological materials and that this electrical contrast can be used to identify and locate geologic materials. Resistivity surveys are being increasingly used in contaminated site investigation programs to delineate the extent and degree of contamination at a site. These surveys rely on the electric contrasts that typically exist between contaminated soils and uncontaminated soils. For example, leachate from a landfill will contain a higher concentration of dissolved solid, which will decrease the resistivity of the groundwater (Shinn 1990). Soils contaminated with hydrocarbons (fuel oils or cleaning solvents) will typically have a higher resistivity than uncontaminated soils because the hydrocarbon can act as an insulator.

The resistivity-ECPT (R-ECPT) is an adaptation of conventional borehole tools. The R-ECPT probe is in intimate contact with the soil and pore fluid, which eliminates two problems associated with borehole resistivity surveys: (1) intrusion of drilling fluids into borehole walls, which changes the resistivity of the media, and (2) the requirement that any casing material be nonconducting.

Figure 2-1 is a schematic of ARA's R-CPT probe. The probe consists of four electrodes separated by ceramic insulators. The outer two electrodes induce an electric current into the soil and the inner two electrodes measure the potential drop, which is proportional to the resistivity of the soil. To avoid polarization effects, the four-electrode array is operated at a frequency of 15 HZ. Electronics in the CPT vehicle are used to modulate and demodulate the current and potential measurement signals to and from the probe. The probe is calibrated in a large water solution in which the conductivity is varied. The data from the calibration tests are used to determine the probe calibration factor, which is dependent on the probe geometry.

2.4 SEISMIC CONE PENETROMETER TEST

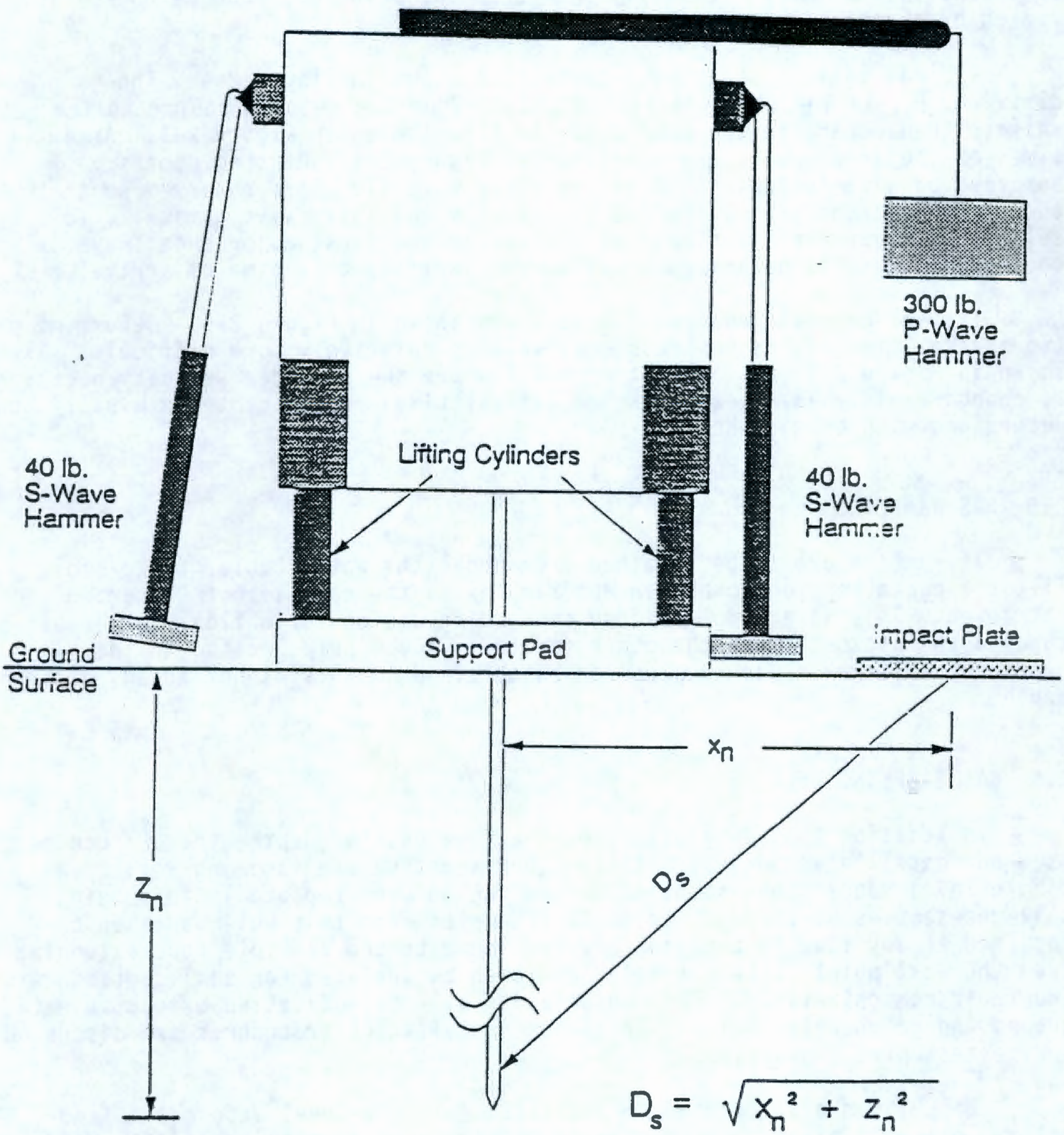
The seismic CPT test was developed in the early 1980's and is gaining rapid acceptance in the geotechnical community (Rice 1984). As with the conventional ECPT, initial development work has concentrated in weak materials. ARA's seismic cone equipment and field procedures were developed specifically for both weak soils and strong, dry, cemented soils. The seismic CPT test utilizes three geophones mounted inside the penetrometer probe to detect the arrival at depth of seismic waves generated on the surface. Two horizontal transducers monitor shear wave (S-wave) traces from which the shear wave velocity can be determined. A third geophone, mounted vertically, is used to measure the compression wave (P-wave) traces and to subsequently derive the compressional velocity.

In the Seismic-Electric Cone Penetrometer Test (S-ECPT), the cone is stopped at prescribed depth intervals, and S- and P-waves are generated on the ground surface near the push tubes. Both average downhole velocities and velocities between the depth intervals can be computed from the arrival time data. The 1.5-in.-diameter expander behind the sleeve (see Figure 2-1) minimizes coupling between the ground and the push tubes, mitigating problems with wave propagation down the push tubes.

High-energy shear waves are generated by lifting 40-lb hammers to a height of between 4 to 8 ft and releasing the hammer as depicted in Figure 2-3. The hammer impacts the front lifting pad of the penetrometer truck and induces a horizontal shear wave. By striking the pad on either end, polarized shear waves can be generated. This pad is 1 ft wide and about 8 ft long and oriented parallel to the axles of the truck. The point of impact of the shear hammers is 44 in. horizontally from the penetrometer push rod.

Compressive waves are generated by dropping a 300-lb weight onto a thick steel plate as shown in Figure 2-3. The 300-lb weight is lifted using a

Figure 2-3. Schematic of ARA's Seismic Wave Generation System.



$$D_s = \sqrt{x_n^2 + z_n^2}$$

$D_s =$ Slant Distance

$$t_{vert} = t_{meas}\left(\frac{z_n}{D_s}\right)$$

hydraulic winch and boom attached to the truck. The weight is dropped freely by the use of a quick-release hook on the end of the lifting cable. The point of impact is 115 in. horizontally away from the push rod. Source energy is varied by changing the drop height of the weight.

Typical seismic shear wave traces are shown in Figure 2-4. The distance, D_s, is the straight-line distance from the seismic source to the seismic transducers in the cone probe as illustrated in Figure 2-3. Arrival times of the shear waves are indicated in Figure 2-4. At some depths, compression wave contamination of the shear wave signal is observed so that the first apparent arrival is not necessarily the shear wave arrival. To select the shear arrival time, the arrival of the first major shear wave is chosen. The use of polarized shear waves clarifies this time of arrival.

Typical compressional wave traces are shown in Figure 2-5. Determining the arrival time of the compressional wave is relatively more difficult. As shown in Figure 2-5, the inflection point where the particle velocity begins to change rapidly is selected as the arrival time. This point can usually be determined with consistency.

2.5 GAS SAMPLING

If samples are to be obtained from above the water table, the piezo filter tip can be used to obtain gas samples as the cone is both inserted and retrieved. This is accomplished by connecting one end of a flexible teflon tube to the piezo tip and the other end to a vacuum pump located in the penetrometer truck. Gas samples can be obtained in this manner at any desired depth.

2.6 GAS SAMPLING WELL

In addition to taking gas samples at any desired depth, the CPT can be used to install a variety of different permanent vadose sampling wells. A single-level vadose zone sampling device can be used repeatedly to obtain soil-gas samples at a specified depth. Samples from this well can then be obtained at any time by applying a vacuum pump to the flexible tube extending from the well point. These samples can then be analyzed for soil contaminants and their concentrations. The contaminants will be indicative of contaminated ground and groundwater below. The probe installation procedures are discussed in the test plan (Rohay 1991).

The CPT can also be used to install a multiple-level vadose sampling well. This well allows gas samples to be retrieved from several different levels in the same well. The push rods are left in the ground until the monitoring process is completed. This well, like the single-point well, can be sampled at any time using a vacuum pump to obtain samples for analysis of soil contamination. By using samples from several depths from several vadose sampling wells, a three-dimensional model of the soil contamination can be developed. Extending this model by taking samples over time, a complete history of the dynamic nature of the soil contamination can be developed. The probe installation procedures are discussed in the test plan (Rohay 1991).

Figure 2-4. Typical Shear Wave Traces from Seismic Cone Penetrometer Tests.

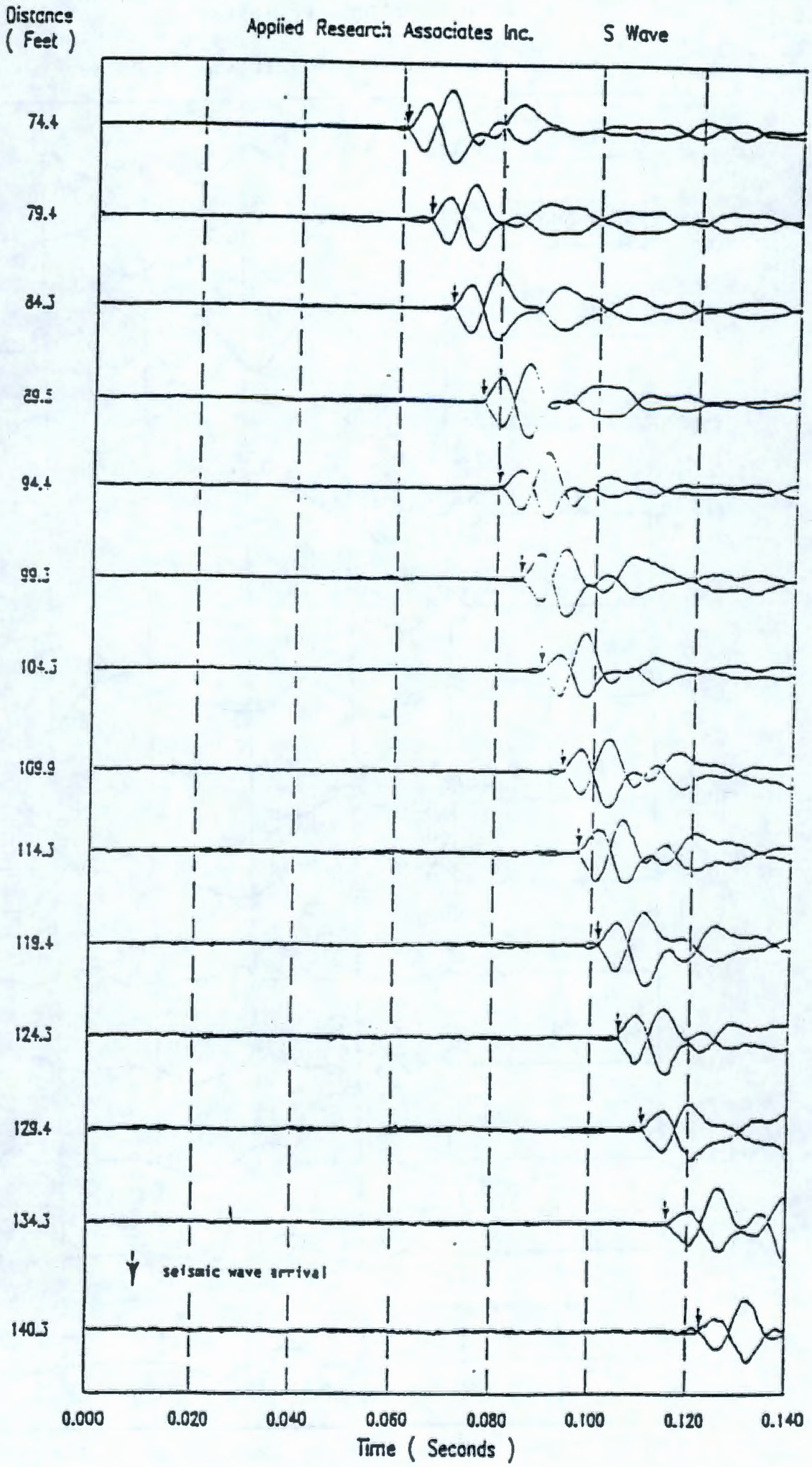
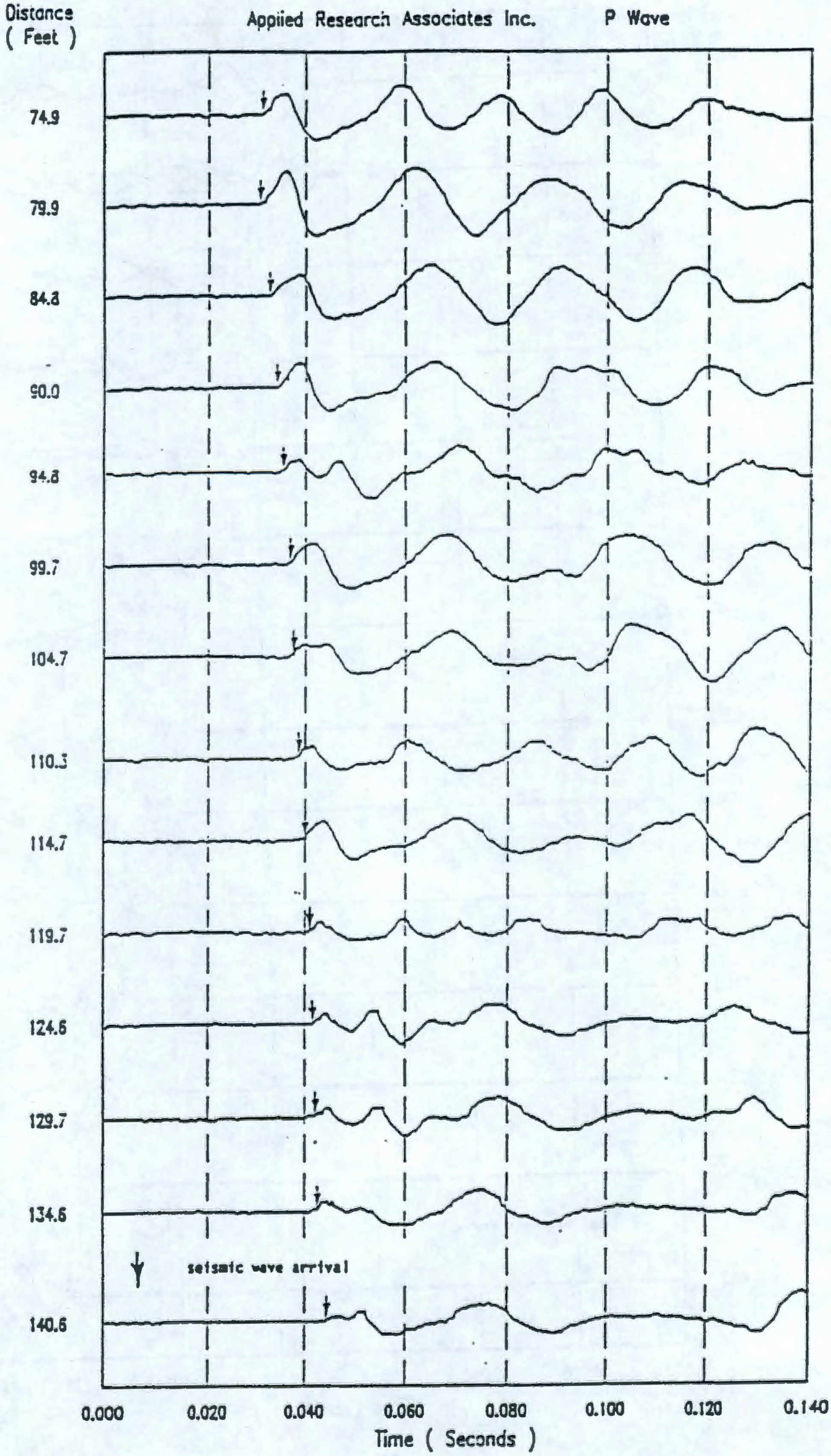


Figure 2-5. Typical Compression Wave Traces from Seismic Cone Penetrometer Tests.



2.7 GROUTING UPON RETRIEVAL

Cone penetration testing leaves holes that represent potential contamination pathways for surface and subsurface contaminants to enter the groundwater and also for contaminated soil vapors to enter the atmosphere. To prevent these types of contamination, the test holes must be grouted to seal the hole and eliminate the contaminant pathway. Grouting of the CPT hole upon retraction increases worker safety and reduces risks to the environment. Because of the importance of retraction grouting, two different self-grouting modules are to be evaluated at the 200 West Area. A third method, called the tremmie grouting method, is also to be evaluated.

2.7.1 Self-Grouting Methods

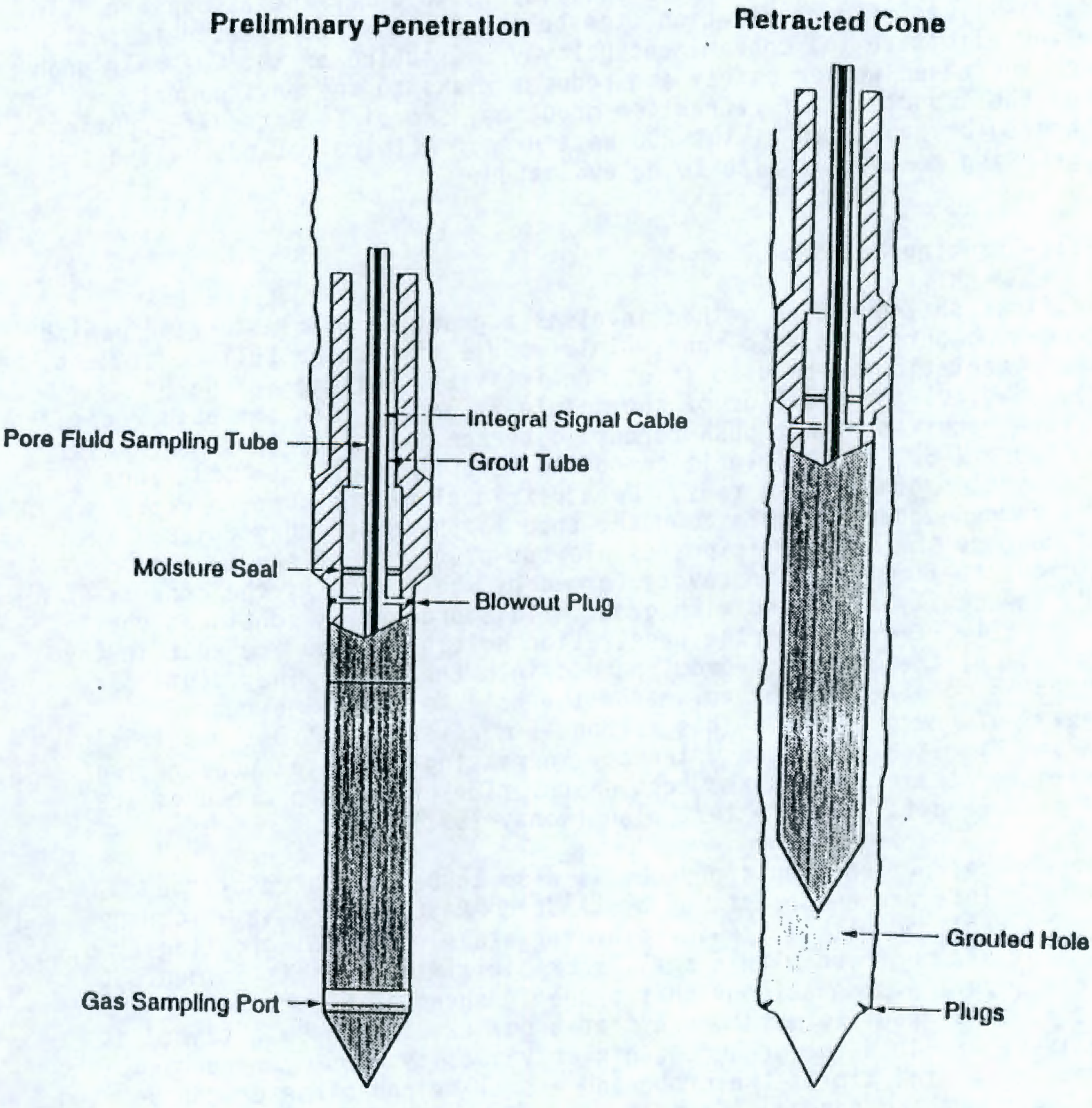
The first self-grouting method involves a grouting module located behind the instrumented portion of the cone. This module allows the full complement of CPT instrumentation to be used (i.e., resistivity, seismic and pore pressure); however, the diameter of the module is larger than the push rod's and therefore requires higher push forces. The schematic for this module is shown in Figure 2-6. The module is connected to a flexible tube that runs through the center of the push rods. Upon retrieval of the cone, a grout mixture is pumped under pressure down the tube to the grouting modules. When the grout reaches the module, it pushes blowout plugs out of the module, allowing grout to flow into the cavity formed by the cone. As the cone is retracted, the cavity is filled with grout. This process is continued until the cone is fully removed from the penetration hole. Records are kept in the field log book of the amount of grout pumped into the hole. The volume of grout pumped is compared to the volume of the hole to determine the effectiveness of the grouting. This method is more efficient but requires the use of larger diameter push tubes, thereby increasing the total penetration force needed to attain the desired test depth. The grouting procedures are discussed in more detail in the test plan (Rohay 1991).

A second retraction grouting probe is also to be evaluated at the Hanford Site. This probe consists of a standard ARA CPT probe in which the piezo gage is replaced with a 1/4-in.-diameter stainless steel grouting tube. The piezo tips are modified with a small sacrificial tip that is pushed out with air pressure. A schematic of this probe is shown in Figure 2-7. Advantages of this grouting method are that a gas sample can be obtained as the probe is pushed into the ground, a higher viscosity grout can be used, and direct grouting at the tip of the probe and a smaller rod diameter can be used requiring lower pushing forces. However, grouting with this probe requires that the seismic and piezo gages be removed to make room for the grouting mechanism. If seismic or piezo measurements are required, the grouting module in Figure 2-6 must be used.

2.7.2 Tremmie Grouting Method

The tremmie grouting method requires that the instrumented cone be fully retracted from the hole and then empty push tubes (not containing a cable or cone tip) be pushed down the same hole. Once the empty push tubes are advanced to the same depth as the ECPT, a flexible tube is inserted into the top of the tubes and grout is pumped down the core. As the grout is pumped,

Figure 2-6. Schematic of ARA's Self-Grouting Cone Penetrometer.



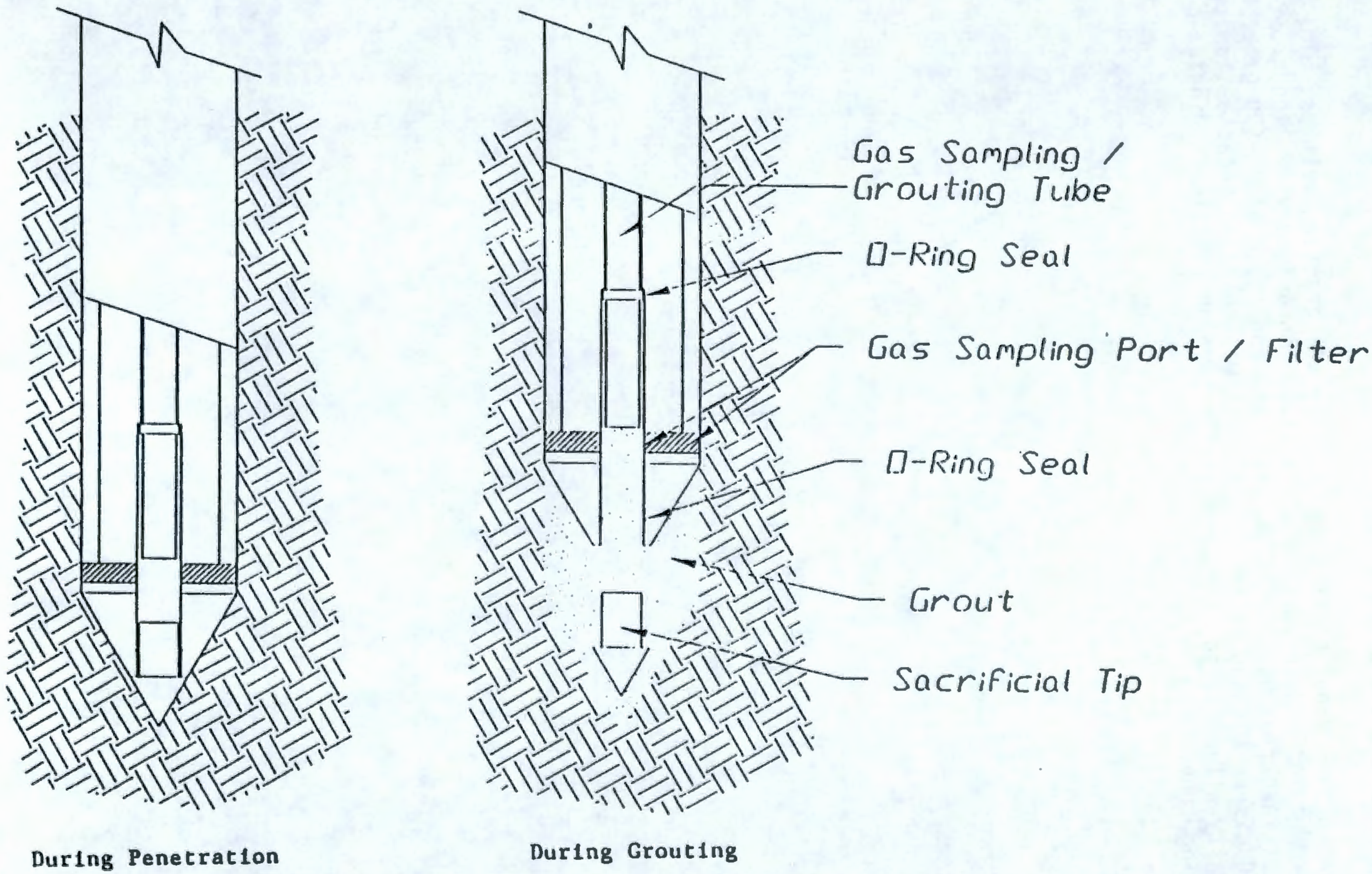


Figure 2-7. Schematic of Self-Grouting Sacrificial Tip Cone.

the rods are retracted and removed from the stack. Grout is continuously pumped into the hole until the hole is full. The volume of grout used is recorded in the field log book.

The same grout mixture is used for all grouting methods. The grout mixture ratios and properties are included in Appendix A. The grout material was obtained from Geochem Corporation and consisted of MC-500 grout mixed with NS-200 dispersant and water. This grout was selected because its low viscosity allows it to be pumped easily through the 1/4-in.-inside-diameter grouting tube.

3.0 TESTING PERFORMED

3.1 TEST SITES

The ARA CPT truck arrived at the Hanford test site on September 23, 1991. The truck was inspected, checked for radiation, and then released by WHC personnel. The truck remained outside the test facility, and demonstrations were performed for interested personnel.

3.1.1 Well 299-W7-10

On September 24, 1991, the CPT truck was moved to the 200 West Area to begin testing. The truck was positioned near Well 299-W7-10, and the crew began preparing for a penetration test with soil-gas sampling. Flexible tubing was strung through the rods, and the free end was connected to a soil-gas monitor operated by WHC personnel. After calibrating the cone system, penetration was started at approximately 4:30 p.m. for test HC1A. The CPT and gas sampling unit were pushed to a depth of 8 ft when the tip encountered a cobble that could not be broken. This caused the tip stresses to reach a level above the truck capabilities, and subsequent penetration was stopped. This condition is referred to as refusal. The recorded data down to a depth of 8 ft are plotted in Figure 3-1. The final tip stress values exceeded 15,000 lb/in^2. The gravelly nature of the soil caused spikes in the sleeve, tip, and calculated friction ratios. These spikes are a result of the cone's breaking gravel particles and pushing the particles aside. The cone was retrieved and the remaining hole was grouted by the tremmie grouting method because the self-grouting sacrificial tip module was plugged.

On the third day, after calibration of the cone instrumentation, testing was continued near Well 299-W7-10 in hole number HC1B. Once again, only the upper 8 ft of soil was successfully penetrated before reaching refusal. The recorded data are presented in Figure 3-2. Once again, the self-grouting sacrificial tip module was tried, but it became plugged and the tremmie grouting method was used to grout the penetration hole. The truck was moved to a new position in the same area and a third attempt was made. In hole HC1C, penetration reached a depth of 32 ft before refusal. Penetration to this depth was difficult, as evidenced by tip stresses above 8,000 lb/in^2 for a majority of the push. The complete penetration profile is presented in Figure 3-3. Upon retrieval, a gas sample was obtained at a depth of 23 ft for gas chromatography (GC) analysis. The sample was obtained by WHC personnel using a Model 5802 OVW sampler (a trademark of Thermo Environmental Instruments). Upon retrieval of the instrumented cone tip, empty cone rods were pushed back down to a depth of 22 ft. This depth was 10 ft less than the depth of the cone push. To ensure that any voids left by the CPT were filled, the grout was pumped under pressure until 10 gal of grout had been pumped. Grouting continued from this depth up to the ground surface. A total of 23 gal of grout was used to grout hole HC1C. The volume of the hole reached by the penetrometer is equal to 2.9 gal. Since 23 gal was pumped, it is assumed that all potential flow paths left open in the range between 22 and 32 ft were filled.

Figure 3-1. First Penetration Test near Well 299-W7-10.

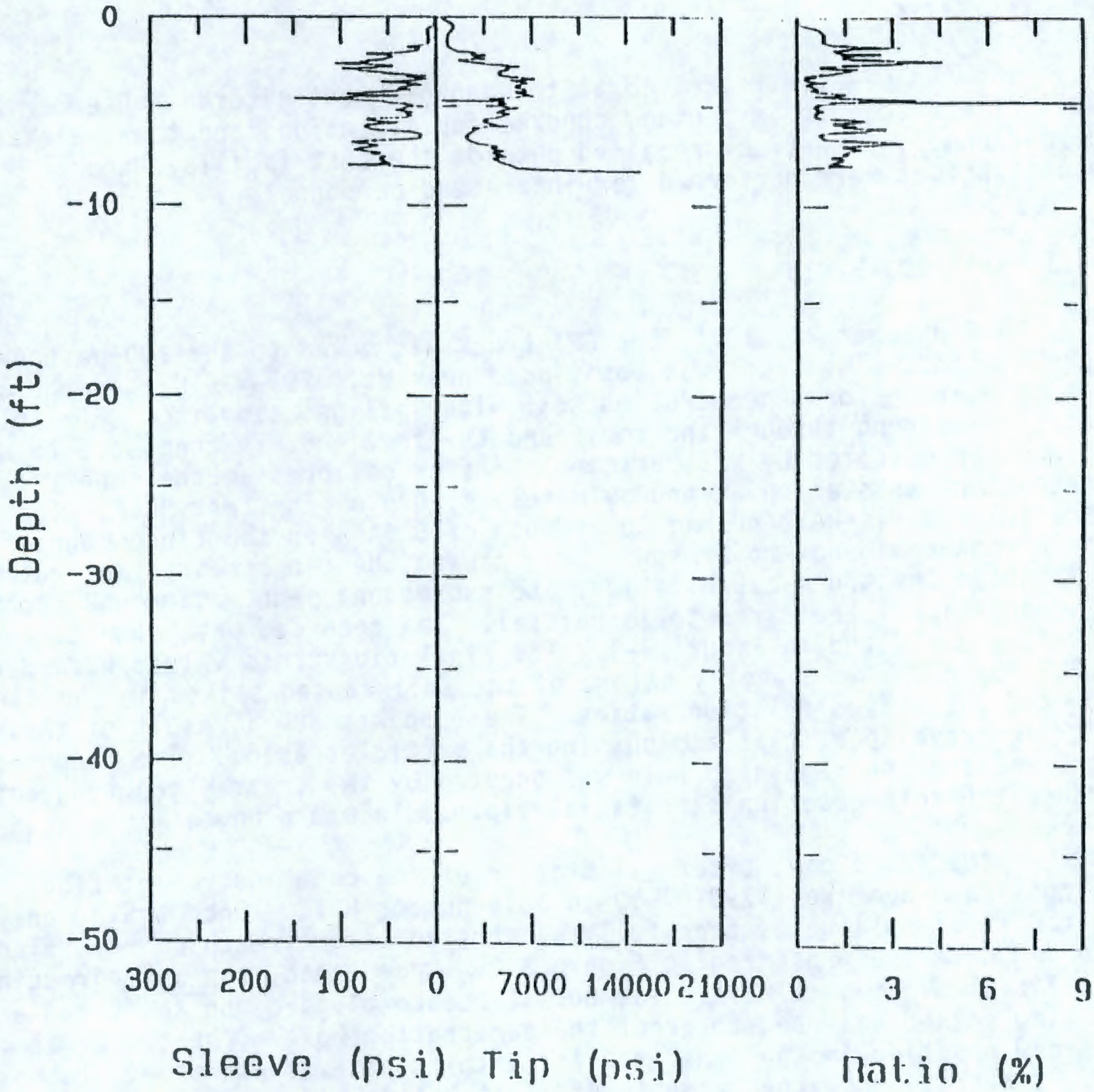


Figure 3-2. Second Penetration Test near Well 299-W7-10.

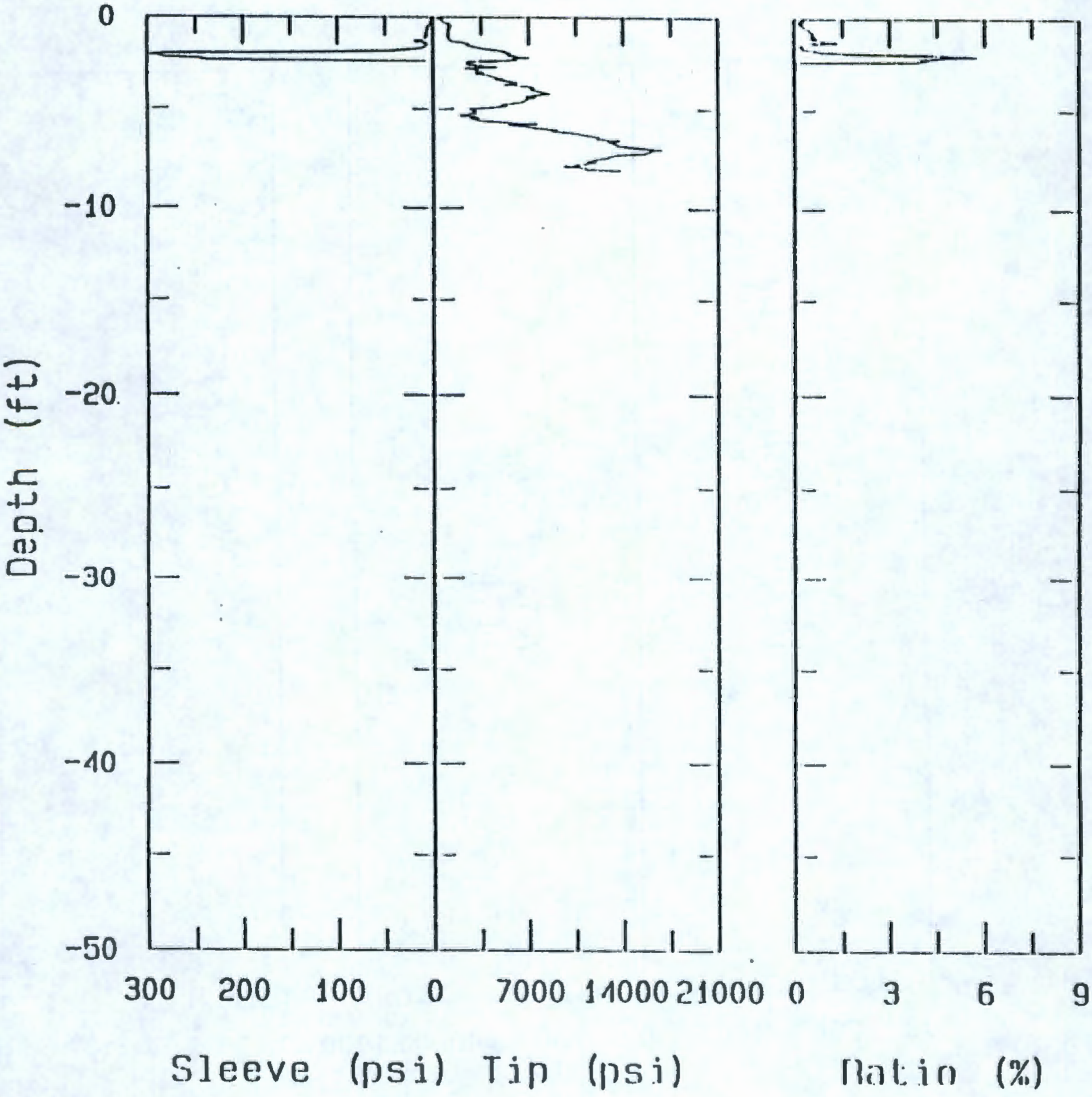
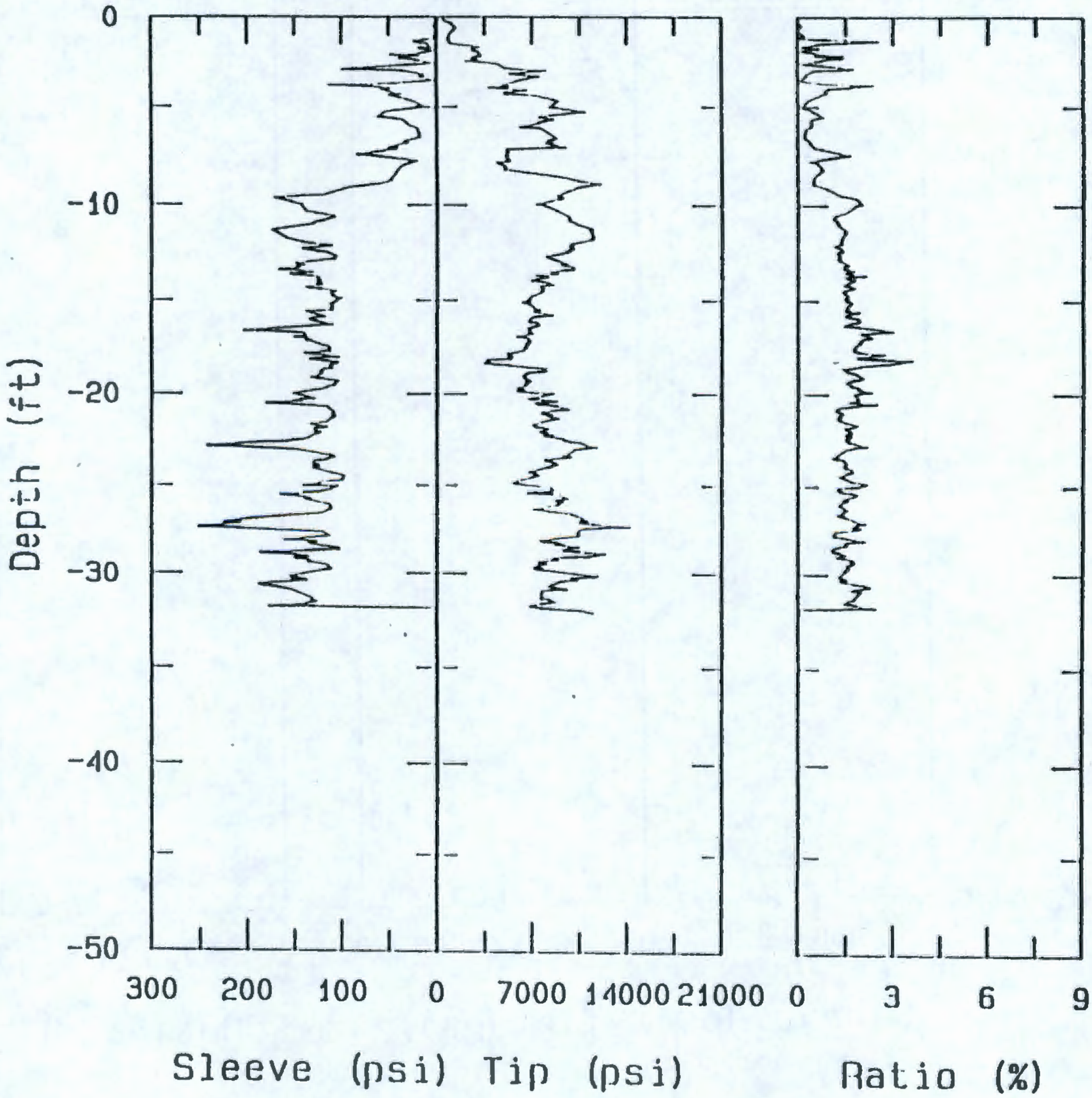


Figure 3-3. Third Penetration Test near Well 299-W7-10.



3.1.2 Well 299-W11-27

The CPT truck was relocated to a position near Well 299-W11-27, and the third test of the day was started. Hole HC2A reached a depth of 6.4 ft before refusal was met. The recorded data are shown in Figure 3-4. The truck was backed up 7 ft and hole HC2B was started. In this hole, penetration reached a depth of 8.8 ft before refusal was met. The results are shown in Figure 3-5. Because of time constraints, a third attempt in this region was not attempted. Because both of the penetration holes were quite shallow and time was limited, the grouting was performed by inserting a funnel and pouring grout into the empty holes. From this point on, this was used on only shallow (less than 10 ft) holes, and is referenced as the funnel method. Both of the CPT holes took a volume of grout significantly larger than the hole volume, indicating that the hole remained open for the entire depth.

3.1.3 Well 699-40-84

On September 26, 1991, the truck was relocated near Well 699-40-84. The cone instrumentation was calibrated and penetration of hole CH3A began. Penetration reached a depth of 7.5 ft before refusal occurred. The penetration profile is shown in Figure 3-6. Two additional attempts were made in this area, and the maximum depths obtained were 5.8 ft and 6.2 ft, respectively, for holes HC3B and HC3C. The penetration profiles are shown in Figures 3-7 and 3-8. All three holes were grouted using the funnel grouting method. Tip stresses over or near 21,000 lb/in^2 were measured at this location in all three penetrations.

3.1.4 Well 699-39-79

After relocating the CPT truck to a location near Well 699-39-79, penetration of hole HC4A was started. Penetration progressed easier than the previous holes because of the different soil conditions. The soil conditions near hole HC4A appear to be sandier with significantly fewer cobbles. This is primarily because of a move from the gravel-dominated facies (HC1-3) of the Hanford formation into the sand-dominated facies. This is especially true in the top 22 ft of the profile shown in Figure 3-9. Below 22 ft, the amount of gravel increases significantly as evidenced by the highly variable tip stresses. Refusal was finally obtained at a depth of 30 ft. At this depth, a gas sample was taken for GC analysis by WHC personnel. The soil gas was monitored by WHC personnel upon retrieval of the cone rods. It was noted that the gas concentration was diminishing, so the probe was returned to a depth of 24 ft and another gas sample was taken for GC analysis. Upon cone retrieval, empty cone rods were installed and pushed to a depth of 26 ft. Grouting began at this depth and continued to the ground surface. The total grout take for this penetration was 8 gal, which is 5.5 gal greater than the hole volume.

3.1.5 Well 299-W26-9

The next test location was near Well 299-W26-9. The penetration was started at 3:30 p.m. Once again the penetration went smoothly, and a final

Figure 3-4. First Penetration Test near Well 299-W11-27.

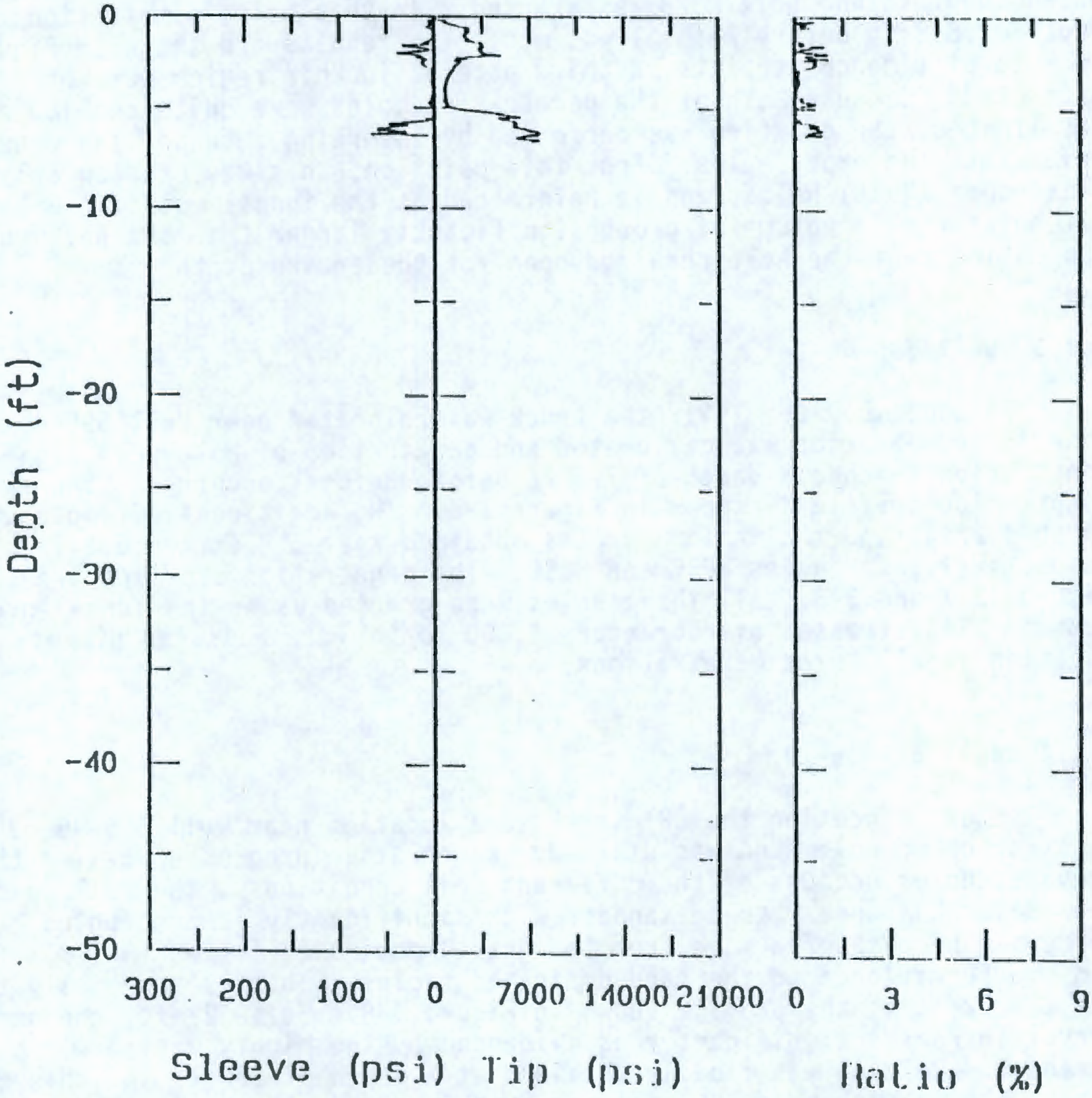


Figure 3-5. Second Penetration Test near Well 299-W11-27.

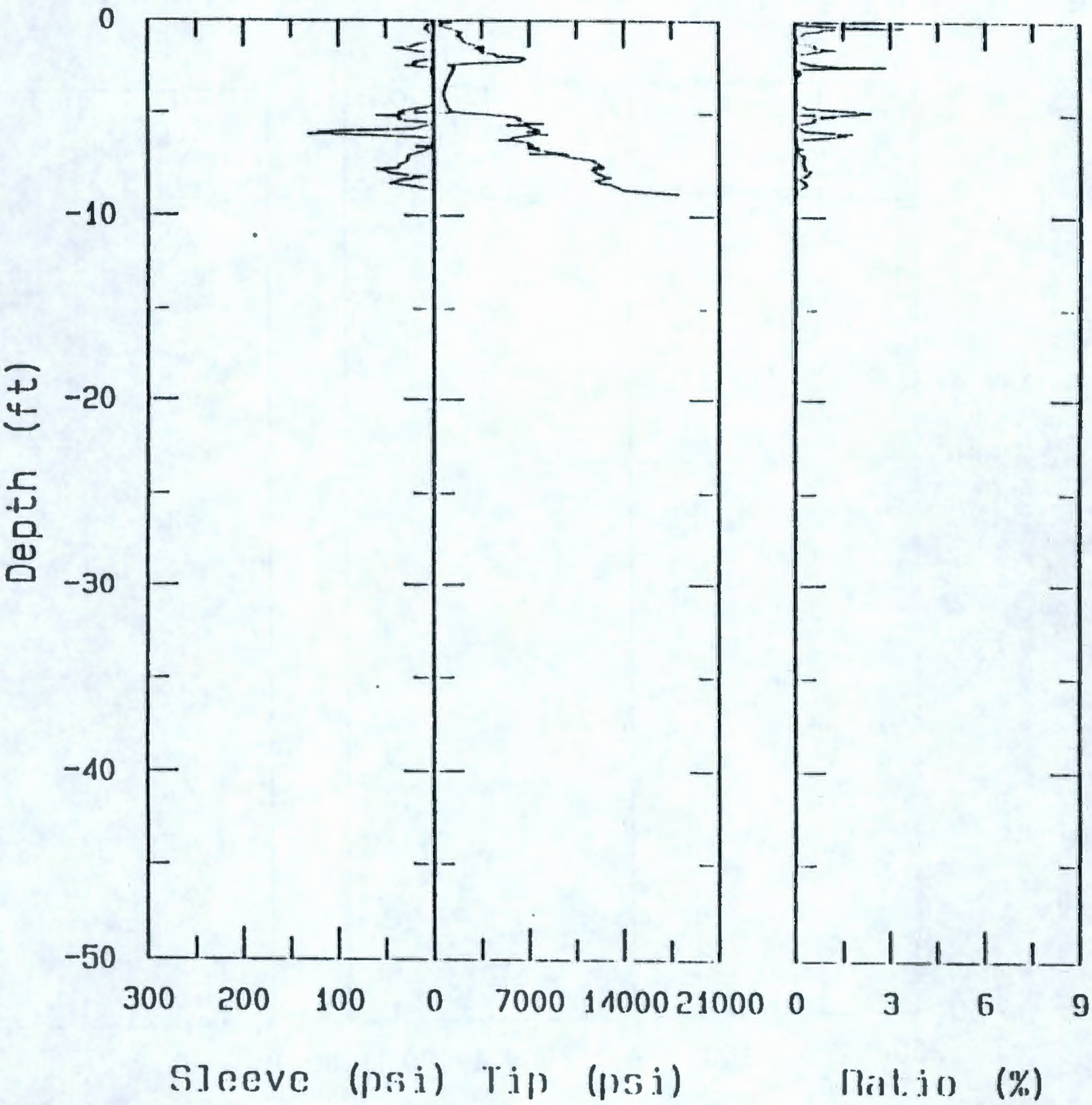


Figure 3-6. First Penetration Test near Well 699-40-84.

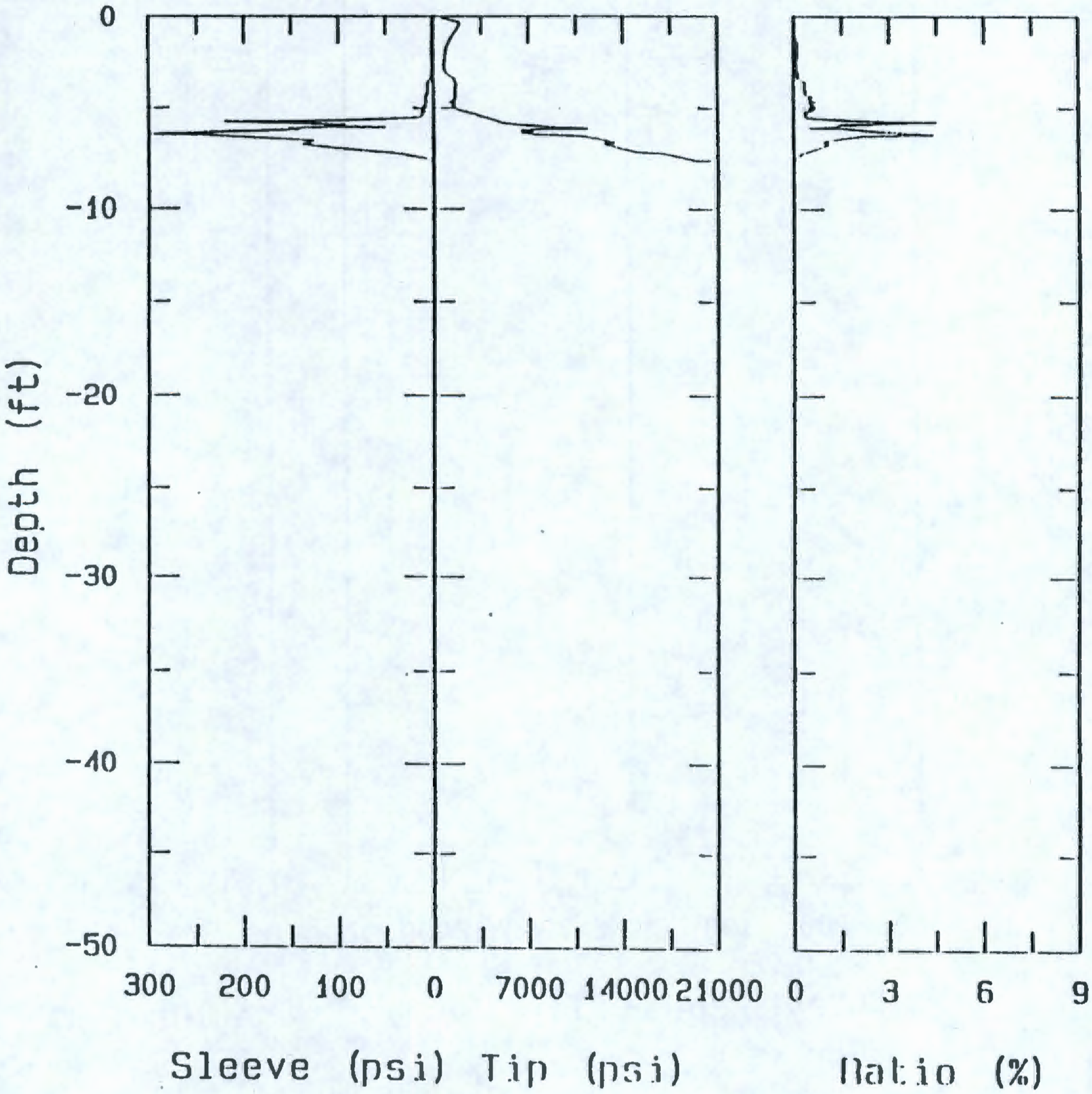


Figure 3-7. Second Penetration Test near Well 699-40-84.

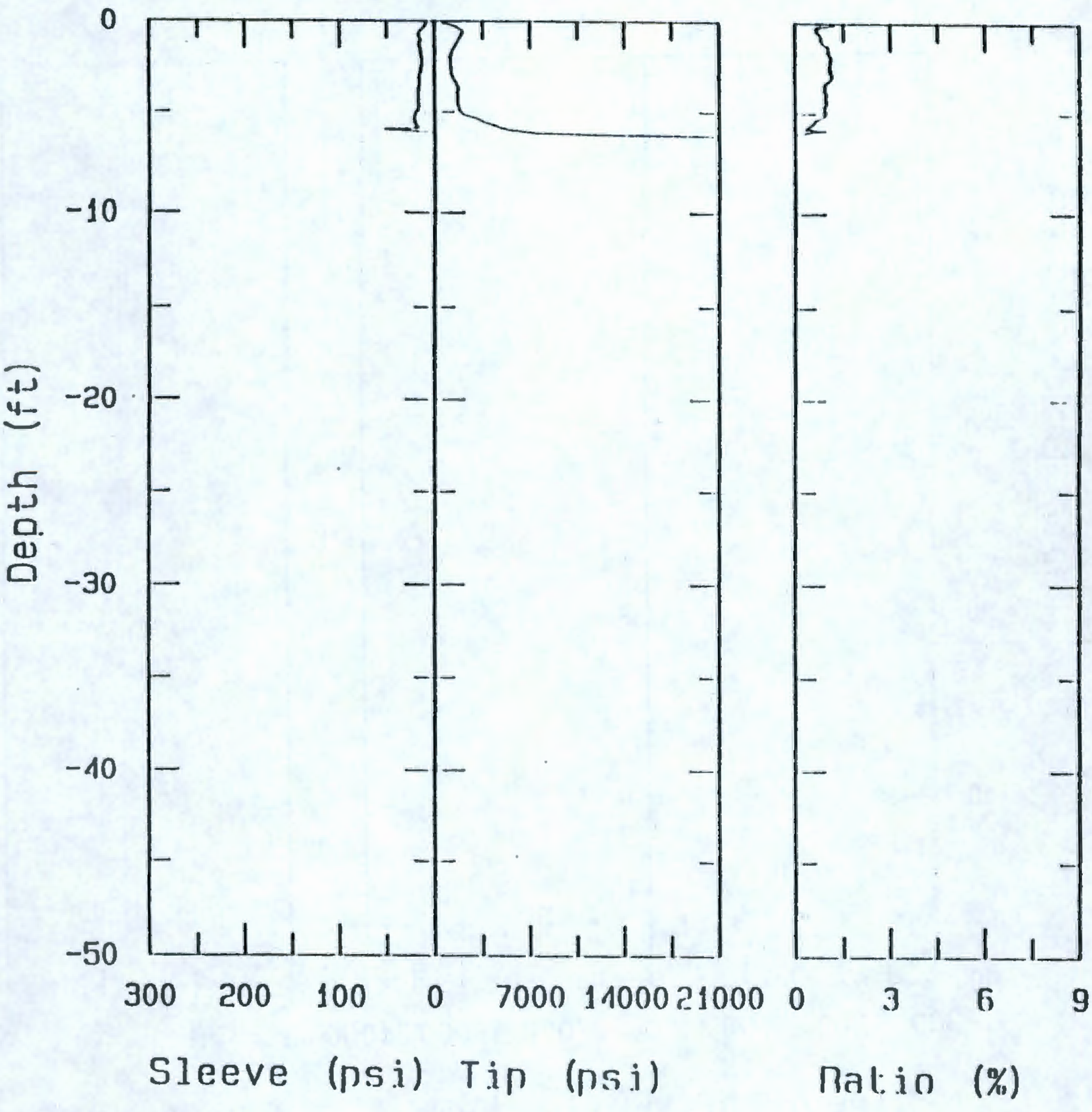


Figure 3-8. Third Penetration Test near Well 699-40-84.

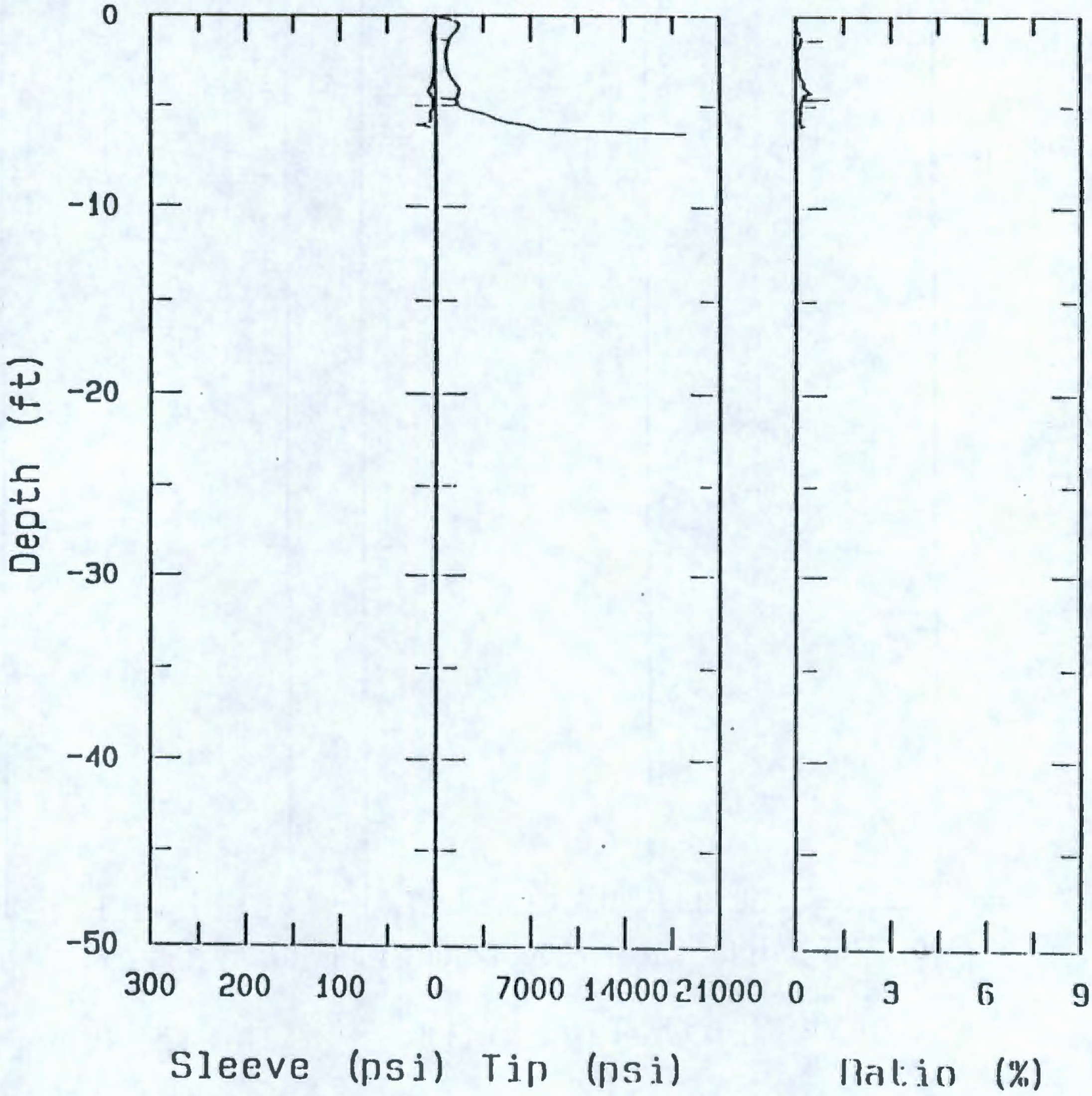
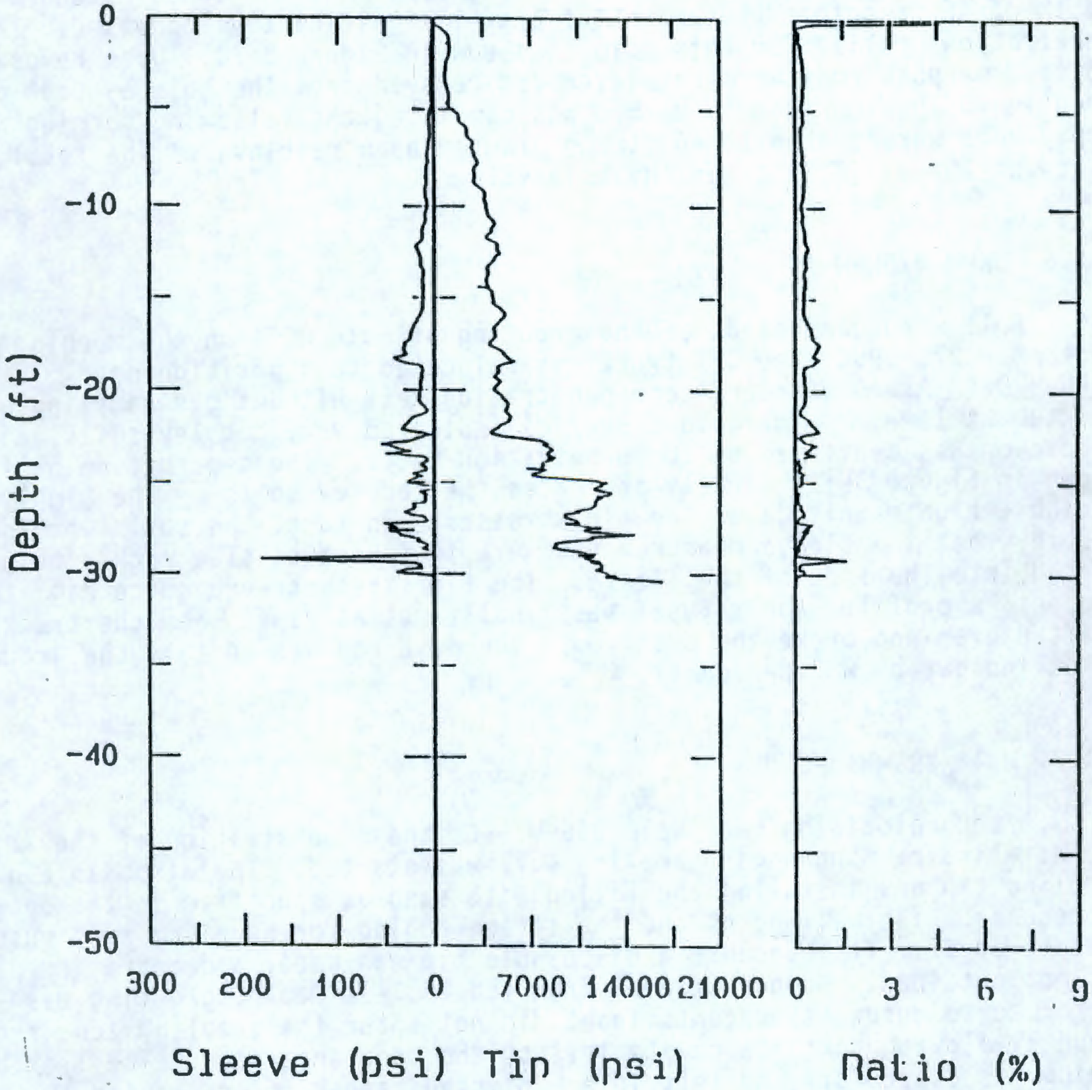


Figure 3-9. Penetration Test near Well 699-39-79.



depth of 45 ft was obtained. The soils at this location were very similar to the upper 22 ft of penetration in HC4A, except that the sands extended to a depth of 45 ft before the amount of gravel significantly increased. The penetration profile for this hole is shown in Figure 3-10. Upon refusal at 45 ft, the push rods were retrieved and removed from the hole by 5:30 p.m. Grouting using the tremmie method was completed the following morning when the empty rods were pushed to 40 ft and grouted upon retrieval. The total grout take was 10 gal (2.75 times the hole volume).

3.1.6 DWPH-V/DWPH-A

Following completion of the grouting at hole HC5A on the morning of September 27, 1991, the CPT truck was relocated to a position near DWPH-V/DWPH-A. A standard cone penetration test without gas sampling was started at 11 a.m. The ground surface indicated very cobbley soils, and this suspicion was confirmed by the penetration tests. The penetration profile, shown in Figure 3-11, clearly indicates the cobbley soils by the highly variable high magnitude of the tip stresses. In fact, the soils were so cobbley that the sleeve measurements were lost because of a rock's being forced into the side of the sleeve. The tip stresses were quite high through the entire profile, and refusal was finally met at 21 ft when the truck shifted over and broke the push rod. The push rod was left in the ground to be pulled out by WHC personnel.

3.1.7 Well 299-W15-6

After relocating near Well 299-W15-6, the demonstration of the ability to install a permanent gas sampling well was started. The disposable gas sampling tip was installed and filled with sand as specified in the operating procedures. The well point and the teflon tubing for sampling were pushed to a depth of 65.7 ft. Because a disposable tip was used, a penetration profile was not obtained. Upon retrieval from the 65.7-ft depth, grouting was performed to ensure that contaminant did not enter the sampling zone from above by flowing down the cavity left by the cone apparatus. The flexible tubing was capped off and left in a protected manner before moving the cone truck. Subsequent analyses of the gas samples obtained from this well were performed by WHC personnel.

3.1.8 Well 299-W19-30

The final test conducted at the Hanford test site was performed near Well 299-W19-30. At this location the piezo CPT was used in conjunction with the gas sampling device. The penetration profile, shown in Figure 3-12, presents both the tip and sleeve data along with the pore pressures that were measured during this test. This profile clearly indicates two soil layers above the cobble layer. The first layer extends from the ground surface to approximately 10 ft, while the second layer extends from a depth of 10 ft to 17.5 ft. Below 17.5 ft, a gravel and cobble soil layer is indicated. Refusal was encountered at 20 ft. This penetration hole was grouted upon retrieval of the cone tip using the grouting module represented in Figure 2-6. Eight gal of grout was pumped to fill the hole. The use of the grouting module is quite

Figure 3-10. Penetration Test near Well 299-W26-9.

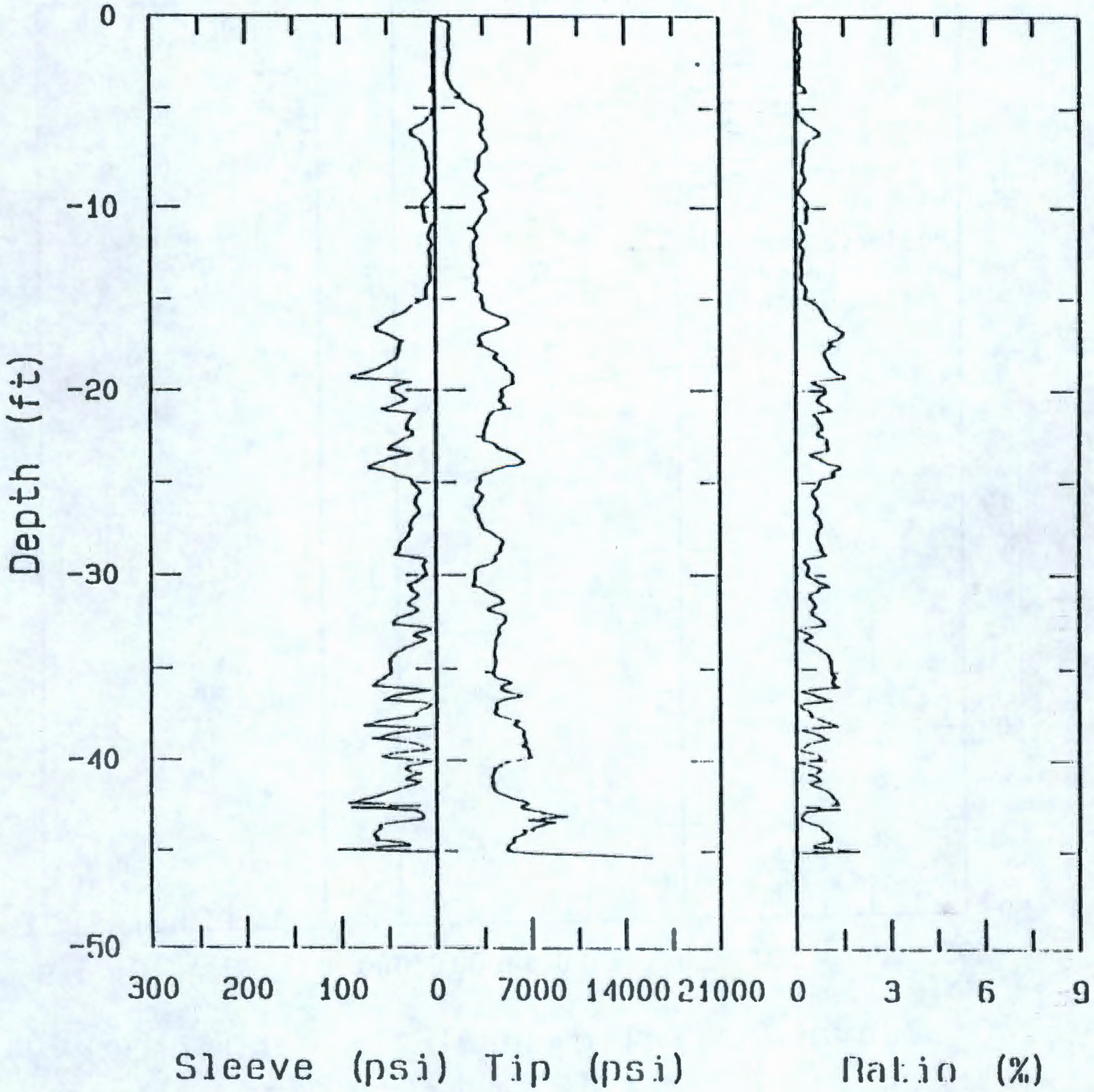


Figure 3-11. Penetration Test near Well DWPH-V/DWPH-A.

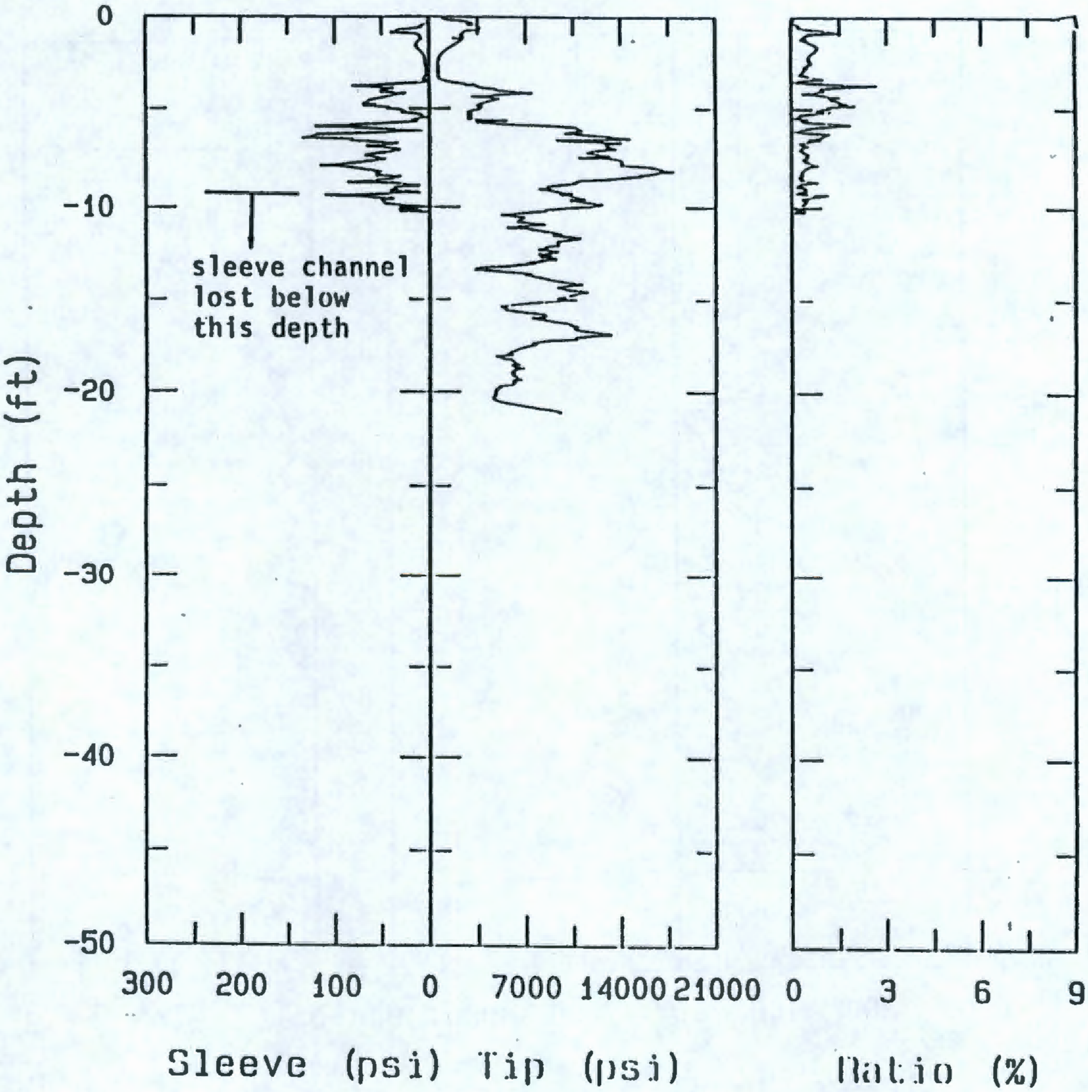
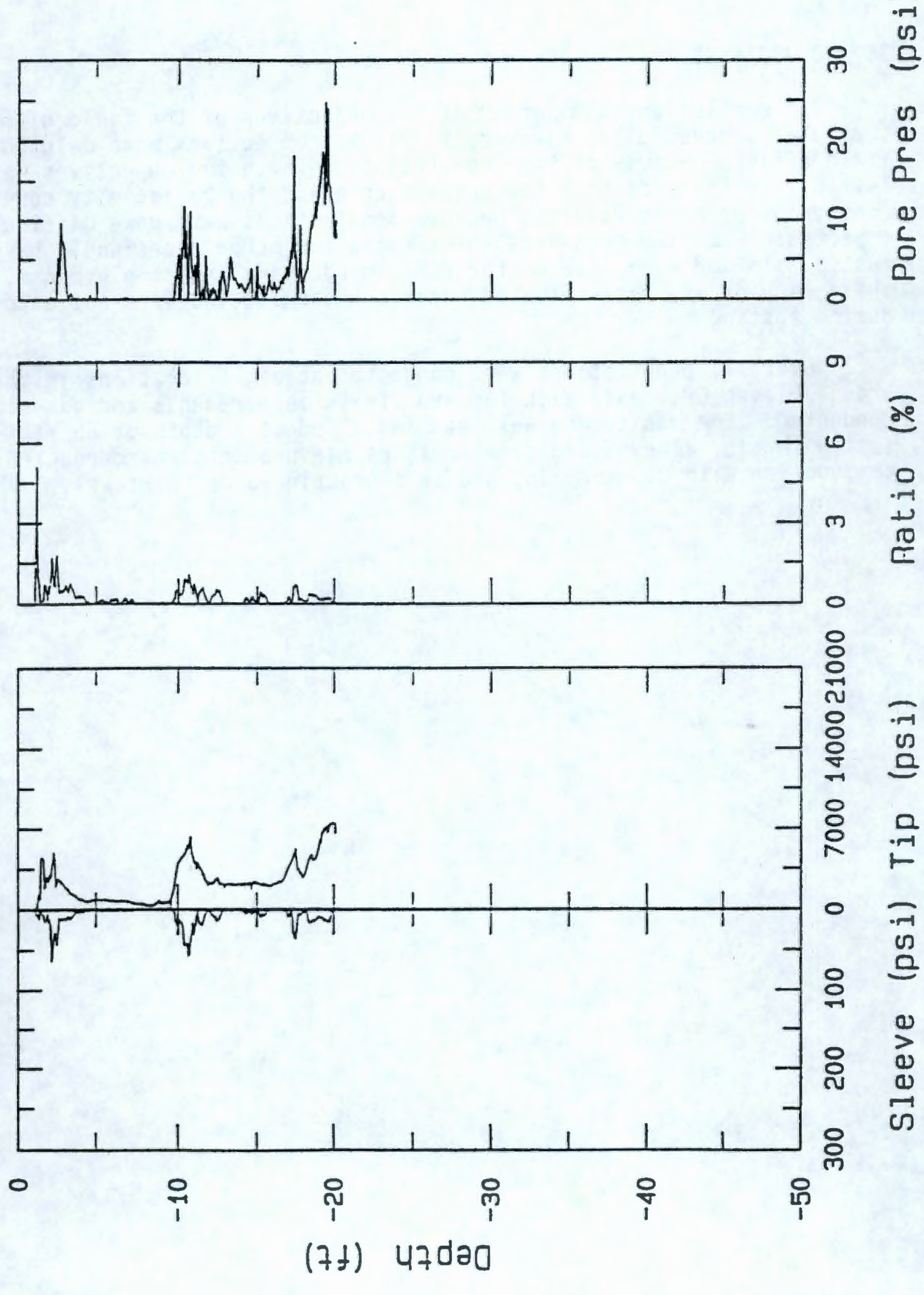


Figure 3-12. Penetration Test near Well 299-W19-30.



effective and significantly reduces exposure to any potential contamination by eliminating the open penetration hole while the instrumental rods are removed and the grouting rods are inserted.

3.2 OBJECTIVES

In conclusion, a majority of the objectives of the field efforts were completed successfully; however, two of the objectives were deleted from the field efforts because of time constraints. These two objectives were the feasibility tests of both the seismic cone and the resistivity cone. The time constraint problems resulted because penetrations were more difficult than expected. Had time been available, these two other cones would have been tested. In addition, use of the ECPT to identify and sample dense, nonaqueous phase liquids was not evaluated because these liquids were not encountered during testing.

Overall, penetrations were conducted at eight locations in the 200 West Area. Eleven CPT tests with tip and sleeve measurements and gas sampling were conducted. One monitoring well was installed at a depth of 65 ft. One CPT test with tip, sleeve, and pore pressure measurements was conducted in conjunction with gas sampling and self-grouting upon retrieval.

4.0 INTERPRETATION OF TEST RESULTS

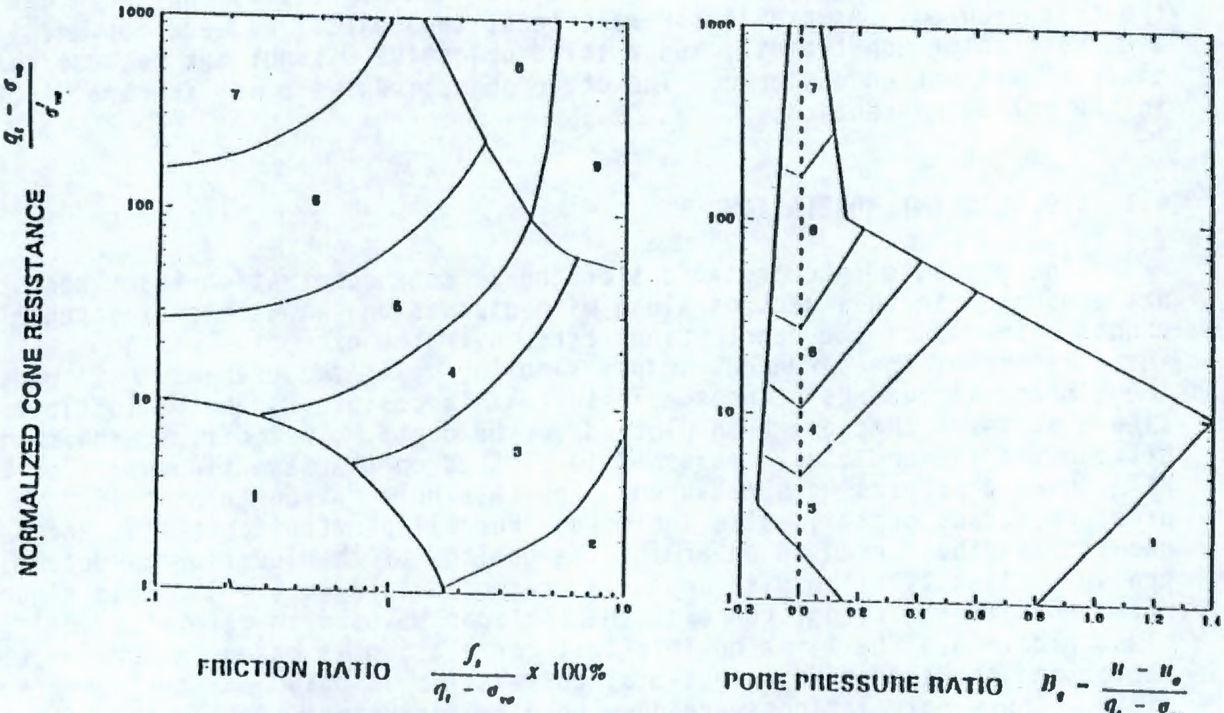
This chapter expands the discussion of the objectives that were met in the test program. As previously mentioned, two objectives were not met because of time constraints, and a third objective was not met because the material was not encountered. The other objectives were met and are discussed in the following sections.

4.1 GEOLOGIC INTERPRETATION

The geologic interpretations of the 11 cone penetration tests conducted are presented in this section along with discussions about the expected blow counts. In all of the penetration tests, with the exception of the installation of the permanent vadose sampling well, measurements were made of the tip and sleeve resistances. These resistances are converted to tip and sleeve stresses that are then plotted versus depth. In addition, the ratio between the tip and sleeve stresses is plotted on the same figures. For test HC7A, pore pressures were measured. For this hole, a fourth plot of pore pressure versus depth is also included. For all penetration tests, the results have been used to determine the geology of the location by determining the soil classification with depth as presented in Figure 4-1. This figure represents two different correlations that can be used to determine soil classification. The first or left-most correlation is based on the friction ratio, and the second, or right-most correlation is based on the pore pressure ratio. These correlations were developed by Robertson (1990) using both published and unpublished data in uncemented soils over recent years. It is important to note that although the charts extend to a normalized cone resistance of 1,000, little of the data used to develop the correlation extends above a normalized cone resistance of 100 (Robertson 1990). This indicates that there is very little cone experience in these high-strength soils and also that the proposed correlations have not been formally evaluated in these soil types. These correlations will give reasonable estimates; however, fine tuning may be necessary to develop a site-specific correlation for the Hanford formation.

The classification charts presented in this section are determined by taking each data point and plotting it on the classification chart to determine which zone or classification number the point falls in. The classification numbers are then plotted versus depth to produce the classification profile. If the data point is outside the classification chart (generally this represents a normalized cone resistance of above 1,000), no classification number is assigned to that depth. Friction ratio classification profiles are shown alongside the drilling logs for all penetrations over 10 ft in depth. For HC2 and HC3, the penetrations were shallow and a large majority of the points fell outside the classification chart; therefore, these charts will not be presented. Because pore pressures were measured on penetration test HC7A, both friction ratio and pore pressure ratio classifications will be shown alongside the drilling log.

Figure 4-1. Soil Classification Using the Cone Penetration Tests (Robertson 1990)



1. Sensitive, Fine Grained
2. Organic Soils-Peat
3. Clays - Clay to Silty Clay
4. Silty Mixtures - Clayey Silt to Sandy Silt
5. Sand Mixtures - Silty Sand to Sandy Silt
6. Sands - Clean Sand to Silty Sand
7. Gravelly Sand to Sand
8. Very Stiff Sand to Clayey* Sand
9. Very Stiff, Fine Grained*

(*) Heavily Overconsolidated or Cemented

4.1.1 Locations HC1A, HC1B, and HC1C

The results from the three penetrations near Well 299-W7-10 in the northern section of the 200 West Area are all very similar. The surface conditions indicated gravelly to cobbley soils, and the penetration profiles (see Figures 3-1 through 3-3) and soil classification in Figure 4-2 also indicate the same conditions. All three profiles have a highly variable tip resistance indicating rapidly changing conditions with depth. The sleeve resistances are also variable and indicate grains of various sizes. These profiles are interpreted as gravel to very coarse-grained sands interbedded with occasional fine sands or silts. This analysis compares favorably with the geologic data from the gravel-dominated facies section of the 200 West Area, which state that the soils generally consist of coarse-grained basaltic sand and granule-to-boulder gravel. These gravels are interbedded with lenticular sands and silts (Lindsey 1991).

Specifically, CPT penetration at HC1C agrees with the drilling logs from Well 299-W7-10. Samples taken every 5 ft by the drillers preparing the drilling logs are used to produce the classifications described here. For Well 299-W7-10, both the 5- and 10-ft samples indicate that the soils are sandy gravel, consisting of 50% gravel and 45% sand. The gravel fraction is broken down further to indicate 5% large cobbles and 15% small cobbles, followed by coarse-to-medium gravels. These large cobbles are most likely the result of refusal at HC1A and HC1B. The cone penetration profiles indicate very gravelly soils to a depth of 10 ft. The classification profile also indicates gravelly soils as a majority of the point plot outside the classification chart. Below 10 ft, the CPT profile shows an increase in the amount of finer grained soils present as indicated by the increase in both the sleeve resistance and the ratio and also a majority of the points plotted on the classification chart. This increase in fines is borne out by the classification of the sample from 15 ft. This sample indicates another sandy gravel; however, the gravel percentage has reduced to 35%, and the sand percentage has increased to 63%. The gravel content increases at the 20-ft sample to 85%, then reduces back to 60% at 25 ft. This shift can be discerned in the CPT profile as a slight increase in the tip resistance at depths of 20 ft or greater (see Figure 3-3). The CPT soil classification system categorizes the soil by major type and cannot delineate small changes in the soil content. This detail is best obtained by examining the tip and sleeve profiles. The final sample for comparison is the 30-ft sample, which consists of 55% gravel and 39% sand. As a final note, the drilling logs indicate the driller felt that the soils were partially cemented, which explains the increased sleeve resistances and the reduction in sensitivity to small changes in the sand contents. In addition, the classification system was developed for uncemented soils; therefore, the cementation may be causing a shift left in the classification system. Overall, the CPT profiles compare favorably to results determined from the drilling logs.

4.1.2 Locations HC2A and HC2B

The soils located near Well 299-W11-27 were once again gravels and cobbles, as indicated by both the surface conditions and the penetration profiles. The two profiles conducted are very similar (see Figures 3-4 and 3-5). The CPT-determined soil classifications are not shown because a

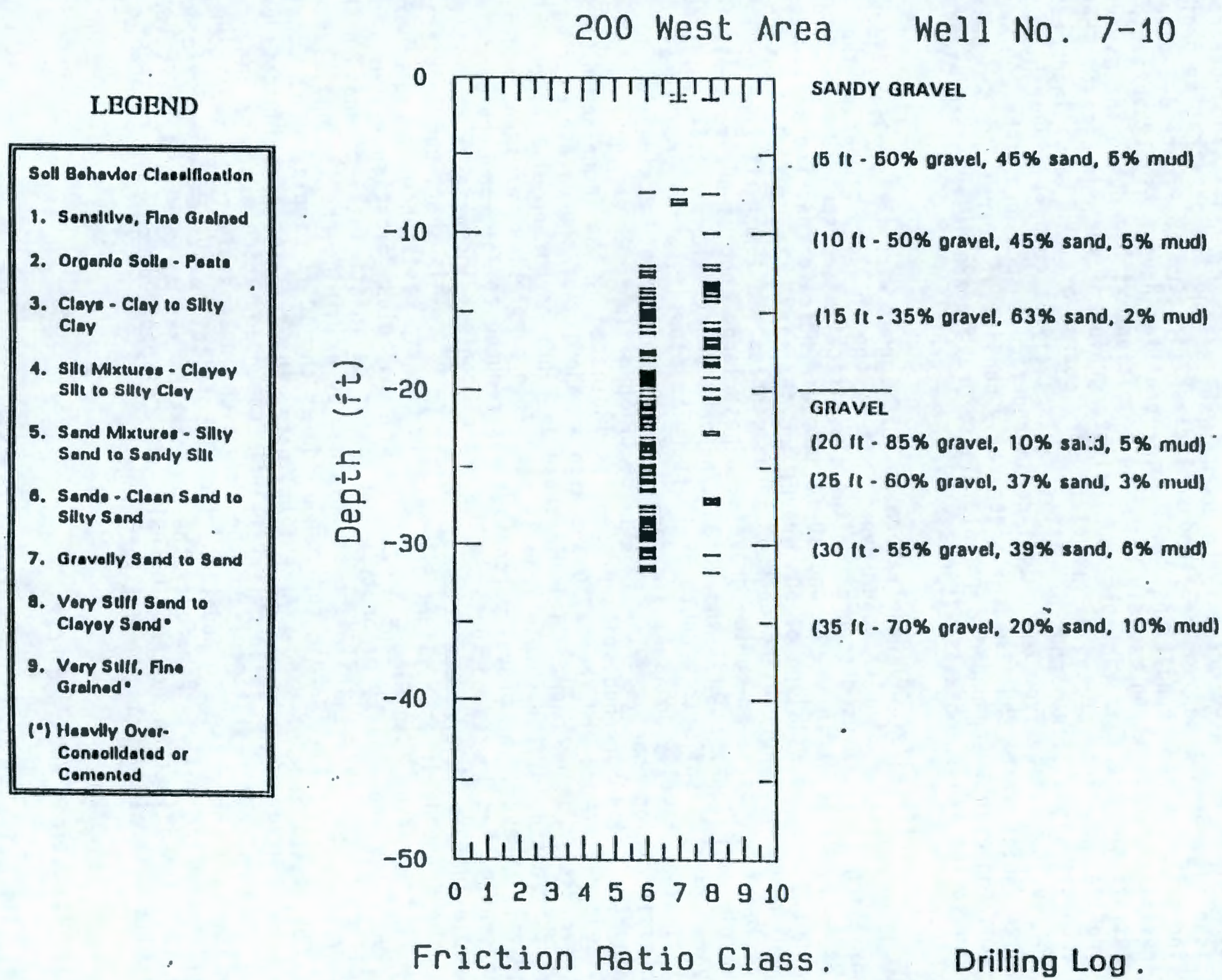


Figure 4-2. Soil Classification and Drilling Log for Penetration Test HC1C.

majority of the points fell outside the classification chart. This, in general, indicates that very coarse gravelly soils are present. Both profiles show a soft layer from 2 to 5 ft followed by a very stiff layer. The soft layer is probably a sand layer that is followed by the more typical gravel layers seen in HC1. The boring log from Well 299-W11-27 indicates that sandy soil extends to a depth of 4 ft. This corresponds to the soft layer seen in the CPT profiles to a depth of 5 ft. Below this layer, the CPT profiles indicate a rapid increase in tip stress caused by an increase in the grain size of the material. The grain size increased to gravel size or larger and eventually led to refusal. This agrees with the drilling log, which indicates that the layer below the sand consists of a muddy, sandy gravel. This material is 70% gravel and 30% sand and silt. The gravel also contains particles as large as 6 to 8 in., which are significant cobble particles. This material extends to a depth of 10 ft. Once again, these test locations are in the gravel-dominated facies of the Hanford formation and compare favorably with the geologic data. As at the HC1 site, the cobbles or boulders are causing refusal of the CPT.

4.1.3 Locations HC3A, HC3B, and HC3C

The three penetration tests that were conducted in the soils surrounding Well 699-40-84 are shown in Figures 3-6 through 3-8. Once again, a majority of the points fell outside (above) the classification chart, and therefore the classification profiles are not shown. All three profiles show a 5-ft-thick upper layer followed by a very stiff lower layer. The upper layer appears to be a sandy material, while the harder lower material is a gravel and cobble layer. The drilling log from Well 699-W40-84 indicates that the top 5 ft is a dense sand, which is immediately followed by a sandy pebble-to-boulder gravel. Penetrations from HC3 compare favorably with those at HC2, even though HC3 is located in the sand-dominated facies at the Hanford formation. The sand-dominated facies is described as consisting of fine- to coarse-grained sand and granule gravel displaying bedding. In addition, these sands may contain pebbles, rip-up clasts, and pebble-gravel interbeds (Lindsey 1991). This geologic data agree with CPT interpretation of a sand layer followed by a coarser or gravel-type layer. It is highly likely that the CPT soundings encountered boulders that caused refusal.

4.1.4 Location HC4A

The soils near Well 699-W39-79 are similar to the soils near Well 699-40-84 in that a sand layer overlays a cobble layer. The depth of the sand layer is approximately 24 ft, as indicated by the penetration profile (see Figure 3-9). Below the sand layer is the familiar gravel and cobble layer that presents a problem for penetration. This layer is once again identified by the highly variable and high-magnitude tip stresses in the profile, which increase with depth. The soil classification profile is shown in Figure 4-3 and indicates that a large majority of the soils are either sands or gravelly sand. Because both sands and gravel have a classification number of seven, the layer change at 24 ft is hard to determine from the classification profile alone. This explains why it is necessary to look at both the classification profile and the tip and sleeve resistances when interpreting the cone penetration data. The ECPT profile interpretation compares favorably with the

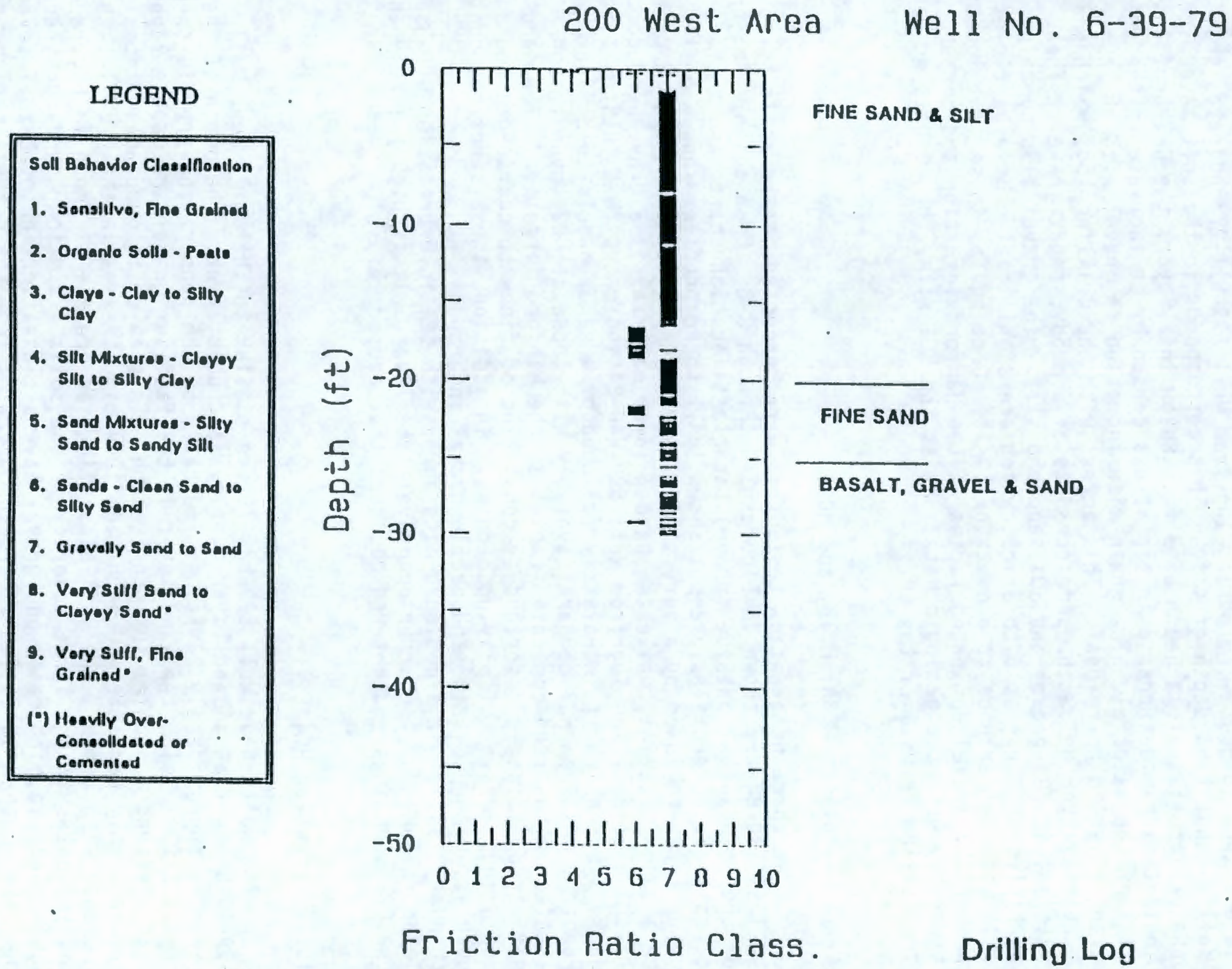


Figure 4-3. Soil Classification and Drilling Log for Penetration Test HC4A.

drilling log. The log indicates that the upper layer material is a fine sand and silt. This material extends through 20 ft but changes to a basalt gravel and sand at 25 ft. The CPT profile indicates this as an abrupt change occurring at 24 ft as the gravel content gradually increases. It indicates also that the material is fairly consistent until refusal at 30 ft. This agrees with the drilling log, which indicates basalt and gravel material through 30 ft. Location HC4, like HC3, is located in the sand-dominated facies of the Hanford formation. However, at HC4, the sand material is more dominant than the gravel material, as indicated by the 24-ft-thick sand layer.

4.1.5 Location HC5A

The soils identified by the penetration profile from hole HC5A (see Figures 3-10 and 4-4) are very similar to those found in HC4A. The top layer, which in this case extends to a depth of 40 ft, appears to be a sand material. This material becomes increasingly more interbedded and increasingly more gravelly in nature with depth. The soil classification profile indicates a sand to gravelly sand from the ground surface to a depth of 15 ft. From 15 ft to 35 ft, the classification indicates clean to silty sands. Below 35 ft, the classification profile indicates an increase in the amount of gravel present as more and more classification points plot in the gravel zone. The drilling logs from Well 299-W26-9 indicate a slightly muddy sand material that extends to 35 ft. This material contains 0% to 5% gravel and 87% to 97% sand. The majority of sand material is medium to fine. The 35-ft sample indicates a significant increase in gravel to 20%, which continues to increase to 50% at 40 ft. Over this same zone, the sand content decreases from 71% to 42%. The transition is seen on the CPT profiles as a slight increase in tip resistance with depth. The CPT profile reaches refusal at 45 ft, which is at the top of the next soil sample from the drilling log. This 45-ft sample indicates that the soil changed back to a sandy material with only a trace of gravels. However, the CPT probe shows a high tip resistance at 45 ft, which is most likely due to gravel. The CPT test was stopped because of the combination of the high tip and friction on the push tubes caused by the gravels in the 30- to 45-ft range.

4.1.6 Location HC6A

The surface conditions present at HC6A indicated that penetration would be difficult because of the large number of cobbles present. This fact is confirmed by the penetration profile (see Figure 3-11) and the soil classification in Figure 4-5. The profile for HC6A contains very high tip stresses below 5 ft. These are variable but high until refusal at a depth of 20 ft. The sleeve stresses are shown to a depth of 10 ft. Below 10 ft, the sleeve stopped working because a stone jammed into the side of the sleeve. Because the sleeve stopped working, the soil classification profile can be produced for only the upper 10 ft of soil. The classification profile indicates gravelly sands to sands in the upper 10 ft, with a significant number of points not plotting on the classification chart. Test location HC6A was near the border between the gravel-dominated and sand-dominated facies of the Hanford formation. The CPT results indicate that HC6A was in the gravel-dominated facies section because of the gravel soils represented in the CPT profile. Once again, higher push capacities are needed to penetrate these

LEGEND

Soil Behavior Classification

1. Sensitive, Fine Grained
2. Organic Soils - Peats
3. Clays - Clay to Silty Clay
4. Silt Mixtures - Clayey Silt to Silty Clay
5. Sand Mixtures - Silty Sand to Sandy Silt
6. Sands - Clean Sand to Silty Sand
7. Gravelly Sand to Sand
8. Very Stiff Sand to Clayey Sand*
9. Very Stiff, Fine Grained*

(*) Heavily Over-Consolidated or Cemented

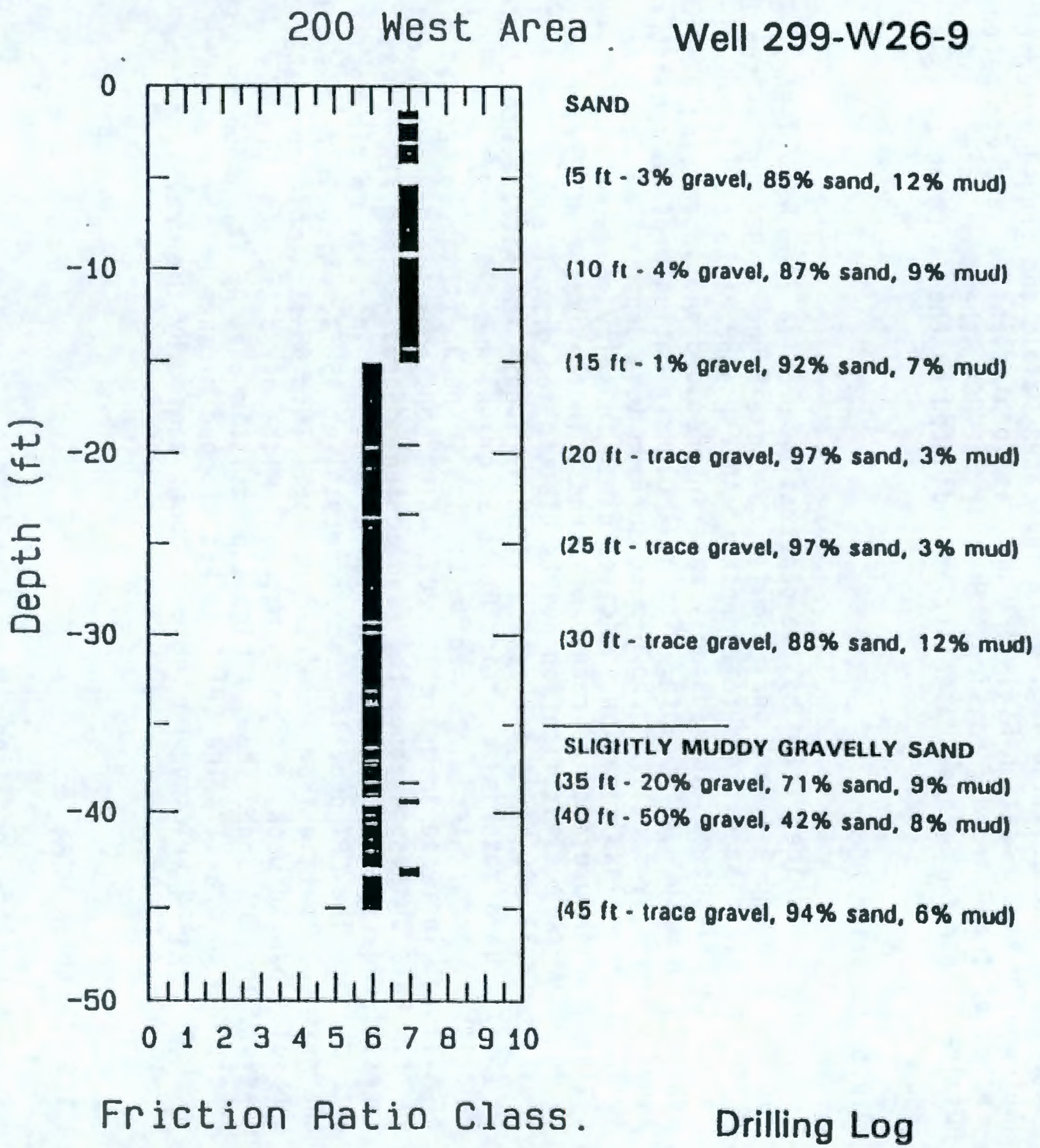


Figure 4-4. Soil Classification and Drilling Log for Penetration Test HC5A.

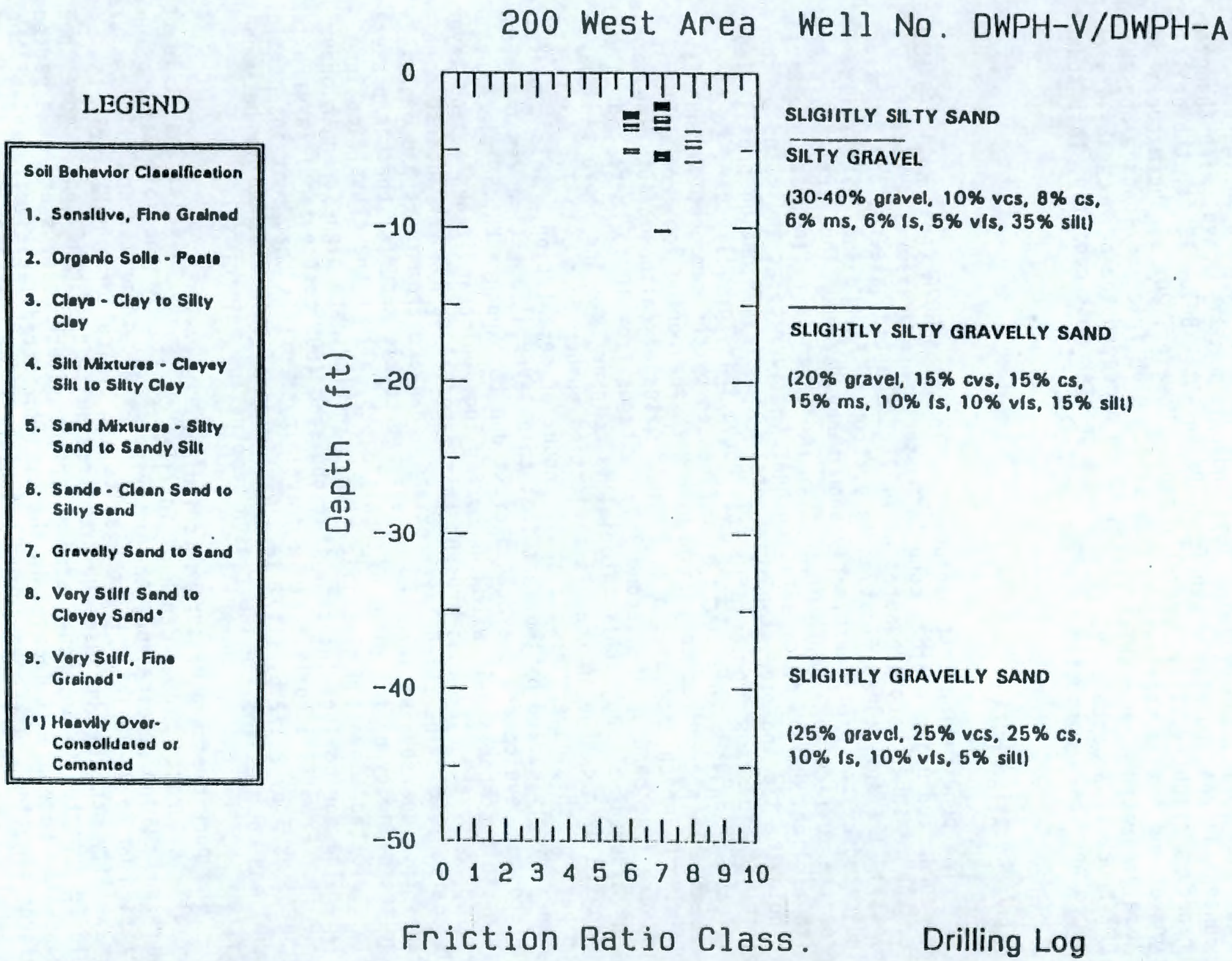


Figure 4-5. Soil Classification and Drilling Log for Penetration Test HC6A.

HC6A soils to deeper depths. Comparing the CPT profile to the drilling log (see Figures 3-11 and 4-5) indicates three separate materials in the top 20 ft. The first layer is a slightly silty sand that extends to a depth of 4 ft. This corresponds to the soft layer from 0 to 3 ft on the CPT profile. From 4 to 15 ft, the drilling logs indicate a silty gravel with the gravel content increasing with depth from 30% to 40%. Below 15 ft, the drilling logs record a slightly silty, gravelly sand. However, 20% of the material is gravel and 45% is coarse-to-medium sand. High friction loads along the push tube generated high pushing force, which exceeded the push capability of the CPT truck at a depth of 20 ft. With a greater push capacity, this sounding could have been conducted to a deeper depth.

4.1.7 Location HC7A

The penetration test performed at location HC7A (near Well 299-W19-30) was conducted using a piezo-cone to measure pore pressures. (See Figure 3-12 for the measured pore pressures as well as the tip, sleeve, and friction ratio plots.) The soil classification is plotted in Figure 4-6. The soils indicated by the profiles clearly show three layers. The first layer extends from the surface to a depth of 10 ft. The layer is a fine, sandy material with a slight amount of cementation near the surface as indicated by increases in both the tip and sleeve measurements. The classification profile indicated silty sand to sands from 6 to 10 ft. Above this, gravelly sand to sand is indicated; however, this could be influenced by the cementation that is present. This compares very favorably with the boring log from Well 299-W19-30, which indicates a silty sand material (although 40% fine sand and 30% very fine sand). The second layer extends from 10 to 18 ft and is another sandy material although this material is coarser than the above sand layer, as indicated by a change in the classification number from 6 to 7. Again, the top part of this layer shows a small amount of cementation. This cementation is most likely caused by the fact that this layer at one time was the ground surface and developed a desiccated crust due to exposure to the elements. Again, this compares well with the boring log, which indicates a sand layer from 10 to 19 ft. The logs present this material as 20% very coarse sand and 50% coarse sand. The third layer extends downward from 18 ft and gradually grades from coarse sand into the gravel and cobble material that is present over the majority of the site. At this depth, all of the classification points plotted above the classification chart indicate high-strength gravelly soils. The boring logs indicate that the sand (50% coarse sand) layer extends to 19 ft. From 19.3 to 19.5 ft, a gravel layer exists that contains particles as large as 3 by 2 1/2 by 1 1/2 in. Particles of this size border between gravel and cobbles and are the reason penetration met refusal.

The pore pressure measurements indicate that the material was at least partially saturated from a depth of 10 ft to 20 ft. As the soil was compressed during penetration, the material became saturated and the pressures increased up to 25 lb/in^2. These results are typical of a relatively low-permeability material because the pressures built up significantly more than would be expected in an open-graded material. These results are as expected because the borehole is located in the sand-dominated facies material of the Hanford formation. The open-graded material is the coarse sand, and the lower permeability material is the interbedded silts in these sands. Overall, this CPT profile compares well with the sand-dominated facies geology and agrees with the boring log for Well 299-W19-30.

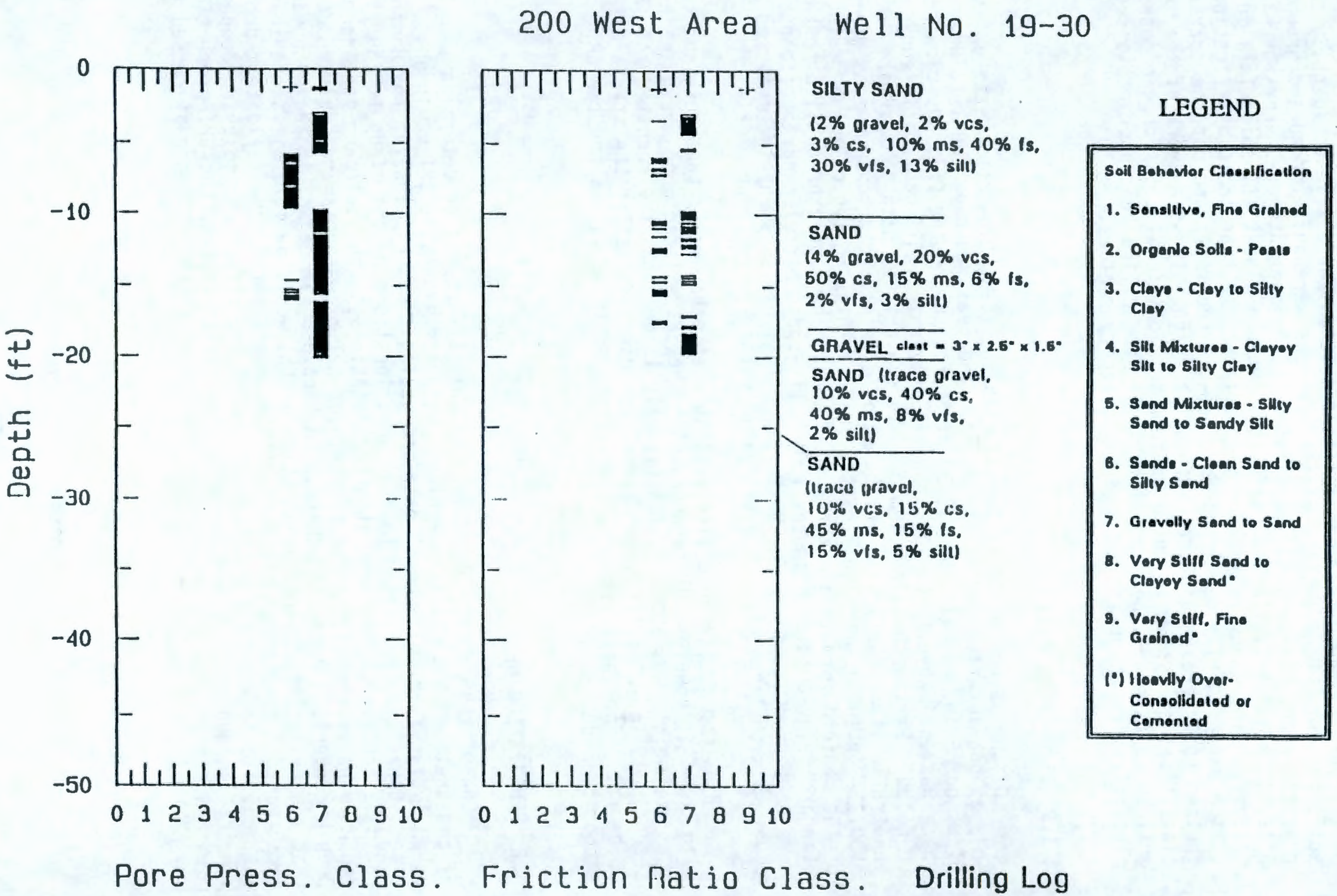


Figure 4-6. Soil Classification and Drilling Log for Penetration Test HC7A.

4.1.8 Soil Classification Summary

Overall, the general soil classifications were able to identify the soils present. However, the classifications were quite broad and grouped gravelly sand, coarse sands, and sands all in one category. For the Hanford Site, this has only limited usefulness because almost all soils fall in this category. The major reason for this weakness is that the classification system was primarily developed for fine-grained soils and not the coarse-grained soils present in the Hanford formation. The framework of the classification system is quite useful, but additional data for the coarse-grained soils should be studied to verify and refine the upper regions of the classification chart and improve the category regions.

4.1.9 Blow Count Data

Of the seven locations tested with the ECPT, blow count data existed only at one location and at one depth. The measured blow count value was 230 blows per 6 in. at Well 299-W19-30 at 30 ft. Using the CPT, the blow count value was estimated to be 103; however, several significant differences should be noted. First, the algorithm used to convert CPT data to standard penetration test (SPT) data was based on data having a maximum mean grain size of 0.254 in. This is significantly smaller than the typical mean grain size of the Hanford formation materials. Second, the algorithm applied to the standard 2-in.-outside diameter (OD) split-spoon barrel, whereas field tests were performed using a 5-in.-OD barrel. This explains why the measured blow count is much larger than the estimated value.

Blow count data were also available at other wells that were not tested with the CPT; however, differences with the SPT existed once again. First, the drop weight was 500 lb, significantly larger than the required 140 lb. Second, a 5-in.-OD split-spoon barrel was used instead of the standard 2-in.-OD barrel. For these reasons, comparisons of these values and the CPT data cannot be made.

4.2 PENETRATION DEPTH

One of the primary objectives of this effort was to determine the depth of penetration that could be achieved with the available CPT equipment. Based on analysis of SPT blow count data and geologic descriptions of the Hanford Site, it has been predicted that at some locations depths of up to 150 ft could be achieved. However, at other locations, much shallower penetrometer depths were predicted because of the high SPT blow counts and boulder and cobble contents. Once the penetration test program began, it became obvious that achieving the desired penetration depths would be more difficult than anticipated. Because of the difficulties encountered, the field test program was modified to expend a greater portion of the effort on achieving deeper penetration depths. To achieve deep penetration depths, the CPT probe tip and push rod diameter were varied. The results of these tests are discussed in the following paragraphs.

4.2.1 Effect of Probe Tip Geometry

Penetration tests HC1A and HC1B were conducted with standard CPT push rods (1.405 in. OD and 0.625 in. inside diameter [ID]) and ARA's CPT probe, modified to conduct active gas sampling and retraction grouting through the self-grouting sacrificial tip. The CPT tip had been modified to incorporate a sacrificial tip that was to be forced out upon retraction so that grout could be pumped out of the tip. Both HC1A and HC1B encountered refusal at a depth of about 8 ft when a cobble layer was encountered that could not be penetrated.

Upon retraction of the probe, it was found that the sacrificial tip could not withstand the tip forces and had failed. Portions of the sacrificial tip were forced up into the tip, which (1) blocked the tip so that grouting could not be accomplished and (2) resulted in a blunter cone tip. Based on these tests, it became apparent that the current design needs to be strengthened for the Hanford Site soils. In addition, it was believed that the blunt tip resulting from the failure of the sacrificial tip was limiting the depth of penetration. The blunt tip was hypothesized to bear on cobbles and not push them aside or even break the smaller cobbles, as has been observed at other sites. To test this hypothesis, a hardened, solid tip was used for the third test at this location.

Results from sounding HC1C (see Figure 3-3) tended to confirm the hypothesis that the shape of the tip influences the depth of penetration. The probe was able to penetrate the cobble layer from the ground surface to a depth of 10 ft and continued to a depth of 32 ft. Refusal occurred as the push capacity of the CPT vehicle was exceeded. The CPT field crew reported that the push through cobble layers was not steady, as is normally observed, but that the rods seemed to vibrate as cobbles were encountered and penetrated. In addition, loud sounds came up the push rods, which the field crew attributed to breaking cobbles. Because samples at the push site were not obtained, the field crew's observations cannot be confirmed.

4.2.2 Effect of Push Rod Diameter

Most of the penetration testing was continued with the 1.405-in.-diameter push rods because large-diameter push rods require higher pushing forces. At most locations, the depth of penetration was limited when the weight of the CPT truck was insufficient to break the cobbles. It would be desirable to increase the truck weights beyond the current push capacity of 45,000 lb so that the depth of penetration could be increased. A heavier truck could break larger cobbles and overcome higher frictional resistance along the rods. However, the 1.405-in. push rods have a limit of 46,000 lb of push force, and it may be desirable to increase the push rod diameter. The 45,000-lb limit is not caused by the axial rod capacity but by the bending capacity. Because bending capacity is proportional to the fourth power of the push rod diameter, small increases in the push rod diameter significantly increase the push capacity of the rods. The push capacity of the 1.74-in.-OD CPT rods is 104,000 lb. If the rod diameter is further increased to 2-in. OD, the push capacity of the rods increases to 187,000 lb. However, increasing the rod diameter will necessitate a heavier truck.

4.2.3 Effect of Grain Size

Cone penetration tests were conducted in two geologic areas. The initial tests were conducted in the gravel facies area. This area is characterized by a high percentage of cobbles and gravel (up to 50% or greater). In this area, the CPT met with very limited success. Depths of penetration were typically less than 10 ft in the gravel facies. The one exception was HC1C, where a depth of penetration of 32 ft was achieved. This test was located by boring W7-10, which is on the northern boundary of the 200 West Area and well within the gravel facies area.

Tests in the sand facies met with much greater success. Depths of penetration of up to 65 ft were achieved with typical depths of greater than 30 ft. In general, the push capacity of the CPT truck was exceeded at these locations.

To summarize, successful deep penetration of the cone probe into these soils depends on the ability of the penetrometer either to break any cobbles that are encountered or miss them entirely. This will require a heavier CPT truck unit because the current CPT cannot generate the high push forces required to penetrate and break cobbles or boulders of large size or strength.

4.3 SOIL-GAS VAPOR SAMPLES

Soil-gas vapor samples were successfully obtained during retrieval from the tests at HC1C and HC4A. At HC1C the sample was collected at a depth of 23 ft. At HC4A a sample was obtained at 30 ft, and the probe was returned to 24 ft to obtain a second sample at this location.

4.4 VADOSE-ZONE MONITORING WELLS

One permanent gas sampling well was installed using the CPT at a depth of 65.7 ft near Well 299-W15-6. Samples were successfully obtained from this well by WHC personnel for analysis of concentrations. This well was installed in less than 4 hours and appears to be a successful sampling well.

4.5 GROUTING TO PREVENT CROSS-CONTAMINATION

Grouting was performed on all 11 of the penetrations that were performed during the test phase. The four different methods described below were used to place the grout.

For shallow holes (less than 10 ft), the grout was poured into the hole using a funnel until the grout reached the ground surface and maintained that elevation. On average, the amount of grout used was approximately five times the hole volume. This indicates that there was significant grout flow into the formation. This was as expected because the formation was very gravelly and contained an open structure. In order to reduce the grout flow into the formation, a higher viscosity grout is required.

All the remaining penetration holes were grouted using the tremmie method, with the exception of HC7A, which was grouted using the third method.

The drawbacks to this method are that the instrumented cone rods must be removed from the hole and the grout rods inserted to the depth of push. Not only can this be time consuming, but it also exposes the workers and environment to an open hole. In addition, the grout tubes cannot always be pushed to the same depth as the CPT because of gravel and cobbles that fall into the hole. In general, the grout volume used was again approximately five times the hole volume. For holes where the grout tubes cannot be pushed to the same depth, this volume is sufficient and ensures that all flow paths are filled.

The third grouting method involved the use of a self-grouting sacrificial tip. This method was not used successfully during the testing program because of the tip's being forced back up into the grouting recess. This weakness can easily be overcome by hardening the steel and making slight design modifications. The advantages to this system are that it can be used with the 1.405-in.-diameter push rods and allows grout to flow out the end, which would allow a higher viscosity grout to be used. Also, grouting is performed upon retrieval with this method, which saves time. The disadvantages are that cycling the cone assembly to reduce rod friction is not allowed with this technique and the piezo and seismic modules cannot be used.

The fourth method involved using the grouting module and was successfully used on penetration HC7A. The major advantage to this grouting method is that grouting is performed during retrieval of the cone assembly. This saves time and eliminates any exposure to the workers or the environment. In addition, the piezo and seismic modules can be used with this technique. The drawback to this method is that the module is 2 in. in diameter and therefore requires larger push forces. Once again, the grout take was approximately five times the hole volume.

In all three of the grouting methods that were used successfully, approximately five times the required grout volume was used, indicating significant penetration into the media surrounding the borehole. To better ensure complete sealing of the borehole, use of a higher viscosity grout in the open-graded Hanford soils would be desirable. Using a high-viscosity grout will make pumping more difficult but also will eliminate some of the flow into the formation, which is the desired result when the grouting module is used. In conclusion, grouting was accomplished successfully, but additional study into grouting mixtures could lead to significant improvements.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

An ECPT test program was conducted by ARA to (1) evaluate the ability of the ECPT to penetrate the soils at the Hanford Site's 200 West Area, (2) determine stratigraphy, (3) obtain vadose zone gas samples, and (4) place vadose zone gas monitoring wells. The soils at the 200 West Area were deposited by the Columbia River in a high-energy environment. Cobbles, boulders, and gravels are commonly encountered in the soil profile and increase the difficulty of drilling and sampling. Cone penetrometer testing was conducted at seven locations to evaluate the ability of the penetrometer to push through the soil and to place monitoring wells.

5.2 RESULTS

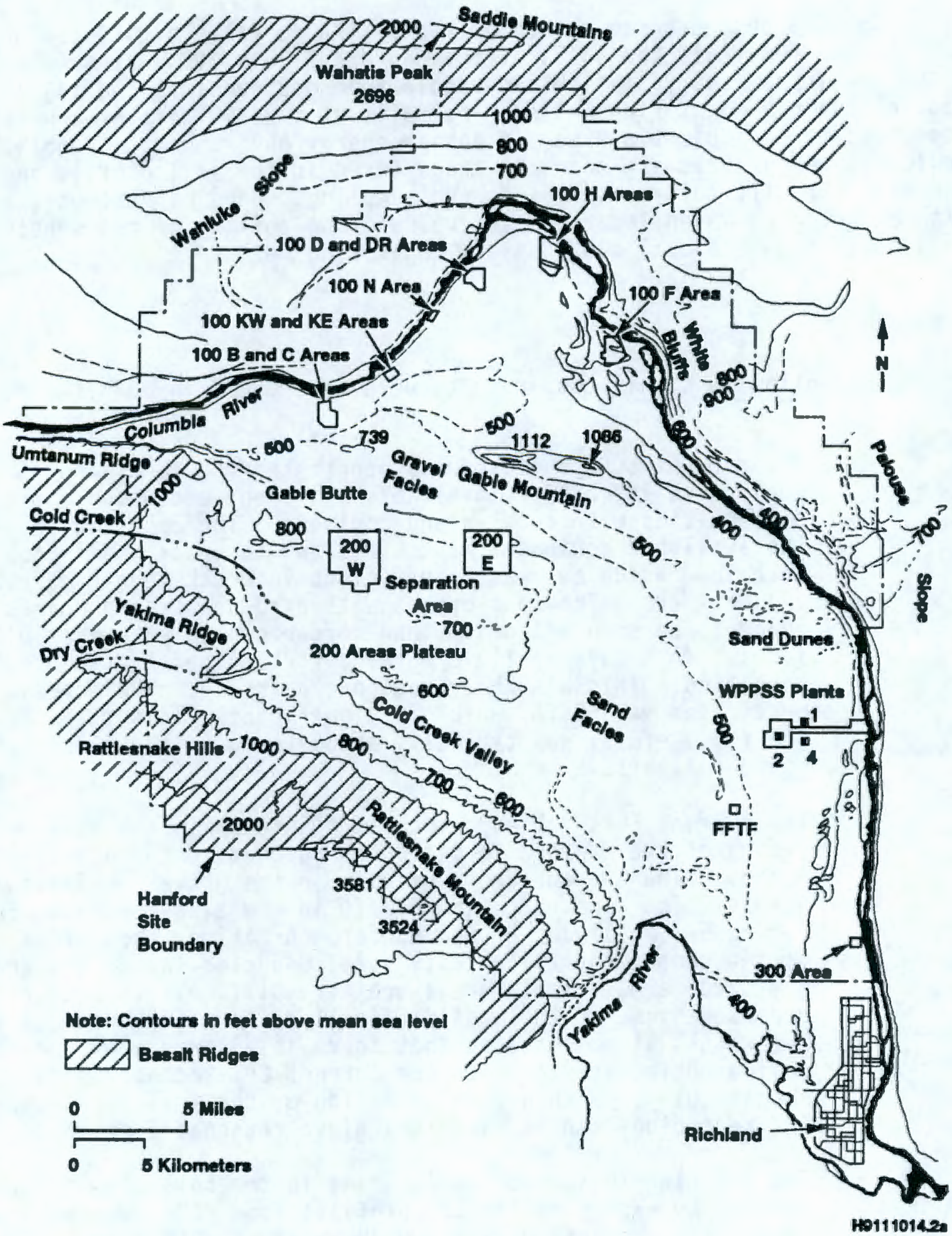
The following significant results were determined through the field study.

- The current ECPT successfully penetrated the sandy and fine-grained soils, but the available equipment encountered difficulties with cobbles and boulders. The penetration force of the available equipment was sufficient to break small cobbles or push them aside but was insufficient to break the large cobbles and boulders. The cone probes with hardened, sharp points were found to be more effective than softer probes or probes with blunt faces. In 4 days of field work, 267 ft of penetration testing was completed. This was an average of 75 ft/day. The deepest depth penetrated was 65 ft, which is significantly less than the desired 150 ft. Refusal was typically encountered in the cobble and boulder layers.

- The current ECPT achieved much more success in the sand-dominated facies of the Hanford formation as opposed to the gravel-dominated facies. The average depth of push in the gravel-dominated facies was 14.2 ft, compared with 26.1 ft in the sand-dominated facies. Figure 5-1, a layout of the Hanford formation, shows that several of the cone penetration tests were conducted inside the gravel-dominated area. These areas are very difficult to penetrate and represent some of the most difficult soils at the Hanford Site. Figure 5-1 also indicates that there is a large area, the sand-dominated facies, in which the current CPT technology can be used successfully. With proper selection of the test location, current CPT technology can be used to achieve reasonable depths.

- The CPT clearly showed the layering in the soil column. This is evident by examining the CPT profiles from HC7A, where three layers are present; HC2A and HC2B, where a soft zone is identified; and HC3A, HC3B, and HC3C, where a similar soft zone is indicated. At locations HC2A, HC2B, HC3A, HC3B, and HC3C, the profiles are very similar, indicating that the ECPT is highly

Figure 5-1. Layout of Hanford Formation Showing Sand-Dominated and Gravel-Dominated Facies.



reproducible. This fact exemplifies the ability of the CPT to identify layer interfaces and layer thicknesses. Cone penetrometer-derived soil classifications and conventional bore logs were in excellent agreement and demonstrate that the CPT can be used to identify different materials and layers and provide the information required to create geologic profiles. The CPT logs show greater detail than did the available boring logs, which were obtained on 5-ft centers.

- The CPT was used to sample the vadose zone as the probe was advanced and retracted. Several samples were collected and the field techniques were easily implemented. These samples were analyzed by WHC personnel to provide near real-time data on the degree of contamination of the soil column.

- At certain locations, the penetrometer truck was unable to advance the grouting push tubes to the depth reached by the CPT. The largest difference in depth between the cone test and the grouting was 10 ft. Cobbles that were moved out of the path of the penetrometer may have fallen into the hole upon cone retraction, preventing the grout tubes from reaching the same depth.

- The push rods and probes were examined for either chemical or radioactive contamination as they were withdrawn from the soil. As expected, there was no observable contamination on either the rods or probes. This demonstrates a major advantage of the CPT in that the sampling and site characterization program, when combined with adequate grouting capability, does not adversely affect the environment, and there is little drilling waste. In addition, there is very limited worker exposure when CPT technology is used.

- A self-grouting probe was used at one location and demonstrated that the CPT hole can be grouted upon retraction. In addition, a technique was demonstrated for placing monitoring wells where the well is grouted after the well point is placed and as the push rods are withdrawn.

- A permanent vadose zone monitoring well point was placed with the penetrometer equipment. The soil gases were monitored as the well point was pushed into the soil. The well was in place, grouted, and operational within 3.5 hr. This technique demonstrates a potential for large cost savings compared with the current technique of drilling to place wells.

5.3 RECOMMENDATIONS FOR FUTURE WORK

Although the results from the project are quite encouraging, several additional items should be addressed to meet the overall objective of penetrating the soil column to a depth of 150 ft to obtain soil stratigraphy and soil-gas samples and to place monitoring wells and possibly vapor extraction wells.

- A better technique is required to penetrate the cobbles and boulders at the site. This would include a heavy truck and possibly a downhole vibratory hammer to break or push aside any cobbles that are encountered. Laboratory testing should be conducted to determine typical properties of 200 West Area cobbles and rocks. This work should include analysis to design optimally shaped penetrators or drilling techniques and laboratory-scale testing to evaluate these prototype designs. Field tests should also be conducted to evaluate these prototype designs.

- Modifications to the truck weight and increases in push capacity should enable the CPT to penetrate to depths of 150 to 200 ft in the sand-dominated facies of the Hanford formation. Successful deep penetrations in the gravel-dominated facies will require implementation of many of the recommendations already mentioned.

- An effort should be initiated to determine design criteria for an ECPT vehicle for the Hanford Site. Important design criteria will include evaluating chemical and radioactive hazards, improving methods to decontaminate the push rods, determining the size of the vehicle and equipment to be contained in the vehicle, as well as push forces required, grouting methods, and sampling techniques.

- All CPT equipment should be set up for grouting upon retraction. This technique was shown to be successful at one location and would increase the rate of testing by elimination of the grout push. In addition, grouting upon retraction ensures grout in the entire depth of the borehole and eliminates the problem of cobbles clogging the borehole and preventing the grout push rods from achieving the same depth. In addition, grouting upon retraction eliminates the penetration hole's remaining open as grout rods are inserted, which significantly reduces worker and environmental exposure. Small-diameter grout systems need to be developed for use with cone push rods. The grout flow into the formation can be calculated as the grouting takes place. If too much grout is being pumped, the pressure head can be reduced, therefore lowering the level of grout in the columns and the flow into the formation. Also, higher viscosity grouts should be investigated for future grouting work.

- Additional analysis techniques are needed to classify the coarse-grained soils encountered by the ECPT. The current framework is sufficient, but additional data need to be analyzed to develop a site-specific correlation chart for the Hanford formation. This correlation would further break down the sand and gravelly sand into sands, coarse sands, gravel, and cobbles, as required by WHC personnel.

APPENDIX A

GROUT INFORMATION

Grout Information

Grout Used : Geochemical Corporation, MC-500 Grout and NS-200 Dispersant

Mix Formula: 1.75:1 mix ratio (water/grout)

Water	4.4 gallons (16.66 liters)
NS-200	0.0177 gallons (0.0688 liters)
MC-500	18.33 lbs (8.33 kg)

Properties: See attached sheets

GEOCHEMICAL CORPORATION

GEO/CHEM®

162 SPENCER PLACE, RIDGEWOOD, NJ 07450 (201) 447 5525 FAX (201) 447 3235

PRODUCT SPECIFICATION

MICROFINE CEMENT

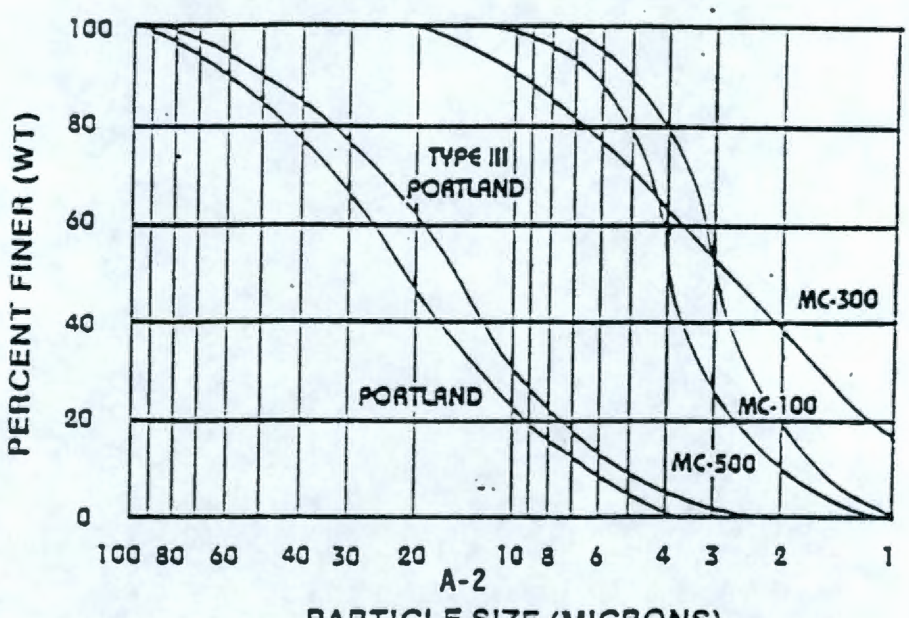
CHEMICAL COMPOSITION

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
MC-500	30.6	12.4	1.1	48.4	5.8	0.8
MC-100	35.4	16.0	0.3	43.3	3.5	0.3
MC-300	17.9	4.9	3.5	61.6	2.6	2.4

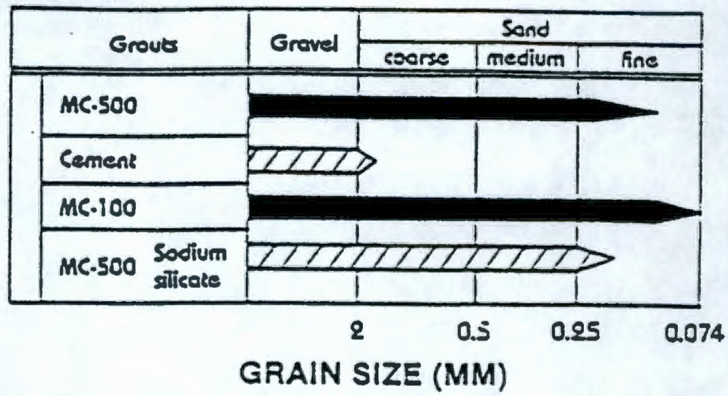
PHYSICAL PROPERTIES

Microfine Cement		MC-500	MC-100	MC-300
Specific gravity		3.00 ± 0.10	3.00 ± 0.10	3.00 ± 0.10
Unit weight (kg/ℓ) (Apparent bulk density)		1.00 ± 0.10	1.00 ± 0.10	1.00 ± 0.10
Odor		None	None	None
Fineness	Blaine specific area (cm^2/g)	about 9000	about 12000	about 10000
	50 percent grain size (um)	about 4	about 3	about 3

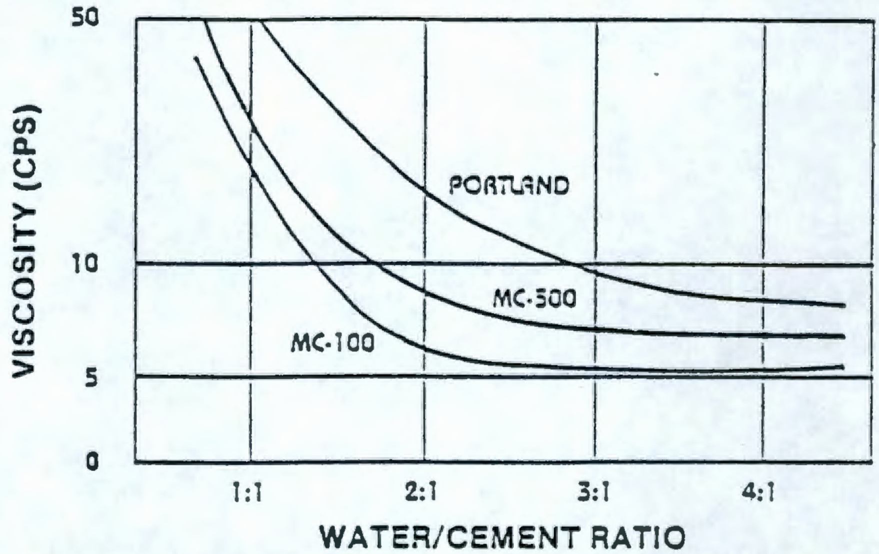
GRADATION CURVES



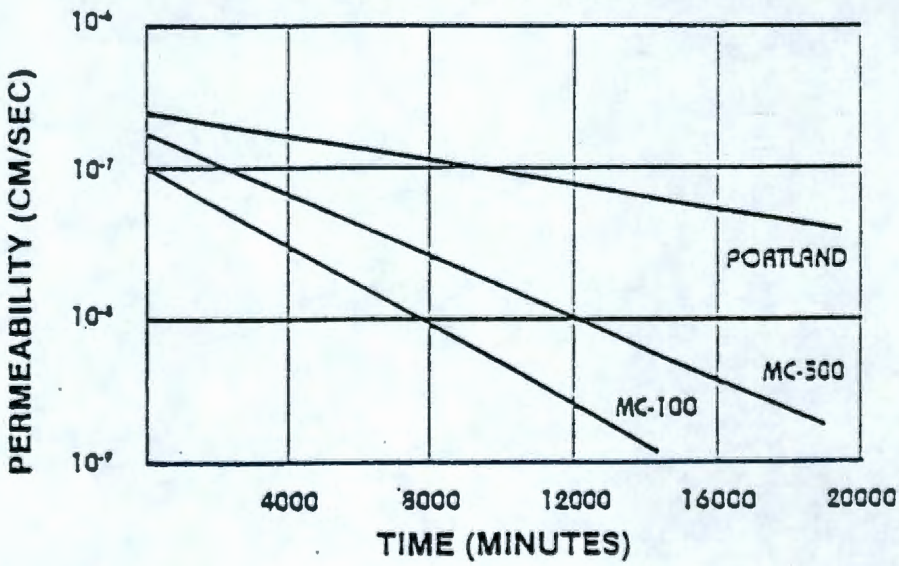
PERMEATION



VISCOSITY



PERMEABILITY



SPECIFICATION

MC-500 microfine cement may be specified as a portland/slag based grouting material with 50 percent of particle size less than 4 microns for permeation grouting with water and one percent NS-200 dispersant on cement. MC-500 may be used to react with sodium silicate to give a nontoxic grout with 3-5 minutes set time for underground water control.

MC-100 microfine cement may be specified as a slag based grouting material with 50 percent of particle size less than 3 microns for permeation grouting with water, one percent CA-600 dispersant and five percent sodium hydroxide on cement. MC-300 microfine cement may be specified as microfine portland cement with 50 percent of particles less than 3 microns and 10 percent at 10 microns.

The microfine cements come in 20 kg (44 lb) bags, 50 bags per pallet or one metric ton (2200 lb) per pallet. The dispersants come in 20 kg (44 lb) cans or plastic pails.