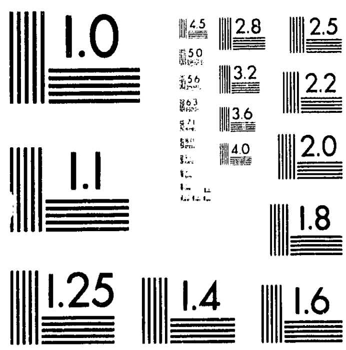
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CONE PENETROMETER TESTING (CPT) FOR GROUNDWATER CONTAMINATION

by

J. E. Jordan

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

R. S. Van Pelt

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J.E. Jordan and R.S. Van Pelt
Westinghouse Savannah River Company
A/M Area Groundwater Program

ABSTRACT

Over the past decade, researchers at the Savannah River Site (SRS) and elsewhere have greatly advanced the knowledge of waste site characterization technologies. As a result, many of the techniques used in the past to investigate waste sites have been replaced by newer technologies, designed to provide greater protection for human health and the environment, greater access to suspected zones of contamination, and more accurate information of subsurface conditions. Determining the most environmentally sound method of assessing a waste unit is a major component of the SRS environmental restoration program.

Assessing the extent of solvents is a top priority of environmental investigators. The cone penetrometer testing (CPT) technology is being applied at SRS to determine the effectiveness of a nontraditional characterization tool at environmental sites. The CPT technology is recognized as a screening tool by local regulatory authorities (South Carolina Department of Health and Environmental Control and Environmental Protection Agency -Region IV) and is a quick and relatively low-cost technology for site characterization.

In an effort to understand the distribution and migration of contaminants in the groundwater system, the cone penetrometer investigation of the A/M-Area Southern Sector was implemented. The program incorporated a phased approach toward characterization by first using the CPT to delineate the plume boundary, followed by installing groundwater monitoring wells. The study provided the additional hydrogeologic information necessary to better understand the nature and extent of the contaminant plume (Fig. 1) and the hydrogeologic system in the Southern Sector. This data is essential for the optimal layout of the planned groundwater monitoring well network and recovery system to remediate the aquifers in the area. A number of other test locations were selected in the area during this study for lithologic calibration of the tool and to collect confirmation water samples from the aquifer.

Cone penetrometer testing and hydrocone sampling were performed at 17 sites (Fig. 2). The hydrocone, a tool modification to the CPT, was used to collect four groundwater samples from confined aquifers. These samples were analyzed by SRS laboratories. Elevated levels of chlorinated compounds were detected from these samples and have aided in further delineating the southern sector contaminant plume.

INTRODUCTION

At the Savannah River Site (SRS), A/M-Area soil and groundwater contamination is a result of previous waste disposal practices, once considered state of the art. The primary source of contamination was the M-Area Settling Basin, an 8-million-gallon impoundment that received waste effluent from the M-Area manufacturing facilities. Large volumes of similar waste were also released at the A014 Outfall to the southeast of the Facility.

The effluents contained heavy metals and chlorinated solvents. Most of the metals (aluminum, nickel, depleted uranium, and lead) were effectively captured in the sediments at the basin and near the outfall. Approximately 2 million pounds of trichloroethylene (TCE) and tetrachloroethylene (PCE), chlorinated degreasing solvents similar to those used in the dry-cleaning industry, were released to these areas. Most of the solvents seeped into the subsurface, contaminating the soil and groundwater. The remainder evaporated.

After the discovery of groundwater contamination below the settling basin in June 1981, SRS established a corrective action program that includes extensive groundwater monitoring and groundwater recovery for treatment.

Also, the M-Area Settling Basin was certified closed in 1991, per Resource Conservation and Recovery Act (RCRA) requirements. The closure and the groundwater remediation activities have been conducted in compliance with a hazardous waste permit with the South Carolina Department of Health and Environmental Control (SCDHEC). The permit requires periodic reports on the remediation program's effectiveness, system performance, and groundwater monitoring results.

In 1991, SRS environmental group identified that utilizing the CPT technology combined with the groundwater data could provide the necessary information for subsurface characterization, reducing the level of effort in the field, and reducing secondary "investigative-derived" waste.

The research branch of SRS, the Savannah River Technology Center (SRTC), had by 1991, already used the CPT technology at the Department of Energy - Office of Technology Development supported Integrated Demonstration Site (IDS) located in A/M Area. The success of the CPT at the IDS provided confidence that the "push" technology would work at other locations in A/M Area.

In this document, the use of cone penetrometer testing to determine the concentration, aerial extent and movement of groundwater contaminants is discussed. The integration of CPT field work results with an existing monitoring well database to improve data quality at minimal cost is presented. Advantages and disadvantages of CPT are contrasted. Data and results are taken from a full-scale RCRA/Comprehensive Environemntal Response, Compensation, and Liability Act (CERCLA) field investigation.

STUDY AREA - A/M AREA SOUTHERN SECTOR

In the Southern Sector, contamination follows the groundwater gradient southwest from the A014 Outfall, see Fig. 1. Waste effluent discharged to unlined ditches and leading to a natural surface stream at the A014 Outfall contained chlorinated solvents and some dissolved metal constituents. Most of the metals (aluminum, nickel, depleted uranium, and lead) were effectively captured in the sediments near the outfall and have not been detected in the groundwater. Approximately 1 million pounds of tetrachloroethylene and 400,000 pounds of trichloroethylene, chlorinated degreasing solvents similar to those used in the dry-cleaning industry, were released over a 25-year period to the A014 Outfall. Discharge to the A014 Outfall was discontinued in 1978, and thereafter piped to the M-Area Settling Basin. Most of the solvents released at the outfall seeped into the subsurface, contaminating the soil and groundwater.

SRS has developed a plan to define the groundwater plume southwest of the A014 Outfall. A large area, approximately 650 acres, has been described with a dissolved phase contaminant plume, including TCE and PCE. Concentrations peak at more than 10,000 ppb at the point source (A014 Outfall), dropping quickly to lower concentrations along the fringe of the plume. The plan involves conducting an extensive hydrogeologic investigation of the TCE and PCE plume in the Southern Sector.

The first phase of these investigations includes conducting cone penetrometer surveys. From the findings of this first study, a groundwater monitoring network can be constructed and eventually, if necessary, a groundwater remediation system installed.

HYDROGEOLOGIC SETTING

In order to understand the distribution and migration of contaminants in the groundwater system, the nature and horizontal and vertical distribution of sediments must be characterized. Potential fluid migration pathways and directions of the sedimentary units must be delineated. Because A/M Area is near the present-day erosional boundary of the Upper Atlantic Coastal Plain, the sedimentary units are thinner, are locally bounded by unconformities, and are laterally discontinuous. Cretaceous to Tertiary-age strata, consisting of unconsolidated to indurated sediments (approximately 750 feet thick), nonconformably overlie metamorphic, igneous, or sedimentary rocks ranging from Early Paleozoic to Triassic in age.

The sedimentary section in A/M Area is divided into aquifer units and zones and confining units and zones based on relative permeabilities. Locally, the Southern Sector is underlain by alternating thick sand and thin clay sediments of the Atlantic Coastal Plain. These thin clay beds control contaminant migration in the subsurface; clayey sand beds also occur within the upper part of the section.

The stratigraphic section also thins and undergoes facies changes across the area. These characteristics play a significant role in controlling the hydraulic regime and are especially important in the Southern Sector.

THE CONE PENETROMETER TECHNOLOGY AT THE SRS

The advantages of the CPT technology in the environmental field are its for low cost and easy mobility. A cone penetrometer system can be located on a push site with minimal support needs. Once in place, the system offers other advantages such as depth-discreet soil and groundwater sampling devices, tool decontamination upon withdrawal, absence of soil cuttings and drilling fluid, small exploration hole size, and depth control. Other advantages attractive to the SRS program needs are described below. The contrasting disadvantages of CPT are the empirical correlations produced from the data, limits to the load-bearing capacity of the tools, and limits to the push-tool depth (dependent on the nature of the geological formations).

WHY USE CONE PENETROMETER TECHNOLOGY?

A technology that offers realtime data returns at the test location is a cost-effective tool. The geotechnical information is accurate and detailed and can be plotted instantly for in-the-field project scope modifications. The data reviewer should keep in mind, though, that the classification of soil types by the system is derived from a reference database comparing known engineering values for typical soil types. The result is an empirical sum of correlations between the field data and the reference information.

The CPT can be used to gather information and define hydraulic gradient or flow direction of the groundwater units. The small diameter push rod can be withdrawn and temporary piezometers or monitoring wells installed in the pushhole.

Tool modifications that include hydraulic transducers and flow meters (experimental) are available to estimate permeability, hydraulic conductivity, and porosity. Optical fiber technologies allied with spectroscopic hardware are also available to analyze for chemical constituents.

Grouting the pushhole, using either the through-the-rod (self-grouting) capabilities or the tremie pipe method, also offers a sanitary seal required at nearly all environmental investigation sites.

When analyses are conducted for a period of time and a dependable reference is available, the CPT data can be matched with a groundwater monitoring database The data from groundwater monitoring wells can be queried to help investigators define areas with the highest dissolved phase of solvents. The candidate areas are investigated with CPT to supplement and enhance the hydrologic and groundwater quality database and to verify the contamination levels. Also, for site screening, past experience at SRS suggests a cost savings of approximately 50% compared to monitoring well installations.

Also, as a cost-effective approach after site characterization, the CPT investigation results can be used at SRS to provide supportive information to optimize monitoring well and recovery well placements. During the Southern Sector characterization project, 17 locations were pushed using the CPT tool. (See Fig. 2.)

DESCRIPTION OF CONE PENETROMETER TESTING EQUIPMENT

The cone penetrometer tests performed in the Southern Sector for this study were conducted using the Applied Research Associates, Incorporated (ARA) penetrometer truck (Fig. 3). The penetrometer equipment is mounted inside a van body attached to a 10-wheel truck chassis with a diesel engine. Ballast in the form of metal weights and a water tank are added to the truck to achieve an overall push capability of 45,000 lbs. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck's frame. For this project, additional ballast was added, raising the push capacity to more than 50,000 lbs.

The penetrometer probe is of standard dimensions having a 1.405-inch diameter, a 60-degree conical tip, and a 1.405-inch diameter by 5.27-inch long friction sleeve. (See Fig. 4.) The shoulder between the base of the tip and the porous filter is 0.08 inches long. A 1.5-inch diameter expander, located 5.25 inches behind the top of the friction sleeve, pushes the penetration hole open and reduces friction drag on the push tubes behind the probe. The penetrometer is normally advanced vertically into the soil at a constant rate of 48 inches/minute, although this rate must sometimes be reduced as hard layers are encountered. The electric cone penetrometer test is conducted in accordance with ASTM-D3441 procedure.

Inside the probe (Fig. 4), 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, which is instrumented with four strain gauges in a full-bridge circuit. Forces are sensed by the load cells, and data is transmitted from the probe assembly via 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 are normally recorded each second, for a minimum resolution of about one data point every 0.8 inch of cone advance. The depth of penetration is measured using a string potentiometer mounted on the push frame.

Electronic data acquisition equipment for the cone penetrometer consists of a graphics monitor and a rack of eight signal conditioners. Analog signals are transmitted from the probe to the signal conditioners, where the CPT data are amplified and filtered at 1 Hertz. Seismic signals are amplified, as required, and filtered at 1000 Hertz. Once amplified, the analog signals are transmitted to a 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 10,000 samples per second for the seismic data. The digital data are then read into memory and written into the internal hard disk for future processing. Upon completion of the test, the penetration, dissipation, and seismic data are plotted.

RESULTS OF STUDY

The focus of this cone penetrometer investigation was to gather data to further characterize the stratigraphy and hydrogeology of the Southern Sector, to optimize placement of monitor wells, and to further define the distribution and migration of dissolved TCE and PCE. Electric cone penetrometer testing was the characterization tool employed, along with the hydrocone, for groundwater sampling. Some of the cone penetrometer tool applications are briefly summarized below with reference to an example of the results (Fig. 5) from the Southern Sector project.

Resistivity

Electrical resistivity is one of the oldest geophysical exploration techniques developed to locate mineral deposits, oil and gas accumulations material's and groundwater supplies. It is a measure of the electrical resistance per unit length of a cross-sectional area. Since an electrical contrast exists between different geological materials, this technique is effective in identifying various soils, minerals, and pore fluids. This study, in particular, dealt with the differentiation between clay and sand lithologies, as well as identifying various groundwater bearing units. Higher resistivity measurements indicated vadose zone sands and saturated sands below the water table. Lower resistivity measurements indicated an increasing clay content, even when obtaining readings below the water table.

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 high concentration of dissolved solids, which will decrease the resistivity of the groundwater. Soils contaminated with hydrocarbons (fuel oils, cleaning solvents, etc.) will typically have higher resistivity than uncontaminated soils because the hydrocarbon can act as an insulator. Chlorinated hydrocarbons associated with the A/M Area would be expected to be poor conductors with high-resistivity values (WSRC-RP-92-1302). Chlorinated hydrocarbons present in the water samples apparently were not reflected in the resistivity curve at each location, which may be because lower concentration values that are not discernible to the tool at this sensitivity level or the water samples were not collected through the entire section.

A schematic of the ARA electric cone penetrometer probe is shown in Fig. 4. The probe consists of four electrodes separated by high-strength plastic reinforced 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 40 Hertz. 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 liquid 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.

Sleeve Resistance / Tip Pressure

Sleeve resistance is a measure of the resistance on the outer friction sleeve of the probe as it is pushed through a porous medium. Recommended maximum sleeve-load measuring capacity of the probe is 7000 lbs. Tip pressure, as a measure of resistance on the conical tip, has a recommended maximum tip load cell-measuring capacity on the standard probe of 40,000 lbs. This is the maximum load under ideal circumstances. Variations in lithology and increasing friction on the sleeve will result in a decrease in the maximum tip load applied prior to rod breakage.

Sleeve and tip pressures varied greatly in the field, depending on the type of formation encountered. Tip pressures were generally less than 500 pounds per square inch (psi) at shallow depths. High tip pressures occurred at depths greater than 75 feet below land surface. Tip pressures up to 30,000 psi were encountered, and an attempt was made to stay below 20,000 psi to avoid rod breakage because of lateral instability from the truck floor into the subsurface. Sleeve pressures also were generally quite low until a resistant formation was encountered. Sleeve pressures greater than 8000 psi resulted in tool refusal as a means to maintain the integrity of the string of rods.

In addition to the tip resistance and sleeve friction, a friction ratio profile is plotted for each location. This ratio is 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. (Fig. 6).

Pore Pressure

Pore pressure is a combination of the induced pore pressure from probe advancement and the hydrostatic pore pressure of the formation. Induced pore pressure reflects the shearing action of the probe in various lithologies, while the hydrostatic pore pressure reflects the weight of a column of water as it lies over a cross-sectional area around the point.[1] An inferred hydraulic conductivity may be made from the measured pore pressure, in a generalized manner, resulting in higher hydraulic conductivity in clean sands and low to moderate conductivity in silty sands and clays. Pore pressure dissipation tests, where excess pore pressures dissipate toward the hydrostatic pore pressure, were executed at each groundwater sampling event. Use of this method coupled with general knowledge of the various water table elevations in A/M Area aided in correlating and determinining of probable water table levels to be sampled.

Groundwater Sampling

Groundwater sampling was successfully conducted at four locations in the Southern Sector. Several attempts to collect a samples at one location proved futile because of the lack of groundwater infiltration into the porous filter. In an effort to confirm and delineate plume distribution of dissolved VOCs, groundwater samples were analyzed for TCE and PCE concentrations. To collect a sample, the hydrocone was lowered to the target depth and then pulled upward one foot to expose the porous filter to the groundwater. Sufficient time was allowed for water to enter the sampler, whereupon a Teflon bailer was lowered to the bottom through the push tube and samples collected. In this technique, a disposable/sacrificial tip is subsequently grouted in the hole upon rod retrieval.

PROBLEMS ENCOUNTERED / LESSONS LEARNED

Zones of highly resistant sediment were commonly found at almost every location. Refusal or resistance to advancing the pushtool prior to reaching the targeted formation depth was the main problem encountered during this project. Cycling the rods (repeated up and down vertical movement) proved effective, but was not always successful at completely penetrating the resistant zone. Furthermore, the potential for malfunction of the self-grouting module was increased by this technique. Rod breakage occurred a number of times during cycling events, and the rod string usually snapped within a few feet of the surface, although downhole breaks also occurred. Through trial and error, a successful cycling guideline was developed in the latter stages of the program. This program consisted of 15 minutes of cycling prior to declaring refusal, with a maximum tip pressure of 20,000 psi, sleeve pressure of 5000 to 8000 psi, and a maximum hydraulic pressure of 1500 psi.

Also, a Drilex system (Fig. 7) was employed to drill through indurated or hardened formations. This system includes a downhole pneumatic pump lowered to the resistant zone. The Drilex system is withdrawn after passing through the resistant zone and the push technology reapplied. When utilizing both the CPT probe and Drilex system, a project should also include setting 5 to 10 feet of retrievable surface casing to prevent rod wobble and breakage. This system is being improved one step further by developing a case-as-you-drill method where casing is automatically advanced downhole with the bit as it drills to target depth (Applied Research Associates, Inc., written communication). At total depth, the bit and assembly is detached from the casing and pulled out leaving the casing downhole.

SUMMARY

Assessing the extent of solvents is of priority interest to environmental investigators. The cone penetrometer testing technology is being applied at SRS to determine the effectiveness of a nontraditional characterization tool at environmental sites. Chlorinated solvent contaminated groundwater in A/M Area has been characterized using the CPT and conventional monitor its well technology. CPT has been used as a screening tool for delineating plume boundaries and for optimizing new locations for monitoring wells.

During the Southern Sector characterization project, 17 locations were pushed using the CPT tool. Geotechnical data collected included sleeve resistance, tip pressure, pore pressure, and resistivity. Pore pressure data was used to approximate static water level in the aquifers. Tip pressure and sleeve friction data were used to generate soil classification plots that allow for a detailed correlation across the various lithologic units in the A/M Area and, in turn, estimate hydraulic conductivity and hydraulic gradients of the aquifers. This subsurface lithologic control allows for detailed hydrostratigraphic, structural interpretations, and geologic mapping.

Multiple refusals were encountered at various locations and were a factor of localized lithology conditions. Refusal in the same areas generally occurred at the same depth. Clay units displayed lower resistivity measurements, higher sleeve resistance, and low tip pressures, while indurated sand units exhibited higher tip measurements, lower sleeve resistance values, and higher resistivity measurements prior to refusal. Soft sands generally had higher resistivity and lower sleeve resistance measurements. Higher pore pressure values were generally an indication of finer grain sediments, i.e., clay, silt. A drilling demonstration test was performed at two locations employing the Drilex mud rotary system.

Groundwater sampling was successful at four locations using the hydrocone sampling method. These groundwater samples were collected approximately 143 feet to 175 feet below the ground's surface. All test holes were grouted to surface upon completion and groundwater samples were analyzed by the SRTC using a Gas Chromatography/Mass Spectrometer instrument.

REFERENCES

1. R.A. FREEZE, and J.A. CHERRY, *Groundwater*, 1979. Prentice-Hall, Inc., New Jersey.
2. R.S. VAN PELT, J. ROSSABI, D.S. KABACK, J.E. JORDAN, B.B. LOONEY, and C.L. BERGREN, 1993, *Application of Cone Penetrometer Technology in Environmental Investigations at the Savannah River Site (SRS), South Carolina.* (Abstract): Geological Society of America 1993 Annual Meeting, p.39.
3. *Savannah River Site A/M Area: Southern Sector Characterization Cone Penetrometer Report (U)*, WSRC-TR-93-188, May 1993, Prepared by Ebasco Services Incorporated for the Westinghouse Savannah River Company.
4. A.I. STRUTYNSKY, R.E. SANDIFORD, D. CAVALIERE, "*Use of Cone Penetrometer Testing with Electrical Conductivity Measurements (CPTU-EC) for the Detection of Hydrocarbon Contamination in Saturated Granular Soils*," Current Practices in Groundwater and Vadose Zone Investigations, presented in Stratigraphics 1991.
5. Westinghouse Savannah River Company, 1992, *Assessing DNAPL Contamination, A/M Area, Savannah River Site: Phase I Results (U)*, WSRC-RP-92-1302, December 1992, Savannah River Technology Center, SRS, Aiken, South Carolina.

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