A NEW GROUND WATER SURVEY TOOL: THE

COMBINED CONE PENETROMETER/VADOSE ZONE VAPOR PROBE

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Abstract

A soil cone penetrometer has been modified to allow sampling of gases in the vadose zone. This tool was developed to obtain information concerning soil type and quantitative volatile organic compound data in the unsaturated zone simultaneouly. The primary uses are in identifying leaks and locating contaminant plumes from underground storage tanks and pipelines, and surveying uncontrolled waste sites to strategically place exploratory borings and ground water monitoring wells.

The Cone Penetrometer/Vadose Zone Vapor (CP/VZV) probe consists of a gas collection barrel positioned 18 inches above the tip of the cone penetrometer. The tool is hydraulically advanced into the ground using a drill rig equipped with an automatic chuck assembly. Wiring from the cone penetrometer and tubing from the gas collection barrel are connected to aboveground equipment. Gas samples are analyzed by either an organic vapor meter or portable gas chromatograph (GC) depending upon the information desired.

The cone penetrometer is used to generate immediate feedback on soil stratigraphy. Depending on the type of soils encountered, gas sampling can be continuous with depth or only in porous soils as identified by the cone penetrometer data.

The CP/VZV probe significantly reduces the time and cost of the investigation of sites contaminated with volatile petroleum hydrocarbons and organic chemicals. It reduces the number of borings ultimately required by allowing more knowledgeable placement of exploratory borings and ground water monitoring wells. By reducing the number of borings its use reduces the number of soil samples which must be taken and, hence, the potential exposure of the field personnel may also be reduced.

Introduction

Investigations of subsurface contamination have typically involved completion of soil borings, obtaining and testing soil samples, installation of ground water monitoring wells, and obtaining and analyzing ground water samples. This can be a time consuming and costly effort. Over the last few years there has been an effort by waste management firms to identify contaminant locations using faster more efficient methods. These techniques can be divided into two groups: surface methods and subsurface methods. Primary surface methods include surface resistivity and magnetometer surveys. Subsurface methods typically involve the use of probes to measure in situ characteristics. Neither type of investigation is intended to replace a soil boring and well installation program, but to allow more knowledgeable placement of borings and wells. This reduces the time in the field, and increases the quality of data obtained.

The purpose of this paper is to describe a new site investigation tool developed by McClelland Engineers which consists of a cone penetrometer modified to allow collection of soil gas samples.

Background

Cone Penetrometer

The cone penetrometer or Dutch cone, developed in the Netherlands was introduced to the U.S. in the 60's. Since its introduction, the cone has been used extensively in geotechnical investigations in the U.S. Figure 1 illustrates the type of cone penetrometer used by McClelland Engineers.

The cone penetrometer has a conical tip with a 60-degree apex angle and a projected area of 10 square centimeters. Immediately behind the tip is a friction sleeve with a surface area of 200 square centimeters. Strain gauges independently measure the tip and sleeve resistance as the probe is hydraulically advanced into the soil. Signals from the strain gauges are transmitted to surface equipment through a cable prestrung through the push rod. Analog and/or digital recordings of the data can be made.

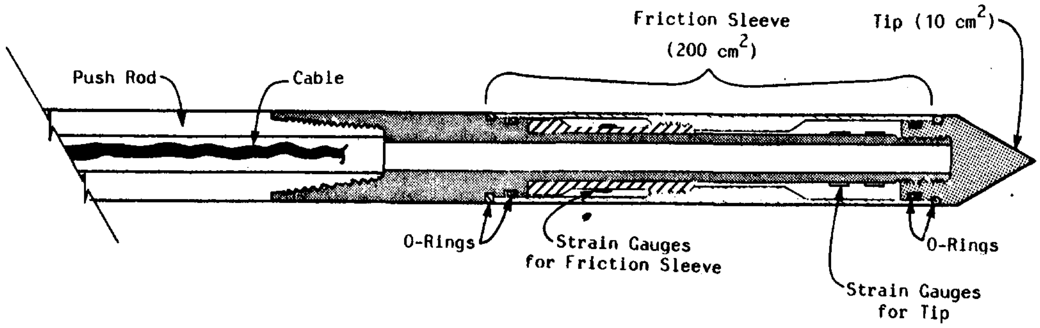

FIGURE 1. ELECTRICAL CONE PENETROMETER

Data from the cone penetrometer test (CPT) can be used to assess:

- o soil type and subsurface stratigraphy;
- o compressibility characteristics, liquefaction potential, and in situ condition of cohesionless soils;
- o undrained shear strength and relative consistency of cohesive deposits;
- o degree of compaction and vehicle trafficability of backfill or natural soils;
- o presence of subsurface voids and determination of the depth of fill;
- o estimate settlements of foundations on sand; and
- o compute axial capacities for various pile types.

For waste management work we are primarily interested in its use to determine soil type and site stratigraphy so that an assessment of contaminant migration can be made. A computer generated CPT plot is shown in Figure 2. Figure 3 is an example of one of the diagrams used to estimate soil type from the CPT data. For this evaluation the bearing capacity is plotted against the friction ratio (sleeve friction divided by cone bearing).

Advantages of the cone penetrometer over soil borings for geotechnical investigations include the speed and ease of obtaining data and, in some case, obtaining superior data. At hazardous waste sites less sample handling is required, reducing the potential exposure to contaminated material. The primary disadvantages are that there are no soil samples for laboratory testing and the depth of investigation may be limited.

Vadose Zone Gas Sampling

Over the past several years there has been a significant interest in the measurement of soil gases to identify subsurface soil and ground water contamination. To date, this method has been used primarily for the identification and location of volatile organics.

Figure 4 illustrates a typical spill or leak of volatile organics. The liquid moves vertically until it intersects the water table. Depending on the type of compounds present, a portion of the material will begin dissolving in the ground water. In most cases, the majority of a volatile organic compound will create a layer above the ground water. Under unconfined aquifer conditions, the organic layer will flow in the general direction of the ground water.

The capillary effect of the soil along with fluctuations of the ground water level will typically distribute organics (liquid phase) in

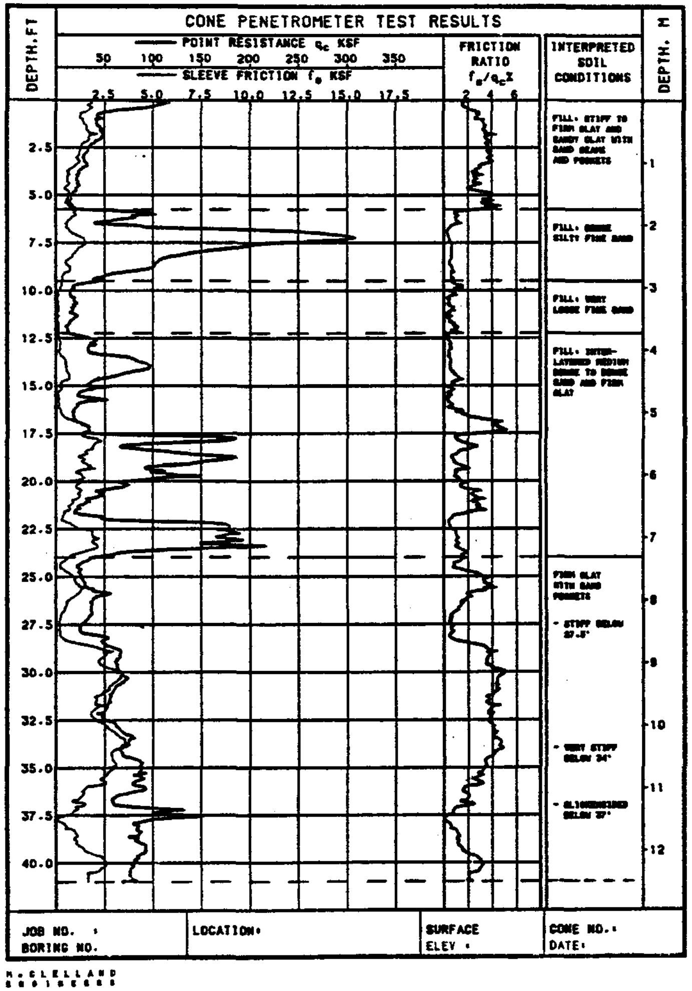

FIGURE 2. TYPICAL COMPUTER-GENERATED CPT PLOT

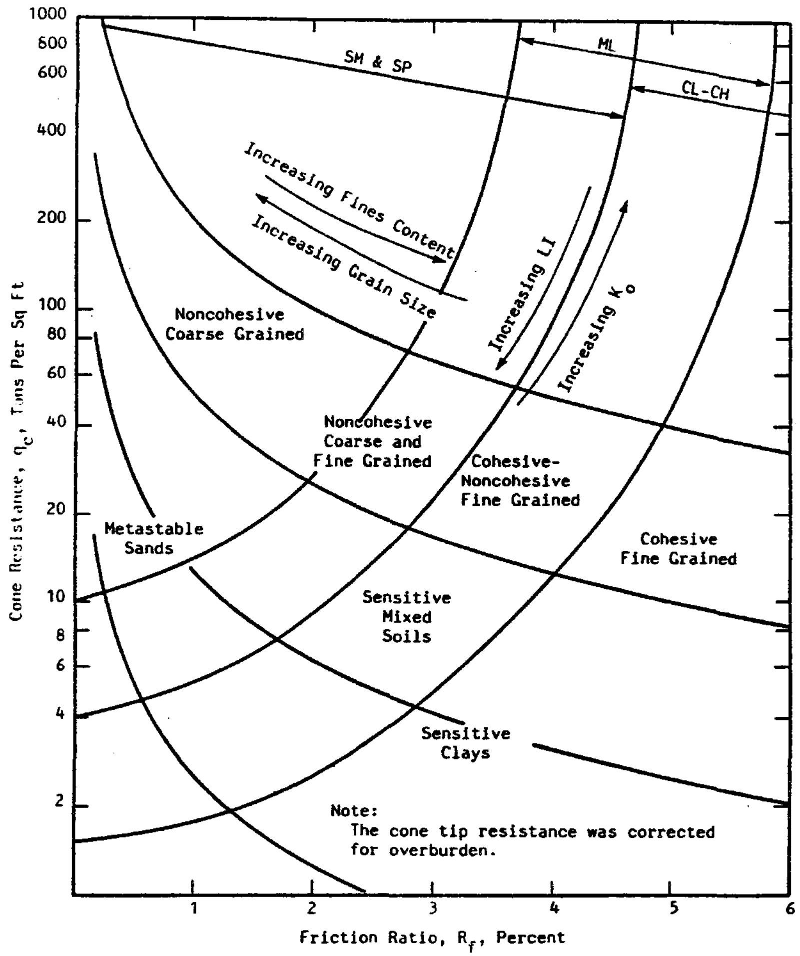

FIGURE 3. CPT SOIL BEHAVIOR TYPE CLASSIFICATION CHART
(After Douglas and Olsen, 1981)

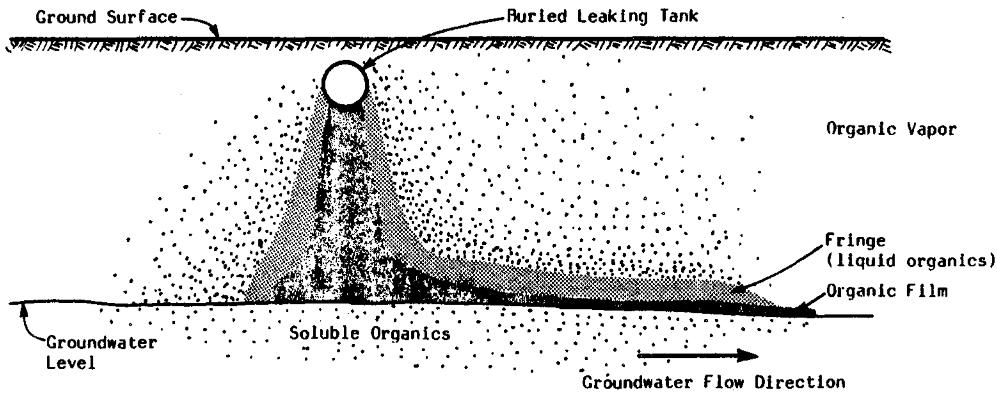

FIGURE 4. SIMPLIFIED DIAGRAM OF DISTRIBUTION OF VOLATILE ORGANICS FROM LEAKING TANK

the soil above the ground water table. The thickness of this band or fringe is dependent on the type of organic compound(s) present, the soil type (organic content, porosity, particle size), and the severity of ground water fluctuations. In this zone, volatilization of the organic compounds results in significant concentrations of organics in the interstitial soil gases. "Clean" soil gases above the contaminated layer create a concentration gradient resulting in diffusion of the compound(s) to the soil above a spill. This movement of the vapors is the basis for identification of volatile organic contaminant plumes using soil gas sampling.

There have been a number of methods used to sample the soil gases from pushing (or driving) a probe or perforated metal pipe into the ground to completing a shallow soil boring. In most cases gas samples have been transported from the probe or well to aboveground equipment for analysis.

McClelland Engineers has developed a probe that is hydraulicly pushed with the same system used for the cone penetrometer. The Vadose Zone Vapor (VZV) probe consists of a hollow barrel covered with a porous material. The probe is connected to an aboveground analyzer by Teflon tubing. The tool has been used at a number of sites to delineate areas contaminated with volatile organic compounds.

The use of a probe to obtain soil gas samples has some of the same advantages as the cone penetrometer: It is fast and inexpensive and reduces the potential exposure to hazardous materials. In addition, immediate feed back as to contaminant location is provided. This allows modification of the field program in response to the information being obtained.

Combined Cone Penetrometer/Vadose Zone Vapor Probe Operation

As illustrated in Figure 5, the Cone Penetrometer/Vadose Zone Vapor (CP/VZV) probe consists of a standard cone penetrometer with a gas

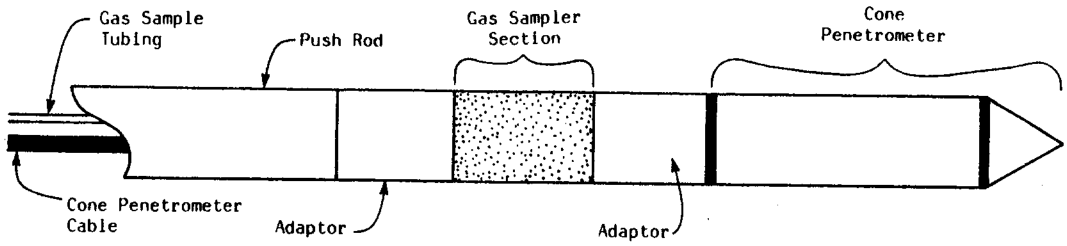

FIGURE 5. DIAGRAM OF CONE PENETROMETER/VADOSE ZONE VAPOR PROBE

collection section positioned 18 inches from the cone tip. The vapor sampler section is connected by Teflon tubing to an aboveground organic vapor analyzer.

Experience indicates that exploration using a cone penetrometer is two to three times faster than completing soil borings. Vapor sampling does not significantly affect the speed of cone penetrometer operation. Exploration with the CP/VZV probe is at least twice as fast as completing borings to obtain soil samples.

The operation of the probe is very similar to that of the cone penetrometer described above. The cable from the cone penetrometer and Teflon tubing from the gas samples section are prestrung through the 1-meter lengths of push rod. Seven to eight lengths of rod are used to allow investigation to depths of 18 or 20 ft. The probe is pushed in three foot strokes as the chuck is moving up the rod. Between pushes a gas sample is taken. From 30 to 60 seconds (depending on the length of tubing used) is required for the gas sample to reach the analyzer.

In low permeable material (clays) the cone penetrometer data may be evaluated immediately so that the gas sampler section can be positioned in a more permeable material (sand or sandy clay) for gas sampling.

Readings from the organic vapor meter are recorded directly on the analog cone penetrometer print out at the appropriate depth. The type of data obtained from the CP/VZV probe is shown in Figure 6.

Applications of the CP/VZV Probe

Situations for which the probe can significantly reduce costs and time in the field include locating plumes from single sources (leaking tanks, pipes, pits, or ponds) and locating plumes from multiple sources (dump site). For a leaking tank, pipe, pit or pond the probe is pushed in a pattern of concentric circles around the suspected source until the extent of the plume is identified. For a site with multiple sources, a grid pattern is more efficient. Both approaches are shown on Figure 7. An analysis of the results can then be used to determine the most appropriate placement of soil borings and monitoring wells.

This tool was developed for surveys of underground leaky tanks and uncontrolled waste sites and is particularly useful when little is known about site stratigraphy. If there are boring logs available that adequately describe the site the cone penetrometer data may not be necessary and the VZV probe can be used independently. If, however, there is little or no stratigraphic data and/or there is considerable change in stratigraphy over short distances, the cone penetrometer can provide invaluable data.

It should be stressed that the CP/VZV probe is a survey tool and that in most cases borings and monitoring wells will be needed. CP/VZV probe results can then be correlated to conventional data (soil classification and chemical analyses) to satisfy technical and regulatory concerns.

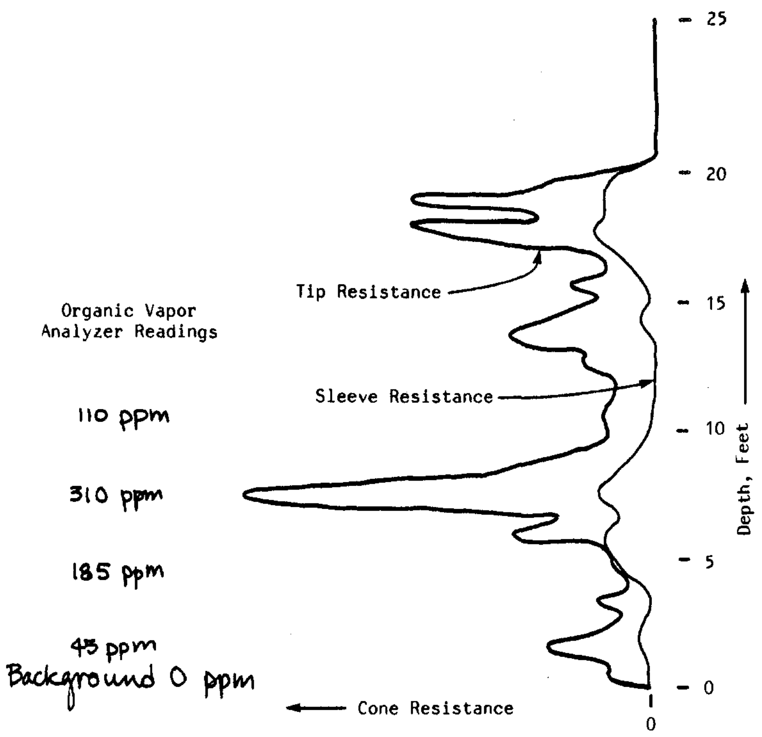

FIGURE 6. CP/VZV PROBE FIELD DATA

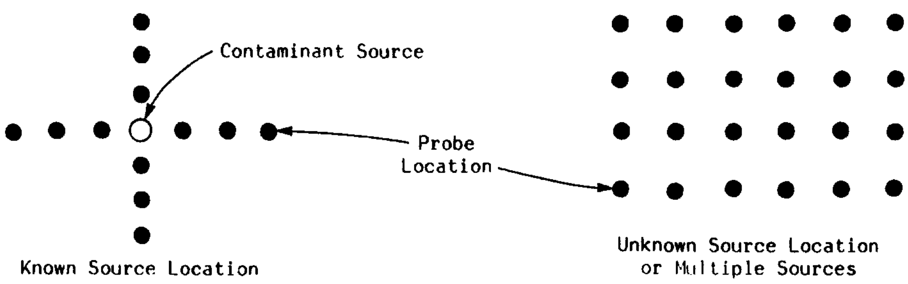

FIGURE 7. EXAMPLE PROBE EXPLORATION PATTERNS

Conclusions

The CP/VZV probe was developed for use at sites contaminated with volatile organic compounds. The probe provides information concerning both soil type and level of contamination.

Potential limitations of the tool include:

- o Very hard materials may be difficult or impossible to penetrate with the cone tip.
- o Depth of exploration is limited typically to about 20 to 25 ft below the surface.

The primary advantages of the tool over conventional methods are:

- o Data concerning soil stratigraphy and contamination can be obtained in a fast and cost-effective manner. Exploration with the probe is approximately twice as fast as traditional methods.
- o The CP/VZV probe survey results can be used to optimize placement of soil borings and monitoring wells, reducing the number required and cost.
- o Fewer borings and wells translate to fewer samples for chemical analysis and lower potential exposure of the field personnel to hazardous materials.

In summary, the ability to obtain soil gas samples combined with the instrumentation for soil classification provides a very powerful tool for the waste manager.

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Susan T. Litherland

Susan Litherland joined McClelland Engineers as a project engineer in Waste Management Services and is now serving as the Chemical Engineering Group Leader. She holds a Bachelor of Science degree in Chemical Engineering from the Univestiy of Texas at Austin, Texas. Currently, she is responsible for process evaluation, optimization and conceptual design for waste management projects. Ms. Litherland has specialized in the development of field screening techniques for contamination and the treatment and processing of contaminated water and soils. She is registered as a Professional Engineer in Texas. Ms. Litherland is a co-author of "Cooling Water Treatment Field Testing for Scaling Control" (Micheletti et.al., 1984).

Thomas W. Hoskings

Dr. Hoskings received BS and MS degrees in Civil Engineering from the Unversity of Texas at El Paso in 1971 and 1972, and a Ph.D. in Civil Engineering from Texas A&M University in 1976. Dr. Hoskings has over ten years of experience in both waste management and environmental engineering. His project involvement includes identifying technologies for sludge stabilization/solidification, wastewater treatment, and ground water recovery. Dr. Hoskings is a professional engineer in Louisiana and Texas. He is the author of a number of technical papers on environmental engineering and waste management.

Ronald L. Boggess

Mr. Boggess received a BSME from Texas A&M University. He is currently Manager of McClelland Engineers' Equipment Development Division. Mr. Boggess has designed many in situ testing tools including a piezometer probe which is in wide use today, a temperature probe with a resolution of .01^{o}C, and a push-in model pile segment which makes in situ measurements of effective stress parameters as well as unit friction and local T-Z behavior. Other accomplishments include a low-cost, portable, 20-ton cone penetrometer thrusting system which can be pulled behind a pick-up or air lifted to remote locations, and a 2-inch diameter submersible pump for collection of water quality samples. Mr. Boggess is a registered professional engineer in Texas and has authored several papers on in situ testing of soils and asphalt.