# *IN SITU* PERMEABILITY MEASUREMENTS WITH DIRECT PUSH TECHNIQUES

## TECHNOLOGY NEED

*In situ* permeability measurements are required to predict contaminant transport and effectively design any soil remediation process relying upon fluid movement. Under a given pressure gradient, flow is directly proportional to permeability. Direct push borehole formation techniques provide fast and inexpensive borehole access for characterization, monitoring, and remediation purposes. However, since cuttings are not removed from the hole and the geologic media are instead displaced outward around the hole, direct push techniques significantly alter the fluid permeability of the soil immediately adjacent to the hole. This effect has precluded the use of standard techniques for measuring *in situ* gas and water permeability with cone penetrometers.

Baseline technologies used for obtaining soil permeability measurements include both borehole and cone penetrometer methods. The most common borehole technique is the measurement of total flow from the borehole under vapor extraction or pump test drawdown conditions. This method has the disadvantage that there is no vertical resolution of the permeability distribution. The second borehole method is to deploy straddle packers and then measure the flow rate and pressure drop from an isolated borehole section under extraction or injection conditions. This approach uses bulky equipment and ideally requires an open borehole. A major disadvantage of both methods is the high cost of drilling a borehole. Using a cone penetrometer, one can determine permeability in saturated media by measuring pore pressure with standard geophysical tools, given the soil has low permeability. The “pore pressure dissipation" technique capitalizes upon the pressure that accumulates adjacent to the penetrometer during emplacement, and the dissipation of this pressure with time. This approach requires some understanding of soil properties and is limited to saturated soils of very low permeability.

There is a need for *in situ*, direct push characterization technologies to provide real-time analysis of volatile organic compounds (VOCs), metals, radionuclides, and hydraulic conductivity. Each year at the Savannah River Site (SRS), approximately 10 Waste Unit sites are characterized, and approximately 200 to 400 samples are collected at each Waste Unit site. The Site Technology Coordination Group (STCG) Need Number addressed is SR-3012 - *In Situ* (Direct Push) Characterization Technologies to Provide Real-Time Measurement of Hydraulic Conductivity and Analysis of Volatile Organic Compounds, Metals, and Radionuclides.

## TECHNOLOGY DESCRIPTION

The Cone Permeameter™ incorporates multiple pressure measurements along the axis of a cone penetrometer rod with a well-defined injection zone and a measured flow rate. The permeability value is obtained by applying a one-dimensional, spherical, steady-state Darcy flow model to the measured injection rate and pressure profile. Near to the injection point the pressure field is distorted by a combination of the cylindrical injection zone and the compacted soil near the rod surface. However, as the distance from the injection point is increased, the resulting pressure distribution will be become spherical. As the radial distance from the source increases, the isobars intersect the cone rod in an almost perpendicular fashion, minimizing any azimuthal gradient that exists across the compacted annulus. By sensing the pressure gradient along the rod at a distance from the injection point, this method is able to essentially ignore the distortion of the pressure field near the injection zone.

A penetrometer rod section is fabricated to allow air or water injection through a screened region. The radial pressure profile is measured with multiple pressure measurement ports distributed above or below the extraction zone. These points are filtered penetrations into the probe that allow pressure communication to sensors embedded in the rod. The Cone Permeameter™ is fabricated in a standard 2-inch diameter rod, with five pressure ports ranging from 0.02 m to 0.8 m from the injection zone. At the surface a fluid pumping system controls the injection flow rate. The data system collects the flow rate and resulting pressure profiles, allowing the calculation of the inferred permeability in real time.

The Cone Permeameter$^{TM}$ rod incorporates a proven fluid injection design and highly accurate pressure sensing elements embedded in the rod. The design allows the permeameter measurements to be conducted simultaneously with standard CPT cone measurements (pore pressure, tip and sleeve stress), which results in real-time, complementary data sets of soil type and hydrologic properties. The data system provides detailed analyses of pressure profiles and process histories for real-time display.

## BENEFITS

The benefits of the Cone Permeameter$^{TM}$ method include:

- Cost for measurements are less than half of borehole measurements.
- Measurement is rapid and integrated with other geophysical measurements.
- Small volumes of injected fluid due to small region of influence.
- Rapid measurements (3-10 minutes per station).
- Minimizes impact of compacted soil due to penetrometer emplacement.
- Integrated with CPT geophysical measurements.
- Makes use of all the benefits of cone penetrometer emplacements:
  --Minimal secondary waste.
  --Rapid mobilization and setup.
  --Low unit measurement cost.
  --Mature technology.

The initial field test of the Cone Permeameter$^{TM}$ system demonstrated its ability to conduct tests rapidly. In a period of 5 hours, 35 measurements were conducted in the saturated zone. These measurements were obtained concurrently with standard cone geophysical measurements, providing a highly integrated data set. Depending on the scenario, this approach will save at least 50% over conventional permeability measurement techniques, primarily because of the cost of borehole formation with drilling techniques.

## CAPABILITIES/LIMITATIONS

The depth of deployment for the Cone Permeameter$^{TM}$ system is the same as the depths achievable with cone penetrometers. The depth is, therefore, highly site-dependent, but penetrometers typically can be deployed to depths of 100 feet or more in unconsolidated soils. The range of permeabilities that can be measured with the Cone Permeameter$^{TM}$ encompass the millidarcy to tens of darcies for air permeability, and $10^{-6}$ to $10^{-1}$ cm/s for saturated hydraulic conductivity measurements. Clays can pose difficulties for two reasons. The first is that the pore pressures accumulated due to the penetrometer emplacement in the saturated zone may require many minutes to dissipate. Very low permeability will impact the Cone Permeameter$^{TM}$ measurement, requiring long waits for steady-state conditions to be achieved. Under these conditions (less than $10^{-6}$ cm/s), the standard pore pressure dissipation technique may be the most appropriate. The second reason is that the pressure ports become plugged during air measurements. The ports can be plugged by clay under saturated conditions, but since it has a finite permeability to water flow the net effect is to only slow the pressure measurement response. For the air measurements, however, the clay may be very close to saturation and have effectively zero permeability to air flow--especially when very low pressure differentials are applied. These conditions can essentially plug the ports. The port design of the Cone Permeameter$^{TM}$ system is being changed to minimize the accumulation of clay over the porous filter material.

## COLLABORATION/TECHNOLOGY TRANSFER

The Cone Permeameter$^{TM}$ technology has a patent pending. SEA Inc. expects to license the technology to a vendor of penetrometer measurement systems once the design is finalized. Applications to smaller direct push systems, such as Geoprobes, are being investigated.

Collaboration with Applied Research Associates, Inc., (ARA) was key to the development of the prototype probe. ARA designed and fabricated the rod section, as well as supported the demonstration tests at Savannah River with their Cone Penetrometer Truck (CPT).

## ACCOMPLISHMENTS

The initial research and feasibility assessment of this system was completed in early 1997 as the first phase of a contract supported by the DOE CMST-CP through the DOE Federal Energy Technology Center (FETC). Numerical simulations and laboratory tests demonstrated the viability of the approach, and are documented in the topical report titled "*In situ* Permeability Measurements with Direct Push Techniques: Phase I Topical Report" published by FETC (November, 1997, SEA Report Number SEA-SF-96-147.)

In the second phase of the development program, a prototype permeameter system was developed and proof-tested in a laboratory test cell. The system was then prepared for initial field trials. The first demonstration of the Cone Permeameter™ was conducted at the SRS D Area Coal Pile Runoff Basin. This area had been characterized prior to installation and testing of a barrier system and interceptor well. The area is underlain by a series of interbedded sand, silt, and clay layers. A dark silty clay, semi-confining unit that is 10 to 15 feet thick separates the water table and semi-confined aquifers. The top of the semi-confining unit is 50 to 60 feet deep.

These tests extended from the water table (at a depth of approximately 4.8 feet) into the top of the confining layer, with the deepest permeameter measurements at approximately 60 feet. The Cone Permeameter™ was integrated with a standard CPT cone tip and deployed by ARA using a 30-ton truck loaded to 26 tons. CPT data (pore pressure, sleeve stress, tip stress) were obtained simultaneously with the permeameter measurements. The permeameter measurements typically required pushing the rod to the desired depth, starting water injection, and observing flow and pressure histories until a relatively steady condition was attained. This required from 3 to 10 minutes per measurement station. On the second day of testing, 35 measurements were obtained in a five-hour period.

**The data system collects the flow rate, and pressure profiles, then it calculates the inferred permeability in real time. The field system is shown below.**

## TECHNICAL TASK PLAN (TTP) INFORMATION

TTP No./Title: AC21-96MC33124 - *In Situ* Permeability Measurements with Direct Push Techniques

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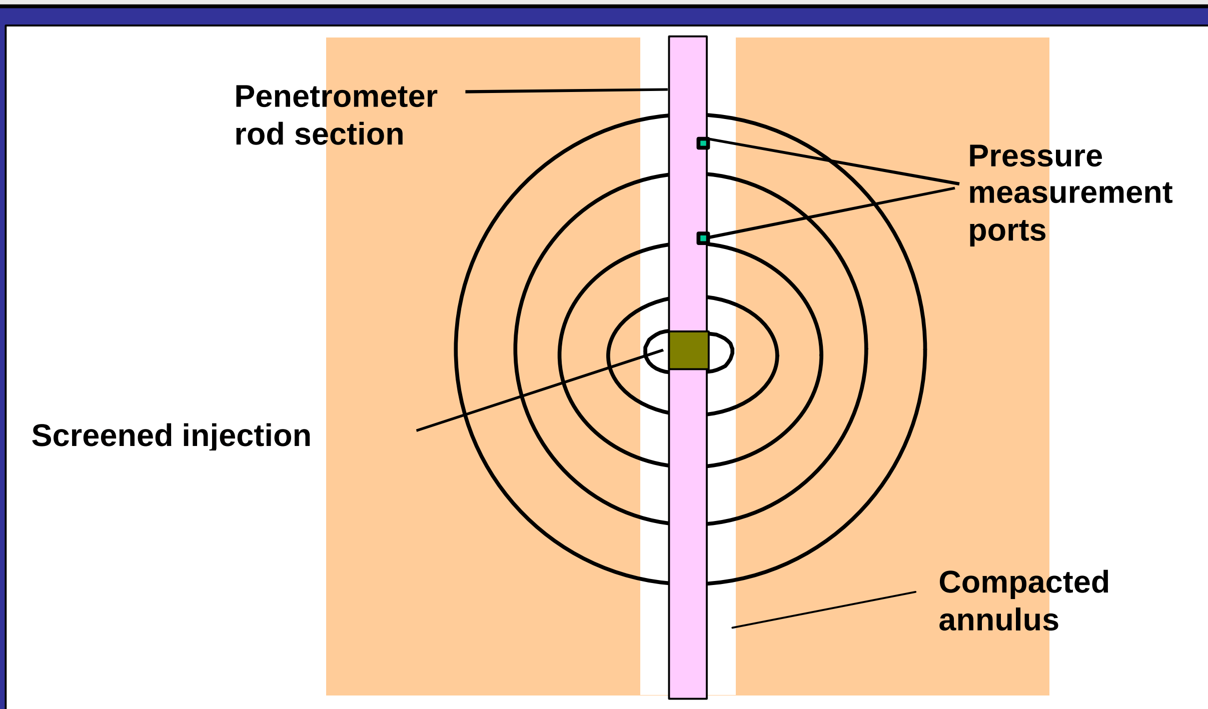


**In the field, the Cone Permeameter™ acquires multiple pressure measurements along the axis of a penetrometer rod with a well-defined injection zone and a measured flow rate.**