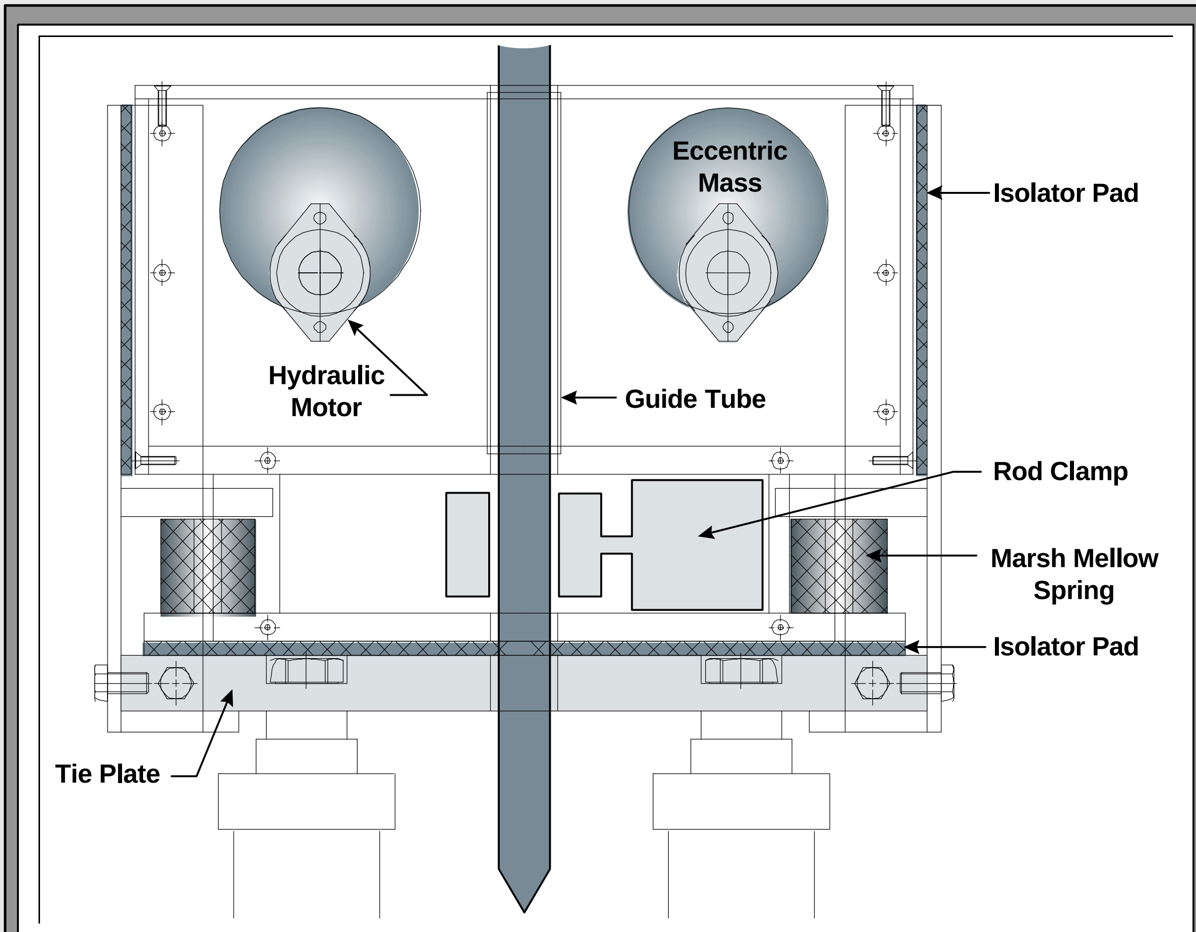
SONIC PENETRATION ENHANCEMENT FOR CONE PENETROMETER

TECHNOLOGY DESCRIPTION

Applied Research Associates, Inc. (ARA) modified a standard Cone Penetrometer Test (CPT) system by mounting a vibratory mechanism above the push-frame, allowing the option of vibrating the rod-string to enhance the effectiveness of advancing sensors into the ground. The drive head uses two counter-rotating eccentric weights to induce a sinusoidal driving force equivalent to the vertical acceleration of the eccentric weights times their mass. The vibratory head is mounted above the CPT clamp-head by vibration isolators that limit the propagation of vibrations into the rest of the clamp system and truck. In this configuration, the vibratory head is clamped directly to the push rod, and the existing hydraulic push cylinders provide the bias load required for vibratory advancement of the CPT rods. The prototype drive-head has a vertical tube through its center to allow the passage of CPT rods without interfering with the normal clamp operation. The cone penetrometer with the sonic enhancement developed for the U.S. Department of Defense (DoD) and the U.S. Department of Energy (DOE) by ARA is referred to as the Sonic CPT.



Schematic View of the Sonic Head Showing the Major Components. The drive head uses two counter-rotating eccentric weights to induce a sinusoidal drive force equivalent to the vertical acceleration of the eccentric weights times their mass.

TECHNOLOGY NEED

The DoD and DOE are pursuing efforts to characterize and remediate thousands of contaminated sites in a cost-effective manner. These efforts are endeavoring to improve the quality of site characterization and remediation processes while minimizing the cost and increasing the efficiency of those processes. CPT technology offers numerous advantages because it is generally faster, less expensive, safer, and generates far less secondary waste than conventional drilling methods. As a result, DoD and DOE efforts have been focused on developing advanced sensors capable of being delivered into the subsurface environment by the cone penetrometer. As probe sizes have increased (from 1.44-inches to 1.75-inches and larger in outside diameter), the ability of the cone penetrometer to reach the desired depth for a given rig weight (reaction force) has been reduced accordingly. The integration of sonic drilling techniques with CPT will advance cone penetrometer sensor packages past the current depths of refusal in many soils and provide an efficient tool and technique for hazardous waste site characterization, remediation, and monitoring. Applicable Site Technology Coordination Group Need Statements:

- SR99-3021 - Alternative Sample Collection and Well Installation Technology That Eliminates or Significantly Reduces Aqueous or Non-Aqueous Investigative Derived Waste (IDW)
- OK99-01 - Characterization and Removal of DNAPLs and Light Non-Aqueous Phase Liquids (LNAPLs) from Soil and Groundwater
- RF-ER14 - Characterization/Detection/Verification of Non-Aqueous Phase Liquids (NAPLs)
- Chemical Form and Mobility of Dense, Non-Aqueous Phase Liquids in Hanford Subsurface Transport of Contaminants RL-SS25-S
- RL-SS25 – Improved, Cost-Effective Methods for Subsurface Access to Support Characterization and Remediation

TECHNOLOGY BENEFITS

The benefits of Sonic CPT have been clearly shown during testing and evaluation demonstrations conducted at several DoD and DOE facilities. The first demonstration was held at Camp Edwards located on the Massachusetts Military Reserve (MMR), Cape Cod, Massachusetts. Previous efforts by the Waterways Experimental Station using standard CPT yielded repeated refusal at approximately 20 feet below ground surface (bgs). The lithology of the site consisted of gravels and cobbles (see following photograph) with occasional boulder-sized fragments that made for difficult pushing. Using the Sonic CPT, six soundings were completed to various depths as deep as 100 feet bgs without meeting refusal. The ability to reach these depths at similar sites could significantly reduce characterization and monitoring costs for responsible parties. For example, during this testing and evaluation program, one of the

Installation Restoration Program (IRP) managers at Camp Edwards expressed an interest in retrieving groundwater samples from approximately 100 feet bgs at one of their sites that is currently in the remediation phase. They were considering placing a recovery well at this particular location and wanted to be sure that it was within the plume. Using the Sonic CPT, several groundwater samples were retrieved for chemical analysis from the area of interest, allowing the IRP to make a more informed and cost-effective decision regarding the location of the recovery well. The other option for them was to bring in a conventional auger drill rig to conduct an exploratory boring at a cost of several thousand dollars.

During a recent weeklong demonstration at Kelly Air Force Base (AFB), the benefits of using the sonic CPT enhancement were realized at sites on and around Kelly AFB. The soil consisted of a very dense, clay-rich gravel layer that is difficult for a standard CPT to penetrate and would typically require the use of a rotary drillrig to penetrate. The combination of a heavyweight truck (30-ton push capacity) and the Sonic CPT enhancement maximized the applicability of CPT technology in this geologic setting. Using the sonic enhancement to the CPT system, several key water samples were collected from sites surrounding the AFB in urban/suburban neighborhoods. The situation at Kelly AFB is politically sensitive, and the sonically enhanced CPT system allowed for the collection of samples with minimal disruption to the environment or to the community surrounding Kelly AFB. In addition, using the sonically enhanced

CPT system resulted in no waste generation to the surface; this lowered characterization costs and reduced work site hazards accordingly.

Typical Cobble-Sized Rock Fragments Found at the LF-1 Site at Camp Edwards, Massachusetts Military Reserve

TECHNOLOGY CAPABILITIES/LIMITATIONS

In general, the sonically enhanced CPT has effectively increased the capability of the standard hydraulic-push cone penetrometer. Testing to date has demonstrated its effectiveness in silty sands (e.g., U.S. Army Cold Regions Research and Engineering Laboratory), gravels and cobbles (e.g., MMR), silty very fine to fine sands (e.g., Savannah River Site) and caliche, a crust of calcium carbonate that forms on the stony soil of arid regions (e.g., Kelly AFB and San Antonio, Texas). Although the sonically enhanced CPT showed marked improvements at all of the aforementioned sites, the most dramatic increase in

penetration capabilities was noted in the gravel and cobble formations at the MMR. With the larger grain size distribution, there is more intergranular space to allow for a more complete reorientation of the soil "fabric." This is a result of a reduction in effective intergranular stresses induced by the vibration.

As with all CPT systems, a trained technician is required to run the sonically enhanced equipment. Additional experience is required to become familiar with the additional controls and safety features of the sonic system. The greater energy developed by the Sonic CPT increases the potential to break equipment; therefore, additional hands-on experience is a must to allow the operator to become familiar with how the equipment performs.

COLLABORATION/TECHNOLOGY TRANSFER

ARA collaborated with several federal agencies and commercial clients during the development of the Sonic CPT. The U.S. Air Force Research Laboratory, Tyndall AFB; the U.S. Army Environmental Center, Aberdeen Proving Grounds, Maryland; and the DOE have provided support for the project.

The DOE Savannah River Site (SRS) hosted a 10-day demonstration and testing event during FY 1997 with interest in using the sonically enhanced cone penetrometer to reach the green-clay layer at a depth of approximately 160 feet bgs. As part of this demonstration, the public was invited to observe the Sonic CPT during a one-day technology demonstration; more than 50 people from both governmental and commercial sectors attended.

During FY 1998, a demonstration was conducted at Kelly AFB to determine the potential of using the Sonic CPT to penetrate a very dense caliche layer to collect groundwater and soil samples. This subsequently led to a commercial contract with CH2M Hill to provide groundwater and soil sampling services during FY 1999.

The DOE Hanford site scheduled a 10-day demonstration and testing event for FY 1999 as part of the Hanford Tank Initiative (HTI) vadose zone characterization. This demonstration evaluated the use of digital CPT sensors under sonic vibration conditions as well as shock isolation techniques for shock-sensitive sensors. In addition, various designs of soil-cutting samplers used to cut through very dense layers were evaluated. The demonstrations at Portsmouth, Ohio and Paducah, Kentucky are planned for June 1999.

Within the commercial sector, ARA has provided Sonic CPT services on Long Island, New York, at a site where perchloroethylene (PCE) contamination has reached a potable water source. The fabrication of sonically enhanced CPT push systems are being discussed with a European CPT company. They are interested in transferring this technology to Europe and will be traveling to the United States to observe a sonically enhanced CPT operation at Kelly AFB or the demonstration at the Hanford Site.

ACCOMPLISHMENTS AND ONGOING WORK

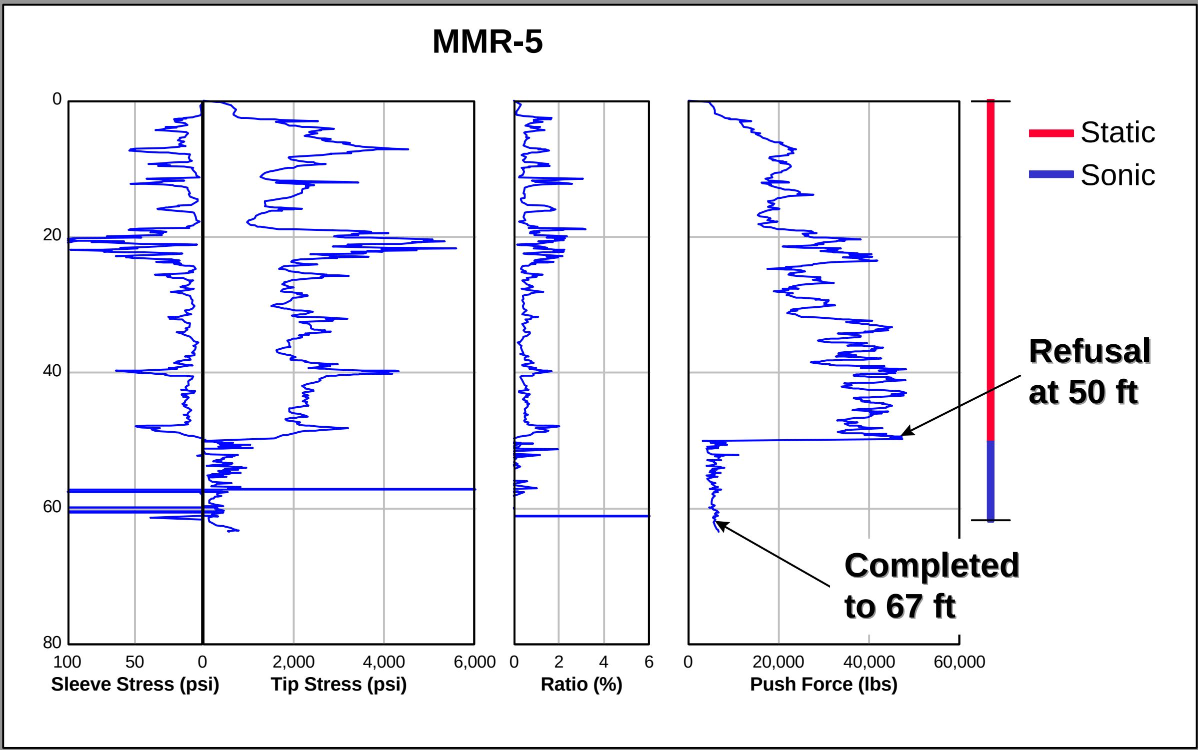
During FY 1997, the sonic enhancement to the DOE CPT truck was field tested at several regional sites. Initial testing was conducted at the Cold Region Research and Engineering Laboratory (CRREL), located in Hanover, New Hampshire. Additional testing and demonstrations were conducted at the U.S. Army's Camp Edwards, MMR.

Testing at the MMR occurred during the week of August 18, 1997, and was conducted at two different sites exhibiting two distinct geologies. During the test program, ARA completed seven CPT soundings and collected four groundwater samples. The first area selected for testing was located along the northwest boundary of the LF-1 landfill. Drilling logs from previous investigations indicated a very dense region at a depth of approximately 20 feet bgs followed by cobbles and boulders from 20 to 60 feet bgs. The MMR IRP geologist described this site as a lateral moraine.

Previous attempts by Waterways Experimental Station personnel to use a conventional CPT at this site were thwarted by repeated refusal at a depth of approximately 20 feet bgs, but this was not a problem for the sonically enhanced CPT (see CPT data in the following figure). Using the sonically enhanced CPT, ARA was able to reach depths of 100 feet bgs without experiencing refusal.

The second area selected for testing was described as a glacial outwash by the MMR geologist and was located in the north-central portion of the MMR. Collecting groundwater samples using the Sonic CPT was the primary focus at this location. The groundwater samples provided vital data for an ongoing remediation program at the site. The site contact for this demonstration was a project manager from the AFB IRP office.

The sonic system was also tested and demonstrated at the DOE SRS in Aiken, South Carolina. The primary goal of the SRS field-testing program was to evaluate the effectiveness of the Sonic CPT in reaching the clay and soil strata characteristic of the M-Basin, with particular emphasis on reaching the green-clay layer at a depth of approximately 160 feet bgs. SRS engineers are anxious to develop an economical method to reach this zone both to characterize the soils and begin cleanup efforts of Dense Non-Aqueous Phase Liquid (DNAPL) contamination known to exist there. The use of a soil sampler with the vibratory system was emphasized during this testing program to demonstrate the utility and robustness of the ARA soil sampler and to provide SRS personnel with soil samples for logging purposes.



Subsurface data showing how adding a sonic vibration capability to the cone penetrometer can be used to overcome refusal and reduce the hydraulic push force required to penetrate some difficult soil conditions.

A secondary, but equally important, objective was to conduct a demonstration of the vibratory system for DOE and DoD personnel as well as representatives from the commercial sector. The goal was to educate the attendees on the utility of a vibratory cone penetrometer and promote its use as a cost-effective technology for site characterization in difficult geologies where conventional hydraulic push approaches are inadequate.

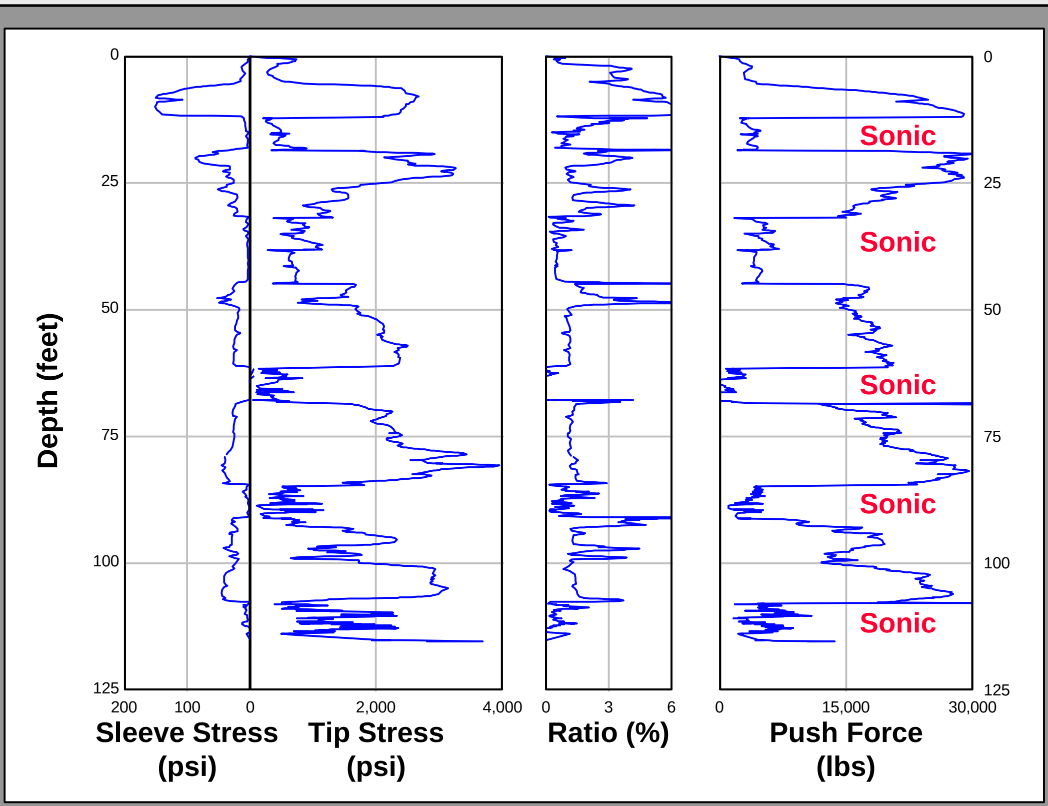
During the 10-day testing program at the SRS, ARA conducted a total of eight soundings. This site offered challenging conditions with a particularly dense, fine sand layer at approximately 120 feet bgs. The soils consisted of dense, fine-to-medium sands with little amounts of clay and were characteristic throughout the site.

Using the sonically enhanced cone penetrometer, ARA was only able to break through this dense layer once, reaching a maximum depth of 183 feet bgs. The following figure illustrates some typical data from the SRS. During our testing at SRS, a prototype core-barrel was developed that was used to "cut" through the dense layer. This provided the impetus for the next stage of development for the sonic system–incorporating coring and rotary capabilities to cut through particularly dense zones. ARA is developing this modification to the Sonic CPT system.

FY 1998 efforts included demonstration and testing at Kelly AFB, at the request of a Waste Policy Institute (WPI) representative. The work was conducted during the week of June 15, 1998. Objectives of the demonstration included testing the sonic system in a geologic area that had proven difficult for conventional CPTs and drill rigs and determining the depth of penetration that could be achieved in this geologic setting with the Sonic CPT. The goal was to find an expedient method of investigating the subsurface conditions at and near Kelly AFB to map a solvent plume that covers a very large area. Through a combination of standard and sonic efforts, the ultimate depth achieved was 37.7 feet bgs. The on-site geologist noted that a drilled hole in the vicinity hit refusal at this depth as well. As a result of our success during the demonstration in FY 1998, the Sonic CPT is being employed at Kelly AFB for a commercial client is being prepared for testing and demonstration at the Hanford Site.

Also during FY 1998, the development of the digital CPT cone and sensor shock isolation concepts were formalized, designed, and fabricated. The digital CPT allows us to use more sensors downhole while limiting the size/weight of the cable needed to transmit the data to the surface. The shock isolation efforts will expand the suite of sensors available to be used downhole with the sonic system. Specifically, optical sensors and gamma radiation sensors are desirable at some sites but they are sensitive to shock loading. By isolating these sensors in specially designed mounts, these sensors can be incorporated into the CPT cone assembly for use with the Sonic CPT system.

FY 1999 efforts to date include bench and field testing of the digital CPT cone and shock isolation concepts. The results of testing show a two orders of magnitude reduction in acceleration delivered to the shock-isolated sensor. These data were collected while penetrating through frozen ground at our New England test facility. This capability will enable us to incorporate the shock-sensitive gamma sensor into the cone assembly without damaging the sensor while using the Sonic CPT.



The above plot illustrates the CPT data from the Savannah River Site, hole SRS-M-004. Note the distinct reduction in tip and sleeve stress as well as the total push force required to advance the sensors into the formation using the sonic system.

TECHNICAL TASK PLAN INFORMATION

TTP No./Title/: HQ07C222 – Sonic CPT Probing in Support of DNAPL Characterization

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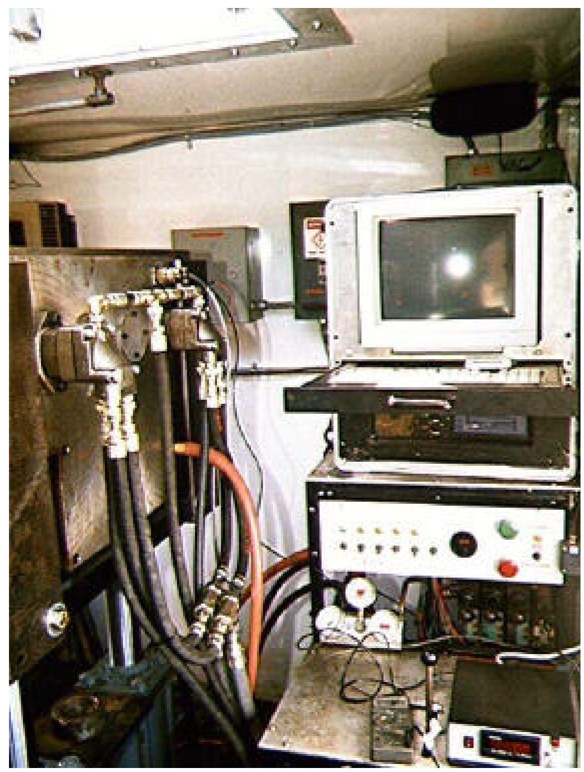

Sonic Cone Penetrometer Test (CPT) Drive System and Controls Installed in a Heavyweight CPT Truck