

Steerable/Distance Enhanced Penetrometer Delivery System

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Introduction

The characterization, monitoring and remediation of many of the nation's highly contaminated sites are among the highest priorities of the Department Of Energy (DOE). Where underground contamination occurs, detection and mapping of the plume are the first steps towards cleanup. Penetrometers are often used for rapid site characterization. This technology requires a depth capability ranging from tens of feet to between 100 to 200 feet, the ability to go around underground obstacles with curvatures that do not damage downhole components, and downhole access for delivery of environmental sensors. In addition, in some instances it is necessary to use lightweight pushing equipment over underground storage tanks so as not to crush the tanks.

The recently developed shallow directional drilling and the traditional "aim and shoot" well drilling use water for a drilling fluid which can spread contamination. In addition, they bring underground contaminants to the surface, requiring costly disposal. The navigational system for directional drills used for environmental work fail around magnetic anomalies and require above ground access directly over the drill bit. As a result directional drilling cannot be performed under steel storage tanks, bodies of water and buildings.

One system which has provided significant advantages over other drilling technologies is the penetrometer. At present, penetrometer applications are restricted primarily to vertical pushes on the order of 100 to 200 feet. Because of their heavy weight, the use of penetrometer trucks over shallow buried storage tanks is restricted and risky. To close the technology gap in the use of penetrometers for environmental purposes, UTD developed a new position location device for penetrometers, referred to as POLO (short for POSition LOCator), which provides real-time position location without blocking downhole access for environmental sensors. UTD subsequently developed a system to make penetrometers steerable and capable of deeper penetration. The product of this work will be a Steerable Vibratory System (SVS) which is a relatively lightweight rig capable of providing greater penetration than traditional penetrometers of the same weight.

Objectives and Approach

UTD's current objective is to complete the development of a steering capability and a vibratory thrusting capability for penetrometer delivery system. Steering provides the means for controlled and directional use of the penetrometer, and vibratory thrusting can provide greater penetration capability. To achieve these objectives, the overall effort was divided into three phases.

The objectives of Phase I included analysis, design and laboratory testing of the individual sub-systems required to perform vibratory thrusting and the steering of penetrometers. These objectives were accomplished, demonstrated and summarized in a Phase I final report [1].

The main objective of Phase II was full-scale system design integration. To achieve this objective, the designs of all the sub-systems that were developed and tested in Phase I were examined and modified as necessary in order to be integrated into a full-scale, field-deployable system. The sub-systems included the steering tip, POLO, steerable rod joints, a torque mechanism and the vibratory/thrusting rig. The results were summarized in a Phase II final report [1].

The objectives of Phase III are to manufacture and debug full-scale components and to demonstrate the full-scale integrated system in a series of field tests under varying soil conditions. The sites selected for full-scale field tests are the DOE Savannah River Site, Aiken South Carolina; the National Test Site at Dover AFB, Dover, Delaware; and the National Test Site at the Naval Facilities Engineering Services Center, Port Hueneme, California.

The approach taken was to use a lightweight rod pushing rig as the main platform for the SVS. The rig pushes rods into the ground by displacing the soil without using water. No cuttings are brought to the surface. The relatively light weight of the rig allows penetration in close proximity of buried storage tanks.

The navigational system selected for integration with the SVS is UTD's POLO system. POLO is not affected by magnetic anomalies and does not require above ground access, making the SVS suitable for site characterization under buildings, steel storage tanks and bodies of water.

SVS Technology

The integrated SVS technology is comprised of five main sub-systems. They are a patented steerable tip, the patented POLO navigational device, steerable penetrometer rods, a vibratory rig and support trailer, and an anchoring system.

Steerable Tip

The steerable tip designed for the SVS is shown in Figure 1. The tip has two modes of operation. In the configuration shown in (a), the tip is in its straight pushing mode, whereas in the configuration in (b), the tip is in its steering position. The switch between the two modes is accomplished by a 180 degree turn of the rod portion of the tip. Once the switch to a steerable mode is accomplished the now-asymmetric tip must be brought to the desired toolface angle. This is done by continuing the tool rotation in the same direction. As the rod is turned, the fins on the conical section of the tip keep the cone from turning in the soil. The fins play two other important roles in keeping each mode of operation of the steering tip stable. First, the fins are bevel biased so that in the symmetrical cone configuration, a clockwise torque is generated on the cone which keeps the cone rotated against its symmetrical position stop [2]. Second, one of the fins has a slightly larger

area than the other which causes a counter-clockwise torque to be generated during pushing in asymmetrical configuration. This torque will keep the cone rotated against its asymmetrical position stop.



(a) Straight pushing mode.



(b) Steering mode.

Figure 1. Modes of operation of the steering tip.

POLO Navigational Device

POLO is the navigational unit of the overall system. It is a patented system that was developed for penetrometer applications under the sponsorship of the DOE METC, Office of Science and Technology. The POLO system has four main modules as shown in Figure 2. They are the POLO rod module, the data acquisition module, the POLO initializer and the data processing module (computer).

The POLO rod module is the sensing element of the system. It is strain gaged in a way that enables the bending strains of the module to be measured as the POLO rod is pushed into the ground. The strain signals are processed by a downhole data acquisition microprocessor and sent to an uphole processor box via a two conductor umbilical. The uphole processor box is linked to a portable personal computer which runs the POLO tracking program.



Figure 2. The POLO system.

To avoid excessive twisting of a continuous POLO umbilical as the rod string is turned for steering purposes a quick-connect concept was developed which uses penetrometer rods as one of the conductors of data. The second conductor is a length of insulated wire, epoxied inside each penetrometer rod and connected at each end to a “quick connector” as shown in Figure 3. When a penetrometer rod joint is tightened, the two halves of the quick-connect meet and provide for electrical connection.

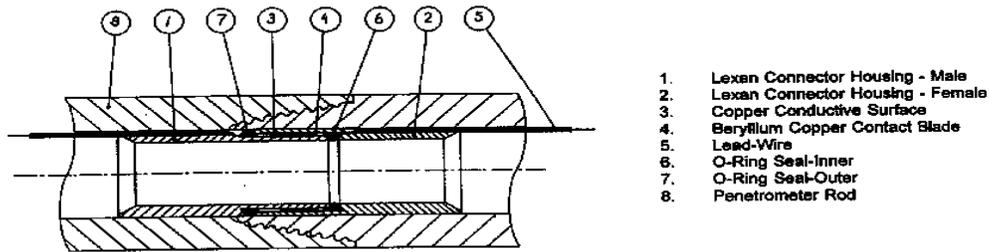


Figure 3. POLO quick-connects.

The POLO tracking program converts strain readings of the POLO rod to global coordinates of the penetrometer at the end of each shove (1 meter). To start tracking, initial angles of the POLO rod just before it is pushed into the ground are needed by the tracking program. The POLO initializer is used for this purpose.

Steerable Penetrometer Rods

In traditional penetrometer applications rods are pushed vertically into the ground. However, in a steerable penetrometer, in order to reach the target of interest the rods are pushed in a curved path. In addition to bending due to a curved path, penetrometer rods will be subjected to steering torques (needed to change the mode of operation of the steering tip). In Phase I it was shown that off the shelf penetrometer rods failed at relatively shallow curvatures (85-100 ft radius of curvature). As a result, a UTD (patent pending) steerable joint concept was adapted to be used with the steerable penetrometer. In order to prevent the rod joints from opening under the steering torque, a locking mechanism was designed for the steerable joint. Figures 4 and 5 show testing of the steerable joint in torque and pushing modes.



Figure 4. Steerable rod torque test.

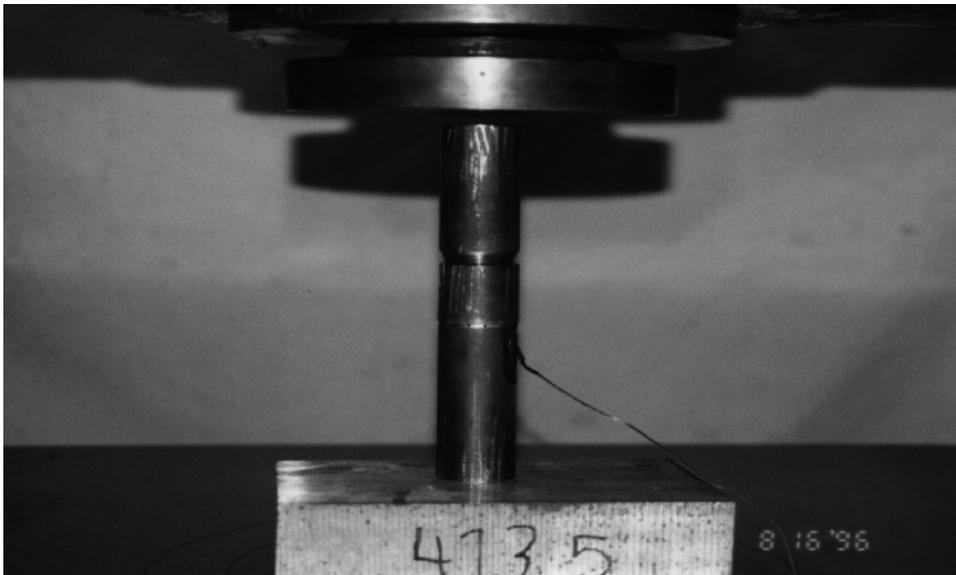


Figure 5. Steerable rod push test.

Vibratory Rig and Support Trailer

During the Phase I contract a search was performed to select and purchase an appropriate penetrometer delivery system. The systems considered included commercial sonic drilling rigs, commercial vibratory penetrometer trucks and vibratory coring equipment. To enable an appropriate selection, the information related to operating envelopes, reliability, user friendliness and adaptability were compared with the requirements of the system.

The selected vibratory system is called META-DRILL (shown in Figure 6) and is manufactured by MPI Drilling. An important feature of the META-DRILL is its modular and off-the-shelf design. The system is made up of five modules that can be upgraded or replaced separately. These modules include the META-PRESS (mast module), vibratory drive, control module, hydraulic reservoir module and power module. The support trailer of the rig is self-contained, road transportable, lightweight and cost effective.



Figure 6. META-DRILL and its support trailer.

Anchoring System

META-DRILL can provide up to 6,000 lbs of hydraulic thrust and 7,500 lbs of vibratory load on penetrometer rods. However, the rig itself is lightweight and can only provide approximately 1,000 lbs of reaction force before it lifts off the ground. Therefore, in order to apply the full thrust on penetrometer rods, the rig has to be anchored to the ground. In Phase II, a screw anchoring system was designed for integration with the META-DRILL. Figure 7 shows the anchoring system in place.



Figure 7. META-DRILL anchoring system.

RESULTS

The results of Phase III (to date) include manufacturing of full-scale components and shakedown testing of the anchoring system. The full-scale components being manufactured include a steering tip, POLO rod module and initializer, steerable rods and electrical quick-connects.

Shakedown testing of the anchoring system was carried out at Ft. Belvoir, Virginia. To install the screw anchors a hydraulic rotary head connected to the hydraulics of the META-DRILL was used as shown in Figure 8. After the screw anchors were installed the META-DRILL was turned on to full thrust and maximum vibratory loading. The screw anchors performed successfully and kept the META-DRILL securely anchored. In the next set of shakedown tests the anchors will be installed in sandy soil in Fredericksburg, Virginia.



Figure 8. Installation of screw anchors.

Other field shakedown activities to be carried out include testing of the steering tip, steerable rods and POLO electronics under vibratory loading, varying paths and soil conditions. Upon completion of shakedown tests the equipment will be transported to the Savannah River Site for the first set of full-scale performance tests.

APPLICATION

The SVS has applications in numerous government and commercial facilities. Within the DOE complex the system will be valuable in environmental site characterization and/or remediation of contaminated basins and ponds, landfills and storage tank farms. The sites expected to benefit most include Savannah River, Hanford, and INEL.

Within the DOD complex there are hundreds of bases or sites with fuel contamination problems under buildings and storage tanks. In the commercial industry oil company tank farm operators and environmental contractors can benefit directly from the SVS.

In addition to inherent benefits of steerability, site characterization by the SVS is more economical compared to current technologies. The sale price for the commercial SVS is expected to be in the \$140k range versus \$100k-\$250k for directional drills. Based on Reference 3, the cost of commercial hole production averages to \$50-\$60/ft. If the target is missed and the hole is redrilled the cost may jump to \$75-\$90/ft. In comparison the cost of hole production by the SVS is estimated to be in the \$40/ft range.

FUTURE ACTIVITIES

Future activities in Phase III include completion of field shakedown tests and full-scale performance field testing and demonstration at government facilities. Upon completion of Phase III, UTD Incorporated is planning to commercialize the SVS and sell its components or the system as a whole. In an effort to commercialize the system UTD has been involved with the Commercialization Assistance Program (CAP) and has developed a business plan.

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