UTILITY OF FLEXIBLE LINERS INSTALLED VIA PUSH RODS

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BACKGROUND

In 1998, Westinghouse Savannah River Co. (SRS) asked Flexible Liner Underground Technologies (FLUTe) to design a color-reactive ribbon for attachment to FLUTe's everting, air-driven, flexible liners for installation and retrieval from stable cone penetrometer (CPT) rod holes. A further request was for the same flexible liner to be installed, with ribbon, through the center of the CPT rods below the water table in unstable media. That request initiated the development of a number of flexible liner designs that have been installed in CPT rods, Geoprobe rods, and even hollow-stem augers. The common feature of these installations is the method called, in patent language, "flexible liner installation via rigid casing." Installations are done with air or water as the pressurizing fluid. The liners have many applications in environmental characterization.

THE INSTALLATION METHOD

The installation of a pressurized flexible liner to support and seal a hole, a common concept for FLUTe everting liners, is used in many places. However, the installation method for such a liner in a hole supported by a steel liner is not obvious. The installation of a flexible liner in a hole temporarily supported by a very slender steel casing, such as a cone penetrometer rod, is more demanding. The liner is left in place as the rod is withdrawn.

Installing a liner in the earth via a slender rod offers two challenges. The first is to emplace a relatively bulky liner into the rod after the rod has been driven to depth. The second challenge is to inflate the liner so as to support the hole wall without developing the extremely high friction of the inflated liner in the rod interior at the same time. The friction of an inflated liner in a rod can produce tons of drag. This drag normally would prevent the rod from being pulled off of the inflated liner.

The essential components of the system are a central tube, a surrounding liner, and an outer compressive wrap. The carrier liner is a strong, impermeable, coated fabric. The actual application dictates whether the system also includes either a reactive covering (DNAPL detector) on the liner, interior sleeves (for multilevel water sampling), or a well screen (single-well system).

The water injector attached to the top of the central tube can be either a water addition device or an air addition device; for simplicity, the water installation procedure is described first.

The carrier liner is too bulky to be pushed down the central hole of a 1-in.-i.d. rod. The compressive wrap compresses the carrier liner onto the central tube for a final outside diameter of the assembly of less than 1 in. This "rope" of compressed material is then lowered into the central hole of a push rod assembly after the rod has been pushed to its full depth. The tip of the rod is "disposable" and is left in place as the rod is withdrawn.

After the liner assembly is lowered to the bottom of the rod, the rod interior is filled with water that surrounds the "rope." The central tube of the liner assembly is connected to a water injector that provides a measured amount of water at a controlled pressure.

Next, the rod is lifted in the hole to expose one rod section of hole wall. The liner assembly is held in place against the bottom of the hole as the rod is raised. Water is added via the central tube under pressure to burst the compressive wrap and to dilate the liner in the exposed hole. The liner dilates in the rod somewhat, but the water in the annulus between the liner and the rod wall (the annular water) resists the dilation of the liner in the rod. Because the geologic formation is usually somewhat permeable, the liner dilates freely against the hole wall to anchor the liner in the hole with very high friction against the hole wall.

The top rod section lifted out of the ground is removed by sliding it off the central tube. The tube is reconnected to the water injector.

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Water is again added to the annulus between the liner and the rod wall at the surface. This water at relatively high head compresses the liner and the water inside the liner. The high pressure in the liner allows the liner to support and seal the hole wall where the liner lies against the hole wall. The water added inside the liner is more than that needed to fill the hole exposed. Hence, some water is stored in the liner interior inside the rod.

A measured amount of water is injected again into the liner interior via the central tube. This amount is sufficient to fill the next section of hole to be exposed by withdrawal of another section of rod. This water addition typically forces some of the annular water out the top of the rod.

The next section of the rod assembly is then lifted and removed. Since the liner is anchored in the exposed hole and the friction in the rod is low because of the annular water, the liner stays in place and dilates out of the bottom of the rod to fill the hole as the rod is raised. Water is again added to the interior of the liner and also to the annulus, if needed, to fill it to the top of the rod. The next section is withdrawn. The procedure is repeated until the rod sections have been entirely removed.

This procedure leaves a water-filled liner in the hole. The interior pressure of the filled liner supports the hole against collapse.

THE REMOVAL METHOD

The liner assembly can be removed by simply pulling upward on the central tube. The liner inverts and is peeled, inside out, from the hole. The unsupported hole is now free to collapse.

In this manner, a liner can be installed and removed from a hole that is temporarily supported by a steel liner. That steel liner can be a push rod, a driven casing (e.g., an Odex casing or sonic-driven casing) or other temporary liner emplaced during the drilling procedure.

UTILITY OF THE TECHNIQUE

The NAPL Mapping Method

The installation of a flexible liner as described above allows the installation of many devices — either included in the compressed assembly, installed in the resulting open liner, or both. The first use described above is installation of a color-reactive cover on the exterior of the liner with the liner assembly. Once the liner is in place, it presses the outer covering against the hole wall for contact with solvents or other materials in the soil pore space. The cover reacts with the contaminants. The cover is removed for identification of the locations of the reactants by simply inverting the liner and the cover with it. In this way, the cover does not make contact with any other part of the hole. The carrier liner is removed from the cover, a tape measure is placed next to the cover, and the locations of the contaminants in the subsurface are deduced from the stains on the cover. This method is called the “Ribbon NAPL Sampler” (RNS) by Westinghouse Savannah River Co. or “NAPL FLUTe” by Flexible Liner Underground Technologies. A patent is pending on both the installation procedure and the reactive cover.

Multilevel Sampling Procedure

A second application of the method allows the installation of a carrier liner that has been specially fabricated with interior sleeves. Once the liner is in place, miniwells of slender, flush-jointed tubing are inserted down the sleeves. A screen at the bottom of each miniwell matches the perforations of the liner into the volume of the sleeve. Thus, water can flow from the formation into the sleeve and the screen of the well, to be collected from the well in a variety of ways. The sleeve is pressed firmly against the miniwell by the excess head in the interior of the liner. The bottom of the sleeve is sealed to prevent communication with the interior water in the liner. The liner seals the hole with its interior pressure. In this way, up to three miniwells have been emplaced in punched holes to depths of 80 ft. Each miniwell has access to the medium at a different elevation.

Extensions of the Method

Recently, the same principle was employed for installation of a blank liner (with no attachments) through a hollow-stem auger as the auger was being rotated out of a hole. The difference was that air was used as the pressurizing fluid in the liner instead of water. The liner was left in place in the vadose zone. Because air does not provide excess pressure in a liner as easily as water does, the top of the liner must be sealed. The equivalent of the push rod was a 3-in.-diameter tremie lowered into the interior of the auger. The tremie did not rotate with the auger. The tremie was capped to contain the air forced down the “annulus” outside the pressurized liner. The rest of the procedure was analogous to that for water installation, in that air was added to the inside of the liner, then to the outside, and the auger was raised.

Once the blank liner had been left in the hole, a second instrumented liner was installed in the same hole beside the sealing and supporting blank liner. The second liner, emplaced via the FLUTe “Duet” technique, was used for multilevel sampling of the pore gas in the formation. Installation in an auger is more complex than water installation via a push rod because of the need to contain the pressurizing fluid and the limited access to the tremie inside the auger.

Another installation was done with the push rod replaced with a sonic-driven casing. The sonic casing is so large that it does not hold the liner upright in the interior of the casing. No compression covering is required. The liner is held in position in the casing by a slender tremie pipe installed in the liner instead of the flexible central tubing. Thereafter, the procedure is the same as for the CPT rods. The sonic casing method of installation and retrieval worked, but the 200 denier liner used was not strong enough to withstand the high head in the casing. A 400 denier liner should overcome the problem.

QUESTIONS OFTEN ASKED ABOUT THE METHODS

The most common questions are as follows:

1. Does the liner seal the hole well?
2. Does the liner survive the friction and other damaging possibilities?
3. How deep can the liner be installed?
4. Does the color-reactive cover work?
5. Are the samples collected in the miniwells representative?
6. Will the liner stand the vibration of the sonic casing?
7. Can the installation be used in Geoprobe rods as well as CPT rods?
8. How much does the installation cost?
9. Can anyone install the liner, or are FLUTe personnel required?
10. Where has the product been used, and did it work?

Most of these questions are answered in this paper.

RESULTS

The NAPL Ribbon ("NAPL FLUTe")

The color-reactive covering has been used in many places. Some of those were reported by Riha et al. (2000). Mapping of TCE, creosote, and other DNAPLs has been done at a variety of sites. The method works very well; it locates only the free-product phase and then only if the product is sufficiently mobile to flow against the hole wall liner. Photos of the resulting stains were published by Riha et al. (2000). Installations at Cape Canaveral were especially colorful with TCE stains.

Interestingly, the reactive hydrophobic covering absorbs hydrophobic liquids that do not leach the dye and stain the covering. The resulting absorption stains (e.g., heavy oils) clearly indicate where the liquid is located in the hole. Fuel oil and other stains have been found where no TCE (the target of the installation) was found. Please contact the authors for more examples of such use.

Originally, Sudan IV was used as the dye for DNAPL detection. However, the toxicity of Sudan IV caused us to abandon that dye. A nontoxic dye in a stripped pattern that is now used is mobilized by solvents wicked into the cover to produce an obvious stain pattern on the cover. This dye is also much less expensive to produce than the original covering loaded with Sudan IV.

These reactive liner systems were recently installed in Denmark in Geoprobe rods of very small size (0.625 in. x 1.25 in.) to depths of ~18 m (59 ft). Such small rod installations have probably reached the limit of the method with the current materials.

The reactive liner systems are currently installed by a number of companies. Some provide a wide range of other push rod services.

The Miniwell System

The miniwell system evolved from the original design by FLUTe for installations into liners everted into holes in the usual manner. However, the low cost of the punched hole made installation into liners in such holes attractive. The miniwell concept has been employed mainly at an Argonne National Laboratory site in Nebraska to monitor carbon tetrachloride contamination in an aquifer of glacial sediments. The liners were installed via a large CPT rod (1.5 in. x 2.25 in.). Subsequent installations have been done elsewhere via Geoprobe rods of slightly smaller size (1.5 in. x 2.125 in.).

Samples from the Mini FLUTe systems, as they are called, have been compared with both nearby CPT water samples and samples from a nearby well to evaluate the water quality of the miniwells in flexible liners. The results, shown in Figure 1, are very good. The single comparison with a nearby water well (65D, 5 ft distant) showed the miniwell concentration to be higher (927 µg/L) than that obtained for the water well (574 µg/L) with the usual purging and sampling procedure. The sample was obtained from the miniwell by positive displacement of the sample to the surface with a compressed gas.

Note that Argonne measured the concentrations of contaminant in the purging and sampling streams from the miniwell to assure collection of sample from a portion of the sample stream that was not affected by purging. The procedural result was that the miniwell was purged of water via two strokes. In the third stroke, the drive pressure was reduced, and the first part of the third stroke was discarded. Thereafter, the sample was collected. Because the miniwell volumes are so small and the sample after purging is drawn directly from the formation with minimal dilution by the former well water, the sample is expected to be very representative. The results (Figure 1) suggest the same. It is satisfying that the result for 71S (which compares least favorably), where the miniwell was 15 ft farther from the plume axis laterally than the comparison CPT well, still fits within the model of the plume.

The seal of the liner was a major concern for the miniwell systems. We initially expected that the pressurized liner would give a seal superior to that obtained by pumping sand and grout into the small annular space of a well emplaced through the rod. Direct comparisons are difficult. To date, the seal seems to be good if the liner has been well filled with fluid. In a couple of the initial installations, the end seal probably failed and the leaking liner did not seal well. Subsequently, all liners have been filled with a Bentonite slurry to preserve a positive pressure in the liner. This approach seems to preserve the seal quality of a continuous packer as originally conceived. We note that the entire hole is sealed by the liner. The wells are interior to the liner and are installed after the liner has been emplaced.

The miniwell liner should be as easily removed by inversion as the color-reactive liners have been. If the hole caved in on the liner (e.g., due to squeezing clays), removal would be difficult. However, miniwells have been removed and replaced in sleeves. No miniwell liners have yet been successfully removed intact. Removal has been attempted only for liners that had lost the excess head needed to stabilize the hole. Overall, most of the first miniwell liner installations attempted are producing good sampling results. The procedure and construction techniques have been much refined.

The miniwell system was installed at Fort Meade via a Geoprobe rod system (1.5 in. x 2.125 in.) in the vadose zone and was removed quite easily.

A newly developed design emplaces a single well in a hole via a push rod. The bottom end of the system is the traditional screen. The hole from the screen to the surface is sealed with a liner that is expanded in the hole as the rod is withdrawn. The perceived advantages are the seal quality of the hole and the ease of installation. No sand or grout must be emplaced in the confinement of the slender hole. The installation procedure is identical to that above. The central tube is the riser. Once the rods are pulled, the well installation

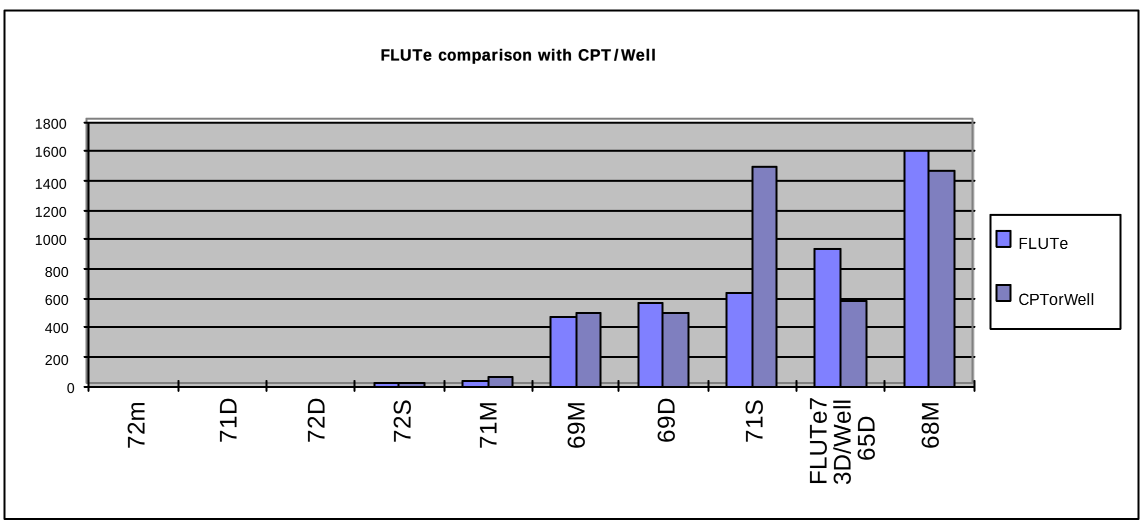

FIGURE 1 Comparison of Samples from FLUTe Systems and CPT Holes or Wells is done. The top can be completed above or below the surface. The well is fully removable by pulling on the central riser, a 1/2 in. x 5/8 in. nylon tube, and inverting the liner out of the hole. A check valve above the well screen allows the system to be purged and sampled easily by using a gas displacement system like that used on all other FLUTe sampling systems. This design works well in the laboratory, but it has not yet been tested in the field.

IN CONCLUSION

The method reported here has been used in many places (e.g., South Carolina, Cape Canaveral, Nebraska, Maryland, Denmark, California, and Texas), in a wide variety of situations, to emplace flexible liners for sealing the hole, mapping DNAPLs, multilevel water sampling, and vadose zone gas sampling. The method involves dilation of a flexible liner in the hole, below the push rod, as the rod is withdrawn. The flexible liner left in the hole seals and supports the hole. Once in place, the liner is used for many purposes; however, in most cases, the liner can be removed from the hole by inversion (peeling the liner out of the hole). This peeling of the liner from the hole allows the recovery of color-reactive materials for mapping of the distribution of a variety of contaminants (mainly solvents and oils) in the subsurface. The pressurized liner in the hole effects a seal that is also useful for a variety of fluid sampling techniques.

A remarkable achievement this year was the repeated installation in Denmark of a color-reactive liner through the very slender rods (0.625 in. x 1.25 in.) of a Geoprobe system to depths as great as 59 ft.

PATENTS

Patents are in place or pending for each of the methods described.

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