IN SITU CONSTRUCTION OF HORIZONTAL SOIL CONTAINMENT BARRIER AT FERNALD

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Abstract

An innovative method of placing soil barriers to contain vertical flow is being prepared for demonstration by the Fernald Environmental Restoration Management Corporation (FERMCO), working in conjunction with the Department of Energy Office of Technology Development (DOE/OTD) and two principle subcontractors. The method employs proven directional drilling techniques, jet grouting technology and unique placement tooling to form horizontal soil barriers in situ. This is done without disturbance to existing land disposed wastes.

This paper is a summary report on the current state of that demonstration, including: a discussion of the construction methods, the results of the initial tool tests, an overview of the Fernald site conditions and, the resulting path of tooling development for the second phase of tool testing.

INTRODUCTION

Temporary or long term containment of mobile contaminants from existing land disposal waste site requires effective surrounding barriers. Current technologies typically require removal and repackaging/reprocessing of waste from its existing location or rely on existing impermeable soil layers beneath the waste. In situ constructed vertical barriers, or cut-off walls for the restriction of horizontal flow, have been used extensively and are relatively well understood. However, a full containment is difficult to achieve unless these walls can be tied into existing impermeable layers (clays). Those layers may be very deep or missing entirely. In either case, the containment then depends on the integrity of the existing geology. This is often difficult to assure.

The use of in situ constructed horizontal containment to restrict vertical flow is not highly developed. When dealing with existing sites, it is a problem to place containment without disturbing the waste. The excavation to or through the waste can create unacceptable health risks and/or regulatory problems.

At several DOE sites natural barriers to vertical migration do not exist at usable depths beneath existing sources of contamination. Examples are both Hanford and Savannah River sites (although their basic geology varies greatly). Like situations exist at government and commercial industrial, chemical and petroleum storage sites. Attempts to produce barriers to vertical flow have generally relied on permeation grouting, using large amounts of material, to form a floor beneath the source. The uncertain nature of these processes and the difficulty of conclusive inspection at depth raises regulatory concerns.

This paper describes a demonstration/innovative adaptation of jet grouting techniques to form a soil barrier in situ, the results of initial tooling tests and, the plan to bring the technology demonstration at Fernald to successful completion.
TECHNOLOGY/PROCESS DESCRIPTION

This innovative process for placing in situ barriers is a self verifying technique that actually moves a solid tool completely beneath existing sources of contamination, leaving a continuous soil and grout (soil-cement) mix behind, in the tool's wake, to form a containment. Multiple passes of the tool can be used to form a barrier of significant size.

The typical jet grouting process uses a cement grout pumped at very high pressure (up to 10k PSI) to a set of nozzles arranged in a single line on a pipe tool. When the grout exits the nozzles of the tool, the pressure is converted to velocity. If the tool is in contact with a soil formation, the high velocity grout transfers its kinetic energy to the soil, erodes the formation and mixes with the spoil. This forms a soil-cement. Both the soil and the grout and their respective ratios determine the properties of the resulting mix. Portland cement in a 1:1 ratio with water is a common grout mix. Bentonite, pozzolans and other additives are often used to modify properties and control costs.

A rod shaped jet-grouting tool (with a single line of jets down its length) may be placed vertically into the soil (by drilling or driving) and used to form a soil-cement cylinder, column or pier by rotating the tool and slowly withdrawing it leaving soil-cement behind. Conceptually, if the same vertically placed tool is moved perpendicular to its axis and along the line of flow of the jets, it will cut the soil and leave a soil-cement "wall" in its wake. This action is the key to placing continuous horizontal barriers.

The equipment set necessary to perform successful jet grouting includes dry grout bulk storage bins or tanks, efficient mixing systems, effective grout cleaning equipment (screens), high pressure pumps (10k PSI) and power systems to support the production equipment. All parts of this supporting suit must deliver sufficient reliable capacity to ensure a steady flow of clean grout to the tooling. In addition, the horizontal barrier formation process requires powerful pulling equipment and directional drilling equipment.

The process of forming a horizontal grout barrier begins by placing two generally parallel directionally drilled holes from the near side (clean) surface, passing completely beneath the source of contamination and emerging again at the (clean) surface on the far side. The drilling stems remain in the holes and are attached to a draw bar and a pulling device at one end. The stems' other ends are attached to the front of a jet grouting tool. A grout feed line and a trailing drill stem are attached to the rear of the jet grouting bar, forming a capital "H"-shaped arrangement with the jet grouting tool as the crossbar of the "H" when viewed from above (see Figure 1). A tractor, winch or pipe puller then pulls on the draw bar attached to the stems forming the top of the "H" and moves the jet grouting tool through the soil along a path between the directionally drilled holes.

Place Figure 1 here

The jet grouting tool is an injector-mixer which leaves a soil-cement (grout and native soil) slab in its wake as it is pulled through the soil and beneath the source of contamination. It emplaces the soil-cement slab by employing grout delivered at high pressure, up to 10k PSI, to develop high velocity
through use of jet nozzles. The high velocity grout streams emerging from the tool’s jets cut soil formations by transferring their kinetic energy (through impact of the grout) to the formation around the tool. The high amount of energy involved and the abrasive nature of the grout currently in use gives a strong cutting action (which can be augmented by mechanical cutting). The remainder of the grout’s energy is dissipated in a turbulent mixing action that forms the soil-cement. The formed barrier slab is continuous back along its path to the surface and remains fluid. Therefore, there is no significant build up of grouting pressure. A flow of excess grout and some spoils to the surface keeps the formation open and is expected to avoid pressure build up and issues of significant slab jacking or extensive fracturing of the soil formation.

Joined slabs, necessary to form an extensive bottom, are to be formed continuously and sequentially by using the previously mentioned trailing drill stem from the last slab and an additional, generally parallel, directionally drilled-in stem to make each additional slab. (see Figure 2) The use of the trailing pipe ensures that each slab overlaps the previous one and that a continuous bottom is formed. Continuous forming and the grout formulation ensures wet joints with commingling along seams to enhance the integrity of the final barrier. This process is repeated until a bottom of the required width is formed.

This process produces grout overflow, drilling spoil, excess soil-cement and washout water, as secondary waste. Because the path of the directional drills and the barrier does not have to contact the waste, these secondary wastes may not be problematic.

Conceptually, the technique is simple to use. It relies on two proven technologies: grout high pressure pumping techniques and DOE/OTD demonstrated directional drilling methods. The difficulties of operating in rocky soil, cobbles, till and other challenging conditions remain to be determined and are challenging areas for additional work.

The horizontal barrier is potentially applicable to containment of a wide range of existing land disposal sites, underground storage tanks, spills and ruptures. The types of grout that may be placed are extensive, the jet grouting tool may be expected to place materials that can be fed to it as a liquid at the required volumes and pressures (grout tolerance to shear and impact may be issues). It should also be noted that this "horizontal barrier" can vary from the horizontal plane through the vertical for special applications, simply by varying the arrangement of the directionally drilled holes.

THE FERNALD DEMONSTRATION PROJECT

The objective of this work is to place a joined, four pass, demonstration horizontal barrier on a radiologically "clean" site at the Fernald Environmental Management Project (FEMP) site in southwest Ohio. The demonstration will build various tooling combinations and test them at a separate location prior to mobilizing to FEMP with at least the two tools
thought best suited to the local conditions. Placement techniques, surface support systems operations and longitudinal joining integrity (seaming) are of primary interest in the work. A simple portland cement-based grout will be employed to control costs.

The FEMP site is a 600' x 200', area clear of surface and below grade obstructions. The site is accessible from plant roadways for trucks and heavy equipment. The completed demonstration barrier will cover approximately 100' x 40' of the test area and will begin near the surface and drop to a nominal placement depth of 12', rising to the surface at the far end. Soils at the site were classified as Pleistocene (6,000 - 10,000 year) glacial till to a depth of 30'. Well developed, historically cultivated A and B loam horizons are located to a depth of approximately 18'. As a homogeneous, semi consolidated unit, the unweathered tills generally consist of approximately 75% mixed brown and gray clays, with 25% silt and fine sand in approximately equal proportion. Organic concentration below the cultivation level is less than 5% and moisture content varies from 3 - 10%. Lenses of moist to saturated sand, 1' to 3' thick, exist at random through the body of the till. Exploratory excavations revealed that the predominantly brown clays are underlain by a discontinuous rocky layer containing both limestone slabs and glacially transported granite schist, at a 12' depth below grade. The gray clays below that depth were distinctly less sandy and silty, and more plastic.

The existence of the rocky layer and strata change at 12' depth on the FEMP site is a concern for both tooling and testing and will impact the final operating depth for the demonstration.

The FEMP demonstration barrier will be placed, allowed to cure and then excavated for testing by an independent academic agency. The testing will include: surveying the site, measuring displacements and tilts during placement, physically sectioning and characterizing the barrier and conducting applicable strength and permeability tests to evaluate the uniformity and integrity of the barrier across seams. Key to the test effort is the issue of determining if adjacent barrier panels, formed on sequential passes of the tooling, can be joined in a reliable and reproducible manner to form a uniform and competent barrier.

PROGRESS/STATUS

The work involved in this project covers more than two years of effort, directly aimed at establishing a viable capability to place in situ soil barriers to vertical flow. Two separate series of tool tests have been conducted and the knowledge gained from those tests was incorporated into the design of a third generation of tooling for up-coming field testing. For all testing completed and planned, the directional drilling was/will be simulated by trenching in the drill pipe, backfilling and compacting the overburden. Directional drilling is considered a DOE proven "enabling technology" at this point. The cost savings to place the drill pipe by trenching, rather than by drilling, were significant to the project.

The initial field work, begun in 1992, involved simple proof of concept work to answer the issues of "can this be done at all." Two basic types of tool were successfully tested in sandy soil and soft sandstone formations in
Oklahoma.
The first tool was a solid bar with a line of forward-pointing jets for distributing grout forward, in the direction of travel, in streams like the teeth on a pocket comb. Also developed was a prototype rotary tool shaped like an automotive camshaft with angled, cross cutting jets distributing grout from the circumference of the lobes. The rotary tool was driven directly by a down hole hydraulic motor with fluid lines to the surface. Each tool was approximately 10' wide.

The solid bar tool produced the strongest cutting action, as its 61 jets were all aimed forward, concentrating the available kinetic energy on the formation directly ahead, shattering the soil and liquefying the path of travel. The solid bar was also relatively efficient in the use of grout since the cutting action all took place forward of the path of travel. Panels could be formed at the rate of 20 to 100 square feet/minute. Several shortcomings were apparent: the barrier formed was thin, barely exceeding the width of the bar; the barrier was irregular, due to the non-homogeneity of the formation and the fixed direction of the jets and; the solid bar was very susceptible to failures from the blockage of one or more jets. These drawbacks to the solid bar led to increased soil resistance and bent or broken tools. While the simplicity of the tool was a plus, improvements were deemed necessary.

The prototype rotary tool produced a thicker and more uniform barrier slab, one that was 10' wide, 12" thick and literally looked like an underground highway when a section of it was excavated. Because the same available energy (as the solid bar) was spread over a greater surface area, the rotary tool formed a panel more slowly; about 10 to 30 square feet/ min. The rotary tool also experienced jet blockage, but it could compensate to a degree as the rotation of the tool brought other jets into play at the cutting face. Nevertheless, the tool exhibited what was considered to be excessive grout use and back flow through the slab, as only the jets at the face aided forward progress. In addition, the size of the down hole motor caused excessive resistance. The use of a down hole hydraulic motor had a second negative: in the event of a mechanical failure, the hydraulic fluid (a RCRA material) could escape into the soil. A combination of drag from the motor case and blocked jets ultimately resulted in the structural failure of the prototype rotary tool during testing. It had to be dug out with a back hoe and was destroyed in the process.

The first round of testing showed that barriers could be formed in situ using the horizontal grout barrier technique. The project goals were redefined to gain increased effectiveness in terms of barrier thickness, surface uniformity, cutting effectiveness and grout use.

The second round of tooling design, fabrication and evaluation concluded in mid 1994 with testing at a more challenging area of the Oklahoma test site. Three second generation tools were produced with the specific objective of optimizing against the new goals. The new tooling items were also about 10' wide but were widely different in design from the first generation and from each other:

The solid bar tool #1 was retained to gain a performance baseline for other tooling. A second solid bar tool, #2, used a 54-jet array placed in a crosscutting arrangement in two horizontal rows.
A mechanical head tool (shuttle tool), the most complex new tool, consisted of a drive mechanism with a reciprocating mobile cutting head consisting of a steel box with two sets of 12 jets arranged in two rows of six (total 24 jets) at each end of the box. This device was approximately the size and shape of a baby grand piano with a shoe box on the keyboard. As the main tool body was moved forward (with the keyboard leading) the shoe box-shaped cutting head shuttled across the keys. The intent was to reduce grout usage through reducing the number of jets (24 vs 61) and to maintain the tool’s cutting effectiveness by concentrating the remaining jets close together on the shuttle. The mechanical complexity of this tool, the cable linkage to the shuttle head, and its related surface support equipment with the long flexible drive shaft necessary to reciprocate the shuttle head was recognized as a negative at the inception. The potential for reduction of grout waste and backflow of spoils through the barrier was considered significant enough to warrant testing the concept.

A catenary (flex) tool was the most innovative of the second generation tools. This tool consisted of two separate cutting heads (subs) attached to a curved structural steel member. This assembly was, in turn, connected to the drill stems by two flexible spring steel straps. The design was to allow the tool to reciprocate across the face of the cut like a cable saw cutting wood, propelled by alternately pulling and playing out alternating drill stems in a coordinated back and forth stroking action. Each sub was equipped with 10 jets in two rows of five. The resulting total of 20 jets was expected to reduce grout waste and retain cutting effectiveness.

The supporting equipment for the second test was a custom flatbed mixing plant with mechanical drive equipment for the shuttle and flex tools, a 1,500 gal. grout surge tank and a tracked power unit to advance (pull) the unit and tool through the length of the barrier. The mixer capacity was 300 - 400 gal./min. with direct transfer to the grout surge tank. High pressure pumping was provided through a 1000 horsepower twin positive displacement pumping unit.

The grout formulation was cement kiln dust and water mixed to an original density of 12.6 lbs./gal. Grout density was later lowered to 11.4 lbs./gal. to increase cutting power. Lignosuphionate was added to act as a retarder. This mix was chosen for reasons of low cost and low hydration shrinkage.

The second round of testing did not produce the same successes as the first. A combination of more challenging soils, mistaken design assumptions and, support equipment shortcomings resulted in multiple failures to form a satisfactory barrier.

The original solid bar tool #1 with 61 jets was tested at both 3,300 PSI and 5,000 PSI. The bar appeared to improve in cutting performance at the higher pressure. In both cases the bar moved forward about 25' and stopped due to exhausting the grout supply in the 1,500 gal. surge tank and exceeding the 300 - 400 gal./min. grout make up capacity. The forward progress of the bar could not be resumed in either test after halting to replenish the grout supply because of plugged jets at the center of the bar.

Solid bar tool #2 with 54 jets was tested at 5,700 PSI on a single twin pump (1,000 horsepower). The tool traveled 15' - 20' into the soil and the tracks on the advancing mechanism began to slip. The grout flow began to drop and
the test was halted. The bar was excavated and 25% - 30% of the jets were plugged with kiln dust from the grout mix and the bar was bowed up from horizontal. After cleaning and straightening the bar, the test was repeated with essentially the same result: 15' of travel, 10% of jets plugged and the bar bowed.

The shuttle tool functioned as designed during surface check out, and then was positioned at the face of the cut. When the tool was moved forward into the cut, the shuttle appeared to bind and the cable drive mechanism stretched. This reduced the travel of the shuttle to less than the full width of the tool body. The shuttle, therefore, could not clear a path for the tool, and progress halted at the face of the cut. The stretched cable could not be expediently corrected and the test was ended.

The flex tool was tested at 5,000 PSI and it was unable to construct a barrier. The system could stroke or reciprocate smoothly, pulling the tool through a 180 degree arc on the surface. When the tool was moved into the face of the cut however, it was able to complete only half a stroke. Upon attempting to recover from that stroke, the tool stuck in the face of the cut and the 40,000 lb. pull of the support system hydraulics could not move it. The main body of the tool was damaged when it was extracted from the cut.

LESSONS LEARNED

It is now clear that barrier formation is more difficult than the initial tests indicated. The second generation tooling did not create any satisfactory panels in the more challenging soils at the Oklahoma test site. Operational problems with the tools included jet plugging on solid bar tools #1 and #2, stretching of the drive cable and possible binding of the shuttle on the shuttle tool, and inability of the stroking mechanism to reciprocate the flex tool across the face of the cut.

A new understanding has been developed of the criticality of the surface support equipment. The grout required for successful employment of jetting methods must be much cleaner than grouts used for other soil amendment. It is necessary to use a high quality screening system to avoid jet plugging. Grout mixing must be more complete, and equipment must be maintained thoroughly clean and free from trash that can plug the grouting jets. The grout mixing, holding and delivery capacity must be sized to ensure no interruption in supply or pressure in order to maintain progress through a complete pass of the barrier. A halt invites failure due to jet plugging.

The skin friction of the emplaced drill stems and the pulling angles for the flex tool may dictate considerably more hydraulic power requirements and/or consideration of scale factors when this type tooling is applied. The belief is that the geometry of a much larger catenary arc with a greater number of jet subs and much more bearing area in the cut would be a better design.

The excess grout flow that is produced with the use of a rotary tool may be a cost of enjoying less impact from the plugging of a few jets. In addition, the backflow of excess grout through to the surface may clear spoils and mix them better to help in barrier formation.
The use of solid bars with fixed jet patterns can cut formations effectively, but the barriers produced are thin and the tools are highly susceptible to failure through plugging of a small percentage of jets.

NEXT STEPS

The success of the prototype rotary tool and the realization that the backflow of grout through the barrier slab to the surface may be acceptable factors have prompted the development of two third generation rotary tools. The first, rotary #1, is driven mechanically through a drive shaft from a surface support power unit. The cutting and mixing action come from the kinetic energy of the grout jetting through the tool. The second, rotary #2, will employ the same mechanical drive system to drive mechanical cutting teeth mounted on the circumference of the lobes of the tool. Grout jets will be used to assist the teeth and to generate the turbulent mixing required to form a uniform slab.

The initial failure of the flex tool pointed up the importance of scale in the design of this tool. A wider tool has been developed and is expected to cut less sharply into the face of a soil formation on each stroke, and therefore operate at more "gentle" angles, reducing the tendency to bind in the cut.

The third field testing session will evaluate these tools in progressively more difficult situations beginning with open air testing with water and progressing through shallow cuts through loose material with water, deeper cuts, cuts into unexcavated strata with water and finally cuts into unexcavated strata using grout at full operating pressures. The two most successful tools will then be taken to Fernald for a full scale demonstration on the prepared site.

The Fernald demonstration is to take place in the summer of 1995 with the full report being completed in winter of 1996.

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