SUCCESS IN HORIZONTAL BARRIER DEVELOPMENTS

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ABSTRACT

A successful proof of concept demonstration has been conducted of operational methods and tooling for the in situ construction of underground horizontal barriers for the control and containment of groundwater and contamination. The method involves jet grouting with specially adapted tools guided between twin, parallel directional wells for the placement of a grout "slurry floor" beneath a waste site.

This paper describes progress by principal subcontractor Brown and Root Environmental on the Fernald Environmental Restoration Management Corporation (FERMCO) In Situ Land Containment Project sponsored by the U.S. Department of Energy (DOE) Office of Science and Technology (OST) through DOE’s Fernald Environmental Management Project (FEMP). Two types of special horizontal grouting tools that operate on different principles have been designed and tested through significant field trials. Experiences with the tools and results of field tests are presented.

INTRODUCTION

Brown and Root Environmental has undertaken a project, under contract to FERMCO and DOE, to develop advanced technology for the construction of underground, horizontal, "slurry floor" barriers for application to environmental restoration of contaminated soil. Horizontal barrier construction capability is desired within the remediation industry and by DOE to enable containment of environmental contamination where inadequate natural barriers exist to mitigate the spread of the contaminants.

The objective of the work is to develop reliable methods of constructing extensive, competent horizontal barriers underneath waste sites without excavating or penetrating the waste during the process. The principal technical objectives of the work include in situ constructability, the ability to form a barrier of sufficient width and length to be of practical value, and the ability to operate in the various types of soil encountered on a significant number of waste sites.

This project stems from an approach developed by Halliburton Services, a sister company of Brown and Root Environmental which provides commercial environmental services. The approach involves an adaptation of a construction method known as jet grouting. The new method is a process for depositing grout (or any pumpable fluid) underground in the horizontal plane using special jetting tools. In late 1992 a proof of concept demonstration was conducted which resulted in the successful construction of a prototype horizontal barrier of limited width. Although successful in placing a horizontal barrier, the demonstration revealed several technical hurdles relating to grouting tool design and operation that need to be overcome to enable practical (economical) application of the method. The following sections describe the progress toward overcoming the hurdles.

HOW THE PROCESS WORKS

To apply the process, parallel, directionally drilled pipes (guide tubes) are installed under the waste site, as indicated in Figure 1. A special horizontal jet grouting tool is attached one end of two of adjacent pipes so that the tool spans between the pair. The other end of the pair of pipes is attached to a controlled pulling device. High pressure grout is supplied through one of the pipes to
the special tool that has jet orifices through which the grout exits with high kinetic energy. The grout jets fluidize the soil into a slurry, and the tool is then advanced along the trajectory between the pair of pipes by withdrawing the pipes using the pulling device. As the tool moves through the soil it continues to fluidize soil in front of it and leaves behind a panel of amended soil. The panel or section of barrier formed by a single pass of the jetting tool is the unit "building block" for construction of a large horizontal barrier formed by joining several panels side-by-side. Figure 2 shows a single panel constructed during the proof of concept field demonstration.

The spacing of the drill pipes, and the degree to which they must be parallel depends on the design of the grouting tool. For example, rigid tools (described below) require placement of the drill pipes within close tolerances, say ± six inches of design centerline, while the flexible tools have a high tolerance (± several feet) for being non parallel.

Forming competent (waterproof) joints between adjacent panels is essential for successful construction of large barriers. The technique devised by Brown and Root for assuring that the next panel formed mates up with the previous panel is to have the jetting tool draw in the next drill pipe along one edge of the panel as it is being formed. This drawn-in pipe is used as one of the pair needed to place the next adjoining panel of the barrier.

The grout planned for use in construction of horizontal barriers is cement-bentonite mixtures of the type commonly used in the construction of vertical slurry walls, although any pumpable grout can be used in the process. Note that the grout must be able to withstand high pressure, shear and impact.

EVOLUTION OF HORIZONTAL JET GROUTING TOOLS

Four different concepts have been investigated for the design of the special tool required for in situ construction of horizontal barriers. The approach planned for use of each design was the same; that is, the tool spans a pair of drill pipes and is advanced by pulling the pipes. The four initial concepts were as follows:

(1) A rigid member (rigid bar tool) with a line of jets facing the direction of advancement of the tool. This tool might resemble a comb, with the teeth of the comb representing the jets. This design was intended to achieve a simple, no moving parts approach but with jets all along the advancing face of the tool.

(2) A rigid tool (Rotary Tool) that rotates and operates in a manner similar to a rototiller with blades, as well as jets that cut through the soil. This design was intended to provide mechanical assist to the jets, form a thicker panel, and allow the rotating jets to compensate for others that may become plugged.

(3) A shuttle tool with a rigid frame and a mechanism with forward facing jets on the leading edge of the tool that shuttles back and forth across the face of the tool. This design was intended to minimize the number of jets required for formation of a single horizontal panel, since the higher the number of jets, the more energy is required to conduct the operation.
A flexible tool (FlexTool) that operates in a manner resembling that of a cable saw. This design was intended to minimize the need for precisely parallel drill pipes, as well as to minimize the number of jets.

The four candidate tool designs were subjected to a series of field trials with the objective of selecting the tool(s) with the highest prospect for successful application. Previous reports (1,2) detail testing and results that eliminated the rigid bar tool (made barriers of variable and insufficient thickness, and failed due to jet plugging), and the shuttle tool which failed from mechanical complications related to subsurface reciprocating parts. The tools selected for further adaptation were the Rotary Tool and the FlexTool, pictured respectively in Figure 3 and Figure 4 in their latest stage of evolution.

The Rotary Tool is powered from the surface by a shaft passing down through one of the drill pipes to transmit torque to a universal gear which rotates the tool. The Rotary Tool is constructed of a 10-ft (width of horizontal tool) section of 6-in pipe with blades affixed to mechanically cut a minimum barrier thickness of 12 inches. Each end is equipped with outboard cutting blades and jets intended to cut into neighboring barrier panels to facilitate seaming.

The FlexTool shown in Figure 4 was constructed of 100 feet of sealed bearing chain resembling the track on heavy earthmoving equipment. This equipment was found to have sufficient strength to withstand the tensile forces placed on it by the pullers, yet have sufficient flexibility to operate during barrier formation between drill pipes at reasonable and approximately parallel spacing. The “treads” of the FlexTool consist of 6” x 12” bearing plates intended to slide horizontally along the subsurface cutting face. Jet substructures (subs) are located at three positions along the tool: one at the center, and at each end of the tool. The center sub has an 8” x 18” port through it to allow passage of small rocks. There are twelve jets in each of the subs.

This report focuses on the advances and results of field tests with the FlexTool, as testing of the Rotary Tool is less advanced, and is intended to be the subject of future detailed reports.

FLEXTOOL TEST RESULTS

Field trials of the FlexTool were conducted in October 1995 at a testing facility in Duncan, Oklahoma operated by Halliburton Services, a provider of high pressure pumping services. The soil at the site is dense, red Oklahoma clay with occasional strata of hardpan, and is considered to provide stringent test conditions since the clay is very dense, with standard penetrometer test results exceeding 100 blow counts in some locations of the site. The purpose of the testing was to check out operating characteristics and mechanical features of the tool, and to practice the type of operations to be performed with the tool and support equipment during construction of horizontal barriers.

Two parallel, 2 3/8-in drill pipes for advancing the FlexTool were installed on 30-ft centers 6 feet below grade. The pipes were installed by cut and cover: trenching, laying the pipe in the trench, and then backfilling and compacting. The pipes formed a gentle arc to the surface at each end, and the horizontal portion of each pipe was 100 feet in length. The cut and cover pipe placement
method was used, instead of installation by drilling, simply as an economy measure to avoid the cost of directional drilling. The cut and cover method is considered to result in a more severe test condition, since friction on the pipes and resistance to advancement is expected to be greater in the compacted backfill than for drilled-in pipes installed using lubricating drilling fluids.

The jetting fluid used in the field trial was water at a pressure of 4,000 psi. With the FlexTool at the surface, jetting was started and the tool pulled into the soil and advanced along the path between the drill pipes. The drill pipes were pulled with a D-6 class bulldozer attached to each pipe. The method of operation was to advance one bulldozer approximately 20 feet, stop it, and then advance the other one a similar distance. This operation was conducted for 60 minutes, advancing the FlexTool a distance of 117 feet and forming 3,510 square feet of subsurface "barrier". The operation progressed smoothly with no interruptions, despite encountering a buried trash disposal pocket containing debris including plastic construction barrier fence and hose. Some fluid breakthrough to the soil surface occurred at the location above the debris, otherwise the surface between the buried drill pipes subsided uniformly by about 1 foot as the tool passed beneath. The subsidence resulted from the use of water as jetting fluid. The water cut through the soil in front of the tool, forming a fluid soil/water slurry which washed out behind the tool through the pathway the tool had traversed. When grout is used as the jetting fluid, the increased density and viscosity of the resulting slurry is expected to minimize washout and reduce subsidence.

CONCLUSIONS

The work produced several advances in the technology of barrier construction and provided the following conclusions relating to equipment and method of operation.

A viable method exists for in situ construction of horizontal, sub surface soil barriers using the FlexTool. Barriers of at least 30 feet width are constructable with present technology.

The FlexTool is operable for barrier formation in clay and other cohesive soil without cobble and large rock.

State-of-the-art precision in placement of directional drilled pipe is adequate for construction of horizontal barriers using the FlexTool.

Horizontal barrier can be formed at a rate of 3,500 sq.ft. per operating hour at an approximate cost of $50 per square foot.

REFERENCES

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