United States
Environmental Protection
Agency

Hazardous Waste Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-87/023 June 1987

EPA

Project Summary

The Block Displacement Method Field Demonstration and Specifications

Thomas P. Brunsing

The Block Displacement technique has been developed as a remedial action method for isolating large tracks of ground contaminated by hazardous waste. The technique places a low permeability barrier around and under a large block of contaminated earth.

The Block Displacement process is composed of separate bottom barrier and perimeter barrier construction processes. The bottom barrier construction is accomplished by propagating horizontal separations from a series of injection wells. A soil-bentonite slurry is pumped into these wells at low pressure, opening the separation and forming a barrier. In the process the ground is displaced upward by an amount corresponding to the thickness of the final barrier placed. The perimeter barrier is constructed by one of various means including slurry wall, jet grouting, or drill notch and blast. The perimeter barrier is constructed prior to the bottom if necessary to induce a favorable *in-situ* stress state.

The technique was demonstrated at Whitehouse, FL where a block of earth 60 ft in diameter and 25 ft deep was lifted. Horizontal fractures were extended from seven injection holes to form the bottom barrier. The block was displaced upward as much as 12 in. by the injection of approximately 2,000 ft^3 of bentonite slurry. Upward displacement was monitored by standard survey techniques during the lifting process. After displacement was completed, a topographic survey was conducted and the quality of the bottom barrier was assessed by core drilling.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Labaoratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Block Displacement is a method for vertically lifting a large mass of earth. The technique produces a fixed underground physical barrier around and beneath the earth mass. The barrier is formed by pumping slurry, composed of a soil bentonite and water mixture, into a series of notched injection holes. The resulting barrier completely isolates the earth mass.

The process is illustrated in Figure 1 for isolating a chemical waste site. In-ground pollution is contained by inhibiting ground-water migration through the contaminated zone. The barrier material should be compatible with *in situ* soil and ground-water chemistry.

A bottom barrier is formed when lenticular separations extending from horizontal notches at the base of injection holes coalesce into a larger separation beneath the ground being isolated.

Continued pumping of slurry under pressure produces a large uplift force against the bottom of the block and results in vertical displacement proportional to the volume of slurry pumped.

A perimeter barrier is constructed with the bottom barrier either prior to, during, or following bottom barrier construction. The perimeter barrier can be constructed including slurry wall, vibrating beam,

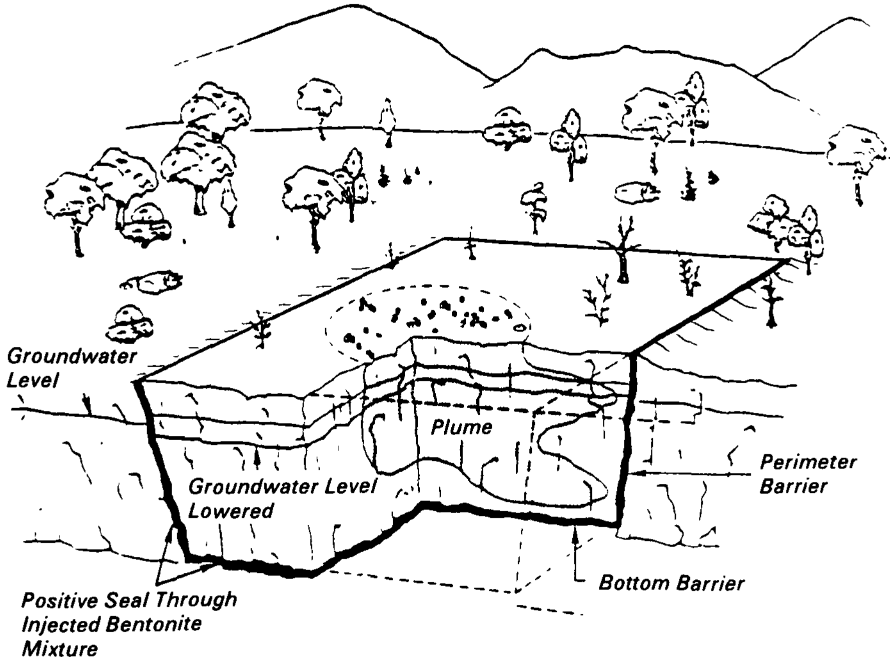

Figure 1. *Block displacement barrier in place.*

dynamic fracturing, or jet groutingtechniques. If constructed prior to bottom separation, the perimeter barrier can be used to enhance the horizontal stress field for the purpose of maintaining the horizontal orientation of the propagating bottom separations. A perimeter separation would first be constructed and then surcharged to increase the horizontal stress field in the formation. A surcharge is additional pressure transmitted to the fluid slurry in the perimeter separation either by raising the slurry fluid level above ground level or by placing a seal in the perimeter separation and pressurizing the slurry below the seal.

The Block Displacement method can be used to increase the width of an initially thin perimeter barrier such as might be constructed by vibrating beam, dynamic fracturing, or jet grouting techniques. To increase perimeter width by means of the block lift, the thin perimeter must be constructed on a slight angle off vertical prior to a substantial portion of the lift. The slight angle off vertical tapers inward toward the block center. Upward displacement of the block resulting from injection along the bottom barrier will then increase the initial thickness of the perimeter separation.

Construction of the bottom barrier proceeds in four phases:

1. Formation of notches at the base of the injection holes
2. Initial bottom separation of the notched holes
3. Propagation of the local separations at each injection point coalescing into a single larger bottom separation
4. Generation of a complete bottom barrier by controlled vertical displacement of the earth mass using low pressure slurry injection into the horizontal separation.

Each of these phases is carried out through control and monitoring of slurry pressure, slurry flow rate, total volume injected, and slurry composition. Deformation and vertical displacement of the isolated soil is also monitored.

The notching operation (Phase 1) requires a high-pressure rotating jet at the base of the injection hole. The jetting slurry is designed to optimize notch erosion, to remove cuttings, and to minimize leak-off into the soil. A mechanical notching tool can be used in lieu of the jet notching tool, but the maximum notch diameter achievable will be reduced. A large notch diameter is desired to reduce fracture initiation pressure and to reduce the tendency for propagating separations to turn upward due to unfavorable *in situ* stress conditions.

The initiation of bottom separation (Phase 2) requires a slurry pressure, P_o, at the separation defined by:

$$P_o = \rho_r g h + \Delta P$$

where ρ_r = the average earth mass density of the soil overlaying the notching operation

g = the gravitation constant

ΔP = the pressure in excess of the overburden

h = the depth of the bottom separation

The pressure in excess of overburden, ΔP, *is a function of soil properties*, notch diameter, slurry properties and the speed of the operation. The strength of a material being fractured is classically measured by its fracture toughness. The pressure required to initiate propagation is the pressure required to open a sufficiently wide gap at the tip of the notch to allow the slurry to flow into the separation. The gap width is dependent on the gel strength of the slurry. The tendency for the slurry to leak off into the soil and form filter cake at the tip of the notch complicates this process and increases the required initiation pressure.

Separation coalescence (Phase 3) occurs by adding slurry volume and by gradually increasing the gel strength and viscosity of the slurry. Slurry pressure required to propagate the horizontal separation will decrease during this phase due to the increased area over which it is acting. The viscosity of the slurry serves to limit flow in one specific direction, thereby avoiding undesirable channeling of slurry material. The higher viscosity increases pressure drop at distances from the injection holes, reducing the pressure available for fracturing. This pressure/distance relationship causes the separations to maintain a generally circular shape in the horizontal plane.

Vertical displacement (Phase 4) utlizes the maximum capacity of the pumping equipment to inject a slurry with high solids content to form the final barrier. When the perimeter barrier separation is constructed prior to displacing the ground, the required injection pressure is dependent on the overburden weight, system geometry, shear resistance in the perimeter and slurry pressure drop across the bottom separation.

The final thickness of the bottom barrier can be controlled to any dimension, from a few inches to several feet. The desired thickness depends on the isolation required by the structure or soil mass being isolated.

Field Demonstration

Site Description

A demonstration of the Block Displacement technique was conducted at a site adjacent to the Whitehouse Oil pits in Whitehouse, FL. The Whitehouse site was selected from a list of 114 top priority EPA superfund sites.

The site was flat and composed of marine sediments of silty sand in excess of 100 ft overlaying limestone bedrock. The silty sand appeared to be sufficiently stratified to be compatible with Block Displacement. Ground-water level in the area varies from 2 to 5 ft, and local drillers indicated that a thick hardpan layer existed at a depth of approximately 20 ft.

Three exploratory holes were drilled and continuously sampled. The soil profile was categorized, and the standard penetration resistance was recorded in all holes. Hardpan was encountered in all three holes at approximately 10-ft depth and continued to between 20 and 25 ft underlaid by unconsolidated brown sand. The contact between hardpan and brown sand below was a gradual transition of interbedded layers and lenses of the two soils.

The transition zone between hardpan and underlying brown sand appeared to be a suitable medium for inducing bottom fracture. A block diameter of 60 ft and depth of 23 ft were selected based on this geology.

Construction

The field operation involved three distinct operations:

- An explosive blast in three adjacent test holes to determine perimeter fracture performance
- Preparation of the block by drilling and slotting 32 perimeter holes, and drilling and casing seven slurry injection holes
- Fracturing both the bottom and the perimenter, and lifting the block.

Perimeter Test Blast

Before commencing with the block perimeter and injection hole drilling, three test holes were drilled to a depth of 27 ft at a 14 degree angle off vertical. The three holes were of 6-in. diameter and spaced at 3-ft and 6-ft intervals along a straight line. They were drilled in an area apart from the proposed test block. This drilling was done to gain experience in angled drilling with the mobile rig, to experiment with hole slotting tools, and to use these holes to conduct an experimental blast for joining the slot tips. The hole spacing and explosive charge load would determine the ultimate number of block perimeter holes required. Twenty-six feet of 50-grain/ft Prima-cord™* explosive were placed to within 1 ft of the top of each hole, and 10 ft were overlapped at the bottom to give this portion of each hole a 100-grain/ft load. The cord was capped at the bottom of each hole using a special cap insertion tool. Post-blast inspection showed that the fractures between the 3-ft spaced holes clearly joined; and that the 6-ft spaced holes had their slots extended far enough to join but not in a straight line, thus making verification difficult.

Injection Hole Drilling

Seven 23-ft deep injection holes were to be cased with 6-in. PVC pipe, and hence required a larger bit for drilling. An 8-in. bit was fabricated, and with the exception of encountering occasional tree roots, the drilling went smoothly. PVC pipe in 25-ft lengths was installed in each hole so that the last 2 ft protruded above ground. Each hole was also bottom grouted using portland cement to ensure a reasonable casing seal. Two cubic feet of grout were placed in each hole displacing the drilling mud. The PVC casing was then pressed through the wet grout using the drill rig downhaul. The cement was later drilled through to earth, and the casings were temporarily capped.

Perimeter Hole Drilling

The experience gained during test hole drilling proved very helpful for the perimeter hole drilling. At each of the 32 hole locations, the drill rig was positioned on the block perimeter and tilted to the desired 14 degree angle by extending the appropriate hydraulic stabilizer jack inside the block. Subsequent measurement indicated that the off vertical anglevaried from 12 to 14 degrees around the block. The 6-in. drill bit was used, and five to seven holes were completed each day. A fresh batch of 10 percent bentonite by weight mud was left in each hole to ensure against hole collapse

Perimeter Slotting

For the perimeter slotting operation, a pile driver was brought to the site and two new and different slotting tools were fabricated. Because of the large surface area and general geometry of the disc slotter, the impact force required to drive it was so great that the pipe bent severely before the tool reached the bottom of the first hole. A second tool with a reduced area, diamond-shaped slotter was fabricated using a single length pipe. The thickness of the slot blades was also reduced by half for this tool. Using the modified diamond slotter, the pile driver heads were angled at 14 degrees off vertical. The pile driver delivered 700- to 1,400-ft-lb blows to the slotting tool, typically driving the tool 6 in./blow. All 32 perimeter holes were slotted in just over 3 days.

Perimeter Fracture

In preparation for the perimeter fracture blasting, a 5-ft long, 18-in. diameter "sona tube" (tubular heavy gauge cardboard cement form) was placed on-end over each perimeter hole, as shown in Figure 2. Each tube was then filled with a very heavy barite (specific gravity of >2.0) mud, which acted as a surcharge to prevent mud loss during the blast, and to force the mud in each perimeter hole out into the separation created by the blast.

With this accomplished, the explosive charges were loaded into each hole and fired. A detectable perimeter fracture appeared to run around almost the entire circumference of the block at the surface. A piece of spring steel was used to probe the fracture to verify hole connection. This device confirmed that most perimeter holes did join down to a depth of several feet, beyond which the spring steel could not penetrate the fracture. The blast-induced fracture appeared continuous.

*Mention of trade names or comercial products does not constitute endorsement or recommendation for use.

Figure 2. Surcharged perimeter holes ready for explosive blast.

Bottom Notching and Fracture

The bottom notching technique employed a high-pressure, slurry jet oriented horizontally and rotated at the bottom of the hole to erode a pancake shaped notch. Initially a 2-percent bentonite slurry was jetted in a slurry medium in all seven injection holes yielding notches 2 ft in diameter. During the first attempt to create a fracture, high pressure was required to induce slurry flow. This indicated the need for larger notches. Renotching of the holes first to a 4-ft diameter and finally to a 6-ft diameter was required to create the bottom fracture.

Block Lift

A mud distribution manifold was fabricated for both fracturing and lift operations. A 3-in. diameter inlet port was connected to the outlet of the mud pump, and each valved 2-in. outlet port was connected to an injection hole casing. Each casing had a pressure gauge installed as a means of monitoring injection pressure and as an aid in detecting connections with other holes. Although the manifold permitted mud injection into any number of the seven holes simultaneously, the pumping was usually confined to one of three holes at a time. The hole selected to receive the mud was determined by measurements of lift at certain points on the block using the engineer's level set up outside the block. When lift was observed at an injection point, the mud was then directed to a different injection hole in an attempt to lift the entire block surface as evenly as possible. This process was continued until each injection hole was lifted between 1/32 and 1/16 in. during mud injection. Separation coalescence between injection holes was observed after approximately 500 gal. of slurry were pumped into the central injection hole. Once lift was detected, the injection slurry was modified by adding local soil to add weight and reduce cost. The added material was surface excavated, silty sand that acted as an aggregate in the bentonite and water matrix. After several days of pumping, primarily into the central injection hole, some lift had been detected nearly everywhere.

Summary of Test Results

Displacement of the block was monitored by recording the change in elevation of 16 fixed rods. Elevations were read through a surveyor's level located 50 ft outside of the block perimeter. Additional survey points beyond the block boundary were monitored during a portion of the lift operation to verify that no lift was occurring outside of the perimeter. Survey points 0 through 6 correspond to rods located approximately 3 ft from the injection holes. The remaining nine survey points, 3p through 30p, correspond to rods located just inside the perimeter. These survey point numbers correspond to the closest hole numbered progressively from 1 to 32 in a counterclockwise direction around the perimeter.

A total of approximately 2,000 ft^3 of bentonite slurry was injected during the block lift operation. A daily tabulation of slurry injected during the lift operation was maintained by counting the number of 1-1/2 yd^3 batches of slurry mixed and verifying this count with a daily bag count of the bentonite used.

Data from surface topographic surveys and from accumulated daily lift records were combined to give the two profiles of the final block position shown in Figure 3. In total, the block was displaced upward in excess of 12 in. at its highest point and tilted approximately one degree from horizontal. A crescent shaped portion of the block outside of injection hole No. 3 was sheared free of the lifting block and did not move appreciably. The entire remaining portion of the perimeter lagged behind the inner portion of the block, lifting only 3 to 6 in.

Tap roots as large as 24 in. in diameter were found at approximate 6-ft intervals extending from roughly 5 ft below the ground surface to the upper boundary of the hardpan layer. In addition, perimeter fractures filled with gelled slurry extended down only a few feet before becoming indistinguishable hairline fractures.

Thin-walled tube soil samples were taken 4 weeks after stopping slurry pumping to determine the integrity of the bottom seal. Obtaining undisturbed soil samples of the soft slurry material bounded by hardpan on top and unconsolidated sand beneath was difficult. In eight attempts, three acceptable samples were obtained. Sample No. 8 shown in Figure 4 indicated that a well defined boundary of separation between injected clay slurry and the overlapping native sand had formed.

Conclusions

The Block Displacement demonstration provided three distinct technical conclusions:

- The bottom barrier construction component of the process is viable and has been demonstrated.

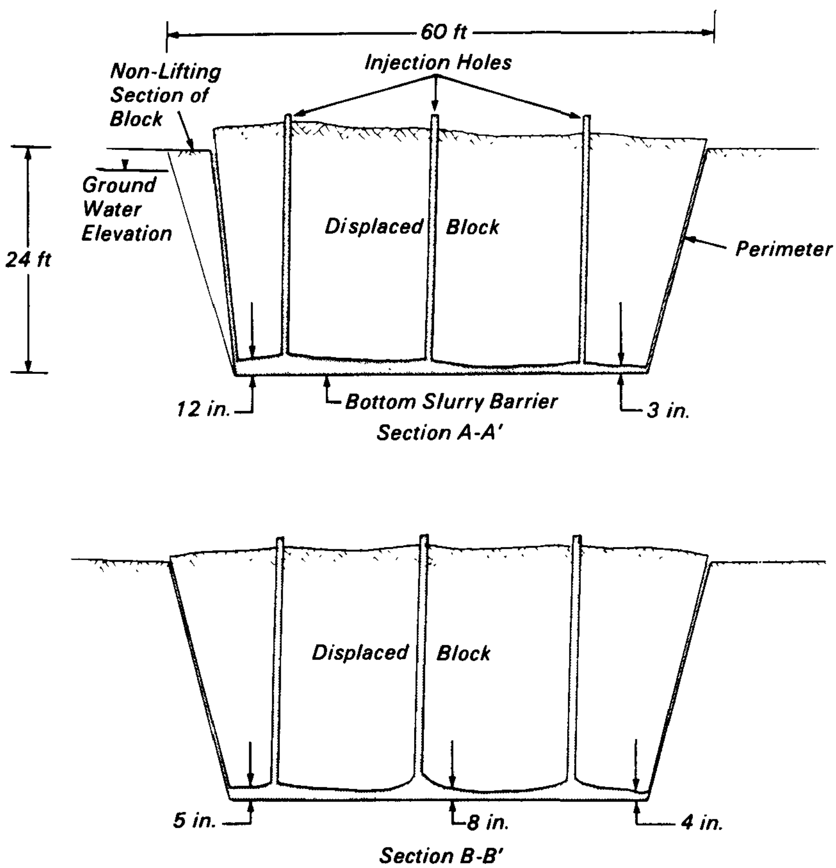

Figure 3. *Final block displacement.*

- The drill, slot and blast perimeter barrier construction technique applied as part of the total isolation process was unsatisfactory and should not be considered for Block Displacement application.

- Construction materials, equipment and procedures for implementing the Block Displacement process were evaluated and refined sufficiently to be considered for field application under geologic conditions similar to those at the demonstration site.

The bottom barrier construction technique, which required repeated modification to notching and sealing techniques, ultimately performed quite consistently. Drilling, notching, separation propagation, and block lift were all adequately demonstrated. Surface displacements, core samples and lift volume versus slurry volume correlations all support this conclusion. Subsequent coring data, lift monitoring data and independently derived conclusions from interpretation of ground penetrating radar records indicate at least 80 percent of the underlying area defined by the design perimeter was covered by bottom barrier material.

The drill, slot and blast perimeter separation technique did not produce a sufficiently smooth continuous fracture to allow the perimeter surfaces to fully override each other during the displacement process. Performance of this perimeter separation technique in the more consolidated hardpan is uncertain, as post lift perimeter mapping could not extend down into the hardpan region. Alternate, more direct perimeter construction techniques such as slurry wall or vibrating beam construction would be more appropriate in unconsolidated ground.

Slurry jetting in a compressed air stabilizing medium proved adequate as a bottom notching method in unconsolidated material. Slurry mix, pumping and distributing equipment demonstrated that the slurry designs used can be adequately mixed and placed in the field. Lift monitoring using standard survey equipment was quite adequate for determining performance and as feedback for correcting slurry injection during the lifting operation. Adequate correlation was obtained between slurry injected and ground volume displaced.

The full report was submitted in fulfillment of Contract No. 68-03-3113, Task 37-2 by JRB Associates under the sponsorship of the U.S. Environmental Protection Agency.

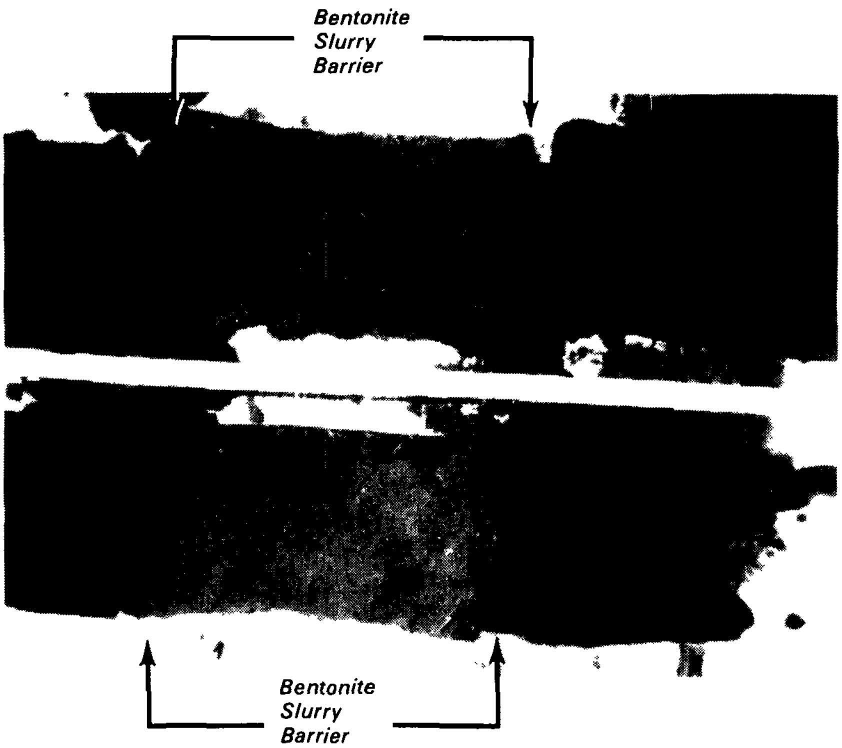

Figure 4. *Test core from hole No. 8.*

Thomas P. Brunsing is with Foster-Miller, Inc., Waltham, MA 02254.
Walter E. Grube, Jr. *is the EPA Project Officer (see below).*
The complete report, entitled "The Block Displacement Method Field Demonstration and Specifications," (Order No. PB 87-170 338/AS; Cost: $18.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

EPA/600/S2-87/023