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Slurry Cutoff Walls: Applications in the Control of Hazardous Wastes

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ABSTRACT: Slurry cutoff walls are nonstructural barriers constructed to intercept and impede the flow of fluids underground. There are two basic types of slurry cutoff walls, soil-bentonite (SB) and cement-bentonite (CB). Depending on the nature of the project, either method may have some technical or economic advantage over the other. In both cases, a narrow trench is excavated into the ground using a backhoe or other more specialized equipment. The trench is prevented from collapsing by keeping it full at all times with bentonite slurry similar to drilling mud. In the case of SB walls, the trench is subsequently backfilled with a mixture of soil and bentonite slurry that forms the permanent impervious cutoff wall. With the CB method, cement is added to the slurry, which later sets up, forming the permanent seepage barrier.

Slurry cutoff walls are being used in an increasing variety of applications to provide a barrier to the lateral underground flow of various fluids. Principal applications are site dewatering, underground pollution control, and seepage barriers under dams. In this paper, case studies are used to provide examples of recent applications in the control of leaching hazardous wastes.

Projects cited include:

1. Containment of oil seeping through a reservoir abutment.
2. Cleanup of a polychlorinated biphenyl (PCB) contaminated site.
3. Containment of leachates and methane gas migration from a sanitary landfill site.
4. Cleanup of a site with spilled phenols.

All of the examples were selected because of the unusual conditions under which they were constructed or because of the dramatic evidence of results.

KEY WORDS: slurry cutoff walls, bentonite, groundwater barriers, seepage barriers

Several case studies have been selected to show the range of potential slurry cutoff wall applications, construction methods, and typical conditions under which they are installed. Tremendous progress has been made in the last ten years or so in understanding the mechanics and chemistry of flow through

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slurry walls. The increase in knowledge has corresponded, from a timing standpoint, with two other phenomena:

1. A tremendous increase in the number of slurry-wall applications to underground pollution control.
2. An increasing public and corporate awareness of the dangers of the effects of buried hazardous wastes.

The federal Environmental Protection Agency (EPA) has been charged with containing the wastes on hundreds of unclaimed sites under the Superfund Act. Meanwhile, thousands of businesses, local governments, and other owners are seeking remedies for underground pollution problems on their property. The slurry cutoff wall has been already applied to several hundred such sites and is contemplated for many more.

Recent advances in the capacity of excavating equipment and refinements in technique have brought the cost of slurry walls down, and they now compete economically on projects where leachate collectors, clay barriers, or sheeting would have previously been used. The types of walls discussed herein are nonstructural; they are relatively impervious but are not capable of supporting bending moments or significant shear stress. Normally, their strength is of the same order as the surrounding ground.

The technique involves excavating a trench which is kept filled with slurry, whose primary ingredients are bentonite clay and water, and whose function is to maintain the trench open with vertical sides, even below the water table. The excavation is carried out through the slurry from the ground surface using any equipment capable of excavating the trench widths and depths required. Once the trench is excavated to its final depth, a mixture of soil and bentonite is placed in the trench, displacing the bentonite slurry. This type of construction is called an SB slurry cutoff wall.

With a variation on the above technique, called a CB slurry trench, cement is added to the bentonite slurry just before it is introduced into the trench. The resultant slurry has properties substantially similar to normal bentonite slurry with respect to maintaining the sides of the trench. However, once excavation is complete, the CB slurry remains in the trench and sets up and forms the permanent watertight wall.

Construction Methods

Types of Cutoff Walls

The SB slurry trench technique has been in use in the United States for almost 40 years. Figure 1 shows the excavation for a SB cutoff. On projects where the material excavated from the trench is suitable for use as backfill, the SB system can be economical because of the minimum amount of materials required. After the trench has been excavated under a bentonite slurry, more slurry is mixed with the soil adjacent to the trench. A bulldozer is used to work the material to a smooth consistency, and it is then pushed into the trench so that the backfill slope displaces the bentonite slurry forward (Fig. 2). Excavation and backfilling are phased to make the operation continuous with relatively small quantities of new slurry required to keep the trench full and to mix backfill.

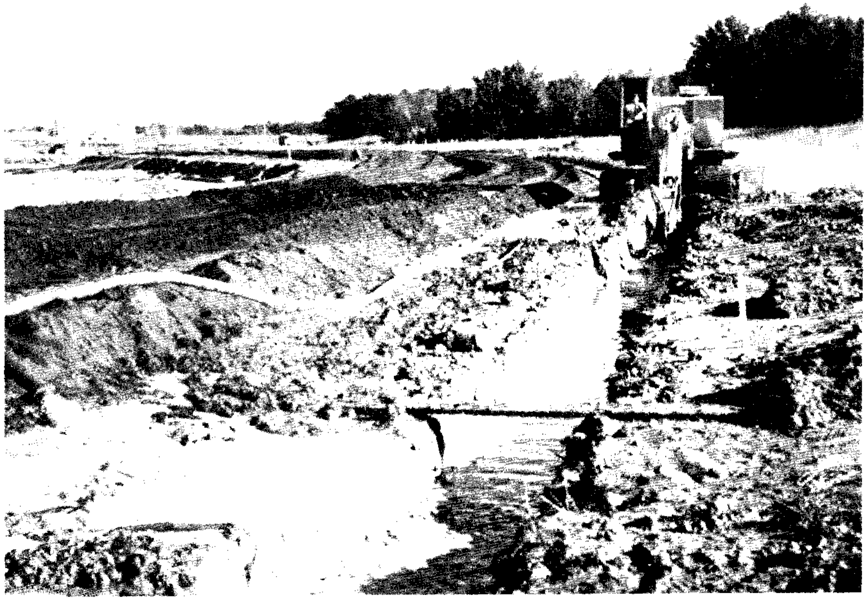

FIG. 1—*Excavation for an SB cutoff.*

CB slurry trenches have been in use in Europe for at least 15 years and in the United States for about 10 years. Figure 3 shows a CB batch plant. Since the entire trench must be filled with slurry materials and since a significant

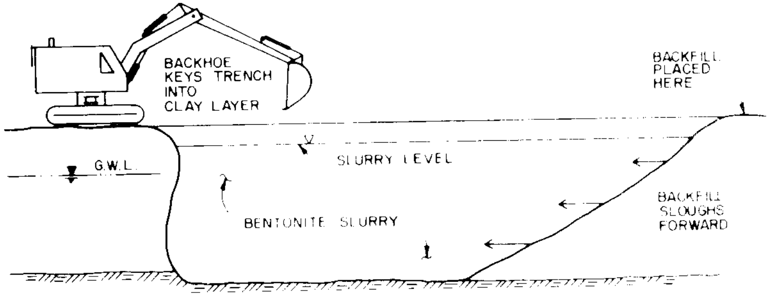

FIG. 2—*Schematic section through an SB cutoff.*

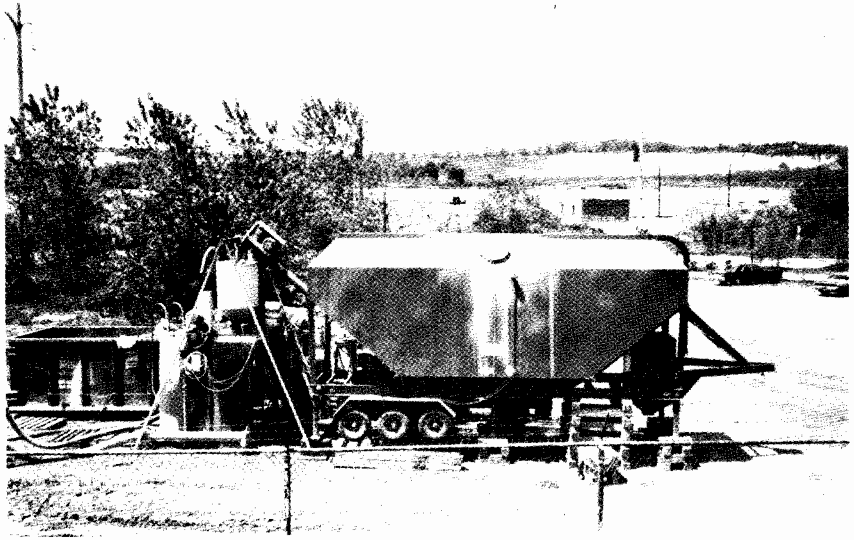

FIG. 3—*CB slurry mixing plant.*

amount of slurry is wasted due to the excavation process and seepage losses through the sides of the trench, the backfill is considerably more expensive than under the SB method. This increased cost is partially offset by the elimination of the backfill mixing operation. However, the CB method can provide the following technical and construction advantages over the SB method:

1. The technique is not dependent on the availability or the quality of soil for backfill.
2. The CB system is more suitable for trenching through areas with difficult access or with not enough room for backfill mixing.
3. Since the trench can be constructed in sections with later sections keyed in by reexcavating a short section, the construction sequence is more flexible to meet site constraints. The long slope of the backfill under the SB system normally requires trenching continuously in one direction.

The SB technique has several advantages over CB, besides lower cost:

1. The resultant wall is generally of lower permeability than CB walls.
2. The backfill can have various materials blended in to suit design conditions.
3. SB backfill is generally more resistant to degradation by most pollutants.
4. Where the excavated material can be mixed as backfill and placed back into the trench, no spoil disposal problem is created.

Given the relative advantages of the two systems, the project requirements should be evaluated to determine the best method to be selected. Where possible, it may be most economical to specify both methods and to allow the contractor to bid with the least expensive system.

Excavating Equipment

The primary requirement for the excavating equipment is the capability to excavate a trench of the design width to the required depths within permissible verticality tolerances. A variety of equipment has in fact been used. In the following paragraphs, the principal types are discussed, along with their relative advantages.

The hydraulic excavator, or backhoe, has been used on many slurry cutoff wall projects in the United States (Fig. 4). The depth limitation of the largest hoes is presently about 20 m (65 ft), but new advances in equipment technology will undoubtedly extend this range. The backhoe, because of its fast cycle time, is the most economical means of excavation. Minimum trench widths are controlled by the thickness of the boom. For large hoes, this can mean 0.9 m (2.5 ft) or more. The thickness of the wall is an important cost factor for CB slurry cutoffs.

The clamshell bucket rigs that were originally developed for cast-in-place concrete slurry walls have been applied to slurry cutoff trenching. These

FIG. 4—*Backhoe excavation.*

buckets may be cable-mounted or attached to a rigid sliding kelly bar (Fig. 5). They may be powered by mechanical means (cables) or by hydraulic cylinders operated by a remote power supply. These rigs have a maximum range up to 76 m (250 ft) and can be used with buckets as thin as 0.6 m (2 ft). Their production is much lower than other methods, so unit costs for excavation are higher.

Another technique more recently introduced into the United States from Europe involves driving a beam into the ground with a vibrating pile-hammer while simultaneously jetting with CB slurry to form a "thin-wall cutoff." The beam is withdrawn while more slurry is injected under pressure. The beam is driven in overlapping imprints to form a continuous wall. The result is a curtain 50 to 100 mm (2 to 4 in) thick with the additional protection of grouting coarse-grained strata with CB slurry. Given the right soil conditions, production is rapid and the thin-wall cutoff uses far less CB slurry than conventional slurry trenching. However, the same narrow width mandates more careful quality control since each square metre of the wall is subjected to one pass of the beam, which does not mix the slurry as in the case of slurry trenching. The principal problem of the vibrated beam has been assuring continuity between adjacent passes at depth. Its range is generally 9 to 15 m (30 to 50 ft), but even within these depths slight deviations may leave "windows" in the wall. Soil profiles with cobbles or boulders are a particular problem and keying into underlying weathered rock or hardpan may not be possible to the extent feasible with excavated slurry trenches. The narrow width of wall makes this type of cutoff less suitable for applications in soil where movements due to settlement, subsidence, etc. can be expected later. Design parameters and quality control for thin-wall cutoffs are specialized topics not treated in this paper.

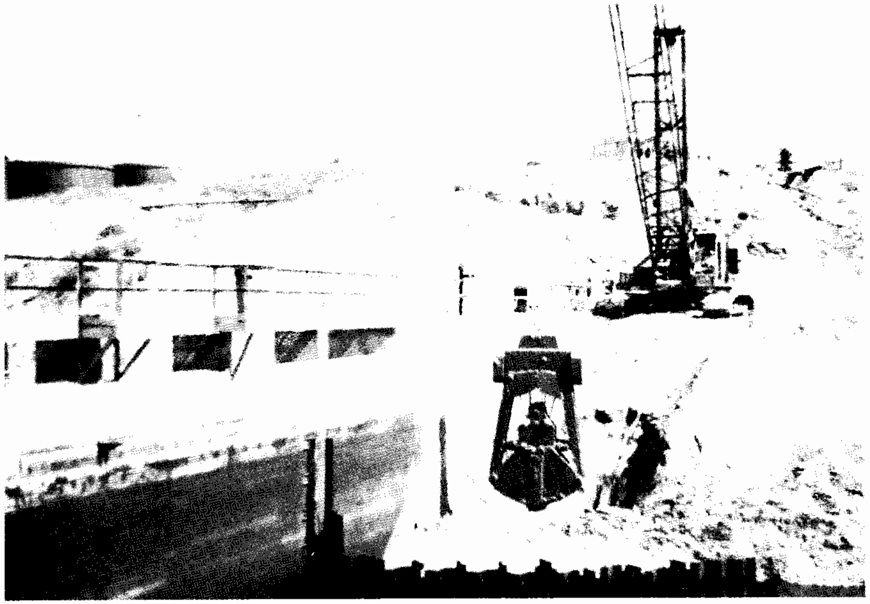

FIG. 5—*Clamshell excavation.*

Applications

Because of the range of slurry cutoff wall applications to the control of hazardous waste leachates, it is difficult to pick a few projects to demonstrate the possibilities. Projects completed include, among many, containments for

1. Sanitary landfill leachates.
2. Oil and gas spills.
3. Low-level radioactive waste.
4. Acid mine drainage.
5. Phenols.
6. Polychlorinated Biphenyl (PCB).
7. Trichlorethylene, benzene, and many other organic chemicals.
8. Phosphate mine tailings.
9. Fly ash impoundments.

To illustrate the range of typical applications, three recent projects have been selected. They are

1. Denver, Colorado—Containment of toxic chemicals from a military reservation. This project illustrates use of an SB wall for remedial action.

2. Long Island, New York—Containment of oily wastes seeping from an oil terminal. This project illustrates the use of a CB wall for remedial action.

3. Tampa, Florida—Underseepage containment for new dike construction for a phosphate mine tailings pond. This project illustrates the use of a slurry wall in the construction of a new facility.

Buried Residues from Military Chemicals

The problems at the Rocky Mountain Arsenal near Denver's Stapleton Airport have been the subject of numerous stories in the national press as well as in various technical publications. Apparently, wartime production of chemicals for gas warfare and other uses resulted in the creation of waste products and out-of-spec chemicals. At the time, the most expedient solution was on-site storage in lagoons and buried dumps. Only recently has the extent of the environmental problems emerged. To date, three contracts have been let to create slurry wall containments at various points along the reservation perimeter, in combination with pumping water for treatment and aquifer recharge.

This project was typical in that it involved a length of about 450 m (1500 ft) to depths of as much as 15 m (50 ft). A rock ledge in the soil profile had to be blasted prior to excavation of the slurry trench. Figure 6 shows the slurry field laboratory. Figure 7 shows the trenching in progress, and Figure 8 shows the trench backfilling operation.

The specifications of this particular job required wasting the material excavated from the trench and using imported material in the trench backfill. In general, it is preferable from an economic and technical standpoint to use as much of the material from the trench as possible. If the material is contaminated with chemicals, the addition of a slight amount of bentonite will counteract the effect of the pollution. A series of permeability tests on potential backfill blends is always advisable.

Oily Wastes

The problem at this Long Island oil terminal is typical of problems at many oil tank farms and other similar facilities. Small spills and leaks over the years had created a substantial pool of oily wastes on the groundwater under the terminal, which threatened to seep laterally into the adjacent harbor waters.

The oil pollution problem is one case in which an aquaclude for the slurry wall to key into is not always necessary. It is frequently possible for the wall to merely intercept the groundwater and literally skim the oily wastes off. The wall is usually built in combination with a central sump to collect the oil contained. There are at least 20 of these types of installations in the United States, and at least 2 are economically as well as environmentally viable; that is, they have paid their own cost in terms of recovered product.

FIG. 6—*Field laboratory for slurry and backfill tests.*

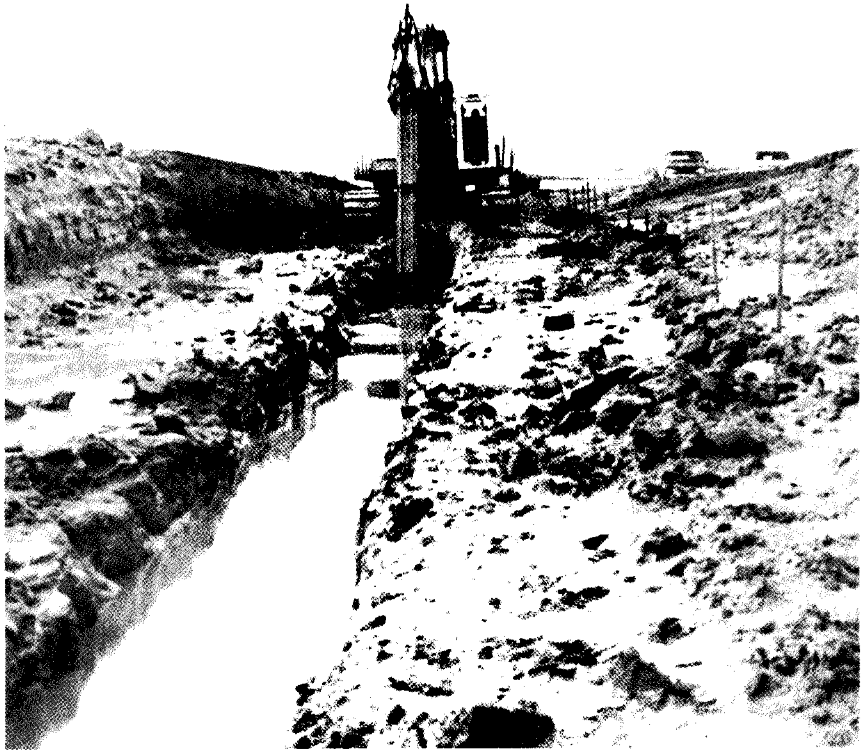

FIG. 7—*Trenching in progress.*

Many of the oily waste applications have been done with the CB technique because the jobs have generally been smaller and have been constructed in areas congested by surface structures and underground lines that would create access problems for the SB technique. CB slurry also has shown none of the detrimental effects when exposed to oily wastes that sometimes occur with other pollutants.

The Long Island case was typical. Figures 9 and 10 show the difficult access and lack of area alongside the trench for backfill mixing. The CB slurry was

FIG. 8—*Backfilling with SB backfill.*

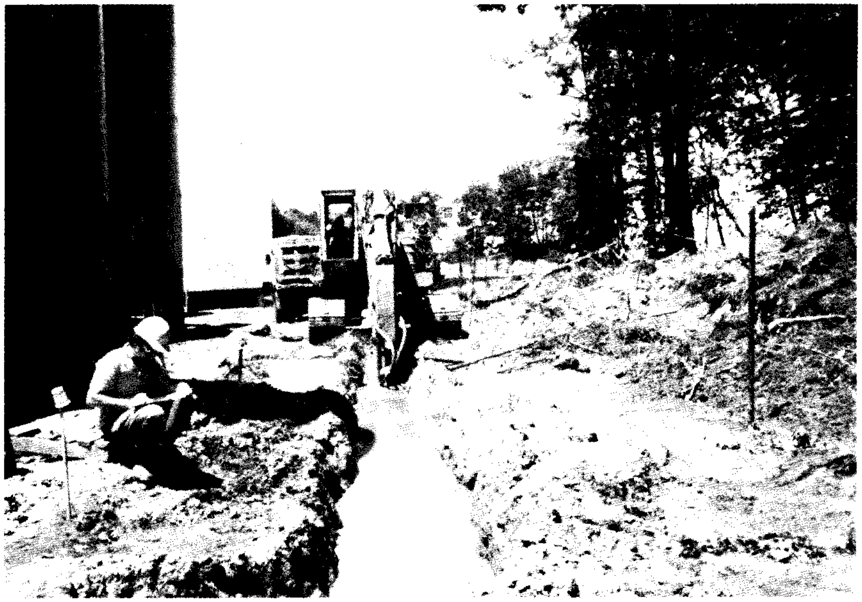

FIG. 9—*CB work in area of tight access.*

FIG. 10 *CB work in area of tight access.*

prepared in an electronically controlled central plant and pumped to the trench. The trenching was carried out much the same as for the SB method (Fig. 11). Numerous underground utilities and other obstructions were successfully passed. After about one day the CB takes its initial set (Fig. 12). Even after full set, the slurry is always soft like a clayey soil, so that it will not impede future underground work at the terminal.

Phosphate Tailings Leachates

Central Florida, in a belt stretching from Tampa to Orlando, is a center for the mining of phosphates. As a part of the process, acidic wastes are created and stored in "gypsum stacks." These impoundments are constructed from gypsum and may be over 30 m (100 ft) high and 500,000 m^2 or more in area. A number of them have experienced dramatic failures due to piping of the dike foundations. Underseepage also creates a nasty environmental problem.

This particular case is the combination of two recent projects in the area. Each job involved the expansion of a gypsum stack into a new area. Both owners wanted to eliminate underseepage for environmental reasons and to ensure the stability of their dikes. Total lineal footage was several kilometers and depths required from 6 to 15 m (20 to 50 ft). Numerous hard ledges of gypsum deposits were penetrated.

FIG. 11—*Trenching under CB slurry.*

FIG. 12—*Setup CB slurry.*

There is one important construction detail that should not be overlooked: the key between the top of the slurry cutoff wall and the overlying dike. To avoid a zone of weakness between the top of the wall and the base of the dam, it is essential to place a cap and to excavate the trench through it. This creates a side contact seal for the slurry cutoff wall and provides a wide area to key the bottom of the dam into. In both cases, gypsum caps were used, although clay would serve as well for a more normal application.

In all other respects, the project was a typical SB slurry cutoff wall. Figures 13, 14, and 15 show slurry mixing, trenching with the extended stick backhoe, and backfilling the trench.

Summary

Slurry cutoff walls have achieved wide recognition in a variety of applications as seepage barriers for pollution control. The two principal techniques, SB and CB, have different relative advantages, but under some conditions are technically interchangeable.

A design for a slurry cutoff wall should take into consideration whether the wall is for permanent or temporary use, the loadings anticipated, and other construction constraints in selecting the technique to be used and the extent to which the work should be controlled by the engineer. Specifications should take account of the built-in safety factors in slurry cutoffs (for example, more

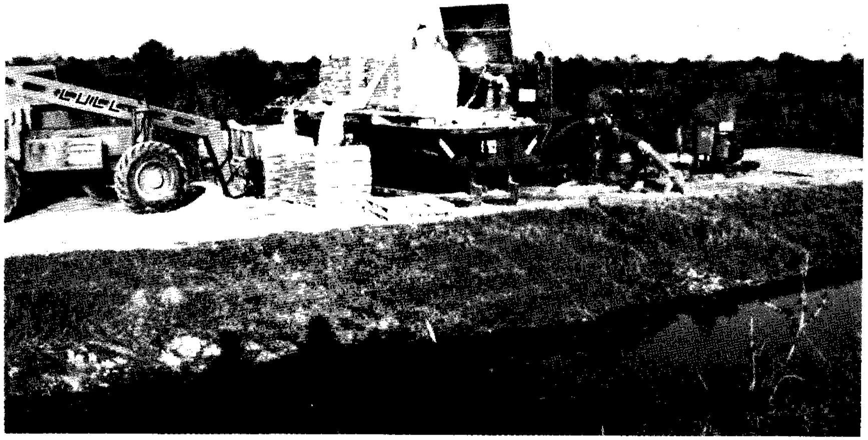

FIG. 13—*Slurry mixing.*

FIG. 14—*Trenching with extended stick.*

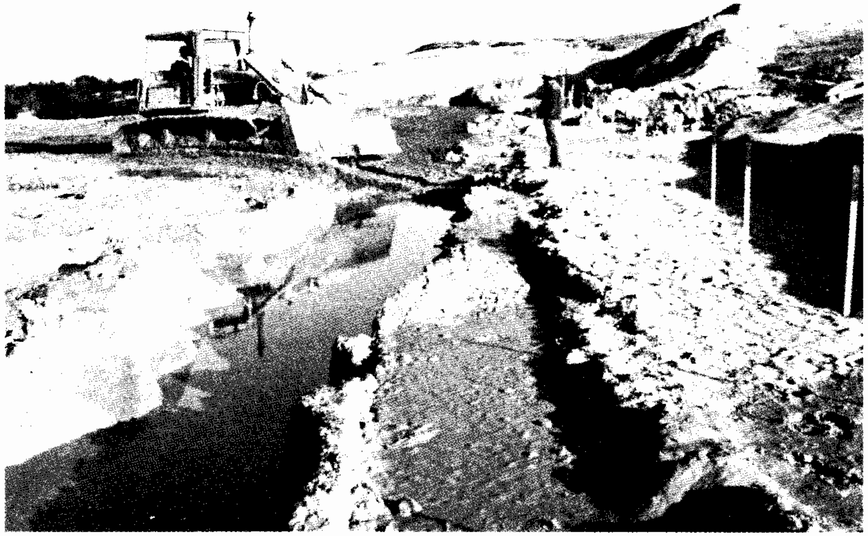

FIG. 15—*Backfilling.*

thickness than required in most cases), allow the variability in slurry properties normally experienced during this type of work, and give maximum flexibility to the contractor in selecting materials, equipment, and technique. The economy, convenience, and positive control of seepage afforded by slurry cutoff walls will bring them acceptance and application on an increasing number of construction projects in the United States.

DISCUSSION

Y. B. Acar[1] *(written discussion)*—The author proposes to use slurry walls as a barrier to hazardous wastes. Slurry walls are usually constructed using high activity clays. Would not such clays be more susceptible to structural changes due to variations in pore-fluid chemistry? In other words, does the author use an activity criteria in constructing such walls?

C. R. Ryan (author's closure)—A specific activity criterion is not used in evaluating potential slurry wall applications. The effects are indirectly measured in the normal compatibility testing that is done on projects with unusual leachates. We have yet to find a leachate whose effect on the SB backfill cannot be counteracted by relatively minor changes in the constituents. More bentonite or more fines may be added to accomplish this purpose.

S. B. Ahmed[2] *(written discussion)*—How would you predict long-range permeability in the field?

C. R. Ryan (author's closure)—The best way to estimate long-term permeability is to perform prejob permeability tests with actual site soils, bentonite, and leachates. These tests, which can be done in a variety of cells, can usually be run to stability in a matter of one to two weeks.

S. B. Ahmed (written discussion)—How would you estimate the quantity of bentonite required say for a slurry cutoff wall in sandy silt with $k = 10^{-4}$ cm/s. Assume the wall is 18 m (60 ft) deep and is keyed into dense stiff impermeable clay?

C. R. Ryan (author's closure)—Between 1 to 3% total bentonite quantity (by dry weight) should be sufficient in most cases to produce a permeability of 1×10^{-7} cm/s. In all cases where the permeability is critical, prejob permeability testing must be done.

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