United States
Environmental Protection
Agency

Hazardous Waste Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-86/020 Aug. 1986

EPA

Project Summary

Grouting Techniques in Bottom Sealing of Hazardous Waste Sites

James H. May, Robert J. Larson, Philip G. Malone, John A. Boa, Jr., and Dennis L. Bean

Bottom sealing of hazardous waste sites involves the injection or insertion of an inert impermeable and continuous horizontal barrier in soil below the source of contamination. This type of containment stragegy could be used in conjunction with other technology such as slurry walls, capping, and counter-pumping to insure that contaminants do not move from the site into surrounding soil or ground water. The objectives of this project were to determine which types of available grouts would be unreactive with hazardous wastes and how effective direct injection or jet grouting techniques would be in forming a grout barrier. The effectiveness of a complete barrier was not evaluated.

Grout formulations used in this study were acrylate, 30% silicate, 50% silicate, urethane, and portland cement. These grouts were tested to determine their ability to set and remain intact in the presence of twelve different simulated waste solutions (acids, bases, fuels, and organic solvents), that could occur at hazardous waste sites. The grouts which showed the greatest ability to set were the two inorganic-based formulations: sodium silicate and Type 1 portland cement. Acrylate grout set in six out of twelve simulated wastes, but the urethane grout tested did not set in any of the simulated wastes.

When grout samples set in water environments were exposed to the same twelve solutions for 20 days, all except the portland cement product showed some swelling or shrinkage. Of the chemical grouts, sodium silicate and acrylate exhibited the best durability.

In a small-scale 2 m x 4 m (6.56 ft x 13.12 ft) test bed of medium sand, neither silicate nor acrylate grout injected into a grid-like pattern of boreholes formed a continuous horizontal seal. The grout bulbs either did not coalesce (silicate) or were displaced after injection (acrylate). In a large-scale test using sodium silicate grout injected at a depth of 2.44 m (8 ft) in fine sand, the shapes of the grout bulbs could not be controlled well enough to produce a seal, and grout shrinkage caused root holes to remain unsealed. Chemical grouting as employed in this test did not produce a continuous bottom seal.

Tests of jet grouting were undertaken in natural (in-place) loess, compacted silt, and medium sand at a depth of 1.67 m (5.5 ft), using three holes spaced on 1.52 m (5 ft) centers. The water jet system succeeded in producing useful cavities in all media but the shape and size of the cavities could not be controlled with sufficient precision in the loess or silt to produce a continuous bottom seal when the cavities were grouted. The less cohesive sand washed out more evenly and the grouted cavities overlapped to form a continuous barrier layer.

These studies indicated that present grouting techniques do not permit close enough control to assure that a bottom-seal will be formed under the conditions tested.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, 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

Grouting has been used in construction for over a century to add strength to earth materials or to control water movement. Grouting involves the pressure injection of suspensions or solutions that set or harden to fill voids and cement earth materials together. Both the grout formulation selected for injection and the technique used for placement are important for grout to produce the desired benefits.

Grouting has been used to emplace a subsurface barrier in remedial action involving radioactive waste and has been indicated as a potentially useful technique for neutralizing, immobilizing, or containing toxic wastes. Proposals for using grout have involved shallow, low-pressure injection to consolidate contaminated soil; injection into waste to provide for solidification or in-situ treatment and injection for sealing soil around the site to form a barrier to lateral or vertical contaminant migration. Projects have also been undertaken where waste was used as a filler in the grout. In all applications of grout at waste sites, two properties are critical:

1. The grout must set or harden in contact with waste components.
2. The grout must not deteriorate in the presence of the waste during normal temperature or moisture cycles occurring within the expected lifetime of the grouted structure.

Two types of grouts, chemical (or solution) grouts and particulate (or suspension) grouts are available for use in producing subsurface barriers. Chemical grouts are solutions that react to produce a gel or polymer that fills the pore space. The solutions typically have a low initial viscosity that increases rapidly during setting. Particulate grouts are suspensions of fine-grained solids that move between the particles of the medium being grouted. The setting of particulate grouts may be produced by a chemical reaction or by the flocculation of the dispersed solid. The grout types differ in their injectability and their effectiveness in producing a durable seal or adding strength to the grouted medium. In applications where grout is to form a barrier in geologic media, the grout must be easily injectable (have low viscosity) and must produce a decrease in permeability.

Grouts typically are injected using pumps and mixers. For effective application it is also necessary that the grout:

1. Have a set time that can be regulated.
2. Be reasonably non-corrosive to mixers and pumps.
3. Be formulated from materials that are low in toxicity.

After a grout has been selected, a technique for grout application must be identified. Chemical grouts are generally low-viscosity liquids that can be directly pumped into porous media. The grain-size of the sediment that can be injected depends on the time available for injection and the viscosity of the grout. Generally, particulate (suspension) grouts cannot be injected into sediments finer than medium sand. In finer grain-size material, chemical (solution) grouts must be used unless a technique for washing out a cavity is applied. Hydraulic excavation of a cavity for placing grout is usually referred to as jet grouting.

Jet grouting is done using a wide array of techniques. A water jet can be operated in a water-filled cavity or in a concentrically-placed air jet. A water jet can also be operated in an air-filled pressurized cavity. A variety of fluids can be employed in jet grouting, including clean water, bentonite clay suspensions, or portland cement suspensions. Cuttings are air-lifted or pumped to the surface. Air or water pressure is maintained in the cavity to prevent collapse of the roof or side walls.

The research reported here consists of three related phases:

1. Screening and selection of grouts for bottom sealing of hazardous wastes.
2. Evaluation of chemical grout technology for producing a continuous bottom seal.
3. Evaluation of jet grouting technology for producing a continuous bottom seal.

The three phases, grout selection, chemical grout evaluation, and jet grout evaluation, combined demonstrate the currently available technology and the limitations involved in attempting to bottom-seal using current grouting techniques. A full-scale barrier test was not undertaken.

Selection of Grouts for Bottom Sealing

Four types of grout (five formulations) selected for testing included silicate (30% and 50-60%), acrylate, urethane, and portland cement. These were tested for compatibility with twelve simulated wastes prepared as shown in Table 1.

The effects of wastes on the grout set times were determined by mixing separate samples of each prepared grout with an equal volume of each simulated waste solution. Setting of the urethane grout tested was completely inhibited by every simulated waste tested. Acids, bases, oxidizers, and copper sulfate inhibited the acrylate grout. Sodium hydroxide solution (10%) inhibited the 30% sodium silicate grout, and it slowed the setting of 50% sodium silicate grout. Ammonium chloride slowed the set of portland cement but produced a flash set with sodium silicate. Copper sulfate produced a flash set with both portland cement and sodium silicate.

Table 1. *Characteristics of Waste Test Solutions Used*

Waste Component	*Character of Waste*	*Concentration of Waste*
Potassium chromate	*Strong oxidizer*	*10%*
Hydrochloric acid	*Inorganic acid*	*10%*
Ammonium hydroxide	*Base*	*10%*
Sodium hydroxide	*Base*	*10%*
Ammonium chloride	*Salt*	*10%*
Copper sulfate	*Salt*	*10%*
Benzene	*Cyclic hydrocarbon*	*Saturated*
Gasoline	*Hydrocarbon mixture*	*Saturated*
Oil	*Hydrocarbon mixture*	*Saturated*
Phenol	*Substituted benzene*	*Saturated*
Toluene	*Substituted benzene*	*Saturated*
Trichloroethylene	*Halogenated hydrocarbon*	*Saturated*

Chemical Grout Injection

Small-scale injection tests of acrylate and silicate grouts were conducted by injecting each grout into a 1 meter deep layer of clean medium-grained sand in a separate test bed. No impervious grout layer was formed in either the silicate or the acrylate test beds.

Several problems related to field conditions were observed during excavation of the grouted sand beds:

(a) The grouted sand masses were often highly assymetrical and large gaps existed between grout bulbs.

(b) Voids larger than those between sand grains (root holes or rootlet holes) were not sealed with grout. The insides of the voids were usually coated with grout, but the holes were still open.

(c) Coarse-grained filter sand used at the bottom of the injection hole was often completely uncemented with no evidence of grouting although the fine-grained sand around the filter sand was completely cemented.

Jet Grouting

Jet grouting is a technique for excavating a cavity in the subsurface using a high-pressure fluid jet. The jetting fluid can be water, water with entrained air, or a water/bentonite suspension. After the cavity has been excavated, grout is introduced to fill the cavity and form an impermeable mass. Jet grouting has the advantage that a wide variety of grouts can be used, even particulate grouts, like bentonite or bentonite/cement.

The jetting system used in this study consisted of a high-pressure positive displacement piston pump that delivers cutting fluid to a downhole jetting nozzle that can be directed from the surface. The grout used was a standard portland cement/bentonite grout. Fluorescein, rhodamine, or methylene blue were used to color the pods so they could be easily identified. The three different soils tested were (1) an undisturbed porous interlocked loess, (2) compacted silt, and (3) a compacted mortar sand.

In all cases cavities could be produced, but cutting was so irregular in the silt and loess that no continuous seal was produced. The sand washed out more evenly and the grouted cavities overlapped to form a continuous layer.

Conclusions

None of the commonly used chemical grouts examined in this study exhibited all of the necessary characteristics for success. Injection grouting tests using sodium silicate demonstrated the following points:

(a) The shape of the chemical grout bulbs cannot be controlled due to inhomogeneity in the soil being grouted. The irregular shapes and positions of the grout bulbs make it difficult to form a continuous barrier by injecting grout bulbs that coalesce.

(b) Large holes in soil masses (root holes) will not adequately seal if the chemical grout undergoes shrinkage (syneresis).

(c) Coarse-grained soils and fine-grained soils in the grouted area may require different chemical grouts to assure that the chemical grout can penetrate, and after penetration will not shrink and pull away from the coarse material.

Jet grouting offers several advantages over injection grouting in the proposed application:

(a) Jet grouting is effective in a wide variety of geologic media (such as silt or fine sand or mixed silt and sand) that cannot be grouted in any other way.

(b) Cutting a cavity allows elimination of inhomogeneities in soil (such as root holes, channel fillings, sand plugs, etc.) when grout is injected.

(c) A wide variety of grouts (chemical, particulate, or mixed) can be used in jet grouting. The large variety of grouts available makes it possible to select material that is chemically non-reactive and durable in soils contaminated with hazardous waste chemicals.

(d) Waste/grout interaction during grout setting is minimized in jet grouting.

The following major difficulties were observed with jet grouting:

(a) The size and shape of the cavity produced in jetting could not be determined without special sensing equipment mounted in the jetting head.

(b) Jet grouting required specialized equipment, usually beyond that available from normal drilling and grouting contractors.

(c) The cutting fluid needed to be recycled or disposed of as a possible hazardous waste.

(d) Jet grouting in the form evaluated in this study required set-up and clean-up times that were far longer than those required for chemical injection grouting.

(e) The grout selected for injection needed to be thoroughly tested to assure that it would remain as an impermeable barrier.

Recommendations

The results obtained in this investigation indicate that chemical grouts, as currently used, are poorly suited to bottom sealing. Many of the problems with chemical grouts noted in bottom sealing tests are identical to deficiencies noted in construction applications. As advances are made in grout technology in construction, the possible applications to bottom sealing should be evaluated. Jet grouting appears to offer the greater promise of being further developed to obtain a satisfactory bottom grouting procedure.

Future research needs include the development of down-hole techniques for monitoring cavity geometry in jet grouting and the development of rapid techniques for inserting a jet and producing a cavity without drilling a hole and setting a casing. Bottom sealing in soft soil possibly could be done from a soil probe (instead of drilling), with great savings of time.

The full report was submitted in fulfillment of Interagency Agreement DW-96930581-01-3 by the U.S. Army Engineer Waterways Experiment Station under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 1982 to June 1985, and work was completed as of September 1985.

James H. May, Robert J. Larson, Philip G. Malone, John A. Boa, and Dennis L. Bean are with USAE Waterways Experiment Station, Vicksburg, MS 39180-0631.
***Herbert R. Pahren** is the EPA Project Officer (see below).*
The complete report, entitled "Grouting Techniques in Bottom Sealing of Hazardous Waste Sites," (Order No. PB 86-158 664/AS; Cost: $11.95, 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

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use $300

EPA/600/S2-86/020