The advent of the "Superfund" legislation and increasing public attention to groundwater quality has created new corporate concern over how industrial liquids are stored and disposed of and, in some cases, how to protect sources of clean water from neighboring pollution. In this paper two types of containments are discussed. Each type is illustrated through a case study of an actual application.

For new work, the best strategy is to prevent industrial liquids from getting into the ground in the first place. The most common method to accomplish this is through a liner system. Different materials for liners are briefly discussed as well as the best ways to use liners in combination with leachate collectors, etc. The selected case study involves the installation of a double synthetic liner with intermediate drainage layer at a municipal waste lagoon.

When remedial work is required, slurry cutoff walls are coming into increasing use. This technique involves the creation of a vertical nonstructural barrier that intercepts and impedes the flow of fluids underground. The construction methods and range of potential applications are discussed. The case study is for a containment constructed at a large utility flyash disposal pond. Performance data for the slurry wall material under the permeation of flyash leachates are provided.

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INTRODUCTION

This paper discusses two of the principal means for groundwater containment that are being increasingly used today. Liners, both soil bentonite and synthetic, are used for containing lagoon and landfill leachates. Since the liners must be constructed under the material to be contained, they generally are used for new work. In the sections that follow, materials and construction methods are discussed. A case study of a project where a synthetic liner was used to contain industrial wastewater from a textile plant is presented to illustrate a typical application.

Slurry cutoff walls are vertical nonstructural seepage barriers constructed underground to stop the lateral flow of water and other fluids. The slurry cutoff wall would normally be keyed into some underlying impervious geologic formation such as clay or bedrock to create a complete containment. Since this type of containment can be made around existing landfills or lagoons that may be leaking, it is frequently used for remedial work and as a redundant backup for surface liners.

In later sections, the slurry construction method is briefly described. A case study is presented that describes the use of a slurry cutoff wall to stop the leachate flowing from an existing flyash pond at a power plant.

SYNTHETIC LINERS

Synthetic liners are a relatively new method of sealing areas to contain liquids or gases that are either too valuable to lose or too hazardous to allow into the environment.

The technology of linings was developed in the 1940's, but only since the early 1970's has it attained recognition as a viable and technically acceptable solution to containment problems. Liner systems for waste or water storage usually consisted of varying thicknesses of clay, asphalt or concrete; however, these materials have sometimes been found to be deficient because of increases of permeability due to subgrade movement. A correctly chosen synthetic membrane will handle most chemical solutions with no increase in permeability and reasonable subgrade movement without tearing.

Another factor that has helped synthetic membranes gain acceptability has been the development of new lining materials and seaming systems that offer high chemical resistance with secure seams. The more common flexible lining materials are polyvinyl chloride (PVC), butyl rubber, low-density polyethylene, EPDM rubber, chlorinated polyethylene (CPE), chlorosulfonated polyethylene (Hypalon) and high-density polyethylene (HDPE), listed in order of improving physical characteristics and chemical resistance properties.
Seaming systems are also improving and have progressed from adhesing to welding seams where welding gives a true homogeneous joint with all the properties of the parent materials. Liners can be interfaced with other earth, concrete or steel structures by using special details.

Membrane materials come in different thicknesses varying from 20 mil to 150 mil (not all the materials have this range) with a wide range of lining materials with different properties and capabilities. The thickness to be chosen depends largely on the physical or mechanical abuse that the liner may have to endure during its installation and during its operating life. The requirements of different containments will vary according to the liquid or gas to be contained and the attendant risk associated with that liquid or gas if it enters the environment. For example, PVC might be suitable for the storage of irrigation water, but if a highly hazardous solution that may contain hydrocarbons is to be contained, then HDPE is the most suitable liner.

In general, synthetic membrane liners have gained engineering recognition as an effective solution to the containment of wastes, liquids and gases. They offer a cost-effective and quick method of sealing an area, are capable of handling a wide range of chemicals and ground movement, and if selected and installed properly, will last a considerable length of time.

SOIL BENTONITE LINERS

A soil Bentonite liner is a thick membrane-like seepage barrier composed of soil and bentonite, a natural clay mineral. When contacted by water, bentonite swells and fills the voids in the soil, thus preventing the passage of water and other liquids. Two of the principal advantages of Bentonite pond liners are the low permeability imparted to a soil by the addition of bentonite and the self-healing nature of the liner.

Bentonite pond liners are most applicable to projects which require a higher quality liner than can be obtained by using native soils or on sites where there is no native clay available. In some cases it may be cost-effective to specify a thinner high-quality Bentonite liner instead of a thicker native clay liner.

Bentonite liners can be used alone or in conjunction with synthetic liners on hazardous waste landfills. The Bentonite liner provides a backup to the synthetic liner and also makes an excellent subgrade for the installation of synthetic liners. The installation of a double liner system using two dissimilar materials may provide an additional margin of safety in hazardous waste applications.

Bentonite pond liners are normally designed to have permeability in the range of $10^{-7}$ cm/sec; however, it is possible to install a lining having a permeability in the range of $10^{-9}$ cm/sec. Most native clays when compacted are more pervious than Bentonite liners.
In the area where the pond liner is to be installed, the working surface should be graded smooth and slopes should preferably not exceed a grade of 3:1 (horizontal to vertical). Steeper grades are more difficult to compact and require special attention. All vegetation and any boulders which might penetrate through the thickness of the seal should be removed. There are two principal methods of mixing and applying the bentonite liner.

The usual method of constructing the bentonite liner is by mixing the liner materials in place. After the working surface is prepared, the dry bentonite is spread uniformly across the prepared soil surface at the specified application rate. Next, the bentonite should be thoroughly mixed into the existing soil to the specified depth. It is critical that the layer be compacted at wet of optimum moisture content. The compaction should be performed with any type of compactor other than a sheepsfoot roller. The spikes on a sheepsfoot roller will often be too long and can penetrate through the soil sealant layer.

A higher quality bentonite seal can be obtained by using an alternate method. When a project requires a bentonite seal to contain hazardous wastes, soil, bentonite and water can be mixed in a computer-controlled pugmill to yield a superior soil sealant. A large blending plant (Figure 1) has been used to prepare liners for several projects. Soil is dropped onto a conveyor belt as it moves over a sensor which continuously weighs the soil. An amount of bentonite is then added to the soil at the specified rate. The bentonite and soil are then mixed in a pugmill with a metered amount of water. After mixing is complete, the prepared soil sealant is loaded for transport to the lagoon area. The mixed soil sealant material is transferred to an asphalt paving machine that precisely distributes the blended soil sealant (Figure 2). After the distribution, the soil sealant is compacted to a specified density to complete the liner.

Bentonite pond liners have been used successfully for over 50 years to seal lakes, dams, ponds, and lagoons. The bentonite soil sealant will not deteriorate with time as long as it is not contaminated by a material that would chemically attack it. In addition, the bentonite pond liner stays flexible as long as it stays wet and will normally heal itself in case of a puncture. Testing methods are now available to ensure the owner that the liner installed will perform as expected for the particular leachate conditions.

SLURRY CUTOFF WALLS

The slurry trench technique has been in use in the U.S. since the late 1940's. The principal type in use today is the soil-bentonite (SB) slurry cutoff wall. Fig. 3 shows the excavation for an SB cutoff. On projects where material excavated from the trench is suitable for use as backfill, the SB system is economical because of the minimum amount of other required materials. After the trench has been excavated under a bentonite slurry, more slurry is mixed with the spoil adjacent to the trench (Fig. 4). A bulldozer is used to work the material to a smooth consistency, which is then pushed into the trench so that the backfill slope displaces the bentonite slurry forward.
Excavation and backfilling are phased to make the operation continuous with only small quantities of new slurry required to keep the trench full and to mix backfill.

The primary requirement for the excavation equipment is the capability to excavate a trench to the specified width and depth within permissible vertical tolerances. The hydraulic excavator, or backhoe, has been used in most slurry cutoff wall projects in the U.S. The depth limitation of the largest holes is presently about 60', but advances in equipment technology will probably extend the range. The backhoe, because of its fast cycle time, is the most economical means of excavation. Other equipment can be used to excavate deeper trenches.

There have been several hundred slurry cutoff walls constructed in the U.S. Applications have included dewatering walls for excavations, seepage cutoffs under dikes and dams, and cutoff walls to contain outflow of various liquid pollutants. In general, this type of construction has a number of advantages over competitive systems such as grouting or continuous pumping: the cutoff wall is more positive; it requires no maintenance; it eliminates headers and other obstructions around the perimeter of the excavation.

There have been numerous applications of slurry cutoff walls for pollution control; many types of municipal, industrial and chemical wastes have been contained. Most slurry wall cutoffs built for containment purposes require a clay or rock layer underlying the site to provide an impervious stratum into which the cutoff wall can key.

SYNTHETIC LINER CASE STUDY

A textile manufacturer was generating a large amount of liquid wastes as a result of washing and dyeing yarn. The waste had a pH of up to 12 and was discharged at 120°F. Obviously, it was discharged into the environment.

A waste water treatment plant had been constructed with two 2.7 million gallons holding ponds lined with clay. After a matter of days, both ponds experienced large sinkholes as a result of water seeping through the clay and into the limestone substrata. It was decided to reconstruct the ponds with a synthetic membrane and leak detector/collection system to ensure that there would be virtual zero seepage. This would prevent any further sinkholes and consequent failure of the liner.
The design called for a sloping base with a crushed stone and perforated pipe subsoil drain at the lowest point, the pipe discharging into a manhole where the waste water could be collected and treated. The whole subgrade was lined with a heavy geofabric and then a 40 mil High Density Polyethylene geomembrane.

The specified allowable leakage rate was 2.7 gallons/min/pond. This meant that a very tough quality assurance/quality control program had to be instituted to achieve this high standard.

The seams were of a fusion extrusion type and were tested by tensile testing of samples taken from preseaming test sections and insitu samples taken from the actual seams. To ascertain the watertightness of the seams, all seams were vacuum box tested and any leaks detected were repaired. The total area of sheeting was marked off using chalk lines and each square visually checked for holes in the membrane itself.

When the liners were completed, the ponds were filled for two weeks (Fig. 5) and the leak rate was monitored. After three months, one pond leak detection pipe was completely dry and the other only had a damp spot in the pipe.

A liner project with these high standards can only be achieved through the use of adhered to quality assurance/quality control program.

SLURRY CUTOFF WALL CASE STUDY

The cited project was located at the TVA owned Widows Creek Power Plant, in northern Alabama. The utility desired to raise the dikes of an existing flyash pond to increase its capacity. The existing dikes showed signs of seepage and instability; an impervious weathered bedrock layer existed at a depth of from 25 to 45 feet below grade. The utility decided that this was an excellent application for a slurry cutoff wall.

preface permeability tests were conducted to assure the government of attaining the required permeability of 10^{-7} cm/sec. It had originally been planned to include some flyash in the soil-bentonite backfill, but it was determined in the test program that the flyash would dissolve when leached by the waste water, so it was eventually necessary to provide some off-site soil as makeup for flyash in the backfill.

The work in progress is shown in the Figure 6. A schematic drawing showing a cross-section of the design for the slurry cutoff wall and raising the dike is shown in Figure 7.
CONCLUSION

Specialized geotechnical construction techniques are helping to investigate the threat to our groundwater caused by the necessary presence of waste products in our environment. The two techniques described -- liners and slurry cutoff walls represent the principal solutions to these types of problems today. The two case studies presented are typical examples of literally thousands of similar projects nationwide. Careful attention to the details of materials and installation technique is necessary to assure successful projects.
Figure 1
Soil Bentonite Blending Plant

Figure 2
Application of Soil-bentonite blend
Figure 3
Excavation of a SB slurry wall

Figure 4
Backfill Blending for a SB slurry wall
Figure 5
Aerial view of completed ponds

Figure 6
Excavation of Widows Creek Slurry Wall