Installation of a composite slurry wall to contain mine tailings

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ABSTRACT: This paper describes a case study on the design, construction and performance of an underground barrier intended to contain copper mine leachates in central Arizona. The barrier was a composite slurry wall composed of high density polyethylene (HDPE) and soil-bentonite (SB). The purpose of the barrier was to retain low pH (<2) and high copper sulfate leachate seeps and groundwater from an existing tailings mine. Challenges to barrier performance included resisting the high hydraulic gradients from the 100 feet + high dam, chemical compatibility of the barrier materials and the leachate, and a maximum allowable hydraulic conductivity of $1 \times 10^{-7}$ cm/sec.

1 INTRODUCTION

A mining company required the construction of a deep cutoff wall at the toe of an existing tailings dam. The cutoff wall provides isolation of copper leach solutions behind the existing dam, and prevents migration of the same solution through a downstream canyon into local aquifers. The cutoff wall was constructed in late 1996. Subsequent groundwater monitoring indicates that the wall is performing well. The cutoff wall was constructed on the premises of a confidential mining company in central Arizona.

2 BACKGROUND AND EXISTING CONDITIONS

The tailings dam was constructed in 1983 in a narrow canyon on coarse alluvial deposits to contain the leach solution, and divert it into a channel for collection and subsequent treatment. Following dam construction, it was noticed that the leach solution flowed over the dam and around its northern end. The dam was extended 20 feet in elevation, and the toe of the dam was extended to prevent the overflow and seepage. The dam extension was constructed by rubber-tired scrapers using mine run dump material and uncertain compactive effort. Analysis of groundwater samples collected from monitoring wells after the toe was extended revealed low pH values as much as 900 feet downstream from the dam.

In a further effort to repair the dam and minimize seepage, the mining company conducted a remedial grouting program to reduce seepage through the bedrock and particularly at its contact with the dam. Additional sampling and testing after grouting indicated that leach solution was still seeping under the dam. The leach solution was a greenish liquid with a pH of 2, 2700 mg/l of copper and 77,100 mg/l of sulfates.
In an effort to finally correct the seepage, the mining company constructed a low permeability cutoff wall from the surface of the downstream canyon to approximately 3 feet into an existing weathered bedrock. The cutoff wall followed the profile of the rock up the sides of the canyon extending up to 60 feet deep (Figure 1).

3 PROJECT DESCRIPTION

Due to previous difficulties experienced in sealing the dam’s foundation, the design of the cutoff wall was carefully considered. The primary factors in the design included resistance to the low pH leach solution, resistance to the hydraulic head from the dam, and a desire for a positive cutoff by creating a low hydraulic conductivity in the cutoff wall materials. A composite slurry wall was selected for installation based on the above factors and cost. The composite slurry wall was composed of a 100-mil-thick (2.5 mm), interlocked HDPE (high density polyethylene) membrane sandwiched within a soil-bentonite mixture.

3.1 Soil-bentonite slurry wall description

Soil-bentonite slurry walls are commonly used as subsurface barriers to lateral flow of groundwater and to water-borne pollutants. The major characteristics of slurry wall construction is the use of a bentonite water slurry during excavation to support the excavation without the use of other lateral supports such as shoring. Slurry walls are built by excavating a narrow trench, which was 2.5 feet wide for this project, while pumping slurry into the trench and maintaining its level at or near the top of the trench during the excavation. Usually, the trench is extended deeper or keyed into an underlying aquiclude, to form a seal with the bedrock, which for this project was weathered granite. The weathered granite formed the impervious base, and the soil-bentonite mixture formed the vertical groundwater barrier.
The greatest economy can be realized when the excavated soils can be reused in the soil-
bentonite backfill. However, on this site the excavated soils were not suitable for preparation of soil-bentonite backfill, and were wasted. The excavated soils contained a low fines content (materials finer than 0.075 mm) and a large proportion of cobbles and coarse gravel. Imported fine
grained soils were selected for preparation of the soil-bentonite backfill.

Bentonite clay is a montmorillonite clay and the most common amendment in soil-bentonite slurry walls. Bentonite has the ability to swell as much as 20 times its volume upon contact with water. Sodium-cation bentonite from mines in Wyoming, U.S.A. is the highest quality bentonite and is available dried and bagged for commercial use. Typical bentonite contents in soil-bentonite are in the range of 1 to 3% by dry weight of the soil are usually adequate to create a barrier with a hydraulic conductivity (or permeability) of 1 x 10\(^{-7}\) cm/sec (D’Appolonia 1980).

### 3.2 Interlocking HDPE membrane

Sheets of 100-mil HDPE membrane are available with an interlocking, sealable joint. The sheets are manufactured into panels with the interlocking joint pre-welded to the sheet to minimize field welds. The joints can be sealed with a hydrophilic rubber cord which can be fed into the joint during installation and that then swells upon contact with water. The panel length depends on the barrier depth, while the width (and therefore number of joints) depends on field conditions such as depth variations, wind gusts during installation, installation equipment capabilities, and available work area. For this project, the panels were manufactured to 8 feet wide due to minimal available work area and significant depth variations. However, panel width can be as wide as 40 feet or more. Figure 2 shows a typical interlocking joint.

The use of HDPE is well established in the mining industry, and the product is well known to be compatible with mining wastes and leach solutions. For the barrier material, the mining company selected the option of a composite slurry wall composed of a very low permeability (approximately 10\(^{-12}\) cm/sec) interlocking HDPE cutoff wall sandwiched within a low permeability (less than 10\(^{-7}\) cm/sec) soil-bentonite mixture.

![Figure 2. Curtain wall™ panel.](image)

### 3.3 Mix design

Prior to construction, the contractor conducted a laboratory mix design to predict soil-bentonite performance and to determine material proportions for the soil-bentonite mixture. The mix design utilized imported soils, various types of bentonite, and the leach solution from the site. The objective of the mix design concentrated on the following areas:
a) Characterize the proposed materials.
b) Test and develop a workable soil-bentonite mixture with a maximum permeability of $1 \times 10^{-7}$ cm/sec.
c) Test the chemical compatibility of three types of commercial bentonites with the leach solution.
d) Formulate and test soil-bentonite backfill mixtures.
e) Test compatibility of the hydrophilic joint sealant with the leach solution.

To gauge the expected performance of the hydrophilic seal, tests were conducted by immersing samples of the material in tap water, bentonite slurry, and the leach solution. Test results indicated that the seal swelled in the bentonite slurry and the leach solution and, therefore, was compatible. This test measured the diameter of the seal swelled in bentonite slurry and then immersed in both tap water and site leach solution after 10 days of immersion. Swelling continued in tap water during the test; however, it had tended to gradually cease in the leach solution. Fortunately, the degree of swelling was sufficient to maintain a seal in the interlocks. Additional testing showed that the seal continued to swell when first immersed in bentonite slurry and later in a solution of 75% slurry and 25% leach solution by volume.

To perform the testing, the mining company obtained representative soil samples from local sources, available mixing water samples, and a sample of the leach solution. The soil sample consisted of 5.6% gravel, 39.4% sand, and 55% silts. Results of the soil gradation were compared to published recommendations for soil-bentonite slurry walls (Evans, 1991) and found to be acceptable.

Compatibility tests were performed on two types of bentonite, “premium grade” Fed Jel 90 and “saline resistant grade” SW 101, and on another non-swelling montmorillonite clay from Florida, atapulgite. Tests were performed as recommend by Day (1995) on the relative flow rates for each product when permeated with the leach solution. All three clays produced acceptable results and were therefore compatible. Additional tests were conducted on the chemical desiccation potential of the commercial clays with leach solution, but, again, no degradation was noted. Based on results and cost, “Fed Jel 90” was selected for additional testing.

Initially five soil-bentonite mixes were tested in fixed wall permeameters. Bentonite is added as a slurry up to the workability limit (about 1% added) with the balance added as a dry powder. Fixed wall tests were performed due to their simplicity, reduced cost, and more rapid turnaround in results. These tests were performed first with tap water and then for an additional two weeks with the leach solution.

The following is a summary of the fixed wall permeability test results of each mix:

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Bentonite Added (%)</th>
<th>Permeability cm/sec with leach solution</th>
<th>with tap water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>$8.8 \times 10^{-8}$ cm/sec</td>
<td>$1 \times 10^{-7}$ cm/sec</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>$2.4 \times 10^{-7}$ cm/sec</td>
<td>$1 \times 10^{-7}$ cm/sec</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>$1.3 \times 10^{-7}$ cm/sec</td>
<td>$5 \times 10^{-8}$ cm/sec</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>$1.4 \times 10^{-7}$ cm/sec</td>
<td>$8 \times 10^{-8}$ cm/sec</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>$1.7 \times 10^{-7}$ cm/sec</td>
<td>$7 \times 10^{-8}$ cm/sec</td>
</tr>
</tbody>
</table>

424
Based on the fixed wall permeability results, two additional tests were performed. For these tests, the flexible wall permeability (ASTM D 5084) apparatus was used. These tests were performed for about 6 weeks when two pore volumes of the leach solution passed through the samples. The flexible wall permeameter permits the application of a confining stress to the soil-bentonite and thus produces an improved model of in-situ conditions. The flexible wall permeameter is also the industry standard for testing. Results are as follows:

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Permeability (leachate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$7.4 \times 10^{-9}$ cm/sec</td>
</tr>
<tr>
<td>2</td>
<td>$6.8 \times 10^{-9}$ cm/sec</td>
</tr>
</tbody>
</table>

Based on the above results and cost, mix No. 2 with 3% bentonite added was selected for construction.

4 CONSTRUCTION METHODS

4.1 HDPE fabrication

Prior to construction activities, the HDPE panels were fabricated in twenty-three panels; each was eight feet wide. The length of each panel varied in accordance with the required depth of the proposed slurry wall based on the information shown in Fig. 1. The length included 4 extra feet beyond the design requirements to accommodate field adjustment, if necessary. The manufacturer required three weeks for fabrication. The panels required one flat bed truck for transportation to the site.

4.2 Bentonite slurry mixing for cutoff wall construction

The bentonite slurry was produced at a batch plant in a custom-designed, high-speed colloidal mixer. This 5-cy mixer has the capability to produce up to 500 gallons of hydrated bentonite slurry per minute. The plant used a multiple blade vertical mixing arm inside a baffled tank in combination with a 6-inch trash pump to mix and recirculate the slurry. The plant was powered by an electric generator. Colloidal mixing was achieved by adding bentonite powder while continuously mixing the water with two layers of mixing blades, and recirculating with a six-inch trash pump. The mixing blades sheared the slurry against vanes positioned inside the mix tank. Shearing action was created by the mixing blades, vanes in the mixer, and the pump impeller. Mixing was continued in the colloidal mixer until the bentonite slurry appeared homogeneous (approximately 5 minutes) and produced a constant rheology.

4.3 Cutoff wall excavation

The cutoff wall constructed at the site was 180 feet long with maximum depth of 60 feet. The slurry trench was excavated 2.5 feet wide from the existing surface to a maximum depth of 60 feet using a 200,000-pound hydraulic excavator specially modified to be capable of excavating to a depth of 67 feet (see Figure 3). Bentonite slurry level was maintained in the trench to within 2 feet of the surface. Excavated soils were placed on the working pad. Imported material was mixed with bentonite slurry and dry bentonite before backfill into the trench. Excavation was completed into the weathered granite. Continuity of the trench was demonstrated by passing the excavator arm through the slurry without encountering unexcavated materials.
Figure 3. Long stick hydraulic excavator.

4.4 HDPE panel installation

The HDPE panels were installed and jointed in the slurry trench. HDPE panels were stored at a location on the site. Prior to installation, each panel was examined to be free of damage. Personnel and equipment were readily available to repair damaged panels.

The steel frames were used for installation of the panels. Installation of the panels began with stretching the panel over the frame. The steel frame eliminated the need for gravel ballast or other weights to aid installation through the slurry. Two frames were utilized during construction. First, a primary HDPE curtain panel was attached to a frame and lowered into the trench using a crane. Next, a second HDPE panel was attached to a second frame, and lifted into position so the interlocks could be joined with the primary panel. Once the panels were aligned and prior to lowering the second panel, seal was started in the interlock between the two panels (see Figure 4). The second panel was then lowered while feeding in the hydrophilic cord as the panel was gradually lowered to the bottom of the trench. The frames were then released from the HDPE, removed and reused. This process was repeated to install 23 panels of HDPE.

4.5 Soil-bentonite backfill preparation

The soil-bentonite backfill (backfill) was mixed at a prepared earthen working pad using a hydraulic excavator until a thoroughly consistent mixture was achieved. Dry bentonite powder and bentonite slurry were added to the imported soil in accordance with the design mix proportions. The dry bentonite was added from 4000-lb bags, and bentonite slurry was added from the trench as it was displaced by backfill and from the slurry mixer.
Prior to backfill placement, the depth of the trench was measured at 10-foot intervals to ensure continuity and depth. Backfill was placed into the trench using a front end loader following installation of the HDPE panels. Backfill was initially placed using a ramp excavated in the soil on one end of the trench. The ramp or lead-in trench permitted a smooth easing of the backfill into place without the potential for segregation of the backfill or the accidental entrapment of slurry. Placement continued from one end of the trench to the other by always placing new backfill on the leading face of previously placed backfill. In this manner, the backfill displaces the slurry, creating a continuous barrier of soil-bentonite backfill without voids or entrapped slurry. A view of the entire operation is shown in Figure 5.

### 5 QUALITY CONTROL

An independent testing laboratory conducted sixteen flexible wall permeability tests of the soil-bentonite samples collected during construction at a frequency of one test every 50 cy. This testing frequency is about 10 times the typical testing frequency used in landfill construction but was justified by the landmark status of this groundwater solution for the mining industry. The test results listed below were consistent with the mix design results and exceeded the maximum criteria of $1 \times 10^{-7}$ cm/sec. Each of these samples were tested in the flexible wall permeameter for two pore volumes of flow through the sample. A summary of the tests results is as follows:

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Permeability</th>
<th>Sample #</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$8.23 \times 10^{-9}$ cm/sec</td>
<td>9</td>
<td>$1.21 \times 10^{-8}$ cm/sec</td>
</tr>
<tr>
<td>2</td>
<td>$7.91 \times 10^{-9}$ cm/sec</td>
<td>10</td>
<td>$1.24 \times 10^{-8}$ cm/sec</td>
</tr>
<tr>
<td>3</td>
<td>$1.041 \times 10^{-8}$ cm/sec</td>
<td>11</td>
<td>$1.19 \times 10^{-8}$ cm/sec</td>
</tr>
<tr>
<td>Sample #</td>
<td>Permeability</td>
<td>Sample #</td>
<td>Permeability</td>
</tr>
<tr>
<td>----------</td>
<td>------------------</td>
<td>----------</td>
<td>------------------</td>
</tr>
<tr>
<td>4</td>
<td>$8.97 \times 10^{-9}$ cm/sec</td>
<td>12</td>
<td>$9.63 \times 10^{-9}$ cm/sec</td>
</tr>
<tr>
<td>5</td>
<td>$1.09 \times 10^{-8}$ cm/sec</td>
<td>13</td>
<td>$1.14 \times 10^{-8}$ cm/sec</td>
</tr>
<tr>
<td>6</td>
<td>$1.19 \times 10^{-8}$ cm/sec</td>
<td>14</td>
<td>$7.706 \times 10^{-9}$ cm/sec</td>
</tr>
<tr>
<td>7</td>
<td>$1.37 \times 10^{-8}$ cm/sec</td>
<td>15</td>
<td>$7.78 \times 10^{-9}$ cm/sec</td>
</tr>
<tr>
<td>8</td>
<td>$7 \times 10^{-9}$ cm/sec</td>
<td>16</td>
<td>$8.22 \times 10^{-9}$ cm/sec</td>
</tr>
</tbody>
</table>

Water samples collected after construction from the monitoring wells located 900 feet downstream of the dam now reveal normal pH values. Recent groundwater sampling shows that water quality continues to improve and water levels downstream of the barrier are gradually decreasing.

![Image](image-url)

Figure 5. View of construction.

6 CONCLUSION

The project was completed by constructing a composite cutoff wall into bedrock. The project was successful due to the cooperation among the mine owner, the design engineer, and the contractor. To facilitate future projects, we recommend the following:

1. Characterize completely and accurately the subsurface soils and the required depth of excavation to construction.

2. Conduct a laboratory mix design utilizing proposed construction materials. The mix design simulates field conditions and provides quality control parameters.

3. Utilize HDPE that is compatible with mining wastes in a soil-bentonite slurry wall which resists high hydraulic gradients and severe groundwater chemistry.
7 ACKNOWLEDGMENT

The information presented herein was developed to discuss a unique remedial solutions for a challenging environmental problem. The permission of the mining company to publish this information is sincerely appreciated. The opinions and conclusions presented herein, however, are solely those of the authors.

REFERENCES

