THE USE OF BENTONITE AMENDED CLAY IN LOW LEVEL LANDFILL LINERS

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ABSTRACT

The Environmental Management Waste Management Facility (EMWMF) is a low level radioactive waste landfill located adjacent to the Y-12 Complex in Oak Ridge, Tennessee. As part of the Procurement 3 expansion to the facility, WEDC, a joint venture formed by Washington Group International and Earth Tech, Inc., was retained to design and construct Cells 3 and 4. Investigations performed to locate sources of low permeability soil liner material failed to identify ideal borrow areas within an economic haul distance. As a previous project had encountered difficulties with failing permeability tests, WEDC explored a number of alternatives to provide a material that would consistently meet project requirements. The option selected consisted of amending local clay with bentonite.

As part of proposal preparation, WEDC performed an investigation into the suitability of nearby sources of clay soil suitable for use as low permeability soil liner. The most promising source was located approximately 10 miles from the EMWMF site along a suitable transportation route. Testing was performed on this soil from samples obtained from test pits. The results of this testing indicated that, at the laboratory scale, the project permeability requirements would usually be met, but there would likely be instances where the requirements would not be met. This understanding, coupled with concern that laboratory-scale results may not be consistent with field-scale results, led to concern regarding the potential for an unacceptable amount of rework on the soil liner. Therefore, the decision was made to amend the clay with bentonite. Although most bentonite-amended soil liners used non-cohesive materials, it was believed that the clay could be successfully amended.

As noted, amending cohesive soils with bentonite to improve the hydraulic characteristics of the material is not commonly performed. The authors hope that their experience in successfully implementing this technology, along with managing the data required to complete the test pad (engineering, field and laboratory testing, construction quality assurance, etc.), will be of interest to others and may be relevant to other projects at other sites around the country. The purposes of this paper are to describe the methodology employed to amend the soil, to describe the test pads constructed and field testing performed on the amended soil, and to share lessons learned on the project.

INTRODUCTION

The Environmental Management Waste Management Facility (EMWMF) is a low level radioactive waste landfill located adjacent to the Y-12 Complex in Oak Ridge, Tennessee. As part of the Procurement 3 expansion to the facility, WEDC, a joint venture formed by Washington Group International and Earth Tech, Inc., was retained to design and construct Cells 3 and 4. Investigations performed to locate sources of low permeability soil liner material failed to identify ideal borrow areas within an economic haul distance. As a previous project had encountered difficulties with failing permeability tests, WEDC explored a number of alternatives to provide a material that would consistently meet project requirements. The option selected consisted of amending local clay with bentonite.

To amend the clay with bentonite, a pugmill was used.(Figure 1) Borrow soils were excavated, stockpiled, and run through a vibrating screen to break-up soil clods and to remove oversized particles. After screening, the soil was moisture-adjusted, amended with bentonite, and mixed. The resulting amended soil was staged in stockpiles prior to hauling to the job site. The material had very small clod sizes, had greatly reduced rock content, and was very close to the target placement moisture content. As a result, at the job site, the material was easy to handle, required only minor moisture adjustment, and was easily placed and compacted.

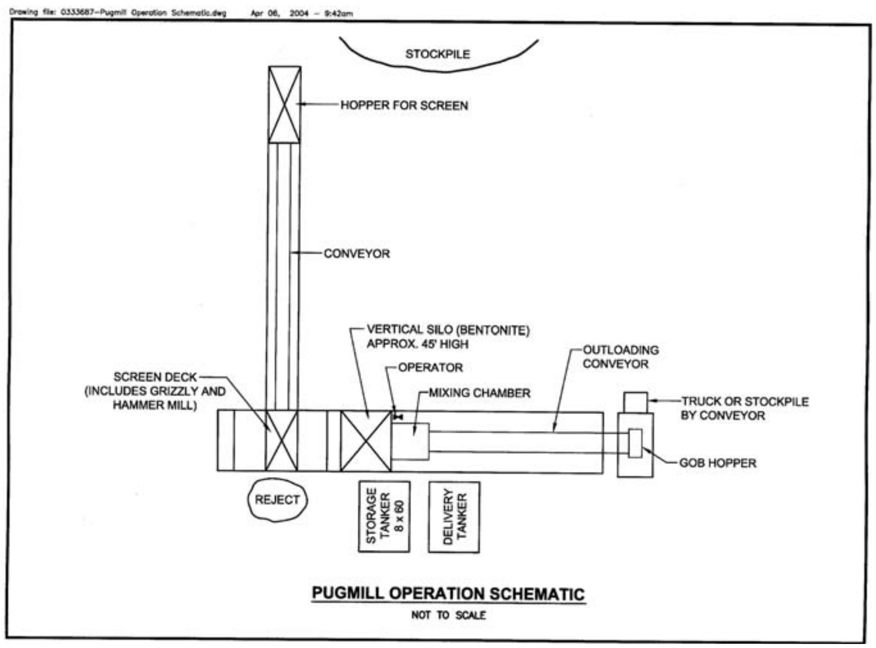

Fig. 1. Pugmill Operation Schematic.

As part of the project, two side-by-side test pads were constructed. The two test pads were constructed to evaluate the effectiveness of different pieces of compaction equipment (Caterpillar 815 and Caterpillar 563). The dimensions of each test pad were the same, approximately 25 ft by 130 ft. Placement conditions (lift thickness, moisture content, number of passes, etc.) were held constant for each test pad. Testing during test pad construction included moisture/density testing and oven moisture content. Shelby tube samples were obtained for laboratory permeability testing. Upon completion of the test pads, six Boutwell permeameters were constructed in each test pad, and field permeability measurements were made.

The results of the test pads indicated that the bentonite-amended soil provided an excellent low permeability liner material. Although the test pad created using the Caterpillar 563 did not meet the project requirements, these problems were believed to result from the compactor’s inability to extend the compactor feet through previously placed material to tie lift interfaces together. All tests performed on the test pad constructed with the Caterpillar 815 met the project requirements.

Upon completion of test pad testing, test pits were excavated into the completed test pad. No deficiencies in the material were noted. Bentonite blending was found to be very uniform. No issues with clod formation were noted. Moisture content was found to be uniform and, with few exceptions, within the moisture window established for the project.

BACKGROUND

EMWMF was designed to meet the requirements of RCRA Subtitle C and Tennessee Department of Environmental Control regulations. These requirements included the need to construct a 3 ft thick layer of low permeability soil. The hydraulic conductivity required for this layer was required to be less than 1 x 10^{-9} m/s.

Overview of Problem

During the previous phase of construction, difficulties in locating, procuring, placing, and accepting low permeability soil were encountered. Seemingly acceptable sources were located. Laboratory testing performed on these sources indicated that acceptable performance should be expected; however, test pad construction and prototype installation encountered difficulties. These difficulties involved unexpected variability in the soil, which resulted in a number of failing hydraulic conductivity tests performed on samples obtained while implementing quality control. These failing tests led to the removal and reconstruction of significant volumes of material.

During the previous construction effort, the low permeability soil was placed significantly above the material’s optimum moisture content to minimize the number of failing hydraulic conductivity tests. Although placement at this moisture content improved the hydraulic conductivity of the completed soil liner, the high moisture content had a negative impact on soil strength and workability. This resulted in some difficulties during soil placement and compaction.

As part of the P3 effort, the WEDC team attempted to identify a borrow source that would:

- Meet the project requirements for hydraulic conductivity;
- Minimize or eliminate the potential for expensive rework;
- Allow for a relatively wide placement moisture content window;
- Be economical to procure and haul to the site; and
- Be relatively simple to place, spread, compact, and fine grade.

The WEDC team identified and evaluated a number of potential solutions that met, or maximized, the items listed above.

Solutions Considered

As noted, a number of options that could potentially meet the requirements listed above were identified and evaluated. These included the following:

- Commercial clay borrow sources
- Greenfield borrow sources
- Importation (by rail) of kaolinite from Georgia
- Admixture of native soils with bentonite
- Revising the design to use a GCL with a higher hydraulic conductivity soil liner

As part of the development of the project, each of these options was considered. Four of the options were discarded; a brief summary of the evaluation performed, as well as the reasons each option was discarded, is presented below.

First, the WEDC team identified and contacted the commercial borrow sources that existed within an economical haul distance of the project. In general, the commercial borrow sources sold materials that were suitable as cohesive structural fill, but were questionable for use as low permeability soil liner. Visits to the sites confirmed information that was received by telephone, that the materials being sold commercially would not likely be sufficiently plastic to consistently achieve the required hydraulic conductivity. Laboratory index tests performed on samples from the commercial borrow sources supported the view that these sources would not be suitable. Therefore, this option was not pursued further.

The WEDC team next attempted to identify potential borrow sources that were non-commercial (greenfield sources, not having been developed previously). These areas were located through a combination of reviews of Soil Conservation Service and geologic maps and discussions with local earthwork contractors.

A number of sources were investigated, with three sites showing significant promise. Based on a review of existing information, test pits were performed at each of the three locations, and samples were obtained for laboratory testing. Laboratory testing performed on these samples included standard Proctor tests, natural moisture content tests, liquid and plastic limits tests, and remolded hydraulic conductivity tests.

Based on a review of the generated laboratory testing, one site (Gibson site) appeared to have slightly preferred soil conditions (these being somewhat more plastic and less variable than the other sites evaluated). In addition, the site was believed to have a greater quantity of acceptable soil than the other sites. The haul distance from each of the sites was not found to differ significantly.

Despite WEDC’s optimism regarding the site, the plasticity properties of the Gibson site was only slightly better than the soil used in the previous phase of construction. In addition, the relatively few test pits performed at the site did not allow a full evaluation of potential soil variability; a review of site geology suggested that significant soil variability should be expected.

Another option explored by the WEDC team was the use of kaoline imported from Georgia. In Georgia, a kaolinite processing facility was identified. This facility produced purified kaoline for manufacturing purposes. The facility also created off-specification product. This material was unsuitable for use in manufacturing, but would be suitable as a low permeability soil liner.

Kaolinite is a clay mineral of moderate plasticity. Natural clays of predominately kaolinite mineralogy are often used for low permeability soil liners. These clays have the advantages of being moderate in plasticity (minimizes shrinkage cracking), having acceptable hydraulic conductivity properties, and retaining significant soil strength in the anticipated range of soil placement. In addition, the manufacturing process had eliminated gravel-sized particles, reduced the amount of sand-sized particles, and created a very uniform soil (by earthwork standards, if not by manufacturing standards).

Although the material could be procured at nominal costs, the costs of transportation to the nearest rail yard and subsequent trucking to the site were very high. In addition, shipment schedules could not be guaranteed by the rail carrier (and soil stockpiles could not be maintained for extended periods of time without generating unacceptable amounts of sediment). Therefore, this option, despite its attractiveness, was discarded.

Another option explored by the WEDC team was to redesign the lining system to use a geosynthetic clay liner (GCL) in conjunction with soil liner with a higher hydraulic conductivity. This approach is commonly used on commercial Subtitle D and Subtitle C facilities. However, the EMWMF has a design life of 1,000 years. At this age, the geosynthetic component of the GCL is assumed to no longer be intact. Therefore, the internal stitching within the product could not be relied upon for strength, and the long-term slope stability analysis would have to be performed assuming the strength of hydrated, un-reinforced bentonite. As this strength is very low, the project team decided that stability could not be demonstrated, and the team elected not to pursue this option.

Therefore, all options, except for one, were discarded.

Solution Selected

As discussed above, the only remaining viable option appeared to be augmenting the native soil at the selected borrow site with bentonite.

To further examine this option, additional testing was performed on samples previously obtained from the selected borrow site. For this testing, remolded hydraulic conductivity tests were performed at various moisture contents, at various compaction levels, and with two different percentages of bentonite added (three percent and five percent). To account for the differences between bench-scale testing and field-scale performance, a half-order of magnitude factor of safety was identified as the passing requirements for testing. This meant that a successful laboratory test would be required to have a maximum hydraulic conductivity of 5×10^{-10} m/s.

Based on the testing performed, a target moisture window and percent compaction were identified. In addition, it was determined that no significant reduction in hydraulic conductivity was noted by increasing the bentonite content from three percent to five percent. Therefore, three percent bentonite was selected as the target admixture quantity.

Concerns Regarding Selected Option

Although the bench scale testing indicated that the bentonite admixed soil would successfully perform in the field, the WEDC team had a number of concerns:

- Soil variability might be greater than the test pits indicated;
- The quantity of acceptable soil might be less than expected;
- Plastic, cohesive soils might be more difficult than expected to process; and
- The process might not be able to blend the bentonite as thoroughly as the laboratory could.

Of these concerns, the first two could be mitigated by performing a more detailed geotechnical investigation of the site. A thorough Borrow Characterization Study was required prior to completion of the scope of work, so this effort would be performed during the design phase (although another search for suitable borrow might cause schedule impacts).

To address the third and fourth concerns, a series of discussions were held with the contractor who would be performing the blending operation (Phillips and Jordan, under subcontract to Avisco). Most bentonite blending operations are performed on friable, non-cohesive soils that readily break apart. These soils can be processed quite easily, and the blending is very uniform. The contractor was certain that this effort could be performed on the materials at the site, and project references were provided for similar materials. A review of these references indicated that the materials being processed were significantly less plastic than the materials proposed for this project. Still, the methodology seemed sound, and the process well-engineered. It was apparent that if the soil could be broken down for processing, adequate bentonite blending would result.

SELECTED OPTION IMPLEMENTATION

Despite concerns regarding the technical implementation of the bentonite blending operation, the admixture option appeared to be the best solution. Therefore, plans were made to proceed with this approach. (See Figure 2)

Fig. 2. Equipment Arrangement.

To blend the bentonite with the soil, the contractor selected to use a Rapidmix 400 pugmill with a vertical silo for bentonite storage. The Rapidmix 400 pugmill is a volumetric continuous mix plant that has an operator's control station containing a plant computer for controlling the proportions of the base soil, bentonite, and water. The mixing plant computer allows the operator to see rates and total volumes of any given component at any time and produces a ticket at the end of the day showing the amounts of base soil, bentonite, and water that were used in the mix.

The plant computer also determines the rate at which bentonite will be added to the base soils. To determine the rate initially, the mixing plant computer was calibrated per the manufacturer's instruction prior to the start of mixing operations, and a calibration report was generated per the project quality control requirements. Further calibrations were conducted on an as-needed basis, based on soil and climate variations (generally to adjust the moisture content so that the material would arrive at the jobsite at the target moisture content). The calibration process for the mixing plant is as follows:

- The base soil was run through the pugmill at a fixed belt scale rate (without admixing) and collected in a truck.
- Dry bentonite was collected in a calibration box and weighed separately.
- Two trucks were driven to a set of scales and weighed to determine the total weight of soil and bentonite.
- The dry weight of soil was determined using laboratory moisture-density relationship curve.

- The weights of the dry soil and bentonite, along with the desired mix design (percent bentonite), were fed into the mixing plant computer to determine the input rate of the bentonite based on the output rate of the pugmill belt scale.

Once production started, the output rate of the belt scale was monitored to ensure that correct tons per hour of mixed soil and bentonite were being produced based on the mix design. In addition, moisture content tests were performed at the borrow site as well as at the jobsite to ensure the material was within the target moisture content window.

Borrow soils were loaded into a hopper to feed a vibrating screen using an excavator. The hopper was continuously fed so a consistent volume of soil exited the vibrating screen. The vibrating screen was situated below the screen deck. The vibrating screen was equipped with a grizzly which automatically rejected material larger than 6 inches. Material that passed through the grizzly was further reduced with the screen's internal hammer mill to pass through a 1-inch screen. Larger material was rejected to the side of the pugmill, while material passing the screen was dropped into the mixing plant soil hopper.

The base soil, bentonite, and water was mixed in a 12-ft mixing chamber containing two counter-rotating shafts, each one comprised of approximately thirty mixing paddles. The paddles were mounted in a spiral configuration which caused the material to move from the input end of the pugmill to the output end as it was mixed in the chamber. Upon exiting the mixing chamber, the soil-bentonite mix was discharged onto a conveyor and dropped onto a stacking conveyor for stockpiling.

Material Processing

Equipment set-up began on May 11, 2004, with equipment calibrations being performed on May 17 and 18, 2004. Material processing began on May 20, 2004. Excavators and pans were used to remove material from the borrow area in a manner consistent with the Erosion and Sediment Control Plan. Excavated borrow soil was stockpiled near the pugmill. Front end loaders were used to load soil from the stockpiles into the soil hoppers. Bentonite blended soil was placed onto stockpiles approximately 4,000 cubic yards in size. Stockpiles were arranged this way so quality control testing could be performed on each stockpile and so each stockpile could be considered tested and released for use as soil liner.

Due to concerns regarding the loss of moisture from drying, moisture content of the stockpiles were monitored closely. The WEDC team preferred that any moisture content adjustments required for the blended material be performed using the pugmill. To minimize any moisture content adjustments being performed at the jobsite, the target moisture content of the completed admixture was set several percent higher than the actual target moisture content in the soil liner. This was done to allow for moisture loss during stockpiling and handling. In addition, the surfaces of the stockpiles were sprayed with water to try to maintain a constant soil moisture.

The production of bentonite-amended soils depended upon construction schedule, weather, and other factors. Production generally exceeded 800 tons of material per day and at times exceeded 1,200 tons per day.

Source Quality Control Testing

As noted above, quality control testing of the stockpiled soils was performed. This testing was performed in accordance with the approved Construction Quality Control Plan generated for the project. Quality control testing of the admixed soil included liquid and plastic limits, natural moisture content, percent fines, percent gravel, soil moisture-density relationship (standard Proctor), and recompacted hydraulic conductivity tests.

In addition, the weights of the feed soil, bentonite, and added water were obtained on a daily basis. This information, along with the moisture-density relationship curves, was used to perform a daily verification of the percent bentonite being added to the mixture.

Fig. 3. Test Pad Construction and Testing.

Two adjacent test pads were constructed in the northeast corner of Cell 4 between Wednesday, May 26, 2004 and Saturday, June 5, 2004. (See Figure 3 above) The test pads were constructed and tested in accordance with the Test Pad Plan; a summary of the construction and testing, as well as the results and conclusions, were presented in the Test Pad Report.

The two pads were constructed to accommodate two types of compaction equipment. Lift thickness was controlled using global positioning systems with elevation controls mounted on a bulldozer. Lift thicknesses were also checked using manual survey.

Test Pad Geometry

Each test pad was constructed to be 25 ft wide by 130 ft long. Test pad dimensions were dictated by the spacing requirements of the Boutwell permeameters and by the number of Boutwell tests desired.

Construction Equipment

The equipment used to compact the test pads included a Caterpillar 815 compactor and a Caterpillar 563 compactor. The Caterpillar 563 is a vibrating, single drum compactor with an operating weight of 33,450 pounds and a cleat height of 4-1/2 inches. The Caterpillar 815 weighs 58,400 pounds and has a cleat height of 7-inches.

Test Pad Construction

The test pad site was inspected by the project Construction Quality Control Engineer and Design Engineer prior to placement of the first lift. The subgrade was noted to be stable and more permeable than the liner soils. Proof-rolling was performed to confirm and document the stability of the subgrade. After proof-rolling, the subgrade was watered and scarified with the Caterpillar 815 to enhance bonding with the first lift.

Low permeability soil liner material from the Gibson borrow site was trucked into the site for placement in the test pad. The material was spread in lifts using a bulldozer with global positioning system elevation controls. The compactors operated parallel to the long direction of the lanes. Six lifts, each with a compacted thickness of about six to eight inches, were placed for a total thickness of about 3.5 ft. During placement of Lifts 1 and 2, the compaction equipment made two initial passes, followed by two additional passes after in-place testing. Subsequent lifts were compacted with four passes prior to testing. A pass was defined as a round trip (backward and forward) of the compactor.

Precipitation during test pad construction required drying of the soils to return the material to the target moisture content range. Although soil drying was also a concern, no additional water was required to be added during test pad construction.

CQC Testing

Nuclear moisture/density testing was performed during test pad construction. Due to concerns regarding potential errors in the nuclear moisture content readings (from micaceous soils), samples from each nuclear moisture/density test were obtained for oven testing. Oven testing consisted of both microwave oven and conventional oven moisture content testing to determine what, if any, of the moisture content testing correlated with conventional oven moisture content.

In addition, nuclear density tests were verified using drive cylinders. Shelby tube samples for laboratory hydraulic conductivity testing were also obtained. Defects in the soil liner as a result of testing were repaired in accordance with procedures established in the Construction Quality Control Plan.

Fig. 4. Hydraulic Conductivity Testing.

Upon completion of the test pad construction, the in-situ hydraulic conductivity of the test pad was measured using the Two-Stage Borehole Permeameter (Boutwell) Method. (See Figure 4 above) A total of six six-inch diameter Boutwell permeameters were installed in each test pad. In addition, one Temperature Effect Gauge was installed between the third and fourth Boutwell permeameter in each test pad.

Each Boutwell permeameter was installed in accordance with ASTM D 6391. During the installation of Stage 1 of the Boutwell permeameters, two permeameters installed on the lane compacted using the Caterpillar 563 were found to be unable to hold water overnight. Attempts were made to reset or reconstruct those permeameters. After these rehabilitation attempts failed, it was decided that the permeameter tests were considered failures, and the tests were terminated. Since the acceptance criteria for each test pad included no more than one failing Boutwell, additional hydraulic conductivity testing on this test pad was not performed. Stage 1 testing for each Boutwell test in the test pad constructed using the Caterpillar 815 was completed without incident.

The Boutwell permeameters from the Caterpillar 815 test pad were then extended for Stage 2 testing. Stage 2 testing was performed on these permeameters without incident.

Hydraulic Conductivity Results

The Boutwell permeameter results indicated that the test pad constructed using the Caterpillar 563 did not meet the required standard for hydraulic conductivity. Excavation of the failed permeameters did not reveal any obvious defects within the soil mass to account for the high hydraulic conductivity. Based on a review of the manner of failure, it was concluded that the most likely cause of failure was the existence of horizontal planes built into the test pad.

Since the cleats of the Caterpillar 563 were not long enough to extend into the underlying soil lift, it is believed that horizontal planes were constructed into the test pad. These planes could be small enough to avoid visual detection, but large enough to enable a significant amount of flow to occur along the planes.

Each Boutwell permeameter test performed in the test pad constructed by the Caterpillar 815 achieved a hydraulic conductivity less than the required 1×10^{-9} m/s. As the cleats of the Caterpillar 815 are sufficiently long to reach through the underlying lift, it was concluded that no horizontal layers were formed during construction of this test pad.

At the end of the test pad, test pits were excavated into the successful test pad. The purpose of these test pits were to identify any physical discontinuities with the test pad, to look for problems with bentonite blending or clod formations, to confirm that lifts were properly bonded together, and to verify that the soil liner had bonded with the underlying subgrade. In addition, the test pits provided an opportunity to perform soil recompaction using a soil rammer and to obtain samples for laboratory hydraulic conductivity testing from the recompacted test pits.

Based on the results of the test pad, it was determined that the prototype soil liner should be constructed using soil amended with the bentonite using the moisture window generated by the laboratory testing phase of the project, using four passes with a Caterpillar 815. It was further concluded that small areas of soil liner that could not be installed using the Caterpillar 815 could be compacted using a soil rammer.

Additionally, it was found that the moisture content of the soil determined using the nuclear gauge was not reliable and did not correlate with the conventional oven moisture content. The microwave oven method of determining soil moisture was found to correlate well with the conventional oven and, therefore, could be used to determine in-situ soil moisture.

Cell Construction

Based on the information generated and lessons learned from test pad construction, the soil liner was installed. This effort started on August 4, 2004. As in the test pad, incoming material was visually observed to ensure that bentonite has been adequately blended and that clod size had been sufficiently reduced. To the greatest extent practical, the soil liner material was trucked to the working area so that the amount of pushing with a bulldozer was minimized. Material was placed, and testing was performed in accordance with the procedures outlined in the Test Pad Report and the Construction Quality Control Plan. As determined in the test pad, the moisture content results from the nuclear gauge were not used; instead, microwave oven moisture content tests were used for quality control purposes.

CONCLUSION

WEDC has concluded that the cohesive soils native to the Oak Ridge area could be successfully blended with bentonite and used to produce an acceptable low permeability soil liner. The results of the test pads indicated that the bentonite-amended soil provided an excellent low permeability liner material. Although the test pad created using the Caterpillar 563 did not meet the project requirements, these problems were believed to result from the compactor's inability to extend the compactor feet through previously placed material to tie lift interfaces together. All tests performed on the test pad constructed with the Caterpillar 815 met the project requirements.

Upon completion of test pad testing, test pits were excavated into the completed test pad. No deficiencies in the material were noted. Bentonite blending was found to be very uniform. No issues with clod formation were noted. Moisture content was found to be uniform and, with few exceptions, within the moisture window established for the project.

In addition to producing a material that met project specifications, a number of other benefits were found from using the soil amending process described above. First, the use of vibrating screens to remove materials larger than one-inch resulted in very effective removal of oversized particles. This resulted in a liner material that was easy to work, easy to place, easy to compact, and easy to test. Additionally, the pugmill and vibrating screen caused a great reduction in clod size. Adding water by using the pugmill resulted in a more thorough and uniform moisture adjustment than is normally possible through watering and disking soils in-place. Finally, the material produced was very uniform, with essentially no areas of the liner that were significantly different from the whole.

As noted, amending cohesive soils with bentonite to improve the hydraulic characteristics of the material is not commonly performed. As a result, this option may not be considered. As this project demonstrates, blending of cohesive soils with bentonite can be a practical and cost-effective alternative to other means of ensuring a soil liner meets the required hydraulic conductivity.

REFERENCES

1. WEDC, Inc., P3 Construction Quality Control Plan, SSRS 3.005, Rev. 3, July 2004

2. WEDC, Inc., Test Pad Plan, SSRS 3.009, Rev. 2, May, 2004

3. WEDC, Inc., Test Pad Report, SSRS 3.905, Rev. 0, July, 2004