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LESSONS LEARNED FROM THE MACON COUNTY SLURRY WALL

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ABSTRACT

A soil-bentonite slurry trench cutoff wall was installed as part of landfill improvements at the Macon County Landfill located in Decatur, Illinois. In order for a soil-bentonite barrier to be continuous and defect-free, a homogeneous, well-graded backfill needs to displace the slurry used to maintain trench stability. Historically, specifications required that the backfill have a unit weight of 15 pounds per cubic foot (pcf) higher than the unit weight of the in-trench slurry and the slurry have a maximum density of 85 pcf. More recently, specifications have also required that the sand content of the slurry, not exceed 10 to 15%. During the course of construction, difficulties arose which gave rise to post-construction investigations of the integrity of the completed cutoff wall. A program of field sampling and testing, which included Osterberg sampling, modified Osterberg sampling, and sonic-core borings, was developed to investigate the integrity of the wall. Since state-of-the-practice quality assurance and quality control measures are based upon field measurements and sampling during construction coupled with laboratory measurements of field-prepared backfill samples, detailed investigations of the in-situ, as-constructed wall are relatively uncommon and even more uncommonly documented in the literature. This paper presents these investigations, findings, conclusions derived from the investigations and provides recommendations for slurry wall design and construction derived from these studies.

INTRODUCTION

Much has been written about the design and construction of soil-bentonite slurry trench cutoff walls (D'Appolonia 1980, Ryan 1987, Millett et al. 1992, Evans 1993). Limited information is also available on the laboratory measured values of hydraulic conduction on field mixed samples (Evans 1994, and others). A recent paper presented results from in-situ testing providing information on the state of stress and in-situ measures of hydraulic conductivity (Filz et al., 2003). Studies have also been conducted to demonstrate the importance of small defects in the overall groundwater and contaminant transport through a vertical cutoff (Lee and Benson, 2000). However, little field data is available in literature on the presence of defects and accompanying construction quality control records permitting an assessment of construction specifications and procedures in the context of the resulting quality of the cutoff wall. State-of-the-practice quality assurance and quality control measures are based upon field measurements and sampling during construction, coupled with laboratory measurements of field-prepared backfill samples, rather than direct measures of the completed barrier properties. This paper presents the results of field sampling and laboratory testing on field samples correlated with construction quality assurance and quality control records. Most importantly, this paper provides insight into the impact of sand content upon the hydraulic conductivity of backfill materials. Finally, this paper provides details regarding the investigations, findings, and conclusions derived from the investigations, and recommendations for slurry wall design and construction supported by the findings and conclusions.

SITE BACKGROUND

A 2030-meter (6,660-foot) long soil-bentonite slurry trench cutoff wall ranging in depth between 5.3 and 21.6 meters (17.4 and 71 feet) was installed as part of landfill improvements at the Macon County Landfill located in Decatur, Illinois. This landfill was purchased by Onyx Waste Services, Inc. (Onyx) in 1998 from the Macon County Landfill Corporation, which was originally formed in 1956 by local waste haulers. Unit 1 of the landfill was constructed pre-1970 above in-situ soil materials of varying hydraulic conductivity without an engineered lining system. Unit 2, Section II began accepting waste in 1970; and Unit 2, Section III began accepting waste in 1978. Both Sections II and III are underlain by a minimum of 3 meters (10 feet) of in-situ glacial till with a low hydraulic conductivity. The purpose of the soil-bentonite cutoff wall was to allow Unit 1 to meet the Groundwater Impact Assessment requirement of 35 IAC 811.317, so the entire facility could be regulated under 35 IAC Part 814.

CUTOFF WALL DESIGN, CONSTRUCTION, AND ANALYSIS

The soil-bentonite slurry trench cutoff wall was designed and constructed in accordance with standard practice. Excavation stability was maintained using bentonite-water slurry. The slurry was then displaced by a soil-bentonite backfill to form the permanent cutoff. The specification called for slurry in the trench to have a Marsh viscosity greater than 40 seconds, a unit weight from 10 to 13 kilonewtons per cubic meter (kN/m^3) (64 to 85 pcf) and at least 2.4 kN/m^3 (15 pcf) less than the backfill unit weight, and a sand content of less than 10%. The sand content specification was later revised to be a maximum of 15%. Note that 15% sand added to the bentonite in the slurry results in a unit weight of approximately 13 kN/m^3 (85 pcf) imparting consistency to the specifications.

Specifications required the backfill to have a 10- to 15-centimeters (cm) (4- to 6-inch) slump and a hydraulic conductivity less than $1x10^{-7}$ centimeters per second (cm/s). The specifications also called for gradation control with the following gradation requirements:

Table 1: Gradation Requirements

Sieve	Amount Passing (dry weight %)
3 inch	100
No. 4	65-95
No. 40	40-90
No. 200	25-75

During the course of construction, difficulties arose which gave rise to post-construction investigations of the integrity of the completed cutoff wall. Specifically, for selected portions of the trench, the sand content of the slurry in the trench exceeded the maximum of 15% specified. Shown on Fig. 1 is a plot of sand content measurements for the project. As seen through the scatter, a substantial number of the records indicate sand content in excess of 15%, and there appear to be trends of increasing/decreasing results with each successive measurement. To smooth the results to look for trends, the data is re-plotted on Fig. 2 using the average of the measurement and the seven preceding measurements. Hence, each data point represents a rolling average of the eight measurements. Figure 2 reveals trends of increasing/ decreasing sand content with each successive reading. These readings are linked to specific trench locations allowing identification of portions of the trench that were constructed with the slurry-containing sand beyond the limits of the specification.

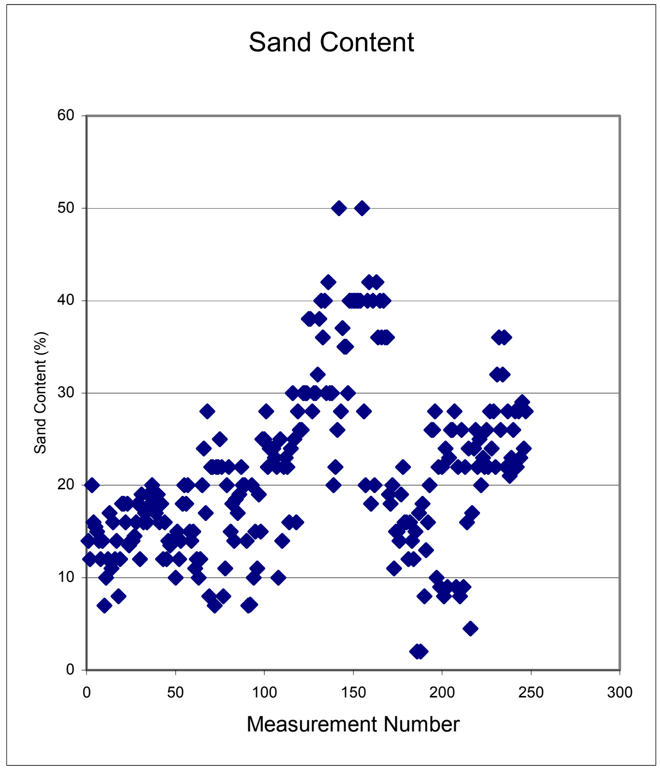

Fig. 1. Sand content measurements

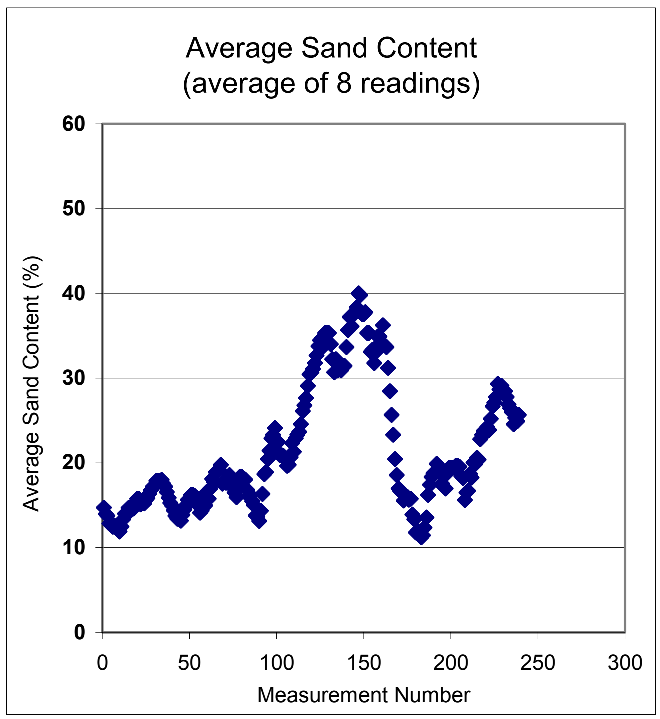

Fig. 2. Sand content measurements averaged

In order for a soil-bentonite barrier to be continuous, homogeneous, and defect-free, the backfill must displace the slurry. Historically, specifications required that the backfill have a unit weight 2.4 kN/m^3 (15 pcf) higher than the unit weight of the slurry and that the in-trench slurry have a maximum unit weight of 13 kN/m^3 (85 pcf) (D'Appolonia

1980). More recently, specifications have also required the sand content of the slurry not exceed 10 to 15%. For example, the Unified Facilities Guide Specification for soil-bentonite walls includes a requirement for a maximum sand content of 10% (US Army Corps of Engineers 1998). On this project, the sand content regularly exceeded the 15% maximum required by project specifications. Based on quality assurance data, it was concluded that in portions of the trench, where the sand content of the slurry exceeded 15% and the density of the in-trench slurry exceeded 13 kN/m^3 (85 pcf), the risk of a defect in the wall was increased compared to that risk had the sand content and density met the project specifications. As a result of this conclusion, a program of field sampling and testing, which included the evaluation of an Osterberg sampler, modified Osterberg sampler, and sonic-core boring, was developed to investigate the potential for construction defects related to the sand content of the slurry.

FIELD SAMPLING METHODS

Three different methods of field sampling were tested for sampling the completed soil-bentonite cutoff wall. Sampling with an Osterberg sampler, modified Osterberg sampler, and sonic-core boring (US Army Corp of Engineers 2000). The objective of the field sampling was to look for the presence or absence of significant imperfection in the soil-bentonite backfill by observation and/or visual classification, and to obtain jar samples for laboratory testing. Osterberg sampling was originally selected as the method to obtain samples of the soil-bentonite backfill for laboratory testing because the method works well in sampling soft clayey soils. However, due to the relatively short sample length, 76 cm (30 inches), a modified Osterberg sampler with a maximum sample length of 152 cm (60 inches) and sonic-core boring with a maximum sample length of 6.1 meters (m) (20 feet) were tested.

Five borings were completed using an Osterberg sampler to investigate another portion of the completed soil-bentonite cutoff wall at depths between 6 to 18 m (20 to 59 feet). The Osterberg sampler was able to obtain a 76-cm-long (30-inch), 7.5-cm-diameter (3-inch) sample. Of the 41 samples collected with the Osterberg sampler, less than half (18 samples) had full recovery. Recovery on the remaining 23 samples ranged between 6 and 68 cm (2 and 27 inches), and averaged about 45 cm (18 inches). After the samples were extruded in the laboratory, it was apparent that clay clods and rocks in the soil-bentonite backfill affected the sample recovery, along with the other inherent sampling difficulties.

Two test borings were completed using a modified Osterberg sampler to evaluate its use in sampling the completed soil-bentonite cutoff wall. The sampler was previously used to collect 152-cm-long (60-inch), 7.5-cm-diameter (3-inch) diameter samples of lake sediments. However, in sampling the soil-bentonite backfill we were not able to obtain complete recovery. Of the six samples attempted, 50% recovery was the most we were able to obtain using the modified Osterberg sampler. The inability to obtain 100% recovery is more attributed to the care taken during sampling than the sampling method. We evaluated this method after the sonic-core test borings were completed, and based on those results, selected that method to sample the wall.

Two test borings were completed using sonic-core boring to evaluate its use in sampling the completed soil-bentonite cutoff wall. The particular sonic-core rig that was initially used was capable of sampling intervals up to 6.1 m (20 feet), depending on the soil properties. In the evaluation process, this particular rig we initially attempted to obtain 6.1-m (20-foot) long samples however, we only able to recover approximately 4.6 m (15 feet) of sample. The sampling interval was reduced to 3-m (10-foot) samples and we were able to obtain 100% recovery on the 4 samples attempted.

Based on previous experience with the Osterberg sampler, test borings with the modified Osterberg sampler, and sonic-core boring, sonic-core boring was selected as the best method to sample and evaluate the soil-bentonite cutoff wall.

FIELD AND LABORATORY INVESTIGATIONS

A total of 22 sonic-core borings were ultimately completed along the portions of the cutoff wall in question. The sonic drill is a relatively new drilling/sampling method which provides a continuous, although disturbed, sample for the entire 3-m (10-foot) sampling interval. The sampler is advanced while vibrating at frequencies in the range of 50 to 200 hertz. Visual examination of the samples was made in order to describe and classify the backfill soil. Laboratory properties of moisture content, grain size distribution, and hydraulic conductivity were measured on collected samples. Selected results are described in the following paragraphs.

Test Area 1

The first area was selected because during the course of construction, the sand content ranged from 20% to 50%. Inspection personnel had also noted that the key was not adequately cleaned prior to backfilling in the area. Visual examination of material recovered from sonic-core sampling indicated that the backfill between 11.6 and 12.2 m (38 and 40 feet) below the ground surface appeared to be a mixture of bentonite slurry and sand, rather than well-graded soil bentonite backfill. Similarly, material sampled from the base of the excavation could best be described as coarse-grained sediment rather than backfill. Thus, the sonic-core sampling confirmed the presence of a "window" or "defect," where the backfill was placed in slurry having a sand content in excess of the specification.

Despite the confirmed presence of a window, from 11.6 to 12.2 m (38 to 40 feet) below the ground surface, the sample from this location was found to meet the grain size distribution requirements for this particular project. More importantly, the material was found to have a hydraulic conductivity of 2×10^{-8} cm/s, meeting the hydraulic conductivity requirement. These findings are encouraging in that a window that might develop from sedimented sands would likely be rich in bentonite and, as found on this project, would be expected to have a relatively low permeability. However, although not tested on this project, such poorly graded backfill would not be expected to be as resistant to degradation due to contaminants (compatibility) as the well-graded backfill as designed.

As a matter of comparison, samples of materials visually described as backfill were tested for both gradation and hydraulic conductivity. The backfill sample test results met the specifications for both gradation and hydraulic conductivity.

Finally, the sample obtained from the base of the cutoff wall at a depth of 49 to 50 feet was tested and found to be too coarse to meet the gradation requirements (fined content 10%) and too permeable to meet hydraulic conductivity requirements ($3x10^{-4}$cm/s). These data confirm an expectation that the coarsest sediment would be expected at the bottom of the trench and, depending upon the grain size characteristics of the material being excavated, the coarse sediments could (and did) give rise to unacceptable permeability and grain size characteristics.

Test Area 2

Another location was also selected for additional investigation because of high sand content (up to 42%) during construction. However, at this location the contractor modified some of their field procedures to limit the volume of trench open and continuously operate a de-sander. Visual classification of samples obtained from sonic-cores indicated three depth ranges included materials not representative of the well-graded backfill. Samples of material from all three of these locations failed to meet gradation requirements of a minimum of 25% fines. The samples were tested and found to have fines contents of 24.6%, 17.6%, and 11.1%, respectively. The corresponding values of hydraulic conductivity were $8.0x10^{-8}$ cm/s, $9.8x10^{-8}$ cm/s, and $1.4x10^{-7}$ cm/s. These data again confirm the need to control the sand content of the slurry to minimize the possibility of a window developing in the barrier wall. However, the hydraulic conductivity values are encouraging in that two of the three samples met the specification (and the other almost met it). Hence, even if a window forms, there is a good possibility that the hydraulic conductivity will still be relatively low. Also, note that even though the backfill did not have the specified fines content of 25%, fines content was still substantial in two of the three samples, and the measured values of hydraulic conductivity on these were still relatively low. This is an indication that a fines content of 25% may not be needed to achieve a hydraulic conductivity less than $1x10^{-7}$ cm/s. However, a fines content of 25% will provide more resistance to contaminant degradation than one of only 10%, so from consideration of permanence, the higher fines content is still recommended.

Other Test Areas

From the investigations conducted after initial completion of the soil-bentonite cutoff wall, a total of ten samples were visually classified and tested, as described above, with similar results. It was concluded that the subsurface investigation corroborated concerns regarding the integrity of the completed wall. That is, where sand content (and thus slurry density) was excessive, the presence of entrapped materials increased. Similarly, where the sand content was held to the specified value of 15%, no defects were found.

Remixing of Questionable Portions of the Cutoff Wall

Subsequent to the post-construction investigations described above, remedial measures were taken to repair any windows that might be present in the wall. Portions of the wall were selected for remedial work based upon the construction quality control data indicating sections built in compliance with the specifications (most often the sand content). The remedial method selected by the contractor and approved by the engineer was the use of a single shaft discontinuous flight auger. The auger was 0.86 m (34 inches) in diameter, and penetrations were every 0.61 m (2 feet) on center. The backfill was mixed using four passes (two up and two down) to the required depth and mixing speed was based upon drilling resistance, such that penetration strokes were generally mixed more slowly than withdrawal strokes.

Post-Remix Investigations

After remixing of the soil-bentonite backfill, sonic drilling methods were used to drill and sample the completed cutoff wall. In each and every case, the post-remix samples showed a backfill that was homogeneous with no signs of stratification and consistent with the design intent.

DISCUSSION OF BACKFILL INTEGRITY

The purpose of the slurry is to maintain trench stability during excavation. The purpose of the backfill is to form a continuous, low permeability vertical barrier to reduce groundwater flow and contaminant transport. For the backfill to perform its function, it must fully displace the slurry and be free of construction defects. Several specifications and construction practices are applied to achieve a uniform backfill in place. First, it is common to maintain a slurry unit weight of at least 15 pcf less than the backfill. This can be achieved either by limiting the unit weight of the slurry or by increasing the backfill unit weight. Increasing the backfill unit weight can be accomplished by decreasing the slump. Increasing the backfill unit weight by decreasing the slump may, however, be counterproductive. Certainly, a higher density backfill is more effective in displacing slurry, but the stiffer backfill will flow less freely and, arguably, is less effective in displacing slurry due to its stiff nature. Increasing backfill density by decreasing slump is not recommended. Another means to minimize the entrapment of materials in the backfill is by cleaning the backfill surface or rodding the backfill surface. If substantial time elapses between placement of batches of backfill, cleaning of the backfill surface can remove sand that may have sedimented on the backfill slope. Rodding the surface of the backfill reduces the risk of a layer of sand becoming entrapped as additional backfill slides down the slope. Any sand on the slope prior to rodding is, however, mixed with the already placed backfill, changing the gradation of the backfill. This may or may not be acceptable, depending upon the original backfill composition. Minimizing work stoppages will minimize the time available for sediment to accumulate on the backfill surface. Another measure sometimes suggested to maintain the integrity of the backfill is the placement of a backfill having a hydraulic conductivity well below that required. In this way, sand that finds its way into the backfill might not cause a detrimental increase in the hydraulic conductivity of the placed backfill. While low hydraulic conductivity is a positive attribute of the placed backfill, it does not directly pertain to the risk of entrapping sand in the backfill and the pocket of entrapped material may well be more permeable than required by the project. Another step taken to minimize defects in the backfill is the preclusion of free-dropping of backfill in the trench. This is a proper, and universally applied, measure to reduce the risk of entrapping sediment in the backfill. Another means taken to maintain the integrity of the cutoff wall is to increase the depth of the key into the underlying aquiclude. A 0.91-m (3-foot.) key is typical. An increased depth of key is useful to preclude under-seepage in areas that may have entrapped coarse materials at the bottom of the trench. Finally, minimizing the unit weight of the slurry, by desanding if necessary, is critical to the backfill readily displacing the slurry. Since trench stability increases with increasing slurry unit weight, a tension exists between high unit weight for trench stability and low unit weight for ease of displacement by the backfill. Field measurements of depth to the backfill slope are taken at intervals varying from 3.1 to 7.6 m (10 to 25 feet). Additional soundings reduce the risk that cave-in materials from the trench sidewall would go undetected.

In summary, there are numerous techniques available to produce a high quality soil-bentonite backfill. Given the indirect means used by the profession to accept or reject soil-bentonite slurry walls, construction procedures that minimize the risk of defects are recommended. The risk of entrapping pockets of sand in the completed wall increases as the sand content of the slurry (and thus unit weight) increases. In most cases, the difficulty is that it is simply not possible to know to what extent, if any, windows exist in the wall. For the case described in this paper, deviation from the specification in the form of increased sand content (and unit weight) resulted in the entrapment of unsuitable materials within the wall.

SUMMARY AND CONCLUSIONS

This paper presents the findings and conclusions derived from post-construction investigations of a soil-bentonite slurry trench cutoff wall constructed and monitored using state-of-the-practice methods. Quality assurance data revealed portions of the barrier wall were constructed with a slurry sand content in excess of the allowable maximum of 15%. Subsequent investigations involving drilling, sampling and laboratory testing were conducted to ascertain the impact of the excess sand content in the slurry upon the integrity of the soil-bentonite backfill. These post-construction investigations demonstrated that backfill placed where the sand content of the slurry was excessive resulted in the presence of defects in the wall. These defects occurred despite the 2.4 kN/m^3 (15 pcf) density difference maintained between the backfill and the slurry. The investigation also demonstrated the viability of sonic-core borings for the extremely soft soil-bentonite backfill materials. Repair of the questionable areas of the trench was accomplished using a deep soil mixing with a single auger having a 34-inch diameter and penetrations 2 feet on-center. Additional sonic-core borings verified that the repair method successfully blended the backfill material to meet the project specifications.

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