CLOSURE OF A STEEL FACILITY DISPOSAL POND BY IN-SITU STABILIZATION (DULUTH, MINNESOTA)

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Abstract

The site is a one-acre disposal pond located in a former steel manufacturing facility in Northern Minnesota. Over time, the disposal pond was filled with non-native material (a mixture of coal tar and slag). The pond is adjacent to a stream that flows into a major river. The goal of the closure was two-fold. First, the non-native material had to be stabilized/solidified by incorporating a soil additive in-situ to the non-native material. Second, a low permeability cap was installed and graded to provide erosion control, prevent surface water ponding, and withstand the 100 year, 24 hour recurrence interval storm event.

Shallow Soil Mixing (SSM) was selected as the in-situ mixing process to accomplish the stabilization/solidification. Prior to full-scale implementation of the SSM process, Laboratory Phase Testing and Field Phase Testing was conducted on various reagent mixtures blended with non-native material. From the testing it was determined that the full scale Stabilization/Solidification would be accomplished using a cement-bentonite slurry. In all, approximately 35,000 cubic yards of non-native material was stabilized using the SSM process.

This paper summarizes the initial testing programs and the final production work at the site. Various testing was performed throughout all phases of the project for the purpose of mix optimization, quality assurance, and verification testing. Testing included permeability, unconfined compressive strength and cone penetration tests (CPTs).

Introduction

The remedial process selected for the site was the in-situ stabilization/solidification of the non-native material using the Shallow Soil Mixing (SSM) technique. For the purpose of this paper, the term stabilization is used interchangeably with stabilization/solidification. The SSM technique blends a stabilization reagent into the non-native soil to bind the non-native material in a mass using a large mixing auger. The purpose of this stabilization is to prevent migration or leaching of various contaminants from the non-native material. To accomplish this stabilization work, the stabilization work was performed in the following three phases: bench-scale testing; pilot-scale testing, and full-scale production work.

Site History and Characterization

The site is approximately one acre in plan area and consists of a former steel facility coke plant settling pond containing non-native material. This material consisted of coal tar and tar contaminated coke fines, flue dust, mill scales, and slag. Stabilization depth averaged about 26' across the site.

Remedial Process

Shallow Soil Mixing was performed using a ten foot diameter mixing auger attached to a crane mounted rotary drill table (Figure 1). Slurry reagents were mixed at a batch plant and pumped to the auger head then injected into the soil while the head is rotated. The rotation of the auger slices and mixes the soil with the slurry reagents to create a uniformly mixed fill material.

Bench-Scale Testing

A two-step laboratory bench-scale testing phase was performed on this project prior to mobilization to the site. The first step consisted of a treatability study using a composite sample of 55 percent soil and 45 percent coal tar to represent a worst case scenario. The primary purpose of this initial step was to verify the applicability of this technology to the project, determine the effectiveness of the stabilization agents to reduce the leachability of the coal tar constituents as determined by the Toxicity Characteristic Leaching Procedure (TCLP) test, and to determine various geotechnical properties of the treated soil matrix. This initial testing was performed by the design/oversight engineer. Based on this initial testing, a minimum unconfined compressive strength (UCS) and maximum hydraulic conductivity was determined for the stabilized soil.

The second step of the laboratory bench-scale testing consisted of soil-additive refinement phase. The purpose of this second step was to provide the contractor an opportunity to refine the soil-additive mix ratio, and to ensure that the stabilization reagents, mixture methods, and stabilized soil characteristics were adequate to meet the desired strength and permeability requirements.

Soil-additive refinement laboratory testing was performed using two different mix designs at various mix ratios. These mix designs consisted of a cement/cement kiln dust (CKD) mix and a cement/bentonite mix. Based on the results of this testing, two mix designs were selected for subsequent pilot-scale field testing. On a percentage basis per wet weight of soil/non-native material, the selected mix designs are as follows:

Cement/CKD

- 1% Type I Portland Cement
- 20% CKD
- 30% Water

Cement/Bentonite

- 15% Type I Portland Cement
- 2% Bentonite
- 19% Water

Pilot-Scale Field Phase

A pilot-scale additive refinement phase was performed to verify the soil additive mix ratio and to evaluate the actual bulking characteristics of the treated soils. Three different mix designs (two Cement/CKD and one Cement/Bentonite) were tested and evaluated by drilling and treating three clusters of 3-4 columns for each different mix. Quality control test parameters were the same as set forth for the full-scale phase

All three mix designs yielded acceptable results. Based on availability, the Cement/Bentonite mix was selected for full-scale stabilization.

Additional pilot-scale testing was performed on the three solidified columns treated with the Cement/ Bentonite mix. This additional testing consisted of in-situ, two stage borehole permeability tests ("Boutwell" tests) and cone penetrometer tests (CPT's).

The in-situ permeability ("Boutwell") results yielded vertical and horizontal permeabilities on the order of $3x10^{-6}$cm/sec. and $5x10^{-7}$ cm/sec. respectively. Although not a specified regulatory requirement, the Boutwell tests were performed to evaluate the in-situ permeability of the solidified material in comparison with permeability results of wet molds taken during the full-scale phase of this project.

Full-Scale Phase

The full-scale stabilization/solidification phase was completed from August 17, 1997 to October 20, 1997. The mixing pattern advanced across the site from south to north of the site. Start and finish time of each column drilled was recorded. An as-built drawing was updated at the end of each shift. A total of 704 shafts were drilled to properly treat the site.

Grout preparation and unit weight testing was completed at the grout batch plant, then the grout was pumped to the soil mix rig. A five cubic yard mixer was used for preparing the treatment reagents. First, water was added to the mixer, followed by dry cement, and the dry bentonite. Bulk cement and bentonite were stored in 30-ton silos and distributed to the mixer with mechanical augers. Proportioning of the cement and bentonite were determined volumetrically. Reagent proportions were then added to the water and verified after mixing by determining the unit weight of the grout with a mud balance.

The calculated unit weight for the mix was 91.6 pounds per cubic feet (pcf). Reagent unit weight testing and confirmation of mix proportions were presented in the SSM Daily QC Reports.

Shaft number, depth of shaft, volume of grout added to each shaft, and cubic yards treated of each shaft were also referenced on the SSM Daily Production sheets. Depth of each shaft was determined by surveying the ground elevation and reading the markings on the Kelly Bar of the soil mixing after achieving the final drill depth. A minimum thirty percent overlap for each shaft was maintained by daily survey layout of the drill hole locations. Volume of grout injected into each shaft was calculated based upon the number of batches of grout needed to treat a column. Cubic yardage of soil treated is based upon depth times the effective square area of each individual shaft. Observed bulking of the stabilized soil due to the addition of the reagents was in excess of 40 percent.

Laboratory Wet Mold QC Testing

Two measures of performance, Hydraulic Conductivity and Unconfined Compressive Strength (UCS) were specified to evaluate the stabilized mass. Samples were extracted by lowering a hydraulic SSM sampler to various depths of different columns. The material was then immediately placed in molds for ex-situ curing in accordance with ASTM standards. Due to the delicacy of the samples, curing was done on site in a humid environment for at least three days prior to transporting them to the testing laboratory.

Hydraulic Conductivity

Permeability testing performed using USACE EM-1110-2-196 method at a frequency of one test every 2,000 sf of treated area or one per day. Permeability molds were cast in 2” PVC pipe 18” long, capped at both ends and cured for seven days prior to testing. The average permeability for all samples tested was $3x10^{-7}$ cm/sec. with a maximum permeability test result of $8x10^{-7}$ cm/sec.

Unconfined Compressive Strength (UCS)

UCS was performed in accordance with ASTM D-1633 with frequencies of one test every 2,000 SF or one per day. Each day’s samples were cured and tested for 7-day and 28-day UCS. In order to minimize disturbance due to transporting, samples were cured on-site initially for at least three days in a moist environment. Samples were initially cast into two-inch cubes and then later in 3" x 6" cylinders. The cylinders yielded better results since they were less impacted by irregularities, due to the larger sample size. The average 7-day UCS for all samples tested was 66 psi, with a minimum test result of 10 psi. The average 28-day UCS for all samples tests was 104 psi, with a minimum test result of 25 psi.

Variability in sample test results was observed, due to make up of each individual sample. For example, fracturing of the cylinders occurred more readily when a small fingernail sized piece of tar was along the fracture zone.

Additional Quality Control Testing

Soil Borings Standard penetration tests and Cone penetration tests were performed to evaluate in-situ strength and uniformity. Continuous split spoon samples were used to evaluate the mixing uniformity of the solidified mass. The stratigraphy of the material was logged in terms of moisture, stiffness, color, grain size and soil type. Visual observation of each split spoon demonstrated that the material was uniformly solidified. SPT blow count readings taken along the length of the split spoon sample indicated that the grout was uniformly stiff and thoroughly mixed through the solidified material. CPT's were also performed during the full-scale phase to evaluate the in-situ strength.

In-situ strength was measured using CPT's which log the stratigraphy of each shaft as it is advanced hydraulically into the treated mass. During full-scale operations, a total of 18 Cone Penetration tests were performed at random locations. The CPT's indicated that the stabilized soil had a strength ranging from 56 psi to 104 psi. The correlation between CPT's and UCS was developed by comparing the average CPT strengths with corresponding laboratory wet mold results is shown in Figure 2. A trend line generated for the data is also shown in Figure 2.

Protective Cap

The protective cap that was installed at the site consisted of four layers: a grade adjusting fill layer, a low permeability clay barrier, a sand drainage layer with overlying geotextile, and a vegetative protective cover. In addition, a berm with a gabion retaining wall was constructed along the perimeter to channel and isolate an unnamed stream flowing near the solidified materials.

Conclusions

SSM is a proven, cost effective means of stabilizing and solidifying contaminated soils in-situ. Using a phased approach, consisting of laboratory bench-scale, pilot-scale, and quality control testing during full-scale operations allows for: 1) the confirmation of the applicability of the technology; 2) determining the effectiveness of various stabilization reagents; 3) optimization of the mix design; 4) confidence in the selected equipment/procedures; 5) refinement of the quality control measures to be used, and 6) providing confidence that an economical remediation process will produce satisfactory results.

As with the use of concrete cylinders in concrete testing, wet mold sampling provides a reasonable means for obtaining samples for strength and permeability testing. This is especially true for stabilized materials that are difficult to obtain relatively undisturbed samples due to the delicate nature (low strength) of the material. Where necessary, this testing can be supplemented with split-spoon sampling or coring (depending on strength) and CPT testing to confirm mixing uniformity, consistency and in-situ strength.

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Figure 1. Shallow Soil Mixing Equipment