Geostructural Construction in Ash:
An Update on the Largest Geostructural Work to Date

Ryan T. Smith[1], PE and Anthony Sak[1], PE

[1]Keller North America, Inc., 515 Nine North Court, Alpharetta, Georgia, 30004

KEYWORDS: Earth retention, sheetpiles, anchors, deep soil mixing, dewatering, instrumentation

INTRODUCTION

The largest geostructural construction effort associated with the clean closure of an existing coal combustion residual (CCR) pond complex commenced over 5 years ago under two separate scopes of work.

For one scope of work, Keller North America, Inc. (Keller), acting as a general contractor, constructed an earthen berm platform across the middle of a CCR pond through which the deep soil mixing (DSM) geotechnical construction technique created a stabilizing impermeable structural core. This work allowed clean closing of alternating sides of the pond while always maintaining half of the pond in service. The dam was completed and, to date, one-half of the pond has been cleaned.

On the second scope of work on the site, Keller, acting as a subcontractor to the closure general contractor, installed over 3,600 linear feet (732 meters) of temporary steel sheetpiles and tieback anchors through CCR and bonded into natural ground. This work facilitated removing CCR up to 30 feet (9.1 meters) deep that underlain one of the primary stormwater channels of the 1,500-acre (607 hectare) watershed.

Since the presentation of these two sub-projects at World of Coal Ash in 2019, an additional 800 linear feet (244 meters) of drainage channel was shored, dewatered, and the CCR removed. Together this work utilized, to varying degrees, eight different geotechnical construction techniques as well as subsurface geotechnical characterization and geotechnical instrumentation programs. This paper presents a description of the scope of this work along with data that helps support its claim as the largest geostructural effort.

OVERALL PROJECT

In the middle stages of a multi-year clean closure of an existing CCR pond complex, the utility and their closure contractor turned to two difficult parts of the closure effort: dividing an existing CCR pond with a structural wall to facilitate clean closure while maintaining process and stormwater operations and constructing a temporary earth retention system to support a closed CCR landfill.

For the pond division, the existing pond received process water from the gas-fired power plant as well as stormwater flows from the 1,500-acre (607 hectare) watershed. If the utility began removing CCR by dredge or lowered the pond level, then the state regulators would begin requiring treating all discharges from the pond, up to 20,000 gallons per minute (76 cubic meters per minute), ten times the current flow rate. The utility intended to split the pond into two using a geostructural barrier (cofferdam) that could resist the unbalanced earth and/or water pressures from the operating side while clean closing the other. Later construction activities rerouted stormwater flow around the existing/new process pond, limiting treatment volumes.

The earth retention system facilitated clean closing CCR that underlain the drainage channel through the pond complex. The clean closure had to stop at the state-regulated boundary of the closed landfill. Technically, room existed to opencut an excavation, without the need of an earth retention system. However, the resulting excavation would cross the landfill boundary, which according to the state regulators essentially reopened the landfill; something the owner was not willing to do. With this temporary system in-place, the closure contractor removed the CCR that was reported up to 30 feet (9.1 meters) deep and backfilled the excavation to the final grade.

Figure 1 shows the two sub-projects within the overall pond complex.

COFFERDAM PROJECT

The utility elected to procure the cofferdam project separately from the CCR pond closure. Keller was selected as the general contractor with a value-engineered design and construction of a cofferdam entailing the construction of a soil mixed earth fill divider structure composed of overlapping deep soil mixed (DSM) columns. Figure 2 is a cross section through the divider berm showing the subsurface profile below the berm, consisting of CCR underlain by residual silty sand, partially weathered rock (PWR) and bedrock. PWR is a regional term for residual soil with Standard Penetration Test resistance greater than 100 blows per foot (0.3 meters), but which soil drilling methods can penetrate.

DEEP SOIL MIXING METHOD

DSM improves characteristics of in-situ materials by mechanically mixing a binder with the soils using a rotary mixing tool advanced by a powerful drill rig. The method addresses a site’s geotechnical challenges, specifically increasing shear strength and/or decreasing permeability of the material once treated. Soil mixing can also stabilize/immobilize/encapsulate contaminants in impacted soil profiles, known as in-situ stabilization (ISS).

The binder may be introduced as a wet slurry (wet DSM) or dry powder (dry DSM). The choice between wet and dry DSM depends on the natural moisture content of the in-situ material (the dividing line being about 60%). With single axis tooling, the column diameter can range between 2 and 12 feet (0.6 and 3.7 meters).

DIVIDER BERM CONSTRUCTION

The divider berm design provided a minimum global slope stability factor of safety equal to 1.3. The foundation of the divider berm was CCR material, which on this site had exhibited unstable behavior. Keller's extensive engineering design, including field and laboratory testing of CCR material, berm & global stability analysis, seepage analysis, and planning work to ensure safety of the crew placing the divider structure material. Construction of the divider structure began with installation of two individual, surge stone berms located outside of the divider structure core. The stone berms were advanced in front of and provided containment for infilling of a site-borrowed, silty sand material, Figure 3.

Placement of the berm material on saturated, sluiced CCR below the free water surface presented significant safety concerns for the operator and equipment working on the leading edge of the berm. The concerns were the global stability of the saturated CCR, either as uncontrolled settlement, bearing capacity failure, or lateral displacement of the ground upon which the equipment works, potentially leading to engulfment of the equipment and threatening the life of the operator and any subsequent rescue personnel. Increases in porewater pressure decrease the shear strength of soil and soil-like materials, such as CCR. Application of the surge stone and infill soil decreases the shear strength and increases the shear stress on the underlying CCR; which can lead to instability of the berm.

Vibrating wire sensors set five feet (1.5 meters) into the CCR monitored for increases in the pore pressure during the stone berm construction. The sensor cables extended to their respective closest shore of the pond then connected to a real-time monitoring system. The system included both in-cab and site alarms that alerted all site personnel of increases in pore water pressure exceeding preset trigger levels. Should this occur, the operators ceased operations and left the area until the pore pressure readings returned below the trigger levels.

Keller placed the earthen berm from south to north, measuring the depth to the top of CCR before and during berm construction. Comparison of these measurements showed CCR pushed out in front, or mudwaved, ahead of the advancing berm. Instrumentation measured increases in pore pressure. However, the mudwave caught the sensors and their connecting cables, stretching the cables. This led to sensors giving faulty measurements up to the point of disabling the sensors.

Pore pressure increases crossed the project-specific threshold values on numerous occasions, which stopped the divider berm construction per the construction and safety plans. Work would then resume once levels stabilized; this typically ranged between 15 and 30 minutes. Several sudden slides of the placed material occurred during fill placement, however due to the instrumentation and safety practices in place no safety incidents occurred.

After completion of the berm began a minimum 30-day waiting for consolidation and stabilization of the CCR under the weight of the new divider berm. However, the waiting period coincided with an unusually wet period and, as such that the waiting period approached 45 days.

Two problem areas became evident during the berm construction. First, placement of the berm material encountered blast rock fill material within the alignment of the DSM core zone. An attempt at excavation of this material and backfill with the silty sand fill was not completely successful due to site constraints.

Second, the surface stability of the north end of the completed berm began to degrade over time, specifically the ground would pump under equipment weight. An investigation for the instability found that the bedding of an abandoned storm line was transmitting water into the newly placed silty sand fill. As an unstable work surface was not acceptable for the large DSM equipment, Keller used the shallow mass mixing method to stabilize the area.

Mass mixing uses an excavator-mounted tool that rotates about its horizontal axis, like a rototiller but much larger, to mix binder slurry with the soil. For this application, Keller stabilized the upper 4 feet (1.2 meters) of silty sand fill material, totaling approximately 1,400 cubic yards (1,070 cubic meters), using the mass mixing method. After treatment and curing of the mass-mixed “soilcrete,” no issues with the berm working surface were noted throughout the following construction.

DSM EQUIPMENT

DSM equipment consisted of a binder slurry plant and a large drill rig. The computer-controlled batch plant automatically batched dry cement from a silo into an agitator tank filled with water. From the agitator tank, the slurry moved to a holding tank and then pumped to the mixing equipment, a distance ranging between 150 and 600 feet (45 and 180 meters).

The slurry grout exits the mixing tool attached at the end of a Kelly bar of a 250,000-pound (1.1 MN), drilling rig. The rig can generate just over 200,000 pound-feet (271 kN-m) of torque to mix the binder slurry with the soil materials. The drilling rig is, to our knowledge, the largest piece of construction equipment that has worked on a CCR pond.

DSM CORE DESIGN AND CONSTRUCTION

The initial concept for the DSM structure called for 100% treatment of a 35-foot (10.6 meters) wide longitudinal strip down the divider berm. Using overlapping, primary-secondary (secant) columns, the mixing tool penetrated the silty sand fill, encapsulated CCR, and into the underlying soils, terminating upon encountering the underlying PWR to create a soilcrete with a design unconfined compressive stress (UCS) of 150 pounds per square inch (psi) [1 MPa] at 28 days.

Changes to the DSM core concept during the final design included:

- The DSM core widened from 35 feet (11 meters) to a maximum of 43 feet (13 meters).

- Partial treatment creating continuous DSM “walls” on the upstream and downstream sides of the core reinforced by shear panels connected the walls, as shown in the layout of Figure 4.
- Due to concerns about underseepage through the highly permeable PWR, the upstream row was deepened to penetrate a minimum 5 feet (1.5 meters) into this material.

Soil drilling procedures penetrate PWR, however DSM is not a drilling procedure nor is it typically applied to such competent material as dense or hard PWR. To address penetration into the PWR, Keller used specially designed and built in-house DSM tooling (both 6-foot and 8.5-foot [1.8 and 2.6 meter] diameter) to penetrate and mix the underlying soil/PWR materials, see Figure 5. However, Keller understood that no DSM tooling could penetrate the PWR without first breaking it up by pattern predrilling with 36-inch (0.9 meter) diameter, caisson-style rock auger.

The depth of the predrill holes penetrating the PWR along upstream columns varied from a minimum of 11 feet (3.4 meters) to 46 feet (14.0 meters) below the divider structure surface. Even with the predrilling to loosen the PWR, this material proved exceedingly difficult and very time consuming to penetrate with the soil mixing tool.

CHANGED SITE CONDITIONS

As mentioned above, blast rock fill underlain the north end of the berm and within the limits of the DSM core. Soil test borings conducted by the owner’s engineer in support of the initial cofferdam design did not encounter blast rock material and with no mention of this material in the project information. Keller attempted removal of this material; however, its depth and extent exceeded the ability to safely conduct the excavation.

The blast rock fill caused early refusal of 16 DSM columns between 10 and 22 feet (3 and 6.7meters) below working grade. Keller discussed other geotechnical construction options with the utility to complete installation of the obstructed columns. The utility chose to complete the bottom of these DSM columns using a program of four jet grout columns below the bottom of each 8.5-foot (2.6-meter) diameter DSM column.

Jet grouting creates in-situ geometries of soilcrete like DSM, except that where DSM uses the shearing action of the mixing tool, jet grouting uses high velocity jets exiting horizontally from ports at the end of a drilling tool. The jets erode and mix the in-situ material with grout as the drill stem slowly rotates while retracted from the hole. Unlike DSM, computer control of the jet grouting process can create circular columns, partial columns, or panels.

The original bid scope included an option for extending the north end of the cofferdam an additional 60 feet (18 meters) with a driven sheet pile cutoff. The utility decided to install the optional sheetpile wall and extend it another 90 feet (27 meters) for a total of 150 feet (46 meters). However, the presence of the blast rock fill eliminated the possibility of using sheet piles. Keller discussed four other geotechnical construction options with the utility, which chose a compaction grouting program

QUALITY CONTROL RESULTS

Quality control verified the field engineering properties of the soil mixed columns and structure. The soil mix column property that was most important to this project was the soilcrete UCS.

During column installation, Keller monitored and recorded with our data acquisition system the soil mixing parameters that influence the engineering properties of the soilcrete, such as binder specific gravity, binder flowrate, tool penetration and withdrawal rate, and tool rotation rate.

Keller cast and cured wet grab samples then formed 3-inch by 6-inch (76 mm by 152 mm) cylinders for curing and UCS testing in on-site testing trailer. The sample depths targeted each of the subsurface strata. Keller also retrieved core samples from cured columns to evaluate the quality of the mixing by visual observation as well as core recovery and rock quality designation and UCS testing. All samples met or exceeded the design parameters.

TEMPORARY EARTH RETENTION

Keller, as a subcontractor, designed and constructed a temporary earth retention system to facilitate the removal of up to 30 feet of CCR underlying the drainage channel. Unfortunately, the drainage channel flowed along the toe of the closed CCR landfill. Excavation of the drainage channel CCR using stable, temporary slopes was not possible as the state regulators viewed disturbing the landfill closure cover as a reopening of the landfill. The utility and their closure contractor decided on a temporary earth retention support system along the perimeter of the landfill. Figure 6 shows a layout of the earth retention system with respect to the landfill. A short section of temporary earth retention also supported an existing ash pond dam,

EARTH RETENTION SYSTEM SELECTION

The design of an earth retention system requires knowledge of the subsurface conditions along the alignment and matching the type of system with those conditions. Keller discussed three typical types of earth retention systems(walls) typically available:

- Soil Nail
- Anchored Soldier Pile and Lagging
- Anchored Sheetpile

Both soil nail and soldier pile walls require the retained soil to maintain a vertical face, long enough (between 1 to 3 days) for installation of excavated face support (soil nails and shotcrete facing or wooden lagging boards between soldier piles) without sloughing and raveling, long. This concept is referred to as standup time. Since the primary purpose of excavation support system was protection of the landfill, the risk to the landfill and construction personnel of destabilizing dewatered, sluiced CCR due to construction-induced vibration was deemed too great for soil nail and soldier pile wall methods.

Therefore, an anchored sheetpile best met the project needs, i.e., safest, least expensive option. With estimated CCR depth up to 30 feet (9.1 meters), sheetpiles required anchors for wall stability. Keller considered bonding anchors into CCR as opposed to the underlying soil or bedrock, with the benefit to the project of shorter anchors. However, the available bond stress between the anchor grout and CCR was unknown. In addition, the strength parameters, depth, and variability of the CCR along the earth retention system alignment was unknown. To answer these questions, Keller conducted subsurface characterization and an anchor test program.

SUBSURFACE CHARACTERIZATION

Existing subsurface information mostly consisted of direct-push sampling for evaluating stratigraphy. However, this information was not suitable for design, so Keller initiated a subsurface characterization using soil test borings and cone penetration soundings. The program revealed significant variation of the CCR along the wall alignment. Furthermore, the investigation found interlayers of CCR and fill material.

ANCHOR TEST PROGRAM

Keller installed six test anchors to evaluate the available bond stress between grout and CCR. Three of the six anchors had post-grouted bond zones, a procedure where additional grout injected into the bond zone results in an increased available bond stress. The resulting bond stresses were so inconsistent that choosing a suitable design value would result in anchor bond lengths longer than the industry norm of 50 feet (15.2 meters). Therefore, Keller planned anchor bond zones in either PWR or bedrock.

EARTH RETENTION DESIGN AND INSTALLATION

The design of the earth retention system assumed active dewatering to remove groundwater. Dewatering reduces the pressures on the retained side of the sheetpiles, pressures that, if not relieved, require additional tieback anchors, higher anchor loads, or both. In addition, the dewatering increased the stability of the CCR working platform during shoring installation.

Keller installed sheetpiles using a vibratory hammer on a crawler-mounted, fixed-mast rig. Predrilling with a 30-inch diameter auger loosened up dense soil and PWR when encountered before the design termination depth. Where predrilling encountered refusal, interpreted as bedrock, before the design depth, Keller installed micropiles to pin the sheetpile toe.

The general contractor excavated the material exposing the front of the sheetpile wall down to the level where Keller drilled holes that penetrated through the sheetpile wall to a termination length of between 85 to 135 feet (26 to 41 meters). Insertion of multi-strand tieback anchors followed then the hole backfilled with a 5,000 psi (XX kPa) grout by tremie method (Figure 7).

The anchor design loads varied between 105 and 215 kips (467 and 956 kN) with the majority being 5-strand anchors designed for 175-kip (778 kN) load. Standard anchor installation procedures included testing each anchor to 133% of the design load (Figure 8). At the end of the load test, the crew locked off the anchor at the design load.

Figure 9 is a panorama view of a portion of the retention system with the closed landfill above the wall.

The long wall length, as indicated in Figure 6, afforded the opportunity to reuse sheetpiles further down the alignment. This process required destressing the anchors as the backfill operation progressed and extracting the sheetpiles for redriving elsewhere.

CCR DEWATERING

Well point and header systems dewatered the CCR behind the sheetpile wall, as well as the material that the general contractor would eventually excavate as part of the clean closure. Figure 10 shows the conditions at the start of dewatering installation.

Keller installed the dewatering wells by drilling temporary casing into the ground and setting slotted, 2-inch (51 mm) diameter PVC pipe then placing sand filter backfill while retracting the casing. Flexible hose connected the wellpoints to a 6-inch (152 mm) diameter header pipe. A pump station, consisting of primary and backup electric pumps, extracted the groundwater to ultimate discharge to the site water treatment system.

For the 2021 dewatering, Keller installed two “rows” of dewatering wells. The first consisted of vertical walls installed behind the sheetpiles. Due to very permeable CCR conditions, based on Keller’s previous pump testing, Keller installed a second row of dewatering wells on a batter through the face of the sheetpile wall, see Figure 11.

GEOTECHNICAL INSTRUMENTATION

For both the cofferdam and the earth retention system scopes of work, Keller and our sister company Geo-Instruments designed and installed comprehensive geotechnical instrumentation systems consisting of vibration monitoring, vibrating wire piezometers, shape accel arrays, standpipe piezometers, and/or extensometers, Figure 12. Solar panels powered all the equipment. The system allowed remote monitoring via website access for office-based project management, design staff, and the general contractor/owner.

Keller worked to establish threshold and trigger values for the various instruments. The system sent notifications of an exceedance of a preset value at a particular instrument to equipment operators, site alarms (both audio and flashing beacon), as well as email and text message. Should an alarm occur, the field crew followed pre-planned actions.

In the end, multiple exceedances of the threshold/trigger levels occurred, resulting in shutdown of the work in the immediate vicinity, with a maximum shutdown of four hours.

LESSONS LEARNED

From the efforts on the work described above, Keller offers the following lessons learned:

- DSM is not meant for hard ground (rock?), but it is possible.
- Bond stress in CCR material is highly variable, do not count on it.
- When loading submerged CCR during berm construction, expect localized failures.
- Have a backup plan for predrilling sheetpile toe embedment into PWR.
- Real-time instrumentation monitoring and notification works, expect work stoppages – this is a good thing!
- Think through threshold values on geotechnical instrumentation data.
- Using retarder in DSM treated-CCR columns does not work.

CONCLUSION

Keller utilized a wide array of geotechnical construction techniques to address site-specific issues for the clean closure of a CCR pond complex. These techniques (with their respective quantities) included:

- Steel sheetpiles
    - 130,000 square feet (12,100 square meters)
    - 3,600 linear feet (1,100 meters)
- Anchors – 812, mostly 5-strand with a design load of 175 kips (778 kN)
- Dewatering – 410 wells points
- Deep soil mixing
    - 19,500 cubic yards (14,900 cubic meters) treated
    - Ninety-two, 8.5-foot (2.6 meter) diameter columns
    - Seventy-one, 6-foot (1.8 meter) diameter columns
- Mass soil mixing – 4,000 cubic yards (3,100 cubic meters) treated
- Micropiles – 61
- Jet grouting – 600 cubic yards (459 cubic meters) in 64 columns
- Compaction grouting – 385 cubic yards (2984 cubic meters)

Taken in total, Keller believes that this work constitutes the largest geostructural application in CCR pond closures.

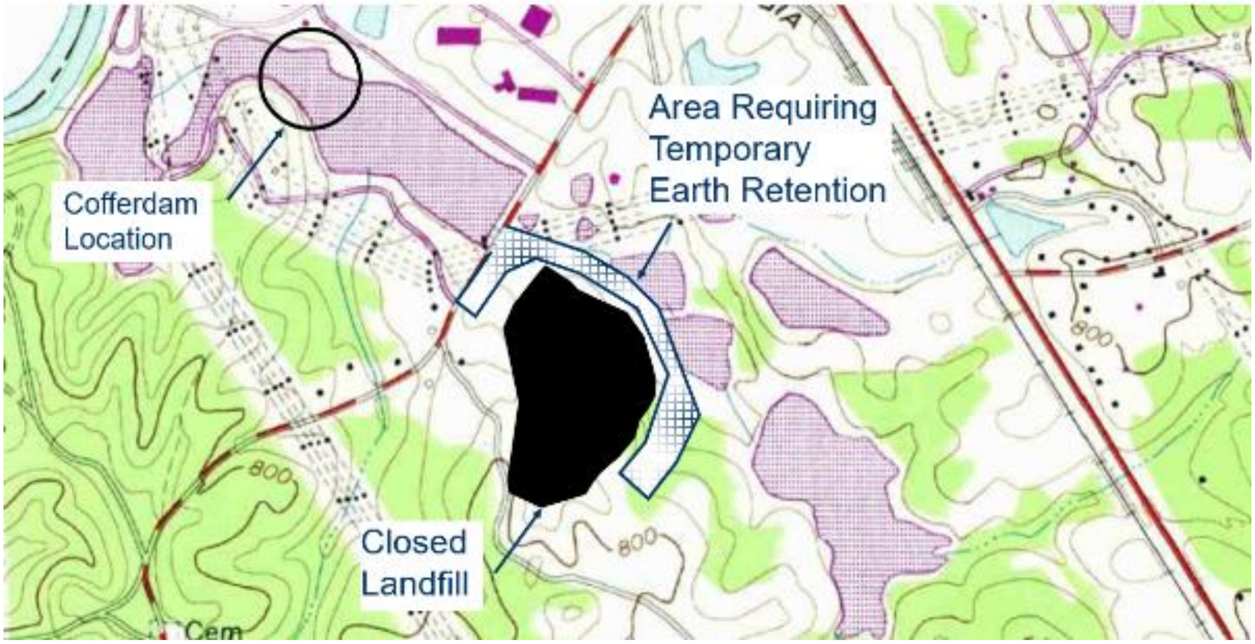

Figure 1. Locations where geostructural work supported CCR pond closure.

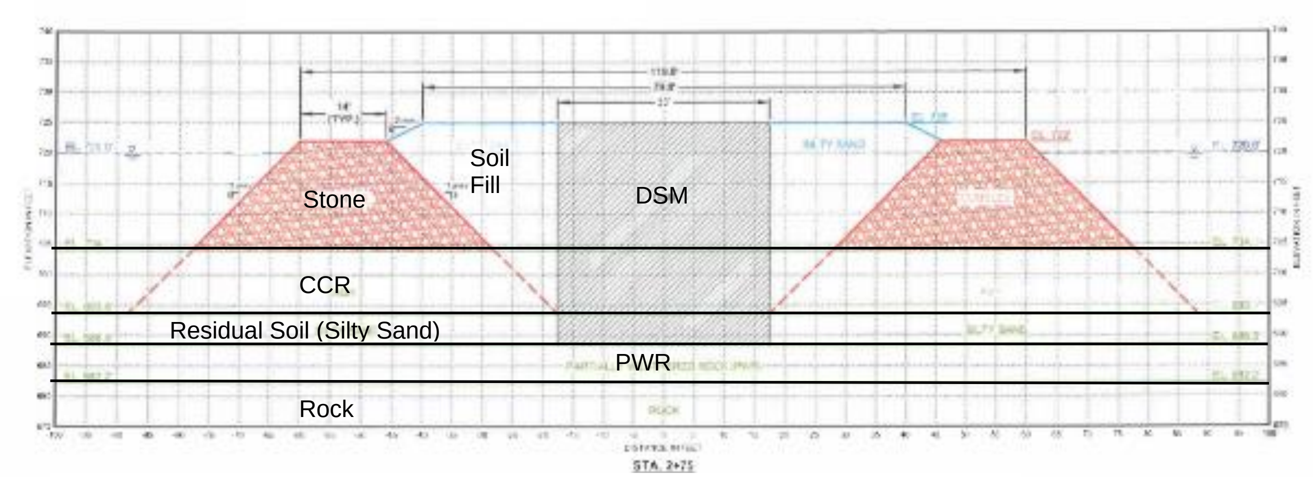

Figure 2. Cross section through divider berm.

Figure 3. Aerial view of divider berm construction, north is on the left.

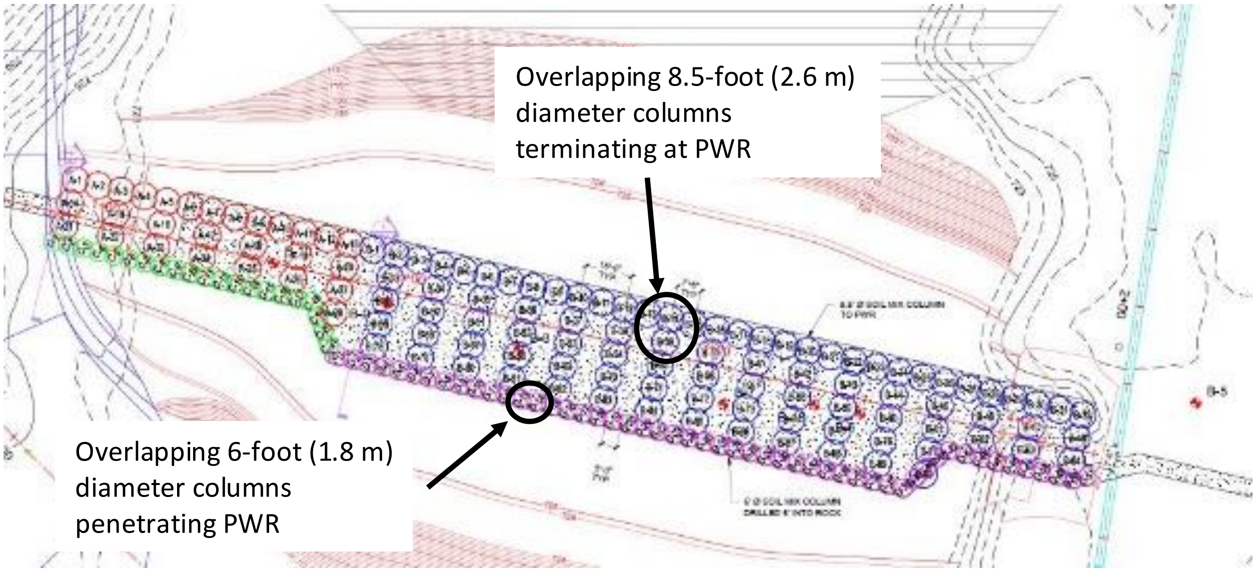

Figure 4. DSM column layout.

Figure 5. DSM operation on divider berm. Grout batch plant in upper right corner.

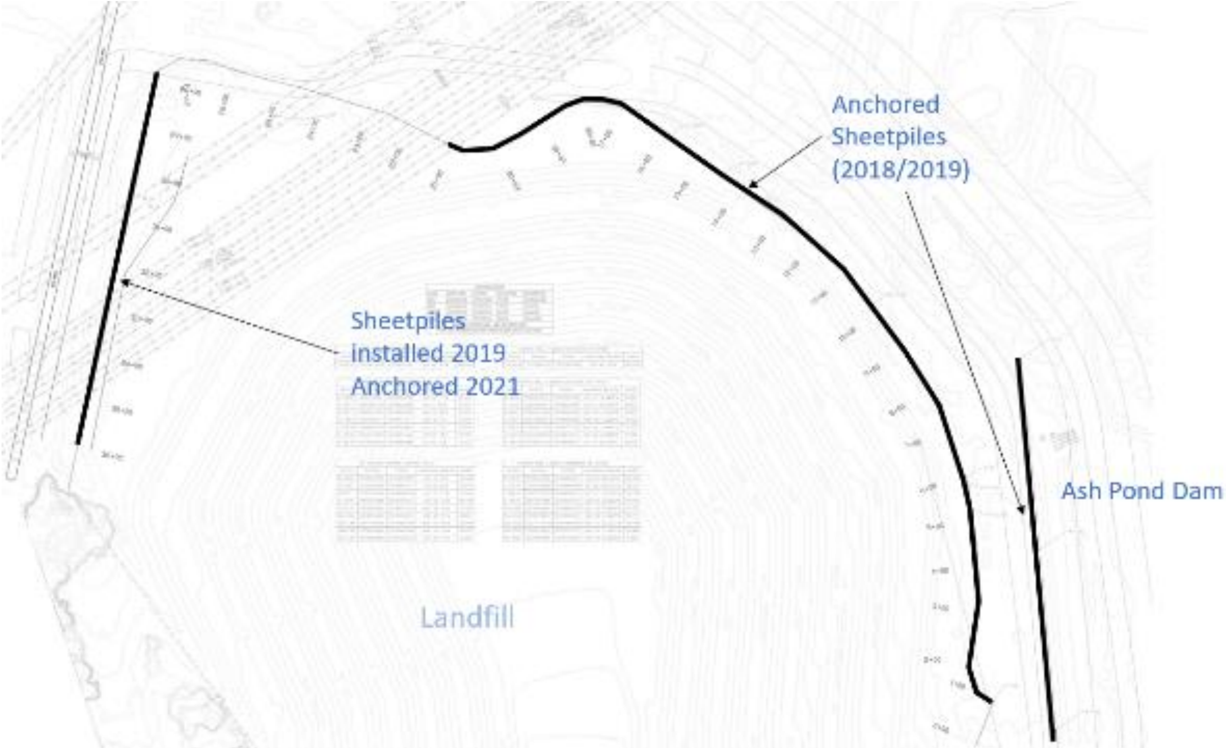

Figure 6. Earth retention system locations around existing landfill.

Figure 7. Drilling the second row of anchors.

Figure 8. Anchor testing and lock off in process.

Figure 9. Panorama showing part of the earth retention system supporting the closed landfill.

Figure 10. Site conditions prior to dewatering.

Figure 11. Earth retention system, 2021 anchor installation. Note the PVC pipe header attached to the wall connected to battered wellpoints installed through the wall face.

Figure 12. Installation of the geotechnical instrumentation system as part of the earth retention system.