Case History – CCR Landfill Cover System
Stormwater and Infiltration Water Design and Management

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CONFERENCE: 2017 World of Coal Ash – (www.worldofcoalash.org)

KEYWORDS: CCR, landfill, closure

INTRODUCTION

Cover system stormwater and infiltration water design and management at coal combustion residual (CCR) landfills poses important challenges. Stormwater runoff and infiltration water converging along the cover system perimeter must be carefully considered and addressed during design and construction. Closure methods used at municipal solid waste landfills may not address some of the unique challenges presented by closing CCR landfills. Also, CCR landfill and impoundment closures are in their adolescence with fewer constructed examples of cover system design, construction, and operations from which to learn. However, several years of post-closure performance experience from an unlined CCR landfill with a soil-geosynthetic cover system prove insightful to future design and construction of CCR landfill and CCR surface impoundment closures. The authors review examples and discuss lessons learned from stormwater management, cover system terminations, and cover system infiltration water management that stand to benefit designers, owners, and contractors.

BACKGROUND

The authors draw their experience from the closure and post-closure observations of an unlined ash landfill located in the southeastern United States. The permitted landfill boundary encompasses approximately 27 hectares (67 acres) and approximately 21 hectares (53 acres) was used for ash management. The landfill is located uphill from, adjacent to, and partially overlying fingers of the plant’s ash basin. Existing landfill conditions in 2003 are illustrated in Figure 1. The landfill is unlined and was operated from approximately 1984 to 2004. The landfill was closed and a final cover system constructed in 2008.

Geologically, the site is characterized by networks of gently rolling ridges and valleys typical of the southeastern United States piedmont region. An east-west trending ridge
bordering the south side of the landfill is a topographic high point. From the ridge, the original topography slopes downward towards the north. The northern portion of the landfill has a relatively consistent elevation. The southern portion of the landfill has a relatively consistent elevation and is approximately 18 meters (60 feet) higher in elevation than the northern portion of the landfill. The elevation differential occurs over a perimeter distance of approximately 400 to 490 meters (1,300 to 1,600 feet) as measured along the northwest and northeast portions of the landfill, respectively. The landfill footprint spans a sequence of three north-south trending ridge and valley formations. The valleys were filled during ash placement.

Ash management was concentrated in the western side of the landfill footprint and encompassed approximately 15 hectares (38 acres). Landfill slopes were on the order of 3 horizontal to 1 vertical (3H:1V) with heights ranging from 12 to 37 meters (40 to 120 feet). This area was closed with a soil-geosynthetic cover system. The cover system is illustrated in Figure 2 and the final cover grading plan is illustrated in Figure 3. Cover system side slopes were 3H:1V with 6 meter (20 foot) wide benches spaced approximately every 9 vertical meters (30 feet). The landfill top deck was designed with a 5 percent slope.

Ash management in the eastern side of the landfill was limited to initial lift placement before stopping in 2004. Ash was placed in an area of approximately 6 hectares (14 acres) and filling only progressed to an elevation nearing the adjacent perimeter elevation of the western landfill operations. This area of the landfill was commonly referred to as the “flat area” as slopes were on the order of 2 percent. This area was closed with a soil cover system.

Final cover system stormwater is collected and conveyed through a network of grass-lined channels on the top deck and benches into pre-cast concrete drop inlets connecting to corrugated double-wall high-density polyethylene (HDPE) down-drain pipes. Stormwater is conveyed around the landfill perimeter through grass-lined channels discharging to a sediment basin northeast of the landfill. The sediment basin (and therefore all landfill stormwater) discharges to the existing ash basin.

Stormwater infiltrating the cover system soil layer (referred to as infiltration water) is conveyed through a geocomposite drainage layer. On the top deck, the geocomposite drainage layer is connected to a geotextile/aggregate wrapped perforated pipe around the perimeter connecting to precast concrete drop inlets. The top deck underdrain is illustrated in Figure 4. In this way, top deck infiltration water is conveyed to down-drain pipes and is outlet at the landfill perimeter. On the side slopes and at the landfill perimeter, infiltration water is conveyed through a prefabricated geotextile-wrapped HDPE edge drain to outlet pipes as shown in Figure 5. The outlet pipes discharge to grass-lined channels at benches and at the landfill perimeter, ultimately discharging to the sediment basin and existing ash basin.
Towards the end of construction and during the post-closure period, the stormwater and infiltration water management systems revealed conditions warranting maintenance or redesign and retrofit. These circumstances are described further below.

ACCESS ROAD/CHANNEL EROSION

An aggregate-surfaced road was constructed to access the top of the landfill. The access road is approximately 4.5 meters (15 feet) wide with a cross slope directing stormwater runoff to the uphill side of the landfill. Stormwater from the access road and the slope uphill of the roadway is conveyed through a grass lined channel. The longitudinal slope of the road and channel is approximately 6 percent. Towards the end of construction, stormwater eroded cover soils at the aggregate/cover soil interface as illustrated in Figure 6. Shortly after construction was completed stormwater eroded aggregate along the edge of the road as illustrated in Figure 7. Aggregate and cover soil was replaced and a riprap berm was constructed along this interface to reduce stormwater flow velocities and stabilize the area.

The material contact (and contrast) along the edge of the aggregate-surfaced road and adjacent grass-lined channel was the origin of preferential stormwater flow resulting in erosion. The authors recommend that owners, designers, and contractors be aware of material contacts/contrasts and the potential for erosion.

DOWN-DRAIN PIPE SEPARATION

Stormwater is conveyed from the top deck and benches through corrugated double-walled HDPE down-drain pipes. Down-drain pipe was joined by bell and spigot connections secured with couplings. In 2008, shortly after construction was completed, ground deformation was observed directly over a segment of down-drain pipe (Figure 8) and sedimentation was observed on the downstream bench. Observations during repair work indicated that pipe joints had separated allowing water to seep out of the joints, resulting in cover soil piping and erosion. The pipe connections were repaired, cover soil was replaced, and this area has performed well since that time.

In 2011, ground disturbance and seepage was observed along another section of the down-drain pipe located uphill of the prior occurrence (Figure 9). To mitigate future concerns with pipe joint separation and pipe performance, in 2011 portions of pipe were replaced with solid wall HDPE pipe that was butt-fusion welded.

Review of construction photographs indicate the original pipes appeared to be installed with ordinary care and backfilled with engineered fill. Despite construction efforts, pipe joints separated enough that water escaped the pipes resulting in piping and soil cover erosion. The authors suggest that solid wall welded HDPE pipe or open channels are preferable alternatives.
COVER SYSTEM TERMINATION – SETTLEMENT/BOILS

The cover system terminated in a “key trench” located around the landfill perimeter. The cover system perimeter detail is illustrated in Figure 10. Cover system infiltration conveyed through the geocomposite drainage layer was designed to outlet through a prefabricated panel drain with pipe outlets spaced 30 meters (100 feet) on center.

In November 2009, approximately one year after closure construction was completed and after a significant storm event, surface settlement and boils were observed at the northeastern perimeter and the northwestern perimeter. Surface settlement was linear on the order of 15 to 23 centimeters (6 to 9 inches) deep and 30 to 45 centimeters (12 to 18 inches) wide, parallel with the cover system perimeter, and located over the cover system key trench. A photograph of a typical linear settlement feature is shown in Figures 11 and 12. One area located at the northeast perimeter exhibited more significant settlement and deformation as shown in Figures 13 and 14. Observations indicated this area was approximately 120 meters (400 feet) long, 3 to 9 meters (10 to 30 feet) wide, with settlement of 1 to 2 meters (3 to 6 feet).

Boils were located downslope (or downstream) of the settlement, where the steeper sloping northeast and northwest perimeter converged at the comparatively level northern perimeter. Water, ash, and soil were observed flowing from the boils during and immediately after rainfall (Figures 15 and 16). Locations of settlement features and the boils are illustrated on Figure 17.

Initial evaluations concluded no eminent threat of large landfill slope failure or ash release. These conditions were reported to the state permitting authority and regularly monitored while forensic evaluations were conducted and a remedy was developed. Though the boils recurred in response to rainfall, future activity was smaller than the original 2009 occurrence. Furthermore, settlement either stabilized or progressed slowly relative to the original 2009 occurrence.

Forensic evaluations showed that the settlement occurred within the cover system limits and indicated that water was flowing under the geomembrane, transporting ash from higher elevations along the perimeter to lower elevations, and emerging as boils. Material loss and the settlement reflected at the ground surface was overall limited to the inside edge of the key trench. However, at the location of largest settlement, material loss extended past the key trench 6 to 9 meters (20 to 30 feet) further into the landfill.

In 2011, a cover system retrofit was designed and constructed. The retrofit consisted of removing cover soils and geosynthetics, restoring cover system subgrade with engineered fill, and replacing the geomembrane, geocomposite and cover soils to original design grades. The existing key trench was removed and a perimeter drain was constructed. The perimeter drain consisted of a perforated pipe bedded in aggregate and wrapped with a geotextile filter as illustrated in Figure 18. The cover system geocomposite drainage layer was laid into the perimeter drain. The perimeter drain was
outlet at the downgradient sides of the landfill perimeter. Post-construction observations indicated the perimeter drains were functioning and discharging clear water after rainfall events.

After a rain event in 2012, one boil was observed on the northwest perimeter in the vicinity of the 2009 boil. No settlement was observed upstream of the boil along the landfill perimeter. The northeast perimeter did not exhibit settlement or a boil. The conditions were reported to the state permitting authority and followed by regular monitoring and reporting to the agency. Later in 2012, the northwest cover system perimeter drain was enhanced by adding intermediate outlets with the goal of moving water away from the landfill perimeter. Regular monitoring showed clear water discharging from perimeter drain and no indications of surface settlement, indicating the system was effectively managing surface and infiltration water.

After a rainfall event in 2015, one ash boil was observed on the northwest perimeter in the vicinity of the 2009 boil. Settlement was observed just upgradient of the boil location. The occurrence was reported to the state permitting authority and followed again by regular monitoring and reporting to the agency. Excavation of the cover system revealed that water was moving ash and soil from under the geomembrane along the northwestern perimeter.

In 2016, the cover system was modified again, this time removing the perimeter drain on the northeast and northwest perimeters, as well as, removing the infiltration water panel drain outlets on select benches. A continuous cover system infiltration water outlet consisting of a geomembrane/geocomposite flap and aggregate blanket were installed around the landfill perimeter and on select benches. The cover system infiltration layer outlet detail is illustrated in Figure 19. Photographs of the constructed outlets are shown in Figures 20 and 21. Observations indicate that infiltration water is being conveyed through the new cover system outlets. Boils and settlement have not been observed since the last round of modifications.

In summary, forensic evaluations revealed that the cover system termination served as an unintended conduit for water. Surface and infiltration water are believed to be the primary water source. Though contributions from perched water interior to the landfill were suspected and evaluated, the presence of perched water was not definitively identified. Review of design drawings indicates the northwest and northeast perimeters exhibited longitudinal slopes ranging from approximately 3 to 6 percent over distances of approximately 400 to 490 meters (1,300 to 1,600 feet), respectively. In addition, along the northeast perimeter, the geosynthetic cover system limits were terminated in ash. This condition existed because the area east of the defined and permitted soil-geosynthetic cover system also contained ash; however, it was closed only with a soil cover system. Review of original construction photographs and observations during retrofit construction showed void space between the geomembrane and subgrade along the corners and edges of the cover system termination in the key trench. Once present in this conduit, water moved ash downslope along the landfill perimeter where it emerged in boils.
Though cover system retrofits with a perimeter drain were effective along the northeast perimeter, settlement and boil activity continued to occur along the northwest perimeter. The authors suspect that despite best efforts to capture and convey water within the perimeter drain retrofit, its construction also introduced flow conduits through voids between the geomembrane and subgrade, as well as, wrinkles in the geotextile wrapping the perimeter drain.

These observations indicate that the cover system termination and infiltration water outlet design are critical to cover system performance. In the presence of water with sufficient gradient and a conduit for flow, ash can by transported by water downslope. Furthermore, intimate contact between the geomembrane (or other geosynthetics) and the subgrade soil is imperative.

SURFACE IMPOUNDMENT CLOSURE CONSIDERATIONS

The authors conclude that CCR landfill lessons learned from managing cover system infiltration water and cover system terminations are relevant to CCR surface impoundment closures. Though CCR landfill side slopes (e.g., 3H:1V to 4H:1V) are steeper than ordinary surface impoundment closure slopes, landfill top deck and surface impoundment slopes (e.g., 3 to 5 percent) are generally similar. Cover system terminations around the CCR unit boundary similar to the unlined landfill described herein may also be encountered with surface impoundments.

Conveying infiltration water out of the cover system drainage layer (geocomposite) is important to cover system performance and common to both landfills and surface impoundments. The authors recommend a continuous infiltration water outlet using a geomembrane flap. Daylighting the drainage layer is straightforward for a landfill cover system (with steeper side slopes); however, it becomes more challenging for shallower cover system slopes. Infiltration water management is potentially exacerbated with impoundment closures as the flat slopes will yield larger volumes of infiltration water and reduces the flow capacity of an underlying geocomposite drainage layer. One solution for shallow cover system slopes is subsurface drains consisting of perforated pipe, aggregate, and geotextiles similar to that used for some CCR landfill top decks (Figure 4). Another solution is to terrace the shallow cover system, thus creating enough elevation change to grade and install a geomembrane flap similar to the landfill detail illustrated in Figure 19.

The experiences summarized herein indicate that cover system terminations founded in or in close proximity to ash can be problematic. Therefore, the authors conclude it is preferred to extend the cover system termination into competent soils (natural or engineered fill) or remove ash within a reasonable distance away from the cover system termination. Some impoundment closures are designed with inverted cover systems where stormwater is conveyed along channels interior to the cover system. If stormwater or infiltration water were able to flow under the geomembrane, perhaps due to a defect or tear, and there was adequate gradient, the condition could be susceptible
to ash piping under the geomembrane. We envision the potential to introduce water to, or under, the geomembrane may also be present when upstream tributary areas contribute run-on to the cover system. In this circumstance we recommend taking precautions to direct stormwater away from the cover system termination.

CONCLUSIONS

Cover system stormwater and infiltration water design and management at CCR landfills pose important challenges. The authors reviewed examples and discussed lessons learned from stormwater management, cover system terminations, and cover system infiltration water management that stand to benefit designers, owners, and contractors.

The material contact (and contrast) along the edge of the aggregate-surfaced access road and adjacent grass-lined channel introduce potential for preferential stormwater flow and erosion. The authors recommend that owners, designers, and contractors be aware of material contacts/contrasts and the potential for erosion.

Buried corrugated HDPE down-drain pipes (with mechanical connections) conveying stormwater down slopes separated at pipe joints, which resulted in surface seepage, cover soil erosion, and surface settlement. In some areas the pipe joints were repaired and are performing as intended. In other areas the corrugated HDPE pipes were replaced with welded HDPE pipe. The authors suggest that solid wall welded HDPE pipe or open channels are preferable alternatives to buried down-drain pipes.

Cover system terminations around the landfill perimeter were prone to water intrusion and served as an unintended conduit for subsurface water flow. Water flow along steeper portions of the landfill perimeter conveyed ash that emerged as boils and caused cover system settlement. The cover system was successfully modified and is performing well. However, the importance of stormwater and infiltration water management along CCR unit perimeters is recognized and the potential vulnerability of cover system terminations to stormwater, infiltration water, and potentially perched water within the ash was exposed.
FIGURES

Figure 1. 2003 Landfill Conditions

Figure 2. Final Cover System Cross Section
Figure 3 - Final Grading Plan 2

Figure 4. Top Deck Infiltration Water Drain 2
Figure 5 – Typical Cap Drain Outlet at Perimeter

Figure 6. Access Road/Channel Erosion during construction.

Figure 7. Access Road/Channel Erosion after construction.
Figure 8. 2008 Deformation and sedimentation over down-drain pipe.

Figure 9. 2011 Deformation and seepage over down-drain pipe.

Figure 10. Cover System Perimeter Detail 1
Figure 11. 2009 Timeframe linear settlement feature.

Figure 12. 2009 Timeframe linear settlement feature.

Figure 13. 2009 – Northeast perimeter settlement.

Figure 14. 2009 – Northeast perimeter settlement.
Figure 15. 2009 North east perimeter boil. Figure 16. 2009 North east perimeter boil.

Figure 17. General Location of Perimeter Cover Settlement and Boils

NORTHEAST PERIMETER
NORTHWEST PERIMETER
NE BOIL
NW BOIL
AERIAL SETTLEMENT
LINEAR SETTLEMENT
NORTHWEST PERIMETER
Figure 18. 2011 Cover System Retrofit – Perimeter Drain

Figure 19. 2016 Cover System Retrofit
REFERENCES
