Hybrid Geotextile Design for CCR Materials in Landfill Drainage and Closure Systems

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ABSTRACT

Dr. Koerner addresses the multiple functions and elements of “Designing with Geotextiles” in the 250 page chapter of his comprehensive reference[1]. Geotextiles are routinely used in landfill design for separation, drainage, and filtration. Coal combustion residuals (CCR) including bottom ash, fly ash, and FGD gypsum present unique challenges and potential opportunities for reuse with geotextiles. When used in a conventional drainage composite material, the single layer nonwoven geotextile in contact with fine grained CCRs is susceptible to clogging, piping, and migration of fines. As demonstrated through bench testing and practical application, a double-layered geotextile material combining nonwoven and woven geotextiles into one needle punched hybrid geotextile provides improved performance in a variety of applications. The hybrid geotextile provides separation and drainage with improved resistance to piping in CCP applications.

Based on over 15 years of experience in CCR landfill development, this paper presents the case study for the protective cover and drainage composite layers in a fly ash landfill expansion. The preliminary testing program evaluated the feasibility of adding a hybrid geotextile to the conventional drainage composite for the purpose of replacing the conventional filter sand protective cover with bottom ash stacked in the adjacent ash pond. Two hybrid geotextiles were evaluated for index properties and clogging performance using ASTM D5101[2]. The test results were used to develop the design requirements for the application. The case study presents design goals, bottom ash characterization, geotextile specification, and representative details for the application. Conclusions provide a summary of key issues and future considerations for hybrid geotextile design for landfill drainage and closure systems.

INTRODUCTION

The project site for the case study is an inactive ash pond converted to a dry ash landfill in the late 1989 and redesigned as a lined landfill in 2003. Recently classified as an Overfill under EPA's CCR disposal rules, the 71-Acre lined landfill unit reused Select Bottom Ash as a protective cover and drainage layer. The Select Bottom Ash generally contains less than 10 percent passing the No. 200 sieve (fines) and a variance up to 20 percent fines. The fines content in Select Bottom Ash was correlated to acceptable permeability requirements for the drainage layer. Over 10 years of operation, the observed leachate flow rates remain steady and approximated EPA HELP model estimates.

In order to add disposal capacity and plan for increasing leachate storage in the landfill, a 20-Acre double-lined cell was designed in 2013 and recently constructed. Based on the design goals for the expansion to include internal drainage improvements, the leachate collection layer is a conventional double-sided 10 ounce nonwoven geotextile/geonet drainage composite. Over the drainage composite, a conventional filter sand is the protective cover and primary filter layer for the fly ash waste. As an option for use with Select Bottom Ash protective cover, the plans include an alternate drainage composite with a double-layered (hybrid) geotextile consisting of needle punched nonwoven and woven geotextiles for use as the top geotextile layer of the drainage composite.

Based on the potential value of reusing bottom ash to replace imported filter sand from the quarry, the project objectives evolved during construction to implement the alternate bottom ash protective cover. When the gradation of the bottom ash source was conformance tested, the fines content exceeded the 20 percent limit for the previously established "Select Bottom Ash." Given the reported performance capabilities of the GSE CoalDrain for use with a fly ash cover, the project considered allowing higher fines content in the bottom ash cover material over a hybrid geotextile. This case study discusses the hybrid geotextile design for use with a silty bottom ash protective cover, with fines content varying from an average 26% up to 54%.

Background includes relevant information for drainage composites, protective cover, hybrid geotextiles, and granular drainage filters. The Landfill Hybrid Geotextile Case Study provides design objectives, test methods and results, and recommended project specific requirements. Recommendations for further study on the long-term performance of hybrid geotextile-cover systems and other considerations are provided in conclusion.

GEOTEXTILE USE IN LANDFILLS

Initially, landfill design utilized geotextiles as separators and cushion layers. Today, it is a common practice in municipal solid waste (MSW) landfills to use a geonet between two nonwoven geotextiles as a drainage composite for the leachate collection layer. For MSW landfills, biological clogging is a primary design concern. With moisture conditioning inputs as high as 40% required for compaction and the stability risks associated with saturated ash conditions, the internal drainage considerations are significantly different for ash landfills. For ash landfills, particle clogging and piping through geotextiles is a primary design concern. An ash landfill primarily consists of fine-grained, silt sized particles which may clog or pipe through the geotextile effecting leachate collection system (LCS) performance.

DEVELOPMENT OF HYBRID GEOTEXTILES FOR CCR APPLICATIONS

The method of needle punching two geotextiles to form a double layered geotextile is an established manufacturing process. The woven layer adds considerable strength while the nonwoven geotextile maintains the filtering capabilities which are held in a stiff matrix due to the additional reinforcement provided by the woven geotextile. Materials and properties of the individual and combined woven and nonwoven geotextiles may be modified in the manufacturing process for specific applications. The use of hybrid geotextiles in a drainage composite provides for improved planar flow over longer runs in the base design for the landfill LCS. When used with a well graded, granular protective cover layer, the hybrid drainage composite is a high performance leachate collection layer. Clogging is an increasing concern with increasing fines content in the overlying materials in contact with the hybrid geotextile. Kutay and Aydilek[2] have conducted successful long-term testing of various two-layer geotextile combinations with fly ash.

PROTECTIVE COVER MATERIALS

The protective cover layer in an ash landfill provides primary retention of the overlying fine grained waste from the leachate collection system and protects the liner system prior to and during initial fill placement.

In MSW landfills, conventional protective cover materials are typically clean sand or stone materials. For ash landfills, a well graded filter sand is a preferred material for conventional protective cover. As successfully demonstrated in the existing lined landfill, performance of the Select Bottom Ash with fines less than 20 percent, reuses materials available at the site in a suitable protective cover and drainage layer. Substituting bottom ash for imported filter sand can provide substantial economic and resource conservation benefits.

Gradation criteria for granular drainage filters can be determined by using the methodology developed by National Resource Conservation Service (NRCS) for evaluating gradation ratios between the retained material and the filter layer. Typically American Society for Testing Materials (ASTM) C-33, Fine Aggregate or blended sand products may be used for sand filters. Bottom ash materials can be also be evaluated as a drainage filter using NRCS.

GEOTEXTILE GRADIENT RATIO

The method for evaluating geotextile clogging by an overlying soil material is based primarily on the plasticity of the soil material. When the overlying material has a Plasticity Index (PI) less than 5, the ASTM method for evaluating the clogging potential of geotextiles with the overlying material is ASTM D5101[3] test method for measuring the filtration compatibility of soil-geotextile systems (Gradient Ratio Test)[3]. Typically, bottom ash and fly ash materials are non-plastic and meet the PI less than 5 criteria. Accordingly, Gradient Ration Testing can be used to evaluate the performance of a hybrid geotextile drainage composite layer against clogging with ash materials.

The Gradient Ratio Test is performed in a permeameter apparatus. The top geotextile layer and geonet are inserted in the base of the apparatus. The cover material is mixed as a slurry and layered onto the geotextile sample. The test cell utilizes manometer or pressure ports at three levels across the soil sample (i.e., 0, 25 and 75 mm above the geotextile) to determine the gradient ratio. The test is run for the following time intervals based on the system gradient (*i*);

$i = 1.0$ until stabilization (48 hours maximum)
$i = 2.5$ until stabilization (2 hours maximum)
$i = 5.0$ until stabilization (46 hours maximum)
$i = 7.5$ until stabilization (2 hours maximum)
$i = 10.0$ until stabilization (46 hours maximum)

The gradient ratio is calculated by the following equation:

$$GR = \frac{i_{0-25}}{i_{25-75}}$$

where:

i_{0-25} = Hydraulic gradient measured between the base of the sample and the port at 25 mm above the geotextile.

i_{25-75} = Hydraulic gradient measured between the port at 25 mm above the geotextile and the port at 75 mm above the geotextile.

The results reported are for each system hydraulic gradient, test time intervals, measured Gradient Ratio, system permeability and the mass of soil collected that piped through the geotextile. With respect to the clogging potential of a geotextile with the overlying cover material and according to U.S. Army Corp of Engineers standard[4], a gradient ratio test result of less than 2.0 indicates acceptable drainage performance.

LANDFILL HYBRID GEOTEXTILE CASE STUDY

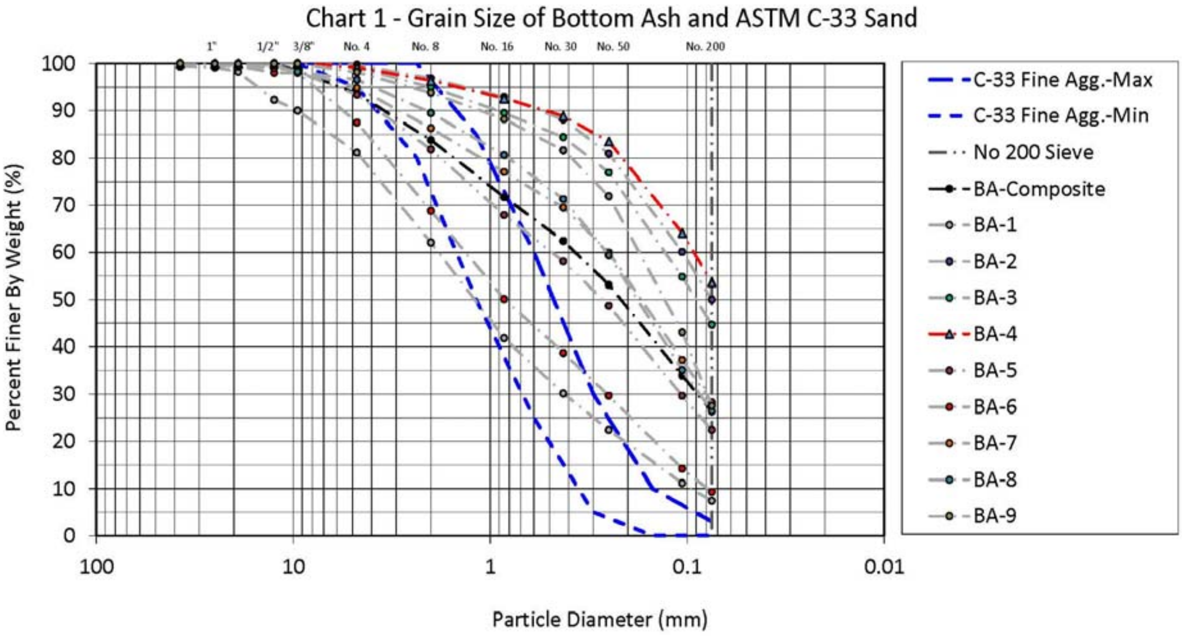
As an option for use with Select Bottom Ash protective cover, the ash landfill plans include an alternate drainage composite with a double-layered (hybrid) geotextile consisting of needle punched nonwoven and woven geotextiles for use as the top geotextile layer of the drainage composite. When the bottom ash source was conformance tested, the fines content exceeded the 20 percent upper limit and did not meet the Select Bottom Ash specification. Subsequently, the project team requested design recommendations for using the bottom ash source with a fines content ranging up to 54 percent as a protective cover layer.

Laboratory and field scale pilot studies have successfully evaluated the feasibility of hybrid geotextile use with fine grained (fly ash) cover materials. However at the beginning of 2014, no information was available on the full scale installation of hybrid geotextiles in an ash landfill drainage project. Based on the successful use of the site's bottom ash in the existing landfill drainage layer and an average fines content of 26 percent in the source bottom ash, the engineering team considered the use of a supplemental hybrid geotextile over the standard drainage composite to allow for the increase in protective cover fines.

This case study discusses the hybrid geotextile design for use with a silty bottom ash protective cover, with fines content varying from an average 26% up to 54%. The preliminary testing program evaluated the physical properties of two candidate hybrid geotextiles and their performance with the composite bottom ash sample (26% fines). The preliminary results indicated acceptable performance for both hybrid geotextiles. Final gradient ratio testing verified acceptable clogging performance of both hybrid geotextiles with the upper case fines content in the silty bottom ash. Design modifications included an alternating strip layout to use the volume of available of silty bottom ash protective cover with the added hybrid geotextile.

BOTTOM ASH SOURCE GRADATION TESTING

The objective of the project modification was to utilize an existing stockpile of bottom ash comprised of approximately 38,400 CY as protective cover in the landfill. Conformance testing for the gradation of bottom ash material in the stockpile included nine (9) individual sample locations (BA 1-9) and one composite sample (BA-Composite). Test results characterized the range of fines content (passing the #200 sieve) in the bottom ash source from 7 – 54 percent. The fines content in the combined or composite bottom ash was 26.3 percent passing the #200 sieve. The gradation curves for the source Bottom Ash materials and ASTM C-33 sand tolerance window are presented in **Chart 1**.



HYBRID GEOTEXTILE EVALUATION

The design evaluation included preliminary and final testing of two hybrid geotextiles. GSE Environmental provided a sample of its CoalTex geotextile, uses in the manufacture of GSE's CoalDrain drainage composite. SKAPS Industries provided a sample of its experimental hybrid geotextile HB113. Preliminary material property testing and interface shear testing were performed to evaluate the strength, tear resistance, drainage and filtering capacity of each hybrid geotextile. The hybrid geotextiles were tested against the samples of raw bottom ash for clogging performance using the Gradient Ratio test. Based on the acceptable clogging results of both geotextiles with the composite bottom ash sample (26% fines), final Gradient Ratio testing was performed with the upper case bottom ash samples with the two hybrid geotextile materials were tested in accordance with ASTM D5101 against the composite and higher percentage raw bottom ash samples to evaluate the gradient ratio.

Considering the relative geotextile properties, the CoalTex is a heavier geotextile, with a greater permittivity and a larger Apparent Opening Size (AOS). The HB113 contains approximately 25% less mass, a lower permittivity and a smaller AOS. While all results of the gradient ratio testing were within acceptable limits, there was variation in the system permeability and gradient ratio results in the average fines and upper case tests.

Table 1: Hybrid Double Layer Geotextile – CQA Test Results

PROPERTIES	TEST METHOD	UNIT	CoalTex	HB113	Proposed Spec.
Mass Per Unit Area	ASTM D5261	oz./sy	16.8	11.6	12.6
Grab Tensile Strength	ASTM D4632	lbs.	297 MD 689 XD	201 MD 239 XD	200
Grab Elongation	ASTM D4632	%	29 MD 104 XD	25 MD 28 XD	20
CBR Puncture Resistance	ASTM D6241	lbs.	873	721	650
Trapezoidal Tear	ASTM D4533	lbs.	132 MD 250 XD	86 MD 111 XD	80
Permittivity	ASTM D4491	sec^{-1}	0.55	0.14	0.11
Apparent Opening Size	ASTM D4751	Sieve No.	140	170	140 – 200
Gradient Ratio Test	ASTM D5101	Ratio	0.33 – 0.96	1.24 – 1.40	< 2.0

Notes: MD = Machine Direction. XD = Cross Direction

The Gradient Ratio test results for both materials were tested with the combined or composite and high fines content Bottom Ash materials. **Chart 2** shows the variability of System Permeability in centimeters per second (cm/s) vs. Time (hours) for all four test configurations. Each line on the chart represents a single Gradient Ratio test performed for the geotextile and Bottom Ash configuration as tested. The test data with dashed lines represents the tests performed with the composite (26% fines) bottom ash sample and the solid line data represents the data from the bottom ash with higher fines content. The data points on each line represent the reported results for each of the required system gradients (i.e., *i* ~ 1.0, 2.5, 5, 7.5 and 10) that were tested. The CoalTex geotextile was observed to have a larger change in system permeability than the HB113 samples. The variation appears to be relative to the difference in permittivity of the two hybrid geotextile samples.

Chart 3 presents a plot of the Gradient Ratio vs. Time results for the four trials. Comparing the average to the upper case fines variable, the CoalTex geotextile showed an increase in the Gradient Ratio where the HB113 geotextile was generally the same for both cover materials. The CoalTex was less than 1.0 for both samples tested. The results for the HB113 geotextile was between 1.2 and 1.4.

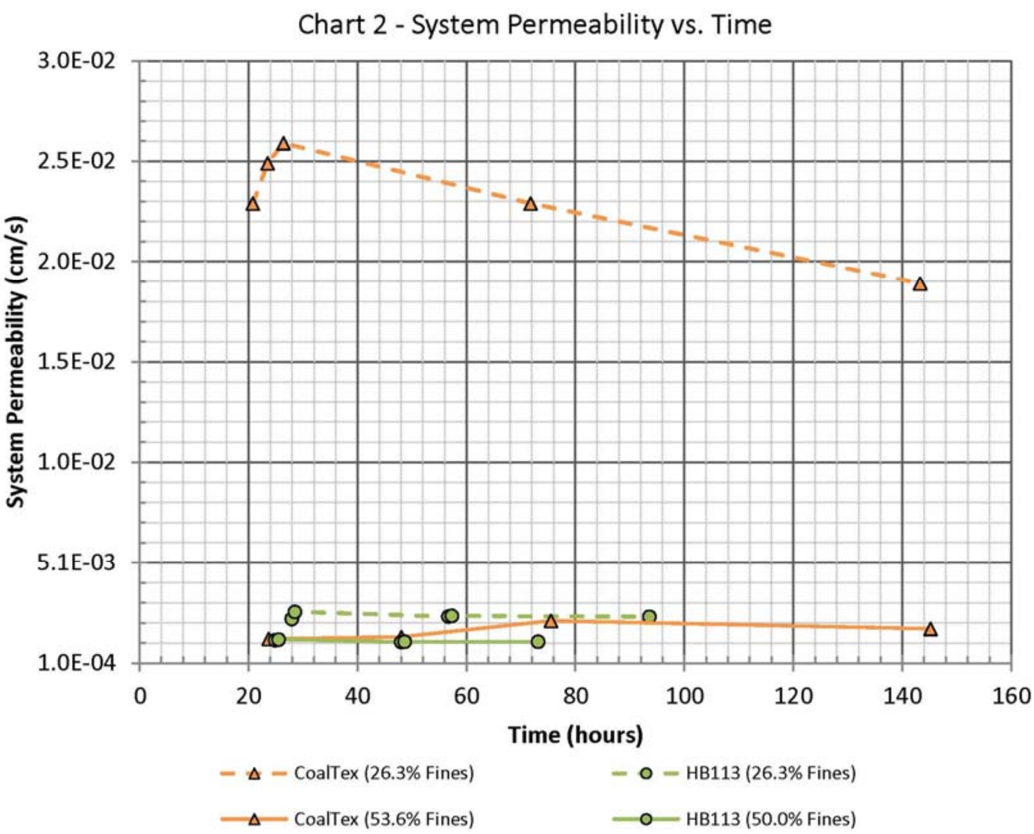


Chart 2 - System Permeability vs. Time
System Permeability (cm/s)
3.0E-02
2.5E-02
2.0E-02
1.5E-02
1.0E-02
5.1E-03
1.0E-04
0
20
40
60
80
100
120
140
160
Time (hours)
CoalTex (26.3% Fines)
HB113 (26.3% Fines)
CoalTex (53.6% Fines)
HB113 (50.0% Fines)

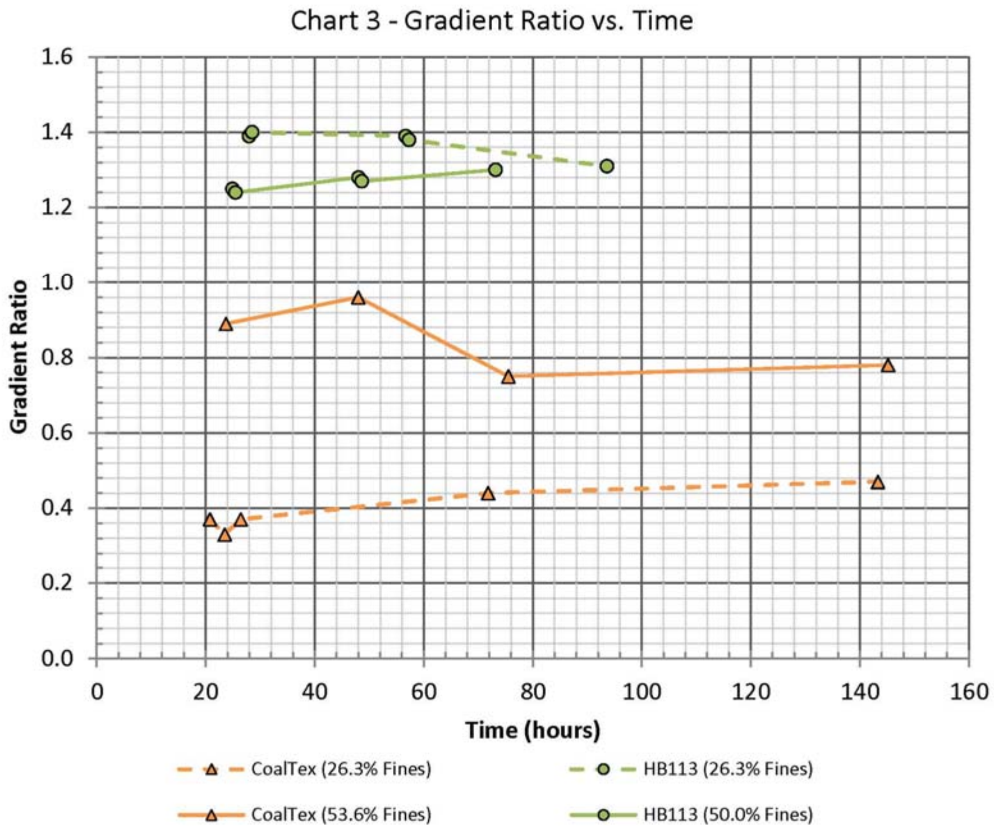


Chart 3 - Gradient Ratio vs. Time
Gradient Ratio
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
Time (hours)
CoalTex (26.3% Fines)
HB113 (26.3% Fines)
CoalTex (53.6% Fines)
HB113 (50.0% Fines)

Layout of Hybrid Geotextile/Bottom Ash Strips

The proposed life of the expansion is limited to approximately 2-3 years. The protective cover plan maintained the originally permitted conventional filter sand around the landfill perimeter and over the pipe zones, covering approximately two-thirds of the cell area. Accordingly, design modifications limited the use of hybrid geotextile/bottom ash cover to one-third of the cell area. The modifications used the bottom ash volume available in the source stockpile. **Figure 1** illustrates the alternating strip plan layout for protective cover construction.

The layout of the cell floor provided manufactured sand filter materials in approximately 100 foot wide strips across the cell floor such that the critical areas were drained by sand filters. Under the main floor of the cell, strips of two layer geotextile materials were deployed over the drainage geocomposite layer. The two layer geotextile materials were installed with a 2 foot overlap of filter sand at the perimeter of the hybrid geotextile strips. The hybrid geotextile layer panels are sewn and heat tacked at the perimeter of the protective cover strips. The double layer geotextile strips were installed perpendicular to the LCS drain pipes. The LCS collection pipes provide stone and sand filter zones at the pipe.

Figure 1 below shows the layout of the hybrid geotextile and bottom ash strip drains utilized in a recent project.

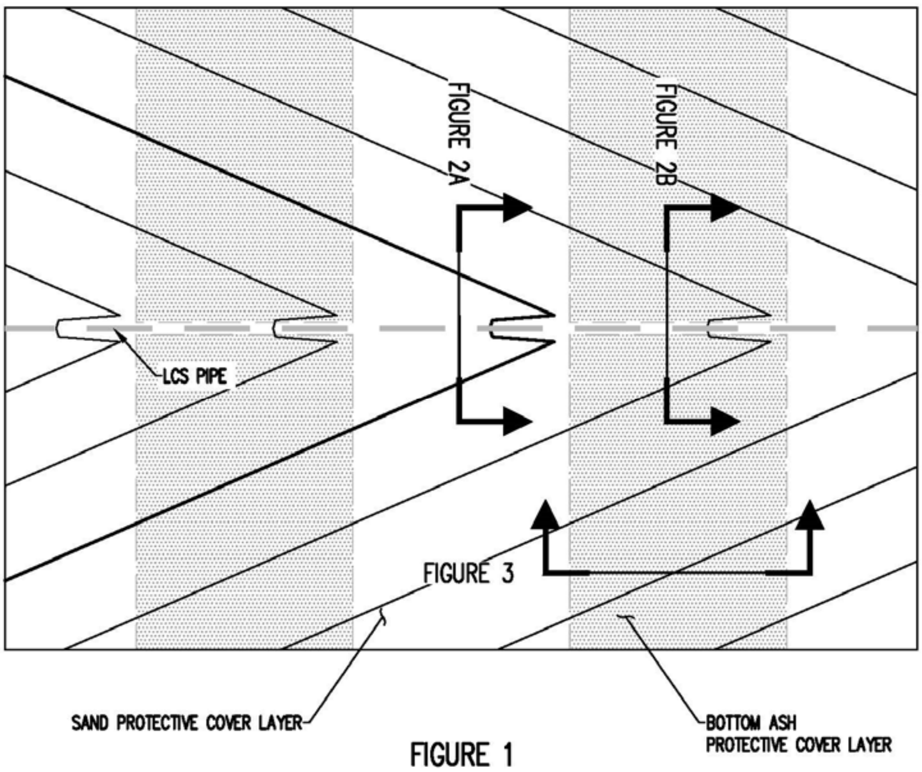


FIGURE 1
NOT TO SCALE

Figure 2A shows the LCS configuration in a sand protective cover zone.
Figure 2B shows the LCS configuration in the hybrid geotextile and bottom ash protective cover zone.

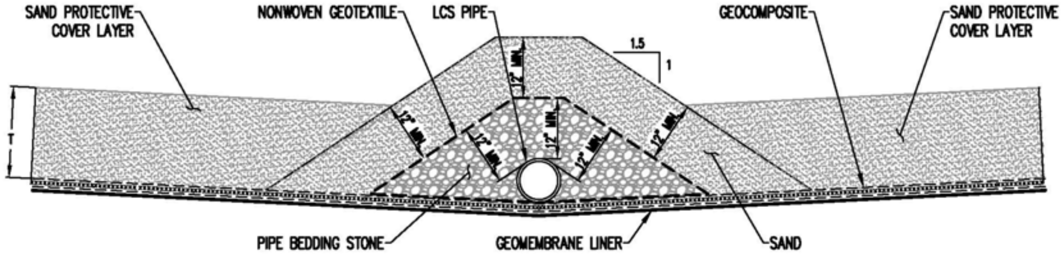


FIGURE 2A
NOT TO SCALE

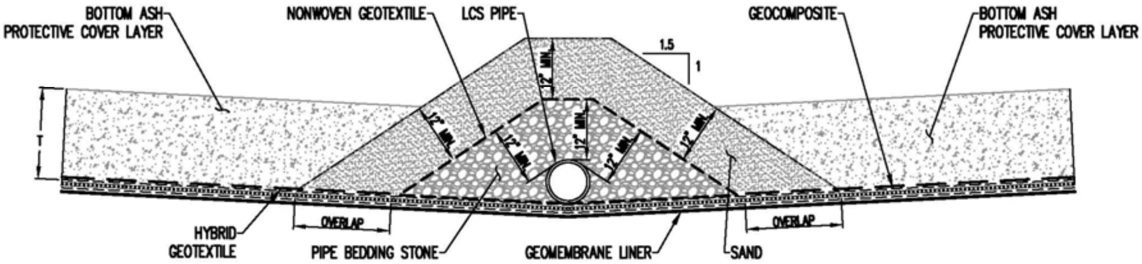


FIGURE 2B
NOT TO SCALE

As detailed in **Figures 2A and 2B**, the graded filter and bedding stone layering around the leachate collection pipes provides multiple paths for leachate flow.

Figure 3 shows the overlap required if different top geotextiles are used in the drainage composite or if the hybrid geotextile is installed as separate layer in the bottom ash layer zone.

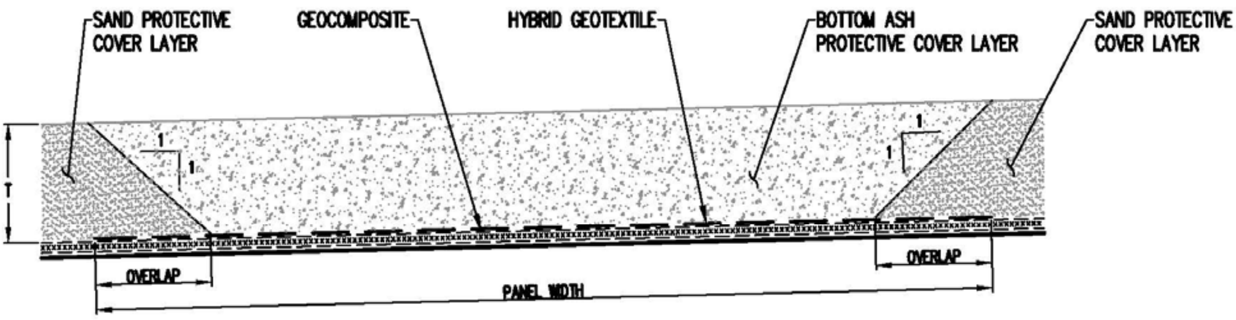


FIGURE 3
NOT TO SCALE

Based on practices from previous construction, the bottom ash protective cover is placed and graded with minimal compactive effort to avoid crushing the sand sized particles. Bottom ash surfaces should be sealed with soil cement to minimize maintenance until the floor lift can be placed with initial landfill operation. The initial waste placement in the CCR landfill should establish the operational surface grades of the cell at approximately 1 percent slope within 2 to 3 months of the landfill cell completion.

CONCLUSION

Similar to a standard composite liner system that uses geomembrane and compacted clay liners, the drainage systems in ash landfills also uses a combination of materials to meet the long-term performance requirements. Hybrid geotextiles provide improved filtration for the high fines content typically present in the CCR landfill. With acceptable evaluation and limitations, bottom ash with a variable range of fines content can be reused as protective cover with hybrid geotextiles. In addition to the landfill drainage application, the design approach used in this case study may prove beneficial to ash pond closures. Based on the results of this study, there appears to be potential to develop a range of geotextiles for specific CCR materials and applications.

The Gradient Ratio test is a short term laboratory test, which typically occurs for approximately 100 hours and utilizes a 4± inch diameter test cell. The Gradient Ratio test is valid for evaluating clogging performance in a hybrid geotextile with a specified cover material. The long term filtration capability of hybrid geotextiles should to be evaluated under the simulated operational conditions and life of the facility.

With increasing regulation, leachate reuse and new wastewater moisture inputs may add new considerations to geotextile performance in CCR landfills. The long term potential for chemical clogging of the geotextiles in CCR landfills due to specific waste inputs, leachates, and heavy metal precipitation should also be evaluated.

The conformance testing performed for the CCR Landfill identified significant variation in AOS testing performed in accordance with ASTM D4751[5]. Current method to determine the AOS of geotextile[5] utilizes dry sieving of uniform glass balls to determine the bead size that represents less than 5 percent passing the geotextile. The size is converted to the nearest standard US sieve size[6]. The dry sieving does not approximate in-situ filtration conditions where leachate liquids would be present. Glass beads can become trapped in thicker geotextiles, electrostatic charges can cause the glass beads to cling to the geotextile being tested and for some geotextiles can allow yarns to move relative to one another which could pass larger beads than would not be representative of the material being tested. The issues with ASTM D4751 should be addressed by modifying the test procedure for testing AOS with either wet sieving or capillary flow testing[7] the Geosynthetic Institute prepared a white paper which discusses evaluation methods for obtaining the opening size for geotextiles[8].

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