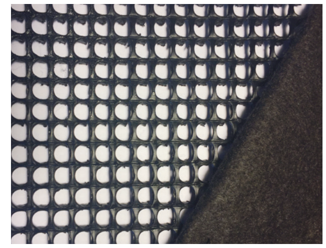
TECHNICAL NOTE

CCR CLOSURES AND GEOCOMPOSITE DRAINS



[GSE TenFlow]

BACKGROUND

This technical note focuses on closure and post-closure care for CCR facilities closing with the CCR waste remaining in place. In the United States, the Resource Conservation and Recovery Act (RCRA) placed the authority and the responsibility on the US Environmental Protection Agency (EPA) to establish rules and regulations for solid waste disposal management practices *"to ensure no reasonable probability of adverse effects on human health or the environment from the disposal of solid wastes."* After years of assessing the management practices associated with the storage and disposal of a particular solid waste, coal combustion residual materials (CCR), EPA established in April of 2015 nationally applicable minimum criteria for CCR landfills and CCR surface impoundments to be constructed and to operate as sanitary disposal facilities under RCRA. These minimum criteria are documented in the Code of Federal Regulations Title 40 Parts 257.50 through 257.107 (the Code). The criteria may be grouped into seven sets of criteria, restrictions and/or requirements the owners and operators of CCR facilities must comply with to establish new facilities, continue to operate existing facilities, and close and care for facilities at the end of their useful lives.

1. Location restrictions
2. Liner design criteria
3. Structural integrity requirements
4. Operating Criteria
5. Groundwater monitoring and corrective action requirements
6. Closure and post-closure care requirements
7. Recordkeeping, notification and internet posting requirements

These Federal standards apply directly to the owners and operators of CCR facilities; they are self-implementing. Effective October 2015, facility owners and operators are directly responsible for compliance to these standards.

CLOSURE AND POST-CLOSURE CARE REQUIREMENTS

The Code sets out minimum standards for the design, execution and operation of the cover system. The minimum standards are based upon practices found to contribute to the long term performance of the closed facility.

Owners and operators must ensure that closure systems for such CCR facilities will, ***at a minimum***, comply with the performance standards identified at 257.102(d)(1) in the Code:

- Control, minimize or eliminate, to the ***maximum extent feasible***, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere;
- Preclude the probability of future impoundment of water, sediment, or slurry;
- Include measures that provide for major slope stability to prevent the sloughing or movement of the final cover system during the closure and post closure care period;
- Minimize the need for further maintenance of the CCR unit; and
- Be completed in the shortest amount of time consistent with recognized and generally accepted good engineering practices.

In the preamble, EPA further stated a number of positions they adopted for rulemaking as a result of their findings.

- The risks to human health and the environment are primarily driven by older units many of which are unlined.

- The final rule does not require the use of composite final covers, such as a geomembrane underlain by a compacted soil infiltration layer. … Nonetheless, in certain locations, composite cover systems may be necessary to achieve the rule's performance standards.
- Fewer problems are typically seen with the use of composite cover systems. And while ongoing oversight and proper maintenance is necessary to ensure the efficacy of any cover system, less effort is generally involved to ensure the continued performance of a composite cover system. EPA therefore generally recommends that facilities install a composite cover system, rather than a compacted clay barrier, as the composite system has often proven to be more effective (and cost effective) over the long term. For these reasons, EPA also anticipates that composite cover systems will be recommended in many circumstances by qualified Professional Engineers.
- Under the established performance standard, if the cover system results in liquids infiltration or releases of leachate from the CCR unit, the final cover would not be an appropriate cover. ***Owners and engineers must ensure that in designing a final cover for a CCR unit they account for any condition that may cause the final cover system not to perform as designed.*** The final rule requires the final over system design to be certified by a qualified professional engineer that the design meets both the performance standard and cover system criteria.

DESIGN OBJECTIVES OF GEOCOMPOSITE DRAINS

Geocomposite drainage materials have been extensively and successfully used in solid waste landfill closures for decades. The same engineering design methodologies can apply to CCR final cover systems for the long-term compliance of the above referenced performance standards.

Drainage geosynthetics are composed of a geonet core with a geotextile laminated to one or both sides. A geocomposite drain is designed for in-plane flow over a large surface area. The critical engineering properties of a geocomposite drain include its flow capacity (or transmissivity) under design loads and boundary conditions. The flow capacity of a geocomposite is evaluated using a laboratory transmissivity test (ASTM D-4716). This equipment allows a range of normal loads and boundary conditions, i.e., soil vs. rigid membrane, to be applied to the face of the geocomposite. The head acting across the 12-inch square sample can be varied to create a range of gradients that simulate field slope conditions. Be aware that the transmissivity of a geonet core is not representative of the geocomposite, even though it is made of the same geonet core. If the end product is a geocomposite, transmissivity test data must therefore be obtained from a geocomposite. The geotextile portion of the geocomposite functions as a filter and separator, therefore, the geotextile should meet filtration and retention criteria, and it is specific to the on-site soil. The interface shear strength of the geocomposite against adjacent soils and/or other 'geo' layers can be verified using the direct shear test (ASTM D5321).

To satisfy the performance standards for a CCR closure, the engineering design must demonstrate slope stability and among other performance standards minimize to the maximum extent feasible post-closure infiltration of liquid into the waste. The presence of a barrier layer within the final cover invites sliding failure of the cover soil on side slopes due to a buildup of pore water pressures above the barrier layer. To ensure the side slope stability of a final cover, proper design of a drain layer over the liner is essential. The designer must confirm that (1) the interface friction between any two layers of the cover is adequate, (2) the capacity to drain water infiltrating the cover soil is sufficient to eliminate seepage forces detrimental to slope stability. For project design scenarios with flatter grades (2 to 8%), slope stability is not a major concern, therefore eliminating infiltration becomes the primary design objective. Minimizing the head acting on the barrier layer controls infiltration of liquid through holes in the liner.

Design Rate of Fluid Supply

The greatest uncertainty in the design of the geocomposite drain is accurately predicting the maximum rate of water infiltration. This rate is dependent upon both future extreme weather events and the materials placed over the drain. One of the common methods used to evaluate both the design rate of fluid supply and lateral drainage system performance is EPA's HELP model. This water-balance model allows the designer to evaluate the performance of a given barrier exposed to synthetic or historical weather data. **Unfortunately the HELP model does not provide a conservative design for lateral drainage systems.** Soong and Koerner (1997) studied eight seepage induced landfill slope failures and found that the HELP model under predicted the required hydraulic capacity of the lateral drains by factors ranging from 10 to 100! Their work suggests that the 24-hour time step employed by HELP and failure to correctly anticipate extreme weather events are the major sources of error. The extreme weather generated by 'El Nino' has made this prediction easier. The high precipitation and mild weather that has accompanied 'El Nino' can produce saturated conditions in the vegetative layer. The design of the pore water pressure drain underlying a saturated vegetative layer was first presented by Thiel and Stewart (1993). The rate of water infiltration into the geocomposite drain can be readily determined since the water is moving down under a unit gradient such that the infiltration velocity is equal to the permeability of the vegetative layer. Typical permeabilities for such systems range from $5x10^{-3}$ to $5x10^{-4}$ cm/sec. Tighter soils do not allow root penetration and soils looser do no provide adequate water storage. (Richardson and Zhao, 1998)

Design Equations for Geocomposite Drain

Using Darcy's Law, the flow velocity within a cover soil under a unit gradient is equal to the permeability of the material. This represents a design limit and is fortunately more definable than future extreme storm events. Water balance in a closure system is shown in Figure 1. The quantity of water, Q_{in}, infiltrating into a unit width of drainage composite having a length L is given by

$$Q_{in} = k_{veg} \times L \times 1 \quad (1)$$

Where k_{veg} is the permeability of the vegetative supporting layer of the cover, and L is the drainage length, measured horizontally.

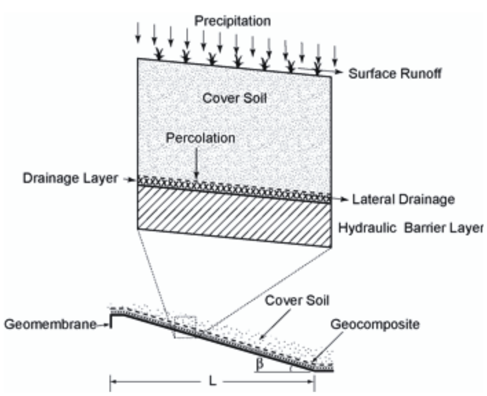


Figure 1 Disposition of precipitation in a typical final cover system

While the quantity of water, Q_{out}, exiting from the drainage layer is calculated by Darcy's Law as follows:

$$Q_{out} = k_d \times i \times A = k_d \times i \times (t \times 1) = \left[k_d \times t \right] \times i = \theta \times i \quad (2)$$

Where k_d is the permeability of the drainage layer, and t is the thickness of the drainage layer, $i = \sin\beta$ is the hydraulic gradient, and $[k_d \times t]$ is defined as hydraulic transmissivity. The required transmissivity for the geocomposite drain can then be calculated

$$\theta_{req} = \frac{k_{veg} \cdot L}{i} = \frac{k_{veg} \cdot L}{\sin\beta} \qquad (3)$$

The laboratory measured transmissivity of a geocomposite drain does not take into account the potential reduction factors during its design life. GRI-GC8 standard (2001) requires the allowable transmissivity being determined under simulated condition for 100-hour duration using the following formula:

$$\theta_{allow} = \theta_{100} \frac{1}{RF_{CR} \times RF_{CC} \times RF_{BC}} \qquad (4)$$

where

- θ_{allow} = allowable design transmissivity
- θ_{100} = laboratory measured transmissivity determined under simulated conditions for 100-hour duration
- RF_{CR} = reduction factor for compressive creep deformation
- RF_{CC} = reduction factor for chemical clogging
- RF_{BC} = reduction factor for biological clogging

A range of clogging reduction factors is provided by GRI-GC8. A higher reduction factor for biological clogging is recommended for landfill capping to account for the growth of biological organisms or by roots growing through the overlying soil and extending downward, through the geotextile filter layer, and into the drainage geonet core. The long term performance of a lateral drain requires a larger allowed transmissivity, $\theta_{allowed}$, than that obtained from the design equations, $\theta_{req'd}$ quantified by an overall safety of factor for drainage, as follows:

$$FS_{dc} = \frac{\theta_{allowed}}{\theta_{req'd}} \qquad (5)$$

Combining equations (3), (4) and (5), the drainage safety factor, FS_{dc}, of the geocomposite drainage layer can then be calculated as follows:

$$FS_{dc} = \frac{\theta_{allow}}{\theta_{req}} = \theta_{allow} \frac{\sin\beta}{k \times L} = \theta_{100} \times \frac{1}{RF_{CR} \times RF_{CC} \times RF_{BC}} \times \frac{\sin\beta}{k \times L} \qquad (6)$$

The selection of drainage FS-value is dependent upon the design life and criticality of the project, 2 – 3 is recommended by Giroud et al (2000), >10 for filtration and drainage by Koerner (2001).

Design Equations for Slope Stability

Surface water percolating through the vegetative soil layer over a barrier layer can produce seepage forces acting parallel to the slope if the soil layer saturates, as illustrated in Figure 2. The slope stability factor of safety for an infinite slope is given as:

$$FS = \frac{Resisting\ \ Forces}{Driving\ \ Forces} = \frac{\gamma_b d \cos\beta \tan\delta}{\gamma_b d \sin\beta + \gamma_W d \sin\beta} = \frac{\gamma_b \tan\delta}{\gamma_{sat} \tan\beta} \approx 0.5 \frac{\tan\delta}{\tan\beta} \qquad (7)$$

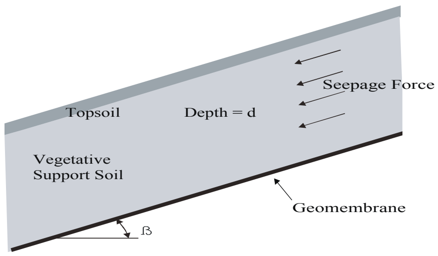


Figure 2 Seepage forces acting on side slope

where γ_{sat} is the saturated unit weight of the soil and γ_b is the buoyant unit weight of the soil, and δ is the interface friction angle. When such seepage forces are eliminated by using a geocomposite drain with adequate transmissivity, the slope safety factor, FS, becomes:

$$FS = \frac{\tan \beta}{\tan \delta} \quad (8)$$

Thus, the use of a geocomposite drainage layer doubles the sliding factor of safety by preventing the formation of seepage forces in the cover soil. **No engineering design would be technically sound and economic to allow such seepage forces in cover soil to occur.**

Leakage Rate through Defects in a Geomembrane Liner

A composite final cover that creates a synergistic relationship between the geomembrane liner and an underlying soil liner provide the best barrier system to minimize liquid infiltration through any defects. Empirical modeling and field observations (Giroud and Badu-Tweneboah 1992) have resulted in the *"Giroud"* equation for estimating leakage through a hole in the geomembrane portion of a composite liner. The empirical equation takes the form of :

$$\frac{Q}{A} = n \cdot 0.976 \cdot C_{qo} \cdot [1+0.1 \cdot (h/t_s)^{0.95}] \cdot d^{0.2} \cdot h^{0.9} \cdot k_s^{0.74} \quad (9)$$

where C_{qo} is the contact quality factor, 0.21 for good contact and 0.15 for poor contact, *"contact"* here refers to the contact between the soil liner and the geomembrane. Good contact conditions correspond to a geomembrane installed with a few wrinkles as possible, on top of a low-permeability soil layer that has been adequately compacted and has a smooth surface; while a poor contact conditions corresponds to a geomembrane that has been installed with a certain number of wrinkles, and/or placed on a low-permeability soil that has not been well compacted and does not appear smooth. Q/A = rate of leakage through defect (m^3/s); n= number of defects, h = head of liquid on top of the geomembrane (m); t_s = thickness of the soil component of the composite liner (m); d = diameter of circular defect (m); and k_s = hydraulic conductivity of the underlying soil liner (m/s), as shown in Figure 3. Equation (9) has been incorporated into the US EPA HELP model used for predicting landfill leachate generation and leakage.

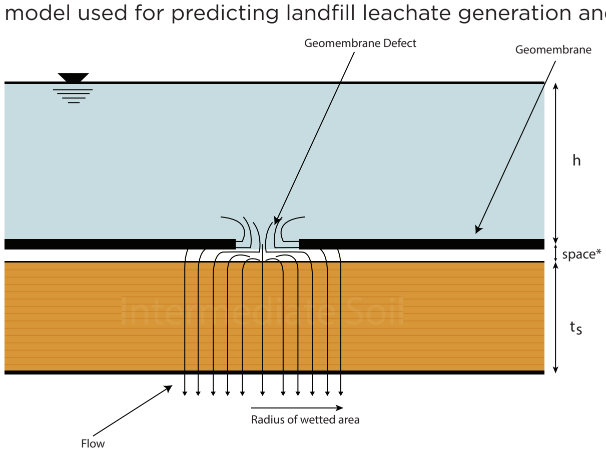


Figure 3 Composite liner variables

Clearly leakage through a composite liner system increases with the following:

1. Increasing head,
2. Decreasing soil liner thickness,
3. Increasing soil liner permeability,
4. Increasing area of defect in GM,
5. Decreasing lack of good contact between the two liner components, and
6. Increasing number of defects in GM.

CCR closure performance standards do not mandate a composite liner system closure. Leakage rate through defects in a single geomembrane liner will be significantly greater than a composite liner. Thus, hydraulic head-control is critical to satisfy CCR closure performance standards for owner and operators to control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste in flatter area of the closure.

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