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Guidance for Liner Construction and Testing for a Municipal Solid Waste Landfill

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1. Liner Quality Control Plan (LQCP)

1.1. Introduction

This guidance document provides assistance in fulfilling the requirements of Title 30 Texas Administrative Code (30 TAC) Chapter 330, Subchapter H, relating to Liner System Design and Operation.

The intent of this document is to provide you, the owner or operator of a municipal solid waste landfill with reasonable technical guidance and a suggested minimum level of construction control and testing for various types of liner systems. This document also provides guidance for the analysis, design, and construction of liners placed below the seasonal high water table.

This guide does not replace the rules or policies for liner system design and operation, which take precedence over any information in this publication, and it does not include all acceptable practices. We also recognized that on-going research and experience in the design and construction of liners may eventually prove superior to the suggestions in this guidance.

1.2. LQCP Preparation

A landfill must have an approved LQCP prepared under the direction of a licensed professional engineer. The LQCP shall be the basis for the type and rate of quality control performance testing, which is reported in the soil liner evaluation report (SLER) as required in 30 TAC 330.341 and 330.339(a).

The construction and testing of all liners must be in accordance with an approved LQCP as required by 30 TAC 330.339(a). A copy of the current LQCP must be maintained on site, or at an alternate location approved by the executive director (ED), as required by 30 TAC 330.125(a) and be available for inspections and used for the construction and testing of the liner.

For ease in LQCP preparation, we recommend that this document be adopted, in whole or in part, as the LQCP for your facility.

Per 30 TAC 330.339, you are required to provide the following information as an attachment to the LQCP:

- ***Discussion regarding each component (e.g. soil liner, geomembrane, leachate collection system, protective cover, etc.) of the proposed liner system.***
- ***Drawing which depicts a cross-sectional view of the construction details of each proposed liner system.*** Please ensure that the drawing is signed and sealed in accordance with the Texas Engineering Practice Act.

1.3. Liner System Requirements for Type I Disposal Units

Liner system designs for: new permits for Type I landfill units; lateral expansions of Type I Landfill units; vertical expansions of Type I landfills over landfills that do not meet the design criteria under 30 TAC 330.331(a)(1) or (2); and expansions of existing

Type IAE landfills that subsequently no longer satisfy the conditions specified in 30 TAC 330.5(b)(1) must be constructed in accordance with one of the following provisions approved by the ED:

1. A design that ensures that the concentration values listed in 30 TAC 330.331(a)(1), will not be exceeded in the uppermost aquifer at the point of compliance, as determined in 30 TAC 330.403; or
2. A composite liner, as defined in 30 TAC 330.331(b), and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner.

Per 30 TAC 330.331(b), "composite liner" means a system consisting of two components; the upper component must consist of a minimum 30-mil geomembrane liner and the lower component must consist of at least a two-foot layer of re-compacted soil with a hydraulic conductivity of no more than 1×10^{-7} centimeters per second (cm/sec). Geomembrane liner components consisting of high density polyethylene (HDPE) must be at least 60-mil thick. The geomembrane liner component must be installed in direct and uniform contact with the compacted soil component.

1.4. Liner System Requirements for Type IV Disposal Units

Type IV disposal units must be constructed under one of the following provisions approved by the ED:

1. There must exist at least four feet of in-situ soil between the deposited waste and groundwater. This in-situ soil must constitute an in-situ liner and must meet all the physical properties for a constructed liner as detailed in 30 TAC 330.339(c)(5). In-situ liners must not exhibit primary or secondary physical features such as jointing, fractures, bedding planes, solution cavities, root holes, desiccation shrinkage cracks etc., that have a coefficient of permeability greater than 1×10^{-7} cm/sec;
2. There must be at least a three-foot thick re-compacted clay liner between the deposited waste and groundwater. The constructed liner must meet all the criteria detailed in 30 TAC 330.339 and must at a minimum have one foot of protective cover overlying the recompacted liner after all quality control testing and final thickness determinations are complete; or
3. An alternative liner design, per 30 TAC 330.335.

1.5. Full Time Quality Assurance

The construction and testing of all elements of the liner system must follow your LQCP.

Quality control of construction and quality assurance of sampling and testing procedures should follow the latest technical guidelines of the ED (30 TAC 330.339(a)(2)). All field sampling and testing, both during construction and after completion, shall be performed by a person acting in compliance with the provisions of the Texas Engineering Practice Act and other applicable state laws and regulations.

Under 30 TAC 330.339(a)(2), the Professional of Record (POR) who signs the Soil Liner Evaluation Report or the Qualified Engineering Technician (QET) should be on site during all liner construction and testing. We recommend that your POR be onsite as often as necessary depending on the experience of the QET and for all extraordinary construction events during all liner system construction.

2. Soil Liner Systems

2.1. Soil Liner Material Requirements

Borrow source material and soil liner systems are required to meet the properties listed in Table 2–1. All borrow source material and constructed soil liners must have the referenced values verified by testing in a soils laboratory.

Table 2–1: Soil Liner Requirements

Soil Property	*Value*
Plasticity Index (PI)	≥ 15
Liquid Limit (LL)	≥ 30
Percent Passing No. 200 Mesh Sieve	≥ 30%
Percent Passing One-Inch Sieve	= 100%
Permeability	$\leq 1 \times 10^{-7}$ cm/sec

2.2. In-Situ Soils

In-situ soils (soils in place and not disturbed through excavation and recompaction) are rarely acceptable as low-permeability liners due to the frequent occurrence of either primary depositional physical features such as bedding planes, desiccation cracks caused by drying at the time of deposition, or sediment distribution. In addition, secondary features that occur subsequent to disposition such as jointing, fracturing due to stress relief, solution weathering, etc., are common. In-situ soils are not a component of the standard composite liner consisting of a constructed soil liner overlain by a geomembrane, but in those cases where primary or secondary features that could adversely affect liner quality do not exist (or where the ED has approved corrective measures), the in-situ soils may be considered as an alternative liner design. Per 30 TAC 305.62(j)(2)(C), authorization to use these in-situ soils in a Type I landfill will require a permit amendment which includes a demonstration using the specific on-site soil and groundwater characteristics and computer modeling showing that the in-situ soils will meet all of the requirements for groundwater protection. Discovery of adverse primary or secondary features, or an adverse change in lithology during landfill development may void the use of in-situ soils even after the landfill has received approval of a permit amendment for an alternative liner.

2.3. Soil Liner Construction Requirements

2.3.1. General

Constructed soil liners include those of over-excavated and recompacted in-situ soils and soils from a borrow source.

2.3.2. Installation

Liners on side slopes of greater than a 3H:1V slope angle (3 horizontal to 1 vertical) should not be constructed in parallel lifts due to both the inherent lack of stability of the compaction equipment on these steep slopes as well as the compaction inefficiency.

Placement of constructed liners must conform to these requirements:

- All liner subgrade areas should be properly scarified a minimum of two inches and prepared to receive the liner.
- The top of each lift should be roughened to a shallow depth prior to the placement of the next lift of soil for compaction.
- No loose lift should be thicker than the pads of the compactor so that complete bonding with the top of the previous lift is achieved.
- Equipment and safety limitations prohibit finish grades with slopes greater than 3H:1V if the liner is constructed parallel to the surface. For an excavated wall with steeper than 3H:1V side slopes, the sidewall liner must be constructed in successive horizontal lifts.
- The top surface of the completed soil liner must be proof rolled with a smooth-wheel roller prior to final liner thickness surveying when placement of a geomembrane liner is required.
- We recommend that the surface of a soil liner be proof rolled when construction is shut down for more than 24 hours and also be done on a routine basis during the summer months at the end of each day’s liner construction to mitigate the effects of desiccation cracking.
- The maximum clod size of the compacted liner soils shall be approximately one inch in diameter. In all cases, reduce soil clods to the smallest size necessary to achieve the coefficient of permeability reported by the testing laboratory (or the maximum value of 1×10^{-7} cm/sec) and to destroy any macrostructure evidenced after the compaction of the clods under density-controlled conditions (30 TAC 330.339(g)).
- The liner soil material shall contain no rocks or stones larger than one inch in diameter or that total more than 10 percent by weight. The final lift for composite liners should not contain any rocks or any other materials that can cause damage to the geomembrane (30 TAC 330.339(h)). We recommend that the soil liner surface that comes into contact with the geomembrane contain no rocks larger than 3/8-inch.

- Soil liners shall not be compacted with a bulldozer or any track-mobilized equipment unless it is used to pull a pad-footed roller. Compact all soil liners with a pad-footed or prong-footed roller only (30 TAC 330.339(g)). When using American Society for Testing and Materials (ASTM) Test Method D698 (Standard Proctor) density, the minimum weight of the compacter should be 1,500 pounds per linear foot of drum length, and multiple passes as needed should be used for the compaction process. Compaction equipment that develops a compactive effort equal to ASTM D1557 (Modified Proctor) will result in greater compaction, lower coefficient of permeability due to decreased void space, and a lower optimum moisture content necessary to achieve the maximum dry density. This lower optimum moisture content may help in controlling the desiccation cracking of high plastic clays frequently used for liner soil. Recognizing the soil variability, the POR or QET may adjust the compaction effort based on the site-specific soil conditions and the compaction experience with the specific soil type.

2.3.3. Liner Tie-in

When a continuous trench (area fill) method of landfill development is in use, the leading twenty (20) feet of the floor liner shall not receive waste to facilitate tie-in with the next liner segment. Continuous floor liners shall not be constructed by "butting" the entire thickness of a new liner segment next to the previously constructed section of liner. We recommend that liner tie-ins are done using one of the following methods:

- Stair-step method: The edge of the old section of liner is cut back on off-set layers (stair-step) so that each unit thickness of the existing liner edge is tied to new construction without superimposed construction joints. The length of the tie-in area should be at least 5 feet per foot thickness of liner (Figure 2–1).
- Sloped transition method: The edge of the previously installed section of liner is cut back on a 5H:1V slope, and is scarified as each successive lift is placed against the 5H:1V slope. Compaction extends from the new liner onto the transition zone with placement of each successive lift, thereby adequately blending the new and old liners together (Figure 2–2).

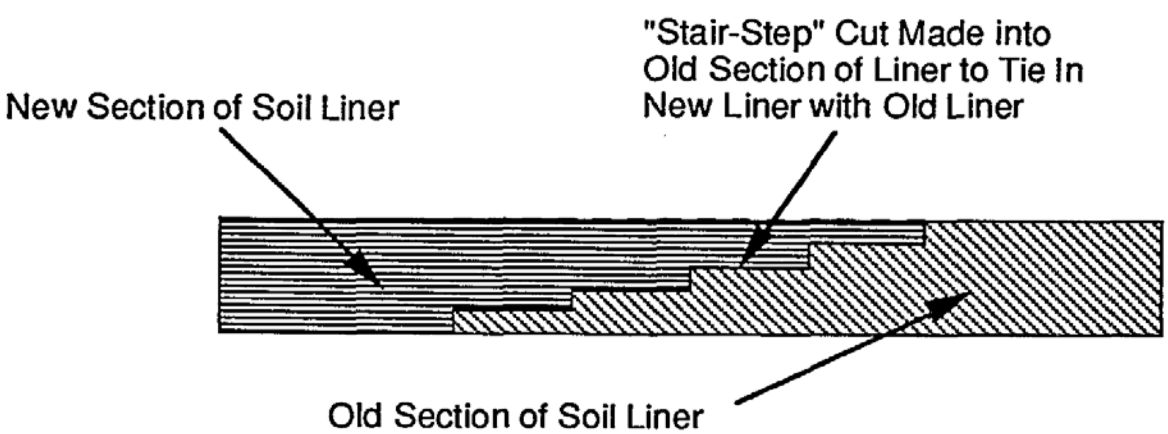

Figure 2–1: Constructed Soil Liner Stair-Step Tie-in Detail

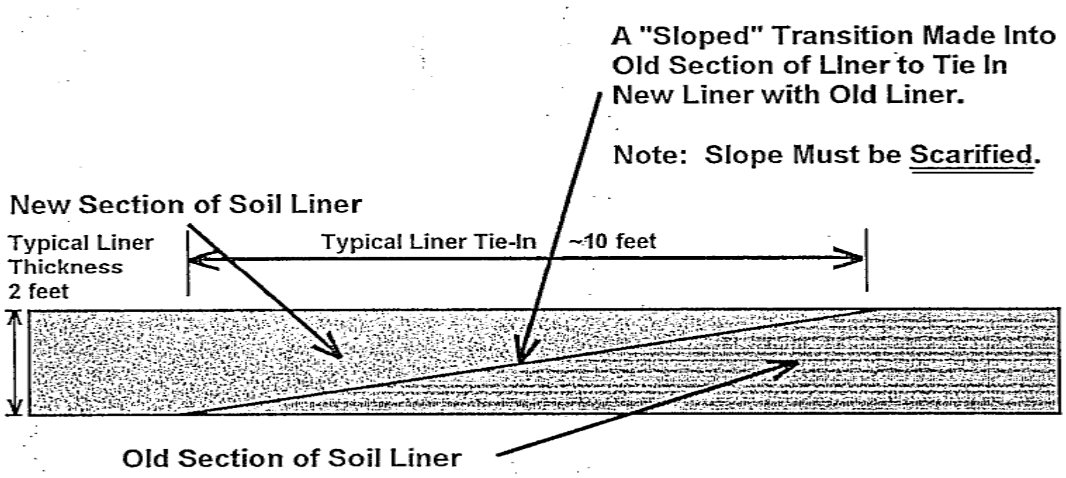

Figure 2–2: Constructed Soil Liner Sloped Tie-in Detail
(from EPA/600/R-93/182, September 1996 Technical Guidance Document)

2.3.4. Construction Timing

Soil liner construction and testing should be conducted in a systematic and timely fashion. Delays should be avoided in liner completion. We recommend that construction and testing of soil liners do not exceed 60 working days from beginning to completion. Reasons for any liner construction project delays should be fully explained in the SLER submittal.

2.3.5. Liner Protection

Constructed and tested liners for which a SLER has been submitted shall have sufficient surface-drainage controls to prevent the accumulation of both contaminated and non-contaminated water. Remove ponded water that accumulates on newly constructed liner surfaces promptly and appropriately. The surface of the completed soil liner must be kept moist prior to placement of geomembrane or other overlying materials to reduce shrinkage cracking, but saturation of these soils by ponding water is not an acceptable practice. Complete saturation of any portion of the liner and its protective cover compromises their structural integrity and increases the degree of shrinkage cracking in the event of drying.

2.4. Testing Requirements for Soil Liners

2.4.1. Borrow Source Materials

Quality assurance and quality control (QA/QC) testing for all borrow source material used to construct the clay component of the liner system must conform to the tests, test methods, and testing frequencies outlined in Appendix B, Table B-1 of this guidance document. Borrow source material must be retested for the requirements listed in Appendix B, Table B-1 if there is a change in borrow source material.

A soil classification system, such as the United States Department of Agriculture Soil Classification System, American Association of State Highway and Transportation

Officials system, and the Unified Soil Classification System may be used to determine whether there is a change in borrow source material.

The liquid limit (LL) and plasticity index (PI) of the soil may also be used to determine if there is a change in borrow source material. If either the LL or the PI varies by 10 or more points when compared against the appropriate moisture/density curve used for that soil borrow source, the soil is considered as a separate soil borrow source. Due to the high shrink/swell and desiccation cracking characteristics of high plasticity clays it is suggested that, where possible, the PI of clay liner soils be limited to be between 15 and 30.

2.4.2. Testing Frequency for Soil Liners

Each in-situ or constructed liner sidewall and floor area developed as a separate segment (non-monolithically) must be considered as separately evaluated areas independent of each other for the purpose of calculating dimensions to determine the required number of samples. Those sidewall and floor areas constructed or excavated as a bowl (monolithically) may be added together for the determination of their testing frequency and locations.

Backfill all holes dug or created during any sampling or testing with a mixture of at least 20 percent bentonite-enriched liner soil and compacted by hand tamping or filled with an approved bentonite grout.

2.4.3. In-Situ Soils Testing Requirements

The tests, test methods, and testing frequencies outlined in Appendix B, Table B-1 must be used to perform QA/QC testing for in-situ soils.

For in-situ liners that are protected by one foot of protective cover added to the top, the entire series of quality assurance testing must be conducted and completed for all three feet (or approved alternate thickness) of liner soils prior to adding the protective cover.

For in-situ liners that are not to be protected by the placement of one foot of protective cover, the top one foot of the in-situ liner must serve as protective cover and the entire series of quality assurance testing must be conducted for the first four feet (or approved alternate thickness) of in-situ soil beginning with the surface of the protective cover.

2.4.4. Constructed Soil Liner Testing Requirements

The tests, test methods, and testing frequencies outlined in Appendix B, Table B-1 must be used to perform QA/QC testing for constructed soil liners.

Sidewall liner evaluations for lifts constructed parallel to the surface of the excavation will be evaluated by using the same criteria and rate of testing as for the bottom.

Sidewall evaluations for lifts constructed horizontally may be evaluated at a frequency not to exceed 12 inches in thickness (i.e. 2 lifts). Sample locations for field density testing should not exceed 100 linear feet and should be located within the 4 feet closest to the protected wall.

The usual sampling practice for quality assurance laboratory testing of the constructed liner is to retrieve representative samples from the same sampling tube. The location of the sampling/testing is adjacent to a field density/moisture test for comparing field and laboratory results.

2.4.4.1. Field Densities and Moisture Content

All field densities and moisture contents must compare with these limits, and to the proper ASTM D698 or ASTM D1557 moisture/density curve for the corresponding soil borrow source in order to be considered passing:

- When using the Standard Proctor Test (ASTM D698), the dry density and moisture content of the compacted clay liner must be at least 95 percent of maximum dry density and at or above the optimum moisture content, respectively.
- When using the Modified Proctor Test (ASTM D1557) the dry density and moisture content of the compacted clay liner must be at least 90 percent of the maximum dry density and at or above a moisture content 1 percent dryer than optimum, respectively.
- For both compaction tests (ASTM D698 and D1557) the moisture content should not exceed a maximum value, which is governed by shear strength requirements and the need to minimize the possibility of rutting under construction equipment or desiccation cracking upon drying.

As an alternative to these as the acceptance criteria, the “line of optimums” (described by Benson et al [1991]) may be used as the basis in field control. Under this alternative procedure, 80 percent of the field densities must lie on or above the line optimums.

The line of optimums as described by Benson et al is essentially a line drawn through the points corresponding to the optimum moisture content/maximum dry density on the moisture/density relationship curves for the modified proctor test, the standard proctor test, and a third compaction test using a reduced energy from the standard proctor test. (It has been shown by Benson et al that compacted soil liners that have approximately 80 percent or more of the field density data points above, or wet, of the line of optimums have a significantly higher probability of achieving the 1×10^{-7} cm/sec permeability standard than liners constructed using the conventional percent compaction basis). If this procedure is used, those field density points that do not lie above the line of optimums must not be concentrated in any specific lift or section of fill.

Sections of compacted soil liner that do not pass both the density and moisture requirements must be reworked and retested until the section in question does pass. All field density test results must be reported in the SLER, whether they indicate passing or failing values. The frequency of testing differ for these two lift placement methods:

- Parallel Lifts—one test for each 8,000 ft^2 of surface area per lift (but no less than 3 density tests per 6 inch lift).
- Horizontal Lifts—one test for each 100 linear feet per each 12 inches of thickness.

2.4.5. Thickness Verification

Thickness of constructed soil liners will be determined by instrument survey methods only. There should be a minimum of one verification point per 5,000 ft^2 of surface area. If the area under evaluation is less than 5,000 ft^2, a minimum of two reference points are required for verification. Reference locations will be noted on a drawing of the area evaluated. All elevation calculations necessary for the thickness determination will be attached as part of the supporting documentation to the SLER including any necessary corrections for the true thickness measured perpendicularly to sidewalls. Cross-sections at approximately 100 foot spacing showing true liner thickness for sidewall liners that are constructed in horizontal lifts should be provided if appropriate.

Thickness of in-situ soil liners should be determined by augering to a depth equal to the required liner thickness plus one foot if top foot is to be used as protective cover. The rate of verification should be at a minimum of one location for each 5,000 feet of surface area. Backfill each augered hole with a mixture of at least 20 percent bentonite by volume and parent soil material and, at a minimum, compacted by hand-tamping.

2.5. Protective Cover Requirements

Protective cover is required to be placed over the liner system and the installation and design requirements are summarized in Table 2–2. Full-time observation by the POR or QET is required during protective cover installation.

Table 2–2: Protective Cover Requirements

Protective Cover Topic	*Protective Cover Installation and Design Requirements*
Material	Earthen material not previously mixed with garbage, rubbish, or other solid waste.
Permeability	Protective cover overlying a leachate collection and removal system (LCRS) in general must have permeabilities ≥ 1 x 10^{-4} cm/sec, or be provided with appropriate passageways for moisture, such as chimney drains, that allow leachate to readily drain to the LCRS.
Protective Cover Thickness	• Thickness ≥ 24 inches for a liner system that includes a geosynthetic clay liner (GCL), a geomembrane, or both. • Thickness of ≥ 12 inches between leachate collection pipes and waste. • Thickness of ≥ 12 inches between clay liners and waste.
Installation General	• The protective cover does not require compaction under density-controlled construction procedures. • Place protective cover as soon as possible, typically after installation of the soil liner, GCL, geomembrane, and any overlying geosynthetics.
Installation over Geomembrane	• Place all soil materials over a geomembrane during the coolest part of the day. Deploy soil in “fingers” along the surface to control the amount of slack and minimize wrinkles and folds in the geomembrane. Deploy soil only up-slope on side slopes to minimize stress on the geomembrane.

Protective Cover Topic	*Protective Cover Installation and Design Requirements*
	• Use clean protective cover (no rocks > 3/8 inch, no vegetation, and no other material that could damage the geomembrane). If the protective cover contains material > than 3/8-inch in size, place a layer of protective geotextile over the geomembrane's surface. • Place protective cover with light equipment (such as dozers with less than 5 psi contact pressure) while maintaining at least 12-inches of material between the dozer and the geomembrane.
Installation over GCL	• Minimize the operation of any equipment over the GCL liner while placing the protective cover or for any subsequent need to mitigate the possibility of tearing the GCL. • Carefully analyze the minimum thickness of any protective cover to ensure it can overcome stresses imposed by equipment on the GCL. Generally, the protective cover thickness should be at least 1.5 to 2 times thicker than the width of the equipment track or tire. • Use clean soil cover material placed over GCL to prevent damage to the GCL and to prevent subsequent localized thinning of the bentonite component. o Clean soil cover material is non-calcareous, with no rocks > 3/8-inch in size (or as recommended by the manufacturer), and no other foreign material. • Place the cover with low-ground-pressure dozers or other light equipment to prevent damage to the GCL. • Place protective cover in the direction of downgradient shingling of the GCL overlaps. • Place on side slopes from the bottom of the slope upward.
Maintenance	Wet the surface of the protective cover during dry periods to keep the liner moist and to prevent desiccation cracking.

3. Geomembrane Liners

3.1. General

Geomembrane is used as a component in a standard composite liner system per 30 TAC 330.331. Your geomembrane material may include HDPE or other materials approved by the TCEQ.

The information provided in this document addresses the use of HDPE geomembranes. Materials, construction, and QA/QC standards for other geomembrane materials should follow industry standards and the manufacturer's guidelines.

Geomembrane must have a minimum thickness of a least 30 mils, or 60 mils if consisting of HDPE. If heat bonding is used for seaming, the geomembrane should have a minimum thickness of 30 mils. Any acceptable geomembrane material used must overlie and be in direct contact with the compacted clay liner or an approved alternative liner (30 TAC 330.331(b)).

3.2. Manufacturing Materials

Geomembrane material must be produced from virgin raw materials. Reground, reworked, or trim material in the form of chips or edge strips may be added if the material is from the same manufacturer and is exactly the same formulation in the geomembrane being produced.

Recycled or reclaimed materials must not be used in the manufacturing process. HDPE material and required welding rods shall contain between 2 percent and 3 percent carbon black and may contain no more than 1 percent other additives.

3.3. Shipping, Handling, and Storage

Ship all HDPE liner material in rolls. Folded or creased sections of panels are not acceptable and shall not be used unless they are a normal part of the manufacturing process.

Upon receipt of your HDPE liner:

- Inspect the delivered materials for damage and defects (conducted by POR or QET).
    - Geomembrane sheets must be free from pinholes, surface blemishes, scratches, or other defects (e.g. non-uniform color, streaking, roughness, agglomerates of carbon black or other additives or fillers, visibly discernible regrind or rework, etc.).
- Offload at the job site with cranes or forklifts in a manner that ensures damage does not occur to any part of the geomembrane.
- Unload rolls or pallets at the job site's temporary storage location in a way to ensure that no damage to the geomembrane occurs.
- Do not push, slide, or drag rolls or pallets of geomembranes.

The temporary storage location at your site should:

- Be dry – it should be in an area where standing water cannot accumulate at any time.
- Protect geomembrane materials from soft, wet, rocky, and rough ground.
- Suitably prepared so that no stones or other rough objects, which could damage the geomembrane materials, are present on the ground.

Temporary storage of liner materials at your site should:

- Protect rolls of HDPE or Liner Low Density Polyethylene geomembranes from crushing of the core or flattening of the rolls. Achieve this by stacking no more than 5 rolls, or following the manufacture’s stacking recommendations.
- Stacking pallets of Polyvinyl Chloride (PVC) or Srim Reinforced Chlorosulfonated Polyethylene (CSPE-R) geomembranes is not permitted.
- Secure the rolls or pallets to prevent shifting, abrasion, or other adverse movement.
- Cover or provide a temporary shelter for rolls or pallets of geomembranes stored at your site longer than 6 months to protect against precipitation, ultraviolet exposure, and accidental damage.

3.4. Geomembrane Installation and Testing

Geomembrane installation and testing requirements are summarized in Table 3-1; Table 3-2; Table 3-3; Table 3-4; and Table 3-5.

Table 3–1: Geomembrane Installation Requirements

Geomembrane Installation Topic	*Geomembrane Installation And Testing Requirements*
Installation	• Follow all manufacturer's recommendations. • Install in direct and uniform contact with the compacted soil component or approved alternate liner.
Subgrade Preparation	• Keep surface of the subgrade soil free of sharp stones, stones larger than 3/8-inch, sticks, or other debris. • Finish soil subgrade surface by rolling with a flat wheel roller until a smooth uniform surface is achieved. • Protect soil subgrade from desiccation cracking, rutting, erosion, and ponding prior to and during placement of the geomembrane. • Preserve subgrade by (1) regular watering and proof rolling, or (2) placing a minimum 12-inches of temporary soil cover over subgrade, removing the temporary soil cover prior to geomembrane placement, and resurveying the soil subgrade surface prior to geomembrane placement.
Geomembrane Deployment	• Ensure the subgrade is not damaged during deployment. • Prevent construction equipment from traveling directly on the lower geosynthetic material if geomembrane is placed over geosynthetic.
Weather	Do not place geomembrane during inclement weather (rain, high winds, or freezing temperatures).
Equipment on Geomembrane	• Limit vehicular traffic on the liner to low-ground-pressure supporting equipment only. • POR or QET must repair any damaged areas of the geomembrane due to vehicular traffic. • Prohibit personnel working on the geomembrane from: o Smoking. o Wearing damaging shoes. o Engaging in any other activity likely to damage the geomembrane.
Placement	• Only unroll geomembrane sheets that are to be placed and seamed in one day. • Position geomembrane with the overlap recommended by manufacturer, but not less than 3-inches for HDPE. • POR or QET must visually inspect placement and overlap of geomembrane to verity requirements.

Geomembrane Installation Topic	*Geomembrane Installation And Testing Requirements*
Folds, Large Wrinkles, and Fish Mouths	• Walk-out or remove wrinkles prior to field seaming. Folds, large wrinkles, or fish mouths are not allowed in the seam. Only normal factory-induced creasing may be acceptable. • Cut, overlap, and weld the material where wrinkles or folds occur. This process should be accomplished in such a manner that constructed seams are not required to carry significant tensile loads. o During wrinkle or fold repairs, adjacent geomembrane may not necessarily be required to meet the 3-inch minimum overlap if approved by the POR or QET. • Remove dirt, water, oil, etc. from the area to be bonded. • Bond and seal all completed seams tightly.
Tack Welds	• Use heat only tack welds (if used) with HDPE geomembrane. • Do not use double-sided tape, glue, or other method when extrusion or fusion welding is used for bonding.
Geomembrane Seaming	• Follow manufacturer recommendations for field seaming and repairs. • For HDPE, fusion or extrusion welding is acceptable.
Seam Joints	• Orient seams on side slopes (e.g. slopes steeper than 6H:1V) parallel to the side slope direction. • Locate seams that join the side slopes and bottom sections at least 5 feet from the side slope and along the floor. • Minimize the number of seams in corners and odd-shaped geometric locations.
Temperature	• Do not attempt seaming when the ambient air temperature is above 104 ˚F. • Follow Geosynthetic Research Institute (GRI) Test Method GM-9 for seaming geomembrane when the ambient air temperature is below 32 ˚F.
End of Each Work Day	• Anchor all unseamed edges with sand bags or other approved devices at the end of each day or installation segment. • Do not use staples, U-shaped rods, or other penetrating anchors.

Table 3–2: Geomembrane Testing Requirements

Geomembrane Testing Topic	*Geomembrane Testing Requirements*
QA/QC Testing	• Use the manufacturing and conformance testing requirements for geomembrane liners as specified in Appendix B, Table B-2. • Meet the manufacturer’s standards and (for HDPE) the values in the GRI Test Method GM13 (GRI GM13) for all geomembrane material properties. • Follow manufacturer’s recommendations and acceptable industry practices for other types of geomembranes.

Geomembrane Testing Topic	*Geomembrane Testing Requirements*
Conformance Testing	• Verify that the geomembrane meets the required specifications prior to acceptance from the manufacturer (performed by the POR or QET). • Perform conformance testing, as required by an independent third party laboratory. • Conduct other testing, not listed in Appendix B, Table B-2 depending on your geomembrane type. Required testing may be obtained from the product manufacture, GRI, or the POR.
Seam Testing	• Observe all test seam procedures and all seam testing (performed by the POR or QET). • Verify (performed by the POR or QET) that all seam testing of the geomembrane liner follows current ASTM standards and GRI Test Method GM19 (GRI GM19).

Table 3–3: Trial Seam Testing Requirements

Trial Seam Testing Topic	*Trial Seam Testing Requirements*
Trial Seam Testing	Each day, prior to commencing field seaming: • Create test seams on fragment pieces of geomembrane to verify that seaming conditions are adequate. o Have every individual employee preforming seamer activities make at least one test seam each day they perform field seaming. • Test the welder and the machine for each new trial seam when using extrusion welding. • Test the machine only for each new trial seam when using fusion welding (since the machine is not operator dependent).

Trial Seam Test Criteria	• Make trial seams least 3 feet long by 1 foot wide.
	• Die-cut four (six when possible if using dual track fusion welding) adjoining one-inch wide specimens from the test seam sample.
	    o Test two specimens in the field for shear.
	    o Test two for peel (four when possible if testing both inner and outer welds for dual track fusion welding).
	• Ensure the extensometer testing apparatus used for peel and shear tests has an updated calibration certificate that is traceable to National Bureau of Standards prior to the start of testing.

Trial Seam Testing Topic	*Trial Seam Testing Requirements*
Trial Seam Failure Criteria	• Trial seam failure criteria are the same as for destructive seam testing (see Passing Criteria in Table 3–4: Destructive Testing Requirements). • Test specimens exhibit acceptable break codes and properties specified in the most current version of GRI GM19. • Elongation measurements are not required for trial seams. • For failed test specimens: o If one test specimen fails, repeat the trial seam. o If the repeated trial seam also fails, then construct and test two more trial seams. o Repeat this process until all test seams pass. • Do no begin field welding, for the machine or welder (if applicable), until all test seams pass.
Additional Trial Seams	Make additional trial seams : • At the beginning of each seaming period for each seaming apparatus used that day (the beginning of each seaming period is considered to be the morning, and immediately after a break); • For each occurrence of significantly different environmental conditions (such as temperature, humidity, dust, etc.); • Any time the machine is turned off for more than 30 minutes; and • When seaming different geomembrane (e.g. tie-ins and smooth to textured).

Table 3–4: Destructive Testing Requirements

Destructive Testing Topic	*Destructive Testing Requirements*
Testing Frequency	Alternative Testing Frequency: • Use the (1) method of attributes and (2) control charts to determine the testing frequency for destructive seam testing. • The procedures should follow GRI GM14 and GRI GM20 and must be submitted and approved by the ED prior to implementation. Standard Testing Frequency: • Take destructive test samples of field seams at a minimum of one stratified location for every 500 linear feet or major fraction thereof. • Take destructive test samples of repaired geomembrane leaks and seams at a frequency of one stratified test every 500 linear feet or major fraction thereof. Individual repairs of leaks or failed seams, which are greater than 10 feet, shall count toward the 500 linear foot testing interval. • Conduct, at a minimum, a destructive test for each welding machine used for seaming or repairs. • Take additional destructive test samples if deemed necessary by the POR or QET.

Destructive Testing Topic	*Destructive Testing Requirements*
Test Specimens	• Maintain a sufficient amount of the seam to conduct field testing, independent laboratory testing, and to retest the seam when necessary (archiving). • Include at least two peel test specimens (four when possible for testing both tracks on dual track fusion welded seams) and two shear test specimens for field testing.
Repairs	• Destructive seam testing locations shall be repaired by installing a cap –strip over the entire length of failed seam. The cap strip must be of the same liner material and extend at least six inches in all directions over the failed seam. The cap strip shall be completely seamed by extrusion welding to the parent geomembrane. Test capped sections non-destructively.
Passing Criteria	• Meet the break codes, strength, elongation, and percent peel separation as described in GRI GM19 for all laboratory-tested specimens from a destructive-test location. • Meet the break codes and strengths as described in GRI GM19 for field-tested specimens.
Retesting	If a destructive test fails: • Conduct additional destructive test at least 10 feet on both sides of the failed destructive test. o If any of these additional destructive tests fail, repeat the sampling and testing process until the failed seam is located by passing destructive tests. • Cap any failed seam between passing destructive tests. Alternatively, all seams done by the welder or machine within the time period (between passing destructive tests or trial welds) represented by the failed destructive test may be capped.

Table 3–5: Non-Destructive Testing Requirements

Non-Destructive Testing Topic	*Non-Destructive Testing Requirements*
Non-Destructive Testing	• Perform continuous non-destructive testing (by the installer) on all factory and field seams. • Observe all non-destructive testing (POR or QET). • Conduct: o Air-pressure testing for dual-track fusion welds. o Vacuum-box testing for all extrusion welds. o Request prior approval for all other types of non-destructive testing. • Isolate all indicated leaks and repair leaks by following the procedures described in Section 3.5 (Repairs and Retesting) of this guidance document.

Non-Destructive Testing Topic	*Non-Destructive Testing Requirements*
Air Pressure Testing	1. Seal the ends of the air channel of the dual-track fusion weld and pressurize to approximately 30 psi for HDPE geomembrane. 2. Shut off air pump (after pressure of 30 psi is reached). 3. Wait 5 minutes. 4. Observe the air pressure. Understanding your results: • A loss of < 4 psi is acceptable if it is determined that the air channel is not blocked between the sealed ends. • A loss ≥ than 4 psi indicates the presence of a seam leak that must then be isolated and repaired (see Section 3.5 of this guidance document).
Vacuum Box Testing	A suction value of approximately 4 to 8 psi must be applied to all extrusion welded seams that can be tested in this manner. Examples of extrusion welded seams that do not easily lend themselves to vacuum testing would be around boots, appurtenances, etc. The seam must be observed for leaks for at least 10 seconds while subjected to this vacuum.

3.5. Repairs and Retesting

Repair all seam leaks and destructive test locations by installing patches or cap strips over the damaged area. The patch or cap strip must be of the same type of liner material and extend for a distance of at least six inches in all directions of the faulty spot or area detected. Use extrusion welding methods to install the patch or cap strip. At a minimum, you must retest these repairs non-destructively and possibly destructively (refer to destructive testing criteria for repaired seams as described in Table 3–4).

3.6. Anchor Trench and Backfilling

The anchor trench should be completed around all portions of the geomembrane where the leading edge(s) of the geomembrane will not be needed for a tie-in for expansion into the next area to be lined. The excavated anchor trench shall have rounded corners in order to help protect the geomembrane. Do not allow loose soil to underlie the geomembrane in the anchor trench. Time excavations of the anchor trench closely with the installation of the geomembrane.

Backfill and compact the anchor trench to at least 90 percent of the maximum dry density as determined by the moisture/density compaction values determined in the soils portion of this document. Use care when backfilling and compacting the trench to prevent damage to the geomembrane. Backfill the anchor trench at the earliest practicable time following geosynthetics deployment. Results of the compaction testing need not be reported.

4. Geosynthetic Clay Liners

4.1. General

You can use a geosynthetic clay liner (GCL) as a component in an alternative liner system if a demonstration is provided to show that the alternative liner system is an equivalent substitute for and that it meets all regulatory requirements of a composite liner system. This demonstration should be made as part of your permit application, or as an amendment to an existing permit (30 TAC 305.62). For a GCL the provisions in 30 TAC 330.331 and 330.335 need to be met.

As used in this document, GCL refers to a factory-manufactured hydraulic barrier consisting of a bentonite layer supported by geotextiles or geomembrane. Depending on the GCL type and the manufacturer, the bentonite may:

- Be bonded to geomembrane or between layers of geotextile with chemical additives.
- Held between layers of geotextile, which are needle punched or stich bonded together.
- Encapsulated within a geomembrane/geotextile composite.

4.2. GCL Required Properties

The GCL and its component materials (bentonite, geotextile, or geomembrane) must be tested as described in Section 4.5 and have the following properties. In addition, the bentonite used in the GCL must be of the sodium montmorillonite variety and have the properties listed in Table 4–1, or as required by the permit.

Table 4–1: Required Properties for a GCL

Component	*Property*	*Value*
Bentonite Used in a GCL	Free Swell	≥ 24 mL
	Fluid Loss	≤ 18 mL
Assembled GCL Product	Bentonite mass/unit area	≥ 0.8 lbs/ft^2
	Permeability	≤ 5×10^{-7} cm/sec

4.3. Manufacturing, Shipping, Unloading, and Storage

Recommended procedures regarding the manufacturing, unloading, and storage of GCL material have been summarized in Table 4–2.

Table 4–2: GCL Manufacturing, Shipping, Unloading, and Storage Requirements

GCL Topic	*Manufacturing, Unloading, and Storage Standards*
Manufacturing	• Verify that needle-punched nonwoven geotextiles were continuously inspected for broken needles using metal detectors and found to be needle-free. • Use magnets or other methods to remove broken needles from GCLs in contact with geomembranes. • Ensure that overlap alignment lines are marked on the top side of the GCL as an installation aid. • Label GCL rolls with the manufacturer’s name, product identification, roll and lot number, roll dimensions, roll weight, and any other information which is necessary to trace the quality assurance documentation. • Wrap GCL rolls around cores that are structurally sound to prevent excessive bending or buckling during handling. • Cover finished rolls with a water proof, tightly fitting, weatherproof wrapping in preparation for shipment. GCL rolls must be stored indoors prior to shipment to the site.
Damaged Product	If at any time from manufacture to: storage, shipment, unloading, or on-site storage the weatherproof wrapping covering the GCL rolls is damaged and the outer portions of the GCL becomes wet or partially hydrated. • Remove the damaged portion of GCL. • Recover the remainder of the roll tightly with weatherproof wrapping.
Unloading	For off-loading and on-site delivery, use a: • crane or front-end loader fitted with a sling and center rod, which is pushed through the core around which the GCL is rolled, or • forklift with a “stinger,” or other equipment that does not damage the GCL rolls.
Storage	• Store GCL rolls on a platform or otherwise elevated off the ground and covered with a tarp to preclude moisture intrusion while awaiting deployment. We recommend that storage be in an enclosed building or closed shipping trailer if possible. • Do not stack the rolls higher than recommended by the manufacturer to protect thinning of the bentonite at contact points.

4.4. Installation and Repairs

Procedures for the installation and repairs of GCL are summarized in Table 4–3.

Table 4–3: GCL Installation and Repair Requirements

GCL Installation and Repair Topic	*GCL Installation and Repair Requirements*
Surface Preparation	• Do not place GCL directly over: o rough or uneven surfaces, o surfaces with protrusions or ruts, or o soil with particle sizes > than 3/4-inch (or as recommended by the manufacturer if < than 3/4-inch). • Roll the soil surface with a flat-wheel roller. • Maintain the soil surface in a smooth, uniform, and compacted condition prior to GCL placement. • Maintain adequate drainage of the soil surface until GCL installation is complete.
Installation Activities	Handling • Prohibit installation personal from smoking or from wearing damaging shoes when working on GCL. • Avoid dragging of the geotextile or bentonite facing of the GCL on the subgrade. • Do not use deployed GCL as a work area unless a protective tarp, rub sheet, or other protective covering is placed over the GCL. • Do not store generators, gasoline or solvent cans, tools, or other supplies directly on GCL. Deployment • Install GCL panels with the proper side up. • Avoid entrapment of stones, trash, or other debris beneath or within the GCL that may cause damage to the GCL or overlying geomembrane, if applicable. • Place-by-hand, or by using light equipment with low contact pressure rubber tires (e.g. smooth-tired ATVs or golf carts), over other geosynthetics. • Cover GCLs that are single geomembrane-backed with a second geomembrane on the bentonite side to prevent hydration of the bentonite. • Reinforce GCLs on slopes steeper than 7H:1V (e.g. lock stitched or needle punched) to provide adequate internal shear resistance. • Unroll GCLs on side slopes in the direction of the slope. • Anchor GCLs at the top of the slope, and then unroll working down to keep the material free of wrinkles and folds.

GCL Installation and Repair Topic	*GCL Installation and Repair Requirements*
	• Do not allow horizontal seams on slopes steeper than 7H:1V. Overlap and Bonding • Overlap each panel in the match lines on both edges of the GCL (at least 6 to 12 inches depending on the manufacturer). • Physical bonding, such as sewing or gluing of the panels edges during placement is not required. o Needle punched manufactured GCLs, however, do normally require dry granular bentonite in the lap-joints between the panel edges. o Ensure a joint essentially as impermeable as the GCL itself, where bentonite enrichment in the lap-joints is required. Use, at least 1/4-lb dry bentonite per linear foot of lap joint (or as recommended by the manufacturer) to produce. o Use the same type of bentonite in the lap-joint as used in the manufacture of the GCL. o Only use other lapping materials with prior approval. Inspect • Ensure deployed GCL panels contain no folds or excessive slack. • Inspect the installed GCL surface to ensure that no stones, cutting blades, tools, or other objects that may damage the GCL are present prior to covering.
Equipment on GCL	• Avoid rutting of the subgrade by carefully selecting appropriate equipment to deploy GCL over soil. • Prohibit vehicular traffic (other than low contact pressure vehicles such as smooth-tired ATVs or golf carts) on the deployed GCL.
Weather	• Avoid placing the GCL in the rain or at times of impending rain. • Avoid placing GCL during excessive winds (especially non-woven GCLs that require dry bentonite between the overlaps). • Remove and replace with new GCL material if the bentonite material becomes partially hydrated prior to being covered. • Anchor installed GCL with sandbags or other appropriate devices to prevent uplift by wind prior to covering. • Cover GCLs on the same day as they are placed with a geomembrane or with other liner system components as required by the design to prevent hydration due to weather conditions.
Repairs	GCL Repairs using Geotextiles • Patch torn or otherwise damaged geosynthetic facing (with no loss of bentonite from the GCL) with the same type of geosynthetic.

GCL Installation and Repair Topic	*GCL Installation and Repair Requirements*
	• Adhere or heat-bond the geosynthetic patch to the main GCL to avoid shifting during backfilling; the patch must extend at least 12 inches beyond the damaged area. GCL Repairs using GCL • If the GCL damage includes loss of bentonite, the patch must consist of full GCL extending at least 12 inches beyond the damaged area. • Follow the same lapping procedures specified for original laps of GCL panels.

4.5. GCL Testing Requirements

The testing requirements for GCL are summarized in Table 4–4.

Table 4–4: GCL Testing Requirements

GCL Testing Topic	*Testing Requirements*
QA/QC Testing	• The tests, testing frequencies, and testing methods are described in this table and are summarized in Appendix B, Table B-3. • Oversee (POR or QET) quality control testing of GCL products – these tests are generally performed by: (1) the supplier of the various components (bentonite, geotextile, and geomembrane), (2) the GCL manufacturer, and (3) a third-party independent laboratory.
Testing Results	Verify that all test results meet the GCL manufacturer's criteria and the values provided in Table 4–1: Required Properties for a GCL.
Lap Joint Permeability	• Demonstrate that the overlap procedure produces a lap joint essentially as impermeable as the GCL itself. • Re-verify the lap joint permeability through testing if any of the component materials change. o We also recommend that the lap joint permeability be periodically retested (as determined by the POR) to account for any small variations in the GCL materials that may occur over time. • Complete lap joint testing as part of the conformance testing, if lap joint permeability testing on the material used has not been done or is not valid.

GCL Testing Topic	*Testing Requirements*
Direct Shear Testing	• Conduct direct shear testing on hydrated GCL (for GCL which is not "sandwiched" between geomembranes) – include: (1) internal shear and (2) shear between GCL and underlying or overlying material (such as soil, geomembrane, geosynthetic material, etc.). • Conduct the direct shear testing with site-specific materials for the initial liner area. o The direct shear testing does not need to be repeated for subsequent areas unless any of the component materials (such as either GCL or adjacent soil or geosynthetic) change. o If any of the component materials change, direct shear testing must be repeated with each material change. • Demonstrate adequate stability of the GCL on the constructed slopes with the minimum strength parameters obtained in the direct shear testing.

4.6. Slope Stability Analysis

Conduct a slope stability analysis regardless of the type of GCL used. Conduct the stability analysis as part of one of these:

1. Site development plan (SDP).
2. LQCP.
3. Liner evaluation reports.

Use your slope stability analysis to verify the stability of the GCL and adjacent slope components on slopes steeper than 7H:1V under hydrated conditions (or non-hydrated conditions if hydration is prevented through double-siding the bentonite with geomembrane).

5. Leachate Collection Layer

5.1. Granular Material

Use clean, granular soil to construct your leachate collection layers. Unless specified otherwise in your SDP, granular soils in leachate collection layers should have permeabilities no less than 1×10^{-2} cm/sec. Material placed in contact with the geomembrane or GCL material should have a maximum particle size as indicated in Table 2–2. Granular material placed around collection pipes must have grain size compatible with the size of the holes in the collection pipes.

5.1.1. Installation

Place and spread granular materials using equipment and methods to minimize generation of fine particles. Granular materials should not be compacted, other than what is incidental to the placement and spreading process.

Materials placed over geomembrane or GCL (or other geosynthetics) should be placed as described in Table 2–2.

5.1.2. Granular Material Testing

Use an independent laboratory to conduct quality assurance testing on granular soils. Conduct testing at a frequency of 1 test per 3,000 yd^3 of material placed for:

- Grain size analysis (ASTM D422).
- Permeability (ASTM D2434).
    - Permeability testing requirements can be waived if it can be shown through correlation with the grain size analysis that the material easily meets the permeability criteria.

Conduct all tests on material after placement to allow for any grain size reduction, which may occur during the placement process.

To pre-qualify material prior to use, you can test the granular material at its source for grain size (and permeability, if necessary). However, you will still need to conduct post-placement testing as required.

Test granular material used in leachate collection layers for calcium carbonate content (using J&L Test Method S-105-89, ASTM D3042, or other appropriate method). The calcium carbonate testing can be conducted by the supplier or an independent laboratory. The measured calcium carbonate content must not exceed 15 percent.

If chimney drains are not provided through the protective cover to the leachate collection system, then you must conduct permeability tests to verify a permeability no less than 1×10^{-4} cm/sec.

The thickness of granular leachate collection and protective cover layers should be verified at a frequency of one verification point per 5,000 ft^2.

5.2. Geocomposite Material

In this document the term geocomposite material refers to a geonet with a geotextile bonded on one or both sides. Geonets are combined sets of parallel ribs positioned in layers such that liquid can be transmitted within their open spaces. Open space exists both in the plane of the geonet (above or under the parallel sets of ribs) and cross plane to the geonet (within the apertures between adjacent sets of ribs). Geonets always function with either geomembranes or geotextiles on their two planar surfaces. Geotextiles are typically bonded to the geonet by heat fusing or by using an adhesive.

Geosynthetic material (i.e. geocomposite, geonet, and geotextiles) used in leachate collection layers must have the transmissivity and other properties as specified in the SDP.

5.2.1. Installation

Follow the installation procedures for geocomposite material as described in Chapter 6 of the U.S. EPA Technical Guidance Document "Quality Assurance and Quality Control for Waste Containment Facilities" (EPA/600R-93/182, September 1993). The document is available for download at <cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=124793>.

5.2.2. Geocomposite Testing Requirements

QA/QC testing required for geocomposite drainage material can be found in Appendix B, Table B-4.

We recommend that you test your geonet, geotextiles, and geocomposite material to ensure that they meet the design requirements provided by the facility.

Quality control certificates from the manufacturer should include proper identification of the product, style, and results of quality control tests. The manufacturer's test results for geocomposite materials should be checked and verified by the POR or QET to meet the minimum requirements for these materials established by the SDP.

6. Liners Constructed Below the Seasonal High Water Table

6.1. Seasonal High Water Table Determination

Per 30 TAC 330.339(b)(2)(B), you are required to provide a determination of the seasonal high groundwater table as an attachment to your LQCP.

The seasonal high water table is the highest measured or calculated water level in an aquifer during investigation for a permit application or any groundwater characterization studies at a site. Groundwater level measurements used for the determination of the seasonal high water table should be performed through at least one cycle of seasonal change (usually a period of 8 months to 1 year) in order to ensure that seasonal variations of the groundwater table are considered.

Complete your assessment of the seasonal high water table as part of your permit application. Use the initial assessment as the basis for the liner and ballast design specified in your approved SDP.

You must adjust your seasonal high water table after your permit is granted, if additional data becomes available that indicates the seasonal high water table is higher than originally determined, as described 30 TAC 330.337(i). Your seasonal high water table may not be adjusted downward.

Additional data, which may be used in the upward revision of your seasonal high water table, could be obtained from water elevation readings from the groundwater monitoring wells, or from groundwater characterization studies performed as a basis of updating the groundwater monitoring system to meet the standards in Subtitle D of the Resource Conservation and Recovery Act (RCRA).

Reevaluate your seasonal high water table as part of each liner evaluation.

In the SLER for each new increment of liner construction include:

- A description of the seasonal high water table established in the SDP or previous SLER, as applicable.
- A summary of the groundwater data collected since the initial assessment in the permit application or previous SLER.
- An evaluation of whether the seasonal high water table must be adjusted upward on the basis of this data.
- An analysis of the changes required in liner design or ballast requirements as a result of the higher water table.

You should conduct additional field investigations at your site if you think that the existing data may be misleading or incomplete. Coordinate with staff at the TCEQ, MSW Permits Section to plan the scope of additional field investigations and for assistance developing a database to help you make an analysis of whether unbalanced hydrostatic forces could occur. The TCEQ, MSW Permits Section can be contacted at (512) 239-2335.

6.2. Demonstrating That the Liner Will Not Undergo Uplift

For Type I landfills, and Type IV landfills (if applicable), one of the methods listed in Table 6-1 must be used to demonstrate that the liner system will not undergo uplift from hydrostatic forces during construction.

As outlined in 30 TAC 330.337(b), provide a discussion to demonstrate that the liner will not undergo uplift. Include the method(s) and tests that will be used to verify that the liner will not undergo uplift during construction and until ballast placement (if applicable) is complete. You should include all associated information with your demonstration.

Table 6–1: Methods of Uplift Protection for Liners

Method	*Description*
Weight of Liner System	Provide calculations satisfactory to the ED that the weight of the liner systems, including any ballast, is sufficient to offset by a factor of 1.2 any otherwise unbalanced upward or inward hydrostatic forces on the liner.
Dewatering	Incorporate an active or passive dewatering system in the design to reduce upward or inward hydrostatic forces on the liner by a factor of 1.2 and by providing calculations satisfactory to the ED that the dewatering system will perform to adequately reduce those forces.
Poor Permeability of Surrounding Soil	Provide evidence satisfactory to the ED that the soil surrounding the landfill is so poorly permeable that groundwater cannot move sufficiently to exert force that would damage the liner.
Seasonal High Water Table Elevation	Provide evidence that the seasonal high water table is below the deepest planned excavation.

Design any required leachate collection system to handle both the leachate generated and the groundwater inflow from materials beneath and lateral to the liner system. Calculate the maximum volume of groundwater inflow based on determination of the permeability and potentiometric conditions of the liner system and of the materials surrounding the liner system.

6.3. Foundation Evaluation

Under 30 TAC 330.337(e), you are required to provide a preliminary foundation evaluation as an attachment to the LQCP, if applicable.

Perform a preliminary foundation evaluation prior to excavating any unit below the seasonal high water table. The foundation evaluation shall consider stability, settlement, and constructability.

6.4. Dewatering

Operate any dewatering systems used to ensure liner stability during construction and filling until the ED determines that such systems are no longer required.

6.5. Ballast

If ballast will be used, please ensure that the information provided in the LQCP will include the measures and tests that will be used to verify that any required ballast meets the criteria established, including, but not limited to, inspections, compaction, weight and density of material, thickness, and top elevations.

Per 30 TAC 330.337(f)(2), if waste will be used as ballast, you are required to include a discussion regarding the use of waste as ballast as an attachment to the LQCP. Please ensure that your discussion demonstrates that:

- The first five feet or the total thickness of the ballast, whichever is less, placed on the liner system will be free of brush and large bulky items, which would damage the underlying parts of the liner system or which cannot be compacted to the required density.
- A wheeled compactor having a minimum weight of 40,000 pounds, or equivalent equipment, was properly used to reach a compaction density of at least 1,200 pounds per cubic yard.
    - For purposes of determining the required ballast thickness, a density of compacted waste of 1,200 pounds per cubic yard was used.
    - The weight of the liner system, including any ballast, is sufficient to offset any unbalanced upward or inward hydrostatic forces on the liner by a factor of 1.5 when waste is used for ballast.
- The method(s) to be used to verify that compaction of waste used for ballast is to a density of not less than 1,200 pounds per cubic yard. If a compactor having a minimum weight of 40,000 pounds is used, no compaction density verification will be required.

- Verification that a compactor having a minimum weight of 40,000 pounds was used or, if not, that compaction was at least 1,200 pounds per cubic yard.

Submit a ballast evaluation report if ballasting or dewatering is used. Submit a ballast evaluation report in duplicate to the ED when you determine that ballasting or dewatering is no longer necessary. If the ED provides no response within 14 days of the date of receipt, you may discontinue dewatering or ballasting operations.

Your ballast evaluation report should include:

- Verification that the liner did not undergo uplift during construction, using the method identified in the LQCP.
- Certification that ballast met the criteria established in this section and in the LQCP.
- Signature and seal of an independent licensed professional engineer performing the evaluation and signature of the facility operator or their authorized representative.

7. Documentation and Reporting

7.1. Liner Evaluation Report

All liner QA/QC testing must be performed in conformance with the LQCP as required by 30 TAC 330.339(a). The data must be submitted as a Liner Evaluation Report (LER), which may be a soil Liner Evaluation Report (SLER), Geosynthetic Clay Liner Evaluation Report (GCLER), or Geomembrane Liner Evaluation Report (GLER), depending on the type of liner construction.

The limits of all constructed liners, including the most recent covered by the current evaluation, must be clearly marked with the placement of red-colored markers. These markers must be readily discernible by site workers and site inspectors, and be maintained at all times during the active disposal operations within the area and may be removed as needed to facilitate operations upon approval of subsequent LER areas. The LER markers must be tied into the master site grid system for reference and shall not be placed through the constructed liner.

Each LER must include a clear and legible site map. The site map may be a print from a master drawing which is annotated and updated with each new submittal. Your site map must depict:

- The area covered by all previous LER submittals with the dates of acceptance by the TCEQ noted on the map.
- Fill layout plan for each sector.
- Filled area.
- Present active area.
- Area covered by the current submittal.
- The grid system of your site.
- Graphic scale.
- North arrow.

Additional LER requirements are outlined in Table 7-1.

Table 7-1: Additional LER Requirements

Additional LER Requirement	*Construction Elements this Applies to*
All field and laboratory test documentation for liner soils and test and sample locations plotted on a location plan.	SLER
All test documentation for leachate collection and protective cover layers.	SLER GCLER GLER
If the liner includes a geomembrane, manufacture's certifications, documentation of all manufacturer's and independent testing, seaming and repair records, seam tests, and a site map showing locations and panels, repairs, and tests.	GLER
If the liner includes a GCL, documentation of all manufacturer's and independent materials tests, manufacturer's certifications, stability analyses (if required), and a site map showing panel layout.	GCLER
Manufacturer's certification and testing documentation for all geosynthetics.	SLER GCLER GLER
A survey documentation of the thickness of the soil liner, leachate collection, and protective cover layers.	SLER GCLER GLER

The POR or QET should supervise all field sampling and testing of components of the liner and its construction to ensure standards and requirements are followed.

The POR or QET must review the results of all field and laboratory testing of the liner and its construction for conformance to the approved LQCP.

Any completed lined area that fails to meet the minimum specified conditions of the required tests must be reworked or reconstructed to achieve the required results. Inability to achieve the required results through reworking is cause for rejection of the area in question.

Retest all reworked areas to prove adequacy to meet all the applicable requirements.

Per 30 TAC 330.341(b) and (c), no area may be used for the receipt of solid waste until the TCEQ has given confirmation of its acceptance of the LER or fourteen days from the date(s) of arrival of the LER at the TCEQ, MSW Permits Section, have lapsed.

We recommend that you call the MSW Permits Section prior to use of the area in question if confirmation of acceptance has not been received and you believe that the fourteen-day review period has lapsed.

7.2. Interim Status Report

Submit an interim status report for portions of the liner that remain uncovered with waste for more than six months from the date that the protective cover was applied. Liner surfaces not covered within six months shall be reevaluated by a geotechnical professional who shall then submit a letter report on the findings to the TCEQ, MSW Permits Section. Any required repairs shall be performed promptly. A new report shall be submitted on the new construction for all liners that need repair due to damage.

7.3. Ballast

Liners constructed below the groundwater table require several elements of evaluation and quality assurance beyond the basic requirements of the LER. Most of these additional documentation and evaluation activities are performed: (1) before construction, as part of the liner design, or (2) at the same time as the monitoring for the clay liner construction.

We recommend that you include these activities in the LER to avoid duplication in reporting requirements. The documentation and evaluation activities for liners constructed below the groundwater table include:

- Summary of soil stratigraphy and properties of soils exposed on the bottom and sidewalls of the area being lined.
- Adjusted seasonal high water table, based on the SDP data, groundwater monitoring well data, or other data.
- Calculation of ballast required, and type of ballast used (soil or waste).
- Discussion of whether subgrade required an underdrain system or other dewatering method, using criteria established in the SDP and LQCP.
- Method of controlling uplift forces during construction (low-permeability foundation soil, dewatering, or combination).
- Monitoring of dewatering system to demonstrate that hydrostatic forces did not develop during liner construction.
- Pre-construction and top-of-liner evaluations of the liner, and confirmation of liner weight. The survey elevations must be performed at the frequency you provided in the LQCP.

7.3.1. Soil as Ballast

If you use soil as ballast, place it immediately after liner or leachate collection system construction.

If soil ballast is placed directly on a clay liner (for sites where no geomembrane is required), the as-built ballast density and thickness should be included with the SLER.

If soil ballast is to be placed on the composite liner system, include a statement in your SLER that the ballast will be documented in the GLER, which will document the as-built density and thickness of the soil ballast.

The soil ballast thickness should be surveyed at the same frequency required in the LQCP for the liner.

7.3.2. Waste as Ballast

We must approve your GLER first before you can use waste for ballast.

After your GLER is approved, submit a follow-up Ballast Evaluation Report (BER) (Form TCEQ-10072). Submit the BER after sufficient ballast is in place to demonstrate adequate uplift resistance against the long-term seasonal high groundwater level for a given waste cell, sector, or LER area. Include documentation in your BER to:

1. Verify the weight of the compactor used to compact the waste.
    a. If the compactor weighed at least 40,000 pounds, attach a certification from the owner that their compactor was used during the entire period of placing the waste ballast.
    b. If a compactor weighing less than 40,000 pound was used, include calculations to show that the in-place density of waste is not less than 1,000 pounds per cubic yard. These calculations must include the following:
        1. Initial survey of the area to receive waste as ballast;
        2. Final survey and calculated volume of waste placed as ballast, and
        3. Weight of waste placed, based on actual measurements of truck weights at the scale-house.
2. Certify the type of waste placed in the lower 5 feet. Provide documentation from the facility owner.
3. Demonstrate that the top of waste thickness calculated in the LER has been met.
4. Show that any dewatering system used to lower the groundwater level during liner construction was in effect throughout the completion of the ballast placement.
5. Validate that groundwater level measurement and pneumatic/vibrating wire piezometer measurements to demonstrate that hydrostatic heads did not exceed the allowable values.

8. References

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Appendix A—Glossary

American Society for Testing and Materials (ASTM) — An organization of industry professionals that develops voluntary testing standards.

Atterberg Limits — a series of six “limits of consistency” of fine-grained soils defined by Swedish soil scientist Albert Atterberg, two of which are frequently used today to establish a soil's physical boundaries dealing with its plasticity characteristics. These soil boundaries or limits used most frequently in geotechnical engineering are based upon the following:

> ***Liquid Limit (LL)*** — the percentage of moisture in a soil, subjected to a prescribed test that defines the upper point at which the soil's consistency changes from the plastic to the liquid state.
>
> ***Plastic Limit (PL)*** — the percentage of moisture in a soil, subjected to a prescribed test that defines the lower point at which the soil's consistency changes from the plastic to the semi-solid state.
>
> ***Plasticity Index (PI)*** — the numerical difference between the LL and the PL of a fine-grained soil that denotes the soils plastic range. The larger the PI the greater a soil's plasticity range and the greater it's plasticity characteristics.

Coefficient of Permeability (also referred to as Hydraulic Conductivity) — the amount of flow per unit of time through soil under unit hydraulic gradient at standard temperature.

Compactive Effort — the amount of compaction energy held constant, and usually transferred into a soil sample with a compaction hammer device, used on soil samples in various laboratory test procedures to establish a soil's density at various moisture contents.

Constructed Soils Liner — soil liner constructed from reworked in-situ soil, soil from a borrow source, or bentonite-amended soil.

Construction Quality Assurance (CQA) — a planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design (EPA, 1993).

Construction Quality Control (CQC) — a planned system of inspections that is used to directly monitor and control the quality of a construction project (EPA, 1993).

Field Permeability Test — a field test performed on a constructed liner or in-situ soils to determine the in-place coefficient of permeability and usually performed as a Sealed Double Ring Infiltrometer Test (SDRI), or series of Boutwell field tests. This type of permeability test method is usually considered to have greater accuracy due to the area tested and the existing field conditions that may be obscured by a laboratory testing environment.

Film Tear Bond (FTB) — a failure in the geomembrane sheet material on either side of the seam and not within the seam itself.

Fish Mouth — a semi-conical opening of the seam that is formed by an edge wrinkle in one sheet of the geomembrane.

Geomembrane Liner — an essentially impermeable geosynthetic composed of one or more synthetic sheets. See HDPE.

Geomembrane Liner Evaluation Report (GLER) — a stand-alone as-built report prepared per the methods and procedures contained in the approved SLQCP that details the installation and testing of the geomembrane.

Geomembrane Stratified Sample — a randomly selected sample location within each 500 linear-foot interval.

Geosynthetic Materials — manufactured or man-made materials that include geomembranes, geogrids, geofilters, geocomposites, geonets, and geotextiles.

Gradation — see Sieve Analysis.

Geosynthetic Research Institute (GRI) — located at Drexel University, the GRI conducts research with geosynthetic materials and develops industry testing standards for these materials. This institute is supported by many geosynthetic manufacturers, installers, and raw materials suppliers to the industry.

High Density Polyethylene (HDPE) — a polymer prepared by low-pressure polymerization of ethylene as the principal monomer and having the characteristics of ASTM D1348, Type III and IV polyethylene. Such polymer resins have densities greater than or equal to 0.941 g/cc as noted in ASTM D1248.

In-Situ Liner — soil liner consisting of in-situ soils that do not exhibit primary or secondary physical features, and meet all physical and quality control testing requirements of the MSWR, and are found acceptable by the Commission.

In-Situ Soil — soil that is in place and has not been disturbed through excavation and recompaction.

Independent Testing Laboratory — a laboratory that is independent of ownership or control by the permittee or any party to the construction of the liner or the manufacturer of the liner products used.

Liner Quality Control Plan (LQCP) — an approved plan that is prepared under the direction a registered professional engineer and is the basis for the construction/installation and testing of soils or flexible membranes materials for liners.

Manufacturing Quality Assurance (MQA) — a planned system of activities that provides assurance that the raw materials were constructed (manufactured) as specified.

Manufacturing Quality Control (MQC) — a planned system of inspection that is used to directly monitor and control the manufacture of a material.

Moisture/Density Relationship — a test in which soil samples are compacted in a known volumetric container at various moisture contents at a constant level of compactive effort and their corresponding densities are determined. The test procedures and compactive efforts used are those normally prescribed in ASTM D698 and D1557. These tests are frequently designated the Standard Proctor and Modified

Proctor compaction tests named after M. M. Proctor, the early developer of these test procedures for the determination of density control on compacted soil fills.

Municipal Solid Waste Regulations (MSWR) — the TCEQ regulations that govern Municipal Solid Waste Management, as published in the Texas Register.

Permeability — see Coefficient of Permeability.

Permeant Fluid — fluid used in a laboratory coefficient of permeability test and limited to tap water or 0.05 Normal solution of $CaSO_4$. Distilled water shall not be used in these test procedures.

Professional of Record (POR) — a professional engineer registered in the state of Texas who possesses professional experience in geotechnical engineering, construction oversight, geosynthetics, and soil testing, or a graduate geologist who has a minimum of four years of experience in engineering geology and is experienced in geotechnical testing and its interpretations. Note: All references to the Geotechnical Professional, Geotechnical Quality Control/Quality Assurance Professional, Professional of Record, etc., within the context of this document and the MSWR are interchangeable and are therefore synonymous.

Qualified Engineering Technician (QET) — a representative of the POR who is NICET-certified in geotechnical technology at level 2 or higher or certified through the Geosynthetic Certification Institute's Inspectors Certification Program (GCI-ICP), an engineering technician with a minimum of four years of directly related experience, or a graduate engineer or geologist with one year of directly related experience.

Representative Sample — a representative sample of geomembrane material consists of one or more specimens (commonly referred to as coupons) from the same rectangular portion of geomembrane material, oriented along a seam that is removed for field or laboratory testing purposes.

Sieve Analysis — a laboratory soil test consisting of placing a known weight of soil sample through a series of wire mesh sieves stacked upon each other in successively smaller mesh size and used to determine the percentage size gradation of the sample.

Soil Liner Evaluation Report (SLER) — a stand-alone, quality control test report prepared per the methods and procedures contained in the approved LQCP that details the installation and testing of the soil liner.

Soil Test Series — tests performed to determine a soil's physical characteristics and to document its ability to satisfy the soil liner MSWR requirements. These tests include sieve analysis (gradation), Atterberg Limits, moisture/density, and coefficient of permeability.

Specimen — with respect to geomembrane destructive testing, a specimen is an individual test strip (sometimes called coupon) from a sample location. A sample location usually consists of many specimens.

Appendix B—Recommended Tests for MSW Liner Systems

Table B–1: Standard Tests for Soils

Soil Test Category	*Type of Test*	*Standard Test Methods*[a]	*Minimum Frequency of Testing*[b]
Borrow Source Materials	Unified Soil Classification	ASTM D2487	One per soil type
	Moisture/Density Relationship	ASTM D698 or D1557	
	Sieve (gradation)	ASTM D422 or D1140	
	Atterberg Limits	ASTM D4318	
	Coefficient of Permeability	ASTM D5084 or CoE EM1110-2-1906	One per Moisture/Density Relationship
In-Situ Liners	Sieve (gradation)	ASTM D422 or D1140	One per 50,000 ft^2, per foot thickness of liner
	Atterberg Limits	ASTM D4318	
	Coefficient of Permeability (laboratory)	ASTM D5084 or CoE EM1110-2-1906	
	Coefficient of Permeability (field)	ASTM D5093 or D6391	One SDRI test or one Boutwell series[c] per 50,000 ft^2
	Thickness	Auger	One per 5,000 ft^2
Constructed Soil Liners	Field Density	ASTM D1556, D2167, or D6938	One per 8,000 ft^2 per 6-inch parallel lift; one per 100 lineal ft per 12-inch sidewall horizontal lift
	Sieve (gradation)	ASTM D422 or D1140	One per 100,000 ft^2 per 6-inch parallel lift; one per 2,000 lineal ft per 12-inch sidewall horizontal lift
	Atterberg Limits	ASTM D4318	
	Permeability	ASTM D5084 or CoE EM1110-2-1906 (laboratory) Air Entry Permeameter (field)	
	Thickness	Registered Surveyor or Professional Engineer	One per 5,000 ft^2 (parallel lifts); 50-ft cross sections (horizontal-lift sidewall liners)

[a] The POR may propose equivalent or better tests.
[b] For liners, a minimum of one test must be conducted for each lift, regardless of liner area or length.
[c] One Boutwell series includes 5 test holes.

Table B–2: Standard Tests for Geomembranes

Test Category	*Type of Test*	*Standard Test Methods* [a]	*Frequency of Testing*
Resin	Specific Gravity/Density	ASTM D792 or D1505	One per 100,000 ft^2 and every resin lot
	Melt Flow Index	ASTM D1238	
Geomembrane Manufacturer	MQC	Testing per GRI Test Method GM13[b]	Testing per GRI Test Method GM13
Conformance Testing by Third-Party Independent Laboratory	Thickness	ASTM D5199 (smooth), D1593 (Textured), or D5994 (Textured)	One per 50,000 ft^2 and every resin lot
	Specific Gravity/Density	ASTM D792 or D1505	One per 100,000 ft^2 and every resin lot
	Carbon Black Content	ASTM D1603	
	Carbon Black Dispersion	ASTM D5596	
	Tensile Properties	ASTM D638[c] or D6693	
Destructive Seam Field Testing	Shear	ASTM D4437 or D6392	Varies for field, lab, and archive
	Peel	ASTM D4437	
Non-destructive Seam Field Testing	Air Pressure	GRI GM-6 or ASTM D5820	All dual-track fusion
	Vacuum	ASTM D4437 or D5641	All non-air-pressure-tested seams when possible

[a] The POR may propose equivalent or better tests.

[b] UV resistance testing not required for HDPE that will be immediately covered.

[c] Break elongation calculated using 2–inch initial gauge length.

Table B–3: Standard Tests for GCL Material

Entity Performing Test	*Test*	*Type of Test*	*Standard Test Methods*[a]	*Frequency of Testing*
Supplier or Manufacturer	Bentonite[b]	Free Swell	ASTM D5890	One per 50 tons and every truck or railcar
	Bentonite[c]	Fluid Loss	API 13B or ASTM D5891	
	Geotextile	Mass/Unit Area	ASTM D5261	One per 200,000 ft^2
		Grab Tensile Strength	ASTM D4632	
	Geomembrane	Mass/Unit Area[d]	ASTM D5261	One per 200,000 ft^2
		Thickness (smooth)	ASTM D5199	
		Thickness (textured)	ASTM D5994	
		Tensile Properties	ASTM D638 or D6693	
Manufacturer	GCL Product	Bentonite Mass/Unit Area	ASTM D5993	One per 40,000 ft^2
		Bentonite Moisture Content	ASTM D2216, D4643, or D5993	
		Tensile Strength[e]	ASTM D6768	One per 200,000 ft^2
		Grab Tensile Strength[f]	ASTM D4632	
		Permeability[g]	ASTM D5084, D5887, or D6766	One per week for each production line[h]
		Lap Joint Permeability	Flow box or other suitable device	One per material and lap type
Independent Laboratory (conformance testing)	GCL Product	Clay Mass/Unit Area	ASTM D5993	One per 100,000 ft^2
		Permeability[i]	ASTM D5084, D5887, or D6766	
		Direct Shear[j]	ASTM D5321 or D6243	One per GCL/adjoining material type

[a] The POR may propose equivalent or better tests.

[b] Test to be performed on bentonite before incorporation into GCL.

[c] Test to be performed on bentonite before incorporation into GCL.

[d] May be calculated using density and thickness of geomembrane.

[e] Not applicable for geomembrane-backed GCL. Manufacturer of geomembrane-backed GCL must, however, certify that product will meet required permeability standards based on prior testing.

[f] See footnote d.

[g] May also be done as conformance testing.

[h] Report last 20 permeability values, ending on production date of supplied GCL.

[i] Test at confining/consolidating pressure simulating field conditions for ASTM D5084. Permeability test not applicable for geomembrane-backed GCL which is installed geomembrane side down and covered with second geomembrane. Permeability test on geomembrane-backed GCL must be done with geomembrane backing removed and may be done at a reduced frequency (one per 200,000 ft^2 to 300,000 ft^2).

[j] Not applicable for slopes of 7H:1V or flatter. Testing must be on material in hydrated state unless GCL is to include geomembrane on both sides of GCL, and must use strain rates, confining pressures, and other parameters which simulate field conditions.

Table B–4: Standard Tests for Geocomposite Material

Test Category	*Product*	*Test* [a]	*Test Method* [b]	*Testing Frequency*
Manufacturer	Resin (geonet)	Density	ASTM D792 or D1505	One test per 100,000 ft^2 and every resin lot
		Melt Flow Index	ASTM D1238	
Manufacturer	Geonet	Density	ASTM D792 or D1505	One test per 100,000 ft^2 and every resin lot
		Mass/Area	ASTM D5261	
		Thickness	ASTM D5199	
		Compression	ASTM D1621	
		Transmissivity	ASTM D4716	
Manufacturer	Geotextile	Mass/Area	ASTM D5261	One test per 100,000 ft^2 and every resin lot
		Grab Tensile Strength	ASTM D4632	
		Trapezoidal Tear Strength	ASTM D4533	
		Burst Strength	ASTM D3786	
		Puncture Strength	ASTM D4833	
		Thickness	ASTM D5199	
		Apparent Opening Size	ASTM D4751	
		Permittivity	ASTM D4491	
Independent Laboratory	Geocomposite Product	Transmissivity	ASTM D4716	One test per product type
		Interface Shear or Ply Adhesion	ASTM D5321 or D413	One test per project

[a] Adapted from EPA/600/R-93/182, September 1993, and *Designing with Geosynthetics*, 6th ed.

[b] The POR may propose equivalent or better tests.