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TEXAS NATURAL RESOURCE CONSERVATION COMMISSION

MUNICIPAL SOLID WASTE DIVISION

Liner Construction and Testing Handbook
Published in Accordance with §330.6
Municipal Solid Waste Regulations
(30 Texas Administrative Code, Chapter 330)

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TNRCC

In keeping with Section §330.6 of the Municipal Solid Waste Regulations (MSWR), the Texas Natural Resource Conservation Commission (TNRCC) has developed this Handbook for assistance in fulfilling the requirements of Sections §330.205 and §330.206. This Handbook is provided as a suggested minimum level of construction control and testing for various types of low-permeability liners to effect ground-water protection. It is not intended to be rules or policy and does not include all acceptable practice. It is also recognized that on-going research and experience in the design and construction of low-permeability liners may eventually prove superior to suggestions detailed herein.

This Handbook therefore is intended for assistance to the regulated community, as a stand alone document such that it may be adopted simply by reference as the Soils and Liner Quality Control Plan (SLQCP) for the Permittee.

TABLE OF CONTENTS

GLOSSARY

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) - One of the largest, professionally recognized voluntary standards development systems in the world.

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 (aka 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 LINERS - Soils liners constructed from reworked in situ soils, soils from a borrow source, or bentonite-amended soils.

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 inplace 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.

FLEXIBLE MEMBRANE LINER (FML) or geomembrane liner. - An essentially impermeable geosynthetic composed of one or more synthetic sheets. See HDPE.

FMLER or FLEXIBLE MEMBRANE LINER EVALUATION REPORT - A stand-alone as-built report prepared in accordance with the methods and procedures contained in the approved SLQCP that details the installation and testing of the FML.

FML STRATIFIED SAMPLE - A randomly selected sample location within each 500-linear-foot interval.

GEOMEMBRANE - See FLEXIBLE MEMBRANE LINER.

GEOSYNTHETIC MATERIALS - Manufactured or man-made materials that include FMLs (geomembranes), geogrids, geofilters, geocomposites, geodrainage nets, and geotextiles.

GEOTECHNICAL PROFESSIONAL (GP) - A professional engineer registered in this state who possesses professional experience in geotechnical engineering and testing, or a graduate geologist who has a minimum of four years 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 handbook and the MSWR are interchangeable and are therefore synonymous.

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.

HDPE (HIGH DENSITY POLYETHYLENE) - 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 D 1248.

IN SITU LINERS - Soils liners consisting of undisturbed 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 SOILS - Undisturbed soils; the term routinely used in describing an in-place-soil liner.

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.

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 (M/D) 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 D 698 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 TNRCC 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. (§330.56(d)(5)(B)(ii), MSWR)

QUALIFIED ENGINEERING TECHNICIAN - A representative of the GP who is represented to be NICET-certified in Geotechnical Engineering Technology at level 1 or higher (must be level 2 for soils within one year of the date of this document for soils testing and within 2 years of the date of this document for FML testing), 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 FML material consists of one or more specimens (commonly referred to as coupons) from the same rectangular portion of FML 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.

SOILS AND LINER EVALUATION REPORT (SLER) - A stand-alone, quality control test report prepared in accordance with the methods and procedures contained in the approved SLQCP that details the installation and testing of the soil liner. (§330.206, MSWR)

SOILS AND LINER QUALITY CONTROL PLAN (SLQCP) - 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 and/or flexible membranes materials for liners. (330.205, MSWR)

SOIL BORROW SOURCE - Soils in which the Liquid Limit (LL) and Plasticity Index (PI) do not vary by 10 points. A soil that varies by 10 or more points from the originally-established LL or PI is considered as a separate soil source for the purpose of this handbook and requires a separate soils test series.

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 FML destructive testing). - A specimen is the individual test strip (sometimes called coupon) from a sample location. A sample location usually consists of many specimens.

CHAPTER 1 INTRODUCTION

1.1 General

All solid waste disposal, storage, and containment areas, including contaminated-water holding ponds, must be designed and constructed to prevent degradation of the existing surface water, subsoils, and ground-water quality through the exfiltration of leachate or contaminants from any particular waste cell, trench, or area. This can be achieved by constructing a liner system along with a leachate collection and removal system.

All references to MSWR pertain to the Commission's "Municipal Solid Waste Regulations."

1.2 Purpose

This handbook contains guidance for both in situ and constructed soils liners for both Type I and Type IV landfills. It's intent is to provide reasonable technical guidance for the construction quality assurance and reporting of liners as required for landfills in §§330.205 - 330.206, MSWR. This handbook is not intended to be written in the format of regulations, but is rather an attempt to detail and explain some of the suggested present-day methods of various types of liner construction such as soil liners from recompacted existing soils, or construction from a borrow source. This handbook includes opinions on the minimum requirements of soil liner quality control testing and evaluation as well as the placement and quality control testing of a Flexible Membrane Liner (FML) and, as such, covers the construction/installation and testing of soil and flexible membrane liners only.

This handbook does not address:

Alternate liner Construction Quality Control (CQC) and Construction Quality Assurance (CQA) for geosynthetic clay liners (GCL). This method of ground-water protection must have prior Commission approval during the permitting process (permit, permit amendment, or permit modification) and can be addressed on a site-specific basis.

Non-HDPE FML liners. High Density Polyethylene (HDPE) liners are the most requested form of FML to date in Texas. Certainly, other FML materials can be acceptable and much of the FML portion of this handbook is applicable with some variations. SLQCPs for non-HDPE FMLs will be considered on landfill-specific basis.

Leachate Collection and Removal Systems (LCRS). This topic is covered in a Municipal Solid Waste Division document entitled "Leachate Collection System Handbook".

The construction and testing of all liners must be in accordance with an approved SLQCP as required by §330.205, MSWR. It is strongly recommended that a copy of the current SLQCP be maintained on site at all times and be available for reference by the Commission's inspector and permittee's employees responsible for the construction or testing of the liner.

The quality control testing must be performed by an independent third party GEOTECHNICAL PROFESSIONAL (GP). (See definition).

1.3 Full-Time Quality Control/Quality Assurance

The GP or his representative should be on site for all liner construction and testing. One hundred percent of all nondestructive testing of seams for FMLs should be directly observed by the GP or his representative. The GP should be on site at least twice weekly and for all extraordinary construction events during all liner construction.

1.4 References

This handbook was developed from many sources including staff experience, various publications (a list of which can be found in Appendix I) and valuable input from experienced geotechnical professionals in the consulting community, academia, and other commission regulatory programs. Construction and testing guidelines stated here are the minimum considered necessary in order to meet the MSWR requirements for the protection of ground water in the state.

CHAPTER 2 SOIL LINERS

2.1 General

In situ soils (soils in place and not disturbed through excavation or 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 deposition 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 an FML, but in those cases where primary and/or secondary features which could adversely affect liner quality **do not** exist or where the executive director has approved corrective measures, the in situ soils may be considered as an alternative to constructed soil liners. Authorization to use these in situ soils in a Type I landfill will require a permit modification which includes a demonstration using the specific on-site soil and ground-water characteristics and computer modeling showing that the in situ soils will meet all the requirements for ground-water protection. Discovery of adverse primary and/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 a permit modification for an alternate liner.

All constructed soil liners must possess a coefficient of permeability no greater than 1×10^{-7}cm/sec, a liquid limit (LL) not less than 30, and a plasticity index (PI) not less than 15. The percent of soil fines passing the 200 mesh sieve must be at least 30%. All of the soil material must pass the one-inch sieve and shall not contain rocks or stones that total more than 10% by weight. The minimum thickness for any constructed soil liner is two feet for a composite liner and three feet for other constructed soil liners. **(§330.205(c)(6) and §330.205(h), MSWR)**

The landfill operator or consultant should contact the Ground-Water Protection Team Leader at the central office at least 48 hours prior to in situ liner evaluation or liner construction to afford Commission staff an opportunity to be on site during construction activity.

The sequence of development as approved in the Site Development Plan (SDP) on file with the Commission must be followed so that liner coverage in a landfill is developed in a fashion that minimizes contaminant migration beyond the constructed limits during filling and maximizes the operational life of the site. This sequence shall not be altered without an approved permit modification from the Commission.

The depth of excavation should be no deeper than that allowed within the SDP and should coincide with the bottom of the liner.

When the individual trench method (as opposed to the continuous trench method) is used, the dividing areas between trenches must be lined prior to placement of aerial fill.

Type IV landfills may consider the use of in situ soils under the same physical criteria that would find them acceptable for a Type I landfill.

2.2 Soil Liner Material Minimum Physical Requirements

Representative samples of the soils to be used for liners must first be tested, in accordance with the following standards, in a geotechnical laboratory to ensure that they meet the following minimum requirements set forth in the MSWR. Table I at the end of this handbook lists the required quality control testing and minimum requirements.

a. Sieve Analysis - ASTM D 422 or ASTM D 1140 - At least 30% passing the #200 mesh sieve.

b. Atterberg Limits - ASTM D 4318 - Liquid Limit (LL) of not less than 30 and a Plasticity Index (PI) of not less than 15.

c. Coefficient of Permeability - Appendix VII of the Corps of Engineers Manual EM 1110-2-1906 or ASTM D 5084 - 1×10^{-7}cm/sec. or less.

2.2.1 In Situ Soils

The presence of cracks, fissures, joints, fractures, bedding planes, and some other primary and/or secondary features which could adversely affect liner quality will disqualify an in situ liner even though laboratory testing indicates that the individual sample meets the specifications given above, unless the executive director approves corrective measures. In si soils may require field permeability testing during Quality Assurance (QA) evaluation to prove acceptability. These field permeability test methods are further discussed in QA for in situ soils in 2.4.1.

2.2.2 Soils for Constructed Liners

Moisture/Density (M/D) Testing

In addition to the minimum test requirements in 2.2, above, a moisture/density relationship must be determined for each soil borrow source to be used in soil liner construction. This moisture/density (M/D) compaction curve must include a zero-air-voids line based upon an estimated or measured Specific Gravity of the compacted soil. The two acceptable standard moisture/density relationship test procedures are:

a. ASTM D 698 (Standard Proctor) -- 12,400 ft-lbf/ft^3 [1](for light-weight equipment), or

b. ASTM D 1557 (Modified Proctor) -- 56,000 ft-lbf/ft^3 (for heavy equipment)

In order to determine that the proposed soil is suitable for use as liner material,

[1] The energy values assigned to each of these two test methods are the compactive efforts used in the soils laboratory to compact each test specimen.

permeability tests must be conducted on samples compacted under the above-listed compactive-effort test procedures. These soils shall be prepared and tested as next described.

Coefficient of Permeability Testing

Once moisture-content/density relationships have been determined for one or more compactive efforts, a soil sample should be compacted to approximately 95% of the maximum dry density at the optimum moisture content using ASTM D 698 or to approximately 90% of maximum dry density at a moisture content 1% drier than optimum using ASTM D 1557. An appropriate coefficient of permeability test should then be performed on this sample. The maximum acceptable coefficient of permeability of 1×10^{-7}cm/sec for any given soil sample must be demonstrated in the laboratory before the material is considered suitable for liner construction.

Once the acceptable coefficient of permeability is demonstrated through testing, the percent compaction and moisture content of the demonstration sample become the minimum standards for use in field control (The minimum standards, however, must not be less than 95% compaction at optimum moisture using ASTM D 698 or 90% compaction at a moisture content 1% dry of optimum using ASTM D 1557).

The permeant fluid for permeability testing must be: tap water, a 0.05N calcium sulfate solution, or captured ground water from the test boring where the soil samples are taken. **Distilled or deionized water is not acceptable as a permeant and shall not be used. (§330.56(d)(5)(B)(ii), MSWR)**

Test methods and all test data calculations must be provided in the Soil Liner Evaluation Report (SLER). Any deviation from the methods listed below must be fully justified and explained to the Commission and its permission granted prior to their use. These variations must also be noted and Commission authorization documented in the SLER.

The two acceptable laboratory test methods for determining the coefficient of permeability are as follows:

a. Falling head -- Appendix VII of the Corps of Engineers Manual EM 1110-2-1906 or ASTM D 5084.

b. Constant Head -- Appendix VII of the Corps of Engineers Manual EM 1110-2-1906 or ASTM D 5084

Note: Field permeability tests -- Alternate methods of testing for the coefficient of permeability by using field testing may be used for tests pads and are discussed later in 2.6.2 of this Section.

2.3 Soil Liner Construction Requirements

Considerable research has centered around the construction of soil liners of low permeability. Construction procedures used for highway subgrades, which are primarily concerned with achieving density controls, have proven to be inadequate to achieve the degree of low permeability required by present-day regulations. Closely-controlled construction a: testing methodologies must be used to achieve the level of ground-water protection requirea of soil liners.

The key elements of soil liner construction are: strong quality control, moisture content, degree of compaction, type and weight of compaction equipment, lift thickness, clod size, lift interface bonding, liner protection from desiccation, protection from ponded water, and conscientious maintenance after the liner is complete.

2.3.1 General

a. There should be no constructed liners parallel to side slopes with greater than a 3:1 slope angle (3 horizontal to 1 vertical) due to both the inherent lack of stability of the compaction equipment on these steep slopes as-well-as the compaction inefficiency.

It should be realized that soil liners constructed parallel to side slopes have inherent construction problems because the full compactive force of the compaction equipment is not perpendicular to the slope. The eccentric weight of the equipment (tendency to slide down the slope) may shear the upper portion of the lift under compaction near its surface. The overall uniformity of the processing and compacting effort on a slope is usually of lower quality than on an essentially-flat section. Accordingly, the large-scale hydraulic conductivity tests performed on a primarily-horizontal test pad will not be representative of the probable worst-case liner-construction conditions where slop liners are involved.

b. A keyway for constructed sidewalls is required unless alternate construction procedures have prior written approval by the executive director. The constructed keyway at the toe of the sidewall may be eliminated for those sidewalls constructed on a slope angle of 4:1 or flatter; those constructed with the floor as one unit (monolithically); or sidewalls placed in horizontal lifts a minimum of 10 ft. in width and having the first six inch lift of the sidewall completely bonded with the top of the floor liner.

c. Placement of constructed liners (clay-type material) should be in accordance with the following:

1. All surface areas should be properly scarified a minimum of six inches and prepared to receive the liner.

2. The top of each lift should be roughened to a shallow depth prior to the placement of the next lift of soil for compaction.

3. 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.

4. Equipment and safety limitations prohibit finished grades with slopes greater tr. 3:1 if the liner is constructed parallel to the surface. For an excavated wall with steeper

than 3:1 side slopes, the sidewall liner must be constructed in successive horizontal lifts.

5. 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.

6. It is recommended that the surface of a soil liner be proof rolled when construction is shut down for more than 24 hours to mitigate the effects of desiccation. It is further recommended that it be done on a routine basis during the summer months at the end of each day's liner construction.

7. It is recommended that all of the final lift of the soil portion of the composite liner pass the 3/8 inch sieve in order to minimize potential damage to the overlying FML.

2.3.2 Constructed Soil Liners

These constructed liners include those of over-excavated and recompacted in situ soils and soils from a borrow source. For additional specific information on bentonite-amended soils see Section 2.5.

2.3.2.1 <u>LINER TIE-IN</u>

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. It is strongly recommended **that either** of the following methods be followed:

a. The edge of the old section of liner shall be cut back on a slope so that the entire existing liner edge is tied to new construction without superimposed construction joints. (See Fig. 1.)

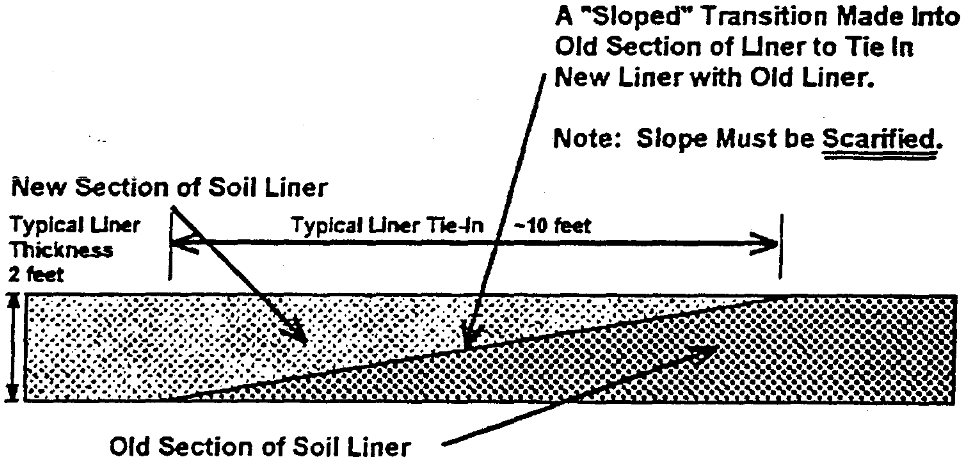

Figure 1. Constructed Soil Liner Tie-In Detail

b. The edge of the old section of liner shall be cut back on one-foot off-set layers (stair-step) so that each foot 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. (See Fig. 2.)

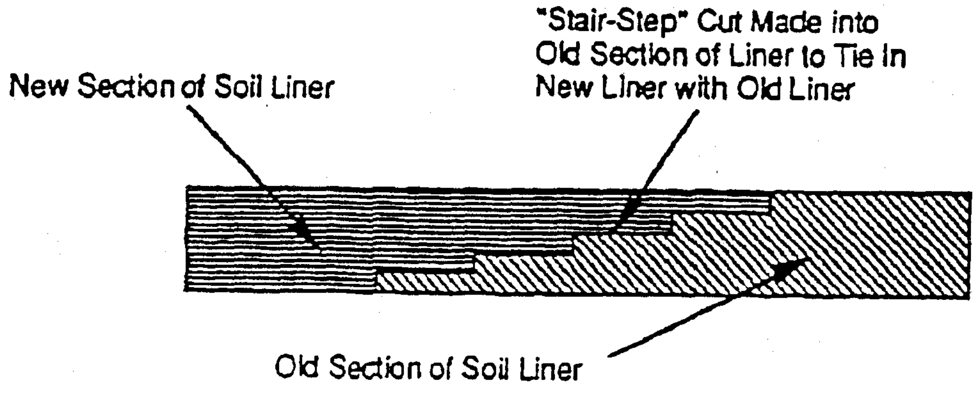

Figure 2. Constructed Soil Liner Tie-In Detail
(Adapted from EPA /600/R-93/182, September 1993 Technical Guidance Document)

2.3.2.2 Hydrating Liner Soil

The proper method of adding water to the liner soil cannot be overemphasized. Because of their cohesive nature, some clay soils are at best difficult to hydrate to the required moisture content necessary for compaction. Therefore, prior to adding water, clod size reduction should be completed through disking, pulverizing, possibly screening, etc. (It is recommended that a minimum of five passes of a disk or three passes of a pulverizer be made at alternating right angles where space permits for soil processing. Additional passes should be performed if necessary to thoroughly break up and blend the liner soil prior to compacting.) Water is added, then the soil is thoroughly mixed and stockpiled if necessary to allow adequate time (usually overnight or longer) to hydrate. The higher the plasticity of the soil, the longer this mixing and hydration process will take. Water used in hydrating liner soils must be clean and shall not have come into contact with waste or any objectionable material.

2.3.2.3 Clod and Rock Size

The maximum clod size of the compacted liner soils shall be approximately one inch in diameter but in all cases soil clods shall be reduced to the smallest size necessary to achieve the coefficient of permeability reported by the testing laboratory and to destroy any macrostructure evidence after the compaction of the clods under density-controlled conditions. (§330.205(g), MSWR)

The liner soil material shall contain no rocks or stones larger than one inch in diameter or that total more than 10% by weight. (§330.205(h), MSWR). One-hundred percent of the material used in the soil liner must pass the 1-inch screen.

The final lift for composite liners should not contain any rocks or any other materials that can cause damage to the FML.

2.3.2.4 Compactive Effort *(Soils Compaction)*

All constructed soil liners must be compacted with a pad/tamping-foot (preferable) or prong-foot roller (§330.205(g), MSWR). No other type of equipment is suitable for the compaction of constructed soil liners.[2] The lift thickness shall be controlled so that there is total penetration through the loose lift under compaction into the top of the previously compacted lift; therefore, *the compacted lift thickness must not be greater than the pad or prong length.* This is necessary to achieve adequate bonding between lifts and reduce seepage pathways. Adequate cleaning devices must be in place and maintained on the compaction roller so that the prongs or pad feet do not become clogged with clay soils to the point that they cannot achieve full penetration during initial compaction. The footed roller is necessary to achieve bonding and to reduce the individual clods and achieve a blending of the soil matrix

[2]It is strongly recommended that the tamping feet have a face area not less than seven nor more than ten square inches. Self-propelled rollers with tamping feet surface areas greater than 10 but less than 30 square inches can be utilized provided the feet have tapered heads that add to the compactive effort.

through its kneading action. In addition to the kneading action, weight of the compaction equipment is important. When using ASTM Test Method D 698 (Standard Proctor) density, t' minimum weight of the compactor should be 1500 pounds per linear foot of drum length, ano a minimum of eight passes is recommended for the compaction process. Compaction equipment that develops a compactive effort equal to ASTM D 1557 (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 highly plastic clays frequently used for liner soil.

Adequate compaction cannot be achieved by track-type (bulldozer) or pneumatic compactors. Bulldozers are by the nature of their weight distribution designed to "float" on the surface, resulting in greatly diminished compaction by track contact and therefore should not be used to compact liner soils. In addition, the use of tracks or rubber tires for compaction does not allow the kneading action required to reduce and blend soil clods as is realized by pad-footed rollers.

Compaction Equipment

The compaction of soil liners must be with appropriate equipment.

1. Pad/tamping-foot rollers, or
2. Prong-foot (sheepsfoot) rollers

The following equipment types are examples of that which is not permitted or appropriate for the compaction of soil liners.

1. Bulldozer
2. Rubber-tired (pneumatic) rollers
3. Flat-wheel rollers
4. Rubber-tired scrapers or belly dumps

2.3.2.5 Soil Plasticity

Quality control of the soil plasticity should be closely adhered to and maintained during material selection for liner construction. Testing of the Atterberg limits and gradation should be continually checked so that any changes in either physical property can be detected and additional appropriate laboratory testing performed. Any time the LL or PI changes by more than 10 points, a new compaction series should be run in the laboratory to determine the maximum dry density, optimum moisture, and the laboratory coefficient of permeability. To adequately determine the variability of the soil used for liner construction, it is strongly recommended that all liner soil borrow sources be thoroughly tested prior to use to establish their Atterberg limits and compaction parameters. This may require drilling auger holes at the borrow source to retrieve adequate samples to determine these factors.

Due to the high shrink/swell and desiccation cracking characteristic of highly-plastic clays it is suggested that, where possible, the PI of clay liner soils be limited to between 15 - 30.

2.3.2.6 Construction Timing

Soil liner construction and testing should be conducted in a systematic and timely fashion. Delays should be avoided in liner completion. Construction and testing of soil liners should generally not exceed 60 working days from beginning to completion. There should **not** be more than a 14-day hiatus in construction unless adverse weather prevents construction progress. Reasons for any liner construction project taking more than 60 working days to complete should be fully explained in the SLER submittal.

2.3.2.7 Ponded Water on Liners

Constructed and tested liners on which a SLER has been submitted shall have sufficient surface-drainage controls to prevent the accumulation of both contaminated and non-contaminated water. Any ponded water that accumulates on newly constructed liner surfaces shall be promptly and appropriately removed. The surface of the completed soil liner prior to coverage with waste must be kept moist 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 accelerates and increases the degree of shrinkage cracking in the event of drying.

2.3.2.8 Protective Cover

Approved alternate liner designs that do not require a leachate collection and removal system and geomembrane liner but are a constructed soil liner must have a minimum one-foot-thick protective soil cover overlying the compacted liner surface. This protective cover is to reduce or eliminate desiccation cracking due to surface drying as well as to prevent damage to the liner surface by equipment. *This protective cover does not require compaction under density-controlled construction procedures.* The surface of the protective cover should be wetted during dry periods to keep the liner moist to prevent desiccation cracking.

Protective cover overlying a leachate collection and recmoval system in general must have permeabilities equal to or exceeding 10^{-4} centimeters per second, or be provided with appropriate passageways for moisture, such as chimneys, in order to allow leachate to readily drain to the LCRS.

Thickness:

a. There must be at a minimum 24 inches of cover material between an FML and waste. Part of this separation can be provided by a suitably designed leachate collection and removal system.

b. There must at a minimum 12 inches of cover between leachate collection pipes and waste.

c. There must be at a minimum 12 inches of cover between clay liners and waste.

2.4 Quality Assurance and 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.

All holes dug or created during any sampling and/or testing shall be backfilled with a mixture of at least 20% bentonite-enriched liner soil and compacted by hand tamping or filled with an appropriate bentonite grout.

2.4.1 In Situ Soils

Samples of the in situ soils must be tested in the laboratory for their gradation, Atterberg limits and coefficient of permeability. (See Table I). Field permeability testing may also be required in addition to gradation, Atterberg limits and laboratory permeability for quality assurance testing. The two acceptable types of field permeability testing are:

a. Sealed Double Ring Infiltrometer (SDRI) (ASTM D 5093) - Floor excavations*

b. Boutwell Permeameter (ASTM Pending) - an approved variation for the sidewall*
* §330.205(b)(8)

The frequency of testing should be at least one SDRI series or approved equivalent number of Boutwell tests for each 50,000 square feet. Table I lists the types of testing, standard test methods and frequency of testing.

For those 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 of liner soils prior to adding the cover.

For in situ liners that are not to be protected by the placement of one foot of protective cover, or are to be used as the soil liner portion of an alternate composite liner design, 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 of in situ soil beginning with the surface of the protective cover.

2.4.2 Constructed Soils Liners

The quality assurance testing and frequency of testing of constructed soil liners is discussed below. Table I provides and easy reference for the types of testing, standard test methods and frequency of testing.

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 liner 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 is adjacent to a field density/moisture test for comparing field and laboratory results.

2.4.2.1 Field Densities and Moisture Content

All field densities and moisture contents must compare with the limits specified below and to the proper ASTM D 698 or ASTM D 1557 moisture/density curve for the corresponding soil borrow source in order to be considered passing. Passing field specifications for the ASTM D 698 moisture/density compaction relationship, are at least 95% of maximum dry density and at the optimum moisture content or up to 5% above optimum moisture content. Passing specifications for the ASTM D 1557 moisture/density compaction relationship are at least 90% of maximum dry density and up to 1% drier than optimum moisture content or up to 3% above the optimum moisture content.

Sections of compacted soils liner which do not pass both the density and moisture requirements should 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 frequencies of testing differ for the two lift placement methods below:

Parallel Lifts--one test for each 8,000 square feet of surface area per lift (but no less than 3 density tests per 6 inch lift).

Horizontal Lifts--one for each 100 linear feet for each 12 inches of thickness.

2.4.2.2 Sieve Analysis

A minimum of one test sample within each 100,000 square feet of surface area per lift, or major fraction thereof, but no less than one per 6-inch lift of parallel liner or one test per 2,000 linear feet per 12 inches of horizontal liner thickness. Note in Section 3.6.1 of this Handbook, that 100% of the final lift for a composite liner should pass the 3/8 inch sieve.

2.4.2.3 Atterberg Limits

Use the same frequency of testing as for sieve analysis.

Note: 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 and a new test series including moisture/density, compaction relationship, sieve analysis and coefficient of permeability should be determined and these results used for field construction control.

2.4.2.4 Coefficient of Permeability

Use the same frequency of testing as for sieve analysis.

2.4.3 Thickness Verification for Constructed Liners

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 square feet of surface area. If the area under evaluation is less than 5,000 square feet, 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 thickness determination will be attached as part of the supporting documentation to the SLER including corrections for true thicknesses 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.

Thickness of in situ soil liners will be determined by augering to a depth of four feet to verify the adequacy of in situ depth or three feet of depth if one foot of protective cover is to be placed on the liner surface. The rate of verification should be at a minimum of one location for each 5,000 square feet of surface area. Each augered hole shall be backfilled with a mixture of at least 20% bentonite by volume and parent soil material and, at a minimum compacted by hand-tamping.

2.5 Bentonite-amended Soil Liners

Properly designed and constructed bentonite-amended soils may be suitable as liner materials but are both expensive and labor intensive to construct. This type of liner consists of soils that possess some, but not all, of the required characteristics without amending with additives. These soils are usually modified with a bentonite additive in order to lower the coefficient of permeability and increase the plasticity to meet the regulatory requirement.

Usually, this is only practical when a source of natural clay material which meets the requirements of liner material is not available on-site or within an economical haul distance. The use of bentonite can be very expensive depending upon the percentage of admixture required to meet the regulatory coefficient of permeability requirements with the on-site available soils. It has been proven, through experience, that only by the correct use of a pugmill can there be a high degree of assurance of uniform blending and moisture conditioning prior to placement. The use of a pugmill in the proper blending of the soil, bentonite and proper percentage of moisture may be, at the discretion of the Commission, justification for waiving the requirement for field permeability testing of the constructed liner. If this waiver is approved by the Commission, laboratory permeability testing will remain as a requirement.

2.5.1 Source Material Acceptance Testing

Baseline characteristics of host soils (prior to amending with bentonite admixtures) must be established by following the same procedures in 2.2 for soils used for constructed liners.

Preliminary laboratory testing of the treated soil material should begin by starting with the addition of a known percentage of bentonite to the untreated soil. The type and grade of the bentonite should be discussed with and approved by the Commission prior to use. No chemically treated bentonite will be allowed. The bentonite source and type used to determine laboratory values should also be used in liner construction. The percentage of bentonite should be increased as needed to reach the required coefficient of permeability and Atterberg limits.

Once the host soil and a known percentage of bentonite are thoroughly mixed, a new sieve analysis and new Atterberg limits must be determined for the amended sample if it is to be considered as acceptable for liner construction. A moisture/density relationship must be developed for each given percentage of bentonite-amended soil appearing to meet the appropriate Atterberg limits criteria. These soil samples with a bentonite additive that are prepared for compaction should be processed with a predetermined percentage of moisture and allowed to hydrate a minimum of 24 hours before compacting for density determination. Once the maximum dry density and optimum moisture content have been determined, a test sample suitable for performing the appropriate coefficient of permeability test should be prepared. For Standard Proctor (ASTM D 698), this should be at approximately 95% of the maximum dry density at the optimum moisture content. For Modified Proctor (ASTM D 1557), this should be approximately 90% of the maximum dry density at no more than 1% dry of optimum moisture content.

Once the acceptable coefficient of permeability and Atterberg limits are demonstrated through testing, the percent compaction and moisture content of the demonstration sample become the minimum standards for use in field control. (The minimum standards, however, must not be less than 95% compaction at optimum moisture using ASTM D 698 or 90% compaction at a moisture content 1% dry of optimum using ASTM D 1557.)

Coefficient of Permeability -- This testing is to be performed once the test sample has had adequate time to hydrate (preferably, prior to compaction). The testing should be in accordance with the appropriate coefficient of permeability test procedure detailed in Section 2.2.2 of Chapter 2 of this Handbook. If the coefficient of permeability of the sample does not meet the regulatory requirements additional samples with increased percentages of bentonite admixture must be prepared and tested as detailed above.

2.5.2 <u>Bentonite-amended Liner Construction</u>

Sections 2.1.3.c and 2.3.2, dealing with constructed soil liners, must be followed for bentonite-amended soils liners. The following additional guidance assumes that the soil and bentonite have been mixed in a pugmill and this mixture has the proper amount of added moisture necessary for full hydration. The area proposed to receive the bentonite liner material should be prepared as follows:

a. Area surface should be as dry as possible with no standing water or wet spots.

b. All vegetation and rock greater than 1 inch in diameter that may interfere with the material placement and compaction must be removed.

c. The area to receive the liner material should be bladed smooth and proof rolled witn a flat wheel roller to remove any soft spots that may exist.

d. This soil/bentonite admixture should be compacted in lifts no greater than 6 inches in thickness with a pad-foot roller ensuring that adequate bonding is achieved between the bottom of the lift under compaction and the top of the previous lift. The final top lift should be rolled with a flat-wheeled or rubber-tired pneumatic roller to ensure a smooth liner surface in contact with the eventual overlying geomembrane liner.

e. This liner material must be compacted to at least 95% Standard Proctor (ASTM D 698) density and must have the moisture content determined to achieve full hydration. Each six inches of the constructed liner should be tested at the rate detailed in Section 2.5.2.

f. The completed liner surface should be covered with a layer of uncompacted protective soil cover and kept wet to ensure maintenance of full hydration and integrity until the geomembrane is placed on its surface. (This should not be construed to mean the liner surface should have standing water for this will compromise its structural integrity.) This cover material should be placed after the bentonite liner thickness is determined and must be removed and liner thickness reestablished by survey just prior to overlaying with a geomembrane.

g. It is strongly recommended that all of the final lift of the soil portion of the composite liner pass the 3/8 inch sieve in order to minimize potential damage to the overlying FML.

2.5.3 Quality Assurance Testing of Bentonite-amended Soils

The same as detailed in Section 2.4.2, and Table I.

Note: Completed bentonite-amended liners should also be tested for their coefficient of permeability in the manner detailed in Section 2.4.1.

The frequency of testing should be at least one SDRI or approved series of Boutwell Permeameter tests for each 50,000 square feet. Table I shows the types of testing, standard test methods and frequency of testing.

2.6 Test Pads

The use of test pads may be considered as an alternative method of construction quality-control testing. It is a method of pre-qualifying the liner construction methods and the resultant coefficient of permeability.

2.6.1 Initial Testing

Initially, the liner source material must be tested in the laboratory for gradation (sieve analysis), Atterberg limits, its moisture/density relationship, and coefficient of permeability to verify its acceptability as a liner source. Upon satisfying all the liner test requirements, a test pad is constructed on site with these soils. A field-moisture/density versus field permeability relationship is established using the same type of compaction equipment and soil that are to be used during liner construction. This procedure may also be used on bentonite-amended soil liners with the concurrence of the Commission. The compaction equipment weight must be considered when performing the initial laboratory compaction testing so that the lab data reflect construction equipment capability. **Warning: If the Atterberg limit values vary by 10 or more points from those earlier determined for the source materials, the constructed liner will be subject to all quality control and quality assurance testing in Table I at the specified frequencies in the table.**

2.6.2 Field Testing

Select and prepare enough liner soil to cover a test section at least 50 feet long, three compaction equipment widths wide, and 24 inches deep, or deeper as needed depending on the selected field permeability test procedure. For example, the Boutwell Permeameter method requires 36 inches of liner depth to perform the test. Individual lifts should not exceed approximately 6 inches in depth. Therefore, a minimum of two lifts are required for each one foot of liner construction.

After these compaction parameters have been verified through field-moisture/density testing, a field permeability test is performed by either of the following methods:

Sealed Double Ring Infiltrometer (ASTM D 5093) or

Boutwell Permeameter (ASTM Pending)

Once field permeability testing is complete, a full cross-section cut of the test pad should be made to allow inspection to determine if there is complete clod "blending" and intra-lift bonding through the compaction processing of the soils.

After the field permeability, density and moisture content have been determined, the Commission may waive additional laboratory or field permeability testing of the constructed liner as long as the Atterberg limits are within 10 points of the test pad soil.

2.6.3 Construction Requirements

The construction and testing method(s) utilized in the test pad must be also be used when constructing the soil liner. Sections 2.3.1.c, 2.3.2, and 2.4.2 for constructed liners and quality assurance testing must also be followed.

The amount of compaction must be recorded by noting the type and weight of the compactor and the number of total passes completed on the test pad. Once sufficient compaction of the lift is suspected, a field-moisture/density test is performed to determine if the optimum moisture/ maximum dry density have been achieved. (This is best undertaken with a nuclear density meter due to the speed with which it can determine these values but the accuracy of these test values should be checked against the test results of either sand cone or water balloon methods of density determination.)

After the test pad is compacted and fully tested, it should be considered as the example for the remaining liner construction. As long as the Atterberg limit values indicate that the soil material remains fairly uniform (within 10 points), the soil should achieve the same permeability if compacted in the same manner as the test pad. This relationship is valid only if the soils remain the same, the lift thickness is no thicker than that of the test section, and the same type of equipment is used during liner construction as was used for test-pad construction and with the same number of equipment passes.

2.7 Hydrostatic Considerations - Ballasting

Placement of soil liners below the seasonal high ground-water table or in areas subject to excess hydrostatic head levels shall be accomplished utilizing the following requirements and guidelines:

a. Liner construction shall not take place in standing water.

b. The construction of any liner system below the ground-water table must be part of the approved SDP of the landfill's permit. Any unforeseen need to construct a liner below the water table for waste disposal or contaminated-water storage areas not covered in the permit will require notification of the Commission prior to planning, designing, and constructing a liner.

c. All such liners must be constructed to a thickness to withstand any hydrostatic uplift pressure or piezometric heads subjected upon them by ground water under hydrostatic head. All liner thicknesses must be designed employing the unit weight characteristics of the liner material itself for constructed stability. As an example, a 3-foot thick liner (if authorized by the permit) may be used to offset up to six feet of hydrostatic uplift pressure. Hydrostatic uplift pressures greater than six feet must be offset by additional liner thickness or soil ballast at the rate of one additional foot of liner for each two additional feet of hydrostatic head. Ballast added above the liner should be compacted at a minimum to that degree achieved by ordinary compaction methods and is not required to be compacted to density-controlled specifications.

d. Material used for ballast above the liner should have prior approval by the Commission. The liner should not be less than the minimum thickness required by the regulations.

e. Ballast soil below the liner should be of liner quality and must be constructed and compacted to same liner specifications for liner construction stated in this handbook. If the ballast materials comes from the same sources as the liner and therefore have the same Moisture/Density relationship as the liner itself, then the coefficient of permeability testing can be waived. All other testing will be in accordance with the soils testing and frequency portion of this handbook for each six-inch lift. The field and laboratory test results of this ballast material shall be reported in the SLER.

2.8 Soils and Liner Evaluation Report (SLER) and Flexible Membrane Liner Report (FMLER) Markers

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 shall 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 SLER/FMLER areas. The SLER/FMLER markers must be tied into the master site grid system for reference and shall not be placed through the constructed liner.

2.9 Soils and Liner Evaluation Report (SLER) Submittals

All liner quality assurance/quality control test data must be performed in conformance with the SLQCP as required by the MSWR. These data must be submitted as a SLER (and FMLER, if applicable).

Each SLER (or FMLER) submittal must include a clearly legible site map which depicts the grid system on site, graphic scale, north arrow, filled area, present active area, and area covered by the current submittal. The site map must show the areas covered by all previous SLER (and FMLER, where appropriate) submittals with the dates of acceptance by the Commission. It may be a print from a master drawing which is annotated and updated with each new submittal.

In addition to the information requested in the above paragraph for all SLER (and FMLER) submittals, each SLER submitted to the Commission must include sample locations plotted on the Plan of Sample Locations. These sample locations must be plotted on drawings representing each six inches of compacted soil liner. As an example, a 2-foot thick soil liner will have four separate drawings depicting the test locations for each six-inch interval. For side liners constructed using horizontal lift layers, the permittee may submit, in place of multiple plan views, an elevation view showing the location of all tests and samples. The test summary should indicate the horizontal distance of each test/sample as measured from the protected sidewall face.

2.10 Soils and Liner Evaluation Report (SLER) Acceptability Determination

All field and laboratory sampling and testing of components of the liner and its construction must be under the direct supervision of a GP as defined in the Glossary or by his qualified representative. Any completed lined area that fails to meet the minimum specified conditions of the required tests must be reworked to achieve the required results. Inability to achieve the required results through reworking shall be cause for rejection of the area in question. All reworked areas shall be retested to prove adequacy to meet all the applicable requirements.

In accordance with §330.206(b), MSWR, no area may be used for the receipt of solid waste until the Commission has given confirmation of its acceptance of the SLER (and FMLER, if applicable) or fourteen days from the date(s) of arrival of the SLER and/or FMLER at the Municipal Solid Waste Division, TNRCC, have lapsed.[3] It is strongly recommended that the permittee call the Ground-Water Protection Team of the Compliance and Enforcement Section of the Municipal Solid Waste Division prior to use of area in question if confirmation of acceptance has not been received and the permittee believes that the fourteen-day review period has lapsed.

2.11 Interim Status Report

Constructed liners not covered by an FML should not remain uncover by waste for a lengthy period of time. The MSWR state, "The surface of a constructed soil liner should be covered with a layer of solid waste within a period of six months to mitigate the effects of surface erosion and rutting due to traffic. Liner surfaces not covered with waste within six months shall be checked by the SLER evaluator, who shall then submit a letter report on his findings to the executive director. Any required repairs shall be performed promptly. A new SLER shall be submitted on the new construction for all liners that need repair due to damage." §330.206(e), MSWR.

[3] The Commission staff will make every effort to notify the permittee by telephone or fax of final submittal status if the needed telephone numbers are listed within the signature block of the SLER or FMLER.

CHAPTER 3 FLEXIBLE MEMBRANE (OR GEOMEMBRANE) LINERS

3.1 General

FML must have a nominal thickness of at least 60 mils if extruded HDPE (high-density polyethylene) and 30 mils if manufactured of other acceptable materials recognized and used for this purpose. Any acceptable FML material used must overly and be in direct contact with an approved clay or alternate liner whose QA/QC was submitted in the form of a SLER and was found acceptable by the Commission. To date, the FML most used in this ground-water protection program is High Density Polyethylene (HDPE). Therefore, in an attempt to adequately cover this liner type, this chapter of the handbook will address only HDPE liners.

The landfill operator or consultant should contact the Ground-Water Protection Team Leader at the central office at least 48 hours prior to liner construction to afford Commission staff an opportunity to be on site during construction activity.

3.2 Manufacturing

HDPE liner material must be produced from virgin raw materials. Reground, reworked, or trim materials from the same lot may be acceptable but recycled or reclaimed materials must not be used in the manufacturing process. This liner material and required welding rods shall contain between 2% and 3% carbon black and may contain no more than 1% other additives. Each manufacturer of FML materials has a detailed description of these items and it is recommended that all involved parties be thoroughly familiar with this information as it relates to the particular FML that will be used.

3.3 Shipping

All HDPE liner material shall be shipped in rolls. Folded sections of panels (which are not a normal part of the manufacturing or packaging process for some non-HDPE FML materials) are not acceptable and shall not be used in HDPE liner construction. Creased sections of panels (which are not a normal part of the manufacturing process for some HDPE manufacturers) are not acceptable and shall not be used in the FML liner construction.

3.4 Delivery

The GP (as defined in the Glossary) or his qualified representative must inspect the delivered materials for damage and defects. Pushing, sliding or dragging of rolls or pallets can cause damage and must be avoided.

3.5 Storage

HPDE must be protected from soft or wet ground and rocky or rough ground, and must not be stacked more than 5 rolls high to avoid crushing the cores of the rolls. A sacrificial cover must be used to protect the HDPE if stored on site more than six months. The rolls shall be stored in such a manner as to avoid shifting, abrasion, or other adverse movements that can damage the geomembrane liner material.

3.6 Installation

FML installations should follow all of the manufacturer's recommendations. All FMLs must overlie and have intimate contact with the constructed soils liner or approved alternate liner portion of a composite liner. The construction and testing of the soils portion must be submitted to the Commission as a QA/QC report in the form a SLER as further described in Section 2.10 of this handbook and should be accepted by the Commission before installation of the FML may commence.[4]

The exposed sub-liner (soils portion) of the composite liner must be protected prior to and during the placement of the FML. It must be protected from desiccation and cracking, rutting, erosion, and ponding. The condition of the soils liner must be preserved by one or more of the following:

a. Regular watering and proof rolling;

b. Protection by a minimum of 12 inches of temporary soil cover which must be removed prior to the placing of the FML, and the soil liner resurveyed;

c. An additional 6-inch lift of compacted soil of liner quality; or,

d. Other means approved by the Commission to prevent deterioration of the soils lin

3.6.1 Subliner (soils portion) Preparation

The appropriate requirements in the sections in Chapter 2 of this handbook must be completed prior to the placement of the FML. It is strongly recommended that all of the final lift of the soil liner element of the composite liner pass the 3/8 inch sieve in order to minimize potential damage to the overlying FML. The surface of the subliner must be finished by rolling with a flat wheel roller until a smooth uniform surface is achieved.

3.6.2 FML Deployment

The FML shall only be placed on the prepared subliner as described in the preceding subsection. The deployment (including equipment used in the handling of the FML) shall not damage the subliner.

3.6.3 Weather

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[4]The permittee may submit both the SLER and FMLER at the same time. It must be understood however that unresolved questions and concerns dealing with the quality assurance testing of the clay liner during construction as revealed in the SLER must be fully resolved ar-d may require the removal of some FML liner to rework and test that portion of the clay liner question.

The FML shall not be placed during inclement weather such as rain or high winds.

3.6.4 Equipment on Liner

No vehicular traffic shall be allowed on the FML. Only low-ground-pressure supporting equipment may be allowed to traverse the FML. If such supporting equipment is operating on the FML it must be placed on a sacrificial surface or rub sheet in order to help protect the geomembrane liner. Personnel working on the FML shall not smoke, wear damaging shoes, or engage in any other activity likely to damage the geomembrane liner.

3.7 Seaming

Field seaming (and repairs) shall be performed in strict accordance with methods approved by the manufacturer. This is usually by fusion or extrusion welding when placing HDPE. Strict attention to the details of seam preparation procedures recommended by the manufacturer is crucial in order to produce consistent seams that will not allow fluid leakage and will pass the QA testing.

3.7.1 Placement

Only those geomembrane liner sheets that are to be placed and seamed in one day should be unrolled. Sheets should be positioned with the overlap recommended by the manufacturer, but not less than three inches. The GP or his representative shall visually inspect the placement and overlap of the FML to verify that the material is placed with sufficient overlap.

3.7.2 Wrinkles

Wrinkles shall be walked-out or removed as much as possible prior to field seaming.

3.7.3 Foreign Material

All foreign matter (dirt, water, oil, etc.) shall be removed from the area to be bonded.

3.7.4 Tack Welds

Tack welds (if used) with HDPE geomembrane liner shall use heat only. No double-sided tape, glue, or other method will be permitted when extrusion or fusion welding is used for bonding.

3.7.5 Seam Joints

Seams should be orientd parallel to the sidewall slope. Seams that join the sidewalls and bottom sections must be located in the bottom and at least five feet from the sidewall. In corners and odd-shaped geometric locations, the number of field seams should be minimized.

3.7.6 Temperature

No seaming should be attempted above 104°F (40°C) ambient air temperature. Below 40°F (5°C) ambient air temperature, preheating of the FML may be required.

3.7.7 Folds, Large Wrinkles, Fish Mouths

No folds, large wrinkles, or fish mouths shall be allowed in the seam. Only normal factory-induced creasing from the blown film process may be acceptable. Where wrinkles or folds occur, the material shall be cut and overlapped, and an extrusion weld applied. During wrinkle or fold repairs, adjacent FMLs may not necessarily be required to meet the three to four-inch minimum overlap if approved by the GP or his representative. All complete seams shall be tightly bonded and sealed.

3.7.8 End Of Each Work Day

At the end of each day or installation segment, all unseamed edges shall be anchored by sand bags or other approved device. Staples, U-shaped rods, or other penetrating anchors shall not be used to secure the FML.

3.8 Testing

The testing of raw materials, manufactured materials, and the installation of these materials is essential and required in order to determine their quality and suitability for FML use. Table II titled "STANDARD TESTS ON HDPE FML MATERIAL" addresses the applicable test methods and the frequency of testing for HDPE liners. The types of testing equipment use and their procedures for testing are described by the manufacturers of HDPE and should be utilized. Test specifications may vary between manufacturers. Therefore, the specifications described in this handbook should be met at a minimum, even if they exceed a manufacturer's specifications. Results of all of these tests will be reported as an attachment to the FMLER.

3.8.1 Manufacturing Quality Control (MQC)

All materials related to the manufacturing of FMLs must be tested by the geomembrane liner manufacturer to determine their quality and suitability for use. The tests, methods, and frequency of testing are found in Table II.

3.8.1.1 Resin Feed Stocks

Resin feed stocks used in the manufacturing of the FML is purchased by the FML manufacture. It must be tested by the geomembrane liner manufacturer for density and melt index. The test methods, and frequency of testing for these two tests are found in Table II.

3.8.1.2 Flexible Membrane Liner

The FML manufacturer conducts many tests throughout the manufacturing process and after the geomembrane liner is produced. At a minimum, the manufacturer must test for thickness, specific gravity, carbon black content, carbon black dispersion, tensile propertie tear and puncture resistance, and dimensional stability (shrinkage). The test methods and frequency of testing are found in Table II.

It should be noted that an acceptable industry standard method for the measurement of thickness for textured HDPE sheet material is to use a micrometer with 1/32-inch radius points. This procedure is recommended in the plant for MQC testing.

3.8.2 Conformance and Field Measurements

Prior to acceptance of the FML from the manufacturer, the GP shall verify that it meets the required specifications. At a minimum, the third party independent laboratory must test thickness, specific gravity/density, carbon black content, carbon black dispersion and tensile properties. The test methods and frequency of testing are found in Table II.

Field thickness measurements must be taken for each panel before it is seamed. The material thickness shall be checked using a micrometer at a minimum frequency of one measurement per five feet along the leading edge of each panel but at least, at a minimum, five measurements along the leading edge of the panel. No single measurement shall be less than 10% below the required nominal thickness in order for the panel to be accepted.

3.8.3 Seams

The GP or his representative should observe all test seam procedures and all seam testing. All seam testing of the FML should follow all of the manufacturer's recommended testing procedures.

3.8.3.1 Trial Seam Testing

Each day, prior to commencing field seaming, test seams shall be made on fragment pieces of FML to verify that seaming conditions are adequate.

3.8.3.1.1 Trial Test Seam Criteria

Each trial test seam shall be at least three feet long by 1 foot wide. Four (six when possible if using dual track fusion welding) adjoining one-inch wide specimens will be die-cut from the test seam sample. Two specimens will be tested in the field for shear and two for peel (four when possible if testing both inner and outer welds for dual track fusion welding).

The failure criteria is the same as that for destructive seam testing described below. These test specimens must exhibit a Film Tear Bond (FTB). If one test seam fails, the trial seam will be repeated. If this trail seam also fails, then two more trial seams must be constructed and tested. This process must continue and no welding can begin for the machine or welder (if applicable) until all test seams are passing.

3.8.3.1.2 Additional Trial Test Seam Criteria

Additional trial seams shall be made for all of the following:

a. 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);

b. each occurrence of significantly different environmental conditions (i.e., temperature, humidity, dust, etc.);

c. any time the machine is turned off for more than 30 minutes; and

d. when seaming different FMLs (tie-ins and smooth to textured).

Both the welder and the machine must be tested for each new trial seam when extrusion welding. Only the machine needs to be tested for each new trial seam when fusion welding since the machine is not as operator dependent. Each individual seaming shall make at least one test seam each day he/she actually performs seaming.

3.8.3.2 Non-Destructive Testing

Continuous, non-destructive testing shall be performed on all seams by the installer. Air-pressure testing on dual-track fusion welds and vacuum-box testing for extrusion welds are the only acceptable methods for HDPE FML seams. All leaks must be isolated and repaired by following the procedures described in Section 3.9 of this handbook.

3.8.3.2.1 Air-Pressure Testing

The ends of the air channel of the dual-track fusion weld must be sealed and pressured to approximately 30 psi, if possible. The air pump must then be shut off and the air pressure observed after five minutes. A loss of less than four psi is acceptable if it is determined that the air channel is not blocked between the sealed ends. A loss of more that four psi indicates the presence of a seam leak which must then be isolated and repaired by following the procedures described under Repairs in this handbook. The GP or his representative must observe and record all pressure gauge readings.

3.8.3.2.2 Vacuum-Box Testing

A suction value of approximately three to five inches of gauge vacuum 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, some sump areas, appurtenances, etc. The seam must be observed for leaks for at least 10 seconds while subjected to this vacuum. The GP or his representative must observe 100% of th testing.

3.8.3.2.3 Other Testing

Other non-destructive testing must have prior written approval from the Commission.

3.8.3.3 Destructive Testing

Destructive samples shall be taken at a minimum of one stratified location for every 500 linear feet of seam testing or major fraction thereof. The total footage of individual repairs of leaks of more than 10 feet and individual repairs of more than 10 feet for failed seams must also be counted and destructively tested using the same frequency of testing described above. At a minimum, a destructive test must be done for each welding machine used for seaming or repairs. A sufficient amount of the seam must be removed in order to conduct field testing, independent laboratory testing, and archiving of enough material in order to retest the seam when necessary. Field testing shall include at least two peel test specimens (four when possible for testing both tracks on dual-track fusion welded seams). Independent laboratory testing shall consist of five shear test specimens and five peel test specimens (ten when possible for both tracks of dual-track fusion welded seams). Destructive seam-testing locations shall be cap-stripped and the cap completely seamed by extrusion welding to the FML. Capped sections shall be non-destructively tested. Additional destructive test samples may be taken if deemed necessary by the GP or his representative.

3.8.3.3.1 Passing Criteria

All field-tested specimens from a destructive-test location must be passing in both shear and peel for the seam to be considered as passing. Field tested specimens, are determined as passing if the specimen tested in peel fails in FTB and all test specimens meet the criteria listed in this subsection. The independent laboratory testing must confirm these field results.

The minimum passing criteria for independent laboratory testing are all three of the following:

All specimens (see GLOSSARY for definition) tested in the peel mode must fail in FTB.

At least four of five specimens from each peel and shear determination must meet the minimum specified value.

The average value from all five specimens from each peel and shear determination must meet the minimum specified value.

The above criteria apply to both tracks from each dual-track fusion welded seam before it is considered as passing.

The test methods, and frequency of testing for FMLs are found in Table II. It should be noted that FML manufacturers may have differing values for their FML sheets and, therefore, the specific values are not stated in this handbook, only percentages. Consequently, the manufacturer's sheet-strength values must be provided in order to determine if the test results are passing.

3.8.3.3.1.1 Shear

The shear strength must be at least 95% of manufacturer's parent sheet strength but not less than 120 pounds per inch (ppi).

3.8.3.3.1.2 Peel

The peel strength must be at least 62% of manufacturer's parent sheet strength but not less than 78 ppi and exhibit FTB.

3.8.3.3.2 Failure Criteria

If less than four of the five specimens from each destructive test location pass, or if the average calculated from all five specimens is less than that listed in Subsection 3.8.3.3.1, above, or if any specimen does not exhibit an FTB failure, the seam has failed.

3.9 Repairs and Retesting

All seam leaks and destructive test locations shall be repaired for a distance of at least six inches on each side of the faulty spot or area detected. At a minimum, these repairs shall be non-destructively retested and possibly destructively tested (refer to destructive testing criteria for repaired seams as described in Subsection 3.8.3.3, above.)

3.10 Anchor Trench and Backfilling

The anchor trench should be completed around all portions of the FML where the leading edge(s) of the FML will not be needed for a tie-in for expansion into the next SLER/FMLER area to be lined. The excavated anchor trench shall have rounded corners in order to help protect the FML. No loose soil shall be allowed to underlie the FML in the anchor trench.

The anchor trench should be backfilled and compacted to at least 90 percent of the density as determined by the moisture/density compaction values detailed in the soils portion of this handbook. Care should be used when backfilling and compacting the trench to prevent damage to the FML. Results of the compaction testing need not be reported.

3.11 Protective Cover and Drainage Materials

3.11.1 Deployment

Naturally-occurring drainage materials and protective cover shall be deployed in "fingers" along the bottom so as to control the amount of slack and minimize wrinkles and folds in the FML. These materials must be deployed only up-slope on sidewalls so that stress imparted to the FML in minimized. Full-time observation by the GP or his representative is required during deployment of these materials in direct contact with the geosynthetic materials.

3.11.2 Thickness

At least 24 inches of cover (including the drainage layer of the LCRS and protective cover) shall be placed over the surface of the constructed FML and shall contain no rock greater than 3/8 inch, vegetation, or other material that may damage the FML. If the protective cover/drainage blanket contains material greater than 3/8 inch in size, a layer of protective geotextile must be placed over the FML.

3.11.3 Drainage Flow Rate

Protective cover overlying a leachate collection and removal system in general must have permeabilities equal to or exceeding 10^{-4} centimeters per second, or be provided with appropriate passageways for moisture, such as chimneys, in order to allow leachate to readily drain to the LCRS.

3.12 Flexible Membrane Liner Report (FMLER) Submittals

All liner quality assurance/quality control test data must be performed in conformance with the SLQCP as required by the MSWR. These data must be submitted as a SLER and FMLER.

Each FMLER submittal must include a clearly legible site map which depicts the grid system on site, graphic scale, north arrow, sectorized fill layout plan, filled area, present active area, and area covered by the current submittal. The site map must show the areas covered by all previous SLER (and FMLER where appropriate) submittals with the dates of acceptance by the Commission. It may be a print from a master drawing which is annotated and updated with each new submittal.

In addition to the information required in the above paragraph, each FMLER submitted to the Commission must include a discussion of the construction and testing, site map showing the area covered by the FML, seam locations, panel numbers, location of patches, all testing, documentation of the results of the compaction of the subgrade, Leachate Collection and Removal System (if applicable), and the type of cover/drainage materials and survey verification of their total thickness.

3.13 Flexible Membrane Liner Evaluation Report (FMLER) Acceptability Determination

All field and laboratory sampling and testing of components of the FML and its construction must be under the direct supervision of a professional as defined in the Glossary, or by his qualified representative. Any completed lined area that fails to meet the minimum specified conditions of the required tests for an FML must be replaced or reworked (seam or liner flaw, etc. patched) to achieve the required results. Inability to achieve the required standards through replacement of materials and/or reseaming shall be cause for rejection of the area in question. All reworked areas shall be retested to prove adequacy to meet all the applicable requirements.

No area may be used for the receipt of solid waste until the Commission has give written confirmation of its acceptance of the SLER and FMLER covering the area or fourteen days from the date(s) of arrival of the SLER and/or FMLER at the Municipal Solid Waste Division, TNRCC, have lapsed.[5] It is strongly recommended that the permittee call the Ground-Water Protection Team of the Compliance and Enforcement Section of the Municipal Solid Waste Division prior to use of the area in question if confirmation of acceptance has not been received and the permittee believes that the 14-day review period has lapsed.

3.14 Interim Status Report

An Interim Status Report for composite liners should be provided to the Commission for portions of the liner that remain uncovered with waste for more than six months from the date that the protective cover was applied, and the area shall be reevaluated by a geotechnical professional as stated in subsection §330.206(e), MSWR for soil liners.

The consultant should contact the Ground-Water Protection Team Leader, Compliance and Enforcement Section at the central office at least 48 hours prior to conducting the inspection for the Interim Status Report in order to afford appropriate TNRCC staff the opportunity to accompany the consultant during the inspection.

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[5]The Commission staff will make every effort to notify the permittee by telephone or fax of final submittal status if the needed telephone numbers are listed within the signature blo of the SLER or FMLER.

Appendix I

Useful References:

ASTM D 374, "Standard Test Methods for Thickness of Solid Electrical Insulation"

ASTM D 422, "Particle-Size Analysis of Soils"

ASTM D 638, "Tensile Properties of Plastics"

ASTM D 698, "Laboratory Compaction Characteristics of Soils Using Standard Effort (12,400 ft-lbs/ft^3 (600 Kn-m/m^3))"

ASTM D 751, "Test Methods for Coated Fabrics"

ASTM D 792, "Specific Gravity and Density of Plastics by Displacement"

ASTM D 1004, "Initial Tear Resistance of Plastic Film and Sheeting"

ASTM D 1140, "Amount of Material in Soils Finer than the No. 200 (75-μm) Sieve"

ASTM D 1204, "Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature"

ASTM D 1238, "Flow Rates of Thermoplastics by Extrusion Plastometer"

ASTM D 1505, "Density of Plastics by the Density-Gradient Technique"

ASTM D 1556, "Density and Unit Weight of Soil In Place by Sand-Cone Method"

ASTM D 1557, "Laboratory Compaction Characteristics of Soils Using Modified Effort (56,000 ft-lbs/ft^3 (2,700 Kn-m/m^3))"

ASTM D 1593, "Standard Specification for Nonrigid Vinyl Chloride Plastic Sheeting"

ASTM D 1603, "Carbon Black in Olefin Plastics"

ASTM D 2167, "Density and Unit Weight of Soil In Place by Rubber Balloon Method"

ASTM D 2487, "Classification of Soils for Engineering Purposes (Unified Soil Classification System)"

ASTM D 2922, "Density of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)"

ASTM D 3015, "Recommended Practice for Microscopical Examination of Pigment Dispersion in Plastic Compounds"

ASTM D 4318, "Liquid Limit, Plastic Limit, and Plasticity Index of Soils"

ASTM D 4437, "Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes"

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"

ASTM D 5093, "Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed Inner Ring"

ASTM D 5199, "Measuring Nominal Thickness of Geotextiles and Geomembranes"

ASTM Standards, Procedures for Testing Soils, American Society for Testing Materials, 1916 Race Street, Philadelphia, PA 19103.

Boutwell, G.P., and Tsai, C.N., 1992, "The Two-Stage Field Permeability Test for Clay Liners," *Geotechnical News*, Vol. 10, No. 2, pp. 32-34.

Daniel, D.E., March 10 & 11, 1993, Seminar on clay liner construction and testing given to Texas Water Commission, Field Operations Municipal Solid Waste Landfill Inspectors and Central Office Personnel.

FTM Std. 101C, "Puncture Resistance and Elongation Test," Federal Test Method 2065, March 13, 1980.

GRI GM6, Standard Practice for "Pressurized Air Test for Duel Seamed Geomembranes".

NSF 54 - 1991, "Flexible Membrane Liners", NSF International Standard

Trautwein, Stephen J. and Boutwell, Gordon P., 1993, "In-situ Hydraulic Conductivity Tests for Compacted Soil Liners and Caps," conference in San Antonio during January 1993, ASTM D-18.

U.S. Army Corps of Engineers, 1970, "Laboratory Soil Testing," Office of the Chief of Engineers, Washington, DC, Engineer Manual 1110-2-1906.

U.S. Environmental Protection Agency, 1993 "Quality Assurance and Quality Control for Waste Containment Facilities," EPA Technical Guidance Document, EPA/600/R-93/182.

U.S. Environmental Protection Agency, 1993 "Solid Waste Disposal Facility Criteria," EPA Technical Manual, EPA 530-R-93-017.

U.S. Environmental Protection Agency, 1991 "Inspection Techniques for the Fabrication of Geomembrane Field Seams," EPA Technical Guidance Document, EPA/53 0/SW-91/051.

TO BE ACCEPTED BY TNRCC, THE FOLLOWING CHECKLIST OF ITEMS MUST BE FULLY ADDRESSED IN THE SOILS AND LINER QUALITY CONTROL PLAN (SLQCP) AND EACH FLEXIBLE MEMBRANE LINER EVALUATION REPORT (FMLER) FOR INSTALLING AND TESTING THESE LINERS. THE ITEMS LISTED BELOW ARE NOT INTENDED TO BE A COMPLETE AND EXHAUSTIVE INVENTORY OF REQUIREMENTS FOR ANY QA/QC PLAN FOR ANY MSWLF BUT SHOULD BE CONSIDERED THE MINIMUM REQUIRED.

The FMLER must include:

- Names of all seamers, for start-up testing and after the lunch or mid-day break, including time and tip temperatures for each seaming apparatus used each day.
- Nondestructive tests including start and stop times, before and after pressure readings (for dual-track testing) for all seams
- Roll shipment/receipt and storage/handling information
- All pertinent drawings including:
  - Sectorized Fill Lay-Out Plan
  - Location of trench or cell with SLER/FMLER markers
  - Previously filled areas, and active areas
  - Panel placement, including patches, repairs, caps, etc.
  - Destructive Tests and Repairs (minimum frequency of testing is at least one stratified [randomly selected] sample per each 500 feet of seaming)
- Verification of protective cover thickness
- Report must include the qualitative results of:
  - Destructive tests for both field and laboratory
    - Shear
    - Peel (both tracks when possible for dual track) [Record failure location by using Failure Codes]

The report must discuss the following:

Full-time quality assurance by the CC/QA Professional or his/her qualified representative

Nondestructive testing equipment, including testing procedures and methods of evaluation and passing criteria

Subgrade acceptance

Anchor trench preparation and backfilling

Wrinkles/Fish Mouths and normal manufacturing creases

Deployment of panels

Seam preparation/orientation

Weather and air temperature/sheet temperature limits

Continuous 100% seam non-destructive testing

Equipment placed on the geomembrane

Repairs, including preparation and procedure, cap and patch sizes and shapes

Failed test seams and testing either side of failed seam

Placement of cover material only up slope for sidewalls

Thickness and sieve analysis requirements of cover material

Field panel identification/placement

Specifications for air-pressure testing/vacuum testing

100% visual inspection of geomembrane for defects, damage, etc.

Handling and storage of geomembrane materials

Quality control/assurance certificates from the manufacturer including the testing required and the frequency of testing as stated in Table II

Conformance Testing certificates by third party Independent Laboratory as stated in Table II

Daily start-up and additional testing for each seamer and each seaming machine

Leachate Collection and Removal System (LCRS), if applicable

§330.205. Soils and Liner Quality Control Plan.

(a) A landfill must have an approved Soils and Liner Quality Control Plan (SLQCP) prepared under the direction of a registered professional engineer, and it shall be the basis for the type and rate of quality control testing performance and reported in the Soil and Liner Evaluation Report (SLER) as required in §330.206 of this title (relating to SLER and Flexible Membrane Liner Evaluation Report (FMLER)). The SLQCP must be included in the Site Development Plan to provide operating personnel adequate procedural guidance for assuring continuous compliance with ground-water protection requirements. The plan shall specify construction methods employing good engineering practices for compaction of clay soils to form a liner. Unless alternate construction procedures are approved in writing by the executive director, all constructed liners shall be keyed into an underlying formation of sufficient strength to ensure stability of the constructed lining. The SLQCP shall address the installation and testing of a FML liner, if used. Proposed dewatering plans shall be included. The SLQCP shall include the following information.

(1) Constructed liner details, where applicable shall be depicted on cross-sections of a typical trench showing the slope, widths, and thicknesses for compaction lifts. The amount of compaction shall be expressed as a percentage of a predetermined laboratory density.

(2) Soil and liner quality-control testing procedures, to include sampling frequency, shall be included in the SLQCP. 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 state laws and regulations. The professional of record who signs the SLER or his representative should be on site during all liner construction. Quality control of construction and quality assurance of sampling and testing procedures should follow the latest technical guidelines of the executive director.

(b) An SLQCP shall also:

(1) describe and illustrate, for operating personnel, all necessary procedures for assuring continuous compliance with this subsection;

(2) provide guidance needed for testing and reporting evaluation procedures to the professional who will prepare the SLERs for the site;

(3) specify materials, equipment, and construction methods for the compaction of clay soils to form impermeable liners for the conditions described in subparagraphs (A) and (B) of this paragraph. The SLQCP shall adhere to the testing frequencies and procedures as specified.

(A) Details for the over excavation and recompaction of the in-situ soils, or the compaction of soils from a borrow source, shall be depicted on cross-sections of a typical trench showing the slope, widths, and thicknesses for compaction lifts.

(B) Procedures to be followed when excavations, trenches, or disposal areas extend into or have the potential to extend into the ground water shall be in accordance with the provisions provided in §330.203 of this title (relating to Special Conditions (Liner Design Constraints)); and

(4) describe installation methods and quality control testing and reporting for any FML that may be required or authorized by the executive director as a part of a composite liner.

(c) Soil liner quality control testing frequencies and procedures shall be in accordance with the executive director's most recent guidelines and the following.

(1) All field sampling and testing, both during construction and after completion of the lining, shall be performed by a qualified professional experienced in geotechnical engineering and/or engineering geology, or under

his direct supervision.

(2) All liners should have continuous on-site inspection during construction by the professional of recc or his designated representative.

(3) The amount of compaction of clay liners shall be expressed as a percentage of a maximum dry density based on a compaction test specified by a registered professional engineer. The compaction of the clay liner shall have been proven by soils laboratory testing to provide a coefficient of permeability of 1×10^{-7} cm/sec or less.

(4) The SLQCP shall define the frequency of testing for each of the test procedures listed in subparagraphs (A)-(F) of this paragraph. These frequencies shall be expressed in numbers of tests per specific area of liner per lift or specific thickness of liner, unless an alternate frequency is approved by the executive director:

(A) coefficient of permeability;

(B) Sieve analysis;

(C) Atterberg limits;

(D) density;

(E) moisture content;

(F) thickness verification.

(5) Unless otherwise approved by the executive director, all soil tests performed on any in-situ or constructed soil liners shall be in accordance with the standards in subparagraphs (A)-(E) of this paragraph.

(A) laboratory permeability tests. Permeability tests shall be run using tap water or .05N solution of $CaSO_4$ and not distilled water. All test data must be submitted on permeability tests regardless of test method used. At a minimum, the calculations of the last data set reported for each sample and the resultant coefficient of permeability shall be reported as supporting data. Tests shall be either constant head with back pressure (Appendix VII of Corps of Engineers Manual, EM 1110-2-1906; ASTM D5084, "Measurement of Hydrau' Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter,") or falling head (Appendix VII ᴗ. Corps of Engineers Manual, EM1110-2-1906);

(B) Sieve analysis +1, 200, -200 sieves; (ASTM D 422 or ASTM D 1140, as applicable);

(C) Atterberg limits (ASTM D 4318);

(D) moisture-density relations (ASTM D 698 or any executive-director-approved modified test whose compactive effort matches the on site construction equipment);

(E) moisture content (ASTM D 2216).

(6) All soils used as constructed liners must have the following minimum values verified by testing in a soils laboratory: Plasticity index-Equal to or Greater than 15; Liquid limit -Equal to or Greater than 30; Percent passing 200 mesh sieve (-200) Equal to or Greater than 30%; Percent passing 1 inch screen-100%; Coefficient of permeability less than or equal to 1×10^{-7} cm/sec.

(7) Permeability tests for proving the suitability of soils to be used in constructing clay liners shall be performed in the laboratory using the procedures and guidance of paragraph (5)(A) of this subsection. Field quality control must be provided by field density tests based on predetermined moisture-density compaction curves, Atterberg limits, and laboratory permeabilities of undisturbed field samples of compacted liner soils, unless an alternate plan is approved by the executive director.

(8) Field permeability testing of in-situ soils or constructed soil liners shall be in accordance with ASTM D 5093 for those soil liners which are in the floor of the excavation and a variation of the Boutwell STEI field permeability test approved by the executive director for the sidewalls, or in accordance with guidance furnished by the executive director.

(9) All quality control testing of soil liners shall be performed during the construction of the liner. In instance shall any quality control field or laboratory testing be undertaken after completion of liner construction,

except for that testing which is required of the final constructed lift, confirmation of liner thickness, or cover material thickness.

(10) All soil testing and evaluation of either in-situ soil or constructed soil liners shall be complete prior to installing the LCRS or, if no LCRS is required, prior to adding the one foot of protective cover on the area under evaluation.

(d) Soil and liner density shall be expressed as a percentage of the maximum dry density and at the corresponding optimum moisture content specified as appropriate by a registered professional engineer experienced in geotechnical engineering. These soils so compacted must upon testing either in the laboratory or as a test pad in the field demonstrate a coefficient of permeability no greater than $1x10^{-7}$ cm/sec.

(e) Unless alternate construction procedures have prior written approval by the executive director, all constructed soil liners shall be keyed into an underlying formation of sufficient strength to ensure stability of the constructed lining.

(f) Each SLER shall be prepared in accordance with the approved SLQCP. Any deviation from an approved SLQCP must have prior written approval from the executive director.

(g) Soil liners shall not be compacted with a bulldozer or any track-mobilized equipment unless it is used to pull a pad-footed roller. All soil liners shall be compacted with a pad-footed or prong-footed roller only. The maximum clod size of the compacted liner soils shall be approximately one inch in diameter. In all cases soil clods shall be reduced to the smallest size necessary to achieve the coefficient of permeability reported by the testing laboratory and to destroy any macrostructure evidenced after the compaction of the clods under density-controlled conditions.

(h) The liner soil material shall contain no rocks or stones larger than one inch in diameter or that total more than 10% by weight. Rock content shall not be a detriment to the integrity of the overlying geomembrane.

Table I

STANDARD TESTS ON SOILS

SOIL TEST CATEGORY	TYPE OF TEST	STANDARD TEST METHOD	FREQUENCY OF TESTING
Quality Control Testing of Source Borrow Materials	Unified Soil Classification	ASTM D 2487	Once per soil type
	Moisture/Density Relationship	ASTM D 698 or D 1557	
	Sieve (Gradation)	ASTM D 422 or D 1140	
	Atterberg Limits	ASTM D 4318	
	Coefficient of Permeability	ASTM D 5084 or CoE EM1110-2-1906	1/Moisture/Density Relationship
In-situ Liners	Sieve (Gradation)	ASTM D 422 or D 1140	1/50,000 ft^2 per foot thickness of liner[A]
	Atterberg Limits	ASTM D 4318	
	Coefficient of Permeability (laboratory)	ASTM D 5084 or CoE EM1110-2-1906	
	Coefficient of Permeability (field)	ASTM D 5093 or Boutwell Tests	1 SDRI test or 1 Boutwell series[B] per 50,000 ft^2[A]
	Thickness	Registered Surveyor	1/5,000 ft^2[A]
Constructed Soil Liners	Field Density	ASTM D 1556, D 2167, or D 2922	1/8,000 ft^2 per 6-inch parallel lift[A]; 1/100 lineal ft per 12 inches sidewall liner (horizontal lifts)[A]
	Sieve (Gradation)	ASTM D 422 or D 1140	1/100,000 ft^2 per 6-inch parallel lift[A]; 1/2000 lineal ft per 12 inches sidewall liner (horizontal lifts)[A]
	Atterberg Limits	ASTM D 4318	
	Coefficient of Permeability	ASTM D 5084 or CoE EM1110-2-1906	
	Thickness	Registered Surveyor	1/5,000 ft^2 (parallel lifts)[A]; 50-ft cross-sections (horizontal-lift sidewall liners)[A]
Test Pads	Coefficient of Permeability	ASTM D 5093-90 or Boutwell Tests	1 SDRI test or 1 Boutwell series/pad[B]

Notes:

A - A minimum of one of each of the designated tests must be conducted for each unit thickness of liner as indicated, regardless of liner area or length.

B - One Boutwell series includes 5 test holes.

Table II

STANDARD TESTS ON HDPE FML MATERIAL

TEST	TYPE OF TEST	STANDARD TEST METHOD	FREQUENCY OF TESTING
Resin	Specific Gravity/Density	ASTM D 1505	per 100,000 ft^2 and every resin lot
	Melt Flow Index	ASTM D 1238	per 100,000 ft^2 and every resin lot
Manufacturer's Quality Control	Thickness	ASTM D 5199 (smooth) or D 1593[A] (textured)	per manufacturer's quality control specifications
	Specific Gravity/Density	ASTM D 1505	per 100,000 ft^2 and every resin lot
	Carbon Black Content	ASTM D 1603	per 100,000 ft^2 and every resin lot
	Carbon Black Dispersion	ASTM D 3015[B]	per 100,000 ft^2 and every resin lot
	Tensile Properties	ASTM D 638[C]	per 100,000 ft^2 and every resin lot
	Tear	ASTM D 1004	per 100,000 ft^2 and every resin lot
	Puncture	FTM Std. 101C Method 2065	per 100,000 ft^2 and every resin lot
	Dimensional Stability (Shrinkage)	ASTM D 1204 NSF 54 Modified	per 100,000 ft^2 and every resin lot
Conformance Testing by 3rd Party Independent Laboratory	Thickness[D]	ASTM D 5199 (smooth) or D 1593[A] (textured)	per 100,000 ft^2 and every resin lot
	Specific Gravity/Density	ASTM D 1505	per 100,000 ft^2 and every resin lot
	Carbon Black Content	ASTM D 1603	per 100,000 ft^2 and every resin lot
	Carbon Black Dispersion	ASTM D 3015[B]	per 100,000 ft^2 and every resin lot
	Tensile Properties	ASTM D 638[C]	per 100,000 ft^2 and every resin lot
Destructive Seam Field Testing	Shear & Peel	ASTM D 4437	varies for field, lab, and archive
Non-destructive Seam Field Testing	Air Pressure	GRI GM6	all dual-track fusion weld seams
	Vacuum	ASTM D 4437	all non-air pressure tested seams when possible
	Other		as necessary with concurrence of Commission

Notes:
A - For textured liners acceptable alternative procedure in accordance with industry standard is to use micrometer with 1/32" radius points
B - NSF 54 Modified (microtome sample preparation procedure)
C - NSF 54 Modified with 2" initial gauge length assumed for elongation at break
D - Field thickness measurements for each panel must be conducted. Use ASTM D374 and perform one series of measurements along the leading edge of each panel, with individual measurements no greater than five feet apart. No single measurement shall be less than 10% below the required nominal thickness in order for the panel to be acceptable.