
USACE / NAVFAC / AFCEC / NASA UFGS-02 56 13 (February 2010)

Preparing Activity: USACE Superseding
UGGS-02 56 13 (October 2007)

UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated April 2018

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02/10

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SECTION 02 56 13

WASTE CONTAINMENT GEOMEMBRANE
02/10

NOTE: This guide specification covers the requirements for geomembrane barrier for waste containment applications.

Adhere to UFC 1-300-02 Unified Facilities Guide Specifications (UFGS) Format Standard when editing this guide specification or preparing new project specification sections. Edit this guide specification for project specific requirements by adding, deleting, or revising text. For bracketed items, choose applicable item(s) or insert appropriate information.

Remove information and requirements not required in respective project, whether or not brackets are present.

Comments, suggestions and recommended changes for this guide specification are welcome and should be submitted as a Criteria Change Request (CCR).

PART 1 GENERAL

NOTE: This section is not to be used for POL systems. UFGS Section 33 56 19 FUEL IMPERMEABLE LINER SYSTEM for POL tank dike liners and Standard Design 078-24-27 for liners under POL tank bottoms.

Typical materials used in waste containment applications include linear low density polyethylene (LLDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), or polypropylene (PP). These materials are produced with both smooth and textured surfaces. The need for a textured versus a non textured material will be based on cover stability analyses. The drawings must clearly indicate the limits of placement for textured and non textured geomembranes.

1.1 MEASUREMENT AND PAYMENT

NOTE: Delete this paragraph when lump sum bidding is used.

Measurement shall be made of the total surface area in square meters feet covered by geomembrane. Final quantities will be based on as-built conditions. Allowance will be made for geomembrane in anchor and drainage trenches; however, no allowance will be made for waste, overlap, repairs, or materials used for the convenience of the Contractor. Geomembrane installed and accepted by the Contracting Officer will be paid for at the respective contract unit price in the bidding schedule.

1.2 REFERENCES

NOTE: This paragraph is used to list the publications cited in the text of the guide specification. The publications are referred to in the text by basic designation only and listed in this paragraph by organization, designation, date, and title.

Use the Reference Wizard's Check Reference feature when you add a Reference Identifier (RID) outside of the Section's Reference Article to automatically place the reference in the Reference Article. Also use the Reference Wizard's Check Reference feature to update the issue dates.

References not used in the text will automatically be deleted from this section of the project specification when you choose to reconcile references in the publish print process.

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

ASTM INTERNATIONAL (ASTM)

- | | |
|------------|--|
| ASTM D1004 | (2013) Initial Tear Resistance of Plastic Film and Sheeting |
| ASTM D1203 | (2016) Standard Test Methods for Volatile Loss from Plastics Using Activated Carbon Methods |
| ASTM D1204 | (2014) Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature |
| ASTM D1505 | (2010) Density of Plastics by the Density-Gradient Technique |

| | |
|-------------------|--|
| ASTM D1593 | (2009) Standard Specification for Nonrigid Vinyl Chloride Plastic Film and Sheetting |
| ASTM D1603 | (2014) Carbon Black Content in Olefin Plastics |
| ASTM D1790 | (2014) Brittleness Temperature of Plastic Sheetting by Impact |
| ASTM D3895 | (2014) Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry |
| ASTM D4218 | (2015) Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique |
| ASTM D4833/D4833M | (2007; E 2013; R 2013) Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products |
| ASTM D5199 | (2012) Measuring Nominal Thickness of Geosynthetics |
| ASTM D5321/D5321M | (2017) Standard Test Method for Determining the Shear Strength of Soil-Geosynthetic and Geosynthetic-Geosynthetic Interfaces by Direct Shear |
| ASTM D5397 | (2007; R 2012) Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test |
| ASTM D5596 | (2003; R 2016) Standard Test Method For Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics |
| ASTM D5721 | (2008; R 2013) Air-Oven Aging of Polyolefin Geomembranes |
| ASTM D5885/D5885M | (2017) Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry |
| ASTM D5994/D5994M | (2010; R 2015; E2015) Standard Test Method for Measuring Core Thickness of Textured Geomembranes |
| ASTM D638 | (2014) Standard Test Method for Tensile Properties of Plastics |
| ASTM D6392 | (2012; R 2018) Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods |

| | |
|-------------------|---|
| ASTM D6497/D6497M | (2002; R 2015; E 2015) Standard Guide for Mechanical Attachment of Geomembrane to Penetrations or Structures |
| ASTM D7238 | (2006; R 2012) Standard Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Condensation Apparatus |
| ASTM D7466 | (2010) Standard Test Method for Measuring Asperity Height of Textured Geomembranes |
| ASTM D751 | (2006; R 2011) Coated Fabrics |
| ASTM D792 | (2013) Density and Specific Gravity (Relative Density) of Plastics by Displacement |
| ASTM D814 | (1995; R 2014) Rubber Property - Vapor Transmission of Volatile Liquids |
| ASTM D882 | (2012) Tensile Properties of Thin Plastic Sheeting |

GEOSYNTHETIC INSTITUTE (GSI)

| | |
|-------------|---|
| GSI GRI GM7 | (1995) Accelerated Curing of Geomembrane Test Strip Seams Made by Chemical Fusion Methods |
| GSI GRI GM9 | (1995; R 2013) Cold Weather Seaming of Geomembranes |

1.3 PANEL LAYOUT

Submit geomembrane panel layout and penetration detail drawings, a minimum of [7] [_____] days prior to geomembrane placement.

1.4 SUBMITTALS

NOTE: Review submittal description (SD) definitions in Section 01 33 00 SUBMITTAL PROCEDURES and edit the following list to reflect only the submittals required for the project.

The Guide Specification technical editors have designated those items that require Government approval, due to their complexity or criticality, with a "G." Generally, other submittal items can be reviewed by the Contractor's Quality Control System. Only add a "G" to an item, if the submittal is sufficiently important or complex in context of the project.

For submittals requiring Government approval on Army projects, a code of up to three characters within the submittal tags may be used following the "G" designation to indicate the approving authority.

Codes for Army projects using the Resident Management System (RMS) are: "AE" for Architect-Engineer; "DO" for District Office (Engineering Division or other organization in the District Office); "AO" for Area Office; "RO" for Resident Office; and "PO" for Project Office. Codes following the "G" typically are not used for Navy, Air Force, and NASA projects.

Use the "S" classification only in SD-11 Closeout Submittals. The "S" following a submittal item indicates that the submittal is required for the Sustainability eNotebook to fulfill federally mandated sustainable requirements in accordance with Section 01 33 29 SUSTAINABILITY REPORTING.

Choose the first bracketed item for Navy, Air Force and NASA projects, or choose the second bracketed item for Army projects.

Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are for [Contractor Quality Control approval.] [information only. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government.] Submittals with an "S" are for inclusion in the Sustainability eNotebook, in conformance to Section 01 33 29 SUSTAINABILITY REPORTING. Submit the following in accordance with Section 01 33 00 SUBMITTAL PROCEDURES:

SD-02 Shop Drawings

Geomembrane Panel Layout
Penetrations
As-Built Drawings; G[, [_____]]

SD-03 Product Data

Materials; G[, [_____]]
Field Seaming; G[, [_____]]
Qualifications

SD-04 Samples

Samples

SD-06 Test Reports

Surface Preparation
Non-Destructive Field Seam Continuity Testing
Destructive Field Seam Testing
Destructive Seam Test Repairs
Interface Friction Testing
Tests

SD-07 Certificates

Samples
Materials

Surface Preparation
Destructive Field Seam Testing
Destructive Seam Test Repairs
Interface Friction Testing
Tests

1.5 QUALITY CONTROL

1.5.1 Qualifications

1.5.1.1 Manufacturer

Manufacturer shall have produced the proposed geomembrane sheets for at least 5 completed projects having a total minimum area of [930,000] [_____] square meters [10] [_____] million square feet.

1.5.1.2 Fabricator

The fabricator is responsible for seaming geomembrane sheets into panels. Fabricator shall have fabricated the proposed geomembrane panels for at least 5 completed projects having a total minimum area of [186,000] [_____] square meters [2] [_____] million square feet.

1.5.1.3 Installer

The installer is responsible for field handling, deploying, seaming, anchoring, and field Quality Control (QC) testing of the geomembrane. The installer shall have installed the proposed geomembrane material for at least 5 completed projects having a total minimum area of [186,000] [_____] square meters [2] [_____] million square feet. At least one seamer shall have experience seaming a minimum of [46,500] [_____] square meters [500,000] [_____] square feet of the proposed geomembrane using the same type of seaming equipment and geomembrane thickness specified for this project.

1.5.1.4 QC Inspector

NOTE: A separate third party quality assurance (QA) contract should be considered based on the qualifications of the Government QA personnel, the size and importance of the project, and impacts of a geomembrane failure.

The QC inspector is the person or corporation hired by the Contractor, who is responsible for monitoring and documenting activities related to the QC of the geomembrane from manufacturing through installation. The QC inspector shall have provided QC inspection during installation of the proposed geomembrane material for at least 5 completed projects having a total minimum area of [186,000] [_____] square meters [2] [_____] million square feet.

1.5.1.5 QC Laboratory

The QC laboratory shall have provided QC and/or Quality Assurance (QA) testing of the proposed geomembrane and geomembrane seams for at least five completed projects having a total minimum area of [186,000] [_____] square meters [2] [_____] million square feet. The QC laboratory shall be

accredited via the Geosynthetic Accreditation Institute's Laboratory Accreditation Program (GAI-LAP) for the tests the QC laboratory will be required to perform.

1.5.2 Submittal Requirements

Submit manufacturer's, and fabricator's qualification statements, including resumes of key personnel involved in the project, a minimum of [7] [_____] days prior to geomembrane shipment. Also submit installer's, QC inspector's, and QC laboratory's qualification statements including resumes of key personnel involved in the project a minimum of [7] [_____] days prior to geomembrane placement. The submittal from the QC laboratory shall include verification that the laboratory is accredited via the Geosynthetic Accreditation Institute's Laboratory Accreditation Program (GAI-LAP) for the tests the QC laboratory will be required to perform. The following shall also be submitted:

- a. Manufacturer's and fabricator's QC manuals, a minimum of [7] [_____] days prior to geomembrane shipment. Installer's QC manual, a minimum of [7] [_____] days prior to geomembrane placement.
- b. Geomembrane QA and QC samples.
- c. Manufacturer's certified raw and sheet material test reports and a copy of the QC certificates, a minimum of [7] [_____] days prior to shipment of geomembrane to the site.
- d. Certification from the QC inspector and installer of the acceptability of the surface on which the geomembrane is to be placed, immediately prior to geomembrane placement.
- e. QC inspector certified test results on all field seams. Installer and certified QC laboratory test results on all destructively tested field seams. QC inspector certified test results on all repaired seams. Certified QC test results.
- f. Certified laboratory interface friction test results including description of equipment and test method, a minimum of [7] [_____] days prior to geomembrane shipment.

1.6 DELIVERY, STORAGE AND HANDLING

1.6.1 Delivery

The QC inspector shall be present during delivery and unloading of the geomembrane. Each geomembrane roll/panel shall be labeled with the manufacturer's name, product identification number, roll/panel number, and roll dimensions.

1.6.2 Storage

Temporary storage at the project site shall be on a level surface, free of sharp objects where water cannot accumulate. The geomembrane shall be protected from puncture, abrasion, excessive heat or cold, material degradation, or other damaging circumstances. Storage shall not result in crushing the core of roll goods or flattening of the rolls. Rolls shall not be stored more than two high. Palletted materials shall be stored on level surfaces and shall not be stacked on top of one another. Ultraviolet sensitive materials (i.e., PVC) shall be covered with a sacrificial opaque

and waterproof covering or placed in a temporary shelter. Damaged geomembrane shall be removed from the site and replaced with geomembrane that meets the specified requirements.

1.6.3 Handling

Rolls/panels shall not be dragged, lifted by one end, or dropped. A pipe or solid bar, of sufficient strength to support the full weight of a roll without significant bending, shall be used for all handling activities. The diameter of the pipe or solid bar shall be small enough to be easily inserted through the core of the roll. Chains shall be used to link the ends of the pipe or bar to the ends of a spreader bar. The spreader bar shall be wide enough to prevent the chains from rubbing against the ends of the roll. Alternatively, a stinger bar protruding from the end of a forklift or other equipment may be used. The stinger bar shall be at least three-fourths the length of the core and also must be capable of supporting the full weight of the roll without significant bending. If recommended by the manufacturer, a sling handling method utilizing appropriate loading straps may be used.

1.7 AMBIENT CONDITIONS

Geomembrane shall not be deployed or field-seamed in the presence of excess moisture (i.e., rain, fog, dew), in areas of ponded water, or in the presence of excess wind. Unless authorized by the Contracting Officer, no placement or seaming shall be attempted at ambient temperatures below 0 degrees C 32 degrees F or above 40 degrees C 104 degrees F. Ambient temperature shall be measured at a height no greater than 150 mm 6 inches above the ground or geomembrane surface. If seaming is allowed below 0 degrees C 32 degrees F, the procedures outlined in GSI GRI GM9 shall be followed. In marginal conditions, seaming shall cease unless destructive field seam tests, conducted by the QC laboratory, confirm that seam properties meet the requirements listed in Table [3] [5]. Tests shall be conducted in accordance with paragraph Destructive Field Seam Testing.

PART 2 PRODUCTS

2.1 MATERIALS

2.1.1 Raw Materials

Resin used in manufacturing geomembrane sheets shall be made of virgin uncontaminated ingredients. No more than [10] [_____] percent regrind, reworked, or trim material in the form of chips or edge strips shall be used to manufacture the geomembrane sheets. All regrind, reworked, or trim materials shall be from the same manufacturer and exactly the same formulation as the geomembrane sheet being produced. No post consumer materials or water-soluble ingredients shall be used to produce the geomembrane. For geomembranes with plasticizers, only primary plasticizers that are resistant to migration shall be used. Submit a copy of the test reports and QC certificates for materials used in the manufacturing of the geomembrane shipped to the site.

2.1.2 Sheet Materials

NOTE: USACE practice on landfill cover systems has been to use a minimum nominal geomembrane thickness of 1 mm 40 mils. This criterion is based on

survivability. USACE practice for landfill liner systems has been to use a minimum nominal geomembrane thickness of 1.5 mm 60 mils. Site-specific analyses should be conducted to determine the appropriate thickness for both landfill liners and covers. Reinforced geomembranes are generally not recommended where geomembrane elongation properties are critical (i.e., landfill covers) but may be suitable for other applications such as liquid surface impoundments. The property values listed in Tables 1, 2, and 4 are based on industry agreed upon Manufacturing Quality Control (MQC) values for 40 mil smooth and textured HDPE and 40 mil smooth PVC. These values are provided as examples only. Refer to GRI Test Method GM-13 when specifying MQC values for other thicknesses of HDPE.

Tables 1 and 2 can also be used for LLDPE geomembranes. Refer to GSI GRI GM17 when specifying MQC property requirements for LLDPE. If LLDPE geomembrane is being specified, omit property requirements for stress crack resistance (ASTM D5397), yield strength (ASTM D882), and yield elongation (ASTM D882).

Include property requirements for multi-axial tensile strength (ASTM D5617). Property requirements for multi-axial tensile tests simulate a void beneath the geomembrane or differential settlement which may stress the geomembrane beyond its multi-axial strain limit. Multi-axial tensile tests are typically specified for HDPE geomembranes only when the geomembrane is likely to be subjected to significant multi-axial stresses. If multi-axial testing will be performed on an HDPE geomembrane, tests should be performed in accordance with ASTM D5617. A minimum multi-axial tensile strain at rupture of 20 percent is typically specified for smooth HDPE geomembranes. For textured HDPE geomembranes, the specified minimum multi-axial tensile strain at rupture should be 15 percent.

Refer to the PVC Geomembrane Institute's PGI 1197 when specifying MQC values for other thicknesses of PVC. For other material types, evaluate at least three current manufacturer's property sheets for each acceptable material type before specifying property test values.

Geomembrane sheets shall be [unreinforced] [reinforced] and manufactured as wide as possible to minimize factory and field seams. Geomembrane sheets shall be uniform in color, thickness, and surface texture. For slopes greater than or equal to 1V on [_____] H, sheets shall be textured on [the upper face] [the lower face] [both faces]. The textured surface features shall consist of raw materials identical to that of the parent sheet material and shall be uniform over the entire face of the geomembrane. The sheets shall be free of and resistant to fungal or bacterial attack and free of cuts, abrasions, holes, blisters, contaminants and other

imperfections. Geomembrane sheets and factory seams shall conform to the requirements listed in Table [1] [2] [3] [4] and [5] for Manufacturing Quality Control (MQC).

| TABLE 1 - SMOOTH HDPE GEOMEMBRANE PROPERTIES | | | |
|---|--|------------------------------------|--------------------------|
| PROPERTY | TEST VALUE | MQC TESTING FREQUENCY (MIN.) | TEST METHOD |
| Thickness (min ave) | [1] [_____] mm [40] [_____] mils | per roll | ASTM D5199 |
| Lowest individual of 10 values | -10 percent | per roll | ASTM D5199 |
| Density (min) | 0.940 g/cc | per 90,000 kg per 200,000 lb | ASTM D1505 |
| Tensile Properties(1)(min ave) | | per 9,000 kg per 20,000 lb | ASTM D638 Type IV |
| yield stress | [15] [_____] kN/m [84] [_____] lb/in | | |
| break stress | [27] [_____] kN/m [152] [_____] lb/in | | |
| yield elong | [12] [_____] percent | | |
| break elong | [700] [_____] percent | | |
| Tear Resistance (min ave) | [125] [_____] N [28] [_____] lb | per 20,000 kg per 45,000 lb | ASTM D1004 |
| Puncture Resistance(min ave) | [320] [_____] N [72] [_____] lb | per 20,000 kg per 45,000 lb | ASTM D4833/D4833M |
| Stress Crack Resistance (2) | [200] [_____] hr | per 90,000 kg per 200,000 lb | ASTM D5397 (Appendix) |
| Carbon Black Content | 2.0-3.0 percent | per 9,000 kg per 20,000 lb | ASTM D1603 (3) |
| Carbon Black Dispersion | Note (4) | per 20,000 kg per 45,000 lb | ASTM D5596 |
| Oxidative Induction Time (OIT)(min ave)(5) | | per 90,000 kg per 200,000 lb | |
| -Std OIT | 100 min | | ASTM D3895 |
| -High Pres OIT | 400 min | | ASTM D5885/D5885M |
| Oven Aging at 85 deg C 185 deg F (min ave) (5), (6) | | per year and change in formulation | ASTM D5721 |

| TABLE 1 - SMOOTH HDPE GEOMEMBRANE PROPERTIES | | | |
|--|---------------|------------------------------------|-------------------|
| PROPERTY | TEST VALUE | MQC TESTING FREQUENCY (MIN.) | TEST METHOD |
| | Std OIT | 55 percent at 90 days | ASTM D3895 |
| or | High Pres OIT | 80 percent at 90 days | ASTM D5885/D5885M |
| UV Resistance (min ave) (7) | | per year and change in formulation | ASTM D7238 |
| High Pres OIT(8)(9) | | 50 percent at 1600 hours | ASTM D5885/D5885M |

| TABLE 2 - TEXTURED HDPE GEOMEMBRANE PROPERTIES | | | |
|--|---|---------------------------------|----------------------|
| PROPERTY | TEST VALUE | MQC TESTING FREQUENCY (MIN.) | TEST METHOD |
| Nominal Thickness | [1] [_____] mm [40] [_____] mils | | |
| Thickness (min ave) | -5 percent of nominal | per roll | ASTM D5994/D5994M |
| Lowest individual for 8 out of 10 values | -10 percent of nominal | per roll | ASTM D5994/D5994M |
| Lowest individual of 10 values | -15 percent of nominal | per roll | ASTM D5994/D5994M |
| Asperity Height (min ave) (10) | 0.25 mm/10 mils | every second roll | ASTM D7466 (11) |
| Density (min) | 0.940 g/cc | per 90,000 kg per 200,000 lb | ASTM D1505 |
| Tensile Properties(1)(min ave) | | per 9,000 kg per 20,000 lb | ASTM D638 Type IV |
| yield stress | [15] [_____] kN/m [84] [_____] lb/in | | |
| break stress | [11] [_____] kN/m [60] [_____] lb/in | | |
| yield elongation | [12] [_____] percent | | |
| break elongation | [100] [_____] percent | | |

| TABLE 2 - TEXTURED HDPE GEOMEMBRANE PROPERTIES | | | |
|---|------------------------------------|--|--------------------------|
| PROPERTY | TEST VALUE | MQC TESTING FREQUENCY (MIN.) | TEST METHOD |
| Tear Resistance (min ave) | [125] [_____] N [28] [_____] lb | per 20,000 kg per 45,000 lb | ASTM D1004 |
| Puncture Resistance(min ave) | [267] [_____] N [60] [_____] lb | per 20,000 kg per 45,000 lb | ASTM D4833/D4833M |
| Stress Crack Resistance (2) | [200] [_____] hr | per 90,000 kg per 200,000 lb | ASTM D5397 (Appendix) |
| Carbon Black Content | 2.0-3.0 percent | per 9,000 kgper 20,000 lb | ASTM D1603 (3) |
| Carbon Black Dispersion | Note (4) | per 20,000 kg per 45,000 lb | ASTM D5596 |
| Oxidative Induction Time (OIT)(min ave)(5) | | per 90,000 kg per 200,000 lb | |
| Std OIT | 100 min | | ASTM D3895 |
| or High Pres OIT | 400 min | | ASTM D5885/D5885M |
| Oven Aging at 85 deg C 185 deg F (min ave) (5), (6) | | per year and change in formulation | ASTM D5721 |
| Std OIT | 55 percent at 90 days | | ASTM D3895 |
| or High Pres OIT | 80 percent at 90 days | | ASTM D5885/D5885M |
| UV Resistance (min ave) (7) | | per year and change in formulation | ASTM D7238 |
| High Pres OIT(8)(9) | 50 percent at 1600 hours | | ASTM D5885/D5885M |

| TABLE 1 AND TABLE 2 NOTES | |
|---------------------------|-------------------------------|
| MQC | Manufacturing Quality Control |

| TABLE 1 AND TABLE 2 NOTES | |
|---------------------------|---|
| Note (1) | Minimum average machine direction and minimum average cross machine direction values shall be based on 5 test specimens in each direction. For HDPE geomembrane, yield elongation is calculated using a gauge length of 33 mm 1.3 inches. For HDPE geomembrane, break elongation is calculated using a gauge length of 50 mm 2.0 inches. For LLDPE geomembrane, break elongation is calculated using a gage length of 50 mm 2.0 inches at 50 mm/min 2 inches/min. |
| Note (2) | For HDPE geomembrane, the yield stress used to calculate the applied load for test method ASTM D5397 (Appendix), shall be the manufacturer's mean value. ASTM D5397 does not need to be run on LLDPE geomembrane. |
| Note (3) | Other methods such as ASTM D4218 or microwave methods are acceptable if an appropriate correlation to ASTM D1603 can be established. |
| Note (4) | Carbon black dispersion for 10 different views: - minimum 8 of 10 in Categories 1 or 2 - all 10 in Categories 1,2, or 3 |
| Note (5) | The manufacturer has the option to select either one of the OIT methods to evaluate the antioxidant content. |
| Note (6) | Evaluate samples at 30 and 60 days and compare with the 90 day response. |
| Note (7) | The condition of the test shall be a 20 hour UV cycle at 75 degrees C 167 degrees F followed by a 4 hour condensation cycle at 60 degrees C 140 degrees F. |
| Note (8) | The standard OIT test (ASTM D3895) shall not be used in determining UV resistance. |
| Note (9) | UV resistance is based on percent retained value regardless of the original HP-OIT value. |
| Note (10) | Textured Geomembrane Only: Of 10 readings; 8 out of 10 must be 0.18 mm 7 mil, and lowest individual reading must be 0.13 mm 5 mil. |
| Note (11) | Textured Geomembrane Only: Alternate the measurement side for double sided textured sheet. |

| TABLE 3 - HDPE SEAM PROPERTIES | | |
|---|--|-------------|
| PROPERTY | TEST VALUE | TEST METHOD |
| Seam Shear Strength (min) (1) | [14.0] [_____] kN/m[80] [_____] lb/in | ASTM D6392 |
| Seam Peel Strength (min) (1) (2) | [8.4] [_____] kN/m[48] [_____] lb/in | ASTM D6392 |
| Note (1): Seam tests for peel and shear must fail in the Film Tear Bond mode. This is a failure in the ductile mode of one of the bonded sheets by tearing or breaking prior to complete separation of the bonded area. | | |

| TABLE 3 - HDPE SEAM PROPERTIES | | |
|---|------------|-------------|
| PROPERTY | TEST VALUE | TEST METHOD |
| Note (2): Where applicable, both tracks of a double hot wedge seam shall be tested for peel adhesion. | | |

| TABLE 4 - SMOOTH PVC GEOMEMBRANE PROPERTIES | | |
|--|---|---------------------|
| PROPERTY | TEST VALUE | TEST METHOD |
| Thickness (nominal) | [1] [_____] mm[40] [_____] mils | ASTM D1593 |
| Thickness (min) | [0.95] [_____] mm[38] [_____] mils | ASTM D1593 |
| Specific Gravity (min) | 1.2 g/ml | ASTM D792 |
| Tensile Properties (min) | | ASTM D882, Method A |
| break strength (Machine direction (MD) and Transvers direction (TD)) | [17.0] [_____] kN/m[97] [_____] lb/in | |
| elongation @ break (MD and TD) | [400] [_____] percent | |
| modulus @ 100 percent (MD and TD) | [7.2] [_____] kN/m[41] [_____] lb/in | |
| Tear Resistance (min) | [46.7] [_____] kN/m[10.5] [_____] lb/in | ASTM D1004, Die C |
| Low Temperature, pass | -29 degrees C-20 degrees F | ASTM D1790 |
| Dimensional Stability (max)(MD and TD) | [3] [_____] percent | ASTM D1204 |
| Water Extraction (max) | [0.2] [_____] percent loss | See Note 1 |
| Volatile Loss (max) | [0.5] [_____] percent loss | ASTM D1203 (A) |
| Resistance to Soil Burial | | See Note 1 |
| breaking factor | +/- 5 percent | |
| elongation @ break | +/- 20 percent | |
| 100 percent modulus | +/- 20 percent | |
| Water Vapor | .00000000005 m/sec | ASTM D814 |
| Hydrostatic Resistance (min) | [827] [_____] kN/sq m[120] [_____] lb/sq in | ASTM D751 (A) |
| | | |

| TABLE 4 - SMOOTH PVC GEOMEMBRANE PROPERTIES | | |
|--|------------|-------------|
| PROPERTY | TEST VALUE | TEST METHOD |
| NOTE 1: Water Extraction and Resistance to Soil Burial testing shall be performed in accordance with manufacturer's approved procedures. | | |

| TABLE 5 - PVC SEAM PROPERTIES | | |
|---|--|-------------------------------|
| PROPERTY | TEST VALUE | TEST METHOD |
| Seam Shear Strength (min) | [13.5] [_____] kN/m[77] [_____] lb/in | Installers approved procedure |
| Seam Peel Strength (min) (1) | [2.6] [_____] kN/m[15] [_____] lb/in | Installers approved procedure |
| Note (1): Where applicable, both tracks of a double hot wedge seam shall be tested for peel adhesion. | | |

2.1.3 Factory Seams

NOTE: Polyethylene geomembranes are not usually factory seamed. Delete this paragraph when factory seaming is not applicable.

Geomembrane sheets shall be factory seamed into maximum sized panels to minimize field seaming. Factory seaming shall be by methods approved by the geomembrane manufacturer. Seams shall meet the minimum shear and peel strength requirements shown in Table [3] [5]. Factory seams shall extend to the end of the sheet so that no unbonded edges greater than 3.2 mm 1/8 inch wide are present.

2.2 TESTS, INSPECTIONS, AND VERIFICATIONS

2.2.1 Interface Friction Testing

NOTE: Interface friction testing should be conducted on all potential slip interfaces. The rate of displacement and normal stresses used for interface friction testing are dependent on the materials being tested and anticipated site conditions. Normal stresses specified should cover the range of anticipated field loads. Selection of peak versus residual values should be based on anticipated interface displacements taking into account seismic activities and long term conditions.

The number of interface friction tests must be determined on a site specific basis considering regulator input and the potential for damage due to a shear failure. This testing should be completed

during design or by the Contractor prior to the start of construction.

A method sometimes used to model saturated conditions at the shear interface is to wet these surfaces prior to shearing.

Laboratory interface friction tests shall be conducted on the following interfaces: [____]. The frequency of testing for each interface shall be [1 per [____] acres of geomembrane placed] [[____] per project]. Tests shall be conducted in accordance with ASTM D5321/D5321M. Normal stresses of [____], [____], and [____] kPa psi along with a displacement rate of [1.0] [5.0] [____] mm [0.04] [0.2] [____] inches per minute shall be used. Interfaces tested shall be [wet] [dry]. Soil components shall be the same as used for full scale construction and shall be compacted to the same moisture-density requirements specified for full scale field placement. Geosynthetics shall be the same materials as those proposed for use during full scale construction. Geosynthetics shall be oriented such that the shear force is parallel to the down slope orientation of these components in the field. A minimum [peak] [residual] interface friction angle of [____] degrees is required for all interfaces.

2.2.2 Manufacturing, Sampling, and Testing

2.2.2.1 Raw Materials

Raw materials shall be tested in accordance with the approved MQC manual. Any raw material which fails to meet the geomembrane manufacturer's specified physical properties shall not be used in manufacturing the sheet. Seaming rods and pellets shall be manufactured of materials which are essentially identical to that used in the geomembrane sheet. Seaming rods and pellets shall be tested for density, melt index and carbon black content in accordance with the approved MQC manual. Seaming rods and pellets which fail to meet the corresponding property values required for the sheet material, shall not be used for seaming.

2.2.2.2 Sheet Material

Geomembrane sheets shall be tested in accordance with the approved MQC manual. As a minimum, MQC testing shall be conducted at the frequencies shown in Table 1. Sheets not meeting the minimum requirements specified in Table 1 shall not be sent to the site.

2.3 EQUIPMENT

Equipment used in performance of the work shall be in accordance with the geomembrane manufacturer's recommendations and shall be maintained in satisfactory working condition.

PART 3 EXECUTION

3.1 PREPARATION

3.1.1 Surface Preparation

NOTE: Ensure other sections of the specification package adequately address compaction requirements

for soil subgrade layers.

Surface preparation shall be performed in accordance with Section 31 00 00 EARTHWORK. Rocks larger than [13] [_____] mm [1/2] [_____] inch in diameter and any other material which could damage the geomembrane shall be removed from the surface to be covered with the geomembrane. Construction equipment tire or track deformations beneath the geomembrane shall not be greater than 25 mm 1.0 inch in depth. Each day during placement of geomembrane, the [QC Inspector] [Contracting Officer] and installer shall inspect the surface on which geomembrane is to be placed and certify in writing that the surface is acceptable. Repairs to the subgrade shall be performed at no additional cost to the Government.

3.1.2 Anchor Trenches

Where an anchor trench is required, it shall be placed [610] [_____] mm [24] [_____] inches back from the edge of the slope to be covered. The anchor trench shall be [610] [_____] mm [24] [_____] inches deep and [460] [_____] mm [18] [_____] inches wide. If the anchor trench is excavated in cohesive soil susceptible to desiccation, only the amount of anchor trench required for placement of geomembrane in a single day shall be excavated. Ponded water shall be removed from the anchor trench while the trench is open. Trench corners shall be slightly rounded to avoid sharp bends in the geomembrane. Loose soil, rocks larger than [13] [_____] mm [1/2] [_____] inch in diameter, and any other material which could damage the geomembrane shall be removed from the surfaces of the trench. The geomembrane shall extend down the front wall and across the bottom of the anchor trench. Backfilling and compaction of the anchor trench shall be in accordance with Section 31 00 00 EARTHWORK.

3.2 GEOMEMBRANE DEPLOYMENT

The procedures and equipment used shall not elongate, wrinkle, scratch, or otherwise damage the geomembrane, other geosynthetic layers, or the underlying subgrade. Geomembrane damaged during installation shall be replaced or repaired, at the [QC inspector's] [Contracting Officer's] discretion. Only geomembrane panels that can be anchored and seamed together the same day shall be deployed. Adequate ballast (i.e., sand bags) shall be placed on the geomembrane, without damaging the geomembrane, to prevent uplift by wind. No equipment shall be operated on the top surface of the geomembrane without permission from the Contracting Officer. Seams shall be oriented parallel to the line of maximum slope. Where seams can only be oriented across the slope, the upper panel shall be lapped over the lower panel. The methods used to deploy and backfill over the geomembrane shall minimize wrinkles and tensile stresses in the geomembrane. The geomembrane shall have adequate slack to prevent the creation of tensile stress. The wrinkle height to width ratio for installed geomembrane shall not exceed 0.5. In addition, geomembrane wrinkles shall not exceed 150 mm 6 inches in height. Wrinkles that do not meet the above criteria shall be cut out and repaired in accordance with the installer's approved QC manual.

3.3 FIELD SEAMING

3.3.1 Trial Seams

Trial seams shall be made under field conditions on strips of excess geomembrane. Trial seams shall be made each day prior to production

seaming, whenever there is a change in seaming personnel or seaming equipment and at least once every four hours, by each seamer and each piece of seaming equipment used that day. Trial seam samples shall be collected and tested in accordance with ASTM D6392. One sample shall be obtained from each trial seam. This sample shall be at least 920 mm long by 305 mm wide 36 inches long by 12 inches wide with the seam centered lengthwise. Ten random specimens 25.4 mm 1 inch wide shall be cut from the sample. Five seam specimens shall be field tested for shear strength and 5 seam specimens shall be field tested for peel adhesion using an approved quantitative tensiometer. Where necessary, accelerated curing of trial seams made by chemical methods shall be conducted in accordance with GSI GRI GM7. To be acceptable, 4 out of 5 replicate test specimens shall meet seam strength requirements specified in Table [3] [5]. If the field tests fail to meet these requirements, the entire operation shall be repeated. If the additional trial seam fails, the seaming apparatus or seamer shall not be used until the deficiencies are corrected by the installer and 2 consecutive successful trial seams are achieved.

3.3.2 Field Seams

Panels shall be seamed in accordance with the geomembrane manufacturer's recommendations. In sumps, corners and odd-shaped geometric locations, the number of field seams shall be minimized. Seaming shall extend to the outside edge of panels. Soft subgrades shall be compacted and approved prior to seaming. The seam area shall be free of moisture, dust, dirt, and foreign material at the time of seaming. Fish mouths in seams shall be repaired.

3.3.2.1 Polyethylene Seams

Polyethylene geomembranes shall be seamed by thermal fusion methods. Extrusion welding shall only be used for patching and seaming in locations where thermal fusion methods are not feasible. Seam overlaps that are to be attached using extrusion welds shall be ground prior to welding. Grinding marks shall be oriented perpendicular to the seam direction and no marks shall extend beyond the extrudate after placement. Extrusion welding shall begin within 10 minutes after grinding. Where extrusion welds are temporarily terminated long enough to cool, they shall be ground prior to applying new extrudate over the existing seam. The total depth of the grinding marks shall be no greater than 10 percent of the sheet thickness.

3.3.2.2 Non-Polyethylene Seams

Non-polyethylene geomembranes shall be seamed by methods as recommended by the geomembrane manufacturer. Seaming adhesives, solvents, or chemical cleaning agents shall be stored away from the geomembrane and only spill-resistant containers shall be used while working on the geomembrane. If low temperatures slow the curing process of chemically fused seams and delay seam testing, GSI GRI GM7 shall be used to accelerate sample curing.

3.4 SAMPLES

One QC sample, 500 mm 18 inches in length, for the entire width of a roll, shall be obtained for every 9,000 square meters 100,000 square feet of material delivered to the site. Samples shall not be obtained from the first three feet of the roll. For accordion folded geomembranes, samples of equivalent size shall be collected from approved locations. The samples shall be identified by manufacturer's name, product identification, lot and roll/panel number. The date, a unique sample number, and the machine

direction shall also be noted. In addition, a [305 by 305 mm] [_____] [12 inch by 12 inch] [_____] QA sample shall be collected, labeled, and submitted to the Contracting Officer each time QC samples are collected.

3.5 TESTS

Provide all QC samples to the QC laboratory to determine density, thickness, tensile strength at break, and elongation at break in accordance with the methods specified in Table [1] [2] [4]. Samples not meeting the specified requirements shall result in the rejection of applicable rolls/panels. As a minimum, rolls/panels produced immediately prior to and immediately after the failed roll/panel shall be tested for the same failed parameter. Testing shall continue until a minimum of three successive rolls/panels on both sides of the original failing roll/panel pass the failed parameter.

3.5.1 Non-Destructive Field Seam Continuity Testing

Field seams shall be non-destructively tested for continuity over their full length in accordance with the installer's approved QC manual. Seam testing shall be performed as the seaming work progresses, not at the completion of field seaming. Any seams which fail shall be documented and repaired in accordance with the installer's approved QC manual.

3.5.2 Destructive Field Seam Testing

A minimum of one destructive test sample per [230] [_____] m [750] [_____] feet of field seam shall be obtained at locations specified by the [QC inspector] [Contracting Officer]. Sample locations shall not be identified prior to seaming. Samples shall be a minimum of 305 mm 12 inches wide by 1.1 m 42 inches long with the seam centered lengthwise. Each sample shall be cut into 3 equal pieces, with one piece retained by the installer, one piece given to the QC laboratory, and the remaining piece given to the Contracting Officer for QA testing and/or permanent record. Each sample shall be numbered and cross referenced to a field log which identifies: (1) panel number; (2) seam number; (3) date and time cut; (4) ambient temperature within 150 mm 6 inches above the geomembrane; (5) seaming unit designation; (6) name of seamer; and (7) seaming apparatus temperature and pressures (where applicable). Ten 25 mm 1 inch wide replicate specimens shall be cut from the installer's sample. Five specimens shall be tested for shear strength and 5 for peel adhesion using an approved field quantitative tensiometer. Jaw separation speed shall be in accordance with the approved QC manual. To be acceptable, 4 out of 5 replicate test specimens shall meet the seam strength requirements specified in Table [3][5]. If the field tests pass, 5 specimens shall be tested at the QC laboratory for shear strength and 5 for peel adhesion in accordance with the QC laboratory's approved procedures. To be acceptable, 4 out of 5 replicate test specimens shall meet the seam strength requirements specified in Table [3][5]. If the field or laboratory tests fail, the seam shall be repaired in accordance with paragraph Destructive Seam Test Repairs. Holes for destructive seam samples shall be repaired the same day they are cut.

3.6 DEFECTS AND REPAIRS

3.6.1 Destructive Seam Test Repairs

Seams that fail destructive seam testing may be overlaid with a strip of new material and seamed (cap stripped). Alternatively, the seaming path

shall be retraced to an intermediate location a minimum of 3 m 10 feet on each side of the failed seam location. At each location a 305 by 460 mm 12 by 18 inch minimum size seam sample shall be taken for 2 additional shear strength and 2 additional peel adhesion tests using an approved quantitative field tensiometer. If these tests pass, then the remaining seam sample portion shall be sent to the QC laboratory for 5 shear strength and 5 peel adhesion tests in accordance with the QC laboratory's approved procedures. To be acceptable, 4 out of 5 replicate test specimens must meet specified seam strength requirements. If these laboratory tests pass, then the seam shall be cap stripped or repaired using other approved methods between that location and the original failed location. If field or laboratory tests fail, the process shall be repeated. After repairs are completed, the repaired seam shall be non-destructively tested in accordance with paragraph Non-Destructive Field Seam Continuity Testing.

3.6.2 Patches

Tears, holes, blisters and other defects shall be repaired with patches. Patches shall have rounded corners, be made of the same geomembrane, and extend a minimum of 150 mm 6 inches beyond the edge of defects. Minor localized flaws shall be repaired by spot welding or seaming as determined by the QC inspector. Repairs shall be non-destructively tested. The Contracting Officer or the QC inspector may also elect to perform destructive seam tests on suspect areas.

3.7 VISUAL INSPECTION AND EVALUATION

Immediately prior to covering, the geomembrane, seams, and non-seam areas shall be visually inspected by the QC inspector and Contracting Officer for defects, holes, or damage due to weather conditions or construction activities. At the Contracting Officer's or the QC inspector's discretion, the surface of the geomembrane shall be brushed, blown, or washed by the installer if the amount of dust, mud, or foreign material inhibits inspection or functioning of the overlying material. Each suspect location shall be non-destructively tested in accordance with paragraph Non-Destructive Field Seam Continuity Testing. Each location that fails non-destructive testing shall be repaired in accordance with paragraph Patches and non-destructively retested.

3.8 PENETRATIONS

NOTE: Minimize the number of penetrations and show their locations on the drawings. Referencing the manufacturer's typical penetration details is generally acceptable.

Geomembrane penetration details shall be [as indicated] [in accordance with ASTM D6497/D6497M or as recommended by the geomembrane manufacturer]. Use factory fabricated boots wherever possible. Non-destructively test field seams for penetrations in accordance with the installer's approved QC manual. Repair seams that fail non-destructive testing in accordance with the installer's approved QC manual and non-destructively tested prior to acceptance.

3.9 PROTECTION AND BACKFILLING

The deployed and seamed geomembrane shall be covered with the specified

material within [5] [14] [_____] calendar days of acceptance. Wrinkles in the geomembrane shall be prevented from folding over during placement of cover materials. Cover soil shall not be dropped onto the geomembrane or overlying geosynthetics from a height greater than 1 m 3 feet. The soil shall be pushed out over the geomembrane or overlying geosynthetics in an upward tumbling motion. Soil shall be placed from the bottom of the slope upward. The initial loose soil lift thickness shall be [350] [_____] mm [12] [_____] inches. Equipment with ground pressures less than 50 kPa 7 psi shall be used to place the first lift over the geomembrane. A minimum of [460] [610] [915] [_____] mm [18] [24] [36] [_____] inches of soil shall be maintained between construction equipment with ground pressures greater than 50 kPa 7 psi and the geomembrane. Cover soil compaction and testing requirements are described in Section 31 00 00 EARTHWORK. Equipment placing cover soil shall not stop abruptly, make sharp turns, spin their wheels, or travel at speeds exceeding [2.2] [_____] m/s [5] [_____] mph.

3.10 As-Built drawings

Submit final as-built drawings of the geomembrane installation. These drawings shall include panel numbers, seam numbers, location of repairs, destructive seam samples, and penetrations.

-- End of Section --