
USACE / NAVFAC / AFCEA UFGS-02372 (March 2005)

Preparing Activity: USACE Superseding
UGGS-02372 (October 2004)

UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated 23 June 2005

Latest change indicated by CHG tags

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SECTION 02372

WASTE CONTAINMENT GEOMEMBRANE

03/05

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SECTION 02372

WASTE CONTAINMENT GEOMEMBRANE 03/05

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

Comments and suggestions on this guide specification are welcome and should be directed to the technical proponent of the specification. A listing of technical proponents, including their organization designation and telephone number, is on the Internet.

Recommended changes to a UFGS should be submitted as a Criteria Change Request (CCR).

Use of electronic communication is encouraged.

Brackets are used in the text to indicate designer choices or locations where text must be supplied by the designer.

PART 1 GENERAL

NOTE: 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 REFERENCES

NOTE: Issue (date) of references included in project specifications need not be more current than provided by the latest guide specification. Use of SpecsIntact automated reference checking is recommended for projects based on older guide specifications.

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 D 1004	(2003) Initial Tear Resistance of Plastic Film and Sheeting
ASTM D 1203	(1994; R 2003) Volatile Loss from Plastics Using Activated Carbon Methods
ASTM D 1204	(2002) Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature
ASTM D 1505	(2003) Density of Plastics by the Density-Gradient Technique
ASTM D 1593	(1999) Nonrigid Vinyl Chloride Plastic Film and Sheeting
ASTM D 1603	(2001) Carbon Black in Olefin Plastics
ASTM D 1790	(2002) Brittleness Temperature of Plastic Sheeting by Impact
ASTM D 3895	(2004) Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
ASTM D 4218	(1996; R 2001) Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
ASTM D 4833	(2000e1) Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products
ASTM D 5199	(2001) Measuring Nominal Thickness of Geosynthetics
ASTM D 5321	(2002) Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method
ASTM D 5397	(1999e1) Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test

ASTM D 5596	(2003) Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
ASTM D 5721	(1995; R 2002) Air-Oven Aging of Polyolefin Geomembranes
ASTM D 5885	(1997) Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry
ASTM D 5994	(1998; R 2003) Measuring Core Thickness of Textured Geomembrane
ASTM D 638	(2003) Tensile Properties of Plastics
ASTM D 6392	(1999) Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods
ASTM D 6497	(2002) Mechanical Attachment of Geomembrane to Penetrations or Structures
ASTM D 751	(2000) Coated Fabrics
ASTM D 792	(2000) Density and Specific Gravity (Relative Density) of Plastics by Displacement
ASTM D 814	(1995; R 2000) Rubber Property - Vapor Transmission of Volatile Liquids
ASTM D 882	(2002) Tensile Properties of Thin Plastic Sheeting

GEOSYNTHETIC INSTITUTE (GSI)

GSI GRI GM11	(1997) Accelerated Weathering of Geomembranes Using a Fluorescent UVA Device
GSI GRI GM12	(1998) Asperity Measurement of Textured Geomembranes Using a Depth Gauge
GSI GRI GM7	(1995) Accelerated Curing of Geomembrane Test Strip Seams Made by Chemical Fusion Methods
GSI GRI GM9	(1995) Cold Weather Seaming of Geomembranes

1.2 MEASUREMENT

NOTE: Delete paragraphs MEASUREMENT and PAYMENT
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.

1.3 PAYMENT

Geomembrane installed and accepted by the Contracting Officer will be paid for at the respective contract unit price in the bidding schedule.

1.4 SUBMITTALS

NOTE: Submittals must be limited to those necessary for adequate quality control. The importance of an item in the project should be one of the primary factors in determining if a submittal for the item should be required.

A "G" following a submittal item indicates that the submittal requires Government approval. Some submittals are already marked with a "G". Only delete an existing "G" if the submittal item is not complex and can be reviewed through the Contractor's Quality Control system. Only add a "G" 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 projects.

Submittal items not designated with a "G" are considered as being for information only for Army projects and for Contractor Quality Control approval for Navy projects.

Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are [for Contractor Quality Control approval.] [for information only. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government.] The following shall be submitted in accordance with Section 01330 SUBMITTAL PROCEDURES:

SD-02 Shop Drawings

Penetrations[; G][; G, [____]]

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

As-Built Drawings[; G][; G, [_____]]

Final as-built drawings of geomembrane installation

SD-03 Product Data

Tests, Inspections, and Verifications[; G][; G, [_____]]

Manufacturer's and fabricator's QC manuals, a minimum of [7] [_____] days prior to geomembrane shipment.

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

Installer's QC manual, a minimum of [7] [_____] days prior to geomembrane placement.

Qualifications[; G][; G, [_____]]

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.

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.

SD-04 Samples

Samples

Geomembrane QA and QC samples.

SD-06 Test Reports

Materials[; G][; G, [_____]]

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.

Surface Preparation[; G][; G, [_____]]

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.

Non-Destructive Field Seam Continuity Testing[; G][; G, [_____]]

QC inspector certified test results on all field seams.

Destructive Field Seam Testing[; G][; G, [_____]]

Installer and certified QC laboratory test results on all destructively tested field seams.

Destructive Seam Test Repairs[; G][; G, [____]]

QC inspector certified test results on all repaired seams.

Interface Friction Testing[; G][; G, [____]]

Certified laboratory interface friction test results including description of equipment and test method, a minimum of [7] [____] days prior to geomembrane shipment.

Tests[; G][; G, [____]]

Certified QC test results.

1.5 QUALIFICATIONS

1.5.1 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.

1.5.2 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.

1.5.3 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.

1.5.4 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.

1.5.5 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.

1.6 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. Palletized 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 WEATHER LIMITATIONS

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.

1.8 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 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. The Contractor shall 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 D 5397), yield strength (ASTM D 882), and yield

elongation (ASTM D 882).

Include property requirements for multi-axial tensile strength (ASTM D 5617). 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 D 5617. 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	per roll	ASTM D 5199
Lowest individual of 10 values	-10 percent	per roll	ASTM D 5199
Density (min)	0.940 g/cc	per 90,000 kg	ASTM D 1505
Tensile Properties (1) (min ave)		per 9,000 kg	ASTM D 638 Type IV

TABLE 1. SMOOTH HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
-yield stress	[15] [_____] kN/m		
-break stress	[27] [_____] kN/m		
-yield elong	[12] [_____] percent		
-break elong	[700] [_____] percent		
Tear Resistance (min ave)	[125] [_____] N	per 20,000 kg	ASTM D 1004
Puncture Resistance (min ave)	[320] [_____] N	per 20,000 kg	ASTM D 4833
Stress Crack Resistance (2)	[200] [_____] hr	per 90,000 kg	ASTM D 5397 (Appendix)
Carbon Black Content	2.0-3.0 percent	per 9,000 kg	ASTM D 1603 (3)
Carbon Black Dispersion	Note (4)	per 20,000 kg	ASTM D 5596
Oxidative Induction Time (OIT) (min ave) (5)		per 90,000 kg	
-Std OIT	100 min		ASTM D 3895
or			
-High Pres OIT	400 min		ASTM D 5885
Oven Aging at 85 deg C (min ave) (5), (6)		per year and change in formulation	ASTM D 5721
-Std OIT	55 percent at 90 days		ASTM D 3895
or			
-High Pres OIT	80 percent at 90 days		ASTM D 5885
UV Resistance (min ave) (7)		per year and change in formulation	GSI GRI GM11
-High Pres OIT(8) (9)	50 percent at 1600 hours		ASTM D 5885

TABLE 1. SMOOTH HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
Thickness (min ave)	[40] [_____] mils	per roll	ASTM D 5199
Lowest individual of 10 values	-10 percent	per roll	ASTM D 5199
Density (min)	0.940 g/cc	per 200,000 lb	ASTM D 1505
Tensile Properties (1) (min ave)		per 20,000 lb	ASTM D 638 Type IV
-yield stress	[84] [_____] lb/in		
-break stress	[152] [_____] lb/in		
-yield elong	[12] [_____] percent		
-break elong	[700] [_____] percent		
Tear Resistance (min ave)	[28] [_____] lb	per 45,000 lb	ASTM D 1004
Puncture Resistance (min ave)	[72] [_____] lb	per 45,000 lb	ASTM D 4833
Stress Crack Resistance (2)	[200] [_____] hr	per 200,000 lb	ASTM D 5397 (Appendix)
Carbon Black Content	2.0-3.0 percent	per 20,000 lb	ASTM D 1603 (3)
Carbon Black Dispersion	Note (4)	per 45,000 lb	ASTM D 5596
Oxidative Induction Time (OIT) (min ave) (5)		per 200,000 lb	
-Std OIT	100 min		ASTM D 3895
or			
-High Pres OIT	400 min		ASTM D 5885
Oven Aging at 85 deg C (min ave) (5), (6)		per year and change in formulation	ASTM D 5721
-Std OIT	55 percent at 90 days		ASTM D 3895
or			

TABLE 1. SMOOTH HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
-High Pres OIT	80 percent at 90 days		ASTM D 5885
UV Resistance (min ave) (7)		per year and change in formulation	GSI GRI GM11
-High Pres OIT(8) (9)	50 percent at 1600 hours		ASTM D 5885

TABLE 2. TEXTURED HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
Nominal Thickness	[1.0] [_____] mm		
Thickness (min ave)	-5 percent of nominal	per roll	ASTM D 5994
Lowest individual for 8 out of 10 values	-10 percent of nominal	per roll	ASTM D 5994
Lowest individual of 10 values	-15 percent of nominal	per roll	ASTM D 5994
Asperity Height (min ave) (10)	0.25 mm	every second roll	GSI GRI GM12 (11)
Density (min)	0.940 g/cc	per 90,000 kg	ASTM D 1505
Tensile Properties (1) (min ave)		per 9,000 kg	ASTM D 638 Type IV
-yield stress	[15] [_____] kN/m		
-break stress	[11] [_____] kN/m		
-yield elong	[12] [_____] percent		
-break elong	[100] [_____] percent		
Tear Resistance (min ave)	[125] [_____] N	per 20,000 kg	ASTM D 1004
Puncture	[267] [_____] N	per 20,000 kg	ASTM D 4833

TABLE 2. TEXTURED HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
Resistance (min ave)			
Stress Crack Resistance (2)	[200] [_____] hr	per 90,000 kg	ASTM D 5397 (Appendix)
Carbon Black Content	2.0-3.0 percent	per 9,000 kg	ASTM D 1603 (3)
Carbon Black Dispersion	Note (4)	per 20,000 kg	ASTM D 5596
Oxidative Induction Time (OIT) (min ave) (5)		per 90,000 kg	
-Std OIT	100 min		ASTM D 3895
or			
-High Pres OIT	400 min		ASTM D 5885
Oven Aging at 85 deg C (min ave) (5), (6)		per year and change in formulation	ASTM D 5721
-Std OIT	55 percent at 90 days		ASTM D 3895
or			
-High Pres OIT	80 percent at 90 days		ASTM D 5885
UV Resistance (min ave) (7)		per year and change in formulation	GS1 GRI GM11
-High Pres OIT(8) (9)	50 percent at 1600 hours		ASTM D 5885

MQC = Manufacturing Quality Control

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 D 5397 (Appendix), shall be the manufacturer's mean value. ASTM D 5397 does not need to be run on LLDPE geomembrane.

TABLE 2. TEXTURED HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
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Note (3): Other methods such as ASTM D 4218 or microwave methods are acceptable if an appropriate correlation to ASTM D 1603 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 7 mil, and lowest individual reading must be 5 mil.

Note (11): Textured Geomembrane Only: Alternate the measurement side for double sided textured sheet.

TABLE 2. TEXTURED HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
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Nominal Thickness [40] [_____] mils

Thickness (min ave)	-5 percent of nominal	per roll	ASTM D 5994
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Lowest individual for 8 out of 10 values	-10 percent of nominal	per roll	ASTM D 5994
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Lowest individual of 10 values	-15 percent of nominal	per roll	ASTM D 5994
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TABLE 2. TEXTURED HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
Asperity Height (min ave) (10)	10 mils	every second roll	GSI GRI GM12 (11)
Density (min)	0.940 g/cc	per 200,000 lb	ASTM D 1505
Tensile Properties (1) (min ave)		per 20,000 lb	ASTM D 638 Type IV
-yield stress	[84] [____] lb/in		
-break stress	[60] [____] lb/in		
-yield elong	[12] [____] percent		
-break elong	[100] [____] percent		
Tear Resistance (min ave)	[28] [____] lb	per 45,000 lb	ASTM D 1004
Puncture Resistance (min ave)	[60] [____] lb	per 45,000 lb	ASTM D 4833
Stress Crack Resistance (2)	[200] [____] hr	per 200,000 lb	ASTM D 5397 (Appendix)
Carbon Black Content	2.0-3.0 percent	per 20,000 lb	ASTM D 1603 (3)
Carbon Black Dispersion	Note (4)	per 45,000 lb	ASTM D 5596
Oxidative Induction Time (OIT) (min ave) (5)		per 200,000 lb	
-Std OIT or	100 min		ASTM D 3895
-High Pres OIT	400 min		ASTM D 5885
Oven Aging at 85 deg C (min ave) (5), (6)		per year and change in formulation	ASTM D 5721
-Std OIT	55 percent at 90 days		ASTM D 3895
or			
-High Pres OIT	80 percent at 90 days		ASTM D 5885
UV Resistance		per year and	GSI GRI GM11

TABLE 2. TEXTURED HDPE GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	MQC TESTING FREQUENCY (MIN.)	TEST METHOD
(min ave) (7)		change in formulation	
-High Pres OIT(8) (9)	50 percent at 1600 hours		ASTM D 5885

MQC = Manufacturing Quality Control

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 D 5397 (Appendix), shall be the manufacturer's mean value. ASTM D 5397 does not need to be run on LLDPE geomembrane.

Note (3): Other methods such as ASTM D 4218 or microwave methods are acceptable if an appropriate correlation to ASTM D 1603 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 7 mil, and lowest individual reading must be 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	ASTM D 6392
Seam Peel Strength (min) (1) (2)	[8.4] [_____] kN/m	ASTM D 6392

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.

Note (2): Where applicable, both tracks of a double hot wedge seam shall be tested for peel adhesion.

TABLE 3. HDPE SEAM PROPERTIES

PROPERTY	TEST VALUE	TEST METHOD
Seam Shear Strength (min) (1)	[80] [_____] lb/in	ASTM D 6392
Seam Peel Strength (min) (1) (2)	[48] [_____] lb/in	ASTM D 6392

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.

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	ASTM D 1593
Thickness (min)	[0.95] [_____] mm	ASTM D 1593
Specific Gravity (min)	1.2 g/ml	ASTM D 792

TABLE 4. SMOOTH PVC GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	TEST METHOD
Tensile Properties (min)		ASTM D 882 Method A
-break strength (MD and TD)	[17.0] [_____] kN/m	
-elongation @ break (MD and TD)	[400] [_____] percent	
-modulus @ 100 percent (MD and TD)	[7.2] [_____] kN/m	
Tear Resistance (min)	[46.7] [_____] kN/m	ASTM D 1004 Die C
Low Temp, pass	-29 degrees C	ASTM D 1790
Dimensional Stability (max) (MD and TD)	[3] [_____] percent	ASTM D 1204
Water Extraction (max)	[0.2] [_____] percent loss	See Note 1
Volatile Loss (max)	[0.5] [_____] percent loss	ASTM D 1203 (A)
Resistance to Soil Burial		See Note 1
-breaking factor	+/- 5 percent	
-elongation @ break	+/- 20 percent	
-100 percent modulus	+/- 20 percent	
Water Vapor Transmission (max)	.00000000005 m/sec	ASTM D 814
Hydrostatic Resistance (min)	[827] [_____] kN/sq m	ASTM D 751 (A)
* MD = Machine Direction		
* TD = Transverse Direction		

NOTE 1: Water Extraction and Resistance to Soil Burial testing shall be performed in accordance with manufacturer's approved procedures.

TABLE 4. SMOOTH PVC GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	TEST METHOD
Thickness (nominal)	[40] [_____] mils	ASTM D 1593
Thickness (min)	[38] [_____] mils	ASTM D 1593
Specific Gravity (min)	1.2 g/ml	ASTM D 792
Tensile Properties (min)		ASTM D 882 Method A
-break strength (MD and TD)	[97] [_____] lb/in	
-elongation @ break (MD and TD)	[400] [_____] percent	
-modulus @ 100 percent (MD and TD)	[41] [_____] lb/in	
Tear Resistance (min)	[10.5] [_____] lb/in	ASTM D 1004 Die C
Low Temp, pass	-20 degrees F	ASTM D 1790
Dimensional Stability (max) (MD and TD)	3 percent	ASTM D 1204
Water Extraction (max)	[0.2] [_____] percent loss	See Note 1
Volatile Loss (max)	[0.5] [_____] percent loss	ASTM D 1203 (A)
Resistance to Soil Burial		See Note 1
-breaking factor	+/- 5 percent	
-elongation @ break	+/- 20 percent	
-100 percent modulus	+/- 20 percent	
Water Vapor Transmission (max)	.00000000005 m/sec	ASTM D 814
Hydrostatic Resistance (min)	[120] [_____] lb/sq in	ASTM D 751 (A)

* MD = Machine Direction

TABLE 4. SMOOTH PVC GEOMEMBRANE PROPERTIES

PROPERTY	TEST VALUE	TEST METHOD
_____	_____	_____

* TD = Transverse Direction

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	Installers approved procedure
Seam Peel Strength (min) (1)	[2.6] [_____] kN/m	Installers approved procedure

Note (1): Where applicable, both tracks of a double hot wedge seam shall be tested for peel adhesion.

TABLE 5. PVC SEAM PROPERTIES

PROPERTY	TEST VALUE	TEST METHOD
_____	_____	_____
Seam Shear Strength (min)	[77] [_____] lb/in	Installers approved procedure
Seam Peel Strength (min) (1)	[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 D 5321. Normal stresses of [____], [____], and [____] kPa [____], [____], and [____] 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.

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 [____]. Rocks larger than [12] [____] 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 [12] [____] 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 [____].

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 D 6392. 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

The Contractor shall 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 shown on the drawings] [in accordance with ASTM D 6497 or as recommended by the geomembrane manufacturer]. Factory fabricated boots shall be used wherever possible. Field seams for penetrations shall be non-destructively tested in accordance with the installer's approved QC manual. Seams that fail non-destructive testing shall be repaired 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 [_____] . 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

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

-- End of Section --