

SECTION 02770

PVC GEOMEMBRANE

PART 1 GENERAL

1.1 SECTION INCLUDES

- A. The GEOSYNTHETICS CONTRACTOR shall furnish all labor, materials, equipment, tools and appurtenances required to complete the installation of all geomembrane, complete with appurtenances, as shown, specified or required by the Drawings.

1.2 RELATED SECTIONS

- A. Section 02278 – Geosynthetic Clay Liner
- B. Section 02595 – Geotextile
- C. Section 02599 – Geocomposite Drainage Layer

1.3 REFERENCES

- A. American Society for Testing and Materials (ASTM):
 - 1. D 618 Conditioning
 - 2. D 751 Hydrostatic Burst Test, Section 33, Procedure A
 - 3. D 792 Specific Gravity
 - 4. D 882 Tensile Properties
 - 5. D 1004 Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting
 - 6. D 1203 Volatile Loss
 - 7. D 1204 Dimensional Stability
 - 8. D 1239 Water Extraction
 - 9. D 1790 Low Temperature Impact
 - 10. D 4354-99 Standard Practice for Sampling of Geosynthetics for Testing
 - 11. D 4551 PVC Plastic Concealed Water Containment Membrane
 - 12. D 4873-01 Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples

13. D 5199-01 Standard Test Method for Measuring the Nominal Thickness of Geosynthetics
 14. D 5321-92 (1997) Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method
 15. D 5820-95 Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes
 16. D 6214 Chemical Seam Evaluation
 17. D 6243-98 Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method
 18. D 6392-99 Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods
 19. D 7176 Standard Specification for Non-Reinforced Polyvinyl Chloride (PVC) Geomembranes used in Buried Applications.
 20. D 7177 Standard Specification for Air Channel Evaluation of Polyvinyl Chloride (PVC) Dual Track Seamed Geomembranes
- B. Environmental Protection, Inc.
1. Quality Control Manual for Fabrication and Installation of PVC Geomembranes. January 1, 2006.
- C. The most current version of the specified test method shall be followed by the MANUFACTURER, GEOSYNTHETICS CONTRACTOR or authorized testing laboratory.

1.4 DEFINITIONS

- A. Minimum Value – Property value representing the lowest individual allowable value obtained when tested according to the specified test method. This applies to individual readings, such as thickness; or where only one specimen is tested for the specified parameter.
- B. Minimum Average Value – Property value representing the lowest allowable value for the average of results for the specimens tested.
- C. Nominal Value – Property value that is representative of a measurable property, determined under a set of prescribed test conditions, by which a product may be described.

- D. Lot - For the purposes of this project, a "Lot" will be defined as a single run of geo synthetic material from the same production facility, where the tooling and raw materials of production have not changed during manufacturing.
- E. Roll - A quantity geomembrane rolled up to form a single package as supplied from the manufacturer
- F. Sheet - A part of the manufactures geomembrane material cut from the roll.
- G. Panel - A series of geomembrane sheets fabricated together to make a larger unit, as supplied by a fabricator usually folded onto a pallet or folded then rolled on a core.
- H. Manufacturer - A company that takes raw materials and calendars or extrudes them into geomembrane rolls
- I. Fabricator - a company that converts geomembrane rolls into panels
- J. Installer – a company that installs PVC geomembrane panels in field applications.

1.5 SUBMITTALS

- A. The GEOSYNTHETICS CONTRACTOR shall submit to the ENGINEER all items included in this Article. Submittals shall be provided as follows:
 - 1. With the GEOSYNTHETICS CONTRACTOR's BID:
 - a. A project reference list documenting the experience of the GEOSYNTHETICS CONTRACTOR on a minimum of 5 projects consisting of at least 10 million square feet of installed PVC geomembrane.
 - b. A copy of the Fabricator's Quality Assurance/Quality Control (QA/QC) Plan for the complete geomembrane fabrication process.
 - c. A schedule of operations, including means and methods of installation.
 - d. The name of the fabricator of the geomembrane panels to be used for the project and the proposed method of joining adjacent geomembrane panels.
 - 2. At least 15 days prior to delivery of geomembrane to the site, unless otherwise noted below:
 - a. Shop drawings, including proposed panel diagram and details of proposed work, pipe boots, and details of sealing around all necessary geomembrane penetrations, to be submitted at least 15 days prior to delivery of geomembrane to the site. The panel

diagram must depict and/or note the planned number and orientation of panels, the panel sizes, seam orientation, placement of seams in corners, treatment of tee seams and the GEOSYNTHETICS CONTRACTOR's preferred sequence of panel placement. The PVC panels shall be orientated in a manner that minimizes seams. The ENGINEER, prior to geomembrane installation must approve the panel diagram. The ENGINEER, in writing, prior to altering the installation, must approve proposed revisions to the panel diagram.

- b. Geomembrane - Manufacturing Quality Control (MQC) data (Material Certifications) for the geomembrane to be delivered to the site. The reports shall include the quality control test results obtained during the manufacture of the material. In the event material is delivered to the site prior to the receipt of the MQC certificates, the material without certificates will be stored separately from the material with certificates. Material with unacceptable MQC data will be segregated from approved material and shall be marked for rejection. The geomembrane will be rejected if it is found to have defects, rips, holes, flaws, deterioration or other damage deemed unacceptable by the ENGINEER.
 - c. Geomembrane Sample - Samples of the proposed geomembrane shall be sent to the OWNER for interface shear testing within 5 days after the OWNER makes such request. The GEOSYNTHETICS CONTRACTOR shall coordinate the quantity and dimensions of the samples with the OWNER.
3. At least 15 days prior to installation:
- a. Resumes of geomembrane crew; including, Supervisor, QC Manager, and Master Seamer. The resumes shall include prior experience in installing PVC geomembrane. Individual geomembrane crew members will be subject to the approval of the ENGINEER and OWNER.
 - b. A copy of the GEOSYNTHETICS CONTRACTOR's standard operating procedure (SOP) for operating an ATV on site,

particularly with respect to specific uses of the ATV and the prevention of damage to materials.

- c. Field tensiometer calibration certificate showing that the equipment to be used for shear/peel testing in the field has been calibrated by a qualified individual within the previous 6 months.
4. During Installation Submitted Daily:
 - a. Completed Subgrade Acceptance Form, as endorsed by the ENGINEER, prior to geomembrane deployment in any area.
 - b. Construction progress reports clearly showing geomembrane placed by date.
 - c. Passing and failing test results for trial seams.
 - d. Documentation of passing and failing destructive and non-destructive testing of installed seams.
 5. Within 5 days after completion:
 - a. Summary and log of all field quality control work completed by the GEOSYNTHETICS CONTRACTOR.
 - b. Certification statement signed by the Supervisor that geomembrane installation is complete and in accordance with these Specifications, with details of any changes or exceptions noted.
 - c. Statement of material and installation warranties.
- B. The above-noted requirements shall apply to all shop-fabricated materials and those items specified for fabrication in the field.

1.6 PRODUCT DELIVERY, STORAGE, AND HANDLING

- A. The GEOSYNTHETICS CONTRACTOR shall protect the work described in this Section before, during, and after installation, and shall protect the installed work specified in other Sections, as well as work completed by the OWNER.
- B. Geomembrane labeling, shipment and storage shall follow ASTM D4551 as modified according to this Specification.
- C. Product labels shall be placed on the top of panels such that they can be seen, clearly showing the fabricator or supplier name, product description, panel number, and panel dimensions.

- D. Each panel of PVC shall include any additional information required to allow the ENGINEER to relate that panel with the manufacturing quality control and raw material quality assurance documentation. Additionally, if any special handling is required, it shall be so marked on the outside surface of the wrapping.
- E. During storage, the geomembrane shall be placed on a stable, relatively flat, dry, well-drained surface. The geomembrane pallets shall not be placed on objects that may cause deformation of the geomembrane panels. Adequate space shall be left between stored panels, such that panel labels can be examined. The geomembrane shall be protected from the following:
 - 1. Site construction damage.
 - 2. Chemicals that are strong acids or bases.
 - 3. Flames, sparks, geomembrane temperatures in excess of 150° F.
 - 4. Any environmental condition that might damage the geomembrane.
- F. Panel numbers on partially used panels must be maintained such that each panel number can be readily identified prior to deployment of the remaining portions of the panel.
- G. If the ENGINEER determines the geomembrane is damaged, the GEOSYNTHETICS CONTRACTOR shall make all repairs and replacements in a timely manner, so as to prevent delays in the progress of the work.

PART 2 MATERIALS

2.1 GENERAL

- A. The geomembrane sheet shall consist of polyvinyl chloride (PVC) resin in amounts greater than 50% of the total polymer content suitably compounded with plasticizers, stabilizers, additives, and pigments, to satisfy the physical property requirements.
- B. The ENGINEER shall conduct conformance testing on the geomembrane. The GEOSYNTHETICS CONTRACTOR shall, at no additional cost to the OWNER, provide whatever reasonable assistance the ENGINEER may require in obtaining samples for conformance testing. Geosynthetic material sampling frequency shall be in accordance with ASTM D4354, unless determined otherwise by the ENGINEER. A qualified laboratory with GAI-LAP accreditation shall conduct conformance testing.

- C. Conformance testing will be at the expense of the OWNER, unless the tests show the material does not comply with the Specifications, in which case the GEOSYNTHETICS CONTRACTOR shall pay the cost of re-sampling and testing.
- D. The GEOSYNTHETICS CONTRACTOR shall be solely responsible for the quality of the material provided. Should any of the tests performed on the material yield unsatisfactory results, the GEOSYNTHETICS CONTRACTOR will be responsible for replacing the material with satisfactory materials without delay to the project or cost to the OWNER.

2.2 GEOMEMBRANE

ASTM D7176 Standard Specification for Non-Reinforced Polyvinyl Chloride (PVC) Geomembranes used in Buried Applications.

Certified Properties	ASTM	PVC 10	PVC 20	PVC 30	PVC 40	PVC 50	PVC 60
Thickness	D 5199	10 \pm 0.5 mil 0.25 \pm .013mm	20 \pm 1 mil 0.51 \pm .03 mm	30 \pm 1.5 mil 0.76 \pm .04 mm	40 \pm 2 mil 1.02 \pm .05 mm	50 \pm 2.5 mil 1.27 \pm .06 mm	60 \pm 3 mil 1.52 \pm .08 mm
Tensile Properties ²	D 882 Min						
Strength at Break		24 lbs/in 4.2 kN/m	48 lbs/in 8.4 kN/m	73 lbs/in 12.8 kN/m	97 lbs/in 17.0 kN/m	116 lbs/in 20.3 kN/m	137 lbs/in 24.0 kN/m
Elongation		250%	360%	380%	430%	430%	450%
Modulus at 100%		10 lbs/in 1.8 kN/m	21 lbs/in 3.7 kN/m	32 lbs/in 5.6 kN/m	40 lbs/in 7.0 kN/m	50 lbs/in 8.8 kN/m	60 lbs/in 10.5 kN/m
Tear Strength	D 1004 Min	2.5 lbs 11 N	6 lbs 27 N	8 lbs 35 N	10 lbs 44 N	13 lbs 58 N	15 lbs 67 N
Dimensional Stability	D 1204 Max Chg	4%	4%	3%	3%	3%	3%
Low Temperature Impact	D 1790 Pass	-10 ^o F -23 ^o C	-15 ^o F -26 ^o C	-20 ^o F -29 ^o C	-20 ^o F -29 ^o C	-20 ^o F -29 ^o C	-20 ^o F -29 ^o C

Index Properties	ASTM	PVC 10	PVC 20	PVC 30	PVC 40	PVC 50	PVC 60
Specific Gravity	D 792 Typical	1.2 g/cc	1.2 g/cc	1.2 g/cc	1.2 g/cc	1.2 g/cc	1.2 g/cc
Water Extraction Percent Loss (max)	D 1239 Max Loss	0.15%	0.15%	0.15%	0.20%	0.20%	0.20%
Volatile Loss	D 1203 Max Loss	1.5%	0.9%	0.7%	0.5%	0.5%	0.5%
Soil Burial	G 160 Max Chg						
Break Strength		5%	5%	5%	5%	5%	5%
Elongation		20%	20%	20%	20%	20%	20%
Modulus at 100%		20%	20%	20%	20%	20%	20%
Hydrostatic Resistance	D 751 Min	42 psi 290 kPa	68 psi 470 kPa	100 psi 690 kPa	120 psi 830 kPa	150 psi 1030 kPa	180 psi 1240 kPa

Seam Strengths	ASTM	PVC 10	PVC 20	PVC 30	PVC 40	PVC 50	PVC 60
Shear Strength ²	D-882 Min	20 lbs/in 3.47 kN/m	38.4 lbs/in 6.7 kN/m	58.4 lbs/in 10 kN/m	77.6 lbs/in 14 kN/m	96 lbs/in 17 kN/m	116 lbs/in 20kN/m
Peel Strength ²	D-882 Min	10 lbs/in 1.8 kN/m	12.5 lbs/in 2.2 kN/m	15 lbs/in 2.6 kN/m	15 lbs/in 2.6 kN/m	15 lbs/in 2.6 kN/m	15 lbs/in 2.6 kN/m

***FTB = Film Tearing Bond *MD = Machine Direction *TD = Transverse Direction**

Notes:

1. Certified properties are tested by lot as specified in ASTM D-7176.
2. Metric values are converted from US values and are rounded to the available significant digits.
3. Modifications or further details of test are described in ASTM D-7176.
4. Index properties are tested once per formulation as specified in ASTM D-7176.

- A. Geomembrane Conformance Testing - The ENGINEER shall take samples of the geomembrane panel for conformance testing. Unless otherwise specified, samples shall be three feet long by the roll width and shall not include the outer

wrap. The ENGINEER or authorized representative shall mark the machine direction on the samples with an arrow.

1. Unless otherwise specified, conformance samples shall be taken at a rate of one per 100,000 square feet. An appropriate number of samples, as determined by the ENGINEER in accordance with ASTM D4354 will be taken. The ENGINEER will ship these samples directly to the COA laboratory.
2. Geomembrane conformance samples selected by the ENGINEER may be tested for any properties specified in Article 2.3, but shall as a minimum be tested for the following:

GEOMEMBRANE CONFORMANCE
MINIMUM TESTING AND FREQUENCY

PROPERTY	TEST METHOD	
Thickness	ASTM D 5199	
Strength at Break	ASTM D 882	
Elongation	ASTM D 882	
Modulus at 100%	ASTM D 882	
Tear Strength	ASTM D 1004	
Low Temperature	ASTM D 1790	

3. Non-conforming material will not be used in the work. In the event non-conforming results are obtained from the laboratory, the nearest numbered rolls on each side of the non-conforming roll shall be sampled and tested for the full suite of conformance tests, until the extent of non-conformance is established, at no cost to the OWNER. The owner reserves the right to reject the lot of rolls at any stage of extended sampling and testing.

E. Interface Shear Testing - Interface shear strength testing of the geomembrane and related materials is the responsibility of the OWNER. The results must comply with the criteria determined by the OWNER, as specified in the Construction Drawings. All testing must meet the minimum requirements, and the analysis of those results must be completed by the ENGINEER prior to installation of the materials. Testing for geosynthetic to

geosynthetic, or geosynthetic to soil interface, shall be conducted according to the current version of ASTM D 5321-92 (97). Testing for interfaces involving geosynthetic clay liner (GCL) shall be conducted according to the current version of ASTM D 6243-98.

2.5 FACTORY FABRICATION

- A. All completed factory seams are 100% inspected. Factory seams will be visually inspected for full seam continuity over their full length. Any areas that do not meet the specified requirements shall be removed and repaired per section.
- B. Destructive tests will be performed to verify that the seam strength requirements of the specifications are met. Random samples shall be taken at a minimum of every 3,000 lineal feet of factory seam or once per factory panel fabricated, whichever is more frequent, and the following quality assurance tests will be performed on each sample:
 - a. Thickness
 - b. bonded seam strength (shear strength)
 - c. peel adhesion
- C. The sample shall be cut into ten one - inch wide specimens. Five peel and five bonded seam specimens are removed. Five specimens shall be tested for bonded seam strength (bss) and five for peel adhesion. To be acceptable, the average of five test specimens for peel and the average of five test specimens for bonded seam strength must meet the minimum peak load requirements of factory seams as follows:
 - a. Bonded Seam Strength: One-inch strips cut with the weld centrally located are tested by stressing the weld in a "shear" configuration. That is, the top sheet is stressed in relation to the bottom sheet in a direction away from the weld. A pass result occurs when the specimen averages meet the minimum peak load requirements stated in the contract (usually 80% of specified sheet strength). A failure occurs when the weld separates or the material breaks at a peak load less than the minimum requirements. The test result to be reported will be the average of the peak loads recorded for each of the five specimens.
 - b. Peel Adhesion: One-inch strips cut with the weld centrally located are tested by stressing the top sheet in relation to the overlapped edge of the lower sheet in an effort to peel the weld away. Each specimen will be peeled one

inch along the seam length. A pass result occurs when the specimen meets the minimum peak load requirements stated in the contract. A failure occurs when the weld peels at a peak load less than the specification without film tearing bond. The test result to be reported is the average of the peak loads recorded for each of the four specimens.

- D. Each test will be identified by panel serial number and the manufacturer's roll number. These tests shall be performed in the fabricators laboratory.
- E. Prior to installation of the geomembrane at the site, the fabricator will provide to the ENGINEER, copies of manufacturer material certifications and a copy of quality control test results for all panels to be supplied, verifying conformance with this specification and the requirements as represented in ASTM D 7176 specification. The location of any defects and repairs and all necessary retesting results will also be documented in the report.
- F. When a seam sample is removed from the panel being fabricated the resulting hole will be repaired with a patch with a minimum of a one inch bonded area around the patch, and the patch will be rounded on all corners.
- G. Factory fabricated geomembrane panels are packaged accordion folded on a sturdy wooden pallet designed for fork lift truck access. Smaller panels (i.e. less than 500 lbs.) can be rolled on a fiber core, and placed on a pallet.
- H. All panels will be packaged with a protective, black stretch wrap or cardboard cover to protect the panel from weather or shipping damage.

2.6 GEOMEMBRANE PENETRATION BOOTS

- A. The GEOSYNTHETICS CONTRACTOR shall furnish all geomembrane penetration boots and other materials required for completion of the geomembrane installation. All geomembrane boots required for the project shall be factory pre-fabricated boots. The geomembrane shall be of the same thickness as the geomembrane panels.
- B. Geomembrane penetrations are to be constructed only at the locations shown on the Plans. The GEOSYNTHETICS CONTRACTOR is cautioned that no deviation in the quantity or configuration of geomembrane penetrations will be accepted without the advance written approval of the ENGINEER.

- C. All penetrations through the geomembrane shall be thoroughly and securely sealed. The seal between the geomembrane and the pipe shall be without any detectable leakage.
- D. In attaching the geomembrane penetration boot in the field, no field seams will be allowed in locations or configurations that do not allow for Construction Quality Control testing. Visual observation is not considered a sole acceptable method for in-field quality control.
- E. Where clamps, fasteners, gasket seals or sealants are used, the GEOSYNTHETICS CONTRACTOR shall use only materials that are compatible with the geomembrane.

PART 3 EXECUTION

3.1 SITE PREPARATION

- A. All required grading, grooming and construction quality assurance (CQA) testing on any low permeability soil or GCL to be covered by the geomembrane shall be complete and accepted by the ENGINEER prior to geomembrane placement.
- B. The surface to be covered by the geomembrane shall be cleared of sharp objects, angular stones, sticks, or any materials that may contribute to punctures, shearing, rupturing or tearing of the geosynthetic materials. The geomembrane subgrade shall have a smooth, finished surface, free from pockets, holes, ruts, and discontinuities that, in the judgment of the ENGINEER, will cause bridging of the material. The subgrade shall be inspected for unsuitable areas or soft spots before the geomembrane is placed, and additional surface preparation will be required to eliminate any unsuitable areas as determined by the ENGINEER.
- C. The GEOSYNTHETICS CONTRACTOR and ENGINEER shall carefully and completely inspect the subgrade surface immediately prior to the deployment of each geomembrane panel. No geomembrane shall be placed on unsuitable subgrade surface, or without the ENGINEER's written approval. The ENGINEER and the GEOSYNTHETIC CONTRACTOR's Quality Control (QC) inspector shall furnish their signatures on a Subgrade Acceptance Log prior to the installation of each panel or series of panels placed on a daily basis.

- D. Under no condition shall the geomembrane be placed over standing water on the subgrade.

3.2 SEAMING METHODS

- A. A six - inch wide overlap must be cleaned of all dust, dirt or foreign debris no more than 30 minutes prior to welding. Only clean, soft rags will be used for cleaning. If mud has adhered to the sheet surface overlap area, it will be removed with clean water and allowed to dry prior to seaming.
- B. During the cleaning operation, the sheet will be inspected for defective areas which must be removed and/or repaired prior to seaming. The seaming operation requires a solid, smooth subsurface. Subsurface voids, hard nodules, rocks, soft areas or unsuitable conditions will be removed or repaired prior to seaming during subgrade preparation.
- C. Seaming cannot be conducted in the presence of standing water. Wet surfaces must be allowed to dry. A slip sheet or seaming board may be used to lift the geomembrane above damp surfaces. If wind conditions contaminate the seaming area or displace the geomembrane sheets, temporary ballast and additional cleaning procedures will be required.
- D. The geomembrane panels shall be joined utilizing approved seaming methods. Dual-track fusion welding shall be the required method on all seams where it is feasible. Chemical welds shall be made only where approved by the ENGINEER.
- E. All geomembrane surfaces that are to become a seam interface are to be free of dust, dirt, excess moisture or any other condition that may affect the quality of the seam.
- F. Seaming will not be allowed during rain or snowfall, unless proper precautions are made to allow the seam to be made on dry subgrade and geomembrane materials. If weather conditions are not satisfactory, panels will not be put into place. If panels are placed and pulled out, the installation crew will do what is necessary to finish or secure those individual panels that day.
- G. The field seams shall be produced using one of the following methods:
 - 1. Dual-Track Thermal Fusion Weld – All field seams shall be fused using Dual-Track Thermal Fusion Welding. A seam produced by melting the two intimate surfaces by running a hot metal wedge or hot air device between the surfaces, followed immediately by pressure to form a homogeneous bond. This seam has a center air channel for non-destructive testing of the seam.

Panels to be seamed shall be overlapped sufficiently to allow proper destructive testing of seams. The CONTRACTOR shall mark the liner where the Dual-Track Fusion Welding machine settings are adjusted (including speed, temperature and pressure). Measurable setting values shall be indicated on the liner.

2. Chemical Fusion Weld – Chemical Fusion Welding shall only be used for repairs and detail work. All field seams will be a minimum of 2 inches wide. A sufficient amount of chemical fusion agent will be applied that, upon compressing the seam surfaces together, a thin excess of chemical fusion agent will be forced out. A high durometer rubber, nylon or steel roller will be used to compress the seam surfaces together until a bond is formed. Roller action will be at a parallel direction to the seam's edge so that excessive amounts of chemical fusion agent will be purged from between the sheets. Trapped chemicals should be rolled out of the seaming area. Care will be exerted in applying the chemical fusion agent. A continuous wet layer of chemical fusion agent is necessary to prevent a leak at the tie - in point between the last chemical fusion agent application and the next. If the chemical fusion agent, which is initially shiny when applied, takes on a dull filmy appearance, the interfaces may require a faster closing together or the ambient temperature is too high to continue seaming. The installer will monitor this condition at sheet temperatures over 105°F. At the completion of seaming, all rags, chemical containers, etc., will be properly removed from the geomembrane.

3.3 INSTALLATION

- A. The number of panels to be deployed in any day will be limited to the number of panels which can be seamed that day. The geomembrane will be placed over the prepared surface in such a manner as to assure minimum handling.
- B. Based on the approved geomembrane panel diagram and material certifications, the individual panels will be numbered and seams will be identified by using the panel numbers that create the seam. The PVC panels shall be installed in a manner that minimizes seams. Where ever possible longitudinal seams shall be oriented to be no greater than ten degrees from parallel with the direction of the slope. Cross seams (i.e. those seams which join the ends of contiguous panels) shall not be placed on any slope that exceeds a ten percent grade. All panels

placed on slopes shall be cut no closer than five feet from the top of the slope or ten feet from the toe of slope. All seam overlaps shall be shingled in a downslope direction. In no case shall parallel seams be placed within five feet of the centerline of any leachate collection pipe.

- C. During installation, and any other period of exposure of geomembrane, pedestrian and equipment activity over the geomembrane shall be kept to a minimum, and restricted to only that which is necessary for geomembrane construction.
- D. Smoking is not permitted on the geomembrane.
- E. Construction workers shall take precautions not to damage the geomembrane surface. Construction workers shall wear smooth-soled footwear, and exercise care not to drag tools across the geomembrane surface. All large tools are to have smooth base plates or shoes. Construction and landfill staff shall be informed of the restricted access to areas of geomembrane placement by use of barriers and signs posted as necessary.
- F. The GEOSYNTHETICS CONTRACTOR shall perform all activities of geomembrane construction in such a way as to avoid damage to the geomembrane. Any damage caused to the geomembrane by the GEOSYNTHETICS CONTRACTOR shall be repaired or the material replaced at the expense of the GEOSYNTHETICS CONTRACTOR.
- G. No tracked or wheeled vehicles, other than low ground pressure ATVs as pre-approved by the ENGINEER, shall be permitted on the geomembrane prior to placement of adequate soil cover, as determined by the ENGINEER.
- H. The GEOSYNTHETICS CONTRACTOR shall complete his work in a manner that will prevent water or wind from getting under the partially installed geomembrane. This could include, but is not limited to, installing sandbags along the leading edges. Should excessive moisture become trapped below the geomembrane, or should wind damage occur due to the negligence of the GEOSYNTHETICS CONTRACTOR, the GEOSYNTHETICS CONTRACTOR, at no extra cost to the OWNER, will be required to perform all work, including removing and replacing as much of the in-place geosynthetic material as the ENGINEER directs, to assure that the integrity of the geomembrane and the underlying subbase or geosynthetic clay liner (GCL) has not been compromised.
- I. Seams shall be welded throughout the entire length of the panels during initial panel seaming.

- J. Sandbags or other approved ballast shall be used to prevent bridging or material movement in areas such as toe of slope or near sumps. Ballast shall not be used to force the geomembrane into contact with the subgrade.
- K. Special care shall be taken to prevent tensile stress in the geomembrane and geomembrane seams in all corners and grade changes.
- L. The GEOSYNTHETICS CONTRACTOR shall exercise his best judgment and care to provide sufficient slack in the PVC geomembrane.
- M. The geomembrane shall not be installed when ambient or sheet temperatures are below 32° F, when the sheet temperature exceeds 158° F, or when the air temperature is above 120° F unless the GEOSYNTHETICS CONTRACTOR demonstrates, to the satisfaction of the ENGINEER, that procedures can be implemented which will result in the proper installation and seaming of the geomembrane.
- N. Adjacent geomembrane panels shall be allowed to reach essentially equivalent temperatures prior to seaming to avoid development of fishmouths.
- O. If fishmouths are created at the seam overlaps, they shall be cut to achieve a flat overlap.
- P. Geomembrane covering operations shall be performed in a manner that does not damage the geomembrane lining system. Geomembrane covering operations shall be performed only in the presence of a Construction Observer such that the condition and cleanliness of the geomembrane is observed at the time the material is covered, and any effects of the covering operation on the geomembrane lining system can be observed.
- Q. Any use of ATV's on the site must be pre-approved by the ENGINEER. The GEOSYNTHETICS CONTRACTOR shall submit an S.O.P. describing how ATV's are to be used, if at all, in the deployment of geomembrane at the site. As a minimum, the following shall apply:
 - 1. Any damage resulting from the use of ATV's, as determined by the ENGINEER, shall be repaired according to Article 3.3, at no additional cost to the OWNER. If repeated repairs are required as the result of the use of ATVs operating on geosynthetic material, further use of ATVs will be prohibited.
 - 2. Any and all ATV's proposed to be used in the deployment of geosynthetics will be inspected by the ENGINEER. ATV's which are found to be leaking oil or fuel, or which in any other way exhibit the potential to damage the lining system components, will not be permitted.

3. Any oil or fuel which leaks onto geosynthetic materials shall be thoroughly removed (cleaned) by the GEOSYNTHETICS CONTRACTOR, or the geosynthetic material shall be replaced at the discretion of the ENGINEER, at no additional cost to the OWNER.
4. Re-fueling of ATVs on geosynthetic materials is prohibited.
5. ATVs shall have tires with low ground pressure, typically less than 5psi, and shall have shallow treads.
6. ATVs shall be operated by a single operator at speeds less than 5 mph.
7. Quick starts, stops, spinning wheels and sharp turns will not be permitted above any geosynthetic material.

3.4 REPAIRS

- A. All geomembrane panels and seams shall be examined by the ENGINEER for defects, holes, blisters, undispersed raw materials, and any sign of contamination by foreign matter. The geomembrane surface shall be clean at the time of examination. Each suspect location shall be repaired and all repairs shall be non-destructively tested.
- B. Damaged geomembrane shall be removed and replaced with acceptable geomembrane if damage cannot be repaired to the satisfaction of the ENGINEER.
- C. Any portion of the geomembrane, or any portion of a seam exhibiting a flaw or failing a destructive or non-destructive test, shall be repaired as follows:
 1. Geomembrane patches shall be used for holes over 1/8 of an inch in diameter, tears, and contamination by foreign matter. Patches shall be constructed of the same geomembrane, and will be joined to the panel using adhesive or chemical fusion welding where possible.
 2. Geomembrane patches or caps shall extend at least 6 inches beyond the edge of the defect or failed seam area, and all corners of material to be patched. The corners of the patch shall be rounded.
 3. Geomembrane caps shall be used to repair failed seams that are left in-place. Seams that fail destructive or non-destructive testing may also be removed and replaced if determined necessary by the ENGINEER.

PART 4 FIELD QUALITY ASSURANCE/QUALITY CONTROL PROGRAM

4.1 GENERAL

- A. Before installation begins, and weekly thereafter (more often if determined necessary by the ENGINEER) project coordination meetings shall be held with the designated representative of the EARTHWORKS CONTRACTOR, GEOSYNTHETICS CONTRACTOR, ENGINEER and OWNER in attendance to review the following information:
 - 1. Progress of the work.
 - 2. Adherence to the Specifications.
 - 3. Adherence to the Construction Quality Assurance Program described in this Section, including the timely submission of the pertinent forms.
 - 4. Planned work and methods for the ensuing week, including estimate of time remaining to completion of the work.
 - 5. Problem resolutions to be implemented during the upcoming week.
- B. All of the Forms specified and required must be submitted to the ENGINEER in a timely fashion.
- C. The OWNER and ENGINEER must approve any changes in the proposed method of work, subcontractors to be utilized, geomembrane resin, or manufacturing in advance.
- D. The GEOSYNTHETICS CONTRACTOR assumes all responsibility relevant to providing an acceptable product.

4.2 INSTALLATION QA/QC

- A. The ENGINEER and GEOSYNTHETICS CONTRACTOR shall visually inspect all material to be included in the work, and compare panel identification numbers with those on the certifications provided by the manufacturer to assure delivery of the appropriate material.
- B. Damage to geomembrane during installation shall be repaired according to Article 3.4. If the ENGINEER determines that any damage cannot adequately be repaired, the damaged material will be replaced.
- C. The GEOSYNTHETICS CONTRACTOR will be required to conduct both destructive and non-destructive testing on seams during the geomembrane installation, as part of the Construction Quality Control program. All trial and installed seam samples shall be tested.
- D. Thermal Weld Trial Seams –
 - 1. Trial seams shall be produced each day, at the start of each workday, after every four hours of continuous operation, after each break in

seaming of 1 hour or more, after a break that results in equipment replacement or shutdown, and if the geomembrane temperature changes by more than 45°F. Trial seams shall be required each day for each piece of seaming equipment and each welding crew combination (including welding technician, seam cleaners and/or helpers). The trial seams will be performed on strips of geomembrane from approved rolls, and shall be produced at the work location such that the conditions mimic those under which production seams will be made.

2. A trial seam shall be a minimum of 5 feet in length for self-propelled seaming devices, and a minimum of 3 feet for hand-held seaming devices. The material for the trial seam and the test fixture for making the field tests shall be provided by the GEOSYNTHETICS CONTRACTOR at no additional cost. One-inch wide cutouts of the trial seams will be subject to shear and peel testing at the site. A minimum of 3 cutouts will be tested for shear, and a minimum of 3 cutouts will be tested for peel. The ENGINEER shall document the locus of break code for each specimen as shown in Figure 3 and Figure 4 of ASTM D6392-99, included at the end of this Section.
3. All trial seam specimens must be acceptable or the trial seam will be repeated until all results from a given trial seam are found acceptable. If any trial seam fails at any time during the workday, the reason for the failure shall be resolved before any production seaming of the geomembrane by the subject equipment and crew. All trial seam welding and testing must be observed by the ENGINEER.
4. A trial seam specimen will be considered a failure if:
 - i. In the shear test, the bonded thickness of the seam fails or the material breaks at a stress lower than specified.
 - ii. In the peel test, the two sheets comprising the seam separate at a peak stress lower than specified.

Should the ENGINEER, at any time during the installation, believe the production seaming process may not be performing adequately, he may, to avoid destructive sampling of the

installed geomembrane, request additional trial seams. The GEOSYNTHETICS CONTRACTOR at no additional cost shall do this.

E. The GEOSYNTHETICS CONTRACTOR shall complete non-destructive testing of all seams along their entire length, in the manner approved prior to installation, in the presence of the ENGINEER. The recommended test methods are as follows:

1. Pressurized Air Channel

- a. All field seams made by a dual-track fusion welding device will be tested by applying air pressure within the air channel to a sealed length of seam, and monitoring the pressure over time. The testing shall be conducted in accordance with ASTM D 7177.
- b. For the geomembrane, the initial inflation pressure shall be equal to or greater than the minimum according to ASTM D 7177. The minimum allowable pressure drop over a 30 second period shall be 5.0 psi.
- c. A pressure gauge shall be inserted into the end of the air channel to check for continuity in the air channel. Alternately, the far end of the seam may be cut to relieve the air pressure. An audible rush of air shall serve as an indicator that the test represents the entire length of seam.
- d. Air channels that do not hold the minimum specified air pressure shall be further inspected to identify the location and nature of any defects or unbonded sections of seam. The seam will then be repaired and retested. The ENGINEER may, at his discretion, require the entire questionable seam area to be capped or replaced.

2. Air Lance Testing

- a. The ENGINEER shall witness the testing, and the seam shall be clearly visible to the ENGINEER and GEOSYNTHETICS CONTRACTOR during the test. Unbonded areas or defects shall be marked by the ENGINEER for repair by the GEOSYNTHETICS CONTRACTOR.
- b. The air lance will be capable of supplying 50 PSI through a 3/16 inch diameter nozzle. The air stream is directed at the upper edge of the seam no more than 2 inches from the seam edge.

Any voids in the seam will be marked, repaired, and re-tested with the air lance. The testing technician and the inspector will mark each seam or repair with an indelible marker as accepted immediately after completion of final air lance testing.

- F. All inadequate seams or portions thereof that fail the non-destructive testing shall be repaired in accordance with this Specification and the method approved by the ENGINEER. Should differences of opinion between the GEOSYNTHETICS CONTRACTOR and the ENGINEER develop during the installation relevant to seam integrity, the ENGINEER may, at his discretion, obtain samples of the seams in dispute for field and/or laboratory testing. The GEOSYNTHETICS CONTRACTOR will be responsible for patching the resulting void in accordance with the previously approved procedures at no additional cost to the OWNER.
- G. Destructive Sample Collection - Samples of the in-place seams shall be cut from the installed geomembrane at a minimum frequency of one sample per 500 linear feet of seam, excluding repair seam length. A minimum of one seam sample shall be obtained for each seaming machine/operator combination for each day, or as directed by the ENGINEER. The cutout sections shall be 12 inches wide by 40 inches long with the seam centered lengthwise. The sample size can be reduced to 30" if the CONTRACTOR does not elect to have a cutout section for their use. A 1-inch wide specimen shall be cut from each end of the sample, and these two specimens shall be peel tested in the field in accordance with 4.2 G. The remaining sample shall be cut into 2 parts and distributed as follows:
 - 1. One 12-inch by 18-inch sample to the ENGINEER for independent laboratory testing; and,
 - 2. One 12-inch by 18-inch sample to the OWNER for archive storage.
 - 3. The remainder of the sample shall be available for the CONTRACTOR if requested at the time of sample collection.
- H. The 12-inch by 18-inch laboratory sample will provide 5 specimens for shear testing and 5 specimens for peel testing. Specimens that will be subject to peel and shear testing shall be selected alternately from the sample. All peel tests shall be performed on the outer track of dual track fusion welds. The laboratory shall report the locus of break code for each specimen according to the definitions included in Figure 3 and Figure 4 of ASTM D 6392, included at the end of this Section. The laboratory sample will be considered acceptable only if all 10

specimens meet the minimum requirements. The specimen will be considered a failure if:

1. In the shear test, the bond of the seam fails or the material breaks at a stress lower than specified.
 2. In the peel test, the two sheets comprising the seam separate at a peak stress lower than specified. Complete peel separation of the seam is allowable.
 3. In the shear or peel test, locus of break codes AD, AD-BRK, BRK, and SE are reported by the ENGINEER.
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- I. If a sample fails destructive testing, the welding path must be retraced to intermediate locations at least 10 feet in each direction from the location of the sample that failed the test, and a second sample shall be taken for an additional field test. If the tracking samples pass, the seam must be reconstructed between the location of the two tracking samples and the original sampled location. If the tracking sample fails, this process must be repeated. The seam between 2 passing test locations shall be capped, the cap seams shall be nondestructively tested, and shall include one field peel and shear test location along the reconstructed seam.
 - J. The ENGINEER and GEOSYNTHETICS CONTRACTOR shall visually inspect all geomembrane seams.
 - K. All welds shall be observed for traces of deformation to the geomembrane panels. Any seams, which in the opinion of the ENGINEER, have caused excessive deformation of the sheet, show signs of discoloration, exhibit thinning or stepping of the sheet, or show visual signs of overheating of the geomembrane panels, shall be repaired at no additional cost to the OWNER regardless of the result of any destructive testing on the seam. The deficient seam or portion thereof shall be cut out, the geomembrane panels again overlapped and seamed, or the questionable seam length shall be capped, as approved by the ENGINEER.
 - L. The GEOSYNTHETICS CONTRACTOR shall not place overlying materials on the installed geomembrane until the ENGINEER has reviewed and accepted the written test results for the geomembrane to be covered. At a minimum, the pre-delivery testing, the daily log of trial seam results, laboratory destructive sample results, non-destructive test results, record drawings of the completed area, and approval of the seams in place will be reviewed.

- M. The GEOSYNTHETICS CONTRACTOR shall provide a report to the OWNER and the ENGINEER at the conclusion of the work which shall include the following:
 - 1. The quality control tests used as specified and/or directed, including all requirements of the Report section of the specified test method.
 - 2. Complete description of field sampling procedure, number of test specimens, size of test specimens.
 - 3. Log of all Construction Quality Control work.
- N. The GEOSYNTHETICS CONTRACTOR shall be responsible for all costs incurred by the OWNER including, but not limited to, additional field and laboratory CQA testing resulting from greater than 5 percent of the CQA testing not meeting or exceeding the Specifications.
- O. All seams that cannot be subjected to the required Construction Quality Control or Construction Quality Assurance (CQA/CQC) testing shall be overcapped.

4.3 WARRANTY

- A. The GEOSYNTHETICS CONTRACTOR shall issue a warranty on the installation of geomembrane for a minimum period of 1 year.
- B. The GEOSYNTHETICS CONTRACTOR shall issue a warranty on the geomembrane material for a minimum period of 20 years.

END OF SECTION 02770