APPENDIX A

Geomembranes

GSE HD • GSE HD Textured • GSE White • GSE White Textured • GSE Conductive • GSE Conductive Textured • GSE Conductive White
GSE Green Textured • GSE HD Weld Edge Textured • GSE UltraFlex • GSE UltraFlex Textured • GSE UltraFlex White • GSE Ultraflex White Textured

Installation Quality Assurance Manual

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GSE®

Geomembranes Installation Quality Assurance Manual

Table of Contents

1.0 Overview

This manual is a guide of the duties and responsibilities for a GSE QA technician.

ASTM Practices that this guide lists include the following and are included separately:

ASTM D-6392 Standard Test Methods For Determining The Integrity Of NonReinforced Geomembrane Seams Produced Using Thermo Fusion Methods

ASTM D-5820 Standard Practice For Pressurized Air Channel Evaluation of Dual Seamed Geomembranes

ASTM D-5641 Standard Practice For Geomembrane Seam Evaluation By Vacuum Chamber

ASTM D-6497 Standard Guide For Mechanical Attachment of Geomembrane to Penetrations or Structures

GRI Standard GM13 Test Properties, Testing Frequency and Recommended Warranty for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes

GRI Standard GM14 Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes

GRI Standard GM17 Test Properties, Testing Frequency and Recommended Warranty for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes

GRI Standard GM19 Standard Specification for Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes

2.0 Material Delivery

2.01 Upon arrival on site, the GSE QA will do an inventory of materials on the job site.

2.02 Roll numbers of liner, textile, geonet and composite will be logged on the Inventory Check List and cross-referenced with bills of lading (Materials Supplied by GSE).

2.03 Copies of the Inventory Check List and signed Bill of Ladings should be sent to the home office with the QA retaining the originals.

2.04 Any visible damage to roll materials should be noted on the roll and Inventory Check List.

3.0 Earthwork

3.01 The General Contractor is responsible for preparing and maintaining the subgrade. The subgrade should be prepared and maintained per the individual job specifications.

3.02 Subgrade Surface Acceptance Certificate - The GSE Site Manager shall be responsible for assuring that the subgrade surface has been properly prepared for deployment of geosynthetics. If GSE is required to sign a Subgrade Surface Acceptance Certificate, please use the form provided by GSE. Under no circumstances sign off on subgrade that is not suitable for deployment of geosynthetics. Sign the Subgrade Acceptance Certificate only on areas to be covered in one day, preferably after deployment.

3.03 If the subgrade is unacceptable and the GC/Owner directs GSE to deploy over, the GSE Site Manager must have the Owner's representative sign the Deployment by Owner's Direction Over Unsuitable Subgrade Certificate which will take the place of the Subgrade acceptance Certificate for the particular area being covered.

3.04 Prior to material installation, whenever possible, the QA should measure the area to be covered and compare it to the area used for the bid. An outline of the area including anchor trenches, top of slopes and toe of slopes will be provided by GSE's Drafting department. Use this outline to log actual on-site conditions, i.e....distances between anchor trenches, length of anchor trenches, top of berms, length of slopes and/or any other relevant distances.

Note: Whenever possible distances will be included on the blank outlines. If actual field dimensions have changed or do not match the GSE outline the QA should notify their Supervisor and then the Project Manager, so that quantities can be reassessed to determine the proper amount of material needed for installation. It is important to establish the limits of deployment with all parties. Any changes must be noted and signed off by the Customer's Representative.

4.0 Panel Placement

4.01 Each panel will be assigned a number as detailed below.

4.01a When there is only one layer, panels may be designated with a number only, i.e....
1, 2, 3, 4 etc.

4.01b When two or more layers are required use a letter and number, i.e....
Secondary Liner S1, S2, S3, S4 etc...
Primary Liner P1, P2, P3, P4 etc...
Tertiary Liner T1, T2, T3, T4 etc...

4.02 This numbering system should be used whenever possible. Agreement to a panel numbering system should be made at the pre-construction meeting if possible. However, it is essential that GSE's system and the Owner's Representative/Third Party QA agree. Do not use different systems.

4.03 Panel numbers shall be written in large block letters in the center of each deployed panel. The roll number, date of deployment and length (gross) should be noted below the panel number. All noting should be made so that they are easily visible from a distance. On long panels it is beneficial to write information at both ends.

4.04 Panel Numbers shall be logged on the GSE Panel Placement Log along with the roll number and gross length.

4.05 If there is a partial roll left after deployment it is important to write the last four digits of the roll number several times for future identification, along with the estimated length.

5.0 Trial Welds

5.01 Seaming apparatus shall be allowed to warm up a minimum of 15 minutes before performing trial welds.

5.02 Each seaming apparatus along with GSE Welding Tech will pass a trial weld prior to use. Trial welds to be performed in the morning and afternoon, as a minimum, as well as whenever there is a power shutdown.

5.03 Fusion or wedge welds will always be performed or conducted on samples at least 6' long. Extrusion welds will be done on samples at least 3' long.

Note: Always perform trial welds in the same conditions that exist on the job. Run the trial welds on the ground, not the installed liner. Do not use a wind break unless you are using one on the job.

5.04 Sampling Procedure

5.04a Cut 4 - 1" wide specimens from the trial weld sample. Operating temperatures should be monitored while welding.

5.04b Specimens will always be cut using a 1" die cutter so the peel values may be used for qualitative analysis.

5.04c When cutting coupons from the trial weld samples, the inside and outside tracks on the coupon should be identified to assist in troubleshooting problems in case the weld fails. The outside track will be defined as the track which would be peeled if pulling the overlap exposed in a typical installation, or the seam which is closest to the edge of the top sheet. The inside track is the seam closest to the edge of the bottom sheet.

5.04d Place a small mark on the exposed (Top) overlap to denote the outside track prior to testing trial welds.

5.05 Die Cutter

5.05a Only cut one sample at a time to avoid damaging the die cutter.

5.05b Samples should be free of sand and grit prior to cutting sample.

5.05c Inspect the die edge weekly for nicks, dents or signs of dullness. Dullness of the cutting edge may damage the units.

5.05d Remove die when edge has been dulled and lightly reshape it with a medium hand file. When wear is excessive return it for a replacement die.

5.05e When the cutting board becomes deeply scored and/or interferes with coupon cutting it should be replaced.

5.05d To adjust the depth of the die cut into the cutting board, after replacing the cutting board or sharpening the die, 0.015" washer shims can be added or removed between the cutting ram and the ram extension. Only add shims when cutting is difficult due to lack of depth of cut.

5.06 Trial Weld Testing

5.06a Allow coupons to cool prior to testing. Avoid separating the coupons while hot as failure of the sheet may be initiated and false readings indicated.

5.06b In extreme heat the coupons may need to be cooled, using water or an insulated cooler prior to peel testing. Lab conditions specify 70 degrees (plus or minus 4 degrees) Fahrenheit. Coupon temperatures greater than 70 degrees may result in lowered strengths.

5.06c Visually inspect the coupons for squeeze-out, footprint, pressure and general appearance.

5.06d Each of the 4 coupons will be tested in peel on the field tensiometer at a separation rate of 2" per minute (for HDPE). Shear tests, in addition to the peel tests, will be performed if required by a site-specific QA. Plan.

5.07 Pass/Fail Criteria

5.07a Criteria for passing trial welds will be as follows:

1) Seam must exhibit film tear bond (FTB). Trial welds should have no incursion into the weld.
2) Peel and shear values shall meet or exceed the values listed below for HDPE smooth or textured sheet (@ 2"/min.):

Material (Mil)	Shear Strength (PPI)	Fusion Peel (PPI)	Extrusion Peel (PPI)
40	81	65	52
60	121	98	78
80	162	130	104
100	203	162	130

3) Peel and shear values shall meet or exceed the values listed below for LLDPE smooth or textured sheet (@ 20"/min.):

Material (Mil)	Shear Strength (PPI)	Fusion Peel (PPI)	Extrusion Peel (PPI)
40	60	50	48
60	90	75	72
80	120	100	96
100	150	125	120

5.07b Both tracks of fusion welded samples must pass for the trial weld to be considered acceptable. If any of the four coupons fail either due to seam incursion (no FTB) or low strength values, the trial weld must be re-done.

5.07c The GSE QA will give approval to proceed with welding after observing and recording all trial welds.

5.08 Trial Weld Documentation

5.08a All trial weld data will be logged on the GSE Trial Weld log

5.08b When logging fusion welded peel values on the GSE Trial Weld log indicate the values for the outside track first, followed by the inside track

5.08c Speed and temperature settings will be recorded for each machine's trial weld

6.0 Geomembrane Field Seaming

6.01 The seam number takes the identity of the panels on each side. The seam between panels 1 & 2 becomes Seam 1/2. These lengths and seam numbers shall be recorded in the GSE Seam Log.

6.02 Welding Technicians will mark their initials/employee number, machine number, date and time at the start of every seam. Technician should also periodically mark temperatures along the seam and at the end of the seam.

6.03 Approved processes for field seaming and repairing are extrusion welding and fusion welding. All welding equipment shall have accurate temperature monitoring devices installed and working to ensure proper measurement.

6.04 Extrusion welding shall be used primarily for repairs, patching and special detail fabricating and may be used for seaming. The GSE Site Manager shall verify that:

1) equipment in use is functioning properly
2) welding personnel are purging the machine of heat degraded extrudate prior to actual use
3) all work is performed on clean surfaces and done in a professional manner
4) no seaming will be performed in adverse weather conditions

6.05 Fusion welding, shall be used for seaming panels together and is not used for patching or detail work. The GSE Site Manager shall verify that:

1) the equipment used is functioning properly
2) seaming personnel are working in a professional manner and are attentive to their duties
3) no seaming will be performed in adverse weather conditions

6.06 Seam preparation, the welding technician shall verify that:

1) prior to seaming, the seaming area is free of moisture, dust, dirt, sand or debris of any nature
2) the seam is overlapped properly for fusion welding
3) the seam is overlapped or extended beyond damaged areas at least 4" when extrusion welding
4) the seam is properly heat tacked and abraded when extrusion welding
5) seams are welded with fewest number of unmatched wrinkles or "fishmouths"

6.07 No seaming will be performed in ambient air temperatures or adverse weather conditions that would jeopardize the integrity of the liner installation.

7.0 Field Destructive Testing

7.01 Destructive seam tests shall be performed to evaluate bonded seam strength. The frequency of sample removal shall be one sample per 500' of seam, unless specific site specifications differ. Location of the destructive samples will be selected and marked by the QA Technician or third party QA. Field testing should take place as soon as possible after seam is completed.

7.02 Samples should be labeled in numerical order, I.e. DS-1, DS-2 etc....This should carry thru any layers and or multiple ponds, do not start numbering from 1 again. (This is the preferred method)

7.03 The size of samples and distribution should be approximately 12" x 39"(size may vary dependent on Job requirements) and distributed as follows:

7.03a 12" x 12" piece given to QA Technician for field testing.
7.03b 12" x 12" piece sent to Home Office for testing, if required.
7.03c 12" x 12" piece given to third party for independent testing, or archiving.

NOTE: All samples will be labeled showing test number, seam number, machine number, job number, date welded and welding tech number.

7.04 The sample given to the QA Technician in the field shall have ten coupons cut and be tested with a tensiometer adjusted to a pull rate as shown below. The strength of four out of five specimens should meet or exceed the values below, and the fifth specimen must meet or exceed 80% of the value below.

1) Seam must exhibit film tear bond (FTB). Welds should have ≤25% incursion into the weld.
2) Peel and shear values shall meet or exceed the values listed below for HDPE smooth or textured sheet (@ 2"/min.):

Material (Mil)	Shear Strength (PPI)	Fusion Peel (PPI)	Extrusion Peel (PPI)
40	81	65	52
60	121	98	78
80	162	130	104
100	203	162	130

3) Peel and shear values shall meet or exceed the values listed below for LLDPE smooth or textured sheet (@ 20"/min.):

Material (Mil)	Shear Strength (PPI)	Fusion Peel (PPI)	Extrusion Peel (PPI)
40	60	50	48
60	90	75	72
80	120	100	96
100	150	125	120

7.05 All weld destructive test data will be logged on the GSE Destructive test log.

7.06 When logging fusion welded peel values on the GSE Destructive Test Log, indicate the values for the outside track first, followed by the inside track.

7.08 Test results will be noted in the GSE Destructive Test Log as P (pass) or F (fail).

7.09 If test fails, additional samples will be cut, approximately 10' on each side of the failed test, and retested. These will be labeled A (after) & B (before). This procedure will repeat itself until a sample passes. Then the area of failed seam between the two tests that pass will be capped or reconstructed.

7.10 In lieu of taking an excessive number of samples, the GSE Site Manager may opt to extrusion weld the flap or cap the entire seam and then non-destructively test according to Section 8.0.

8.0 Non-Destructive Testing

8.01 GSE shall non-destructively test all seams their full length using an air pressure or vacuum test. The purpose of this test is to check the continuity of the seam.

8.02 Air testing; the following procedures are applicable to those seams welded with a double-seam fusion welder.

8.02a The equipment used shall consist of an air tank or pump capable of producing a minimum 35 psi and a sharp needle with a pressure gauge attached to insert into the air chamber.

8.02b Seal both ends of the seam by heating and then squeezing together. Insert the needle with the gauge into the air channel, it may be necessary to heat the liner to make this easier. Pressurize the air channel to 30psi. Note time test starts and wait a minimum of 5 minutes to check. If pressure after five minutes has dropped less than 2 psi then the test is successful (Thickness of material may cause variance).

8.02c Cut opposite seam end and listen for pressure release to verify full seam has been tested.

8.02d If the test fails, follow these procedures.

a) While channel is under pressure walk the length of the seam listening for a leak.
b) While channel is under pressure apply a soapy solution to the seam edge and look for bubbles formed by air escaping.
c) Re-test the seam in smaller increments until the leak is found.

8.02e Once the leak is found using one of the proceedures above, cut out the leak area and retest the portions of the seams between the leak areas as per 8.02a to 8.02c above. Continue this proceedure until all sections of the seam pass the pressure test.

8.02f Repair the leak with a patch and vacuum test again.

8.02g All non-destructive tests will be noted in the GSE Non-Destructive Test/Repair log.

8.03 Vacuum testing; the following procedures are applicable to those seams welded with a extrusion welder.

8.03a The equipment used shall consist of an vacuum pumping device, a vacuum box and a foaming agent in solution.

8.03b Wet a section with the foaming agent, place vacuum box over wetted area. Evacuate air from the vacuum box to a pressure suitable to affect a seal between the box and geomembrane. Observe the seam through the viewing window for the presence of soap bubbles emitting from the seam.

8.03c If no bubbles are observed, move box to the next area for testing. If bubbles are observed, mark the area of the leak for repair as per Section 10.0 and retest as per Section 8.03.

Note: If vacuum testing fusion welded seams, the overlap flap must be cut off to perform the tests.

9.0 Defects and Repairs

9.01 Identification; all seams and non-seam areas of the geomembrane lining system shall be examined for defects in the seam and sheet.

9.02 Identification of the defect should be made using the following procedures:

9.02a For any defect in the seam or sheet that is an actual breach (hole) in the liner, installation personnel shall circle the defect and mark with the letter "P" along side the circle. The letter "P" indicates a patch is required.

9.02b For any defect that is not an actual hole, installation personnel shall only circle the defect indicating that the repair method may be only an extruded bead and that a patch is not required.

9.02c Each suspect area that has been identified as needing repair shall be repaired in accordance with this section and Non-Destructively tested as per Section 8.0. After all work is complete, the GSE Site Manager will conduct a final walk-through to confirm all repairs have been completed and debris removed. Only after this final evaluation by GSE's Site Manager and Owner/Agent shall any material be placed over the installed liner.

10.0 Repair Procedures

10.01 Any Portion of the Geomembrane liner system exhibiting a defect which has been marked for repair may be repaired with any one or combination of the following procedures:

1) Patching - used to repair holes, tears, undispersed raw materials in the sheet and dented areas.
2) Grind and Reweld - used to repair small sections of extruded seams.
3) Spot Welding - Used to repair small minor, localized flaws.
4) Flap Welding - Used to extrusion weld the flap of a fusion weld in lieu of a full cap.
5) Capping - Used to repair failed seams.

6) Topping - Application of extrudate bead directly to existing seams.

10.02 The following conditions shall apply to the above methods:

1) surfaces of the geomembrane which are to be repaired shall be roughened
2) all surfaces must be clean and dry at the time of the repair
3) all seaming equipment used in repairing procedures shall be qualified
4) all patches and caps shall extend at least 4" beyond the edge of the defect, and all patches must have rounded corners
5) all cut out holes in liner must have rounded corners, 3" min. radius

11.0 As-Built Drawing Procedures

11.01 Liner Layout

11.01a Submitted As-built Drawings should always be on blank outlines supplied by GSE's Drafting Department. (Phone 281-230-2518 Don Sharkey). When outlines are not available plain paper may be used, but only after permission from GSE's Drafting Department.

11.01b Accuracy to the way seams fit or join.

11.01c Using different colors makes information easier to see. Drawings may be done in ink or pencil, but writing must be neat.

11.01d Do not write so small that it is hard to read.

11.01e Suggested scale is 1" = 40' (Other scales may be used if required).

11.02 Anchor Trenches

11.02a The amount of liner actually in the trench should be noted on the drawing. If amount differs, show all differences and approximate locations.

11.02b If anchor trench is larger than shown on GSE's construction drawings then a written approval should be obtained from the Owner/Agent representative. This should be included in the as-built package.

11.03 Panel & Roll Numbers

11.03a Each panel will be assigned a number as detailed below. When there is only one layer panels may be designate with a number only, i.e.... 1, 2, 3, 4 etc.

11.03b When two or more layers are required use a letter and number, i.e....

Secondary Liner S1, S2, S3, S4 etc...
Primary Liner P1, P2, P3, P4 etc...
Tertiary Liner T1, T2, T3, T4 etc...

11.03c This numbering system should be used whenever possible. Agreement to a panel numbering system should be made at the pre-construction meeting if possible. However, it is essential that GSE's system and the Owner's Representative/Third Party QA agree. Do not use different systems.

11.03d Panel numbers shall be written in large block letters in the center of each deployed panel. The roll number, date of deployment and gross length should be noted below the panel number. All notations should be made so that they are easily visible from a distance. On long panels it is beneficial to write information at both ends.

11.03e Panel Numbers shall be logged on the Daily Report Forms along with the roll number and gross length.

11.03f Whenever possible, roll numbers should be placed next to panel numbers on the field copies of the as-built drawing.

11.04 Seam Lengths

11.04a Every seam length that is not a cross-seam must be noted. This includes rectangles, squares, pies and any other shape (See Fig. A).

11.04b GSE assumes that all regular cross-seams are either 22' or 34' wide, unless they are not full width panels they do not have to be noted on the drawing. Panel widths are measured perpendicularly across the panels.

11.04c All dimensions should be called out in tenths of a foot.

11.05 Tests

11.05a All test markings should conform to the "Legend" on the blank outline.

11.05b It can be assumed that all seam junctions will have a patch, therefore, it is only necessary to note if they don't.

11.06 Seam Numbers

11.06a Since the seam number is drawn from the adjoining panels (I.e. 1/2, 10/11 etc.) there is no need to call out seam numbers on the drawings.

11.06b Each seam must be logged in the Daily Report.

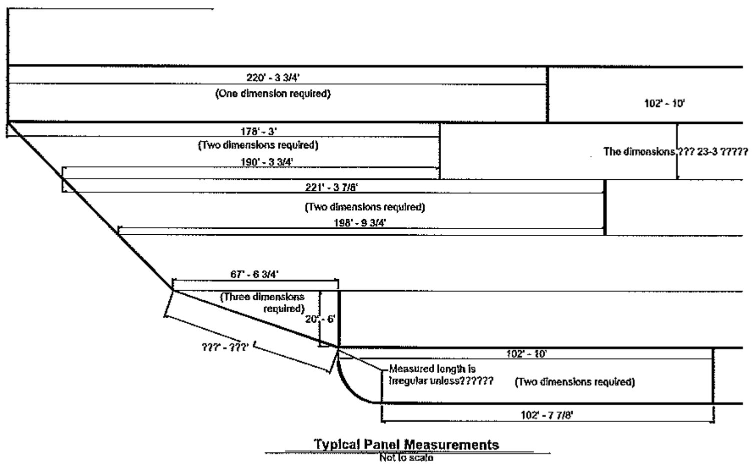


Fig A

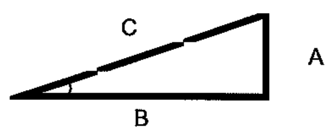
11.07 Miscellaneous

11.07a QA's name should be on all drawings and paperwork.

11.07b Any questions arising in the field about reporting issues may be handled by calling Don Sharkey at 800-435-2008, ext 2518 or 281-230-2518.

12.0 Formulas

12.01 Here are some procedures using trig formulas to enable you to deal with slope corrections concerning seam lengths on as-built drawings in order to do these calculations you will need a calculator that performs trigonomic functions.



A = Rise
B = Base
C = Slope

12.02 Useful Formulas

12.02a rise divided by base = Tangent of the angle

12.02b base divided by cosign of the angle = slope

12.02c slope multiplied by cosign of the angle = base

12.02d rise divided by Tangent of the angle = base

12.03 Slope factors

12.03a Slope factors can be used as a quick method of calculating seam lengths in a flat plan, such as an as-built drawing. Most of the time when field drawings do not fit the outline provided by the Drafting Department it is because actual seam lengths were used instead of lengths calculated with a slope factor. Once you determine the slope factor (a percentage of the actual length) it will probably make field drawings fit the outlines better. As usual, there are always exceptions to this theory.

12.03b To determine a slope factor simply divide the base length by the slope length. Lets use a 3:1 slope as an example. With a base of 100' and a rise of 33.34' the angle of the slope becomes 18.435 degrees. 100' divided by the cosign of 18.435 degrees equals 105.41'. Thus, if you divide 100' by 105.41' you get a slope factor of .9487 or rounded to the nearest one hundredth 0.95.

Now, if you multiply your slope lengths by .95 you will get the actual plan view or paper view length of a seam.

12.04 Typical Slope factors

Slope	Slope Factor	Degrees
2 to 1	0.895	26.565
3 to 1	0.949	18.435
4 to 1	0.970	14.036
5 to1	0.981	11.310
2.5 to 1	0.928	21.802

GSE Panel Placement Log

Project Name: ____________________ Site Manager: ____________________

Location: ____________________ Material: ____________________

Job Number: ____________________ Sheet Thickness: ____________________

Q.A. Technician: ____________________ Smooth: ______ Textured: ________

Panel Number	Roll Number	Deployment Date	Width (Feet)	Length (Feet)	Square Feet Smooth	Square Feet Textured

GSE Seam Log

Project Name: ____________________ Site Manager: ____________________

Location: ____________________ Material: ____________________

Job Number: ____________________ Sheet Thickness: ____________________

Q.A. Techncian: ____________________ Smooth: ______ Textured: ______

Seam Number	Time of Weld	Date of Weld	Type of Weld	Length of Seam	Machine Number	Technician ID Number

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Geomembranes Installation Quality Assurance Manual

Quality Assurance Forms

GSE Destructive Test Log

Project Name:	Site Manager:	Fusion (ppi)	Extrusion (ppi)
Location:	Material:	Min. Peel	Min. Peel
Job Number:	Sheet Thickness:	Min. Shear	Min. Shear
Q.A. Technician:	Smooth: Textured:		

Sample No.	Date Welded	Seam Number	Technician ID Number	Machine Type & No.	Location	Peel ppi	Peel ppi	Peel ppi	Peel ppi	Peel ppi	Shear ppi	Shear ppi	Shear ppi	Shear ppi	Shear ppi	FTB Y / N	Pass/ Fail

GSE Non-Destuctive Test / Repair Log

Project Name: ______________________ Site Manager: ______________________

Location: ______________________ Material: ______________________

Job Number: ______________________ Sheet Thickness: ______________________

Q.A. Technician: ______________________

Seam Number	Test Date	Technician ID Number	Test Type (A or V)	Air Pressure Test psi start	psi finish	Test Result (P or F)	Repair Locations

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Quality Assurance Forms

GSE Trial Weld Log

Project Name: ______________________ Site Manager: ______________________

Location: ______________________ Material: ______________________

Job Number: ______________________ Sheet Thickness: ______________________

Q.A. Technician: ______________________ Smooth: __________ Textured: __________

Trial No.	Date of Trial	Time of Trial	Technicians ID Number	Machine Number	Ambient Temp.	Wedge Mass	Speed Preheat	Peel ppi	Peel ppi	Peel ppi	Peel ppi	Shear ppi	Shear ppi	Shear ppi	Shear ppi	FTB Y / N	Pass Fail

Subgrade Surface Acceptance

Date: ____________

Project: ______________________ **Site Manager:** ________________

Project #: ______________________

Location: ______________________ **Partial:** ____________ **Final:** ____________

This document only applies to the acceptability of surface conditions for installation of geosynthetic products. GSE does not accept responsibility for compaction, elevation or moisture content, nor for the surface maintenance during deployment. Structural integrity of the subgrade and maintenance of these conditions are the responsibility of the owner or earthwork contrator.

For GSE Lining Technology, Inc.: ______________________

For Owner / Contractor: ______________________

Acceptance Number: ____________ Area Accepted: ____________ s.f. Total Area Accepted to date: ____________ s.f.

Spark Test Log

Project Name: ______________________ Site Manager: ______________________

Location: ______________________ Material: ______________________

Job Number: ______________________ Sheet Thickness: ______________________

Q.A. Technician: ______________________

Seam or Panel No.	Time of Test	Date of Test	Technician ID Number	Location of Repairs

GSE Lining Technology, Inc.
19103 Gundle Road
Houston, Texas 77073-3598
800-435-2008
281-443-8564
281-875-6010 Fax

Job No.: ______________
Project: ______________
Client: ______________
Bill To: ______________

Job Description: ______________
% Complete of Total Job: ______________

Certificate of Acceptance

Material	Estimated Square feet	Final Quantity/Description

I, the undersigned, duly representative of:
Do hereby take over and accept the work described above from the date hereof and confirm to the best of my knowledge the work has been completed in accordance with the specifications and the terms and conditions of the contract.

Name	Signature	Title	Date

Certificate accepted by GSE Lining Technology, Inc Representative.

Name	Signature	Title	Date

GSE Inventory Check List

Date: ____________

Project: ____________ **Site Manager:** ____________

Project #: ____________ **QA Technician:** ____________ **Page:** ______ of ______

Material	Roll #	Date Used	Material	Roll #	Date Used	Material	Roll #	Date Used	Material	Roll #	Date Used

GRI Standard GM 13*

STANDARD SPECIFICATION FOR TEST PROPERTIES, TESTING FREQUENCY AND RECOMMENDED WARRANTY FOR HIGH DENSITY POLYETHYLENE (HDPE) SMOOTH AND TEXTURED GEOMEMBRANES

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1.0 Scope

1.1 This specification covers high density polyethylene (HDPE) geomembranes with a formulated sheet density of 0.940 g/ml, or higher, in the thickness range of 0.75 mm (30 mils) to 3.0 mm (120 mils). Both smooth and textured geomembrane surfaces are included.

1.2 This specification sets forth a set of minimum, physical, mechanical and chemical properties that must be met, or exceeded by the geomembrane being manufactured. In a few cases a range is specified.

1.3 In the context of quality systems and management, this specification represents manufacturing quality control (MQC).

Note 1: Manufacturing quality control represents those actions taken by a manufacturer to ensure that the product represents the stated objective and properties set forth in this specification.

1.4 This standard specification is intended to ensure good quality and performance of HDPE geomembranes in general applications, but is possibly not adequate for the complete specification in a specific situation. Additional tests, or more restrictive values for test indicated, may be necessary under conditions of a particular application.

1.5 This specification also presents a recommended warrant which is focused on the geomembrane material itself.

1.6 The recommended warrant attached to this specification does not cover installation considerations which is independent of the manufacturing of the geomembrane.

Note 2: For information on installation techniques, users of this standard are referred to the geosynthetics literature, which is abundant on the subject.

*This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This specification will be reviewed at least every 2-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

2. Referenced Documents

2.1 ASTM Standards:

D 638	Test Method for Tensile Properties of Plastics
D 792	Specific Gravity (Relative Density) and Density of Plastics by Displacement
D 1004	Test Method for Initial Tear Resistance of Plastics Film and Sheeting
D 1238	Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
D 1505	Test Method for Density of Plastics by the Density-Gradient Technique
D 1603	Test Method for Carbon Black in Olefm Plastics
D 3895	Test Method for Oxidative Induction Time of Polyolefms by Thermal Analysis
D 4218	Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
D 4833	Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D5199	Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
D 5397	Procedure to Perform a Single Point Notched Constant Tensile Load -(SP-NCTL) Test: Appendix
D 5596	Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefm Geosynthetics
D 5721	Practice for Air-Oven Aging of Polyolefin Geomembranes
D 5885	Test method for Oxidative Induction Time of Polyolefm Geosynthetics by High Pressure Differential Scanning Calorimetry
D 5994	Test Method for Measuring the Core Thickness of Textured Geomembranes

2.2 GRI Standards:

GM10	Specification for the Stress Crack Resistance of Geomembrane Sheet
GM 11	Accelerated Weathering of Geomembranes using a Fluorescent UVA-Condensation Exposure Device
GM 12	Measurement of the Asperity Height ofTextured Geomembranes Using a Depth Gage

2.3 U. S. Environmental Protection Agency Technical Guidance Document "Quality Control Assurance and Quality Control for Waste Containment Facilities," EPA/600/R-93/182, September 1993, 305 pgs.

3.0 Definitions

Manufacturing Quality Control (MQC) – A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract specifications. ret. EPA/600/R-93/182

Manufacturing Quality Assurance (MQA) – A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract specifications. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials (resins and additives) and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract specifications for the project. ref. EPA/600/R-93/182

Formulation, n – The mixture of a unique combination of ingredients identified by type, properties and quantity. For HDPE polyethylene geomembranes, a formulation is defined as the exact percentages and types ofresin(s), additives and carbon black.

4.0 Material Classification and Formulation

4.1 This specification covers high density polyethylene geomembranes with a formulated sheet density of 0.940 g/ml, or higher. Density can be measured by ASTM D1505 or ASTM D792. If the latter. Method B is recommended.

4.2 The polyethylene resin from which the geomembrane is made will generally be in the density range of 0.932 g/ml or higher, and have a melt index value per ASTM D1238 of less than 1.0 g/10 min.

4.3 The resin shall be virgin material with no more than 10% rework. If rework is used, it must be a similar HDPE as the parent material.

4.4 No post consumer resin (PCR) of any type shall be added to the formulation.

5.0 Physical, Mechanical and Chemical Property Requirements

5.1 The geomembrane shall conform to the test property requirements prescribed in Tables 1 and 2. Table 1 is for smooth HOPE geomembranes and Table 2 is for single and double sided textured HDPE geomembranes. Each of the tables are given in English and SI (metric) units. The conversion from English to SI (metric) is soft.

Note 3: There are several tests often included in other HDPE specifications which are omitted from this standard because they are outdated, irrelevant or generate information that is not necessary to evaluate on a routine MQC basis. The following tests have been purposely omitted:

- Volatile Loss
- Dimensional Stability
- Coeff. of Linear Expansion
- Resistance to Soil Burial
- Low Temperature Impact
- ESCR Test (D 1693)
- Wide Width Tensile
- Water Vapor Transmission
- Water Absorption
- Ozone Resistance
- Modulus of Elasticity
- Hydrostatic Resistance
- Tensile Impact
- Field Seam Strength
- Multi-Axial Burst
- Various Toxicity Tests

Note 4: There are several tests which are included in this standard (that are not customarily required in other HDPE specifications) because they are relevant and important in the context of current manufacturing processes. The following tests have been purposely added:

- Oxidative Induction Time
- Oven Aging
- Ultraviolet Resistance
- Asperity Height ofTextured Sheet

Note 5: There are other tests in this standard, focused on a particular property, which are updated to current standards. The following are in this category:

- Thickness of Textured Sheet
- Puncture Resistance
- Stress Crack Resistance
- Carbon Black Dispersion (In the viewing and subsequent quantitative interpretation of ASTM D 5596 only near spherical agglomerates shall be included in the assessment).

Note 6: There are several GRI tests currently included in this standard. Since these topics are not covered in ASTM standards, this is necessary. They are the following:

- UV Fluorescent Light Exposure
- Asperity Height Measurement

5.2 The values listed in the tables of this specification are to be interpreted according to the designated test method. In this respect they are neither minimum average roll values (MARV) nor maximum average roll values (MaxARV).

5.3 The properties of the HDPE geomembrane shall be tested at the minimum frequencies shown in Tables 1 and 2. If the specific manufacturer's quality control guide is more stringent and is certified accordingly, it must be followed in like manner.

Note 7: This specification is focused on manufacturing quality control (MQC). Conformance testing and manufacturing quality assurance (MQA) testing are at the discretion of the purchaser and/or quality assurance engineer, respectively.

6. Workmanship and Appearance

6.1 Smooth geomembrane shall have good appearance qualities. It shall be free from such defects that would affect the specified properties of the geomembrane.

6.2 Textured geomembrane shall generally have uniform texturing appearance. It shall be free from agglomerated texturing material and such defects that would affect the specified properties of the geomembrane.

6.3 General manufacturing procedures shall be performed in accordance with the manufacturer's internal quality control guide and/or documents.

7. MQC Sampling

7.1 Sampling shall be in accordance with the specific test methods listed in Tables 1 and 2. If no sampling protocol is stipulated in the particular test method, then test specimens shall be taken evenly spaced across the entire roll width.

7.2 The number of tests shall be in accordance with the appropriate test methods listed in Tables 1 and 2.

7.3 The average of the test results should be calculated per the particular standard cited and compared to the minimum value listed in these tables, hence the values listed are the minimum average values and are designated as "min. ave."

8. MQC Retest and Rejection

8.1 If the results of any test do not conform to the requirements of this specification, retesting to determine conformance or rejection should be done in accordance with the manufacturing protocol as set forth in the manufacturer's quality manual.

9. Packaging and Marketing

9.1 The geomembrane shall be rolled onto a substantial core or core segments and held firm by dedicated straps/slings, or other suitable means. The rolls must be adequate for safe transportation to the point of delivery, unless otherwise specified in the contract or order.

10. Certification

10.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

11. Warranty

11.1 Upon request of the purchaser in the contract or order, a manufacturer's warrant of the quality of the material shall be furnished at the completion of the terms of the contract.

11.2 A recommended warranty for smooth and textured HDPE geomembranes manufactured and tested in accordance with this specification is given in Appendix A.

11.3 The warranty in Appendix A is for the geomembrane itself. It does not cover subgrade preparation, installation, seaming, or backfilling. These are separate operations that are often beyond the control, or sphere of influence, of the geomembrane manufacturer.

Note 8: If a warrant is required for installation, it is to be developed between the installation contractor and the party requesting such a document.

APPENDIX "A"

TYPICAL HDPE GEOMEMBRANE WARRANTY

ENGLISH UNITS

Table 1(a) – High Density Polyethylene (HDPE) Geomembrane -Smooth

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness (min. ave.)	D5199	nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Per roll
• lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density mg/l (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,00 lb
Tensile Properties *(1)* (min. ave.)	D 6693 Type IV								20,000 lb
• yield strength		63 lb/in.	84 lb/in.	105 lb/in.	126 lb/in.	168 lb/in.	210 lb/in.	252 lb/in.	
• break strength		114 lb/in.	152 lb/in.	190 lb/in.	228 lb/in.	304 lb/in.	380 lb/in.	456 lb/in.	
• yield elongation		12%	12%	12%	12%	12%	12%	12%	
• break elongation		700%	700%	700%	700%	700%	700%	700%	
Tear Resistance (min. ave.)	D 1004	21 lb	28 lb	35 lb	42 lb	56 lb	70 lb	84 lb	45,000 lb
Puncture Resistance (min. ave.)	D 4833	54 lb	72 lb	90 lb	108 lb	144 lb	180 lb	216 lb	45,000 lb
Stress Crack Resistance *(2)*	D5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI-GM10
Carbon Black Content (range)	D 1603 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	20,000 lb
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(5)*									200,000 lb
(a) Standard OIT	D 3895	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	
— or —									
(b) High Pressure OIT	D 5885	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	
Oven Aging at 85°C *(5), (6)*	D 5721								
(a) Standard OIT (min. ave.) - % retained after 90 days	D 3895	55%	55%	55%	55%	55%	55%	55%	per each formulation
— or —									
(b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5885	80%	80%	80%	80%	80%	80%	80%	
UV Resistance *(7)*	GM 11								
(a) Standard OIT (min. ave.)	D 3895	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	N.R. *(8)*	per each formulation
— or —									
(b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	D 5885	50%	50%	50%	50%	50%	50%	50%	

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 1.3 inches
Break elongation is calculated using a gage length of 2.0 in.
(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(3) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3
(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (METRIC) UNITS

Table 1(b) – High Density Polyethylene (HPDE) Geomembrane - Smooth

Properties	Test Method	Test Value 0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	Testing Frequency (minimum)
Thickness - mils (min. ave.) • lowest individual of 10 values	D5199	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	per roll
Density (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties *(1)* (min. ave.) • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	 11 kN/m 20kN/m 12% 700%	 15 kN/m 27 kN/m 12% 700%	 18 kN/m 33 kN/m 12% 700%	 22 kN/m 40 kN/m 12% 700%	 29 kN/m 53 kN/m 12% 700%	 37 kN/m 67 kN/m 12% 700%	 44 kN/m 80 kN/m 12% 700%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	240 N	320 N	400 N	480 N	640 N	800 N	960 N	20,000 kg
Stress Crack Resistance *(2)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM-10
Carbon Black Content - %	D 1603 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	9,000 kg
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(5)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(5)*, *(6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	 D 3895 D 5885	 N. R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	per each formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm
(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(3) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3
(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

ENGLISH UNITS

Table 2(a) – High Density Polyethylene (HDPE) Geomembrane - Textured

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mils (min. ave.) *(1)*	GM 12	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	every 2^{nd} roll *(2)*
Density (min. ave.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,000 lb
Tensile Properties (min. ave.) *(3)* • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	 63 lb/in. 45 lb/in. 12% 100%	 84 lb/in. 60 lb/in. 12% 100%	 105 lb/in. 75 lb/in. 12% 100%	 126 lb/in. 90 lb/in. 12% 100%	 168 lb/in. 120 lb/in. 12% 100%	 210 lb/in. 150 lb/in. 12% 100%	 252 lb/in. 180 lb/in. 12% 100%	20,000 lb
Tear Resistance (min. ave.)	D 1004	21 lb	28 lb	35 lb	42 lb	56 lb	70 lb	84 lb	45,000 lb
Puncture Resistance (min. ave.)	D 4833	45 lb	60 lb	75 lb	90 lb	120 lb	150 lb	180 lb	45,000 lb
Stress Crack Resistance *(4)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM10
Carbon Black Content (range)	D 1603 *(5)*	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	20,000 lb
Carbon Black Dispersion	D 5596	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(7)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	200,000 lb
Oven Aging at 85°C *(7)*, *(8)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(9)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(11)*	GM11 D 3895 D 5885	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	per each formulation

(1) Of 10 readings; 8 out of 10 must be ≥ 7 mils, and lowest individual reading must be ≥ 5 mils

(2) Alternate the measurement side for double sided textured sheet

(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 1.3 inches
Break elongation is calculated using a gage length of 2.0 inches

(4) P-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(5) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.

(6) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3

(7) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(8) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(9) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(10) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(11) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (METRIC UNITS)

Table 2(b) – High Density Polyethylene (HDPE) Geomembrane - Textured

Properties	Test Method	Test Value							Testing Frequency (minimum)
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mils (min. ave.) *(1)*	GM 12	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm	0.25 mm	every 2nd roll *(2)*
Density (min. ave.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties (min. ave.) *(3)* • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	11 kN/m 8 kN/m 12% 100%	15 kN/m 10 kN/m 12% 100%	18 kN/m 13 kN/m 12% 100%	22 kN/m 16 kN/m 12% 100%	29 kN/m 21 kN/m 12% 100%	37 kN/m 26 kN/m 12% 100%	44 kN/m 32 kN/m 12% 100%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	200N	267 N	333 N	400 N	534 N	667 N	800 N	20,000 kg
Stress Crack Resistance *(4)*	D 5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI GM10
Carbon Black Content (range)	D 1603 *(5)*	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	9,000 kg
Carbon Black Dispersion	D 5596	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(7)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(7)*, *(8)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(9)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(11)*	GM11 D 3895 D 5885	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	 N.R. *(10)* 50%	per each formulation

(1) Of 10 readings; 8 out of 10 must be ≥ 0.18 mm, and lowest individual reading must be ≥ 0.13 mm
(2) Alternate the measurement side for double sided textured sheet
(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm
(4) The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(5) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(6) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3
(7) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(8) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(9) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(10) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(11) UV resistance is based on percent retained value regardless of the original HP-OIT value.

ADOPTION AND REVISION SCHEDULE FOR HDPE SPECIFICATION PER GRI-GM13

"Test Properties, Testing Frequency and Recommended Warrant for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes"

Adopted:	June 17, 1997
Revision 1:	November 20, 1998; changed CB dispersion from allowing 2 views to be in Category 3 to requiring all 10 views to be in Category 1 or 2. Also reduced UV percent retained from 60% to 50%.
Revision 2:	April 29, 1999: added to Note 5 after the listing of Carbon Black Dispersion the following: "(In the viewing and subsequent quantitative interpretation of ASTM D5596 only near spherical agglomerates shall be included in the assessment)" and to Note (4) in the property tables.
Revision 3:	June 28, 2000: added a new Section 5.2 that the numeric table values are neither MARV or MaxARV. They are to be interpreted per the the designated test method.
Revision 4:	December 13, 2000: added one Category 3 is allowed for carbon black dispersion. Also, unified terminology to "strength" and "elongation".
Revision 5:	May 15, 2003: Increased minimum acceptable stress crack resistance time from 200 hrs to 300 hrs.
Revision 6:	June 23, 2003: Adopted ASTM D 6693, in place of ASTM D 638, for tensile strength testing. Also, added Note 2.

GRI Standard GM14

SELECTING VARIABLE INTERVALS FOR TAKING GEOMEMBRANE DESTRUCTIVE SEAM SAMPLES

1. Scope

1.1 This guide is focused on selecting the spacing interval for taking destructive seam samples of field deployed geomembranes as a particular job progresses based on an installers ongoing record of pass - or - fail testing.

Note 1 - While subjective at this time, the guide is most applicable to large geomembrane seaming projects, which require more than 100 destructive seam samples based upon the typical sampling strategy of 1 destructive sample per 150 m (500 ft).

1.2 This guide is essentially applicable to production seams. Caution should be exercised in using the guide for projects that involve complex geometries, multiple penetrations, or extreme weather conditions.

1.3 The primary target audiences for this guide are construction quality assurance (CQA) organizations, construction quality control (CQC) organizations, facility owner/operators and agency regulators having permitting authority.

1.4 The outcome of using the guide rewards good seaming performance resulting from a record of passing destructive seam tests. It also penalizes poor seaming performance resulting from a record of excessively failing seam tests.

1.5 This guide does not address the actual seam testing procedures that are used for acceptance or failure of the geomembrane seam test specimens themselves. Depending on the type of geomembrane being deployed one should use ASTM D4437, D3083, D751 and D413 for testing details in this regard. The project-specific CQA plan should define the particular criteria used in acceptance or failure.

1.6 An appendix is offered using control charts, which is intended to be of assistance to geomembrane installers, i.e., construction quality control (CQC) organizations, to identify salient aspects of good and poor seaming performance.

2. Referenced Documents

2.1 ASTM Standards:

D4437 Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes

D3083 Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining

D751 Method of Testing Coated Fabrics

D413 Test Methods for Rubber Property - Adhesion to Flexible Substrate

2.2 Other Standards:

ANSI/ASQC Z1.4 [1993]

Sampling Procedures and Tables for Inspection by Attributes

3. Summary of Guide

3.1 Use of this guide requires the establishment of an anticipated geomembrane seam failure percentage (ranging from 1 to 8%) and an initial, or start-up, sampling interval.

Note 2 - The value of anticipated failure percentage is an important consideration. It dictates each decision as to a possible increase or decrease in interval spacing from the preceding value. The percentage itself comes from historical data of the construction quality assurance (CQA) organization or regulatory agency. It is related to a number of factors including criticality of installation, type of geomembrane, type of seaming method and local ambient conditions.

The actual value is admittedly subjective and should be made known in advance to the geomembrane installer before bidding the project. Use of an unrealistically low value of anticipated failure percentage, e.g., < 1.0%, will likely result in field difficulties insofar as decreased sampling intervals are concerned. Conversely, use of an unrealistically high value of anticipated failure percentage, e.g., > 8.0%, will likely result in very large sampling intervals and quite possibly sacrifice the overall quality of the seaming effort.

3.2 The guide then gives the procedure for establishing the initial number of samples needed for a possible modification to the start-up sampling interval. This is called the initial batch. Based upon the number of failed samples in the initial batch, the spacing is increased (for good seaming), kept the same, or decreased (for poor seaming).

3.3 A second batch size is then determined and the process is continued. Depending on the project size, i.e., the total length of seaming, a number of decision cycles can occur until the project is finished.

3.4 It is seen that the number of samples required for the entire project is either fewer than the start-up frequency (for good seaming); the same as the start-up frequency (for matching the initial anticipated failure percentage); or more than the start-up frequency (for poor seaming).

4. Significance and Use

4.1 Construction quality assurance (CQA) and construction quality control (CQC) organizations, as well as owner/operators and agency regulators can use this guide to vary the sampling interval of geomembrane seam samples (i.e., the taking of field samples for destructive shear and peel testing) from an initial, or start-up, interval. This initial interval is often 1 destructive seam sample in every 150 m (500 ft) of seam length.

4.2 The guide leads to increasing the sampling interval for good seaming practice (hence fewer destructive samples) and to decreasing the sampling interval for poor seaming practice (hence additional destructive samples).

4.3 Use of the guide should provide an incentive for geomembrane installers to upgrade the quality and performance of their field seaming activities. In so doing, the cutting of fewer destructive samples will lead to overall better quality of the entire liner project, since the patching of previously taken destructive samples is invariably of poorer quality than the original seam itself.

Note 3 - It is generally accepted that field patching of areas where destructive samples had been taken using extrusion fillet seaming is less desirable than the original seam, which was made by hot wedge welding.

4.4 Control charts are illustrated in Appendix A, which can be used by geomembrane installers and their construction quality control (CQC) personnel for improvement in overall job quality and identification of poorly performing seaming personnel and/or equipment.

5. Suggested Methodology

Using the concepts embodied in the method of attributes, the following procedure is based on adjustments to sequential sampling.

5.1 Typical Field Situation - In order to begin the process, a project-specific total seam length must be obtained from the installers panel (roll) layout plan. Also, an initial, or start-up, sampling interval must be decided upon. From this information the total number of samples that are required based on the start-up sampling interval can be obtained.

Example 1 - A given project has 54,000 m (180,000 ft) of field seaming. The start-up sampling frequency is 1 sample per 150 m (500 ft). Therefore, the total number of samples required if the start-up interval is kept constant will be:

$$\frac{54{,}000}{150} = 360 \text{ Samples}$$

5.2 Determination of Initial Batch Size - Using the table shown below, the initial batch size from which to possibly modify the start-up sampling interval is obtained.

TABLE 1. BATCH SIZE DETERMINATION, AFTER ANSI/ASQC Z1.4 [1993]

No. Of Required Samples Based on Initial	No. Of samples Needed (Batch Size)
Or Modified Sampling Interval	To Determine Subsequent Sampling Interval
2-8	2
9-15	3
16-25	5
26-50	8
51-90	13
91-150	20
151-280	32
281-500	50
501-1200	80
1201-3200	125

Example 1 (cont.) - For 360 samples, a batch size of 50 is necessary. As production seaming progresses, these 50 samples are tested (either as they are taken or in a batch) and the number of failures is determined.

5.3 Verification of Start-Up Sampling Interval - A sampling table is now used which separates the number of failures within this initial batch size into three categories: a relatively low number of failures (where the sampling interval can be increased), the anticipated number of failures (where the sampling interval is maintained), or a relatively high number of failures (where the sampling interval should be decreased). Table 2 provides this information that is based upon the operation characteristic (OC) curves of Appendix B.

Example 1 (cont.) - Assuming an anticipated failure percentage of 2% (recall Note - 2), Table 2 results in the three categories shown below:

- 0 or 1 failure out of 50; the sampling interval can be increased
- 2 or 3 failures out of 50; the sampling frequency should remain at 1 sample per 150 m (500 ft)
- 4 or more failures out of 50; the sampling interval should be decreased

TABLE 2. SAMPLING TABLE CONTAINING THE NUMBER OF FAILED SAMPLES TO BE USED FOR INTERVAL

Sampling Interval Modification, see Appendix B for details

No. Of Required Samples Based on Initial or Modified Sampling Interval	No. Of Samples Needed (Batch Size) to Determine Subsequent Sampling Interval	Anticipated Failure Percentage*							
		1%		2%		3%		4%	
		I	D	I	D	I	D	I	D
2-8	2	0	1	0	1	0	1	0	1
9-15	3	0	1	0	1	0	2	0	2
16-25	5	0	1	0	1	0	2	0	2
26-50	8	0	1	0	1	0	2	0	2
51-90	13	0	1	0	2	0	2	0	3
91-150	20	0	2	0	3	1	3	1	4
151-280	32	0	2	1	3	1	4	2	5
281-500	50	0	3	1	4	2	5	3	6
504-1200	80	1	4	2	6	3	7	5	9
1201-3200	125	2	5	4	7	5	9	7	11

No. Of Required Samples Based on Initial or Modified Sampling Interval	No. Of Samples Needed (Batch Size) to Determine Subsequent Sampling Interval	Anticipated Failure Percentage*							
		5%		6%		7%		8%	
		I	D	I	D	I	D	I	D
2-8	2	0	1	0	1	0	2	0	2
9-15	3	0	2	0	1	0	2	0	2
16-25	5	0	2	0	1	0	3	0	3
26-50	8	0	3	0	1	1	3	1	4
51-90	13	1	4	1	2	1	4	1	5
91-150	20	1	5	2	3	2	5	2	6
151-280	32	2	6	3	3	3	7	4	7
281-500	50	4	7	4	4	5	9	6	10
504-1200	80	6	10	7	6	8	12	9	14
1201-3200	125	9	13	10	7	12	17	13	19

No: *To be selected by CQA, owner or regulatory organizations
I = Increase the sampling interval if the number of failed samples found in the batch does not exceed the tabulated value.
D = Decrease the sampling interval if the number of failed samples found in the batch equals or exceeds the tabulated value.

5.4 Modification of Start-Up Sampling Interval - Depending upon the outcome of the previous section, the start-up sampling interval may be modified to a new value which will then require a new batch size to verify the modification. The process is then continued until the project is finished. Two examples will be provided using the above sampling tables both with anticipated failure percentages of 2.0%: Example 2 illustrates good seaming, and Example 3 illustrates poor seaming.

Example 2 - Using the same project seam length and start-up sampling frequency as in the previous example assume that the start-up batch of 50 samples in the previous example had 2-failures. The decision is then to continue at a 1 destructive sample in 150 m (500 ft) sampling interval. Thus the second batch size from Table 1 is again 50 samples, see Table 3. Table 3(a) is in S.I. units and Table 3(b) is in English units. Now assume in the second batch there are no failures. This allows the sampling interval to be increased, e.g., to 1 sample in 180 m (600 ft). From Table 1, the third batch size is then decreased to 32 samples. The process is continued in this manner until the project is concluded. For this hypothetical situation Table 3(a) illustrates that 265 samples (or 266 samples when using the English units in Table 3(b)) are necessary. Note that by using a constant interval of 1 sample in 150 m (500 ft), 360 samples would have been necessary. Also note that the maximum sampling interval was fixed at 310 m (1000 ft).

Note 4 - This example, and the following one, use a changing sampling interval of +/- 20% from the previous value. That is, when good seaming allows for an increase in sampling interval; the progression being from 150, 180, 215, 260 to 310 m (500, 600, 720, 850 to 1000 ft), respectively. A maximum interval of 310 m (1000 ft) is recommended, but clearly this value is at the discretion of the organizations involved. Conversely, poor seaming requires a decrease in sampling interval, the progression being from 150, 120, 100, 80 to 65 m (500, 400, 320, 250 to 200 ft), respectively. A minimum interval of 65 m (200 ft) is recommended, but clearly this decision is also at the discretion of the organizations involved

Table 3(a) - Results of Example 2 (in S.I. Units) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Good" Quality Installer

Batch Number	Sampling Interval (m)	No. Of Remaining Samples Required	Batch Size	Cumulative Distance (m)	Number of Failures	Decision Made
1	150	360	50	7500	2	Stay
2	150	310	50	15000	0	Increase
3	180	217	32	20760	0	Increase
4	215	155	32	27640	2	Stay
5	215	123	20	31940	1	Stay
6	215	103	20	36240	0	Increase
7	260	68	13	39620	1	Stay
8	260	55	13	43000	0	Increase
9	310	35	8	45480	0	Stay
10	310	27	8	47960	0	Stay
11	310	19	5	49510	0	Stay
12	310	14	3	50440	0	Stay
13	310	11	3	51370	0	Stay
14	310	8	2	51990	0	Stay
15	310	6	2	52610	0	Stay
16	310	4	2	53230	0	Stay
17	310	2	2	53850	0	Done

Total Number of tests per 54,000 m of seam project = 265

Table 3(a) - Results of Example 2 (in English Units) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Good" Quality Installer

Batch Number	Sampling Interval (Ft)	No. Of Remaining Samples Required	Batch Size	Cumulative Distance (Ft)	Number of Failures	Decision Made
1	500	360	50	25000	2	Stay
2	500	310	50	50000	0	Increase
3	600	217	32	69200	0	Increase
4	720	155	32	92240	2	Stay
5	720	123	20	106640	1	Stay
6	720	103	20	121040	0	Increase
7	850	68	13	132090	1	Stay
8	850	55	13	143140	0	Increase
9	1000	35	8	151140	0	Stay
10	1000	27	8	159140	0	Stay
11	1000	19	5	164140	0	Stay
12	1000	14	3	169140	0	Stay
13	1000	11	3	172140	0	Stay
14	1000	8	2	174140	0	Stay
15	1000	6	2	176140	0	Stay
16	1000	4	2	178140	0	Stay
17	1000	2	2	179140	0	Done

Total Number of tests per 180,000 ft of seam project = 266

Example 3 - Using the same project seam length and start-up sampling frequency as Example 1, assume that the start-up batch of 50 samples had 3- failures. The decision is then to continue at a 1 destructive sample in 150 m (500 ft) sampling interval. Thus the second batch size is again 50 samples as it was with Example 2, see Table 4. Table 4(a) is in S.I. units and Table 4(b) is in English units. Now assume in the second batch there are 2-failures. The decision is to again continue at a 1 destructive sample in 150 m (500 ft) sampling interval. From Table 1, the third batch size is then decreased to 32 samples. The process is continued in this manner until the project is concluded. For this hypothetical situation Table 4 illustrates that 412 samples are necessary. Note that by a constant interval of 1 sample in 150 m (500 ft), 360 samples would have been necessary. Furthermore, a good seamer (as illustrated in Example 2) would only have had to take 265 samples.

Table 4(a) - 150Results of Example 3 (in S.I. Units) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Poor" Quality Installer

Batch Number	Sampling Interval (m)	No. Of Remaining Samples Required	Batch Size	Cumulative Distance (m)	Number of Failures	Decision Made
1	150	360	50	7500	3	Stay
2	150	310	50	15000	2	Stay
3	150	260	32	19800	2	Stay
4	150	228	32	24600	3	Decrease
5	150	245	32	28440	3	Decrease
6	150	256	32	31640	1	Increase
7	150	186	32	35480	1	Increase
8	150	123	20	38480	2	Stay
9	150	103	20	41480	1	Stay
10	150	83	13	43430	2	Decrease
11	150	88	13	44990	2	Decrease
12	150	90	13	46290	1	Stay
13	150	77	13	47590	1	Stay
14	150	64	13	48890	1	Stay
15	150	51	13	50490	0	Increase
16	150	32	8	51150	1	Stay
17	150	24	5	51750	1	Decrease
18	150	23	5	52250	0	Increase
19	150	15	3	52610	0	Increase
20	150	9	2	52910	1	Decrease
21	150	9	2	53150	1	Decrease
22	150	11	3	53210	0	Increase
23	150	7	2	53390	0	Increase
24	150	5	2	53510	0	Increase
25	150	3	2	53750	0	Done

Total Number of tests per 54,000 m of seam project = 412

Table 4(b) - Results of Example 3 (in English Units) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Poor" Quality Installer

Batch Number	Sampling Interval (Ft)	No. Of Remaining Samples Required	Batch Size	Cumulative Distance (Ft)	Number of Failures	Decision Made
1	500	360	50	25000	3	Stay
2	500	310	50	50000	2	Stay
3	500	260	32	66000	2	Stay
4	500	228	32	82000	3	Decrease
5	400	245	32	94800	3	Decrease
6	320	266	32	105040	1	Increase
7	400	187	32	117840	1	Increase
8	500	124	20	127840	2	Stay
9	500	104	20	137840	1	Stay
10	500	84	13	144340	2	Decrease
11	400	89	13	149540	2	Decrease
12	320	95	13	153700	1	Stay
13	320	82	13	157860	1	Stay
14	320	69	13	162020	1	Stay
15	320	56	13	166180	0	Increase
16	400	35	8	169380	1	Stay
17	400	27	5	171380	1	Decrease
18	320	27	5	172980	0	Increase
19	400	18	3	174180	0	Increase
20	500	12	2	175180	1	Decrease
21	400	12	2	175980	1	Decrease
22	320	13	3	176140	0	Increase
23	400	10	2	176780	0	Increase
24	500	6	2	177140	0	Increase
25	600	5	2	177980	0	Done

Total Number of tests per 54,000 m of seam project = 412

5.5 Summary

This guide illustrates by means of hypothetical examples how a CQA and/or CQC organization can modify the sampling interval for taking destructive samples from a geomembrane-seaming project. It is based on the method of attributes that are common to statistical control methods. The methodology uses sequential sampling to proceed from one decision to the next until the project is complete.

The result in using this guide for the above purpose is to reward good seaming performance by taking fewer destructive samples, and to penalize poor seaming performance by taking additional destructive samples. In the example illustrations, good seaming resulted in taking 265 samples (versus 360), or a decrease of 26% from the originally set constant interval of 1 sample per 150 m (500 ft). Conversely, poor seaming resulted in taking 412 samples (versus 360), or a 14% increase in the originally set constant interval of 1 sample per 150 m (500 ft.) of seam length.

Appendix A - General Principles of Control Charts

In order to control a production process, like the field seaming of geomembranes, it is necessary to identify and quantify characteristics that reflect the quality of the product. Such quality characteristics can be either discrete or continuous variables. For example, the number of pinholes in a sheet of geomembrane is a discrete variable. Variation in the thickness of a sheet of geomembrane, however, is considered to be a continuous variable.

Whether quality characteristics are discrete or continuous, variability in the observed values is unavoidable. In the theory of control charts, this variation is considered due to either random (common) or assignable (special) causes, Wadsworth (1989) and Deming (1982). Random causes are generally smaller, uncontrollable influences that cannot be removed from the process without fundamental changes in the process itself. An assignable cause, however, is an influence considered to be significant, unusual, and capable of being removed form the process. Such causes may be due to human error, variation in raw materials, or the need for machine adjustment.

An important tool used to reduce process variation is the use of control charts. When using control charts, control limits are used to determine whether the variability of the statistic over time appears to be due to random variation only, or if an assignable cause is present. In other words, the purpose of control charts is to establish a "statistical control" of the assignable causes of variation within of a process.

The control chart generally used to monitor conforming or non-conforming data, called attributes, is the p-chart, where "p" stands for the proportion of non-conforming items in the entire population. In the case of inspecting the quality of the seams of field-deployed geomembranes, the p-value would be the historic failure percentage of the installer.

Suppose we have m subgroups (e.g., m different operators, or m different welding machines, or m working days, etc.) of varying sample sizes n_1, n_2, ..., nm. The number of non-conforming (failed) samples in the ith subgroup is Di, i =1, 2, ..., m, so the proportion of non-conforming items (failure rate) in the ith subgroup is as follows:

$$\hat{P}_i = \frac{D_i}{n_i} \quad 1 = 1,2,...,m \tag{A1}$$

For the p-chart, the values of pi are plotted against the subgroup number with a control limit, CL, set at the following:

$$CL = p + 3 \left[\frac{p(1-p)}{n} \right]^{1/2} \tag{A2}$$

Where $\bar{n} = \frac{1}{m}\sum_{i=1}^{m} n_i$ = average sample size.

Two examples follow:

Example A1 - Assume that a seaming project is expected to take 25-days for completion, i.e., m=25. The installer has a historic data indicating that the company's average failure percentage is 2.0%. As the work progresses, the number of destructive seam samples and the respective numbers of failures are listed in tabular form as shown in the following table. Note that the daily failure rates, i.e., , are also shown in the table. The control chart of this project can now be developed.

Subgroup No. (days)	No. Of destructive samples	No. Of failures in subgroup	Failure Percentage P
1	12	0	0.000
2	14	0	0.000
3	9	0	0.000
4	7	0	0.000
5	13	1	0.077
6	15	0	0.000
7	19	1	0.053
8	13	0	0.000
9	14	1	0.071
10	9	0	0.000
11	17	1	0.059
12	16	0	0.000
13	7	0	0.000
14	22	1	0.045
15	18	0	0.000
16	16	0	0.000
17	15	0	0.000
18	16	0	0.000
19	14	0	0.000
20	16	0	0.000
21	22	1	0.045
22	18	0	0.000
23	16	0	0.000
24	9	0	0.000
25	13	1	0.077

Solution: From Equation (B2), the control limit is calculated as follows:

$$CL=0.02+3\left[\frac{0.02(1-0.02)}{360/25}\right]^{1/2}=0.13$$

The control chart can now be obtained by plotting the subgroup failure rate against the subgroup number (i.e., days) along with the control limit, CL = 0.13. The results are shown in the following figure, note that the 2.0% historic failure rate is also shown.

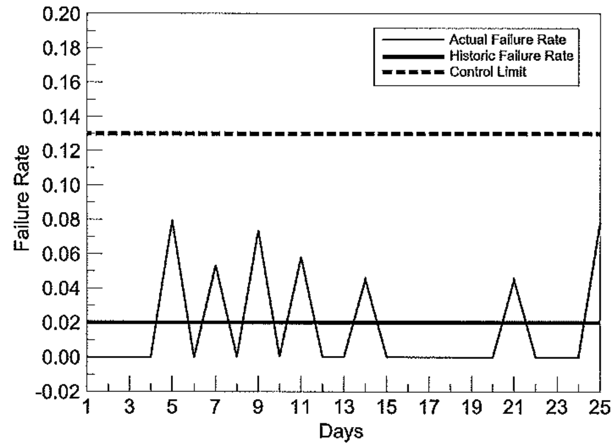

Figure A1 – The Resulted Control Chart of Example A-1.

As seen in the above control chart, the entire 25-day record of the failure rate of this project falls below the control limit set on the basis of the installer's 2.0% historic failure rate. That is to say, the variations in the daily failure record were due to random causes only and no assignable cause was identified. The above control chart indicates that no corrective action is necessary. This is an example of good seaming control.

Example A2 - For a similar size seaming project and historic record (i.e., 2% failure rate) as presented in Example A-1, a second installer has a poorer destructive seam record as shown in the following table. The control chart of this particular situation can also be developed.

Subgroup No. (days)	No. Of destructive samples	No. Of failures in subgroup	Failure Percentage
1	12	1	0.083
2	14	0	0.000
3	9	1	0.111
4	7	0	0.000
5	13	1	0.077
6	15	1	0.067
7	19	3	0.158
8	13	2	0.154
9	14	1	0.071
10	9	0	0.000
11	17	0	0.000
12	16	1	0.063
13	7	1	0.143
14	22	2	0.091
15	18	1	0.056
16	16	2	0.125
17	15	0	0.000
18	16	1	0.063
19	14	0	0.000
20	16	1	0.063
21	22	2	0.091
22	18	1	0.056
23	16	3	0.188
24	9	0	0.000
25	13	1	0.077

Solution: Since the historic failure rate is the same as shown in Example A-1.A new control chart can now be obtained by plotting the subgroup failure rate against the subgroup number (i.e., days) along with the control limit, CL = 0.13. The results are shown in the following figure. Again, the 2.0% historic failure rate is also shown.

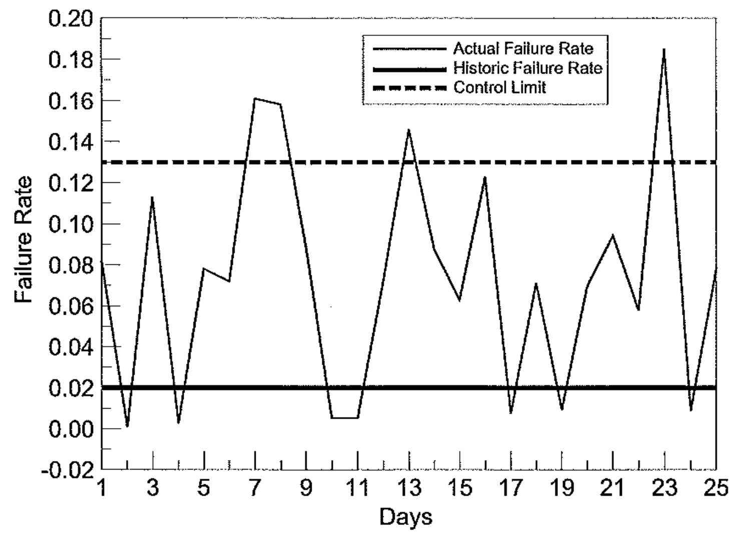

Figure A2 - The Resulted Control Chart of Example A-2.

As seen in the above control chart, the daily failure rates at day 7, 8, 13 and 23 exceed the control limit set on the basis of the installer's 2.0% historic failure rate. That is to say, there are possible assignable causes on those days. From the standpoint of construction quality control, the installer should check the record on those days, identify the cause(s) of such variations, and take necessary corrective actions. This is an example of poor seaming.

GM 14 - Appendix B - The Selection of the "I" and "D" Values

In this appendix, the procedure used for selecting the "I" and "D" values listed in Table 2 is presented. The required background, e.g., the concept of sampling risk and the operating characteristics (OC) curves, are briefly discussed.

Sampling Risk

Sampling involves a degree of risk that the actual samples do not adequately reflect the conditions of the lot. For example, when using the sampling plan recommended in this guide, there are two common risks [see Juran and Gryna (1980) and Juran el. al (1974) for details]:

1. A good seaming practice might be penalized. This is generally referred as the installer's risk and denoted as the risk.
2. A poor seaming practice might go undetected. This is generally referred as an owner/regulators risk and denoted as the risk.

The effects (impacts) of the relative degree of these two risks are summarized in Table B1.

TABLE B1 - THE EFFECTS OF THE RELATIVE DEGREE OF AND RISKS.

Relative	Types of Risks	
Degree	Installers (α) Risk	Owner/Regulators (β) Risk
Low	Loose CQA control; low testing cost	Tight CQA control; high testing cost
High	Tight CQA control; high testing cost	Loose CQA control; low testing cost

Operating Characteristics (OC) Curves

Both of the risks can be quantified by sampling-plan-specific operating characteristics (OC) curves. The OC curve for a sampling plan is a graph that plots the probability that the sampling plan will accept a lot (i.e., the Pa value) versus the percent defective samples in that particular lot. Note that the term "sampling plan" used here corresponds to a batch of "n" destructive testing samples and the criteria for adjusting the sampling interval. Recall Table 2 in the main body of this guide. Figure B1 illustrates the concept of OC curves. In Figure B1, the dashed curve represents an "ideal" OC curve. Here it is desired to accept all lots having less or equal than 2% and reject all lots having greater than 2% failures. In reality, all sampling plans have risks that a "good" lot will be rejected or a "bad" lot will be accepted. This is illustrated by the solid S-shaped curve shown in Figure B1. It is seen that this particular sampling plan will have a 5% risk (100% - 95%) of rejecting a lot having only 1% defects (i.e., a "good" lot) and a 10% risk of accepting a lot having 5% defects (i.e., a "bad" lot).

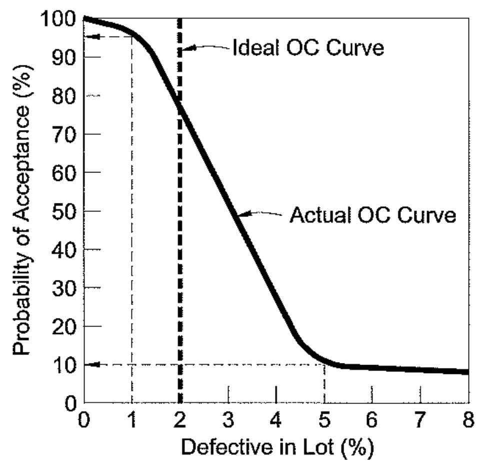

Figure B1 - Ideal and Actual Operating Characteristics Curves for a Sampling Plan

An OC curve can be developed by determining the probability of acceptance for several values of the percent defects. To do so, a statistical distribution of the acceptance probability has to be assumed first. There are three distributions that can be used: hypergeometric, binomial and Poisson distribution. The Poisson distribution is generally preferable due to the ease of calculation. It is used in this guide. The Poisson distribution function to be applied to an acceptance-sampling plan is as follows:

$$P\left(\begin{array}{l}\text{exactly "c" defects} \\ \text{in a batch of size "n"}\end{array}\right) = \frac{e^{-np}(np)^{c}}{c!} \qquad \text{(B1)}$$

Most statistics books provide Poisson distribution tables that give the probability of "c" or fewer defects in a batch of size "n" from a lot having a fraction of defect "p".

The Selection of the "I" and "D" Values Listed in Table 2

As mentioned earlier, each of the sampling plans recommended in this guide consists of three variables: the batch size "n", the values of "I" and "D". Note that the values of "I" and "D" are specific values of "c" mentioned in Equation B1. The "I" value corresponds to the judgment criterion of rewarding good seaming practice, i.e., increasing the sampling interval if the number of failed samples does not exceed this particular value. The "D" value, on the other hand, corresponds to the judgment criterion of penalizing poor seaming practice, i.e., decreasing the sampling interval if the number of failed samples equals or exceeds this particular value.

The concept of the OC curves is used to determine the actual values of I's and D's for different sampling plans. The criteria used are as follows:

- For a batch of size "n", the "I" value should yield a 80~90% probability of rewarding good seaming practice, i.e., 80% < Pa < 90%.
- For a batch of size "n", the "D" value should yield a risk of 0.5% or less of penalizing

good seaming practice, i.e., Pa >99.5%. In other words, the probability for good seaming practice to be penalized is extremely small, i.e., less than 0.5%.

The above criteria are subjective. Nevertheless, it is felt to be adequate since the rights of both the installer and the owner/regulator are protected. Recognize that a sampling plan with tighter control (i.e., smaller values of "I" and "D") might seem to be more ideal at first glance, but it may result in a significant increase in the required number of destructive tests, i.e., it may be counter productive.

As an illustration, Figure B2 shows the graphic procedure of obtaining the "I" and "D" values for a batch of 50 samples (n=50) and an anticipated failure percentage of 4%. [In other words, it illustrates the procedure of obtaining one particular pair of numbers listed in Table 2, namely, "I" and "D" equal to 3 and 6, respectively.] Note that each OC curve shown in Figure B2 corresponds to a specific "c" value and is obtained via a Poisson distribution table.

Figure B2 can also used to determine the values of "I" and "D" for sampling plans with the same batch size (i.e., n = 50) but different anticipated failure percentage. The rest of the values listed in Table 2 can be verified in a similar manner using OC curves corresponding to different batch sizes.

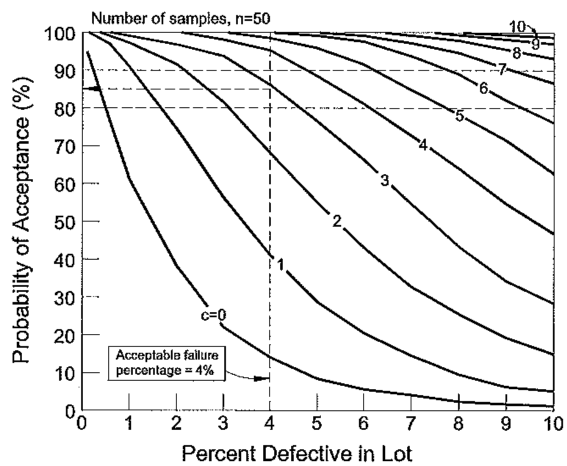

Figure B2 - The Determination of the Values of "I" and "D" for a Batch with 50 Samples and an Anticipated Failure Percentage of 4.0%.

Revision Schedule:

Adopted: March 27,1998

GRI Standard GM17

STANDARD SPECIFICATION FOR TEST PROPERTIES, TESTING FREQUENCY AND RECOMMENDED WARRANTY FOR LINEAR LOW DENSITY POLYETHYLENE (LLDPE) SMOOTH AND TEXTURED GEOMEMBRANES

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

1.1 This specification covers linear low density polyethylene (LLDPE) geomembranes with a formulated sheet density of 0.939 g/ml, or lower, in the thickness range of 0.50 mm (20 mils) to 3.0 mm (120 mils). Both smooth and textured geomembrane surfaces are included.

1.2 This specification sets forth a set of minimum, maximum, or range of physical, mechanical and endurance properties that must be met, or exceeded by the geomembrane being manufactured.

1.3 In the context of quality systems and management, this specification represents manufacturing quality control (MQC).

Note 1: Manufacturing quality control represents those actions taken by a manufacturer to ensure that the product represents the stated objective and properties set forth in this specification.

1.4 This standard specification is intended to ensure good uniform quality LLDPE geomembranes for use in general applications.

Note 2: Additional tests, or more restrictive values for the tests indicated, may be necessary under conditions of a particular application. In this situation, interactions with the manufacturers are required.

1.5 This specification also presents a recommended warranty which is focused on the geomembrane material itself.

1.6 The recommended warranty attached to this specification does not cover installation considerations which are independent of the manufacturing of the geomembrane.

Note 3: For information on installation techniques, users of this standard are referred to the geosynthetics literature, which is abundant on the subject.

*This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This specification will be reviewed at least every 2-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

2. Referenced Documents

2.1 ASTM Standards:

D 638	Test Method for Tensile Properties of Plastics
D 792	Specific Gravity (Relative Density) and Density of Plastics by Displacement
D 1004	Test Method for Initial Tear Resistance of Plastics Film and Sheeting
D 1238	Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
D 1505	Test Method for Density of Plastics by the Density-Gradient Technique
D 1603	Test Method for Carbon Black in Olefin Plastics
D 3895	Test Method for Oxidative Induction Time of Polyolefins by Thermal Analysis
D 4218	Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
D 4833	Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D 5199	Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
D 5323	Practice for Determination of 2% Secant Modulus for Polyethylene Geomembranes
D 5994	Test Method for Measuring the Core Thickness of Textured Geomembranes
D 5596	Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
D 5617	Test Method for Multi-Axial Tension Test for Geosynthetics
D 5721	Practice for Air-Oven Aging of Polyolefin Geomembranes GM17 - 3 of 14 rev. 2 - 12/13/00
D 5885	Test method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry

2.2 GRI Standards:

GM 11	Accelerated Weathering of Geomembranes using a Fluorescent UVA-Condensation Exposure Device
GM 12	Measurement of the Asperity Height of Textured Geomembranes Using a Depth Gage

2.3 U. S. Environmental Protection Agency Technical Guidance Document "Quality Control Assurance and Quality Control for Waste Containment Facilities," EPA/600/R-93/182, September 1993, 305 pages.

3. Definitions

Manufacturing Quality Control (MQC) - A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract specifications ref. EPA/600/R-93/182.

Manufacturing Quality Assurance (MQA) - A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract specifications. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials (resins and additives) and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract specifications for the project ref. EPA/600/R-93/182.

Linear Low Density Polyethylene (LLDPE), n - A ethylene/ -olefin copolymer having a linear molecular structure. The comonomers used to produce the resin can include hexane, octane, or methyl pentene. LLDPE resins have a natural density in the range of 0.915 to 0.926 g/ml (ref. Pate, T. J. Chapter 29 in Handbook of Plastic Materials and Technology, I.I. Rubin Ed., Wiley,1990).

Formulation, n - The mixture of a unique combination of ingredients identified by type, properties and quantity. For linear low density polyethylene geomembranes, a formulation is defined as the exact percentages and types of resin(s), additives and carbon black.

4. Material Classification and Formulation

4.1 This specification covers linear low density polyethylene geomembranes with a formulated sheet density of 0.939 g/ml, or lower. Density can be measured by ASTM D1505 or ASTM D792. If the latter, Method B is recommended.

4.2 The polyethylene resin from which the geomembrane is made will generally be in the density range of 0.926 g/ml or lower, and have a melt index value per ASTM D1238 of less than 1.0 g/10 min. This refers to the natural, i.e., nonformulated, resin.

4.3 The resin shall be virgin material with no more than 10% rework. If rework is used, it must be of the same formulation (or other approved formulation) as the parent material.

4.4 No post consumer resin (PCR) of any type shall be added to the formulation.

5. Physical, Mechanical and Chemical Property Requirements

5.1 The geomembrane shall conform to the test property requirements prescribed in Tables 1 and 2. Table 1 is for smooth LLDPE geomembranes and Table 2 is for single and double sided textured LLDPE geomembranes. Each of the tables are given in English and SI (metric) units. The conversion from English to SI (metric) is "soft". It is to be understood that the tables refer to the latest revision of the referenced test methods and practices.

Note 4: There are several tests sometimes included in other LLDPE geomembrane specifications which are omitted from this standard because they are outdated, irrelevant or generate information that is not necessary to evaluate on a routine MQC basis. The following tests have been purposely omitted:

- Volatile Loss
- Dimensional Stability
- Coeff. of Linear Expansion
- Resistance to Soil Burial
- Low Temperature Impact
- ESCR Test (D 1693 and D 5397)
- Solvent Vapor Transmission
- Water Absorption
- Ozone Resistance
- Hydrostatic Resistance
- Tensile Impact
- Small Scale Burst

- Wide Width Tensile
- Water Vapor Transmission
- Various Toxicity Tests
- Field Seam Strength

Note 5: There are several tests which are included in this standard (that are not customarily required in other LLDPE geomembrane specifications) because they are relevant and important in the context of current manufacturing processes. The following tests have been purposely added:

- Oxidative Induction Time
- Oven Aging
- Ultraviolet Resistance
- Asperity Height of Textured Sheet

Note 6: There are other tests in this standard, focused on a particular property, which are updated to current standards. The following are in this category:

- Thickness of Textured Sheet
- Tensile Properties, incl. 2% Secant Modulus
- Puncture Resistance
- Axi-Symmetric Break Resistance Strain
- Carbon Black Dispersion (In the viewing and subsequent quantitative interpretation of ASTM D 5596 only near spherical agglomerates shall be included in the assessment).

Note 7: There are several GRI tests currently included in this standard. Since these topics are not covered in ASTM standards, this is necessary. They are the following:

- UV Fluorescent Light Exposure
- Asperity Height Measurement

5.2 The values listed in the tables of this specification are to be interpreted according to the designated test method. In this respect they are neither minimum average roll values (MARV) nor maximum average roll values (MaxARV).

5.3 The various properties of the LLDPE geomembrane shall be tested at the minimum frequencies shown in Tables 1 and 2. If the specific manufacturer's quality control guide is more stringent, it must be followed in like manner.

Note 8: This specification is focused on manufacturing quality control (MQC). Conformance testing and manufacturing quality assurance (MQA) testing are at the discretion of the purchaser and/or quality assurance engineer, respectively. Communication and interaction with the manufacturer is strongly suggested.

6. Workmanship and Appearance

6.1 Smooth geomembrane shall have good appearance qualities. It shall be free from such defects that would affect the specified properties and hydraulic integrity of the geomembrane.

6.2 Textured geomembrane shall generally have uniform texturing appearance. It shall be free from such defects that would affect the specified properties and hydraulic integrity of the geomembrane.

6.3 General manufacturing procedures shall be performed in accordance with the manufacturer's internal quality control guide and/or documents.

7. MQC Sampling

7.1 Sampling shall be in accordance with the specific test methods listed in Tables 1 and 2. If no sampling protocol is stipulated in the particular test method, then test specimens shall be taken evenly spaced across the entire roll width.

7.2 The number of tests shall be in accordance with the appropriate test methods listed in Tables 1 and 2.

7.3 The average of the test results should be calculated per the particular standard cited and compared to the minimum value listed in these tables, hence the values listed are the minimum average values and are designated as "minimum average."

8. MQC Retest and Rejection

8.1 If the results of any test do not conform to the requirements of this specification, retesting to determine conformance or rejection should be done in accordance with the manufacturing protocol as set forth in the manufacturer's quality manual.

9. Packaging and Marketing

9.1 The geomembrane shall be rolled onto a substantial core or core segments and held firm by dedicated straps/slings, or other suitable means. The rolls must be adequate for safe transportation to the point of delivery, unless otherwise specified in the contract or order.

9.2 Marking of the geomembrane rolls shall be done in accordance with the manufacturers accepted procedure as set forth in their quality manual.

10. Certification

10.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

English Units

Table 1(a) – Linear Low Density Polyethylene (LLDPE) Geomembrane (SMOOTH)

Properties	Test Method	Test Value								Testing Frequenc (minimum)
		20 mils	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness - mils (min. ave.)	D5199	nom.	nom.	nom.	nom.	nom.	nom.	nom.	nom.	per roll
• lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density g/ml (max.)	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	200,00 lb
Tensile Properties *(1)* (min. ave.)	D 6693 Type IV									20,000 lb
• break strength - lb/in.		76	114	152	190	228	304	380	456	
• break elongation - %		800	800	800	800	800	800	800	800	
2% Modulus – lb/in. (max.)	D 5323	1200	1800	2400	3000	3600	4800	6000	7200	per formulation
Tear Resistance - lb (min. ave.)	D 1004	11	16	22	27	33	44	55	66	45,000 lb
Puncture Resistance - lb (min. ave.)	D 4833	28	42	56	70	84	112	140	168	45,000 lb
Axi-Symmetric Break Resistance Strain - % (min.)	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content - %	D 1603 *(2)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	45,000 lb
Carbon Black Dispersion	D 5596	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(4)*										
(a) Standard OIT	D 3895	100	100	100	100	100	100	100	100	200,000 lb
— or —										
(b) High Pressure OIT	D 5885	400	400	400	400	400	400	400	400	
Oven Aging at 85°C *(5)*	D 5721									
(a) Standard OIT (min. ave.) - % retained after 90 days	D 3895	35	35	35	35	35	35	35	35	per formulation
— or —										
(b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5885	60	60	60	60	60	60	60	60	
UV Resistance *(6)*										
(a) Standard OIT (min. ave.)	D 3895	N. R. *(7)*	N.R. *(7)*	N.R. *(7)*	N.R. *(7)*	N.R. *(7)*	N.R. *(7)*	N.R. *(7)*	N.R. *(7)*	per formulation
— or —										
(b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(8)*	D 5885	35	35	35	35	35	35	35	35	

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 2.0 in. at 2.0 in./min.

(2) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(3) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(4) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(5) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(6) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(7) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(8) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (Metric) Units

Table 1(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane (SMOOTH)

Properties	Test Method	Test Value 0.50 mm	0.75 mm	1.0 mm	1.25 mm	1.50 mm	2.00 mm	2.5 mm	3.0 mm	Testing Frequency (minimum)
Thickness - mm (min. ave.)	D5199	nom.	nom.	nom.	nom.	nom.	nom.	nom.	nom.	per roll
• lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density g/ml (max.)	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	90,000 kg
Tensile Properties *(1)* (min. ave.) • break strength – N/mm • break elongation - %	D 6693 Type IV	13 800	20 800	27 800	33 800	40 800	53 800	66 800	80 800	9,000 kg
2% Modulus – N/mm (max.)	D 5323	210	370	420	520	630	840	1050	1260	per formulation
Tear Resistance - N (min. ave.)	D 1004	50	70	100	120	150	200	250	300	20,000 kg
Puncture Resistance - N (min. ave.)	D 4833	120	190	250	310	370	500	620	750	20,000 kg
Axi-Symmetric Break Resistance Strain - % (min.)	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content - %	D 1603 *(3)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	20,000 kg
Carbon Black Dispersion	D 5596	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(4)* (a) Standard OIT — or — (b) High Pressure OIT	D 3895 D 5885	100 400	100 400	100 400	100 400	100 400	100 400	100 400	100 400	90,000 kg
Oven Aging at 85°C *(5)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	35 60	35 60	35 60	35 60	35 60	35 60	35 60	35 60	per formulation
UV Resistance *(6)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(8)*	D 3895 D 5885	N. R. *(7)* 35	N.R. *(7)* 35	N.R. *(7)* 35	N.R. *(7)* 35	N.R. *(7)* 35	N.R. *(7)* 35	N.R. *(7)* 35	N.R. *(7)* 35	per formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 50 mm at 50 mm/min.

(2) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.

(3) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(4) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(5) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(6) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(7) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(8) UV resistance is based on percent retained value regardless of the original HP-OIT value.

English Units

Table 2(a) – Linear Low Density Polyethylene (LLDPE) Geomembrane (TEXTURED)

Properties	Test Method	Test Value								Testing Frequency (minimum)
		20 mils	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mils (min. ave.) *(1)*	GM 12	10	10	10	10	10	10	10	10	Every 2nd rc *(2)*
Density g/ml (max.)	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	200,000 lb
Tensile Properties *(3)* (min. ave.) • break strength – lb/in. • break elongation - %	D 6693 Type IV	 30 250	 45 250	 60 250	 75 250	 90 250	 120 250	 150 250	 180 250	20,000 lb
2% Modulus – lb/in. (max.)	D 5323	1200	1800	2400	3000	3600	4800	6000	7200	per formulatioı
Tear Resistance – lb (min. ave.)	D 1004	11	16	22	27	33	44	55	66	45,000 lb
Puncture Resistance – lb (min. ave.)	D 4833	22	33	44	55	66	88	110	132	45,000 lb
Axi-Symmetric Break Resistance Strain - % (min.)	D 5617	30	30	30	30	30	30	30	30	per formulatioı
Carbon Black Content - %	D 1603 *(4)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	45,000 lb
Carbon Black Dispersion	D 5596	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(6)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	200,000 lb
Oven Aging at 85°C *(7)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	per formulatioı
UV Resistance *(8)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(10)*	 D 3895 D 5885	 N. R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	per formulatioı

(1) Of 10 readings; 8 out of 10 must be 7 mils, and lowest individual reading must be 5 mils
(2) Alternate the measurement side for double sided textured sheet
(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
  • Break elongation is calculated using a gage length of 2.0 in. at 2.0 in./min.
(4) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(5) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
  • 9 in Categories 1 or 2 and 1 in Category 3
(6) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(7) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(8) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(9) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(10) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (Metric) Units

Table 2(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane (TEXTURED)

Properties	Test Method	Test Value								Testing Frequency (minimum)
		0.50 mm	0.75 mm	1.0 mm	1.25 mm	1.50 mm	2.00 mm	2.5 mm	3.0 mm	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mm (min. ave.) *(1)*	GM 12	10	10	10	10	10	10	10	10	Every 2nd roll *(2)*
Density g/ml (max.)	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	90,000 kg
Tensile Properties *(3)* (min. ave.) • break strength – N/mm • break elongation - %	D 6693 Type IV	5 250	9 250	11 250	13 250	16 250	21 250	26 250	31 250	9,000 kg
2% Modulus – N/mm (max.)	D 5323	210	370	420	520	630	840	1050	1260	per formulation
Tear Resistance – N (min. ave.)	D 1004	50	70	100	120	150	200	250	300	20,000 kg
Puncture Resistance – N (min. ave.)	D 4833	100	150	200	250	300	400	500	600	20,000 kg
Axi-Symmetric Break Resistance Strain - % (min.)	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content - %	D 1603 *(4)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	20,000 kg
Carbon Black Dispersion	D 5596	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	note *(5)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(6)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	90,000 kg
Oven Aging at 85°C *(7)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	per formulation
UV Resistance *(8)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(10)*	 D 3895 D 5885	 N. R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	 N.R. *(9)* 35	per formulation

(1) Of 10 readings; 8 out of 10 must be ≥ 0.18 mm, and lowest individual reading must be ≥ 0.13 mm
(2) Alternate the measurement side for double sided textured sheet
(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 50 mm at 50 mm/min.

(4) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.
(5) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(6) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(7) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(8) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(9) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(10) UV resistance is based on percent retained value regardless of the original HP-OIT value.

11. Warranty

11.1 Upon request of the purchaser in the contract or order, a manufacturer's warranty of the quality of the material shall be furnished at the completion of the terms of the contract.

11.2 A recommended warranty for smooth and textured LLDPE geomembranes manufactured and tested in accordance with this specification is given in Appendix A.

11.3 The warranty in Appendix A is for the geomembrane itself. It does not cover subgrade preparation, installation, seaming, or backfilling. These are separate operations that are often beyond the control, or sphere of influence, of the geomembrane manufacturer.

Note 9: If a warranty is required for installation, it is to be developed between the installation contractor and the party requesting such a document.

Adoption and Revision Schedule for GRI Test Method GM17

"Test Properties, Testing Frequency and Recommended Warranted for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes"

Adopted: April 3, 2000

Revision 1: June 28, 2000: added a new Section 5.2 that the numeric tables values are neither MARV nor MaxARV. They are to be interpreted per the designated test method. Also, corrected typographical error of textured sheet thickness test method designation from D5199 to D5994.

Revision 2: December 13, 2000: added one Category 3 is allowed for carbon black dispersion. Also, unified terminology to "strength" and "elongation".

Revision 3: June 23, 2003: Adopted ASTM D 6693, in place of ASTM D 638, for tensile strength testing. Also, added Note 4.

GRI Test Method GM19*

STANDARD SPECIFICATION FOR SEAM STRENGTH AND RELATED PROPERTIES OF THERMALLY BONDED POLYOLEFIN GEOMEMBRANES

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

1.1 This specification addresses the required seam strength and related properties of thermally bonded polyolefin geomembranes; in particular, high density polyethylene (HDPE), linear low density polyethylene (LLDPE) and flexible polypropylene both nonreinforced (fPP) and scrim reinforced (fPP-R).

1.2 Numeric values of seam strength and related properties are specified in both shear and peel modes.

Note 1: This specification does not address the test method details or specific testing procedures. It refers to the relevant ASTM test methods where applicable.

1.3 The thermal bonding methods focused upon are hot wedge (single and dual track) and extrusion fillet.

Note 2: Other acceptable, but less frequently used, methods of seaming are hot air and ultrasonic methods. They are inferred as being a subcategory of hot wedge seaming.

1.4 This specification also suggests the distance between destructive seam samples to be taken in the field, i.e., the sampling interval. However, project-specific conditions will always prevail in this regard.

1.5 This specification is only applicable to laboratory testing.

1.6 This specification does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards

D751 Standard Test Methods for Coated Fabrics

D6392 Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods

2.2 EPA Standards

EPA 600/2.88/052 (NTIS PB-89-129670)

Lining of Waste Containment and Other Containment Facilities

2.3 NSF Standards

NSF International Standard, Flexible Membrane Liners, NSF 54-1993 (depreciated)

2.4 GRI Standards

GM13 Test Properties, Testing Frequency and Recommended Warranty for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes

GM14 Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes

GM17 Test Properties, Testing Frequency and Recommended Warranty for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes

GM18 Test Properties, Testing Frequency and Recommended Warranty for Flexible Polypropylene (fPP and fPP-R) Geomembranes

3. Definition

3.1 Geomembrane, n – An essentially impermeable geosynthetic composed of one or more synthetic sheets used for the purpose of liquid, gas or solid containment.

3.2 Hot Wedge Seaming – A thermal technique which melts the two opposing geomembrane surfaces to be seamed by running a hot metal wedge or knife between them. Pressure is applied to the top or bottom geomembrane, or both, to form a continuous bond. Seams of this type can be made with dual bond tracks separated by a nonbonded gap. These seams are referred to as dual hot wedge seams or double-track seams.

3.3 Hot Air Seaming – This seaming technique introduces high-temperature air or gas between two geomembrane surfaces to facilitate localized surface melting. Pressure is applied to the top or bottom geomembrane, forcing together the two surfaces to form a continuous bond.

3.4 Ultrasonic Seaming - A thermal technique which melts the two opposing geomembrane surfaces to be seamed by running a ultrasonically vibrated metal wedge or knife between them. Pressure is applied to the top or bottom geomembrane, or both, to form a continuous bond. Some seams of this type are made with dual bond tracks separated by a nonbonded gap. These seams are referred to as dual-track seams or double-track seams.

3.5 Extrusion Fillet Seaming – This seaming technique involves extruding molten resin at the edge of an overlapped geomembrane on another to form a continuous bond. A depreciated method called "extrusion flat" seaming extrudes the molten resin between the two overlapped sheets. In all types of extrusion seaming the surfaces upon which the molten resin is applied must be suitably prepared, usually by a slight grinding or buffing.

4. Significance and Use

4.1 The various methods of field fabrication of seams in polyolefin geomembranes are covered in existing ASTM standards mentioned in the referenced document section. What is not covered in those documents is the numeric values of strength and related properties that the completed seam must meet, or exceed. This specification provides this information insofar as minimum, or maximum, property values are concerned when the field fabricated seams are sampled and laboratory tested in shear and peel. The specification also provides guidance as to what spacing intervals the samples should be taken at typical field installation projects.

5. Sample and Specimen Preparation

5.1 The spacing for taking field seam samples for destructive testing is to be 1 per 500 feet (1 per 150 m) of seam length, or as by directed by the construction quality assurance inspector. As the project continues and data is accumulated, however, this sampling interval should be varied according to the procedure set forth in GRI GM14. Following this procedure three different situations can result.

5.1.1 Good seaming with fewer rejected test results than the preset historic average can result in a sequential increase in the spacing interval, i.e., one per greater than 500 ft. (one per greater than 150 m).

5.1.2 Poor seaming with more rejected test results than the preset historic average can result in a sequential decrease in the spacing interval, i.e., one per less than 500 ft. (one per less than 150 m).

5.1.3 Average seaming with approximately the same test results as the preset historic average will result in the spacing interval remaining the same, i.e., one per 500 ft. (one per 150 m).

Note 3: The method of attributes referred to in GRI GM14 is only one of several statistical strategies that might be used to vary sampling frequency. The use of control charts should also be considered in this regard.

5.2 The size of field seam samples is to be according to the referenced test method, e.g., ASTM D6392 or site-specific CQA plan.

5.3 The individual test specimens taken from the field seam samples are to be tested according to the referenced test method, i.e., ASTM D6392 for HDPE, LLDPE and fPP, and ASTM D751 (as modified by NSF 54) for fPP-R. The specimens are to be conditioned prior to testing according to these same test methods and evaluated accordingly.

6. Assessment of Seam Test Results

6.1 HDPE seams – For HDPE seams (both smooth and textured), the strength of four out of five 1.0 inch (25 mm) wide strip specimens in shear should meet or exceed the values given in Tables 1(a) and 1(b). The fifth must meet or exceed 80% of the given values. In addition, the shear percent elongation, calculated as follows, should exceed the values given in Tables 1(a) and 1(b):

$$E = \frac{L}{L_O}(100) \qquad (1)$$

where

E = elongation (%)
L = extension at end of test (in. or mm)
Lo = original average length (usually 1.0 in. or 25 mm)

Note 4: The assumed gage length is considered to be the unseamed sheet material on either side of the welded area. It generally will be 1.0 in. (25 mm) from the edge of the seam to the grip face.

For HDPE seams (both smooth and textured), the strength of four out of five 1.0 in. (25 mm) wide strip specimens tested in peel should meet or exceed the values given in Tables 1(a) and 1(b). The fifth must meet or exceed 80% of the given values.

In addition, the peel separation (or incursion) should not exceed the values given in Tables 1(a) and 1(b). The value shall be based on the proportion of area of separated bond to the area of the original bonding as follows:

$$S = \frac{A}{A_O}(100) \qquad (2)$$

where

S = separation (%)
A = average area of separation, or incursion (in^2 or mm^2)
A0 = original bonding area (in^2 or mm^2)

Note 5: The area of peel separation can occur in a number of nonuniform patterns across the seam width. The estimated dimensions of this separated area is visual and must be done with care and concern. The area must not include squeeze-out which is part of the welding process.

Regarding the locus-of-break patterns of the different seaming methods in shear and peel, the following are unacceptable break codes per their description in ASTM D6392 (in this regard, SIP is an acceptable break code);

Hot Wedge: AD and AD-Brk > 25%

Extrusion Fillet: AD1, AD2 and AD-WLD (unless strength is achieved)

6.2 LLDPE seams – For LLDPE seams (both smooth and textured), the strength of four out of five 1.0 in. (25 mm) wide strip specimens in shear should meet or exceed the values given in Table 2(a) and 1(b). The fifth must meet or exceed 80% of the given values. In addition, the shear percent elongation, calculated as follows, should exceed the values given in Tables 2(a) and 2(b).

$$E = \frac{L}{L_O}(100) \qquad (1)$$

where

E = elongation (%)
L = extension at end of test (in. or mm)
L_O = original average length (usually 1.0 in. or 25 mm)

Note 4: The assumed gage length is considered to be the unseamed sheet material on either side of the welded area. It generally will be 1.0 in. (25 mm) from the edge of the seam to the grip face.

For LLDPE seams (both smooth and textured), the strength of four out of five 1.0 in. (25 mm) wide strip specimens tested in peel should meet or exceed the values given in Tables 2(a) and 2(b). The fifth must meet or exceed 80% of the given values.

In addition, the peel separation (or incursion) should not exceed the values given in Tables 2(a) and 2(b). The value shall be based on the proportion of area of separated bond to the area of the original bonding as follows:

$$S = \frac{A}{A_O}(100) \qquad (2)$$

where

S = separation (%)
A = average depth of separation, or incursion (in.^{2} or mm^2)
A_O = original bonding distance (in.^{2} or mm^2)

Note 5: The area of peel separation can occur in a number of nonuniform patterns across the seam width. The estimated dimensions of this separated area is visual and must be done with care and concern. The area must not include squeeze-out which is part of the welding process.

Regarding the locus-of-break patterns of the different seaming methods in shear and peel, the following are unacceptable break codes per their description in ASTM D6392 (in this regard, SIP is an acceptable break code);

Hot Wedge: AD and AD-Brk > 25%

Extrusion Fillet: AD1, AD2, AD-WLD (unless strength is achieved)

6.3 fPP Seams – For fPP seams (both nonreinforced and scrim reinforced), the strength of four out of five specimens in shear should meet or exceed the values given in Tables 3(a) and 3(b). The fifth must meet or exceed 80% of the given values. Note that the unreinforced specimens are 1.0 in. (25 mm) wide strips and the scrim reinforced specimens are 4.0 in. (100 mm) wide grab tests. In addition, the shear percent elongation on the unreinforced specimens, calculated as follows, should exceed the values given in Tables 3(a) and 3(b).

$$E = \frac{L}{L_O}(100) \tag{1}$$

where

E = elongation (%)
L = extension at end of test (in. or mm)
L_O = original gauge length (usually 1.0 in. or 25 mm)

Note 4: The assumed gage length is considered to be the unseamed sheet material on either side of the welded area. It generally will be 1.0 in. (25 mm) from the edge of the seam to the grip face.

Shear elongation is not relevant to scrim reinforced geomembranes and as such is listed as "not applicable" in Table 3(a) and 3(b).

For fPP seams (both nonreinforced and scrim reinforced), the strength of four out of five specimens in peel should meet or exceed the values given in Tables 3(a) and 3(b). The fifth must meet or exceed 80% of the given values. Note that the unreinforced specimens are 1.0 in. (25 mm) wide strips and the scrim reinforced specimens are grab tests. In addition, the peel percent separation (or incursion) should not exceed the values given in Tables 3(a) and 3(b). The values should be based on the proportion of area of separated bond to the area of the original bonding as follows.

$$S = \frac{A}{A_O}(100) \tag{2}$$

where

S = separation in (%)
A = average depth of separation, or incursion (in.^{2} or mm^2)
A_O = original bonding distance (in.^{2} or mm^2)

Note 5: The area of peel separation can occur in a number of nonuniform patterns across the seam width. The estimated dimensions of this separated area is visual and must be done with care and concern. The area must not include squeeze-out which is part of the welding process.

Regarding the locus-of-break patterns of the different seaming methods in shear and peel, the following are unacceptable break codes per their description in ASTM D6392 (in this regard, SIP is an acceptable break code);

Hot Wedge: AD and AD-Brk > 25%

Extrusion Fillet: AD1, AD2 and AD-WLD (unless strength is achieved)

7. Retest and Rejection

7.1 If the results of the testing of a sample do not conform to the requirements of this specification, retesting to determine conformance or rejection should be done in accordance with the construction quality control or construction quality assurance plan for the particular site under construction.

8. Certification

8.1 Upon request of the construction quality assurance officer or certification engineer, an installer's certification that the geomembrane was installed and tested in accordance with this specification, together with a report of the test results, shall be furnished at the completion of the installation.

Table 1(a) – Seam Strength and Related Properties of Thermally Bonded Smooth and Textured High Density Polyethylene (HDPE) Geomembranes **(English Units)**

Geomembrane Nominal Thickness	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils
Hot Wedge Seams(1)							
shear strength(2), lb/in.	57	80	100	120	160	200	240
shear elongation at break(3), %	50	50	50	50	50	50	50
peel strength(2), lb/in.	45	60	76	91	121	151	181
peel separation, %	25	25	25	25	25	25	25
Extrusion Fillet Seams							
shear strength(2), lb/in.	57	80	100	120	160	200	240
shear elongation at break(3), %	50	50	50	50	50	50	50
peel strength(2), lb/in.	39	52	65	78	104	130	156
peel separation, %	25	25	25	25	25	25	25

Notes for Tables 1(a) and 1(b):

1. Also for hot air and ultrasonic seaming methods
2. Value listed for shear and peel strengths are for 4 out of 5 test specimens; the 5th specimen can be as low as 80% of the listed values
3. Elongation measurements should be omitted for field testing

Table 1(b) – Seam Strength and Related Properties of Thermally Bonded Smooth and Textured High Density Polyethylene (HDPE) Geomembranes **(S.I. Units)**

Geomembrane Nominal Thickness	0.75 mm	1.0 mm	1.25 mm	1.5 mm	2.0 mm	2.5 mm	3.0 mm
Hot Wedge Seams(1)							
shear strength(2), N/25 mm.	250	350	438	525	701	876	1050
shear elongation at break(3), %	50	50	50	50	50	50	50
peel strength(2), N/25 mm	197	263	333	398	530	661	793
peel separation, %	25	25	25	25	25	25	25
Extrusion Fillet Seams							
shear strength(2), N/25 mm	250	350	438	525	701	876	1050
shear elongation at break(3), %	50	50	50	50	50	50	50
peel strength(2), N/25 mm	197	263	333	398	530	661	793
peel separation, %	25	25	25	25	25	25	25

Table 2(a) – Seam Strength and Related Properties of Thermally Bonded Smooth and Textured Linear Low Density Polyethylene (LLDPE) Geomembranes **(English Units)**

Geomembrane Nominal Thickness	20 mils	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils
Hot Wedge Seams[1]								
shear strength[2], lb/in.	30	45	60	75	90	120	150	180
shear elongation[3], %	50	50	50	50	50	50	50	50
peel strength[2], lb/in.	25	38	50	63	75	100	125	150
peel separation, %	25	25	25	25	25	25	25	25
Extrusion Fillet Seams								
shear strength[2], lb/in.	30	45	60	75	90	120	150	180
shear elongation[3], %	50	50	50	50	50	50	50	50
peel strength[2], lb/in.	22	34	44	57	66	88	114	136
peel separation, %	25	25	25	25	25	25	25	25

Notes for Tables 2(a) and 2(b):

1. Also for hot air and ultrasonic seaming methods
2. Values listed for shear and peel strengths are for 4 out of 5 test specimens; the 5th specimen can be as low as 80% of the listed values
3. Elongation measurements should be omitted for field testing

Table 2(a) – Seam Strength and Related Properties of Thermally Bonded Smooth and Textured Linear Low Density Polyethylene (LLDPE) Geomembranes **(S.I. Units)**

Geomembrane Nominal Thickness	0.50 mm	0.75 mm	1.0 mm	1.25 mm	1.5 mm	2.0 mm	2.5 mm	3.0 mm
Hot Wedge Seams[1]								
shear strength[2], N/25 mm	131	197	263	328	394	525	657	788
shear elongation[3], %	50	50	50	50	50	50	50	50
peel strength[2], N/25 mm	109	166	219	276	328	438	547	657
peel separation, %	25	25	25	25	25	25	25	25
Extrusion Fillet Seams								
shear strength[2], N/25 mm	131	197	263	328	394	525	657	788
shear elongation[3], %	50	50	50	50	50	50	50	50
peel strength[2], N/25 mm	109	166	219	276	328	438	547	657
peel separation, %	25	25	25	25	25	25	25	25

Table 3(a) – Seam Strength and Related Properties of Thermally Bonded Nonreinforced and Reinforced Flexible Polypropylene (fPP) Geomembranes **(English Units)**

Geomembrane Nominal Thickness	30 mil-NR	40 mil-NR	36 mil-R(4)	45 mil-R(4)
Hot Wedge Seams(1)				
shear strength(2), lb/in. (NR); lb (R)	25	30	200	200
shear elongation(3), %	50	50	n/a	n/a
peel strength(2), lb/in. (NR); lb (R)	20	25	20	20
peel separation, %	25	25	n/a	n/a
Extrusion Fillet Seams				
shear strength(2), lb/in. (NR); lb (R)	25	30	200	200
shear elongation(3), %	50	50	n/a	n/a
peel strength(2), lb/in. (NR); lb (R)	20	25	20	20
peel separation, %	25	25	n/a	n/a

Notes for Tables 3(a) and 3(b):

1. Also for hot air and ultrasonic seaming methods
2. Values listed for shear and peel strengths are for 4 out of 5 test specimens; the 5th specimen can be as low as 80% of the listed values
3. Elongation measurements should be omitted for field testing
4. Values are based on grab tensile strength and elongations per D751 for laboratory tested specimens

Table 3(a) – Seam Strength and Related Properties of Thermally Bonded Nonreinforced and Reinforced Flexible Polypropylene (fPP) Geomembranes **(S.I. Units)**

Geomembrane Nominal Thickness	0.75 mm-NR	1.0 mm-NR	0.91 mm-R(4)	1.14 mm-R(4)
Hot Wedge Seams(1)				
shear strength(2), N/25 mm (NR); N (R)	110	130	890	890
shear elongation(3), %	50	50	n/a	n/a
peel strength(2), N/25 mm (NR); N (R)	85	110	90	90
peel separation, %	25	25	n/a	n/a
Extrusion Fillet Seams				
shear strength(2), N/25 mm (NR); N (R)	110	130	890	890
shear elongation(3), %	50	50	n/a	n/a
peel strength(2), N/25 mm (NR); N (R)	85	110	90	90
peel separation, %	25	25	n/a	n/a

1.0 Basic Drawing Tools

1.01	**Line**	A straight line from one point to another
1.02	**Pline**	A line that can be modified to have width and/or be joined to other lines or poly-lines.
1.03	**Arc**	A curved line, usually with a starting point, middle point and an end point
1.04	**Circle**	A perfect circle. Can be defined by radius, diameter, two points or three points.
1.05	**Ellipse**	An egg shape, sort of.
1.06	**Polygon**	A shape, such as a triangle, that can be made with as many sides as desired.
1.07	**Donut**	A thick circle defined with an inner diameter and an outer diameter.

2.0 Basic Modification Tools

2.01	**Move**	Command line: move Select objects you want to move, press enter, select a base point, select the point you want to move to.
2.02	**Trim**	Command line: trim Select line or object you want to trim to, hit enter, then trim the lines or objects that are to be trimmed.
2.03	**Extend**	Command line: extend Select line or object you want to extend to, hit enter, then pick the lines you want extended
2.04	**Hatch**	Command line: hatch Pick the hatch you want, look at rotation and scale, associated or not, and then pick how you want to select the area to be hatched. You will need to play with these commands to learn.
2.05	**Explode**	Command line: explode This command is used to separate a block or break up a pline. Select the items you want to explode then hit enter.
2.06	**Stretch**	Command line: stretch This command must be started with a crossing window, window the objects you want to stretch, hit enter, provide a base point then stretch to a new point. It is sometimes helpful to use "snap" setting when using this command.
2.07	**Scale**	Command line: scale Select objects, pick a base point, type in how you want to scale the object. You can also do a reference scaling, Say you have a line in an object that is 6" long and you want it to be 24" long, you input the first dimension and then input the new dimension.
2.08	**Break**	Command break: Select the line you want to break, and then pick the two points you want to open.

2.09 **Break at**

Similar to Break, but you only break at one point.

2.10 **Fillet** Command line: Fillet

Create a fillet by picking two lines. Requires input of the two distances.

2.11 **Radius** Command line: Radius

Creates a radius by picking two lines. Requires inputting a radius. You can radius all corners of a polylines by picking 'polylines' from the side menu.

2.12 **Rotate** Command line: rotate

Pick object to rotate, hit enter, pick a base point, then the angle of rotation.angles are clockwise unless you use a negative, ie.. -90o

2.13 **Mirror** Command Line: mirror

Mirror places an mirror image around a reference line. Pick objects to be mirrored, hit enter, thin pick two points along reference line.

2.14 **Array** Command line: array

Pick objects to array, hit enter, enter number of times you wish to array, then pick the distances between arrays.

2.15 **Polar array** Command line: array p

Same as array but this arrays around a center point. Pick objects, then pick center point, then number of arrays, then the amount of angle, 0 to 360.

3.0 Drawing Commands

3.01 **Offset** Command Line: Offset

Offsets line to a defined distance entered by user.

3.02 **Draw Line w/ Typed Command** Command Line: line

Lines drawn from specific point with typed distance and rotation, ie... @24<45 this draws a line 24" long from a given point at a 45° angle

3.03 **Drawing Lines with Coordinates**
Command Line: line

Lines drawn from two points using given coordinates such are found on customer's drawings. You may enter coordinates in feet or inches. East coordinate goes first. Inches = 10",10" (enter) 20",20" always put a comma between east and north

Feet = 10',10' (enter) 20',20'

North America	GSE Lining Technology, Inc.	Houston, Texas	800 435 2008	281 443 8564	Fax: 281 230 8650
South America	GSE Lining Technology Chile S.A.	Santiago, Chile		56 2 595 4200	Fax: 56 2 595 4290
Asia Pacific	GSE Lining Technology Company Limited	Bangkok, Thailand		66 2 937 0091	Fax: 66 2 937 0097
Europe & Africa	GSE Lining Technology GmbH	Hamburg, Germany		49 40 767420	Fax: 49 40 7674234
Middle East	GSE Lining Technology-Egypt	The 6th of October City, Egypt		202 2 828 8888	Fax: 202 2 828 8889

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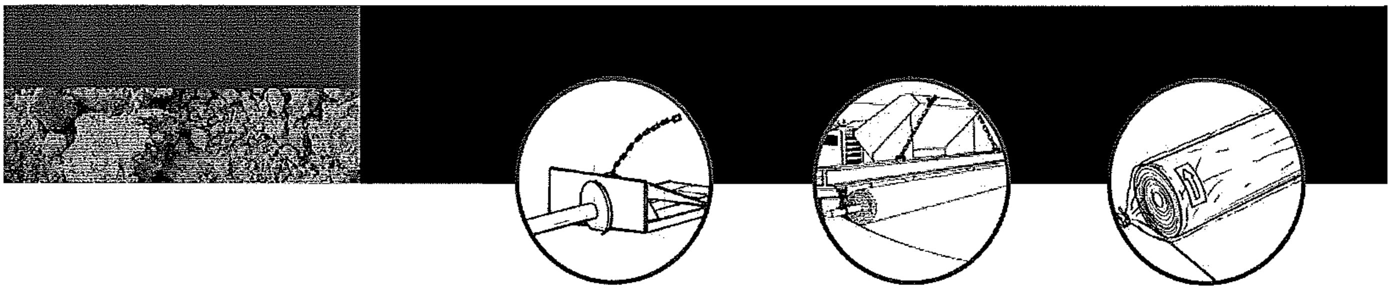
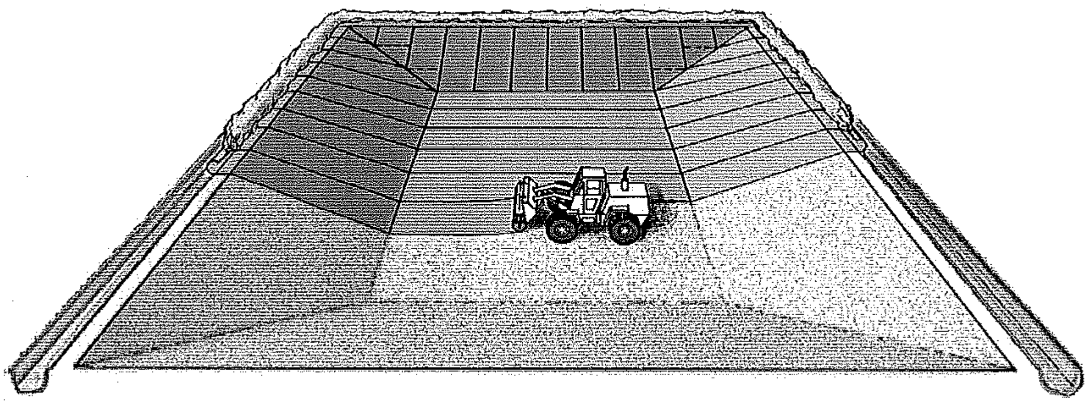
APPENDIX B



Installation Guidelines



BENTOMAT® CLAYMAX®

Geosynthetic Clay Liners

CETCO®
LINING TECHNOLOGIES
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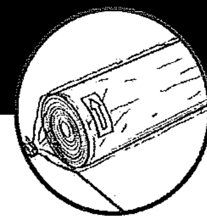
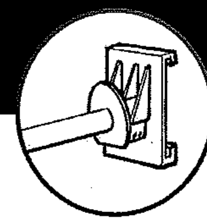




1 INTRODUCTION

1.1 This document provides procedures for the installation of CETCO's GCLs in a manner that maximizes safety, efficiency, and the physical integrity of the GCL.

1.2 These guidelines are based upon many years of experience at a variety of sites and should be generally applicable to any type of lining project using CETCO's GCLs. Variance from these guidelines is at the engineer's discretion.

1.3 The performance of the GCL is wholly dependent on the quality of its installation. It is the installer's responsibility to adhere to these guidelines, and to the project specifications and drawings, as closely as possible. It is the engineer's and owner's responsibility to provide construction quality assurance (CQA) for the installation, to ensure that the installation has been executed properly. This document covers only installation procedures.

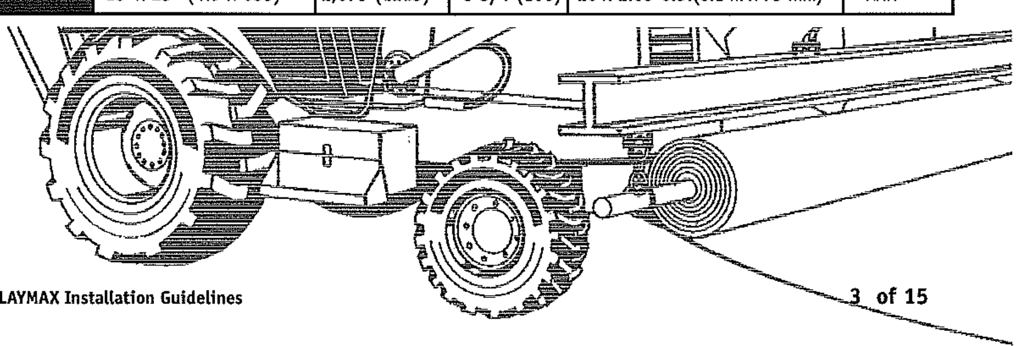
1.4 For additional guidance, refer to ASTM D5888 (Standard Guide For Storage and Handling of Geosynthetic Clay Liners) and ASTM D 6102 (Standard Guide For Installation of Geosynthetic Clay Liners).

2 EQUIPMENT REQUIREMENTS

2.1 CETCO GCLs are delivered in rolls typically 2,600-2,950 lbs (1180-1340 kg). Roll dimensions and weights will vary with the dimensions of the product ordered. It is necessary to support this weight using an appropriate core pipe as indicated in Table 1. For any installation, the core pipe must not deflect more than 3 inches (75 mm) as measured from end to midpoint when a full GCL roll is lifted.

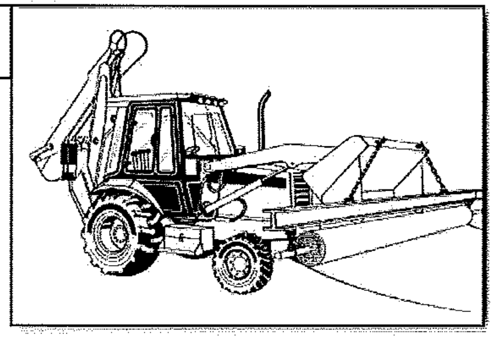
TABLE 1 CORE REQUIREMENTS

Product(s)	Nominal GCL Roll Size W x Dia. Ft. (m) x in. (mm)	Typical GCL Roll Wt., lbs. (kg)	Interior Core Size, in. (mm)	Core Pipe Length x Diameter, ft. x in. (m x mm)	Minimum Core Pipe Strength
Bentomat DN, SDN	16' x 24" (4.9 x 610)	2,650 (1200)	3 3/4 (100)	20 x 2.88"O.D.(6.1 m x 73 mm)	XXH
Bentomat ST	16' x 24" (4.9 x 610)	2,600 (1180)	3 3/4 (100)	20 x 2.88"O.D.(6.1 m x 73 mm)	XXH
Bentomat CLT	16' x 26" (4.9 x 660)	2,950 (1340)	3 3/4 (100)	20 x 2.88"O.D.(6.1 m x 73 mm)	XXH
Claymax 200R	16' x 20" (4.9 x 510)	2,750 (1250)	3 3/4 (100)	20 x 2.88"O.D.(6.1 m x 73 mm)	XXH
Bentomat CL	16' x 25" (4.9 x 635)	2,675 (1213)	3 3/4 (100)	20 x 2.88"O.D.(6.1 m x 73 mm)	XXH



2.2 Lifting chains or straps appropriately rated should be used in combination with a spreader bar made from an I-beam as shown in Figure 1.

FIGURE 1 **SPREADER BAR LIFTING ASSEMBLY**



2.3 The spreader bar ensures that lifting chains or straps do not chafe against the ends of the GCL roll, allowing it to rotate freely during installation. Spreader bar and core pipe kits are available through CETCO.

2.4 A front end loader, backhoe, dozer, or other equipment can be utilized with the spreader bar and core pipe or slings. Alternatively, a forklift with a "stinger" attachment may be used for on-site handling. A forklift without a stinger attachment should not be used to lift or handle the GCL rolls. Stinger attachments (Figure 2-4) are specially fabricated to fit various forklift makes and models.

FIGURE 2 **HOOK MOUNT**

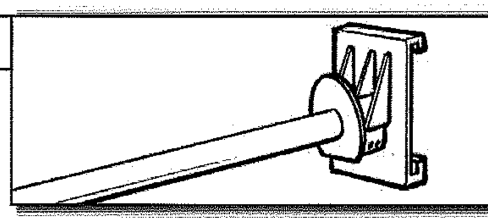


FIGURE 3 **FORK MOUNT** (with fork pockets)

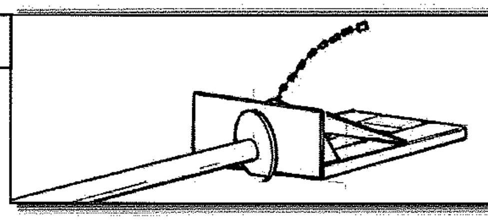
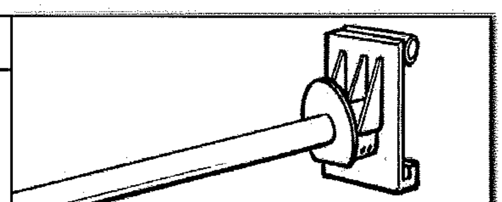


FIGURE 4 **PIN MOUNT**



2.5 When installing over certain geosynthetic materials, a 4-wheel, all-terrain vehicle (ATV) can be used to deploy the GCL. An ATV can be driven directly on the GCL provided that no sudden stops, starts, or turns are made.

2.6 Additional equipment needed for installation of CETCO's GCLs includes:

- Utility knife and spare blades (for cutting the GCL).
- Bentonite mastic (for sealing around structures and details) and/or granular bentonite (for end-of-roll seams of GCLs with needle punched, non-woven geotextiles and for sealing around structures and details). Both are available from CETCO.
- Waterproof tarpaulins (for temporary cover on installed material as well as for stockpiled rolls).
- Optional flat-bladed vise grips (for positioning the GCL panel by hand).

2.7 The CETCO Easy RollerTM GCL Deployment System is a preferred method of installing geosynthetic clay liners. Use of the Easy Roller system eliminates the need for spreader bars and heavy core pipes. Installation speed and worker safety are significantly increased. For further details, contact CETCO.

3 SHIPPING, UNLOADING & STORAGE

3.1 All lot and roll numbers should be recorded and compared to the packing list. Each roll of GCL should also be visually inspected during unloading to determine if any packaging has been damaged. Damage, whether obvious or suspected, should be recorded and the affected rolls marked.

3.2 Major damage suspected to have occurred during transit should be reported immediately to the carrier and to CETCO. The nature of the damage should also be indicated on the bill of lading with the specific lot and roll numbers. Accumulation of small amounts of moisture within roll packaging is normal and does not damage the product.

3.3 The party directly responsible for unloading the GCL should refer to this manual prior to shipment to ascertain the appropriateness of their unloading equipment and procedures. Unloading and on-site handling of the GCL should be supervised.

3.4 In most cases, CETCO GCLs are delivered on flatbed trucks. There are three methods of unloading: core pipe and spreader bar; slings; or stinger bar. To unload the rolls from the flatbed using a core pipe and spreader bar, first insert the core pipe through the core tube. Secure the lifting chains or straps to each end of the core pipe and to the spreader bar mounted on the lifting equipment. Hoist the roll straight up and make sure its weight is evenly distributed so that it does not tilt or sway when lifted.

3.5 At the customer's request, CETCO GCLs may be delivered with two 2" x 12' (50 mm x 3.65 m) Type V polyester endless slings on each roll. Before lifting, check the position of the slings. Each sling should be tied off in the choke position approximately one third (1/3) from the end of the roll. Hoist the roll straight up so that it does not tilt or sway when lifted.

3.6 In some cases, GCL rolls will be stacked in three pyramids on flatbed trucks. If slings are not used, rolls will require unloading with a stinger bar and extendible boom fork lift. Spreader bars will not work in this situation because of the limited access between the stacks of GCL. Three types of stingers are available from CETCO (Figures 2-4). To unload, guide the stinger through the core tube before lifting the GCL roll and removing from the truck.

3.7 An extendible boom fork lift with a stinger bar is required for unloading vans. Rolls in the nose and center of van should first be carefully pulled toward the door using the slings provided on the rolls.

3.8 Rolls should be stored at the job site away from high-traffic areas but sufficiently close to the active work area to minimize handling. The designated storage area should be flat, dry and stable. Moisture protection of the GCL is provided by its packaging; however, an additional tarpaulin or plastic sheet is recommended.

3.9 Rolls should be stacked in a manner that prevents them from sliding or rolling. This can be accomplished by chocking the bottom layer of rolls. Rolls should be stacked no higher than the height at which they can be safely handled by laborers (typically no higher than four layers of rolls). Rolls should never be stacked on end.

4 SUBGRADE PREPARATION

4.1 Subgrade surfaces consisting of granular soils or gravel may not be acceptable due to their large void fraction and puncture potential. In high-head (greater than one foot or 30 cm) applications, subgrade soils should possess a particle size distribution such that at least 80 percent of the soil is finer than a #60 sieve (0.250 mm) unless a membrane-laminated GCL (Bentomat CL or Bentomat CLT) is used.

4.2 When the GCL is placed over an earthen subgrade, the subgrade surface must be prepared in accordance with the project specifications. The engineer's approval of the subgrade must be obtained prior to installation. The finished surface should be firm and unyielding, without abrupt elevation changes, voids, cracks, ice, or standing water.

4.3 The subgrade surface must be smooth and free of vegetation, sharp-edged rocks, stones, sticks, construction debris, and other foreign matter that could contact the GCL. The subgrade should be rolled with a smooth-drum compactor to remove any wheel ruts, footprints, or other abrupt grade changes. Furthermore, all protrusions extending more than 1 inch (25 mm) from the subgrade surface shall be removed, crushed, or pushed into the surface with a smooth-drum compactor. The GCL may be installed on a frozen subgrade, but the subgrade soil in the unfrozen state should meet the above requirements.

5 INSTALLATION

5.1 GCL rolls should be taken to the work area of the site in their original packaging. The orientation of the GCL (i.e., which side faces up) may be important if the GCL has two different types of geosynthetics. Check with the project engineer in order to determine if there is a preferred installation orientation for the GCL. If no specific orientation is required, allow the roll to unwind from the bottom rather than pulling from the top (Figure 5). The arrow sticker on the plastic sleeve indicates the direction the GCL will naturally unroll when placed on the ground (Figure 6). Prior to deployment, the packaging should be carefully removed without damaging the GCL.

FIGURE 5 **THE GCL CAN BE UNROLLED IN ITS "NATURAL" ORIENTATION (A) OR CAN BE PULLED FROM THE TOP OF THE ROLL (B)**

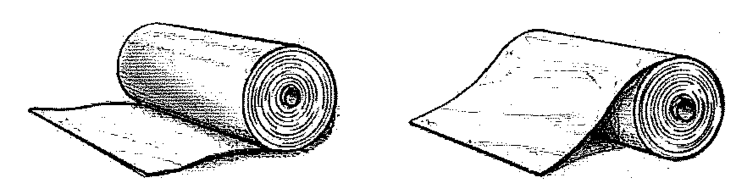
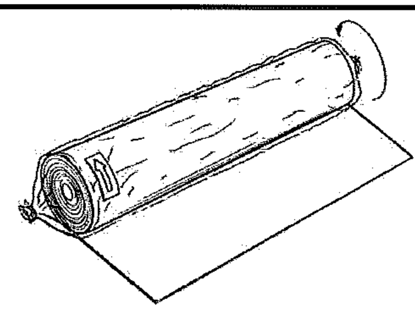
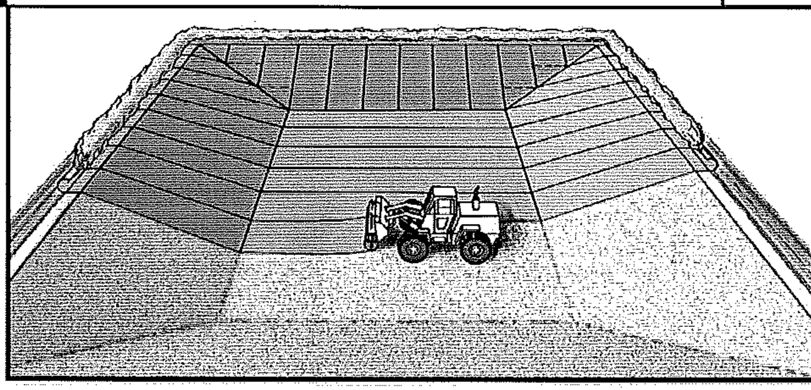


FIGURE 6 **DIRECTION TO UNROLL GCL ON GROUND PER FIGURE 5(A)**



5.2 Equipment which could damage the GCL should not be allowed to travel directly on it. Acceptable installation, therefore, may be accomplished such that the GCL is unrolled in front of backwards-moving equipment (Figure 7). If the installation equipment causes rutting of the subgrade, the subgrade must be restored to its originally accepted condition before placement continues.

FIGURE 7 TYPICAL BENTOMAT®/CLAYMAX® INSTALLATION TECHNIQUE

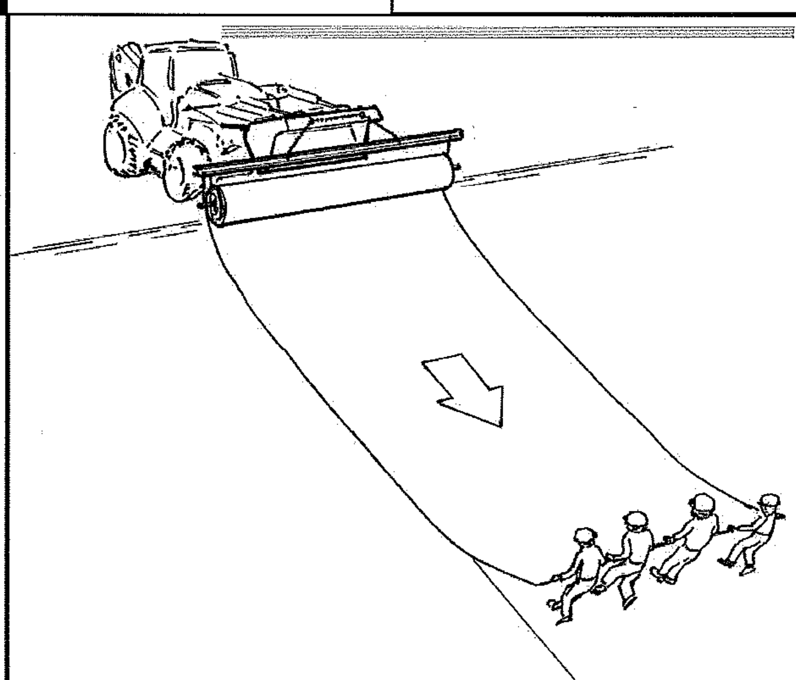


5.3 If sufficient access is available, GCL may be deployed by suspending the roll at the top of the slope with a group of laborers pulling the material off of the roll and down the slope (Figure 8).

5.4 GCL rolls should not be released on the slope and allowed to unroll freely by gravity.

5.5 Care must be taken to minimize the extent to which the GCL is dragged across the subgrade in order to avoid damage to the bottom surface of the GCL. Care must also be taken when adjusting Bentomat CLT panels to avoid damage to the geotextile surface of one panel of GCL by the textured sheet of another panel of GCL. A temporary geosynthetic subgrade covering, commonly known as a slip sheet or rub sheet, may be used to reduce friction damage during placement.

FIGURE 8 UNROLLING BENTOMAT



5.6 The GCL should be placed so that seams are parallel to the direction of the slope. End-of-panel seams should also be located at least 3 ft (1m) from the toe and crest of slopes steeper than 4H:1V. End-of-roll seams on slopes should be used only if the liner is not expected to be in tension.

5.7 All GCL panels should lie flat, with no wrinkles or folds, especially at the exposed edges of the panels. When Bentomat with SuperGroove® is repositioned, it should be gripped inside the SuperGroove by folding the edge.

5.8 The GCL should not be installed in standing water or during rainy weather. Only as much GCL shall be deployed as can be covered at the end of the working day with soil, geomembrane, or a temporary waterproof tarpaulin. The GCL shall not be left uncovered overnight. If the GCL is hydrated when no confining stress is present, it may be necessary to remove and replace the hydrated material. The project engineer, CQA inspector, and CETCO's TR-312 should be consulted for specific guidance if premature hydration occurs.

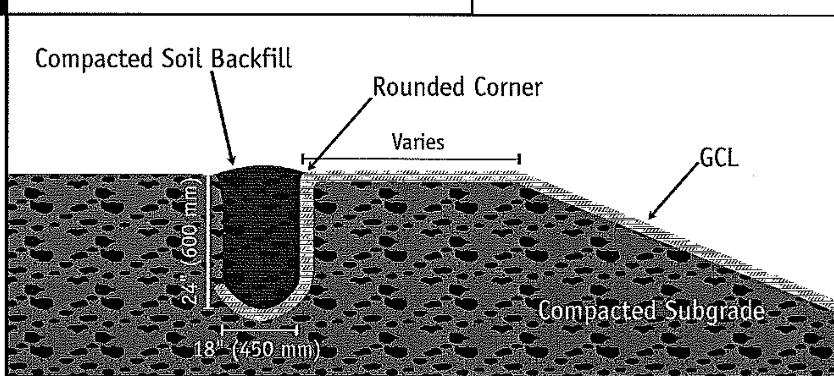
5.9 For the convenience of the installer, hash marks are placed on Bentomat every 5′ (1.5 m) of length.

6 ANCHORAGE

6.1 If required by the project drawings, the end of the GCL roll should be placed in an anchor trench at the top of a slope. The front edge of the trench should be rounded to eliminate any sharp corners that could cause excessive stress on the GCL. Loose soil should be removed or compacted into the floor of the trench.

6.2 If a trench is used for anchoring the end of the GCL, soil backfill should be placed in the trench to provide resistance against pullout. The size and shape of the trench, as well as the appropriate backfill procedures, should be in accordance with the project drawings and specifications. Typical dimensions are shown in Figure 9.

FIGURE 9 TYPICAL ANCHOR TRENCH DESIGN



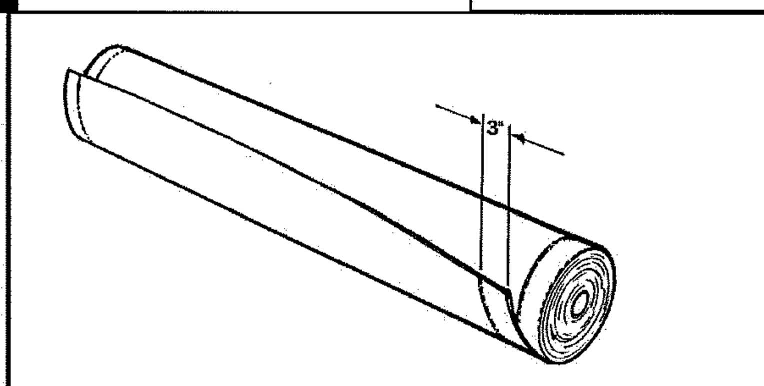
6.3 The GCL should be placed in the anchor trench such that it covers the entire trench floor but does not extend up the rear trench wall.

6.4 Sufficient anchorage may alternately be obtained by extending the end of the GCL roll back from the crest of the slope, and placing cover soil. The length of this "runout" anchor should be prepared in accordance with project drawings and specifications.

7 SEAMING

7.1 GCL seams are constructed by overlapping adjacent panel edges and ends. Care should be taken to ensure that the overlap zone is not contaminated with loose soil or other debris. Supplemental bentonite is not required for Claymax 200R. Bentomat ST, DN, SDN, or YSDN with Supergroove® have self-seaming capabilities in their longitudinal overlaps (Figure 10) without the need for supplemental bentonite. For pond applications, CETCO supplemental bentonite must be used in longitudinal seams regardless of the CETCO GCL used.

FIGURE 10 SUPERGROOVE



7.2 Longitudinal seams should be overlapped a minimum of 6 inches (150mm) for Bentomat and 12 inches (300mm) for Claymax.

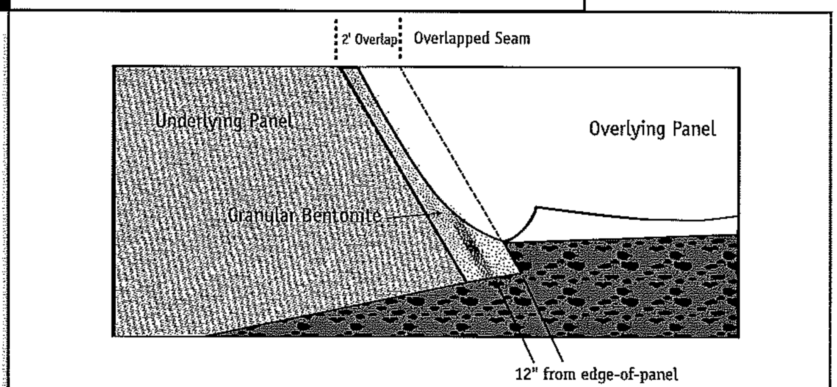
7.3 End-of-panel overlapped seams should be overlapped 24 inches (600mm) for Bentomat and 48 inches (1,200mm) for Claymax.

7.4 End-of-panel overlapped seams are constructed such that they are shingled in the direction of the grade to prevent runoff from entering the overlap zone. End-of-panel seams on slopes are permissible, provided adequate slope stability analysis has been conducted (i.e., the GCL is not expected to be in tension). Bentonite-enhanced seams are required for all Bentomat end-of-panel overlapped seams.

7.5 Bentomat end-of-panel, bentonite-enhanced, overlapped seams are constructed first by overlapping the adjacent panels, exposing the underlying panel, and then applying a continuous bead or fillet of granular sodium bentonite (supplied with the GCL) 12" from the edge of the underlying panel (Figure 11). The minimum application rate at which the bentonite is applied is one-quarter pound per linear foot (0.4 kg/m).

7.6 If longitudinal bentonite enhanced seams are required, they are constructed first by overlapping the adjacent panels by a minimum 6-inches (150 mm), exposing the underlying edge and applying a continuous bead of granular bentonite approximately 3-inches (75 mm) from the edge. The minimum application rate for the granular bentonite is one quarter pound per linear foot (0.4 kg/m).

FIGURE 11 BENTOMAT END-OF-PANEL OVERLAPPED SEAM



8 SEALING AROUND PENETRATIONS AND STRUCTURES

8.1 Cutting the GCL should be performed using a sharp utility knife. Frequent blade changes are recommended to avoid irregular tearing of the geotextile components of the GCL during the cutting process.

8.2 The GCL should be sealed around penetrations and structures embedded in the subgrade in accordance with Figures 12 through 14. Granular bentonite or a bentonite mastic shall be used liberally (approx. 2 lbs. /ln ft. or 3 kg/m) to seal the GCL to these structures.

FIGURE 12A CROSS-SECTION OF A HORIZONTAL PIPE PENETRATION

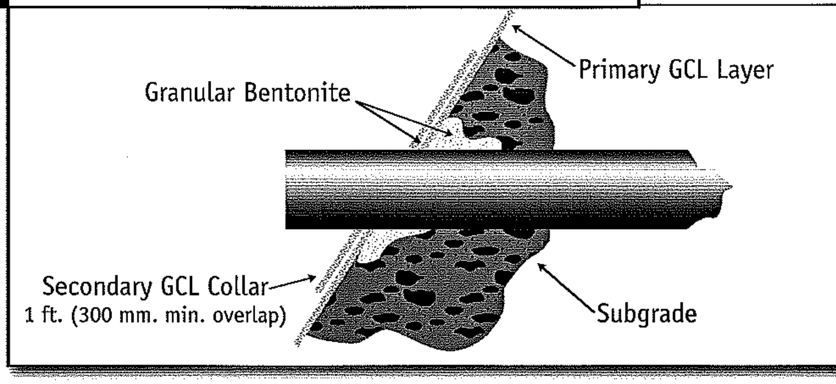
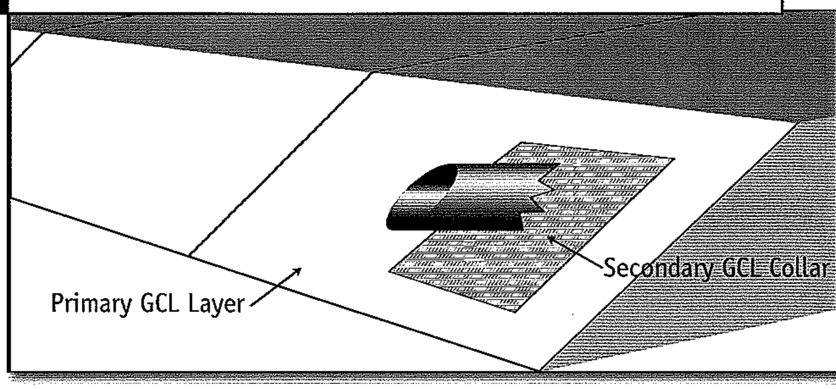
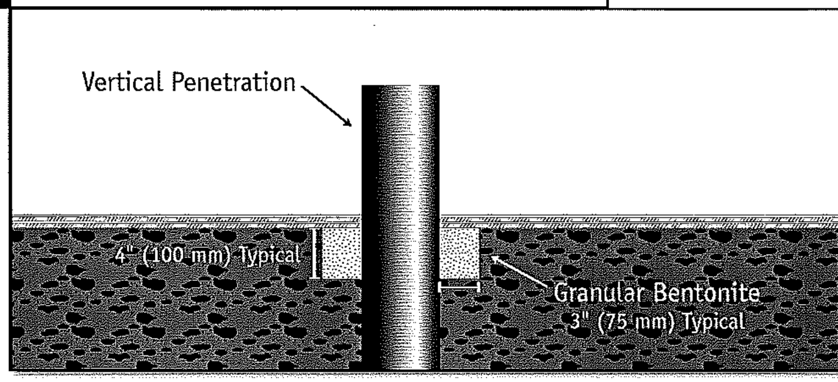


FIGURE 12B ISOMETRIC VIEW OF A COMPLETED HORIZONTAL PIPE PENETRATION



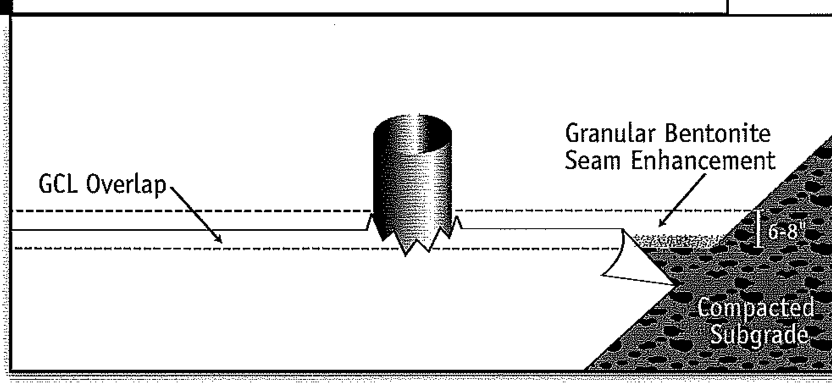
8.3 When the GCL is placed over a horizontal pipe penetration, a "notch" should be excavated into the subgrade around the penetration (Figure 12a). The notch should then be backfilled with granular bentonite. A secondary collar of GCL should be placed around the penetration as shown in Figure 12b. It is helpful to first trace an outline of the penetration on the GCL and then cut a "star" pattern in the collar to enhance the collar's fit to the penetration. Granular bentonite should be applied between the primary GCL layer and the secondary GCL collar.

FIGURE 13A CROSS-SECTION OF A VERTICAL PENETRATION



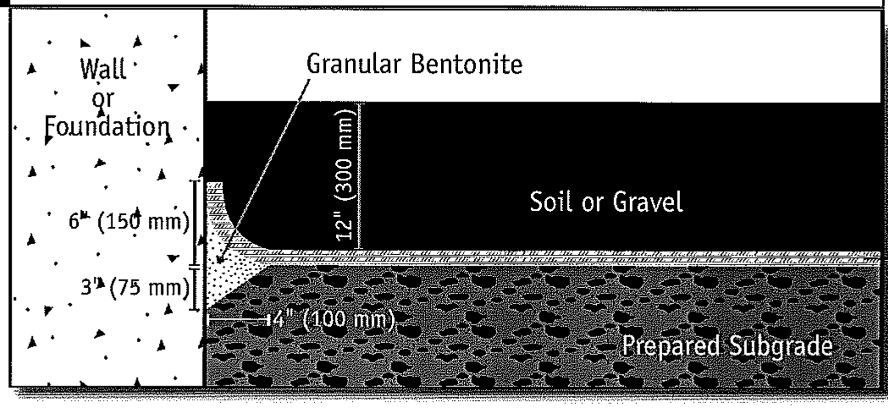
8.4 Vertical penetrations are prepared by notching into the subgrade as shown in Figure 13a. The penetration can be completed with two separate pieces of GCL as shown in Figure 13b. Alternatively, a secondary collar can be placed as in Figure 12a or 12b.

FIGURE 13B ISOMETRIC VIEW OF THE COMPLETED VERTICAL PENETRATION



8.5 When the GCL is terminated at a structure or wall that is embedded into the subgrade on the floor of the containment area, the subgrade should be notched as described in Sections 8.3 and 8.4. The notch is filled with granular bentonite, and the GCL should be placed over the notch and up against the structure (Figure 14). Connection to the structure can be accomplished by placement of soil or stone backfill in this area. When structures or walls are at the top of a slope, additional detailing may be required. Contact CETCO for specific guidance.

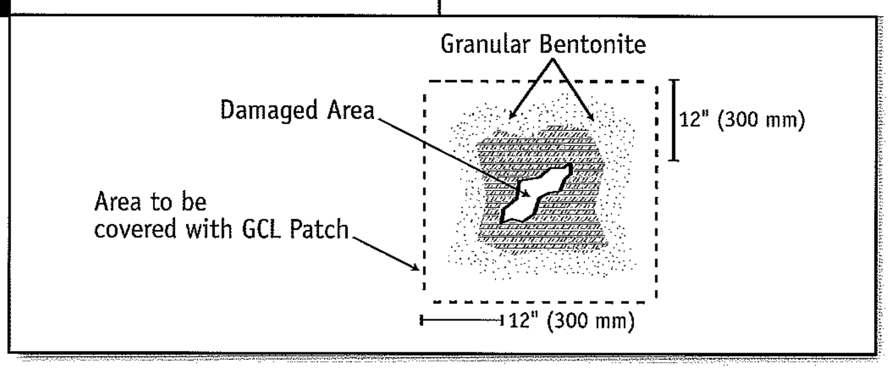
FIGURE 14 CROSS-SECTION OF GCL SEAL AGAINST AN EMBEDDED STRUCTURE OR WALL



9 DAMAGE REPAIR

9.1 If the GCL is damaged (torn, punctured, perforated, etc.) during installation, it may be possible to repair it by cutting a patch to fit over the damaged area (Figure 15). The patch should be cut to size such that a minimum overlap of 12 inches (300 mm) is achieved around all parts of the damaged area. Granular bentonite or bentonite mastic should be applied around the damaged area prior to placement of the patch. It may be necessary to use an adhesive such as wood glue to affix the patch in place so that it is not displaced during cover placement. Smaller patches may be tucked under the damaged area to prevent patch movement.

FIGURE 15 DAMAGE REPAIR BY PATCHING



10 COVER PLACEMENT

10.1 The final thickness of soil cover on the GCL varies with the application. A minimum cover layer must be at least 1 foot (300 mm) thick to provide confining stress to the GCL, eliminate the potential for seam separation and prevent damage by equipment, erosion, etc.

10.2 Cover soils should be free of angular stones or other foreign matter that could damage the GCL. Cover soils should be approved by the Engineer with respect to particle size, uniformity, and chemical compatibility. Consult CETCO if cover soils with high concentrations of calcium (e.g., limestone, dolomite, gypsum, seashell fragments) are present.

10.3 Recommended cover soils should have a particle size distribution ranging between fines and 1 inch (25 mm), unless a cushioning geotextile is specified.

10.4 Soil cover shall be placed over the GCL using construction equipment that minimizes stresses on the GCL. A minimum thickness of 1 foot (300 mm) of cover soil should be maintained between the equipment tires/tracks and the GCL at all times during the covering process. In frequently high-traffic areas or roadways, a minimum thickness of 2 feet (600 mm) is required.

10.5 Soil cover should be placed in a manner that prevents the soil from entering the GCL overlap zones. Soil cover should be pushed up slopes, not down slopes, to minimize tensile forces on the GCL.

10.6 When a textured geomembrane is installed over the GCL, a temporary geosynthetic covering known as a slip sheet or rub sheet should be used to minimize friction during placement and to allow the textured geomembrane to be more easily moved into its final position.

10.7 Claymax must be covered with a geomembrane and/or 12" (300 mm) of cover material within 8 hours of deployment to prevent the potential for shrinkage by desiccation.

10.8 Cyclical wetting and drying of GCL covered only with geomembrane can cause overlap separation. Soil cover should be placed promptly whenever possible. Geomembranes should be covered with a white geotextile and/or operations layer without delay to minimize the intensity of wet-dry cycling. If the GCL is covered only with a geomembrane for an extended period, longitudinal seam overlaps must be increased to 12" (300 mm).

10.9 To avoid seam separation, the GCL should not be put in excessive tension by the weight or movement of textured geomembrane on steep slopes. Check with project engineer for the potential for GCL tension to develop.

11 HYDRATION

11.1 Hydration is usually accomplished by natural rainfall and/or absorption of moisture from soil. However, in cases where the containment of non-aqueous liquid is required, it may be necessary to hydrate the covered GCL with water prior to use.

11.2 If manual hydration is necessary, water can be introduced by flooding the covered lined area or using a sprinkler system.

CETCO LINING TECHNOLOGIES

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APPENDIX C

QUALITY STANDARDS

MANUFACTURE, PRE-ASSEMBLY, AND INSTALLATION

OF

GEOMEMBRANES

2005

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TABLE OF CONTENTS

1 GENERAL INFORMATION

1.1 PURPOSE

The purpose of this manual is to provide details of Manufacturing Quality Control (MQC), Manufacturing Quality Assurance (MQA), Construction Quality Control (CQC), and Construction Quality Assurance (CQA) for the manufacture, pre-assembly, and installation of geomembrane products supplied by Watersaver Company, Inc (WCI).

1.2 CONFORMANCE WITH PROJECT SPECIFICATIONS

It is the intent of WCI to comply with the generally recognized MQC, MQA, CQC and CQA standards and practices for governmental, manufacturing, pre-assembly and installing industries. If required, modification to this manual can be made via addendum in order to accommodate individual job specific requirements.

2 GEOMEMBRANE MANUFACTURING

2.1 RAW MATERIALS

WCI requires all manufacturers to certify that their sheeting is formulated and manufactured from 100% virgin raw materials that are specifically compounded for use in hydraulic structures. See Appendix V for additional raw material qualifications.

The manufacturers are required to submit written certification that each lot of material meets or exceeds WCI specifications located in Appendix I.

2.2 ROLL GOODS

All roll goods received from WCI suppliers are visually inspected for imperfections and contaminants. Manufacturer certifications show that physical property testing is conducted on each lot of roll goods. Materials tested must meet or exceed the values specified. The following properties are evaluated:

PROPERTY	TEST METHOD (Non-reinforced)	TEST METHOD (Reinforced)
Thickness (inches, nominal)	ASTM D751	ASTM D751
Breaking Factor (lbs/in)	ASTM D882	ASTM D751
Elongation at Break (percent)	ASTM D882	N/A
Modulus @ 100% Elongation	ASTM D882	N/A

3 GEOMEMBRANE FABRICATION

3.1 FACTORY FABRICATION

Individual calendered widths (roll goods) are factory pre-assembled into large panels to minimize field seaming during installation.

Factory seams are produced using chemical, dielectric or thermal method. Each seaming method is tailored for optimum seam strength.

Nominal seam widths, Non-reinforced 1" / Reinforced 1 ½" scrim to scrim.

Factory pre-assembly production records identify each panel by panel number, size, date of pre-assembly, material lot number and seam station identification. Each panel is prominently marked with the panel number and panel size to coincide with production records.

3.2 IN-FACTORY SEAM TESTING

Visual and non-destructive inspection is performed on 100% of factory pre-assembled seams, including ASTM D4545, through a combined use of sections 7.1.1 (OSHA limits) and 7.1.4. Seam type will determine procedure and ratio. All seams are warranted for two (2) years.

In addition, WCI performs destructive testing on factory fabricated seams in order to verify quality compliance.

Samples of factory seams are taken at the beginning and at the end of each production shift. All seams are tested for compliance and the results are archived at the WCI facility. Test results are available upon request (job specific).

3.3 FACTORY SEAM REQUIREMENTS

All factory seams are tested for Bonded Seam and Peel strength in accordance with industry (ASTM) standards. Specified values and test methods are listed in Appendix I.

Primary and secondary seaming methods are listed by material in Appendix IV.

4 PACKAGING, HANDLING, AND TRANSPORTATION

4.1 PACKAGING AND HANDLING

After factory pre-assembly, the geomembrane panels are double accordion folded on a pallet or rolled on a cardboard core. Folded panels are shrink wrapped (light reflectant) using a water and UV resistant polymer sheeting with outer cardboard insert banded to a heavy duty wooden pallet. Rolled panels are wrapped in a protective layer and shrink wrapped (light reflectant). All pallets/rolls are identified by panel size, type, and number. Geomembrane panels delivered to the jobsite are unloaded on level ground, stored in their original, unopened containers in a secure, dry area, and protected from weathering. Whenever possible, a six-inch minimum air space between the pallets should be maintained, especially when the geomembrane panels are to be stored over an extended period of time. Pallets must not be stacked. Banding is not to be removed from the pallet until actual deployment, to insure stability.

Material Safety Data Sheets (MSDS) to be provided on all chemicals which include handling and personal protection during usage.

4.2 TRANSPORTATION

Transportation of the geomembrane will be arranged by WCI through an independent trucking firm, and will be shipped via a closed or flat bed trailer. Adequate tarps (flat bed) are recommended during transport. It is the responsibility of the receiver at the time of delivery to indicate condition of shipment on the Bill of Lading. Any visual damage MUST be noted in WRITING and WCI should be contacted within 24 hours or (extreme conditions) before accepting delivery.

5 INSTALLATION

5.1 ANCHORAGE SYSTEM

Unless otherwise specified, the anchor trench should be excavated by the earthwork contractor or others to the lines and grades shown on the design drawings. Store excavated material away from the area to be lined.

Complete trenching process prior to geomembrane placement.

A smooth transition surface from anchor trench to subgrade should be provided.

Following the completion of the seaming operation, the anchor trench shall be backfilled and compacted (as soon as possible) by the earthwork contractor to lock in the geomembrane. During ongoing backfilling operations, backfill should be kept a minimum of 10 feet from un-seamed areas.

5.2 SUBGRADE

5.2.1 Preparation

Surfaces to be lined will be free of all rocks, roots, vegetation, sharp objects, or debris of any kind. The surface shall provide a firm, unyielding foundation for the geomembrane with no sharp or abrupt changes in grade.

If an herbicide is required, it must be suitable for use with geomembranes and shall be applied as per the manufacturer recommendations. Suitability for use with the geomembrane shall be confirmed by the herbicide manufacturer.

5.2.2 Repair and Maintenance

Prior to geomembrane installation, the surfaces to be lined shall be inspected for acceptability by the installers. Any necessary repairs will be made by the owner or earthwork contractor. It is the responsibility of the owner or earthwork contractor to maintain the integrity of the subgrade prior to, and during the geomembrane installation. This includes the control of ground water in the area to be lined.

5.3 GEOMEMBRANE PANEL PLACEMENT

5.3.1 Panel Location

Install the geomembrane as indicated in the approved layout drawing. The installer may modify the proposed layout to best meet the intent of the project specification and/or to accommodate existing site conditions.

5.3.2 Weather Conditions

Consideration must be given to low temperature (<40°F) handling characteristics of the geomembrane before installation, in some cases, before the liner is actually ordered. Please contact Watersaver Company, Inc. if the above condition exists.

5.3.3 Geomembrane Panel Deployment

The number of panels to be deployed in any day shall be limited to the number of panels which can be seamed or secured that day.

The geomembrane shall be installed in a relaxed manner and free of tension and stress. In areas where grade transitions occur, "bridging" or "trampolining" of the geomembrane shall not be allowed. To accommodate grade transition, adequate slack is necessary. Wrinkling of the geomembrane is acceptable and indicates proper slack consideration.

Deploy geomembrane panels to meet a minimum panel overlap of six inches. During cold weather deployment, consideration must be given to residual packaging geometry (ability to lay flat) as it relates to installation quantity. Shingle all panels in the down gradient direction whenever possible.

5.3.4 Preparation for Seaming

WCI approved installer shall verify the following:

- All personnel walking on the geomembrane liner shall have smooth soled shoes. Personnel working on the geomembrane shall not smoke and shall not engage in activities that could damage the geomembrane.
- Tools used in the installation process shall be properly stored and carried. Knives and other sharp objects shall be carried in protective sheaths.
- The method used to unfold panels will not cause damage to the geomembrane or underlying geosynthetics.
- Any geosynthetic elements directly underlying the geomembrane shall be clean and free of debris.
- Adequate temporary anchoring shall be placed to prevent wind uplift of the geomembrane panels. Typical items are sandbags and ballast tubes. In cases of high wind, continuous loading may be required along the edges of the geomembrane panel.
- High traffic areas may require temporary wear surfaces (i.e. geotextile, additional geomembrane, clean fill, etc.).
- Vehicles shall not be allowed on the geomembrane unless approved by the installer.
- Chemical cleaners, seaming agents and fuels shall be stored separately, away from geomembrane panels. Spill resistant containers shall be used while working directly on the liner and shall be stored upon a sacrificial material such as scrap geomembrane or heavy cardboard.

5.4 FIELD SEAMING

5.4.1 Seam Preparation

See Appendix IV for Primary and Secondary Field Seaming Methods

The overlapped geomembrane panels must be clean at the surfaces to be joined. Any foreign material (e.g. dirt, moisture) must be removed with clean, dry rags before seaming commences.

If seaming must be conducted over rough substrate, seaming boards are recommended. A one-foot by eight or ten-foot pine shelf board will work well as a seaming platform.

5.4.1.1 Repairs

All fish mouths shall be slit, laid flat, bonded, then patched with a round or oval patch of the same geomembrane material. All patches shall extend a minimum of six inches beyond the repair area in all directions, and seamed along the entire perimeter.

5.4.2 Chemical Fusion Field Seaming

Chemical fusion agent shall be applied between the two surfaces to be joined. These surfaces shall be mated together and pressure applied to the upper surface by means of a roller (high durometer rubber, nylon, or steel).

A sufficient amount of chemical fusion agent shall be applied between the two geomembrane surfaces to be joined so when rolled, a thin excess of agent will be forced out of the seam. Any excess chemical agent shall be wiped from the geomembrane. The lower of the two surfaces to be joined shall be completely wet by the chemical fusion agent. See Field Seam Geometry Table in Appendix III.

If any discontinuities are noted, allow approximately ½ hour before reapplying agent. This process can be expedited by using artificial heat.

5.4.3 Cold Weather Chemical Fusion Field Seaming

Generally for cold weather seaming, when the geomembrane surface is below 50°F, the surfaces to be joined must be preheated.

If the soil beneath the geomembrane is frozen, the application of heat to the area to be seamed may result in moisture condensing between the surfaces to be joined. This condition may be eliminated by placing a seaming board, or slip-sheet made from the same geomembrane material, between the frozen surface and the geomembrane to be seamed.

See Field Seam Geometry Table in Appendix III.

5.4.4 Thermal Fusion Field Seaming (Continuous Width)

The two most common seaming methods are Hot Wedge and Hot Air. Either method is capable of producing a quality seam. These units are equipped with speed and temperature controls with digital (LED) readout along with pressure adjustment.

- Thin gauge materials (<30 Mil) combined with high ambient temperatures can affect seam quality.
- Hand Held Leister or equal can be used for pipe boots, details and patching for the majority of non-crystalline geomembranes.
- Each method must be capable of producing sufficient amount of controlled heat and pressure applied to the seam overlap contact zone, resulting in a continuous thermal weld.
- Pressure squeeze out along seam edge to be kept to a minimum in order to maximize overall seam thickness.
- Exercise caution when operating welder in direct contact with subgrade. Drive (pressure) rollers must be kept clean at all times.

5.4.5 Pipe Penetrations

Penetrations are sealed via the use of WCI factory fabricated pipe seals. Pipe seals are thermally constructed using the same material as the specified geomembrane. For reinforced material, the tube section of the pipe seal can be constructed using non-reinforced parent material. The method of bonding is as outlined in the field seaming section.

5.5 LINING SYSTEM ACCEPTANCE

WCI authorized installer shall retain responsibility for the geomembrane installation until acceptance by the Engineer and/or Owner.

The geomembrane liner installation will be accepted by the Owner when the following conditions have been met:

1. Installation of the geomembrane is complete.
2. Verification of the integrity of all seams and repairs, as required by the specifications, is complete.
3. All documentation pertaining to the geomembrane installation is completed and submitted to the Owner/Engineer.

6 FIELD QUALITY ASSURANCE

6.1 OVERVIEW

Field seam quality shall be demonstrated by non-destructive (NDT) and destructive (DT) test methods.

The primary purpose of the NDT method is to demonstrate continuity along the entire length and to validate 100% of the field seam. NDT methodology is described in section 6.3 below.

The purpose of the DT method is to determine the quality of a given seam by removing a representative seam sample, and testing the given sample for compliance with accepted applicable industry standards. Testing may be conducted either at the job site, or at a remote testing laboratory. DT methodology is discussed in section 6.4 below.

6.2 TEST STRIP/TRIAL SEAMS

A general requirement of most CQA Documents is that "test seams" or "test strips" be made on a periodic basis. Test strips generally reflect the quality of field seams but should never be used solely for the final field seam acceptance. Final field seam acceptance requirements should be specified in the contract specification and should include a minimum level of destructive testing of the field seams. Test strips are made to minimize the amount of destructive sampling/testing on the finished panels. Typically these test seams, for each seaming crew, are made once per day, or every time equipment is changed, or if significant changes in site conditions are noted, or as required in the contract specification. The purpose of these tests is to establish that proper seaming materials, temperatures, pressures, rates, and techniques along with the necessary geomembrane pre-seaming preparation are being accomplished. Test strips may be used for CQA/CQC evaluation, and must be of sufficient size in order to conduct required testing.

While cursory test seams are evaluated, the seaming crew may begin and continue to work as long as the field seam being constructed is completely traceable and identifiable. If a test seam fails to meet the field seam design specification, then an additional test seam sample is constructed and re-tested by the same seaming crew, equipment, and materials.

Field seams will not be accepted unless CQC seam test result criteria as per the design specification are met.

One of the following procedures shall apply whenever a sample fails a destructive test:

1. The field seam shall be reconstructed between two test locations shown to have acceptable results; one located on either side of the failed sample.

2. The seam shall be traced outward to intermediate points (a maximum of 10 feet from the failed sample in each direction) and sampled for additional testing. If the samples are found to provide acceptable test results, the seam is reconstructed between these two sample locations. If an intermediate sample fails, the process is repeated to establish the zone in which the seam is to be reconstructed. All reconstructed seams shall be defined by two locations from which samples passing other destructive tests have been taken.

Reconstruction of field seams shall be accomplished by removing the suspect seam, repositioning panels and re-seaming, or by installing a cap strip to cover the seam under reconstruction. Cap stripping shall extend a minimum of six inches beyond the reconstructed seam in all directions.

For geomembrane seams that are bonded by the chemical fusion method, the seams must be cured prior to testing. Without the application of heat, the cure times can range from a few hours to a few days. Accelerated curing for on site CQC testing requires the use of an oven or other suitable heat source to condition the seam samples from 1 to 16 hours in a temperature range of 122°F to 158°F. Following the accelerated cure period, a post-cure conditioning period of at least ½ hour at ambient conditions prior to testing is required.

During the CQC and CQA test requirement periods, a liner should not be covered, and it cannot be placed into service. This will insure the ease of repairing or reconstructing in the event it is required. During this period, it is imperative that the liner be properly ballasted and otherwise secured so as to prevent wind or unusual weather damage.

6.3 NON-DESTRUCTIVE SEAM TESTING

6.3.1 Test Methods

The following test methods are acceptable for non-destructive testing of field seams:

A. Air Lance
B. Vacuum Chamber

See Appendix II for application of these methods based on seam type or location.

Testing Reference Refer to ASTM D 4437-84.

6.3.2 Remedial Action

If unbonded areas are located, they can often be repaired by using detail method 5.4 or 5.4.1.1. All patches shall extend a minimum of six inches beyond the area in all directions.

6.4 DESTRUCTIVE SEAM TESTING

6.4.1 Sampling Frequency

Destructive seam testing can be conducted along completed field seams at intervals of 1000 feet (or at intervals indicated in the project specification, and as addressed by addendum to this document). Wherever possible, test strips should be taken out of the anchor trenches so as not to disturb the integrity of the functional lining system.

6.4.2 Sampling Procedure

Samples shall be removed from the completed geomembrane seam by the installer. The sample shall be labeled in a clear and logical manner. The sample location must be identified and recorded.

Any holes in the geomembrane resulting from destructive seam sampling shall be immediately repaired by patching the sampled area with identical geomembrane material. The patch must extend a minimum of six inches beyond the repair area in all directions. The continuity of repaired sampling locations shall be confirmed via NDT methods described above.

6.4.3 Sample Geometry

The *minimum* sample geometry shall be as follows:

Sample width shall be determined as the width of the field seam plus six inches on both sides of the seam.

Sample length can be up to forty-eight (48") inches for non-reinforced material and can be up to one hundred four (104") inches for reinforced material.

See Appendix III for seam diagram.

6.4.4 Disposition of Samples

The sample described above shall be cut into three equal segments. One segment of the sample shall be submitted for laboratory (or field) testing; one segment to the installer, and the remaining segment to the owner.

6.4.5 Sampling and Testing

6.4.5.1 Conditioning

Conditioning of all samples prior to testing is imperative. Field seams produced using a chemical fusion agent must be allowed to cure until the required strength values can be achieved. *Accelerated curing can be accomplished by conditioning the samples at temperature of 122°F-158°F for sixteen hours. Following the accelerated cure period, a post-cure conditioning period of at least ½ hour at ambient conditions prior to testing is required. *Ref: EPA/530/SW-91-051-5/91

Chemical seam samples shall be considered ready for testing when the chemical fusion agent odor is no longer detectable.

6.4.5.2 Sampling

Test specimens shall be prepared as per Section 6.4.3.

6.4.5.3 Testing

Specimens shall be tested in order to determine bonded seam strength and peel adhesion. Testing Methods per ASTM procedures indicated by Appendix I.

A. Bonded Seam Strength (ASTM D882)

Non-reinforced Material

Specimen dimensions shall be one inch in width and shall extend a distance of four inches (4") on both sides of field seam. Samples must be cut in a manner which eliminates nicks or tears in the specimen which could cause premature failure (refer to ASTM D882 for further information). Specimens must be cut so that the long dimension of the specimen is perpendicular to the length of the seamed sample.

Reinforced Material (ASTM D751)

Specimen dimensions shall be four inches (4") in width and shall extend a distance of four and one-half (4-1/2") on both sides of field seam. Samples must be cut in a manner which eliminates nicks or tears in the specimen which could cause premature failure (refer to ASTM D882 for further information). Specimens must be cut so that the long dimension of the specimen is perpendicular to the length of the seamed sample.

B. Peel Adhesion (ASTM D882)

Non-reinforced and reinforced material.

Prepare specimens as described above for bonded seam strength.

C. Quantity of Specimens

A total of ten specimens shall be cut from the sample. Five specimens will be used to perform bonded seam strength testing with the remaining five specimens to be used for peel adhesion testing. Details of the test procedures are outlined in ASTM D751, Modified (Bonded Seam Strength), and ASTM D413, Modified (Peel Adhesion). Specimens to be selected (cut) alternately from samples (i.e. peel, shear, peel).

6.4.6 Acceptance of Destructive Test Results

See Appendix I for minimum specified seam strength values.

6.4.7 Remedial Action – Destructive Test Failure

One of the following procedures shall apply whenever a sample fails a destructive test:

1. The field seam shall be reconstructed between two test locations shown to have acceptable results; one located on either side of the failed sample.

2. The seam shall be traced outward to intermediate points (a maximum of 10 feet from the failed sample in each direction) and sampled for additional testing. If the samples are found to provide acceptable test results, the seam is reconstructed between these two sample locations. If an intermediate sample fails, the process is repeated to establish the zone in which the seam is to be reconstructed. All reconstructed seams shall be defined by two locations from which samples passing other destructive tests have been taken.

Reconstruction of field seams shall be accomplished by either removing the suspect seam, repositioning panels and re-seaming, or by installing a cap strip to cover the seam under reconstruction. Cap stripping shall extend a minimum of six inches beyond the reconstructed seam in all directions.

6.4.8 Verification of Repairs

Any repair requiring a patch or cap strip shall be identified on the as-built drawing. Each repair shall undergo non-destructive testing as described in section 6.3 above. Repairs which pass the NDT shall be taken as an indication of proper repair. Failed NDT's will result in reconstruction and re-testing of the repair area until a passing result is obtained.

REFERENCES

ENVIRONMENTAL PROTECTION AGENCY (EPA)
Lining for Waste Containment and Other Impoundment Facilities
EPA/600/2-88/052
Inspection Techniques for the Fabrication of Geomembrane Field Seams
EPA/530/SW-91/051 – 5/91

AMERICAN SOCIETY FOR TESTING AND MATERIALS

NATIONAL SANITATION FOUNDATION (NSF)
Joint Committee on Flexible Membrane Liners

Standard 54-1991

PVC Geomembrane Institute

ASTM Committee D – 35.10

APPENDIX I PRODUCT SPECIFICATIONS

Section I	
Polyvinyl Chloride *PVC*	PGI 1104

Section II	
Polypropylene *PP-R*	Carlisle-Syntec Stevens Geomembranes

Section III	
XR-5 8130 / 8140 *High Performance Geomembrane* **XR-3 8130** *Potable Water Applications NSF 61*	Seaman Corp

Section IV	
Hypalon *Chlorosulfonated Polyethlene (CSPE)*	Stevens Geomembranes

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POLYVINYL CHLORIDE (PVC)

PROPERTIES	TEST METHOD	SPECIFIED VALUES				
Thickness	ASTM D 5199	20 ± 1 mil 0.51 ± 0.03 mm	30 ± 1.5 mil .76 ± .04 mm	40 ± 2 mil 1.02 ± .05 mm	50 ± 2.5 mil 1.27 ± .06 mm	60 ± 3 mils 1.52 ± .08 mm
Tensile Properties	ASTM D 882 Min					
Strength at Break		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		360%	380%	430%	430%	450%
Modulus @ 100%		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	ASTM D 1004 Min.	6 lbs 27 N	8 lbs 35 N	10 lbs 44 N	13 lbs 58 N	15 lbs 67 N
Dimensional Stability	ASTM D 1204 Max Chg	4%	3%	3%	3%	3%
Low Temperature Impact	ASTM D 1790 Pass	-15°F -26°C	-20°F -29 °C	-20°F -29°C	-20°F -29°C	-20°F -29°C
Index Properties						
Specific Gravity	ASTM D 792 Typical	1.2 g/cc	1.2 g/cc	1.2 g/cc	1.2 g/cc	1.2 g/cc
Water Extraction % loss (max.)	ASTM D 1239 Max Loss	0.15%	0.15%	0.20%	0.20%	0.20%
Average Plasticizer Molecular Weight	ASTM D 2124	400	400	400	400	400
Volatility Loss	ASTM D 1203 Max Loss	0.9%	0.7%	0.5%	0.5%	0.5%
Soil Burial Break Strength Elongation Modulus at 100%	G160 Max Chg	5% 20% 20%	5% 20% 20%	5% 20% 20%	5% 20% 20%	5% 20% 20%
Hydrostatic Resistance	ASTM D 751 Min.	68 psi 470 kPa	100 psi 690 kPa	120 psi 830 kPa	150 psi 1030 kPa	180 psi
Seam Strengths						
Shear Strength	ASTM D 882 Min	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 20 kN/m
Peel Strength	ASTM D-882 Min	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

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POLYPROPYLENE

Reinforced Geomembrane

Physical Property	Test Method	Property of Unaged Sheet	Property After Aging 30 days @ 185°F
Tolerance on nominal thickness, %	ASTM D 5199	± 10	
Thickness over scrim, in (mm) 36-mil 45-mil 60-mil	ASTM D 4637 Optical Method	0.010 (0.254) min 0.013 (0.330) min 0.018 (0.457) min	
Mass per unit area, lb/ft^2 (g/ft^2) (kg/m^2) 36-mil 45-mil 60-mil	ASTM D 5261	0.17 (77) (0.83) typical 0.21 (95) (1.03) typical 0.29 (132) (1.42) typical	
Breaking strength, lbf (kN) (grab tensile at strain rate of 12 in./min) 36-mil 45 & 60-mil	ASTM D 751 Grab Method (A)	200 (0.9) min 260 typical 250 (1.1) min 300 typical	200 (0.9) min 260 typ. 250 (1.1) min 300 typ.
Elongation at break of fabric, %	ASTM D 751	25 typical	25 typical
Tearing strength, lbf (N) (2 in/min strain rate) 36-mil 45 & 60-mil	ASTM D 5884 (max. load)	80 (356) min 130 (578) typ. 100 (445) min 160 (712) typ.	
Low temperature flexibility, °F (°C)	ASTM D2136 1/8 in mandrel 4 hour @ Temp.)	-40 (-40) max. -50 (-46) typical	
Linear Dimensional Change (shrinkage), %	ASTM D 1204		± 1.0 max. - 0.5 typical
Ozone resistance, 100 pphm, 168 hrs	ASTM D 1149	No cracks	No cracks
Resistance to water (distilled) absorption After 30 days immersion 122°F (50°C) Change in mass, %	ASTM D 471 (coating compound)	1.0 max. 0.5 typical	
Hydrostatic resistance, lbf/in^2 or psi (MPa) (Mullen burst) 36-mil 45-mil 60-mil	ASTM D 751 Procedure A	350 (2.4) min 400 (2.8) typical 450 (3.1) typical 500 (3.4) typical	350 (2.4) min 400 (2.8) typical 450 (3.1) typical 500 (3.4) typical
Water vapor permeance, Perms	ASTM E 96	0.10 max. 0.05 typical	
Puncture resistance, lbs (N) 36-mil & 45-mil 60-mil	ASTM D 4833 (index puncture)	85 (378) min. 110 (489) typical 120 (534) typical	
Resistance to xenon-arc weathering[1] Xenon-Arc, 10,080 kJ/m^2 total radiant exposure, visual condition at 10X	ASTM G 155 0.70 W/m^2 80°C B.P.T.	No cracks No loss of breaking or tearing strength	
Typical Fabricated Seam Properties: [2]			
Bonded Seam Strength, lbs (kN/m)	ASTM D-751 Modified	200 (0.89)	
Peel Adhesion, lbs (kN/m)	ASTM D-413, Modified	20 (3.5) or FTB	

[1] Approximately equivalent to 8000 hours exposure at 0.35 W/m^2 irradiance B.P.T. is black panel temperature.
[2] Factory bonded seam strength is the responsibility of the fabricator.

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POLYPROPYLENE

Reinforced Geomembrane

Minimum Specifications

PROPERTY	TEST METHOD	TYPICAL VALUES		
Gauge (nominal) mils (mm)		.036 (0.90)	.045 (1.14)	.060 (1/52)
Plies, Reinforcing		1	1	1
Thickness, mils, Minimum 1. Overall, mil (mm 2. Over scrim, mil (mm)	ASTM D-751 Optical Method	.036 (0.90) 11 (0.28)	.044 (1.12) 12 (0.30)	.057 (1.45) 18 (0.46)
Breaking Strength-Fabric min. lbf. (kN)	ASTM D-751 Method A	275 (1.22)	300 (1.34)	325 (1.45)
Low Temperature °F (°C)	ASTM D-2136, 1/8 in. Mandrel, 4 hrs., Pass	-65 (-54)	-65 (-54)	-65 (-54)
Puncture Resistance, min Lbs (kN)	FTMS 101C Method 2031	350 (1.56)	400 (1.78)	425 (1.89)
Tear Strength, min lbf. (kN)	ASTM D-5884	100 (0.45)	100 (0.45)	100 (0.45)
Dimensional Stability, (% chg, max)	ASTM D-1204 180°F/82°C, 1 hr	-0.5 (-0.5)	-0.5 (-0.5)	-0.5 (-0.5)
Hydrostatic Resistance, min. psi, (MPa)	ASTM D-751 Method A, Procedure 1	375 (2.58)	400 (2.75)	425 (2.93)
Ply Adhesion, min, lbs./in. (kN/m)	ASTM D-413 Machine Method Mod.	30 (5.25)	30 (5.25)	30 (5.25)
Water Absorption, max, % wt chg	ASTM D-471, 30 days @ 70°F (21°C)	<1.0	<1.0	<1.0
Env. Stress Crack Resistance (Min. hrs. w/o failure)	ASTM D-1693 3000 hrs.	Unaffected by ESC	Unaffected By ESC	Unaffected By ESC
UV Resistance	ASTM G26 Xenon Arc @ 80°C, 4000 hrs.	Pass	Pass	Pass
Typical Fabricated Seam Properties.**				
Bonded seam strength, lbs (kN/m)	ASTM D-751, modified	175 (0.78)	200 (0.89)	200 (0.89)
Peel Adhesion, lbs (kN/m)	ASTM D-413, Modified	20 (3.5) or FTB	20 (3.5) or FTB	20 (3.5) or FTB

** Factory bonded seam strength is the responsibility of the fabricator

WATERSAVER XR-5®

GEOMEMBRANE LINER
ENGINEERING SPECIFICATION GUIDE

XR-5® 8130

High Performance Reinforced Geomembrane

XR-5® 8130 Reinforced	Standard	Metric
Base Fabric Type ASTM D3776	Polyester	
Basic Fabric Weight (nominal ASTM D3776	6.5 oz/yd^2	220/g/m^2
Thickness ASTM D751	30.0 mils min	0.76 mm min.
Weight ASTM D751	30.0 ± 2 oz/yd^2	1020 ± 70 g/m^2
Tear Strength ASTM D4533 Trapezoid Tear	35/35 lbs_f min	155 / 155 N min.
Breaking Yield Strength ASTM D751 Grab Tensile	550/550 lbs_f min	2450/2450 N min.
Low Temperature ASTM D2136 4 hr – 1/8" mandrel	Pass @ -30° F	Pass @ -35° C
Dimensional Stability ASTM D1204 212° F – 1 hr	1.5% max each direction	
Adhesion Heat Sealed Seam ASTM D751 Dielectric Weld	35 lb_f/2 in min	150 N/5 cm min
Dead Load - Seam Shear Strength ASTM751	2 in seam, 4 hr, 1 in strip 210 lb_f @ 70°F 105 lb_f @ 160°F	5 cm seam, 4 hrs, 2.5 cm strip 934 N @ 21° C 467 N @ 70 ° C
Bursting Strength ASTM D751 Ball Tip	650 lb_f min 800 lb_f typical	2892 N min. 3560 N typical
Hydrostatic Resistance ASTM D751 Method A	800 psi min	540 N/sq.cm min.
Blocking Resistance ASTM D751 (180°F/82°C)	#2 Rating max.	
Adhesion – Ply ASTM D413	15 lbs_f/in min or Film Tearing Bond	65 N/2.5 cm min. or Film Tearing Bond
Bonded Seam Strength ASTM D751 as modified by NSF 54	550 lb_f min	2447 N min.
Abrasion Resistance ASTM D3389 (H-18 Wheel 1000 g Load)	2000 cycles (min) before fabric exposure 50 mg/100 cycles max weight loss	
Weathering Resistance ASTM G23 (Carbon-Arc)	8000 hrs (min)-No appreciable changes or stiffening or cracking of coating	
Water Absorption ASTM D471 Section 12, 7 Days	0.025 kg/m^2 @ 70°F/21°C 0.14 kg/m^2 max @ 212°F/100°C	
Wicking ASTM D 751	1/8 in max.	0.3 cm max.
Puncture Resistance ASTM D4833	250 lb_f min	1112 N min.
Coefficient of Thermal Expansion/Contraction ASTM D696	8 x 10^{-6} in/in/°F max	1.4 X 10^{-5} cm/cm/°C max.

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WATERSAVER XR-5®

GEOMEMBRANE LINER
ENGINEERING SPECIFICATION GUIDE

XR-5® 8138

High Performance Reinforced Geomembrane

XR-5® 8138 Reinforced	Standard	Metric
Base Fabric Type ASTM D3776	Polyester	
Basic Fabric Weight (nominal) ASTM D3776	6.5 oz/yd^2	220 g/m^2
Thickness ASTM D751	40.0 mils nominal	1.0 mm nominal
Weight ASTM D751	38.0 ± 2 oz/yd^2	1288 ± 70 g/m^2
Tear Strength ASTM D4533 Trapezoid Tear	35/35 lbs_f min	155 / 155 N min.
Breaking Yield Strength ASTM D751 Grab Tensile	550/550 lbs_f min	2447/2447 N min.
Low Temperature ASTM D2136 4 hr – 1/8" mandrel	Pass @ -30° F	Pass @ -35° C
Dimensional Stability ASTM D1204 212° F – 1 hr	1.5% max each direction	
Adhesion Heat Sealed Seam ASTM D751 Dielectric Weld	35 lb_f/2 in min	150 N/5 cm min
Dead Load - Seam Shear Strength ASTM D751 (modified) Para 4.5.2.19	2 in seam, 4 hr, 1 in strip 210 lb_f @ 70°F 105 lb_f @ 160°F	5 cm seam, 4 hrs, 2.5 cm strip 934 N @ 21° C 467 N @ 70 ° C
Bursting Strength ASTM D751 Ball Tip	650 lb_f min 800 lb_f typical	2892 N min. 3560 N typical
Hydrostatic Resistance ASTM D751 Method A	800 psi min	5.51 MPa min.
Blocking Resistance ASTM D751 (180°F/82°C)	#2 Rating max.	
Adhesion – Ply ASTM D413	15 lbs_f/in min or Film Tearing Bond	65 N/2.5 cm. min. or Film Tearing Bond
Bonded Seam Strength ASTM D751 as modified by NSF 54	550 lb_f min	2447 N min.
Abrasion Resistance ASTM D3389 (H-18 Wheel 1000 g Load)	2000 cycles (min) before fabric exposure 50 mg/100 cycles max weight loss	
Weathering Resistance ASTM G23 (Carbon-Arc)	8000 hrs (min)-No appreciable changes or stiffening or cracking of coating	
Water Absorption ASTM D471 Section 12, 7 Days	0.025 kg/m^2 @ 70°F/21°C 0.14 kg/m^2 max @ 212°F/100°C	
Wicking Shelter-Rite® Procedure	1/8 in max.	0.3 cm max.
Puncture Resistance ASTM D4833	250 lb_f min	1112 N min.
Coefficient of Thermal Expansion/Contraction ASTM D696	8 x 10^{-6} in/in/°F max	1.4 X 10^{-5} cm/cm/°C max.

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WATERSAVER XR-3®

GEOMEMBRANE LINER
ENGINEERING SPECIFICATION GUIDE

XR-3® 8130 PW

For Potable Water Applications NSF 61 Approved

XR-3® 8130 PW	Standard	Metric
Base Fabric Type	Polyester	
Basic Fabric Weight (nominal	6.5 oz/yd^2	220/g/m^2
Thickness ASTM D751	30.0 mils min	0.75 mm min.
Weight ASTM D751	30.0 ± 2 oz/yd^2	1020 ± 70 g/m^2
Tear Strength ASTM D4533 Trapezoid Tear	35/35 lbs min	155 / 155 N min.
Breaking Yield Strength ASTM D751 Grab Tensile, Procedure A	550/550 lbs min	2450/2450 N min.
Low Temperature ASTM D2136 4 hr – 1/8" mandrel	Pass @ -30° F	Pass @ -35° C
Dimensional Stability ASTM D1204 212° F – 1 hr	1.5% max each direction	
Adhesion Heat Sealed Seam ASTM D751 Dielectric Weld	35 lb/2 in min	150 N/5 cm min
Dead Load - Seam Shear Strength ASTM D751, 4 hr Test	2 in seam, 1 in strip 210 lb @ 70°F 105 lb @ 160°F	5 cm seam, 2.5 cm strip 935 N @ 21° C 465 N @ 70 ° C
Bursting Strength ASTM D751 Ball Tip	650 lb min 800 lb typical	2890 N min. 3560 N typical
Hydrostatic Resistance ASTM D751 Method A	800 psi min	540 N/sq cm min.
Blocking Resistance ASTM D751 (180°F/82°C)	#2 Rating max.	
Adhesion – Ply ASTM D413, Type A	15 lbs/in min or Film Tearing Bond	65 N/2.5 cm min. or Film Tearing Bond
Bonded Seam Strength ASTM D751, Grab Test Method , Procedure A	550 lb min	2450 N min.
Abrasion Resistance ASTM D3389 (H-18 Wheel 1000 g Load)	2000 cycles (min) before fabric exposure 50 mg/100 cycles max weight loss	
Weathering Resistance ASTM G 153 (Carbon-Arc)	8000 hrs (min)-No appreciable changes or stiffening or cracking of coating	
Water Absorption ASTM D471 Section 12, 7 Days	0.025 kg/m^2 @ 70°F/21°C 0.14 kg/m^2 max @ 212°F/100°C	
Wicking ASTM D 751	1/8 in max.	0.3 cm max.
Puncture Resistance ASTM D4833	250 lb$_f$ min	1110 N min.
Coefficient of Thermal Expansion/Contraction ASTM D696	8 x 10^{-6} in/in/°F max	1.4 X 10^{-5} cm/cm/°C max.

WATERSAVER HYPALON®

GEOMEMBRANE LINER
ENGINEERING SPECIFICATION GUIDE

INDUSTRIAL GRADE HYPALON® CHLOROSULFONATED POLYETHYLENE (CSPE)

PROPERTIES	TEST METHOD	SPECIFIED VALUES	
Gauge (nominal) mils (mm)	--	36 (0.9)	45 (1.14)
Plies, Reinforcing	--	1	1
Thickness, min Overall	ASTM D 751, Optical Method	34 (0.86)	41 (1.04)
Thickness, min. Over Scrim	ASTM D 751, Optical Method	11 (0.28)	11 (0.28)
Breaking Strength-fabric min lbf (kN)	ASTM D-751, Method A	220 (.89)	250 (1.1)
Low Temperature, Flex, °F (°C)	ASTM D 2136, 1/8 in. mandrel, 4 hrs., Pass	-40 (-40)	-40 (-40)
Puncture Resistance, min, lbs, (kN)	FTMS 101C, Method 2031	190 (0.84)	200 (0.89)
Tear Strength, min. initial lbf, (Kn)	ASTM D 5884	70 (0.31)	70 (0.31)
Tear Strength, min After Aging lbf (kN)	ASTM D-5884	35 (0.16)	35 (0.16)
Dimensional Stability, (% chg, max)	ASTM D 1204 (180°F/82°C) 1 hr.)	2%	2%
Hydrostatic Resistance min. psi ((MPa)	ASTM D 751, Method A Procedure 1	350 (2.4)	350 (2.4)
Ply Adhesion, min.lbs/in (kN/m)	ASTM D 413, Machine Method	7 (1.2) 10 (1.75)	7 (1.2) 10 (1.75)
UV Resistance	ASTM G26 Xenon Arc 80°C/4000 hrs	Pass	Pass
Typical Fabricated Seam Properties**			
Bonded Seam Strength, lbf (kN/m) Peel Adhesion, lbs/in (kN/m)	ASTM D 751 ASTM D-413 *	160 (0.71) 10 (1.75)	200 (0.89) 10 (1.75)

* As modified in Annex A, NSF-54
** Factory bonded seam strength is the responsibility of the fabricator.

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APPENDIX II NDT METHODS FOR FIELD SEAMS

A. Air Lance Testing

This method is applicable for all field seams, including seams around pipe penetrations, repairs and accessories. A description of the air lance test follows.

All field seams shall be non-destructively tested over their full length. An air lance apparatus shall be used for this testing as described in this Appendix. The air lance shall be capable of supplying 30 psi through a 3/16 inch diameter nozzle. The air stream shall be directed at the edge of the seam no more than two inches from the seam edge. <u>Enough time shall be allowed for the seams to develop adequate strength before commencement of testing</u>. Any defects found during testing shall be marked, repaired, and retested with the air lance. All repairs shall be performed as described in Section 6.3.2 (Remedial Action).

B. Vacuum Box Testing for Hot Air Field Welds

For areas where air lance or pressurized seam testing is inappropriate, vacuum box testing may be used.

This method consists of creating a pressure differential across a seam and observing for bubbles in a film of liquid medium over the low pressure side, within the vacuum chamber. The vacuum chamber has a viewing port that allows observation of the seam area being tested. The sensitivity of the method is dependent on the pressure differential and the liquid used for testing. As long as the pressure differential can be maintained across the area tested, this method can be used. (ASTM E515, 5/90)

The following equipment comprises the vacuum box apparatus:

Vacuum Pump. The vacuum pump shall be fuel or electric powered and capable of sustaining the required vacuum for the duration of the test.

Vacuum Gauge. The vacuum gauge shall be capable of registering, as a minimum to 70kPa (10 psi) in increments of 5 kPa (3/4 psi).

Calibration and adjustment. The calibration of the vacuum gauge shall be checked and adjusted periodically, and routinely at a minimum of once every 12 months.

Foaming Solution. The foaming solution shall be pre-mixed with water at a ratio conducive to the formation of bubbles. It shall be dispensed by spray, brush, or any other convenient means. The foaming solution should not be detrimental to the geomembrane.

NOTE: If the component to be tested has parts made of polyethylene or structural plastics, the test fluid must not promote environmental stress cracking (E.S.C.) (ASTM E515, 5/90)

Vacuum Chamber. The vacuum chamber shall have an open bottom and a clear viewing panel on top. It shall be an appropriate and convenient size and shape, made of rigid materials and equipped with a vacuum gauge, valve, and soft, pliable gasket around the periphery of the open bottom.

Testing of the field seam proceeds as follows:

The area of the seam to be evaluated should be clean and free of soil or foreign objects which might prohibit a good seal from being formed between the vacuum chamber and the geomembrane. Energize the vacuum pump.

Wet an area immediately adjacent to and including the geomembrane seam measuring approximately twice the width and length of the vacuum chamber with a foaming solution.

Place and center the long axis of the vacuum chamber over the long axis of the seam or defect with the gasket in contact with the geomembrane surface over the wet area of geomembrane seam or test area.

For evaluation of geomembrane defects, center the vacuum chamber over the defect.

Apply a normal force to the top of the vacuum chamber to affect a seal and open the vacuum valve.

Ensure that a leak tight seal is created between the vacuum chamber gasket and the geomembrane material. For most cases, minimum vacuum of 28 to 55 kPa (4 to 8 psi) should be registered on the vacuum gauge is appropriate.

With the vacuum applied, maintain the normal force and observe the geomembrane seam through the viewing port for bubbles resulting from the flow of air through defects in the seam. The vacuum should be held over the test site for a duration of not less than 10 seconds. If the vacuum cannot be held for the minimum 10 seconds, the test area shall be marked as untested.

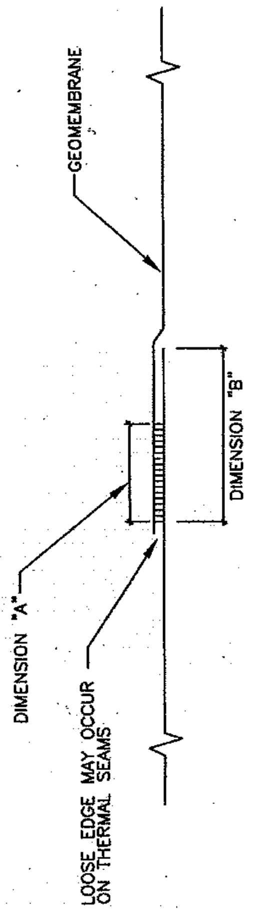
If bubbles appear on the geomembrane seam, turn the three-way vacuum valve to vent the chamber and remove the vacuum chamber from the seam. The defective area should then be marked for later repair.

If bubbles do not appear through the geomembrane seam within the specified dwell time, turn the vacuum valve to vent the chamber and remove the vacuum chamber from the seam.

Move the vacuum chamber to the adjoining portion of the seam length overlapping the previously tested area by a distance no less than 10 percent of the minimum chamber length or at least 50mm (2 inches), whichever is the greater and repeat the procedure until the entire seam has been tested.

Any defects found during testing shall be marked, repaired, and retested with the vacuum box. All repairs shall be performed as described in Section 6.3.2 (Remedial Action).

APPENDIX III FIELD SEAM DETAIL



GEOMEMBRANE CLASSIFICATION	GAUGE (X .001 ")	DIMENSION "A" (INCHES, MIN.)	DIMENSION "B" (INCHES, MIN.)
CHEMICAL			
REINFORCED	ALL	3	6
NON-REINFORCED	≤ 20	1	4
NON-REINFORCED	30 - 40	1.5	4
NON-REINFORCED	50 +	2	4
THERMAL			
ALL	ALL	1.5	5

FIELD SEAM / SPLICE DETAIL

N.T.S.

WATERSAVER COMPANY INC.
P.O. BOX 16465 DENVER, CO 80216-0465
VOICE: (303)289-1818 FAX: (303)287-3136

DETAIL NUMBER: DETAIL
DATE: DATE
DRAWN BY: DRAWN

APPENDIX IV SEAM REQUIREMENTS

PRIMARY FACTORY SEAM METHODS		
PVC	-	Chemical <1% Solids
PP-R		Thermal
CSPE		Thermal
XR PRODUCTS		Thermal
SECONDARY FACTORY SEAM METHODS		
PVC	-	Thermal
PRIMARY FIELD SEAMING METHODS		
PVC	-	Chemical <1% Solids or Thermal
PP-R	-	Thermal
CSPE	-	Thermal
XR PRODUCTS	-	Thermal
PRIMARY DETAIL & REPAIR METHODS		
PVC	-	Chemical <1% Solids or Thermal
PP-R	-	Thermal
CSPE	-	Thermal
XR PRODUCTS	-	Thermal

APPENDIX V RAW MATERIAL QUALIFICATIONS

2.1 RAW MATERIAL QUALIFICATION

2.1.1 PVC

Only first quality phthalate and/or phosphate plasticizers shall be used. The compound must also contain a biocide at a viable formation level. The use of water soluble ingredients is prohibited.

2.1.2 CSPE

Industrial Grade Hypalon sheeting is produced from a composition of high quality ingredients, suitably compounded, of which Hypalon 45 synthetic rubber resin is the sole elastomer. Zinc compounds of any kind, including zinc oxide, zinc stearate and zinc dusting agents are prohibited. Dusting agents of any kind are prohibited on the finished product.

APPENDIX VI PGI 1104 Appendix B

Testing Clarifications and Details

This appendix lists the clarifications and details of the testing methods used in the PGI specification. In some cases multiple test procedures exist within test methods and testing choices are required. This appendix makes note of the test criteria that was used to compile these specifications.

General When both US and metric values are shown the value for acceptance is the US value. Metric values are conversions and may contain rounding errors.

Test Method Clarification and Details

ASTM **D751** Test Methods for Coated Fabrics
- For Hydrostatic Burst use Section 33, Procedure A, "Pressure Application by Mullen Type Hydrostatic Tester"
- Units of pressure in pounds per square inch (psi) or kiloPascals (kPa)

ASTM **D882** Tensile Properties of Thin Plastic Sheeting
- Use Method A
- D882 method may be used for PVC film up to 60 mil (1.5mm) thick
- Units are in pounds of force per inch of width (lbs/in)
- Metric units are in kiloNewtons per meter of width (kN/m), or Newtons per millimeter of width (N/mm) which are equivalent units
- Factory Seam Shear Testing
  - Use ASTM D882 Method A
  - ASTM D882 may be used for thicknesses greater than 1.0 mm (40 mil) for seam testing
  - Use 25.4 mm wide (1") specimens
  - Use grip separation of 51 mm (2 in) plus the seam width
  - Crosshead speed of 510 mm/min (20 in/min)
- Factory Seam Peel Testing
  - Use ASTM D882 Method A
  - Use 25.4 mm wide (1") specimens
  - Position grips 13 mm (1/2") on either side of seam
  - Crosshead speed of 51 mm/min (2 in/min)

ASTM **D1004** Initial Tear Resistance of Plastic Film and Sheeting
- Units are in pounds of force to initiate tear in the specially die-cut specimen (lbs) or in Newtons of force (N)

ASTM **D1203** Volatile Loss from Plastics Using Activated Carbon Methods
- Use method A

ASTM **D1204** Linear Dimensional Changes of Thermoplastic Film at Elevated Temp.
- Test specimens at 100C for 15 minutes
- Measure percent change in lineal dimensions

ASTM **D1239** Resistance of Plastic Films to Extraction by Chemicals
- ASTM D1239 may be used for thicknesses greater than 1.0 mm (40 mil)
- Test specimens in 50° C (122° F) water for twenty-four hours
- Measure percent change in weight

ASTM **D1790** Brittleness Temperature of Plastic Sheeting by Impact
- 50% of specimens must pass at specified temperature

ASTM **D 2124** For plasticizer extraction, followed by GC or GCMS for identification and molecular weight determination.

ASTM **D5199** Measuring the Nominal Thickness of Geosynthetics

- o US units of thousandths of an inch (0.001 inches = 1 mil)
- o Metric unit of millimeters of thickness (mm)

ASTM **G160** Evaluating Microbial Susceptibility of Nonmetallic Materials by Soil Burial

- o Bury sample in prepared soil for 30 days
- o Perform test on actual liner sheet samples
- o Measure maximum change in properties as shown in specification

APPENDIX VII Enhanced Testing Information For Reinforced Geomembranes.

ASTM D751 Test Methods for Coated Fabrics

Dimensions and Mass - (Thickness & Weight)

Breaking Strength
Procedure A - (Grab) 4" wide specimen / 1" Grip
Procedure B - (Strip) 1" wide specimen / 1" Grip

Elongation - % at fabric break

Bursting Strength - Tension Testing Machine with Ring Clamp (1.000" Dia. Steel Ball)

Hydrostatic Resistance
Procedure/Method A – Mullen Type Tester

Adhesion Coating (to fabrics) - Two 1" wide Specimens welded together leaving two free ends for peel.
"It can be difficult to separate the polymer directly from the scrim"

Seam Strength - NSF Modified – 4" Wide Specimen - Most field tensiometers are only wide enough for 1" Wide Specimens.

Dead Load Seam Test - TD & MD

ASTM D3776 - Mass Per Unit Area

ASTM D2136 – Low Temp - 5X Magnifier, 1" x 4" samples.

ASTM D5884 – Tear - D-35 Committee (index test)
Typically, the higher value indicates ganging of fibers,
Lower values indicate fibers breaking one at a time.
Standard strain rate (12 +/- 0.5"/min)

ASTM D4833 – Puncture – D-35 Committee (index test)
Rod Diameter 0.35"/flat end chamfered 45 deg.
May be inappropriate for some large interstices.

UV Resistance
(Weathering Wet/Dry Cycle) ASTM G26 withdrawn, replaced by G155
Weathering Resistance (Carbon-Arc) –ASTM G23 withdrawn, replaced by G152 &G153
See ASTM – D151 for detailed information covering difference between Carbon & Xenon – Arc.

Ply Adhesion (Modified Machine Method) Under ASTM D 413 Similar To ASTM D 751 ADHESIVE COATING.

FTMS 101C cancelled.
Incorporated into Mil-Std-3010, Puncture Resistance – Method 2065
Puncture Probe 1/8" Spherical Radius W \ 2" Long Taper. http://assist.daps.dla.mil

ASTM 1204 – Linear Dimensional Changes % (MFG Specified Test Temperatures)

UV Resistance (General *)

Shorter wavelengths of radiation contain more energy.
Narrow Band wavelengths used for testing in the US.
Broad Band wave lengths used for testing in Europe.

* Sun Spots, Atlas Testing.

APPENDIX D

installation guide

INSTALLATION RECOMMENDATIONS FOR TENDRAIN™ GEONETS AND GEOCOMPOSITES

HANDLING AND STORAGE

Drainage geonets and drainage geocomposites rolls shall be shipped to the jobsite in a manner not to damage the rolls. The rolls shall be stored away from dirt, mud, and excessive heat. Refer to ASTM D4873 (Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples) for more detailed handling and storage of geosynthetics.

PLACEMENT

1. After the geomembrane/ substratum has been installed/ constructed, tested and approved by the Engineer, the surface shall be clean and free of excess dirt and debris.
2. The Contractor and the Installer shall handle all geonet/geocomposite materials in such a manner as to ensure it is not damaged in any way. Precautions shall also been taken to prevent damage to underlying layers during placement of the geonet/geocomposite.
3. The geonet/geocomposite roll should be installed down the slope, and precautions taken to minimize wrinkles. The tri-planar geocomposite directs flow predominately in the machine direction (along the roll length) and thus should be installed in the intended direction of flow. This is generally directly down slope unless the Engineer specifies an alternative drainage path.
4. In the presence of wind, all geonet/geocomposite materials shall be weighted with sandbags or the equivalent. Such sandbags shall be installed during placement and shall remain until replaced with specified overlying material.
5. If there are any obstructions (such as outlet pipes or monitoring wells) while deploying the geonet/ geocomposite, the geonet/geocomposite shall be cut to fit around the obstruction. Care should be taken as to make sure there is no gap between the obstruction and the geocomposite, to prevent any soil particles from migrating into the geonet core.

SEAMS AND OVERLAPS

The geonet and each component of the geocomposite (geonet & geotextile(s)) will be secured or seamed to the like compoment at overlaps.

Geonet:

- Adjacent edges of the geonet along the roll length of the geonet/geocomposite, should be overlapped 2-3 inches, see Figure 1 (a), or if approved by the Engineer based on the site specific conditions, placed with the edges of each geonet butted against each other, see Figure 1(b). These overlaps shall be joined by tying the geonet cores together with white or yellow plastic fasteners (minimum tensile strength of 100 lbs). These ties shall be spaced at a maximum of every 5 feet along the roll length.

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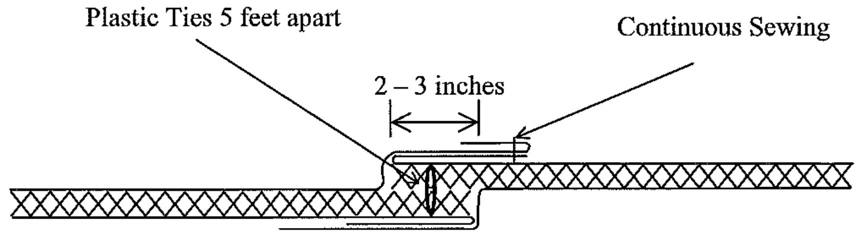
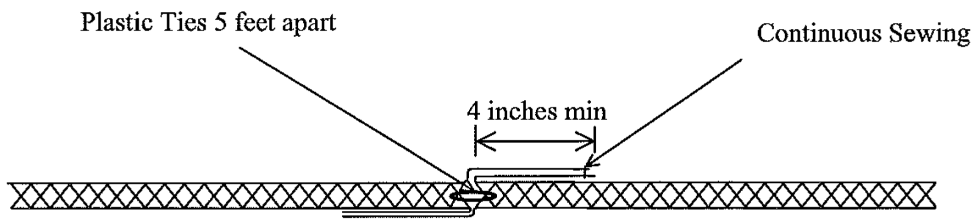
TENAX®



(a) Geonet Overlapped



(b) Geonet Ends Butted

Figure 1 Overlap Along Roll Length

- Adjoining geonet/geocomposite rolls (end to end) along the roll width should have the geonet overlapped a minimum of 12 inches across the roll width, see Figure 2. Geonet should be tied every 12 inches across the roll width or as specified by the Engineer.

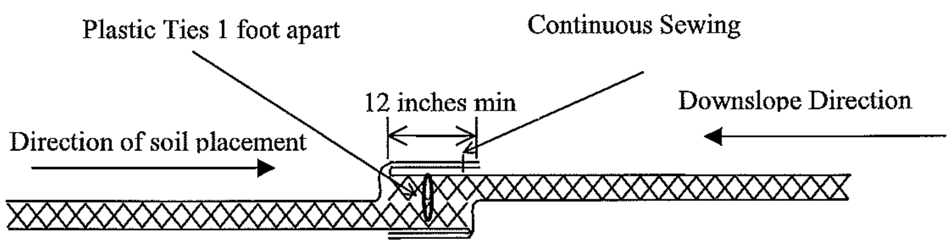


Figure 2 Overlap Along Roll Width (CD)

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Geotextile:

- The bottom layer of geotextile (if any) shall be overlapped, unless the Engineer specifies differently.
- The top layers of geotextiles shall be sewn together, or at the discretion of the Engineer may be heat bonded or wedge weld. Geotextiles shall be overlapped a minimum of 1 inch prior to seaming or heat bonding, if heat bonding is to be used, care must be taken to avoid burn through of the geotextile. It is important that the geotextiles be joined continuously to the adjacent and adjoining rolls as to prevent any fugitive particle migration into the geonet core flow channels.

Slope Corners:

- In the slope corners, the direction of the slope changes at the corner diagonal line as illustrated in Figure 3. It's recommended to first place an additional panel along the corner diagonal line of the adjacent slope. The panels from the opposite slope should be placed to extend on top of the additional panel. Then the panel for the slope which contains the additional panel should be placed to meet (butted) the opposite slope panels.

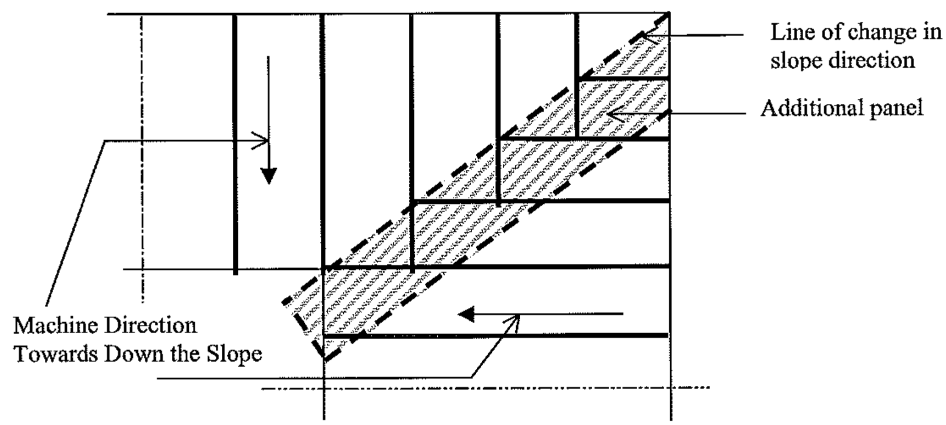

Figure 3 Details of Slope Corners

REPAIR

Prior to covering the deployed geocomposite, each roll shall be inspected for damage. Potential repair techniques will be addressed separately for just geotextile damage and for geonet damage on the geocomposite.

Geotextile damage:

Tenax recommends patching small holes with an 8" x 8" geotextile piece. Apply the spray adhesive (Note: 3M Hi-Strength 90 adhesive is the recommended adhesive.) to one side of the 8x8"textile patch. Center and apply the 8x8" textile patch over the small holes in the geotextile. Firmly press 8x8" textile patch over repair area. If the damaged area of the geotextile is greater than this patch size, a bigger patch is recommended instead of using a multitude of 8" x 8" patches. If the geotextile is damaged beyond 50 percent of the width of the roll, a full width piece of geotextile shall be cap-striped over the damaged area as recommended above and seamed to the adjacent panels.

Geonet damage:

Damage to the geonet portion of the deployed geocomposite shall be patched by placing a geonet or geocomposite patch extending 12 inches beyond the edges of the damaged area. The patch shall be secured to the original geonet by tying every 6 inches with approved tying devices. If the damage on the geonet portion of the deployed geocomposite is more than 50 percent of the width of the roll, this entire full width section shall be cut out, and the two portions of the geonet (end to end) shall be joined as explained above.

Continued on back...

COVER SOIL PLACEMENT

1. Placement of the cover soil shall proceed immediately following the placement of the geocomposite and its consequent approval by the responsible party. All "70% retained strength after 500 hrs UV exposure" geotextiles shall be covered within 14 days; all UV "95% retained strength after 500 hrs UV exposure" geotextiles shall be covered within 40 days.
2. Any cover material shall be placed to assure that the geocomposite is not damaged. No construction equipment shall operate directly on the geocomposite. The use of lightweight machinery (i.e. general low ground pressure machines such as ATV's to facilitate deployment is allowed). The specified fill material shall be placed at a minimum of 12 inches thick above the geocomposite to prevent damage, and spread utilizing wide track equipment. The cover soil shall be placed on the geocomposite from the bottom of the slope proceeding upwards and in a manner which prevents instability of the cover soil, minimize wrinkles, or damage to the geocomposite.

APPENDIX 4

BEST MANAGEMENT PRACTICES

EAST BEND STATION

WEST LANDFILL

BEST MANAGEMENT PRACTICES/ POLLUTION PREVENTION PLAN DUKE ENERGY EAST BEND STATION

Duke Energy, Kentucky
East Bend Station
6293 Beaver Rd.
Union, Kentucky 41091

4/18/2017

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BACKGROUND & STATEMENT OF BMP POLICY & OBJECTIVES

Overview of Facility Operations

The East Bend Station is a coal-fired steam electric power plant. The station produces electricity by means of converting potential chemical energy of fuel into electrical energy. Fuel is used to heat the boiler, which produces steam that expands through the turbine causing it to spin. This motion also spins the generator causing a magnetic field hence creating electricity. A plant water balance is included in Appendix D.

Regulatory Background

The NPDES permit for Duke Energy East Bend Station (KPDES Permit No. KY0040444), contains a condition that requires the Station to prepare and implement a best management practices/pollution prevention plan (BMP3). The BMP3 must be prepared in accordance with good engineering practices and identify potential sources of pollution that may reasonably be expected to affect the quality of storm water and wastewater discharges from the East Bend Station. The BMP3 also describes and ensures the implementation of best management practices that will be used to reduce the pollutants in station discharges and to assure compliance with the terms and conditions of the NPDES permit.

Purpose of the Best Management Practices/Pollution Prevention Plan

The purpose of this best management practices/pollution prevention plan (BMP3) is to focus operating personnel at East Bend Station on potential sources of water pollution and to control those sources to eliminate or minimize the risk of water pollution. As the name implies, the emphasis of the BMP3 is towards pollution prevention.

Key Elements of the Best Management Practices/Pollution Prevention Plan

1. Identification of potential sources of storm water and waste water pollution at the East Bend Station and an evaluation of their significance;
2. Where required, management of potential pollution sources by the implementation of best management practices; and
3. Review of the physical site, operations and BMP3 at least annually to insure that the management controls (i.e., BMPs) are still effective and that the BMP3 is up to date.

Due to the nature of electric production operations, changing economic conditions, chemical substitutions, changes in operations, management and personnel changes, and a variety of other factors, the BMP3 must be a dynamic plan to remain an effective tool in minimizing waste and storm water pollution. It must be updated at least annually to ensure that the plan achieves what it was designed to accomplish – prevention of waste and storm water pollution.

Best Management Practices/Pollution Prevention Plan Distribution

Site Environmental Field Professional's office
Document Control Center
Corporate CCP Environmental Services

Statement of Corporate Policy

Duke Energy requires full compliance with all laws and regulations at each of its facilities, including the provisions of the Clean Water Act. It is the policy of Duke Energy that no pollutant will be discharged from its facilities to surface waters unless the discharge occurs in compliance with a current NPDES permit. Further, the facility will adopt reasonable practices to ensure that chemical products, oils, and other materials used or stored on-site will not be inadvertently discharged to surface waters as a result of accidental spills or storm water conveyance.

BEST MANAGEMENT PRACTICES/ POLLUTION PREVENTION PLAN CERTIFICATION

Facility Name: Duke Energy, Kentucky – East Bend Station

Facility Type: Coal-fired Steam Electric Power Generating Facility

Facility Address: 6293 Beaver Rd.
Union, Kentucky 41091

Designated person who will be accountable for Storm water Pollution Prevention at this facility:

Craig Daniels, Site Environmental Field Professional

I certify under penalty of law that this document and all attachments were prepared under my direction of supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for known violations.

Gary Cook — 4-18-17

Gary Cook
Station Manager

Date

Engineer Certification

Signature Nick Sellet

Printed name Nick Sellet

Job Title Technical Supt

Date 4/18/17

SECTION 1
BEST MANAGEMENT PRACTICES/POLLUTION PREVENTION COMMITTEE

The purpose of the best management practices/pollution prevention committee is to develop and implement this BMP3. The committee's goal is to prevent or minimize the introduction of pollutants from station operations to the Ohio River.

Members of the committee shown below were selected because each of them satisfied one or more of the following criteria:

- Position of authority to implement provisions of the BMP3
- Scope of the BMP3 is within the range of assigned duties
- Knowledgeable of plant operations
- Familiar with the facility's present and past operations and waste management practices

Table 1-1 lists the individuals who comprise the BMP3 committee, and a list of their individual responsibilities as members of the committee. Job titles of committee members include: Station Manager, Environmental Coordinator, Production Manager, CCP Environmental Permitting and Compliance Specialist and Laboratory Technician(s). Based on the size and complexity of the facility, this committee is sufficient to ensure the BMP3 is developed and implemented.

Communication, in addition to the selection of the proper committee members, is an important factor in ensuring the BMP3 is successful and continues to improve along with dynamic station operations. The make-up of the committee addresses all aspects of the BMP3, and its size will not pose a problem scheduling regular BMP3 meetings. Also, with the close interaction of station personnel, regular, informal contact will further strengthen the lines of communication. The committee will utilize other plant personnel, as needed, to gather information or accomplish tasks related to the BMP3.

The committee meets annually to discuss the BMP3 and address action items as identified by the committee leader. The committee leader may request additional meetings depending on the number and complexity of the action items. Prior to each scheduled meeting the committee leader or his or her designate will prepare a meeting agenda to ensure all critical items are discussed. If the committee leader cannot make a scheduled meeting he or she will ensure one of the alternates listed in the BMP3 will be available. If a committee member cannot attend he or she will make all reasonable efforts to secure a competent substitute for the meeting. Any major items from this meeting are found in the inspection report in Appendix C. This annual meeting will follow the annual storm water inspection by the committee leader and an environmental services representative. The findings from this inspection will be discussed at the annual meeting. The committee will also discuss any spills or BMP excursions, which have occurred over the past year.

Appendix B is a contact list for current members of the BMP3 Committee.

TABLE 1-1 BMP3 COMMITTEE AND RESPONSIBILITIES

Job Title	Role	Responsibilities
Site Environmental Field Professional	Committee Leader	• Perform initial site assessment • Identify pollutant sources and risks • Specification of BMPs with input from committee • Establish spill emergency procedures and reporting requirements • Develop and Implement (BMP3) • Schedule and chair committee meetings • Assist other committee members, as needed, to implement, maintain, and revise the BMP3 • Facility contact for outside inquiries concerning BMP3 • Review inspection reports and follow up action items. • Schedule and participate in the annual comprehensive site compliance inspection • Evaluate effectiveness of BMP3 by conducting periodic inspections
CCP Environmental Field Professional		• Assist in implementation of BMP3 • Assist in identification of pollutant sources and risks; Serve as liaison to CCP operating groups and gives input on CCP projects which may affect BMP3 • Follow up on inspection report action items related to CCP projects • Serves as backup for Site Environmental Professional for outside inquiries concerning BMP3 • Support Team Leader as requested • Participate in annual site compliance inspection
Station Manager	Member	• Participate in committee meetings • Review action item list and provide resources needed for completion.
Production Manager	Member	• Provide input to development of spill emergency procedures • Participate in committee meetings • Alternate facility contact • Provide assistance and follow-up as necessary to ensure that action items from the inspections are completed on

		schedule.
CCP Environmental Permitting and Compliance Specialist	Primary Alternate for Committee Leader	• Serve as Team Leader in his/her absence • Participate in annual compliance inspection • Participate in committee meetings • Senior reviewer of BMP3 • Provide technical/regulator advise to Team Leader
Laboratory Technicians	Members	• Assist in implementation of BMP3 • Assist in identification of pollutant sources and risks • Support Team Leader as requested • Perform sampling and inspections of storm water outfalls and equipment inspections. • Participate in annual site compliance inspection

SECTION 2
RISK IDENTIFICATION AND ASSESSMENT

2.1 Pollutant Sources for Storm Water Outfalls and Existing Control Measures

Outfall	Pollutant Sources	Control Measures
Outfall 001 *NPDES Permit No. KY0040444*	East Scrubber sludge landfill runoff	The maximum active landfill area is 55 acres based on current management practices (limits the contact area for storm water runoff). Scrubber sludge is fixed with fly ash/lime (minimize the metals concentration in the leachate).
	Runoff from portions of the closed, inactive landfill (contains fixed scrubber sludge)	Inactive landfill areas vegetated to minimize soil erosion.
	Coal pile runoff (internal Outfall 010)	Diversion ditch around the coal pile (controls runoff and conveys it to the ash basin).
	Gasoline aboveground storage tank runoff	The gasoline aboveground storage tank area includes a concrete secondary containment structure and storm water runoff is collected and treated with an oil/water separator prior to discharge to the ash basin.
	Fertilizers and pesticides on agricultural land prior to landfill expansion	Licensed contractors used for fertilizer/pesticide application; they follow current laws.
	Coal conveyer runoff	The coal conveyer catch basin receives storm water runoff for solids control prior to discharge to the ash basin.
	Storm water runoff	Concrete dikes are used to control storm water runoff in the cooling tower area and the water treatment area.
	Dewatering, ash removal and repurposing activities have the potential to add pollutants from interstitial water in the ash basin.	Ash basin dewatering for the free water with low TSS (targeting <24 mg/L) will be pumped directly to the Ohio River at location of 001 discharge. Approved polymer logs and sediment curtains will be utilized as needed to control TSS as the level of the pond is lowered and therefore retention time is reduced. Once interstitial water level is reached (TSS > target 24 mg/L), water will be processed through the new Holding Basin where it can be treated with polymer to aid in the TSS removal. Temporary diesel pump set up for dewatering. The pump and tank will have containment and be inspected daily. These will be replaced with electric pumps once an electric feed is installed to the area(s).
	West Landfill sedimentation pond discharge to the ash basin	The maximum active landfill area is 55 acres based on current management practices (limits the contact area for storm water runoff). Scrubber sludge is fixed with fly ash/lime (minimize the metals concentration in the leachate). Settling time in the sedimentation pond prior to pumping to the ash basin where additional treatment

		will occur prior to discharge at Outfall 001.
	Bottom ash pyrites and economizer fly ash sluice water	Discharges directed to the ash basin for settling.
	Miscellaneous plant drains	
	Cooling tower blowdown (internal Outfall 010)	
	Sanitary wastewater (internal Outfall 007)	
	Demineralizer regeneration water	
	Metal cleaning waste (internal Outfall 008)	
Outfall 003 *NPDES Permit No. KY0040444*	Closed cooling water heat exchanger by-pass water	Storm water does not influence this outfall.
Outfall 013 *NPDES Permit No. KY0040444*	Exterior embankment of the ash basin	Embankment of ash basin is vegetated to minimize soil erosion.
	Ash basin water (Outfall 001) release from external discharge line (temporary placement during maintenance/repairs to ash basin)	Embankment of ash basin is vegetated to minimize soil erosion.
	Generator/tanker truck diesel oil (temporary placement during dewater, ash removal and repurposing of the ash basin.	Generators include secondary containment for fuel oil reservoirs. Absorbents staged nearby during refueling from tanker trucks.
	Potential for hose leak from dewatering operation if/when the discharge hose is placed outside the footprint of the existing basin.	Contingency plan in place for this event which involves immediately stopping the pumping operation and remediating the problem.
Outfall 014 *NPDES Permit No. KY0040444*	Fuel oil No. 2 aboveground storage tank and the fly ash silo.	A lined earthen dike (secondary containment) used to control storm water runoff from the fuel oil tank area. Outfall has sorbent socks in the event trace amounts of oil are present in the discharge.
	Liquid fertilizers/pesticides used once per month as needed.	Licensed contractors used for fertilizer/pesticide application; they follow current laws.
	Equipment containing lime slurry in varying degrees of density.	Systems maintained to minimize discharge to storm water. Outfall 014 is monitored on a quarterly basis for station NPDES permit (flow, total suspended solids, oil and grease, hardness, pH, Total Recoverable metals.)
	The cooling tower blowdown valves (drain the cooling tower in the event of a unit outage or to adjust the cooling tower level discharge to this outfall).	
	Ammonia storage tank, vaporizer skids, and associated piping.	Secondary containment around storage tank. Systems maintained to minimize discharge to storm water. Outfall 014 is monitored on a quarterly basis for station NPDES permit (flow, total suspended solids, oil and grease, hardness, pH, Total Recoverable metals.)

Outfall 015	Fly ash precipitator, Trona	Runoff directed to holding area; determined to be non-polluted or pumped to building sump.
	Lime unloading area	A large portion of the drainage area vegetated; low-lying areas have brush and trees (nonstructural controls minimize soil erosion and filters any runoff solids).
	Nitrogen farm, parking lots	
	Liquid herbicides used as needed.	Licensed contractors used for herbicide application; they follow current laws.
Outfall 016	Lime silo.	Outfall 016 drainage area is vegetated to minimize soil erosion and acts as a filter for any runoff solids.
	Service water (river water).	
Outfall 017 *Landfill surface-water-monitoring program*	Runoff from a portion of the closed, inactive landfill (contains fixed scrubber sludge).	Inactive landfill areas vegetated to minimize soil erosion. Outfall monitored for the landfill surface water monitoring program on a semi-annual basis (flow, pH, chlorides, sulfate, iron, sodium, organic carbon, COD, specific conductivity, TSS and TDS).

2.2 Storm water Map

The storm water map, Appendix A, includes drainage areas that would predict the direction of flow in the event that there was a spill in one of these areas.

2.3 Materials Inventory and Risk Assessment

A Safety Data Sheet (SDS) database is kept for the company. SD sheets for chemicals at East Bend station can be accessed on the Duke Energy web site. Chemicals that are purchased are tagged with SD sheet required status and the material cannot be received and issued out until the SD sheet has been verified in the system.

The purchase of chemicals not already in use at East Bend requires the approval of Corporate Environmental Services to ensure it will not pose an unnecessary risk to East Bend personnel or the environment.

East Bend, as required under EPCRA regulations, files a SARA-Section 312 (EPCRA 312), annual chemical inventory report. A map of the site is included with this inventory detailing the location of these chemicals on the plant site. The EPCRA 312 inventory report is also sent to the local fire departments to assist them in the event they respond to the station.

Hazardous and Toxic Chemicals

Chemical	Average Quantity	Location, Direction & Rate of Flow If Spilled	Risk of Release to Surface Water
Anhydrous ammonia	150,000 lbs.	Ammonia storage tank, pipes, equipment, & vaporizer skid; tank would spill into containment; all spills would rapidly vaporize to air	L (tanks in containment, will evaporate if released)
Bituminous Coal	200,000 tons	Coal pile, mills, conveyer, unloader, & bunkers; spill during unloading would fall to river, spill from conveyor to bank or storm drain	H (incidental spillage)
Coal fly and bottom ash	200,000 tons	Precipitators, hoppers, WSP fly ash silo, main plant fly ash silo;	M (incidental spillage)
Carbon dioxide	18,000 lbs.	Storeroom #30 tank house, SE ash pond dike, basement, main steam plant; release to atmosphere	L/none (stored as gas)
Caustic soda	125,000 lbs.	Demineralizer caustic tank, storeroom #30, building #1, demineralizer caustic day tank, main plant lab; building sumps to ash pond	M (floor drain goes to building sumps to ash pond)

Diesel Fuel No. 2	300,000 gallons	Landfill garage, diesel fire pump fuel tank, main fuel oil storage tank, fuel oil day tank, Boone (station tugboat), generator reservoirs for pumping ash pond water (temporary); spill to secondary containment, then storm drain to river	M (high volume, but secondary containment)
Lime	7,000 tons	FGD day bin, FGD lime silo, WSP lime silo, unloader, conveyers; spill to river during unloading, spill from conveyor to bank or storm drain	H (incidental spillage)
Hydrazine	23+2576+5160 =8,000 LBS	Warehouse, , Storeroom #30, building #1, demineralizer room; spill to containment, then building sump to ash pond	L (floor drains to sump to ash pond)
Nitrogen	5,062 lbs.	Nitrogen farm; release to atmosphere	L/none (stored as gas)
Polymer (exact chemical to be determined, future use)	Amount TBD 5-50 ppm, TSS dependent	The permanent location of the chemical feed building (polymer only) is identified on the Temporary WR Phase drawings. Feed location will be in the Boiler Sump discharge line, just ahead of the split in the line directing water to the Holding Basin. This will provide same feed point for either flow direction. See sheet SKC012	
Sulfur molten	45,000 lbs.	FGD slaker building; spill inside building to sump, solidifies when released	L (solidifies when released)
Sulfuric acid (70-100%, 98%, 15-40%, concentrate)	92+23+15+5+2 08565+10+6,0 98=15,000 lbs.	Batteries, main plant, fire pump house, main plant lab, storeroom #30 building #1, warehouse, demineralizer acid day tank, demineralizer acid tank, cooling tower acid tank, waste stabilization plant; spill to containment or building sumps to ash pond, or to cooling tower to ash pond	M (drains to sump to ash pond)
Trona T-50, T-200	50 tons	Trona silo; spill to containment ditch	L (incidental spillage to containment ditch)

2.4 Ash basin Dewatering, Ash Removal and Repurposing

Dewatering operations were approved by KDEP in a letter dated October 17, 2016. This letter will need to be renewed every 90 days until a permit modification has been received. In December 2016, the bottom ash divider dike between the East and West halves of the pond was breached returning the pond to one continuous area. This allowed gravity dewatering to begin in the West portion so that ash removal could begin. In spring 2017 the dewatering of the pond will begin by lowering the pond level by 10 feet so that ash can be transported to the West Landfill as drainage layer for cell 1. This will allow for further dewatering of the ash in the West side of the pond for removal of the ash and installation of the sheet pile wall. After this wall has been installed and flows to the West side have been rerouted to the East the ash removal, lining and repurposing as the West Retention Basin (WRB) can continue. This work should be completed in fall 2018. During this timeframe, the Holding Basin construction will be completed and the Holding Basin put into service in spring 2018. Bottom Ash sluice water will have also ceased during the spring of 2018, resulting in a reduction of overall solids and flow volume to the basin.

Once the WRB is complete, the eastern portion of the Ash basin will be taken out of service for dewatering, ash removal, lining and repurposing as the East Retention Basin (ERB). This work will be initiated in spring 2019 and should be completed in summer/fall 2020. The complete dewatering plan is contained in Appendix F.

Because the overall pond level is being lowered by 10 feet and held at that level until work on the East half begins, the discharge line will need to be run along the dike wall or within the concrete ditch at the base of the dike in order for the dewatering operation not to interfere with earthwork that is on-going. In the event that the discharge pipe is located outside the basin footprint the following contingency plan will be in place.

The temporary discharge line will not have secondary containment and will be located on the south face of the ash basin diking, directly uphill from the river. It will be exposed to freezing ambient temperatures over the period of use. In the event of a break or leak in the line, ash basin water discharging from the leak may erode soil on the diking or river bank, and may reach the river at a location other than the permitted outfall. Should this happen, East Bend personnel will take the following steps:

1. Immediately discontinue pumping to stop the discharge.
2. Quickly assess the release. If the discharge has been in sufficient quantity to reach the river, notify KDEP Division of Water. If the release has involved ash basin water gushing to the river, immediately notify KDEP using the state's 24-hour number for environmental emergencies: (800) 928-2380.
3. Promptly repair the piping to return the discharge line to good working condition.

4. Characterize impacts and damages from the release, and assess actions necessary to mitigate environmental harm, or repair erosion to the ash basin diking or slope.

Portable diesel generators will be present during this project to provide power for the ash basin pumps, and these generators will be periodically resupplied with diesel fuel transferred from a tanker truck. Oil absorbents will be available during fuel transfers to capture drips from hose connections. Any spillage will be promptly cleaned up to remove all residual oil. Should an oil spill occur from a generator or tanker truck to the river, the event will be immediately reported to federal and state agencies as outlined in the SPCC Plan.

Construction storm water management practices (see section 5.2) will be employed to minimize any discharge of soil that may be disturbed during the ash removal and lining of the basin sections.

2.5 Hazardous Waste & PCB Management

Hazardous Waste

The East Bend site includes various satellite collection areas for temporary storage of drums containing hazardous waste. These are all located inside buildings and enclosed within self-contained storage cabinets, providing protection from precipitation and secondary containment against leaks and spills. Consequently, these areas cannot impact storm water or floor drains. Each accumulation area is inspected weekly in addition to examinations conducted as part of the regular storm water inspections described in section 7.1.

PCBs

East Bend is designated as a PCB free station. All transformer oil containing PCBs has been replaced with non-PCB oil.

2.6 Landfill Management

East Bend has a landfill used for disposal of stabilized FGD sludge. Storm water from the active portion of the landfill drains to the station's ash pond in accordance with the station's NPDES permit. Storm water from inactive areas drains to storm water outfall 017, (012 and 019 were re-routed to the active area run-off through the leachate collection system. See Section 6). The potential for contamination of this storm water outfall is minimized through material stabilization, landfill construction techniques and storm water monitoring. The sludge is stabilized with fly ash and lime to create Poz-O-Tec©. Once in place, the Poz-O-Tec© is covered with a layer of topsoil and then seeded to create vegetation that minimizes erosion of the cover and potential storm water contamination. The station also monitors for potential releases through periodic sampling of storm water runoff from the inactive portion of the landfill and visual inspections of the landfill. In the event of a potential release into the storm water runoff from the inactive portions of the landfill is identified, the station will conduct further analysis and characterization to confirm the nature and sources of any release. If a release is identified, the station then will develop and implement and appropriate action to address the cause. Response measures such as replacement of a portion of the soil/vegetation cover or removal of a portion of the land filled material in conjunction with replacement of a portion of the soil/vegetation may be considered. The station added two new landfill cells to accept "off-spec." gypsum from the Miami Fort station. These two new cells have a different design than the old cells, including a synthetic liner, a drainage layer, and leachate collection system.

New Landfill Construction

East Bend is in the process of creating a new solid waste landfill on Station property west of the main plant. Construction activities are expected to occur from spring 2015 through fall 2017. The project will include installation of: new landfill Cell 1; an associated sediment pond; permanent and temporary access roads; a 4,000-foot pipeline and access road to convey water from the new sediment pond to East Bend's existing ash pond; and a soil stockpile for the landfill construction. The new landfill will include a liner system, a leachate collection system, and surface water and contact water collection systems.

Best management practices to protect storm water during landfill construction are summarized in the attached document, Appendix E, "Storm water Pollution Prevention Plan for East Bend Station, Cell 1 Construction". The earthwork contractor will be responsible for fulfilling the requirements of this landfill construction SWPPP, under direction from East Bend personnel.

2.7 Periodically Discharged Process Waters

East Bend may discharge other process water streams that are not specifically addressed by effluent limitations within the NPDES permit. The following water streams are subject to control through this BMP Plan.

Intake Strainer Backwash

East Bend withdraws water from the Ohio River at the plant intake, located within the Service Water Building, for use throughout the plant. Strainers (screens) at the intake remove coarse debris from river water; a stream of service air from the plant is used to periodically flush this debris from the screen surface and back into the river.

Leaks may occasionally occur from pumps or piping connections within the Service Water Building. In the event of a leak that could flow from the building and reach a storm water drain or the river, plant personnel will visually inspect the discharge for contaminants (e.g., solids or sediment from erosion). If a contaminant is observed, the plant will take appropriate action to control the discharge, including covering storm drains, or filtering the discharge through straw bales.

Fire Protection Water

Water for East Bend's fire protection system is drawn from the cooling tower basin, consisting of service water (i.e., river water that has passed through strainers to remove debris). Fire hydrants are located throughout the property, and these are flushed approximately twice per year to remove sediment and assure functional availability in the event of a fire. Infrequently, a buried water line within the fire protection system may leak or break and flow over the ground surface to plant storm drains (discharging from Outfall 014) or the river. Fire Protection Water is also used for roadway dust suppression by spraying on the roads from a water truck. In the even that water used for dust suppression doesn't allow enough capacity for fire protection the water trucks will be filled by drawing water either from the cooling tower basin or directly from the river. Any release of fire protection water, whether intentional or accidental, will be visually monitored to assure that it does not carry oil or sediments to storm drains or the river. If a contaminant is observed, the plant will take appropriate action to control the discharge, including covering storm drains, or filtering the discharge through straw bales.

Purified Water: Filtered, Boiler, and Drinking Water

Water from East Bend's deep wells is passed through sand filters and stored in the Filtered Water Tank, which has a 100-gallon capacity. From this tank, water may be chlorinated and used in East Bend's potable (drinking) water system, or it may pass through the demineralizers to one of the two Condensate (Demin Water) Storage Tanks for use as boiler water. In the event that an overflow occurs from Filtered Water or Condensate Storage Tanks, the water may flow over the ground surface to plant storm drains (discharging from Outfall 014). Ultra-pure boiler water in the form of steam condensate may also leak to the ground from the ammonia skid.

Any release from these sources will be visually monitored to assure that it does not carry oil or sediments to storm drains or the river. If a contaminant is observed, the plant will take appropriate action to control the discharge, including covering storm drains, or filtering the discharge through available filtering media (such as a fabric filter, silt fence, or straw bales).

Routine Cooling Water System Maintenance (NPDES permit section (3.2.2.2))

Approximately every one to two years, East Bend must perform routine maintenance on the cooling towers and cooling water system. When this occurs, both the cooling tower basin and circulating lines must be drained. Water in the cooling tower basin drains by its normal path, discharging to the ash pond through Outfall 010. Because the circulating lines are below ground elevation, water in the lines cannot drain to the ash pond. Instead, the plant must drain this water into a storm water line, discharging to the Ohio River via Outfall 014.

Prior to drainage, water in the cooling tower basin will be visually inspected to assure the absence of oil, foam, scum, or discoloration that may be discharged from Outfall 014 to the Ohio River. The cooling water system will not be drained until traces of these pollutants have been removed. During the draining event, the Outfall 014 discharge will be visually inspected to assure there are no adverse impacts to the environment, including erosion of the river bank. If adverse impacts are identified, the draining event will be discontinued until the cause has been resolved (visual assessment).

The discharge water will be sampled at least once during the drainage event, and analyzed to assure that it meets the following criteria. Should analysis show that the discharge has failed to meet the criteria for any of these parameters, East Bend will notify the KDEP Division of Water about the exceedance within 24 hours of discovery. The discharge monitoring results will be maintained at the site for at least three years with other NPDES monitoring records.

Parameter	Average	Maximum	Units
Chromium, total recoverable	0.2	0.2	mg/l
Zinc, total recoverable	1.0	1.0	mg/l
126 Priority Pollutants	No detectable amount (may be demonstrated using engineering calculations as described in 40 CFR 423.43(d)(3))		
Flow	Report	Report	MGD
Temperature	Report	105	°F
pH	6.0 (minimum)	9.0 (maximum)	SU
Total Suspended Solids	Report	Report	mg/l
Oil & Grease	Report	Report	mg/l