INSTALLATION GUIDELINES

RAVEN ADVANCED TECHNOLOGY GEOMEMBRANES

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Full Appendix

1.0 INTRODUCTION

The Engineered Films division of Raven Industries has developed and continues to develop, advanced technology geomembranes. These reinforced and unreinforced, smooth and textured/structured geomembranes are made by round-die blown-film and flat cast extrusion techniques with up to 7 co-extruded layers to provide sheet materials with a wide range of properties and performance characteristics.

While this Manual has been prepared primarily to help geomembrane installers to achieve durable liner installations, it will also be useful for CQA personnel, project engineers, and regulators, who all need to be working in an integrated manner to achieve maximum geomembrane performance and durability.

2.0 SCOPE

The scope of the Manual includes guidance and integrated protocols to ensure that Raven's products delivered to the construction site meet Raven and project specifications through to final installed liner testing to assure the integrity of the complete lining system (not just the welds), before it is handed over to the owner or project engineer.

There are three primary objectives:

1. To provide an easy-to-follow protocol for the proper installation and record-keeping of each Raven geomembrane product
2. To provide a vehicle that integrates Raven's specifications and QC/QA program with typical geomembrane Project Specifications such that there are no confusing conflicting overlaps or any gaps through which installation details might fall
3. To ensure that, if any nonconformance is found during installation or subsequent service, the records of personnel, materials, equipment, and installation activities are sufficient to enable a rapid definition of the full extent of the nonconformance and to facilitate its resolution

The Manual therefore includes guidance through all required installation activities and the provision of logs and data sheets to ensure that all necessary steps have been taken. For instance, it requires that all non-conformances and all non-passing test results be recorded, not just passing ones. Such comprehensive data are invaluable in pursuing the reason for and extent of, any performance problems at any stage of installation or service.

The Manual has been prepared as a single document with appropriate section introductions applicable to all products followed, where necessary, by sub-sections specific to each type of product.

3.0 GEOMEMBRANE PRODUCTS

There are four basic classes of geomembrane covered by the Manual:

1. Unreinforced (Absolute Barrier® / HydraFlex™)

2. Reinforced with a tri-axial pattern scrim (Dura♦Skrim® J-series)
3. Reinforced with a 7 X 7 per inch scrim including 1300 denier polyester (PET) fiber (Dura♦Skrim® K-series and KQ-series)
4. Reinforced with a weft inserted 9 X 9 per inch scrim including 1000 denier polyester (PET) fiber (Dura♦Skrim® N-series and NQ-series)

The more common geomembrane designations within each of these classes are listed below. Technical data sheets for individual products are attached as Appendix A.

ABSOLUTE BARRIER® PRODUCTS (UNREINFORCED)

Y-SERIES

- Absolute Barrier® Y30BAC, Y40BAC

X-SERIES

- Absolute Barrier® X40BAL, X60BAL, X60BC1, X60BCS

HYDRAFLEX™ PRODUCTS (UNREINFORCED)

H-SERIES

- HydraFlex™ H20B, H30B, H40B

HP-SERIES

- HydraFlex™ HP30BD, HP30DD, HP40DB

HT-SERIES

- HydraFlex™ HT30B, HT30BG, HT40B, HT40BG

HU-SERIES

- HydraFlex™ HU20B, HU30B, HU40B

PP-Series

- HydraFlex™ PP30, PP40

DURA♦SKRIM® PRODUCTS (REINFORCED)

J-SERIES (TRI-AXIAL REINFORCEMENT)

- Dura♦Skrim® J25DT1, J30DT1, J36B

K-SERIES (7 X 7 REINFORCEMENT)

- Dura♦Skrim® K30B, K36B, K36BT1, K40BT2, K45B, K45BT2, KQ36B, KQ45B

KQ-SERIES (7 X 7 REINFORCEMENT)

- Dura♦Skrim KQ36B, KQ45B

N-SERIES (9 X 9 REINFORCEMENT)

- Dura♦Skrim® N30B, N30BT1, N36B, N36BT1, N36BT2, N45B, N45BT1, N45BT2

NQ-SERIES (9 X 9 REINFORCEMENT)

- Dura♦Skrim® NQ36B, NQ45B, NQ60B

Additional products may be assigned to these different classes as they are developed.

4.0 NOMENCLATURE

The legend that more specifically identifies each product is listed below:

The first two available digits of each number equate to the nominal thickness in mil (0.001 in.). HydraFlex® HU20B is 20 mil thick as an example.

B black, W white, D gray, W/B white one side black the other side, T textured.

5.0 TEST METHODS

There are two types of tests; 1) **Index** tests such as thickness, density, tensile strength, tear, and puncture resistance measurements that are used primarily for basic specification and QC/QA testing, and 2) **Performance** tests such as UV resistance, thermal aging, direct shear, and VOC diffusion rates that provide information on the performance of the geomembrane. Performance tests facilitate the selection of an appropriate geomembrane, but are used sparingly for conformance testing due to time constraints.

Test methods directly and indirectly referenced in this Manual are listed in Appendix B.

Where possible, internationally recognized standard test methods (ASTM, GRI) are used. Custom tests developed by Raven for the more unique products are described in detail at the appropriate location.

Test methods must be strictly followed. Any deviations should be explained in detail.

Failing test results should be provided.

6.0 ACCEPTANCE OF MANUAL

Prior to the start of each project the Installer will designate one person as its on-site CQC representative (QCR). The QCR will be responsible for all installation QC activities including the preparation of a comprehensive final report.

Prior to the start of each project copies of this Manual will be presented by the Installer's designated QCR to the General Contractor (GC), CQA firm, and Project Engineer (PE) for their review and confirmation that they understand, agree with, and will comply with all its requirements. They will return a signed copy of the Compliance Memorandum of Understanding (MOU) in Appendix C together with details of any conflicting, omitted, and unclear items.

The QCR will be responsible for seeing that all queries and comments are adequately addressed as will be confirmed on the MOU.

The intent of this action is to remove conflicts in, and gaps between, other project documents so that installation may continue without undue interruption.

7.0 PANEL LAYOUT DIAGRAM

As soon as the Installer has generated a proposed panel layout diagram it shall be submitted to the PE for approval.

In general the number of field seams will be minimized, particularly in corners. Seam orientation will typically be up and down slopes. Special considerations should be addressed by the Project Engineer (PE).

There shall be no floor seam parallel to the toe of slope closer than 5 ft. to the toe of any slope.

Seams at sumps will be minimized or avoided if at all possible. This may require the cooperation of the PE.

It must be recognized by all project parties that the panel layout diagram is a general outline and not a firm commitment, since modifications may be required to suit final grades, distances, and related structures.

8.0 MATERIAL DELIVERIES AND INVENTORY

A record (Appendix D) shall be maintained of all material delivered to site. This record shall be compared to Raven's resin, geomembrane manufacturing, and panel fabrication QA/QC certificates, and shipping manifests. These records will be maintained by the Installer's QCR in a construction record file.

Each roll/panel will be labeled on the end(s) to show:

- Product type
- Roll/panel number
- Date manufactured
- Width
- Length
- Weight

The Installer shall confirm that:

- All geomembrane for a project is made from the same resin type
- Welding rods are made from the same resin class as the geomembrane
- Manufacturing QC (MQC) and fabrication QC (FQC) certificates cover every roll or fabricated panel received.

9.0 MATERIAL CONFORMANCE TESTING

Conformance testing is not an opportunity to reproduce the MQC testing program. Rather it is intended to double check some key properties of the material. Typically, conformance testing will not be done by the installer but by the PE or CQA firm. However, if not done by others, it is good practice for the installer to do a few spot tests.

When possible, and certainly for overseas projects, conformance testing shall be done before the material leaves Raven's plant. Conformance tests should be performed every 100,000 ft. of material.

When roll and panel numbers are assigned for each project and are received by the installer relevant ones shall be identified by the installer (or the CQA firm) for conformance testing. Selection of rolls/panels to test will be a function of the sequencing of resin lot and roll numbers. Thus, if there is an orphan (out of sequence) resin lot or roll number it should be tested. If roll numbers are sequential but two resin lots are used, a roll from each resin lot should be tested, etc.

Full roll width samples about 18 in. wide can be cut freehand (with intentional curves, and appropriate match marks) by Raven's MQC/FQC personnel. After test specimens have been removed from the sample the sample remnant will be sent to the installer.

When passing conformance test results are received, the installer (or CQA firm) will approve material shipping to the site. When received on site the QCR will match the cut edges and match marks of the sample and the tested roll to confirm that the correct roll has been tested.

If any nonconformance is found, the next numbered rolls on each side will be tested, and so on until the range of nonconformance is identified. All nonconforming rolls will be clearly marked and set aside and not used. They will be replaced by Raven.

Suggested conformance tests for the different geomembranes are shown in Table 1

Table 1 Conformance Tests:

Parameter	ASTM Test Method	Unreinforced	Reinforced
Thickness	D5199/5994/7466	×	×
Weight	D751		×
Tensile Strength at Break	D6693	×	
Tensile Elongation at Break	D6693	×	
Grab Tensile at Break	D7004		×
Grab Elongation at Break	D7004		×
Tear Resistance	D1004	×	
Tongue Tear	D5884		×
CBR Puncture Resistance	D6241		×
Puncture Resistance	D4833	×	×

10.0 MATERIAL STORAGE AND HANDLING

Rolls and fabricated panels (accordion-folded in one direction, rolled in the other direction) will be unloaded from trucks in such a way that no damage occurs to the geomembrane.

Fabricated panels accordion folded in both directions will not be used.

Rolls will be moved using sufficiently long stingers, spreader bars, or other equipment using at least two slings. Rolls will be lifted vertically off, and not dragged along, the truck bed.

Fabricated panels on pallets will be moved by forklifts.

The folds of fabricated panels that are visible shall be examined for damage, particularly at kinks in the folds.

All material will be stored on smooth clean dry level surfaces such that it will not be damaged, become dirty, or get wet internally.

Rolls shall be stored no more than three high and with sufficient space between ends such that access is available to read identification labels

Depending on the size of project, material shall be stored in a safe central location then staged at appropriate intermediate locations for deployment.

Fabricated panels will ultimately be placed in the correct location and in the correct orientation for deployment as shown on the protective packaging or in contained deployment instructions.

11.0 SUBGRADE PREPARATION

The function of the geomembrane is to act solely as a barrier and not to be a load-bearing member of the lining system. The subgrade is the structural member of the lining system so should not be the cause of stress in the geomembrane. It should not be susceptible to differential settlement.

Specification and preparation of the subgrade are the responsibility of the geotechnical engineer (PE) and should not be assumed by the installer.

The installer should confirm that the subgrade is smooth, firm, and unyielding.

There should be no step elevation changes exceeding 1 in. and no desiccation cracks exceeding 0.25 in. in width.

There should be no rocks, roots, or any other protruding objects in the 2 in. surface layer. If there is any potential for vegetation growth a suitable sterilant shall be applied to the surface layer by the GC before final compaction. Such sterilant shall not be chemically incompatible with the geomembrane material.

However, unreinforced LLDPE and PP geomembranes may be placed on rounded gravel up to 0.5 in. in diameter.

The Installer will approve the subgrade and sign the form in Appendix E. The form will also be signed by the PE or CQA superintendent. Only as much subgrade that can be covered in one day should be approved.

It is the GC's responsibility to maintain the subgrade to the requirements of the installer.

There shall be no standing water on the subgrade when liner is placed.

12.0 MATERIAL DEPLOYMENT

Rolls and panels shall be deployed in such a way that they are not damaged. Deployment shall not be done in strong or gusty winds or during precipitation events and lightning storms.

Rolls shall be suspended from a spreader bar and material pulled off the roll. Alternatively the end of the roll shall be fixed and the roll unrolled manually.

Rolls shall not be allowed to unroll freely down slopes. They shall be kept under control at all times.

Vehicles shall not be used to carry and unroll the geomembrane as the vehicle traverses the subgrade unless the vehicle leaves no tire or track impressions in the subgrade. Any damaging rocks or roots, etc. seen in the subgrade during deployment shall be removed and not covered.

Final adjustments to the location of the panel can best be done by lifting and flapping the liner so it "floats" on air. In gusty conditions the panel shall be kept close to the ground.

In gusty conditions that might unexpectedly lift the liner no one shall walk on the liner until it has been effectively ballasted. Many injuries have been caused by uplifted and blowing liner.

Panels shall be overlapped no less than 4 in. for extrusion welding, and no less than 6 in. for fusion welding. These overlaps will ensure sufficient material for seam peel testing.

If friction between the panel and substrate is too high to float and adjust the liner it may be necessary to deploy a slip sheet of geotextile below the liner to facilitate minor positional adjustments.

Large prefabricated panels shall be unrolled and unfolded as indicated in the deployment instructions included with the panel. Unfolding shall be done with a man every 15 to 30 ft. depending on the size/weight of the panel.

During deployment, folds and kinks in folds shall be carefully examined for thinning and cracking damage particularly at low temperatures.

Deployment will generally commence on side slopes and proceed down-gradient with the up-gradient sheet on the floor overlapping the down-gradient sheet for easy shedding of water. There should be no horizontal seams on slopes. All seams should be oriented up and down slopes.

Panels will be clearly numbered in the sequence in which they are placed.

Only as much material as can be seamed that day shall be placed.

13.0 BALLASTING AGAINST WIND UPLIFT

Un-welded edges shall be ballasted with sandbags or other non-damaging items (tires, rolls, etc.) in such a way as to protect the liner from uplift due to reasonably expected winds prior to the resumption of work. This may require an end-to-end row of sandbags along the leading edge.

On slopes, such as landfill closures, the liner may be ballasted with sandbags approximately every 10 ft. across the slope and every 5 ft. up and down the slope. On steep slopes sandbags may be held in place by ropes anchored at the top of the slope. The PE should approve the spacing used.

The PE will determine whether sand bags can be allowed to "leak" their contents and whether they can be allowed to stay in place at the conclusion of the project. Preferably, to facilitate subsequent testing, they should be removed.

Sandbags may be used to hold the liner in place at the toes of slopes and in corners but they shall not be used as ballast to force the liner into corners. Remember the geomembrane should function as a barrier only and not be a load-bearing member of the lining system.

If not shown in project drawings, a method of supporting the geomembrane in 90 degree corners will be discussed with, and decided by, the PE (see Appendix F).

Panels shall be overlapped between 4 and 6 in. or to the appropriate edge markings, for extrusion and fusion welding, respectively.

14.0 ANCHOR TRENCH

Liner shall be placed down the front wall and across the bottom of anchor trenches. The geomembrane will not be folded in the anchor trench.

The front edge of the anchor trench will be rounded, with no sharp stones that might damage the liner. There shall be no loose stones/rocks in the anchor trench and no standing water. The GC shall be responsible for maintaining the anchor trenches in good condition for the installer.

It is frequently suggested that the liner in the trench not be covered until it has gone through one cold (overnight) cycle that will allow it to contract without major stress. However this will require the liner to remain un-ballasted, with the potential that unexpected winds will blow it away. Appropriate care should be taken.

The anchor trench shall be filled with soil that does not damage the liner and that will not damage the liner when compacted. The soil shall be compacted sufficiently to preclude standing water in the trench. If there are holes in the liner on the front face of the anchor trench, and the soil is not compacted such as to preclude standing water, water might seep through the holes and erode the slopes.

The anchor trench is a critical part of the design and must not be modified by the installer in any way. In addition to conventional rectangular trenches the use of V trenches is increasing. Flat run-outs with ballast soil on top of the liner are occasionally used.

If no anchor trench design is available, and slope gradients and lengths are not excessive, a trench 2 ft. deep, 1 to 2 ft. wide, and 2 to 3 ft. back from the slope crest is a good place to start. However, the PE should approve the proposed anchor trench design.

15.0 COMPENSATION WRINKLES

Material shall not be allowed to bridge corners and the toes of slopes – it shall be fully supported by the subgrade at the time of covering. Depending on the geomembrane temperature during installation and the temperature at which it will be covered it may be necessary to build in some slackness between fixed points to allow for thermal contraction. This applies only if the expected temperature at covering is lower than the temperature during installation.

When the liner is to be left exposed sufficient compensation shall be installed between any two fixed points to prevent contraction stresses at the lowest service temperatures.

Appendix G provides more detailed guidance.

The amount of slackness required between any two fixed points is the difference in liner temperatures at installation (higher) and covering (lower) multiplied by the distance between fixed points multiplied by the coefficient of linear thermal expansion (CTE) of the material (Appendix G).

When the geomembrane temperature at covering will be higher than the temperature at installation the liner should be installed flat without any compensation.

Note that the only temperature of importance is the **geomembrane temperature**. Ambient temperature is not important. White surfaces will be at lower temperatures than black surfaces in the sun. When it is cloudy, both will effectively be at the same temperature.

16.0 GENERAL REQUIREMENTS

There shall be no smoking on the liner. Soft sole shoes shall be worn. Only hook blade knives with automatic blade retraction will be used on the liner. Equipment such as generators are not allowed on the liner without a protective cushion. Fuel containers will only be allowed on the liner if they have leak-tight secondary containment.

ATVs may be used on large sites provided tire ground pressures are less than 8 psi. They must not be started or stopped suddenly and wheels must not be turned when stationary. They must not be operated when wrinkles are large enough to be folded over.

Deployment shall not be done in strong winds, precipitation, lightning, or when there is standing water on the subgrade.

The QCR shall constantly monitor the weather forecasts.

17.0 WELDING/JOINING

17.1 GENERAL

Welding should be done as uniformly and consistently as possible. The objective is to melt the two surfaces and to allow them to cool and solidify as one integral body.

When the weld is sectioned there should not be a well-defined interface, nor should there be any particulates or voids along the weld line. There should be no crimps due to overheating. The adjacent geomembrane should not be overheated and oxidized such that it becomes brittle.

Acceptable field welding methods are thermal fusion and extrusion. The thermal energy for fusion welding can be provided by hot wedges, hot air, or a combination. Any other method (laser, ultrasonic, etc.) must be approved by Raven and the PE.

Chemical bonding is not acceptable.

Extrusion welding rod should be made from the same resin class as the bonding surface of the geomembrane surfaces being extruded too.

17.2 TRIAL WELDING

Trial welding is essential to confirm that welding machines are fully functional. Production welding shall not be started until trial welding has been successfully completed. Trial welding will be done at the start of every 4 hr. (approx.) shift, after the machine has been turned off and restarted, and when the geomembrane changes temperature by more than 25ºC.

Trial welds, at least 4 ft. long, shall be made on scraps of the same material as will be installed.

Welds will be made with sheet in the same orientation (flat floor, slope, wall etc.) and on the same substrate as the planned production welds. Trial welding conditions shall not be optimized.

For unreinforced material three peel specimens shall be cut from the last two thirds of the weld and tested in peel mode according to the parameters in (Table 2) for peel separation, peel elongation, and locus of break (Appendix H) as also listed in Table 2. Results, both passing and failing, will be reported on the Trial Seaming log in Appendix I.

For reinforced materials five specimens shall be tested in peel mode according to the parameters in Table 2. The minimum geomembrane tab elongation of 50% allows for scrim break but the polymer layers must not break.

Table 2. Trial seam peel test parameters:

Parameter	Unreinforced	K-series	N-series	J-series
Width specimen (in.)	1	1	1	2
Number of specimens	3	5	5	5
Grip/Specimen distance (in.)	1	1	1	1
Crosshead speed (in./min)	2	2	2	2
Break locus	Refer to Appendix H	Refer to Appendix H	Refer to Appendix H	Refer to Appendix H
Elongation (% min)	100	50	50	50
Separation (%)	25	0	0	0

Specimens shall be prepared from the different materials as described in Sections 18.2.1 to 18.2.4.

All specimens must pass before production welding commences.

If three trial weld attempts fail, the equipment shall be put aside and repaired. When used again, two passing trial welds shall be made before that equipment can be used for production welding.

The cross sections of welds shall be examined for symmetry, lack of crimping (overheating), and the presence of voids and foreign particulates. If voids and particulates are present the weld will be rejected, even if the weld passes a peel test. Such flaws may be the cause of weld failures in service, particularly in exposed liners.

When geomembrane temperatures during welding are below 40ºF or above 100ºF 5 peel specimens will be tested for unreinforced material seams. All must pass.

17.3 FIELD WELDING

Three types of weld geometry are acceptable:

1. Double track fusion welding for long straight seams with free flaps on each side of the weld for peel and shear testing.
2. Single track fusion welding (typically more than 1 in. wide) for long straight seams with no external flap, but with a flap on the underside.
3. Extrusion welding for detail work such as pipe boots and patches with a flap on the underside.

Sheet overlaps should be sufficient to facilitate seam peel testing, typically 4 in. for extrusion seams and 6 in. for fusion seams.

For double track fusion welds the outer flap shall be wide enough to facilitate peel testing.

Welding shall not be done in strong winds, during precipitation, and during lightning storms, nor where there is standing water on the subgrade.

The surfaces to be bonded shall be dry and clean for fusion welding. Dry with a clean cloth, or carefully with a hot air gun. Clean with a cloth or carefully with isopropyl alcohol and water.

For extrusion welding materials >45 mil in thickness surfaces will be ground or abraded carefully so as not to remove more than 10% of geomembrane thickness. For material thicknesses of 45 mil and below grinding is not necessary, but thorough cleaning is required.

For extrusion welds on unreinforced materials 40 mil and more in thickness the top corner of the top sheet shall be beveled to about 45 degrees for a depth of at least 50% of the thickness to help ensure contact of the weld bead with the complete edge of the sheet.

Under no circumstances will reinforcement yarns be exposed during grinding/abrasion, and all abrasion debris must be removed.

Welding shall be done within 30 minutes of surface preparation.

All preparatory abrasion marks shall be covered by the extruded weld bead.

Special attention will be required in blowing dust, on GCL substrates, and on moist subgrades, to avoid weld contamination. A plywood sheet placed under the edges to be welded might help in this regard, but be sure not to damage the subgrade or underside of the liner with sharp edges and splinters.

Welding shall continue to the edge of the liner in the anchor trench.

Fishmouths in reinforced materials shall be cut along the peak, overlapped, laid flat, and extrusion welded along the full length. A minimum 6 in. diameter patch will be placed over the end of the cut. For unreinforced materials the overlap shall be extrusion welded where it exceeds 1 in. A keyhole shall be made at the end of the cut and the remainder of the overlap patched. The keyhole will minimize the potential for further propagation of the cut.

When a conductive ground wire/tape is placed in extrusion welds for spark testing it shall be positioned and retained just under the edge of the upper sheet. When DC spark testing is required one end of the wire shall be grounded under the liner prior to closure seaming.

If there is a tendency for a wedge welder to dig into a soft subgrade (the subgrade should not be soft) and seize up, a strip of plywood can be moved under the overlapped liner to provide support for the welding machine. However, care must be taken that the board does not scoop up subgrade soil and contaminate the weld.

If a weld burn-through does occur any large blobs of material shall be ground down before patching. There should be no point stresses on the underside of the patch.

Weld seams on slopes going upslope

At the end of every weld write on the liner:

- Initials of operator
- Number of welding machine
- Machine speed, temperature, pressure settings
- Date
- Time started

18.0 SEAM TESTING

Two types of tests will be performed on the field seams – nondestructive and destructive. All seams shall be 100% tested nondestructively. Destructive tests will be performed at a defined frequency.

18.1 NONDESTRUCTIVE TESTING

Four test methods are available:

- center air channel pressure testing for double track fusion seams
- vacuum box testing for single track fusion and extrusion seams
- spark testing for detail extrusion seams that cannot otherwise be tested
- air lance testing for single track fusion seams.

18.1.1 AIR CHANNEL TESTING

The test procedure is defined in ASTM D5820 and summarized below:

- Clamp or otherwise seal both ends of the seam to be tested – distance not to exceed 450 ft.
- Insert pressure feed needle into the air channel at one end and pressurize according to Table 3.
- Allow conditions to stabilize for 2 minutes.
- Note starting pressure.
- Note pressure after 5 minutes.
- Ensure pressure loss does not exceed that allowed in Table 3.
- If pressure cannot be generated or if pressure loss is excessive walk the length of the seam listening for the whistling noise at a leak. If a leak is found repair and re-test.

- If pressure loss is acceptable release seal at far end of seam and confirm loss of pressure.
- If pressure is not lost locate blockage in the channel and test the untested section.
- Repair needle hole with one extrusion bead.
- Write on the liner the tester's initials, date, start time/pressure, finish time/pressure, pressure drop, pass/fail.

Table 3. Air pressure test parameters for double track fusion welds

Thickness (mil)	Pressure (psi)	Time (min)	Loss (psi)
20-45	24	5	4
40-100	30	5	2

18.1.2 VACUUM BOX TESTING

Vacuum box testing is performed on extrusion welds and single track fusion welds with no free flap, i.e. bonded to the outer edge. It is not normally performed on double track fusion welds, but if it is required the edge flap must be carefully cut off back to the edge of the outer weld track. A hook blade knife shall be used. Under no circumstances will the flap be torn off.

The test procedure is defined in ASTM D5641 and is summarized below:

- Apply soapy solution to seam area to be tested.
- Place vacuum box with clean viewing glass along seam.
- Ensure sealing foam around bottom of box is well seated and provides a good seal.
- It may be necessary to "work" the box into place and to use some wet rags to get a good seal.
- Reduce pressure difference in the box to about 4 psi.
- Monitor the seam for soap bubbles for at least 5 seconds.
- Mark any locations where bubbles indicate leaks for repairs.
- If no bubbles occur after 5 seconds relieve vacuum and move to next seam section.
- Overlap sections tested by about 3 in. and re-test.
- Write on the liner the tester's initials, date, time tested, test pressure, and "VB pass/fail".

With thinner products it may be beneficial to install a rigid mesh over the bottom of the box to prevent the liner being sucked into the box. Avoid rough edges that might damage the liner.

18.1.3 SPARK TESTING

Spark testing is usually done at locations, such as pipe boots, where vacuum box testing cannot be done. There are two methods of spark testing – AC and DC. The DC method is recommended for its higher sensitivity. Both methods require a conductive wire/strip behind the extrusion weld. This wire/strip does not need to be grounded for AC testing. It is grounded for DC testing.

Very high voltages are used. Due care must be taken and warning signs placed.

The liner must be dry when being tested.

The test procedure is defined in ASTM D6365 and summarized below:

- Ensure the liner is dry.
- Place warning signs at edge of work area.
- Connect the negative of the power supply to a grounding rod.
- Connect the positive of the power supply to the survey probe, preferably a brass wire brush that exceeds the width of the weld bead.
- Determine the length of leak that needs to be detected, usually the distance from the edge of the weld bead to the conductive wire in the weld.
- Set the voltage to the required value as determined in Table 4.
- Check that a leak will be indicated on a test weld with a fabricated leak of the required length.
- Check that the liner adjacent to the weld will not be damaged at this voltage setting. Too high a voltage could punch a hole in the liner.
- At the established voltage pass the brass brush steadily along, and in contact with the weld bead.
- Look for sparks and listen for discharges.
- Mark hole locations for repair.
- Switch off power supply when not testing.
- Do not step off liner or contact ground while the voltage is switched on.

Table 4. Spark test voltage for various distances

Distance (in.)	Distance (mm)	Voltage (kV)
0.250	6	20
0.375	10	25
0.500	13	28
0.625	16	31
0.750	19	35

AC equipment often has a single point wand as the survey probe. In this case pass the probe along each edge of the weld bead and along the center of the bead. Note that if the voltage is set to discharge through a 0.5 in. long leak from edge of bead to conductive wire, a leak will not be indicated if the single point probe is passed along the center of the bead. This would require a voltage setting to discharge over about 1 in.

18.1.4 AIR LANCE TESTING

Air lance testing is typically used on flexible sheet less than 50 mil (1 mm) in thickness when there is no flap on the edge of the weld.

Refer to ASTM D4437 section 4.2 for the test procedure.

Air at a pressure of 50 psi is passed through a 0.188 in. diameter nozzle directed perpendicularly to the edge of the seam from a distance of no more than 2 in.

The air jet must be maintained on the edge of the weld and not above it.

A flapping sound indicates an area of inadequate bonding.

A whistling sound indicates a leak passageway through the weld.

Mark, repair, and re-test these locations.

18.2 DESTRUCTIVE TESTING

Conventional seam destructive testing (on HDPE geomembrane seams) typically requires the periodic removal of seam samples, from which ten specimens are typically die-stamped, five for testing in shear mode (sheet to sheet) and five in peel mode. However, the testing protocol on Raven (non-HDPE) geomembrane seams, has been updated to better assess the associated bond strengths.

Note that for HDPE geomembrane seams, both peel and shear strengths are a function of geomembrane thickness when what we are trying to assess is independent of geomembrane thickness. We are not measuring seam strength. In fact, if bond efficiency exceeds only about 20%, shear strength tests are only measuring geomembrane tab strengths.

All required information is obtained from a peel test:

- Bond efficiency is adequate, which is challenged more in a peel test than in a shear test.
- Bond strength is adequate, shown by no peel separation.
- Ductility showing that the adjacent geomembrane has not been embrittled during welding.
- That break occurs outside the weld.

Remove samples from field seams at an average frequency of every 500 ft. for each welding machine/operator combination. Unless there is a reason to suspect the quality of seams on the floor of a pond liner, remove samples from the upper levels of the slopes.

If independent CQA is being performed the CQA monitor will identify the locations for destructive testing.

Prior to cutting the full test sample remove one specimen from the proposed testing location and test as described below. If this specimen meets the criteria in Table 5 cut a full size sample for testing. However, if this specimen fails to meet the criteria in Table 5, cut two additional strip specimens for testing from 10 ft. each side of the failed specimen. Continue outwards until two good specimens define the limits of the seam nonconformance. Test two full size samples at these locations.

Table 5. Field peel test parameters

	Unreinforced	K-Series	N-Series	J-Series
Width specimen (in.)	1	1	1	2
Number of specimens	5	5	5	5
Grip/Specimen distance (in.)	1	1	1	1
Crosshead speed (in./min.)	2	2	2	2
Break locus (ppi)	Refer to Appendix H	Refer to Appendix H	Refer to Appendix H	Refer to Appendix H
Elongation (% min.)	100	50	50	50
Separation (%)	25	0	0	0

If either of these full samples fails continue sampling in the direction of nonconformance until a passing test is obtained. Repair the seam between the two passing samples.

18.2.1 UNREINFORCED MATERIALS

18.2.1.1 ABSOLUTE BARRIER® / HYDRAFLEX™ SERIES

Unreinforced material seam samples will be 3 ft. long and minimum 12 in. wide with the seam centered lengthwise.

One half of the sample will be used for CQC testing and the other half will be made available to the PE or CQA firm for CQA testing.

Five 1 in. wide specimens will be cut from across the seam (with seam centered and at 90 degrees to the length) for peel testing. Shear testing will not be required.

Peel testing on extrusion welds will be performed according to ASTM D6392 at a crosshead displacement rate of 2 in./min. and with each grip 1 in. from the edge of the weld. I.E. a gage length of 1 in., since only one of the geomembrane tabs will elongate and break. Therefore the grip on the top sheet will be 1 in. from the edge of the extrusion weld bead on the top sheet (about 1.5 in. from the center of the weld bead), and the grip on the bottom sheet will be 1 in. from the center of the weld bead.

Both sides of the fusion welds will also be tested with 1 in. gage lengths. Fusion welds will require an outer flap at least 1.5 in. wide.

Peel testing may be stopped when one of the geomembrane gage length elongations exceeds 1 in. (100%).

Acceptance criteria are (see Table 5):

- Zero peel separation.
- Break in the geomembrane outside the weld.
- Elongation of geomembrane tab >100%.

When the specimens are cut their cross sections shall be examined for porosity and contaminants in the weld bead and on the weld interface. If such features are present the seam shall be rejected.

All five specimens shall meet these specifications for the sample to be accepted.

Test results shall be recorded on the form in Appendix J.

Tested specimens shall be retained until completion of the project.

Note that all geomembranes incorporating a layer of EVOH will peel on the EVOH interface. This cannot be avoided.

18.2.2 REINFORCED MATERIAL

18.2.2.1 DURA♦SKRIM® K-SERIES (7 X 7 REINFORCEMENT) AND N-SERIES (9 X 9 REINFORCEMENT)

7 x 7 reinforced material and 9 x 9 reinforced material seam samples will be 3 ft. long and minimum 12 in. wide with the seam centered lengthwise.

One half of the sample will be used for CQC testing and the other half will be made available to the Owner's Project engineer for CQA testing.

Five 1 in. wide specimens will be stamped from the sample and tested only in peel mode. Every attempt must be made not to cut the reinforcing yarns that are parallel to the length of the specimen.

Grips will be positioned 1 in. from the nearer edge of the seam. Crosshead displacement rate will be 2 ipm. Both sides of the fusion seams will be tested.

Results must meet the following criteria (see Table 5):

- Zero peel separation.
- Break in the geomembrane outside the weld.
- Elongation of geomembrane tab >100% without polymer break.

All five specimens must meet these criteria for the sample to be accepted.

18.2.2.2 DURA♦SKRIM® J -SERIES (TRI-AXIAL REINFORCEMENT)

The seam samples for tri-axially reinforced products will be 3 ft. long and minimum 12 in. wide with the seam centered lengthwise.

One half of the sample will be used for CQC testing and the other half will be made available to the PE or CQA firm for CQA testing.

Five 2 in. wide specimens will be stamped from the seam for peel testing using 2 in. wide grips.

Transverse specimens will include 8 diagonal reinforcing yarns. If machine direction specimens are tested they shall incorporate three longitudinal yarns.

Both sides of the fusion welds shall be tested.

Shear testing will not be performed at a crosshead displacement rate of 2 ipm.

All 5 specimens shall meet the requirements of Table 5 for the sample to be accepted.

18.3 SEAM SAMPLE FAILURES

If any sample fails seam testing two new samples shall be taken about 10 ft. each side of the failing sample, and so on until two passing samples define the limits of the non-conforming seam.

The seam shall be repaired between the two passing samples.

19.0 FLAWS AND REPAIRS

All non-penetrating linear flaws less than 0.125 in. wide may be repaired with no more than one extrusion bead of the same base polymer as the geomembrane.

Penetrating holes less than 0.125 in. in diameter that do not expose scrim yarns may also be repaired with no more than one bead application.

Holes that expose scrim yarns and those that are more than 0.125 in. in diameter shall be patched with the same geomembrane with patch yarns oriented in the same direction as in the geomembrane. The patch shall extend at least 3 in. from the edge of the nearest damage if the damaged area is less than 1 in. in diameter. When damage exceeds 1 in. in diameter the patch shall extend at least 6 in. from the nearest damage.

Under no circumstances will parallel and overlapping beads be used to fill in a flawed area or a gap.

All corners on patches shall be rounded.

All patch extrusion welds shall be vacuum box tested and hot air patches can be either air lanced or vacuum tested and the results recorded.

All patches shall be numbered and their sizes and locations recorded.

A single extrusion bead may be used to repair the edge of a fusion weld but only after the free flap has been carefully cut back to the edge of the weld using a hook blade knife. The free flap shall not be torn off.

For geomembranes that have an encapsulated edge, all cut edges of reinforced materials that expose scrim shall be covered with a single extruded bead to prevent access of liquids into the scrim yarns.

20.0 APPURTENANCES

This section covers connections of the geomembrane to concrete structures (ramps, walls, sumps, etc.) and to pipe penetrations. Such connection details are primarily the responsibility of the design engineer but they are often left to the discretion of the installer.

Where possible liner/structure connections should be above liquid levels and pipe penetrations should be avoided wherever possible.

Basic guidance for appurtenance connection design is provided in ASTM D6497. Some of these designs are attached as Appendix K.

20.1 BATTEN STRIPS

Stainless steel batten strips are often used to seal geomembrane to concrete pads and walls. Such batten strips shall be no less than 1.375 in. wide and 0.25 in. thick. Fastening bolts will be no less than 0.375 in. in diameter with bolts spaced no more than 12 in. on centers. These details are strictly the responsibility of, and should be approved by, the PE.

Concrete surfaces shall be smooth and not friable.

Neoprene gaskets (or another material that is compatible with the contained liquid) shall be placed between geomembrane and concrete and between batten and geomembrane.

Bolt shafts shall be smooth (not threaded) between the surface of the concrete and the center of the batten strip. Holes a little less than the diameter of the bolt shall be stamped, not drilled or punctured in the gasket strips.

Nuts shall be tightened such that the compressive deformation of the gasket does not exceed its elastic limit. It is not necessary to fully tighten the nuts. The batten strip should remain straight and not be bowed between bolts. Thus the gaskets remain uniformly compressed between bolts.

Butt joints in batten strips should have no more than a 0.10 in. gap with the nearest fasteners no more than 2 in. from the joint. Joints in gaskets shall not be coincident with batten strip joints. Joints in gaskets shall be scarfed (angled) and glued.

Geomembrane welds, particularly extrusion welds should not pass under the batten strips. To avoid this, a wide strip of liner the shape of the batten seal can be cut and secured by the batten strip. The geomembrane can then be welded to this strip.

When the batten strip has been tightened an encapsulating bead of caulking (GE RTV 103, or equivalent) shall be placed along the edge of the geomembrane between the batten strip and the concrete.

Before leaving the site all batten strips should be revisited to ensure there are no loose nuts.

20.2 CAST-IN LOCK STRIP

Instead of a batten strip, a rigid extruded plastic profile (lock strip) can be cast-into the concrete when it is poured to which the geomembrane can be welded, if both are the same polymer, e.g. PP and LLDPE.

The strip must be well embedded in the concrete so there is no air trapped under it and so the surface of the strip is level with the surface of the concrete. The strip and the concrete will be a significant heat sink during welding so must be preheated with hot air in order that surface melting will occur when the extruded weld bead is applied.

There is no standard ASTM or GRI procedure to test such a weld. It is suggested that a trial weld bead about 6 in. long be bonded to the top of a short spare piece of lock-strip then run onto an incompatible substrate that prevents bonding to the strip. The un-bonded tab can then be pulled in peeling mode using a set of liner clamps to see if the bead can be peeled off the strip.

Butt joints in the strip shall contain no gap. Any gaps that do occur shall beveled on each side and fillet welded. Before welding all loose material shall be blown out of the joint. The proud surface of the weld bead shall be ground to be level with the surface of the strip.

Corners shall be mitered and any gaps shall be filled by fillet welding as above.

The concrete surface under the liner shall be smooth and any corners shall be rounded to a radius of no less than 0.75 in.

Soil surfaces at the edges of the concrete shall be well compacted to be level with the surface of the concrete to minimize differential settlement.

A protective strip of nonwoven geotextile should be placed between geomembrane and concrete and adjacent soil. This strip may be adhered to the concrete but shall not extend beyond the edge of the geomembrane when welding is performed. The geotextile shall not extend into the weld.

20.3 PIPE PENETRATIONS

Pipe penetration boots may be fabricated in the field or prefabricated in a controlled plant environment. Before any boot is finally installed it should be checked for leakage by a water ponding test or a water pressure hose test.

The boot should be fabricated such that, when installed, it is fully supported by the pipe and the surrounding subgrade, particularly in the low angle between the underside of the pipe and the subgrade.

The number of welds made to fabricate a boot should be minimized. There shall be no more than two extrusion welds in any one location, except where they cross or meet for continuity. Weld beads shall not be placed side by side.

For as-installed nondestructive testing, a ground wire could be installed in each extrusion weld to facilitate spark testing (see section 18.1.3 above). In this case the wire(s) should be well-grounded under the boot.

The skirt of the boot shall be welded to the liner first.

At the pipe clamp end, prior to placement of the boot, any free weld flap on the underside of the geomembrane shall be carefully cut back to the edge of the weld using a hook-blade knife.

Weld beads at the pipe sealing end shall be ground flat to a thickness no less than twice the thickness of the geomembrane. Squeeze-out beads along the edge of the primary bead shall be removed by careful grinding that does not contact and damage the surface of the liner.

A gasket or chemically resistant sealant shall be placed between the end of the boot and the pipe. A strip or two of sacrificial geomembrane shall be placed between geomembrane and fastening clamps.

Clamps shall be tightened at the end of a low temperature period when thermal contraction has allowed the boot to contract along the pipe towards the slope.

Before leaving the site, pipe boot clamps shall be revisited to ensure they are still tight.

Underwater seals are frequent locations of leaks so it is most important that they be properly installed and checked.

Every effort shall be made to avoid underwater seals.

20.4 VENTS

Vents at the crests of slopes are extremely important for the release of trapped air, air pushed up under the liner as groundwater rises, naturally generated gas (Radon), and methane generated by leaking waste water.

Simple vents can be constructed by cutting a 1 in. diameter hole in the liner just below the crest of the slope (but above the maximum water line) and covering with a patch about 12 in. square welded on the top and both vertical sides. The bottom un-welded edge should be flat so that rodents cannot get into the hole and under the liner.

Vents will typically be no more than 100 ft. apart.

The PE is responsible for designing a gas venting and leak drainage system under the liner that will ensure that any gas can reach the vents. This will typically require a sloping floor with a leakage collection and removal sump at the low end. Floor gradients typically exceed 1.5%.

A nonwoven geotextile that may act to cushion the geotextile from the subgrade will usually not serve double duty as gas vent and leak drainage system. At a minimum a network of drainage geocomposite strips leading to each vent should be installed. A blanket geocomposite is better.

Any Leakage Detection System (LDS) proposed by the installer must be approved by the PE.

21.0 GEOELECTRIC LINER INTEGRITY SURVEYS (LIS)

These surveys are often called "leak location surveys" but for CQC/CQA purposes it is preferred they be called "liner integrity surveys" (LIS). They cover the complete surface of the liner. They can be performed on soil-covered, water-covered, and exposed liners.

Relevant ASTM standards are D6747 (guide to test methods), D7002 (exposed liner), D7007 (water and soil-covered liners), and D7240 (conductive liner).

Statistics have proven that no matter how well the liner has been installed, and no matter how effective the CQA, there are invariably a few leaks in the liner that are not detected. Therefore, an LIS is a valued final phase of CQC and CQA. For the installer it is a final check (proof) of liner integrity before handing over the liner to another party that might subsequently damage it.

An effective LIS requires the following conditions:

1. A conductive medium on top of the geomembrane
2. A conductive medium through the holes being sought

3. A conductive medium immediately under the geomembrane
4. No, or little, contact between the media above and below the liner other than through the holes being sought

A direct current potential is applied across the geomembrane from a current injector electrode in the soil/water above the liner to a current return electrode in contact with the conductive layer under the liner. Because the geomembrane is an electric al insulator current inly flows through the holes (leaks) we are trying to find. A dipole (two electrode) survey probe is passed through the water or over the surface of the soil to measure potential gradients, which have a unique pattern at a leak. Small leaks (~50 mil) can be pinpointed.

For exposed liners a positively charged stream or puddle of water is moved over the surface of the liner. When this water penetrates a hole and contacts the negatively charged subgrade current flows through the water stream/puddle and is recorded.

It is therefore difficult to perform an effective survey on a single soil-covered liner if the cover soil is in contact with the subgrade soil around the edge of the liner – Condition 4 above is not met. It also difficult with a double liner where there is only a geonet or geocomposite (both non -conductive) between the two liners – Condition 3 is not met.

Approximately 2 acres can be surveyed in one day.

Additional LIS-specific information or training should be sought if such surveys are desired or are a regulated requirement.

22.0 FINAL LINER INSPECTION

On the completion of geomembrane installation representatives of all parties concerned, shall perform a thorough walkover of the complete liner surface checking for any remaining flaws that need repairing prior to the installer handing over the geomembrane to the next contractor for further work e.g. covering with soil.

At the conclusion of the walkover the Final Liner Visual Inspection document in Appendix M will be signed by all parties acknowledging the repairs and adjustments that are needed. The installer will make required repairs and adjustments.

Another visual examination of the repairs and modifications will then be made by the installer and the Project Engineer/CQA Firm to confirm the adequacy of those repairs and modifications as indicated by additional signatures on the Final Visual Inspection form.

23.0 RECORD DRAWINGS

Detailed record drawings shall be made of all liner installations. A record drawing is the single most important document for the installer, the CQA firm, and the project owner should performance problems occur during service.

The drawings shall show:

- Panel numbers, usually in order of installation
- Roll number from which each panel was removed
- Locations of field seams
- Orientation of factory seams in prefabricated panels

- Whether material is smooth, textured/structured, reinforced/unreinforced, or otherwise surface treated
- Destructive seam sample numbers and locations
- Repair numbers, types (bead, patch, cap strip, etc.), and locations
- Toe of slope locations
- Crest of slope locations
- Gas vent locations
- Sump locations
- Pipe penetration locations

24.0 PROJECT DOCUMENTATION

A full set of records will be accumulated for each project. Suggested forms/logs are attached in Appendix L. Records may include:

- Raven geomembrane manufacturing QC certificates
- Raven panel fabrication QC certificates
- Raven bills of lading for shipping
- Compliance Memorandum of Understanding
- Material inventory
- Conformance testing
- Subgrade acceptance
- Material deployment
- Trial seaming
- Production seaming
- Repairs
- Seam nondestructive testing
- Seam destructive testing
- Liner integrity survey details when applicable
- Problems/Resolutions
- Daily work report including sketch of panels installed
- Weekly work summary

These records will allow full traceability of materials, personnel, and equipment to determine the full extent of a concern should a problem occur in service.

25.0 CLOSURE

These geomembrane installation guidelines do not take precedence over Project Specifications.

However, if a potential conflict with the Project Specifications is noted the Installer's QC designate should discuss the matter with the CQA Superintendent and/or the Project Engineer. If, in the opinion of the Installer, a satisfactory conclusion is not reached, as will be recorded in the Problem/Solution log, the Installer will contact Raven for further technical and procedural advice:

Raven Contact: Stacy Coffin or Pat Elliott

Email Address: geo@ravenind.com

Office Phone: +1 (800) 635-3456

Date: 11-01-2017

If this date is more than six months past, please contact Raven for possible updated contact details.

Click HERE
to see
Full Appendix