Guidelines for Installation of:

Factory Fabricated Compounded 0.25 to 1.52 mm (10 to 60 mil) Thickness Unsupported Geomembranes

International Association of Geosynthetic Installers

www.iagi.org

*This installation guideline was developed in partnership with the **Fabricated Geomembrane Institute (FGI)** & the **International Association of Geosynthetic Installers (IAGI).***

FGI

Fabricated Geomembrane Institute

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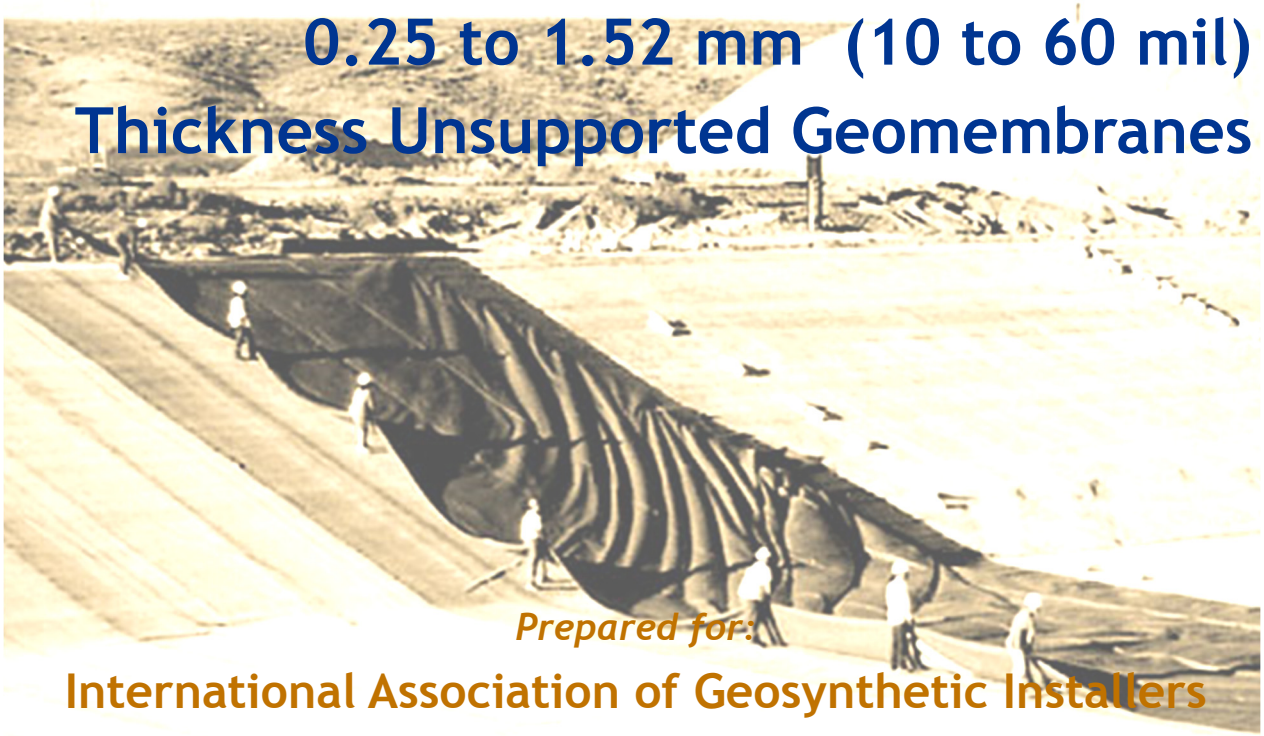

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Part 1 — GENERAL

1.01 Guideline Scope

A. This document is an installation guideline for **Factory Fabricated Compounded Unsupported Geomembranes 0.25 to 1.52 mm (10 to 60 mil) in thickness** as measured by ASTM D5199, D751 or D1777. The applicable product types are as outlined in Part 2 of this guideline, such as PVC. This guideline is designed to provide a minimum set of standards for site installation. However, depending on the complexity and project specific requirements, a qualified design engineering firm may be required for design and installation of the geomembrane. All work shall be in accordance with the project drawings, specifications and QC requirements.

B. Applications

Typical applications for Factory Fabricated Compounded Unsupported Geomembranes include but are not limited to:

- Irrigation and canal liners
- Landfill liners
- Leach pad liners
- Moisture barriers and covers for athletic fields
- Golf course and decorative pond liners
- Soil remediation pads
- Interim and final landfill and mine reclamation cover systems
- Shale oil and gas development, e.g., drill pads and various liquid containments
- Oil and gas production, e.g., various secondary containment applications
- Mining leach pads and various liquid containment and transport applications
- Tailings ponds
- Water reservoirs and ponds
- Subgrade protection
- Barriers, blankets, and curtains
- Rain sheets for ore in mining applications
- Underslab vapor retarders

1.02 References

American Society for Testing and Materials (ASTM)

1. ASTM D4437. "Standard Practice for Non-destructive Testing (NDT) for Determining the Integrity of Seams Used in Joining Flexible Polymeric Sheet Geomembranes". ASTM International, West Conshohocken, PA.
2. ASTM D5199. "Standard Test Method for Measuring the Nominal Thickness of Geosynthetics". ASTM International, West Conshohocken, PA.
3. ASTM D751. "Standard Test Methods for Coated Fabrics". ASTM International, West Conshohocken, PA.
4. ASTM D1777. "Standard Test Method for Thickness of Textile Materials". ASTM International, West Conshohocken, PA.
5. ASTM D5641. "Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber". ASTM International, West Conshohocken, PA.
6. ASTM D5820. "Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes". ASTM International, West Conshohocken, PA.
7. ASTM D7865 “Standard Guide for the Identification, Packaging, Handling, Storage, and Deployment of Fabricated Geomembrane Panels”. ASTM International, West Conshohocken, PA.
8. ASTM D7177. “Standard Specification for Air Channel Evaluation of Polyvinyl Chloride (PVC) Dual Track Seamed Geomembranes.” ASTM International, West Conshohocken, PA.
9. ASTM D6392. “Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods”. ASTM International, West Conshohocken, PA.
10. ASTM D6214. “Standard Test Method for Determining the Integrity of Field Seams Used in Joining Geomembranes by Chemical Fusion Methods.” ASTM International, West Conshohocken, PA.

Interesting Historical Fact:

Before Australia adopted the metric system, they used the term “thou” to mean thousandth of an inch instead of using the term “mil.” So 30 mil geomembranes would be referred to as “30 thou.” For clarification, the use of the term mil in this guideline means “thousandth of an inch.”

11. ASTM D6497. "Standard Guide for Mechanical Attachment of Geomembrane to Penetrations or Structures." ASTM International, West Conshohocken, PA.
12. ASTM D7176. "Standard Specification for Non-Reinforced Polyvinyl Chlorides Used in Buried Applications." ASTM International, West Conshohocken, PA.
13. ASTM 7272. "Standard Test Method for Determining the Integrity of Seams used in Joining Geomembranes by Pre-manufactured Tape Methods." ASTM International, West Conshohocken, PA.
14. ASTM D7077. "Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earth Materials. ASTM International, West Conshohocken, PA.
15. ASTM D7465. "Standard Specification for EPDM used in Geomembrane Applications." ASTM International, West Conshohocken, PA.
16. ASTM D7408. "Standard Specification for Non Reinforced PVC (Polyvinyl Chloride) Geomembrane Seams." ASTM International, West Conshohocken, PA.

Other References

1. USEPA (1991). *Inspection Techniques For The Fabrication Of Geomembrane Field Seams*. Cincinnati, Ohio 45268: U.S. Environmental Protection Agency.
2. Koerner, R. M. (2005). *Designing with Geosynthetics* (5 ed.). Upper Saddle River, NJ 07458: Pearson Education, Inc.
3. Geosynthetic Research Institute (2012). "Test Frequencies for Destructive Seam Testing Selecting, variable intervals for taking geomembrane destructive Sample Using the Method of Attributes" GRI GM 14, Geosynthetic Institute, Folsom, PA.
4. Firestone Specialty Products (2011). Technical Specification Guidelines. Indianapolis, IN 46420.

Pulling out a Fabricated Geomembrane Panel

1.03 Submittals

Documents to be included in a submittal to the owner/engineer for review or approval:

1. Example material warranty and Geomembrane installation warranty.
2. Sample of Geomembrane(s) to be installed including the technical data on the product.
3. Reports on the results of examinations and testing shall be prepared and submitted to the Owner's Representative.
4. Shop drawings/panel layout for Geomembranes with panel numbers, field seam locations and details, corresponding to shipping labels.
5. Submit resumes or qualifications of the installation supervisor and certified welding technicians.
6. Documentation of manufacturer's and installer's qualifications (see section 2.02 below). It is recommended that the welding technicians hold an International Association of Geosynthetic Installers (IAGI) Certified Welding Technician (CWT) certification in reinforced geomembranes
7. The installer shall submit a list of at least ten completed facilities. For each installation, provide: name and type of facility; its location; the date of installation; name and telephone number of contact at the facility; type and thickness of geomembrane and; surface area of the installed geomembrane.
8. The documentation to be submitted by the Fabricator to the Owner varies depending on the Owner's requirements. Documentation may include copies of tested seam results, certifications, or any other document related to the quality of the geomembranes and their installation.
9. Fabricator and Installer QC Manuals.

Additional submittals to owner/engineer for review or approval (at completion):

1. Leave the panels packaged until the day the panels are to be installed. If extremely hot or cold temperatures are present, keep the panels inside at a moderate temperature. This reduces the force required to unfold the panels.
2. Geomembrane installation warranty. The installer shall guarantee the geomem-

brane installation against defects in the installation and workmanship for one (1) year commencing with the date of final acceptance.

3. Compilation of pre-qualification test seam samples reports (see section 3.01.D.1 below).
4. Compilation of destructive and non-destructive field seam tests reports (See section 3.01.D below).

Part 2 — PRODUCTS

2.01 Geomembrane Materials

A. Geomembranes included

1. This Document is an installation guideline for Factory Fabricated Compounded Unsupported Geomembranes of 0.25 to 1.52 mm (10—60 mil) in thickness (as measured by ASTM D5199, D751 or D1777). The geomembranes included in this guideline may be comprised of the following polymers:
    a. Chlorosulfonated Polyethylene (CSPE)
    b. Polyvinyl Chloride (PVC) and alloys of PVC with other polymers
        1. Alloys with Ethylene Interpolymer Alloy (EIA)
        2. Alloys with nitrile or other types of rubber
        3. Blends and alloys with other compatible polymers
    c. Ethylene Propylene Diene Monomer (EPDM)

2.02 Quality Control

A. Manufacturer's Qualifications

The manufacturer of the specified geomembrane or similar product shall have at least five years of continuous experience in the manufacture of the geomembrane. Additionally, the Manufacturer shall have produced a minimum of 1,000,000 m^2 (10,500,000 square feet) of the specified geomembrane or similar product during the last 5 years.

B. Fabricators Qualifications

The fabricator of the geomembrane shall have fabricated a minimum of 500,000 m^2/ year (5,381,955 ft^2/year) of the specified type or similar geomembranes.

C. Installer's Qualifications

The Geomembrane Installer shall be the Fabricator, approved Fabricator's Installer, or an installer/ contractor approved by the Owner's Representative. The geomembrane installer shall have installed at least 10 projects involving a total of 500,000 m^2 (5,381,955 ft^2) using the specified geomembrane.

Fabricated Geomembrane Being Folded onto the Pallet.

It is the responsibility of any of the aforementioned parties to select a Geomembrane Installer with the appropriate degree of experience, personnel, and equipment to accomplish the required quality standards.

Depending upon the complexity of the project, it might be required to perform the installation of the geomembrane(s) under the direction of a field installation Supervisor who shall be responsible throughout the geomembrane installation, for geomembrane panel layout, field seaming, testing, patching, repairs, and all other activities of the Geomembrane Installer.

Fabricated Geomembrane on Pallet.

2.03 Geomembrane Arrival at Project Site

A. Geomembrane Unloading

1. Follow ASTM D7865 Guideline for the Identification, Packaging, Handling, Storage, and Deployment of Fabricated Geomembrane Panels.
2. Inspect fabricated geomembrane panels prior to unloading from vehicle at project site (e.g. type of material, conditions, etc.). Make any claims for damage with the carrier prior to unloading or shortly after geomembrane unloading.
3. Materials delivered to site should be off-loaded (using forklift or similar equipment) in a location where minimum handling steps will be required.
4. While unloading or transferring the fabricated panels from one location to another, prevent damage to the wrapping and the fabricated panel itself.
5. Any damage during offloading and transferring should be documented by the contractor unloading the material and the installer.

B. Storage

1. Leave the panels packaged in UV protected wrap until the day that the panels are to be installed. If extremely hot or cold temperatures are present, keep the panels inside at a moderate temperature. This reduces the effort required to unfold the panels.
2. Fabricated panels, when possible, should be stored on pallets off the ground. The storage area should be dry, level, and with a firm base to facilitate lifting; so the panels are not damaged, do not become dirty, and remain dry externally and internally.

Part 3 — EXECUTION

3.01 Installation

A. Subgrade Preparation

1. A pre-installation inspection shall be requested by the geomembrane installer and ALL interested parties before moving panels from the storage location to the placement area. If the subgrade is deemed to be inappropriate for any reason, e.g., roughness, moisture, rock, etc., it should be remediated prior to geomembrane movement and placement.
2. The geomembrane installer and owner's representative shall provide daily written acceptance for the surface to be covered by the geomembrane in that day's operations.
3. Subgrade surfaces should be free of loose rock fragments (>10 mm or 0.4 inches), sticks, sharp objects, or debris of any kind. The surface should provide a smooth, flat, firm, unyielding foundation for the geomembrane with no sudden, sharp or abrupt changes or break in grade that can tear or damage the geomembrane.
4. No standing water, mud, vegetation, snow, frozen subgrade, or excessive moisture is allowed before geomembrane placement.
5. All pipes, drains, fitting, etc., which are to be installed beneath the geomembrane, should be in place, backfilled, and ready to be covered with the geomembrane before panel deployment.
6. An anchor trench in the shape of a "U" or "V" can be used as a perimeter termination point for the geomembrane. Installation of the geomembrane shall be started from the anchor trench.

B. Unfolding and Deploying Prefabricated Panels

1. The geomembrane shall be supplied as a continuous panel with factory seams in the panel to reduce the amount of field seaming and testing.

2. The geomembrane shall be installed to the limits shown on the project drawings and essentially as shown on approved panel layout drawings.
3. Fabricated geomembrane panels are normally placed at a starting point on one corner of the area to be lined. The deployment markings on the packaging or label indicate which direction the panel will unfold. Note accordion-folded and rolled panels will unroll in only one principal direction while double accordion-folded panels may unfold in either principal direction.
4. While unrolling and/or unfolding the geomembrane, inspect the fabricated panel for proper material type and thickness, damage, and/or defects. Repair any damage found.
5. Provide suitable wind uplift protection with sandbags, sand tubes or other engineer approved ballast such as geotextile rolls after the geomembrane panel is unfolded and deployed into position.
6. Only material that is to be immediately welded, i.e., during that work-day, should be deployed.
7. Once the geomembrane is properly placed, the material should be seamed as soon as practical.
8. After the panels are initially placed in the proper position, remove as many wrinkles as practical. If possible, allow the panels to “relax” by allowing the panel to warm in the sun and then seaming. The edges to be seamed need to be smooth and free of wrinkles to ensure good field seams and no “fish mouths”.

C Field Seaming

A large advantage of factory fabricated geomembranes is that manufactured rolls of material are fabricated into large panels in a factory before shipment to the project site. This minimizes the amount of the field seaming and maximizes the amount of factory seaming which results in more high quality seams. In particular, the individual widths of the manufactured geomembrane rolls shall be assembled into large panels that are custom-designed for the specific project and correspond to the panel layout diagram. If factory seaming is maximized, field seaming can be reduced by 80 to 95

percent. In other words, only 5 to 20 percent of all seams need to be made in the field depending on the unit weight of the geomembrane material. This reduction in field seaming improves seam quality by seaming in controlled conditions, accelerates construction, minimizes or eliminates destructive field seam tests, reduces weather exposure issues, allows modular construction, and reduces project costs.

The seaming operation requires a solid, dry, smooth subsurface (see section 3.01 A Subgrade Preparation).

1. Field Cleaning of Seams
   a. A minimum overlap of 100 mm to 150 mm (4—6 inches) for all field seams types, e.g., thermal fusion, tape, chemical fusion, etc., must be cleaned of all dust, dirt, water, and foreign debris no more than 30 minutes prior to the seaming operation. Only clean, soft rags should be used for cleaning the areas to be seamed.
   b. During the cleaning operation, the Geomembrane sheets will be inspected for proper type, thickness, and defective areas which must be removed and/or repaired prior to seaming.

2. Field Seaming
   a. Factory Fabricated Compounded Unsupported Geomembrane Panels can be field seamed by either of the following methods:
      i. Thermal Fusion Welding
      ii. Chemical Fusion Welding
      iii. Adhesive Bonding
      iv. Pre-manufactured Tape Seaming

3. Field Thermal Welding
   a. A major advantage in specifying Compounded Geomembranes is the fact that the roll goods for these polymeric materials can be easily factory seamed together using chemical fusion, tape, or thermal fusion methods.
   b. Thermal seaming is performed with a hot wedge welding machine, which uses a heated element to melt the geomembranes to be welded and then presses the two melted sheets together to form a fusion bond. When performed

properly, wedge welders produce high quality and consistent seams.

c. All thermal welders employ a set point controller to accurately maintain the welding temperature within the most efficient welding temperature for the material. The pressure wheels are normally adjustable to allow for good material bonding after heating.

d. Two wedge arrangements may be used for thermal seaming of Compounded Unsupported Geomembranes. The single (or solid) wedge arrangement produces a continuous bonded weld not less than 25 mm (1 inch) in width. A double (or split) weldge produces two welds with an un-bonded channel between them. This channel is intended for use in non-destructive air pressure testing; however, air lance and pick tests may also be used on split wedge welded seams as well (see section 3.01.D Field Seaming Test Requirements below) The double wedge seaming is only performed on geomembranes made of PVC or PVC alloys (see section 2.01 Geomembranes Included above).

e. Seaming with a thermal welder is to be undertaken only by persons that have been trained and qualified in the use of the equipment (see section 2.02C Installer's Qualifications above). Repairs, maintenance, adjustments, and modifications are to be performed only by trained personnel.

f. Temperature controllers on the thermal welding device should be set according to type of geomembrane, thickness, ambient temperature, type of heating (air v. wedge), rate of seaming, and location of thermocouple within the device.

g. It is necessary for the operator to keep constant visual contact with the temperature controls, as well as the completed seam exiting the welder to ensure adequate welding is occurring. It is not recommended to adjust welding parameters without first constructing and testing a trial seam. If the trail seam meets minimum acceptable values, the adjustments can be used on the field seam (See section 3.01.D.1 Trial Seaming Test Requirements below).

h. Pre-heating of the geomembrane in the seaming area is optional. The amount or type of preheating and its timing preceding the actual seaming is at the option of the installer.

i. Properly functioning portable electric generators must be available within

close proximity of the seaming region and with adequate extension cords to complete the entire seam. These generators should be of sufficient size or number to handle all seaming electrical requirements. The generator must have rubber tires, or be placed on a smooth plate such that it is completely stable and it does not damage the geomembrane. Fuel (gasoline or diesel) for the generator must be stored away from the geomembrane, and if accidentally spilled on the geomembrane it must be removed immediately. The areas should be inspected for damage to the geomembrane and repaired if necessary.

4. Chemical Fusion Welding
   a. Chemical fusion welding consists of the application of a chemical substance (seam bonding solvents) between the overlap of the geomembrane sheets that are going to be seamed. This chemical dissolves the surface of the geomembrane creating a bond when the material is pressed together. A permanent bond is created when the solvent evaporates.
   b. All field seams should overlap a minimum of 100—150 mm (4—6 inches) wide. A sufficient amount of chemical fusion agent should be applied that, upon compressing the seam surfaces together, a thin excess of chemical fusion agent is forced out of the seam. Enough time should be provided to make the chemical soften the surfaces of the geomembranes in contact before pressing them together.
   c. A high durometer rubber, nylon, or hand steel roller can be used to compress the seam surfaces together releasing any air bubbles until a bond is formed.
   d. Chemical solvents are designed to produce adhesive welds in compatible plastic films. Contact the geomembrane manufacturer to determine the optimum bonding agent for the geomembrane being installed.
   e. Chemical seaming is a time dependent process. Enough time should be allowed prior to non-destructive or destructive testing. Often a 24 hour cure time is required before testing.

5. Adhesive Bonding
    a. Most unsupported compounded geomembranes can be joined with adhesive welding. Contact the material manufacturer for a listing of appropriate adhesives for the geomembrane in use.
    b. Adhesive seams also consist of the application of a chemical substance. However, in adhesive seams, the chemical acts as a cementing material and does not soften the geomembrane sheets.
    c. A minimum overlap of 152 mm (6 inches) should be provided for adhesive seaming.
    d. Similar to chemical seaming, adhesive seaming is also a time dependent process and requires enough time to set up prior to non-destructive or destructive testing.

6. Pre-manufactured Tape Seaming
    a. The seaming of adjacent panels should be performed immediately after the relaxation of the geomembrane.
    b. All panels must be installed without tension and without overlapping by at least 102 mm (4 inches). All seams on side slopes must be parallel with the slope.
    c. For soft or rough subsoils a board of piece of conveyor belt is used under the EPDM geomembrane in the area of the seam. The seaming board is moved by means of a rope as the seaming process progresses.
    d. Moisture in the seam will cause failure.
    e. A ballast is not required in tape seaming operations and sufficient bond is created using nylon roller pressure.
    f. Different tape seaming procedures are available, the 76 mm (3 inch) “in seam” and the 152 mm (6 inch) wide tape placed at the overlap.
    g. Contact the EPDM geomembrane manufacturer for specific details and methodology in Pre-Manufactured Tape Seaming.

D. Field Seaming Test Requirements

1. Test Seams (Trial Seams)
   a. Test seams shall be prepared and tested by the Geomembrane Installer to verify that the seaming parameters meet accepted seam values at the start of each welding session or at the beginning of each working day whichever comes first.
   b. Test seams also may be made whenever personnel or equipment are changed and when climatic conditions reflect wide changes in geomembrane temperature or other conditions that could affect seam quality.
   c. A minimum of one test strip per seaming apparatus shall be conducted at the start of each welding session during a day and at least every 4 hours or 915 lineal meters (3000 lineal feet) of field seam per machine, whichever is more frequent.
   d. Field test seams shall be made using "scrap" material from the same lot as the geomembrane being welded in the field because the geomembrane is pre-fabricated into panels in a factory. This requirement is necessary to ensure that the installed geomembrane panels are not damaged prior to the onset of the field welding process because no destructive seam tests shall be conducted on factory fabricated seams to preserve integrity of the fabricated panels (See section 3.01.D.2.a Non-Destructive Testing of Seam Testing below).
   e. Test seaming shall be conducted under ambient conditions and with the same equipment, geomembrane, and operator as field seaming on the fabricated panels. The test seams shall be at least 1.8 meter (6 feet) long for all types of field seams.
   f. Test seams prepared with chemical bonding or adhesives may need to cure for a period of time before testing. Follow the manufacturer's instructions for the curing times of seaming chemicals and adhesives.
   g. If there is no area or equipment on site to provide for these seam requirements, seam strength can be verified for production using trial welds sent to an independent testing laboratory to verify quality.
   h. If a test seam fails, an additional test seam shall be immediately completed.

If the additional test seam fails, the seaming apparatus shall be rejected and not used until the deficiencies are corrected and a successful full test seam is produced.

i. Each test seam shall be labeled with date, geomembrane temperature, weather conditions, number of seaming unit, panel identification, seam number or test location, technician performing the test seam, and a pass or fail description.

j. There is a variance in the ASTM seam testing methods utilized for the geomembranes specified in this document. The Design Engineer should include the specific ASTM test methods that are relevant to the specified material.

2. Non-Destructive Testing (NDT) of Seam Testing

   a. ALL FIELD SEAMS shall be non-destructively tested by the Geomembrane Installer over the full length of the seams before the seam is covered. Each seam shall be numbered or otherwise designated. The location, date, test unit, name of the technician, name of QC person, and outcome of all NDT shall be recorded and submitted to the Owner's Representative.

   b. Testing should be performed as the seaming progresses, not at the completion of all field seaming, unless agreed to in advance by the Owner's Representative. All defects found should be repaired, re-tested, and remarked to indicate acceptable completion of repair.

NDT of field seams shall be performed using one or more of the following methods:

3. Air Channel Test (ASTM D7177)

   a. Air channel testing is only applicable to double (split) wedge seams.

   b. Equipment for testing dual track thermal seams shall be comprised of but not limited to: an air pump equipped with a pressure gauge capable of generating and sustaining a pressure of 350 kPa (50 psi), mounted on a cushion to protect the geomembrane; and a manometer equipped with an approved pressure feed device.

   c. The testing activities shall be performed by the geomembrane installer. Both ends of the seam to be tested shall be sealed and an approved pressure feed device.

d. The testing activities shall be performed by the geomembrane installer. Both ends of the seam to be tested shall be sealed and an approved pressure feed device inserted into the channel created by the dual track thermal weld. The air pump shall be adjusted as per ASTM D7177.
e. Inflated seams shall be inspected by the geomembrane installer during the air pressure test to identify any irregular shape of the inflated seam which may be an indicator of a lower quality weld.
f. Results of the air pressure testing shall be marked on the seam tested and logged on the air pressure testing record.

4. Air Lance Testing (*ASTM D 4437)*
   a. The Geomembrane Installer shall provide an air compressor, air hose, and air lance wand with a pressure gauge capable of measuring air flow to the tip. The testing shall be performed by experienced technicians familiar with this testing procedure.
   b. This non-destructive test involves placing the air lance wand 6 to 12 mm (¼ to ½ inch), but not more than 50 mm (2 inches), from the edge of a completed seam and closely monitoring the backside of the sheet for any air penetration through the seam, loose edges, riffles, and/or noise. If air penetrates the seam area, the technician will either see this visibly or hear it audibly and the area shall be marked for repair.

5. Vacuum Box Testing (ASTM D5641)
   NOTE: Vacuum box testing is not appropriate for all flexible products. Some flexible materials will pull up or adhere to the screen of the vacuum box and false values can result. Contact the material manufacturer for guidance on whether you should vacuum box test the geomembrane being used.
   a. Apply soapy solution to seam area to be tested.
   b. Place vacuum box with clean viewing glass along seam.
   c. Ensure sealing foam around bottom of box is well seated and provides a good seal.
   d. It may be necessary to “work” the box into place and to use some wet rags to get a good seal.

e. Apply a minimum pressure in the box of about 27.6 kPa (4 psi) to test the seams.
f. Monitor the seam for soap bubbles for at least 5 seconds.
g. Mark any locations where bubbles indicate leaks for repairs.
h. If no bubbles occur after 5 seconds, relieve vacuum and move to next seam section.
i. An overlap of about 75 mm (3 inches) should be tested between two consecutive testing sections along the field seam being tested.
j. With thinner products it may be beneficial to install a rigid mesh over the bottom of the box to prevent the geomembrane from being sucked or pulled into the vacuum box. Avoid rough edges that might damage the geomembrane.

6. Electric Leak Location (ELL) Survey (ASTM D7002 or ASTM D7007)
   a. An ELLS is applicable for geomembranes made of polyethylene, polyvinyl chloride, chlorosulfonated polyethylene, bituminous geomembrane, and any other electrically-insulating materials.
   b. The water puddle detection system usually consists of a horizontal water spray manifold with multiple nozzles to spray water on the geomembrane, a squeegee to push resultant water puddle, and a hand assembly. A pressurized water source is connected to the spray manifold using a hose.
   c. Direct current power supplies are used for ELLS; however an alternating current (output of 12 to 30 volts AC) could be used.
   d. The water puddle created is pushed systematically over the geomembrane to locate the points where the electrical current flow increases.
   e. The signal of the probe is connected to an electronic detector assembly that converts the electrical signal to the detector and an audible signal that increases in pitch and amplitude as signal increases.
   f. When a leak is detected, the location of the leak is then marketed or measured relative to fixed points.

g. The leak detection sensitivity can be very good for this technique. Leaks smaller than 1 mm in diameter and leaks through seams in the geomembrane are routinely found.
h. The survey rate depends primarily on the manifold and squeegee and presence of wrinkles and waves in geomembrane.

7. Destructive Field Seam Testing

The frequency of destructive field samples to be taken at a specific project depends on the type of geomembrane material.

a. The Geosynthetics Research Institute give the following recommendation: One destructive test sample per 150 lineal meters (492 linear feet) of field seam length or another predetermined length in accordance with GRI GM 14 shall be obtained by the Geomembrane Installer from a location specified by the Owner's Representative. The Geomembrane Installer shall not be informed in advance of the sample location. Testing should be arranged such that test results are provided prior to completion of geomembrane installation. Samples shall be cut by the Geomembrane Installer as directed by the Owner's Representative as seaming progresses.
b. All field samples shall be marked with their sample number and seam number. The sample number, date, time, location, and seam number shall be recorded. The Geomembrane Installer shall repair all of the holes in the geomembrane created during the seam sampling process. All patches shall be vacuum box tested or spark tested to ensure no leakage. If a patch cannot be permanently installed over the test location the same day of sample collection, a temporary patch shall be tack welded or hot air welded over the opening until a permanent patch can be affixed.
c. The destructive sample size shall be 300 mm (12 inches) wide by 1 m (39 inches) long with the seam centered lengthwise. The sample shall be cut into three equal sections and distributed as follows: one section given to the Owner's Representative as an archive sample; one section given to the Owner's Representative for laboratory testing as specified in paragraph (g) below; and one section retained by the Geomembrane Installer for field testing as speci-

fied in paragraph (d) below.

d. For field testing, the Geomembrane Installer will follow ASTM D6392 for thermally welded seams, ASTM D6214 for chemically welded or adhesive seams and ASTM D7272 for taped seams.

e. Standard ASTM non-destructive test (NDT) methods shall be used to evaluate seams. The Engineer shall designate the appropriate standard NDT method dependent on the type of geomembrane to be installed.

f. Reports of the results of examinations and testing shall be prepared and submitted to the Owner's Representative.

g. For field seams, if a laboratory test fails, that shall be considered as an indicator of the possible inadequacy of the entire seamed length corresponding to the test sample. Additional destructive test portions shall then be taken by the Geomembrane Installer at locations indicated by the Engineer; typically 3 m (10 feet) on either side of the failed sample.

h. On either side of the failed sample and laboratory seam tests shall be performed. Passing tests shall be an indicator of adequate seams. Failing tests shall be an indicator of non-adequate seams and all seams represented by the destructive test location shall be repaired with a cap-strip extrusion weld to all sides of the capped area by one of the methods discussed above but

NOTE: Historically, destructive seam testing has been conducted every 150 lineal meters. (approximately 500 lineal feet). There is a movement toward doing less destructive testing mid field seam. The rationale behind this change is that when a hole is cut from a seam, it is repaired with a seam that is not as good as the original. There are several methods used within the industry to reduce the amount of destructive seam sampling done. One method involves the use of both destructive and non-destructive methods for testing seam integrity. First, the seam must be made with split-wedge welder and successfully air channel tested. Also a destructive seam sample is taken from the anchor trench and tested. If both tests are successful, then no destructive seams are taken from the field seam. If either test fails, then destructive sampling is conducted on the field seam. A second method is detailed in GRI's GM 14 guideline "Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes." A simplified explanation of this method is that good seaming performance is rewarded by extending the destructive sampling interval. Poor seaming performance is penalized.

most likely chemical or adhesive. All cap-strip seams shall be non-destructively vacuum box tested until adequacy of the seams is achieved. Cap strip seams exceeding 50 m (164 feet) shall be destructively tested.

8. Identification of Defects
   a. Seams shall be inspected by the geomembrane installer and the owner's representative before, during, and after field seaming to identify all dirty and wrinkled areas and any defects.

9. Evaluation of Defects
   a. Each suspect location (both in geomembrane seam and non-seam areas) shall be non-destructively tested. Each location which fails non-destructive testing shall be marked, numbered, measured, and posted on the daily installation drawings and subsequently repaired.
   b. Defective seams, tears or holes shall be repaired by capping or cutting out the defective seam and re-seaming. Single seams in excess of 20% of their length requiring repair should be entirely removed and re-welded.
   c. Each patch or cap strip shall extend a minimum of 150 mm (6 inches) in all directions beyond the defect.
   d. All repairs shall be located, measured, non-destructively tested, and recorded.

E. Geomembrane Penetrations

Any structure or containment area built from man-made materials (metal, concrete, etc.) shall not allow protrusions, pinch points, or movement of the supporting structure that might damage the geomembrane and adversely affect the ability of the geomembrane to perform its containment function. Follow ASTM D6497 for guidance for the attachment of geomembranes to structures. All pipes, drains, fitting, etc., which are to be installed beneath the geomembrane, should be in place and ready to be covered with the geomembrane before geomembrane deployment. If possible, avoid cutting the geomembrane at details by using factory fabricated pipe boots that can be seamed to panels in the field.

The following directions provide additional details for handling geomembrane penetrations:

1. Pipes
    a. Whenever possible, avoid slitting geomembrane panels for piping details until a prefabricated pipe boot is ready for immediate installation. Cuts made in the geomembrane for clearance over penetrations should always be made as small as possible to minimize patch work. Generally, it is preferred to let the geomembrane straddle a relatively small protrusion (for later detail work) provided that a rag or towel is taped over the pipe to avoid damage to the geomembrane.
    b. Factory prepared pipe boots should fit snugly but not require excessive force to pull over a pipe. If a pipe boot feels overly snug but workable, try applying either talc powder or using compressed air with a nozzle to float the boot sleeve over and along the pipe.
    c. Pipe boots should never be used if the force required to install them stresses or weakens the boot. When properly installed, the pipe boot will lay flat against grade surrounding pipe without leaving pockets that may become stressed during or after placement of backfill.
    d. Pipe boot aprons should be seamed to the parent geomembrane using one of the repair techniques described in the Seaming Section above (see 3.01C Field Seaming).
    e. Proper leak-proof sealing of pipe boots should be verified by non-destructive methods (see section 3.01 D Field Seaming Test Requirements). The pipe boot sleeve should be attached to the pipe using butyl tape between the pipe and boot and two stainless steel clamps.
    f. When cover materials are not used (see section 3.01.F Cover Materials below), splash pads or additional geomembrane layers shall be used for all inflow pipes to prevent long term wear and damage to the geomembrane caused by the direct impact of the inflow on the geomembrane panels. The pads should be welded on top of the geomembrane panels and tested according to sections 3.01.C and D, respectively. Common splash panel sizes are 1.2 to 1.8 m (4 to 6 ft.) in all directions. However, larger sizes may be required depending on the amount of inflow pipes and the height to the discharge point.

2. Concrete
    a. Where bonding a geomembrane to concrete (or masonry) is required, the concrete surface should be smooth, clean, dry, and free of any sharp protrusions or rock in the backfill. Geomembrane to concrete seals shall be accomplished with mechanical anchors (e.g. fasteners, termination bars). An approved sealant and an approved gasket material is placed between the geomembrane and the concrete surface to ensure sealing.
    b. The geomembrane fixed to a concrete structure must be on firm soil subgrade that will not deform and stretch the geomembrane. Compacting of the soil subgrade around such structures must be performed with particular care so excessive differential movement between the concrete and soil subgrade does not occur.
3. Drains
    a. The geomembrane shall be mechanically fastened to the concrete structure at the location of water discharge. This detail requires the installation of a concrete base or structure at the location of the drain.
    b. Where water enters or exits the geomembrane area, e.g., ponds, reservoirs, and canals, this point must have proper geomembrane termination so as not to damage the geomembrane. The area of inflow must be anchored with a trench or attached to a structure as designed by the Project Engineer or Design Professional. The geomembrane is installed and then anchored to the concrete prior to the covering with soil.
4. Aerators
    a. Geomembrane design in lagoons with aerators should require ballast, e.g. precast concrete slab, on the geomembrane to prevent uplift and to provide a pad to support the aerator when the water level is lowered. Many examples exist of geomembrane damage due to an aerator settling on the geomembrane or where the geomembrane was lifted into the aerator. Other aerator damage is frequently evidenced as cuts in the geomembrane along a specific elevation on the side slope where the aerators have been pulled to shore for maintenance. Geomembrane sheets are easily damaged by the sharp edges of a 6 mm (0.25 inch) thick stainless steel plate of an aerator.

F. Cover Materials

1. When placing cover material or initially filling the containment area, it is important to ballast the geomembrane into the perimeter anchor trench before covering or filling. This can cause undue stress and tension on the geomembrane along flat and sloped areas during the covering process. The anchor trench or perimeter shelf area should be the last area covered to complete the cover process.
2. Under all operating conditions, protection of the geomembrane will be required. Care should be taken when covering the geomembrane to prevent any damage. At no time will construction equipment be allowed to operate or drive directly on the geomembranes unless it is under 5 psi ground pressure and approved by the engineer.
3. Any damage to the geomembrane should be repaired prior to proceeding with cover material placement. Costs associated with repairs are the general contractor's responsibility.
4. The cover material shall be placed as soon as practical, in conjunction with or upon completion of the geomembrane installation or as the installation progresses to minimize traffic on the geomembrane and damage.
5. Access roads for clean soil cover should be maintained to provide 0.45 m (18 inch) minimum and for heavier equipment on haul roads a minimum of 0.90 m (36 inch) preferable between the excavation equipment and geomembrane at all times. Cover soil requirements should be verified before placement with the Design Professional and geomembrane installer. Heavy equipment should operate on a minimum 1 meter (3 foot) thick roadway where the "haul road" is established in and out of the containment area.
6. Additionally, a protection geotextile layer may be needed in rougher soil conditions between the geomembrane and the cover materials. The use of a protection layer should be verified with the Design Professional and geomembrane fabricator.
7. Cover material shall consist of 12 mm (0.5 inch) minus particles, clean rounded soils or gravels free of sharp edges, sticks, metal, rubbish, and debris or foreign materials. Site specific materials or sizes may be acceptable. It is recommended that the contractor receive prior written approval of acceptance of the cover ma-

terials from a geomembrane representative and/or Design Professional before covering the geomembrane.

8. Cover soils should be dumped and leveled over the geomembrane and not pushed from one end to the other to minimize rolling and wrinkling of the geomembrane beneath the soils. Cover soil should always be placed from the bottom to the top of slopes to avoid stressing the geomembrane and slope stability problems.
9. Equipment should be turned in long sweeping turns and not spun quickly to eliminate the chance of tires digging down to the geomembrane thru the cover soil and wrinkling or stretching the geomembrane.
10. If geomembrane damage does occur during construction, cover placement, and/or filling, DO NOT COVER IT UP. Advise the foreman and CQA personnel so repair can be made and documented which will make doing the repair a lot easier than after cover soil placement or filling.

G. Field Acceptance

1. The Geomembrane will be accepted by the Owner's Representative when all of the following have been completed:
   a. The entire installation is finished or on agreed upon subsections of the installation are finished (3.01 A through 3.01F).
   b. All Installer's QC documentation is complete and submitted to the Owner.
   c. Verification of the adequacy of all field seams and repairs and associated geomembrane testing is complete.

H. Site Clean Up and Demobilization

1. On completion of installation, the geomembrane installer shall dispose of all waste and scrap material in a location provided and approved by the owner. The installer should also remove all equipment used in connection with the work herein, and shall leave the premises in a neat and acceptable manner. No scrap material shall be left on the completed surface of the geomembrane.
2. Excess material shall be cut from the anchor trench areas and all scrap, sand bags, and debris, shall be removed just prior to final backfill of anchor trench with select cover soil.

Part 4 — MEASUREMENT AND PAYMENT

4.01 Measurement & Payment

As per project specifications.

Thank you to Mr. Ronald Frobel for reviewing and commenting on this document.

Acknowledgments:

This document was prepared by graduate student Rafael Villarreal and Professor Timothy D. Stark of the University of Illinois at Urbana-Champaign.