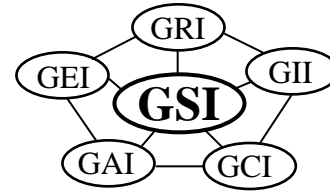


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GRI Test Method GM29*

Standard Practice for

“Field Integrity Evaluation of Geomembrane Seams (and Sheet) Using Destructive and/or Nondestructive Testing”

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 It is completely optional in this regard and can be superseded by other existing or new practices on the subject matter in whole or in part.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

1. Scope

- 1.1 This standard practice provides guidelines to assess the integrity of geomembrane field seams (and sheet) in a progression ranging from fixed interval destructive seam testing eventually to electrical leak location nondestructive testing of both seams and sheet.
- 1.2 The need for the practice is to acknowledge that the fixed interval destructive seam testing concept of one sample in 150 m (500 ft.) is now over 30-years old and antiquated. Significant improvement in concepts, equipment, personnel, training, and technology have occurred in the interval.
- 1.3 The practice describes three separate tracks that may be considered when developing a construction quality assurance (CQA) plan.
- 1.4 This practice is field oriented toward both construction quality control (CQC) and construction quality assurance (CQA) of geomembranes for all applications.
- 1.5 This standard may involve hazardous operations, equipment and climates. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

*This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This practice will be reviewed at least every 5-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

2. Reference Documents

2.1 ASTM Standards:

D4439 Terminology for Geosynthetics

D5820 Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes

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

D6747 Guide for Selection of Leaks in Geomembranes (see also D7703, D7230, D7852, D7002, and D7007 for specific practices in this regard)

2.2 GRI Standards:

GM1 Practice for Seam Evaluation by the Ultrasonic Shadow Method

GM6 Practice for Pressurized Air Channel Test for Dual Seamed Geomembranes

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

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

GM20 Practice for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using Control Charts

2.3 EPA Documents:

EPA/530/SW-91/051, "Inspection Techniques for Fabrication of Geomembrane Field Seams"

EPA/600/R-93/182, "Quality Assurance and Quality Control for Waste Containment Facilities"

EPA/530/SW-91/051, "Inspection Techniques for the Fabrication of Geomembrane Field Seams"

EPA/600/R-93/112, "Proceedings of the Workshop on Geomembrane Seaming, Data Acquisition and Welders," June, 1993, 64 pgs.

2.4 References:

Koerner, R. M. (2012), "Designing With Geosynthetics," 6th Edition, Xlibris Publ. Co., 914 pgs.

GSI White Paper #3, (2003), "Providing Flexibility in Destructive Seam Sampling/Testing," Geosynthetic Institute, Folsom, PA, 14 pgs.

GSI White Paper #26 (2012), "Need For and Justification Of Quality Management Systems for Successful Geosynthetic Performance," Geosynthetic Institute, Folsom, PA, 20 pgs.

Lord, A. E., Koerner, R. M. and Crawford, R. B. (1986), "Nondestructive Testing Techniques to Assess Geomembrane Seam Quality," Proceedings 7th Natl. Conf. on Management of Uncontrolled Hazardous Waste Sites, Washington, DC, pp. 272-276.

Noski, V. and Touze-Foltz, N. (2000), "Geomembrane Liner Failures," Proceedings 2nd European Geosynthetic Conference (GeoEuro 2), Italy, pp. 557-560.

Peggs, I.D., Micelli, G. F., McLearn, M.E., (1994), "Infrared Thermographic Nondestructive Testing of HDPE Geomembranes Seams: A Feasibility Study," 5th International Conference on Geotextiles, Geomembranes and Related Products, Singapore, September 1994, pp. 941-944.

3. Terminology

3.1 Definitions of Generic Terms

3.1.1 *field seams* - The seaming of rolls or panels together in the field thereby making a continuous liner system; also sometimes called *production seams*.

3.1.2 *trial seams* - Trial seams are spare scraps of geomembrane that are field seamed and tested to establish welding machine settings of temperature, pressure and travel rate for a specific device under a specific set of atmospheric conditions as well as establishing procedures to be correctly used by the installation personnel.

3.1.3 *thermal fusion seams* - A seam which involves the temporary, thermally-induced reorganization in the polymer structure at the surface of two opposing geomembranes which, after the application of pressure and the passage of a certain amount of time, results in the two being joined together.

Note 1: The dual track hot wedge seam is considered to be the premier technique for making geomembrane seams. It is always accompanied by using air pressure in the opening between the welded inner and outer tracks, thereby allowing for an air pressure test on both tracks as a nondestructive test method.

3.1.4 *nondestructive test* - Test performed on geomembranes in the field to verify integrity and completeness without taking physical samples and testing them to failure.

- 3.1.5 *destructive test* - Test performed on geomembrane samples cut from a field installation or test strip to verify specification performance requirements, e.g., shear and peel tests of geomembrane seams are destructive tests in which the specimens are tested to failure.
- 3.1.6 *seam shear test* - A destructive test in which two seamed sheets or panels on opposite sides of the seam specimen are pulled in tension such that the seam is placed in a shear mode of stress.
- 3.1.7 *seam peel test* - A destructive test in which two seamed sheets or panels on opposite sides of the seam specimen are pulled in tension such that the seam is placed in a peel mode of stress.
- 3.1.8 *Construction Quality Control (CQC)* - A planned system of inspections that is used to directly monitor and control the quality of a construction project. Construction quality control is normally performed by the geosynthetics installer and is necessary to achieve quality in the constructed or installed system. Construction quality control (CQC) refers to measures taken by the installer or contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project. (See GSI White Papers #3 and #26)
- 3.1.9 *Construction Quality Assurance (CQA)* - A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design. Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Construction quality assurance (CQA) refers to measures taken by the CQA organization to determine if the installer or contractor is in compliance with the plans and specifications of the project. (See GSI White Papers #3 and #26)

4. Summary of Practice

The benchmark destructive seam test interval for geomembrane was established pre-1980 at one sample per 150 m (500 ft.) length of seam irrespective of the type of seam and the quality of the seaming crew. This is unfortunate since good seaming results should allow for greater intervals and poor results vice versa. The methods of attributes and control charts allows for these variations. Furthermore, entirely new concepts (certified installers, taped edges, automatic welders and ultrasonic or infrared (US/IR) testing) should allow for the initial interval to be increased, e.g., to one sample per 225 m (750 ft.). Even further, the electrical leak location (ELL) method which evaluates both seams and sheet can be used to investigate and approve a completed geomembrane system. This standard practice explains each of these value-added advances insofar as current practice of developing construction quality assurance (CQA) plans is concerned. Of course, if site-specific regulations call for a particular strategy with no options, it must be followed accordingly.

This entire practice is embodied in the flow chart of Figure 1 which will be described throughout the discussion. In viewing it, one will observe that three separate tracks are possible. All three concepts are mature and can, and should, be implemented immediately.

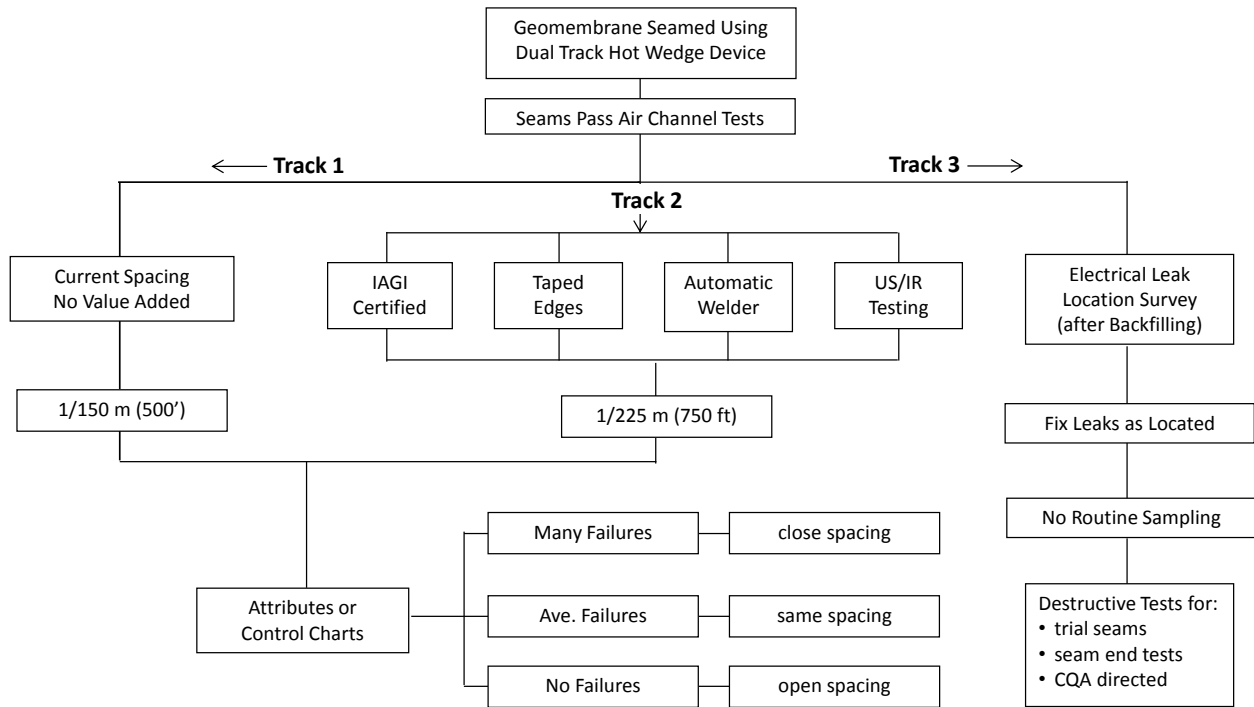


Figure 1. Flow chart of methods and techniques to be described herein in assessing the field integrity of geomembrane seams and sheets.

5. Significance and Use

5.1 Geomembranes are used as liquid and/or gas barriers and, as such, should be leak-free. While field seaming of the edges and ends of the panels has received almost all of the past attention, the sheet itself should also be evaluated. This standard addresses each aspect of the recommended practice so as to have the best possible quality field completed liner system.

Note 2: In this context this standard represents current “best practice” with respect to CQC and CQA.

5.2 Seaming equipment and personnel have improved considerably since pre-1980 when the one destructive seam sample in 150 m (500 ft.) distance was established. This standard practice is focused on increasing this interval (as described) and optimally using the electric leak location (ELL) method which replaces the need for designated destructive tests, but nevertheless provides safeguards as considered necessary.

6. Procedure

Using the flow chart of Figure 1, each item listed thereon will be described in sequence. As seen there are three different tracks that can be taken. Each will be described accordingly. The precursor of all three tracks is that acceptable dual track hot wedge seams have been made and have successfully passed air channel testing, e.g., see GRI-GM6 and ASTM D5820.

The dual track hot wedge seam method consists of an electrically heated element in the shape of a wedge that travels between the two sheets to be seamed. As it melts the surface of the two opposing sheets being seamed, a shear flow occurs across the upper and lower surfaces of the wedge. Roller pressure is applied as the two sheets converge at the tip of the wedge to form the final seam. Hot wedge units are operated as far as temperature, amount of pressure applied, and travel rate. Getting these parameters/variables adjusted to produce a quality weld requires the utmost attention to details and site conditions. A standard hot wedge creates a single uniform-width seam, while a dual (or *split*) hot wedge forms two parallel seams with a uniform unbounded space between them. See Figure 2. This space is used to evaluate seam quality and the continuity of the seam by pressurizing the unbounded space with air and monitoring any drop in pressure that may signify a leak in the seam. *The dual hot wedge seam is considered to be the preferred seaming method for all thermoplastic geomembranes* (ref. Koerner, 2012).

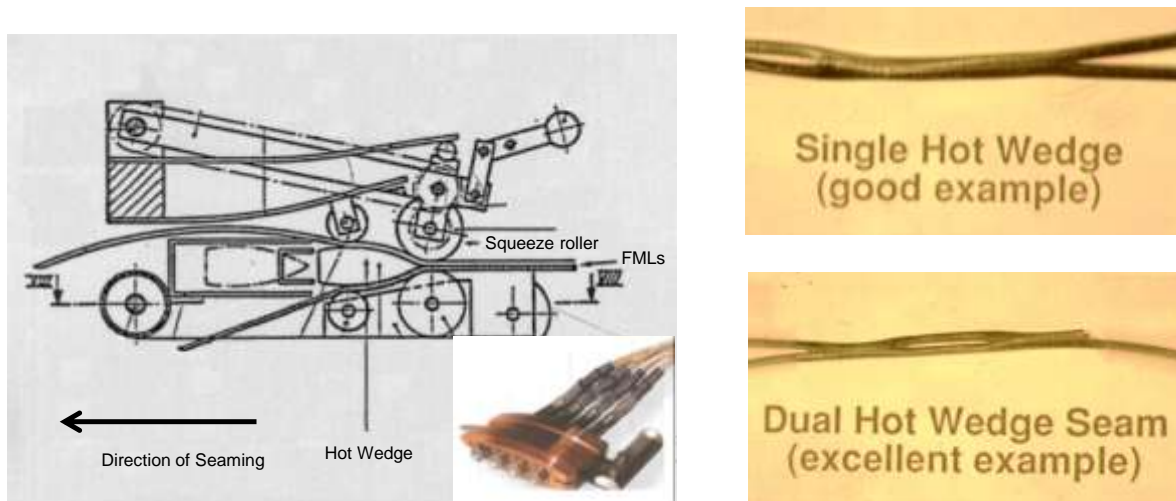


Figure 2. Hot wedge welding device, the wedge itself and resulting single and dual track geomembrane seams, the latter with an open air channel for pressure testing.

The *pressurized dual seam* method uses the air channel that results between the two parallel seams which is inflated using a needle and is pressurized to approximately 200 kPa (30 lb/in²). If no drop on a pressure gauge occurs over a given time period, the entire seam is acceptable. The test method is standardized as ASTM D5820 and by the Geosynthetic Research Institute as GRI-GM6. If an excessive drop in pressure occurs, a number of actions can be taken: The distance can be systematically halved until the leak is located, the section

can be tested by some other detection method, or a cap strip can be seamed over the entire exposed edge. Because there is no limitation in seam length, a single test can extend from one end of a facility to the other. The test is generally performed by the installation contractor, but with the CQA personnel viewing the procedure and assessing the results.

Note 3: For the purposes of the remainder of this practice, it is assumed that a successful air channel test (or one that is suitably repaired) has resulted for the entire seamed geomembrane facility.

6.1 **Track 1:** Initial Historical Spacing, Then Systematically Modified

The historical spacing for taking destructive samples from field fabricated geomembrane seams appears to be initiated (prior to 1980) by Henry Haxo under contract for the U.S. Environmental Protection Agency. The spacing interval was set at one sample per 150 m (500 ft.) of seam length. The removed sample was divided into parts for testing and archiving by the various parties involved, e.g., CQA, CQC, owner, see Figure 2a. Of course, it eventually requires a patch as shown in Figure 2b.

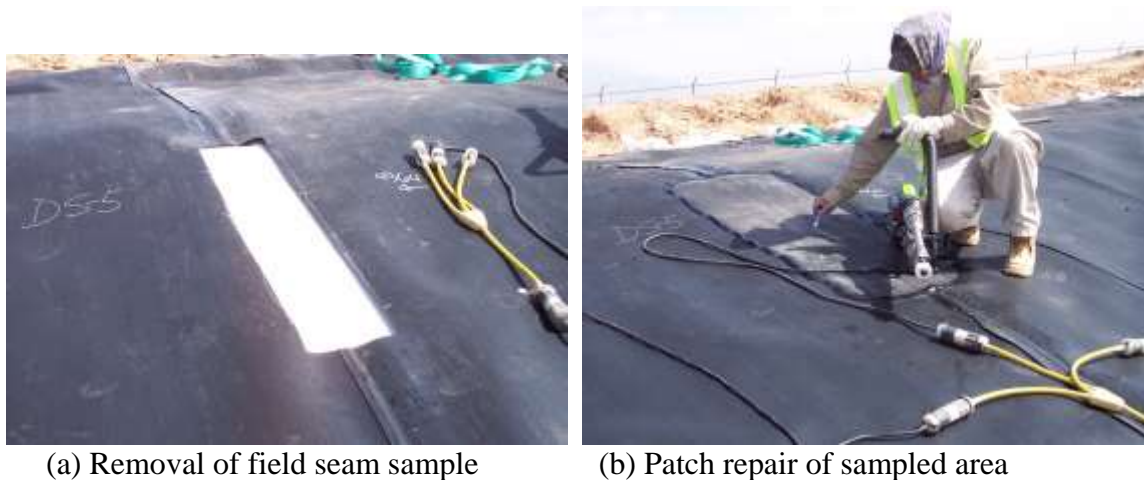


Figure 2. Removal, and subsequent patching, of destructive seam sample of field installed geomembranes.

This removal and replacement process is the essence of the issue to which this practice is focused. The following negative points in taking destructive seam samples are relevant in this regard.

- The removed seam sample has already passed the nondestructive air channel test
- There are actually two parallel seams that are properly functioning
- Patching of the geomembrane invariably decreases the local region's original strength and elongation
- Patches result in a discontinuity for the possible transfer of mobilized stresses and strains from panel-to-panel

- The welding of the replacement patch is by the extrusion fillet method (recall Figure 2b) which is clearly an inferior weld to the hot wedge method
- Extrusion fillet welding requires grinding of the sheets in the area to be bonded which is difficult and must be done with great care so as to avoid thinning of the sheets and inducing stress risers
- The two T-seam tie-ins of extrusion welding to the original dual-track weld is very difficult to fabricate and requires excellent workmanship
- The testing of the adequacy of extrusion fillet welds is by the vacuum box method which is quite subjective and qualitative in its usual application

The removed field seam sample is then sent to a laboratory and tested in both tensile shear and tensile peel with results compared to the site-specific CQA plan. Decisions are then made accordingly.

Note 4: There are several available specifications for the acceptable performance of laboratory sheet, shear and peel testing. See ASTM D6392 for the testing protocol and GRI-GM19 for specification values.

The results of these destructive seam tests, aka, the failure rate, has historically not been used to vary the sampling rate. *This standard encourages that the field sampling interval should be increased when seam failure rates are low, and decreased when seam failures rates are high. Thus, good seaming is rewarded, while poor seaming is penalized.*

Note 5: According to recent data of the International Association of Geosynthetic Installers (IAGI) the seam testing failure rates for certified welders is currently about 2%.

Rather than arbitrarily increasing or decreasing the sampling interval there are two standard practices available that are based on statistical methods.

The *Method of Attributes*, see GRI-GM14, gives details of this first procedure and illustrates example situations.

In general, the guide gives the procedure for establishing the initial number of samples needed for a possible modification to the start-up sampling interval. This is called the initial batch. Based upon the number of failed samples in the initial batch, the spacing is either increased (for good seaming), kept the same, or decreased (for poor seaming). A second batch size is then determined and the process is continued. Depending on the project size, i.e., the total length of seaming, a number of decision cycles can occur until the project is finished.

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

The *Method of Control Charts*, see GRI-GM20, gives details of this second procedure as well as example situations.

In general, use of the guide requires the establishment of an upper control limit (UCL) and lower control limit (LCL) of seam failure rates. It also requires the establishment of an initial, or start-up, sampling interval. It then proceeds with the calculation of the seam failure rate beginning with the first sample's test result. Thus, it is an ongoing process.

When the failure rate exceeds the UCL, the sampling frequency, or interval, should be decreased. The establishment of this interval is an arbitrary decision. When the failure rate drops beneath the LCL, the sampling frequency, or interval, should be increased. The establishment of this interval is also an arbitrary decision. When the failure rate is between the UCL and the LCL, the sampling frequency, or interval, should remain the same.

Note 6: Since both attributes and control chart methods are statistically based, either can be used. That said, attributes appear to be better suited to large projects, while control charts to smaller ones.

6.2 **Track 2:** Modified Historical Spacing, Then Systematically Modified

As indicated in Figure 1, there should be an initial benefit toward a more open spacing for installation organizations who have invested in people and programs to provide high quality geomembrane seams. In this regard four situations are considered. In providing any of them it is felt that the historical spacing interval for taking destructive tests should be increased. Suggested is one sample per 300 m (1000 ft.). Of course, as the project develops the initial spacing can be increased, remain the same, or decreased as results of the laboratory tests develop over time. Four separate situations will be presented.

6.2.1 Certified Installers – If a geomembrane installer has trained (by means of an independent certified process) for the adequacy of its workforce in fabricating field geomembrane seams, there should be an immediate benefit derived. Such a program is available for both individual and companies.

The International Association of Geosynthetic Installers is an association of geosynthetic professionals created by and for installers. IAGI's mission is to advance installation and construction technologies as well as to provide a central clearinghouse for worldwide industry information. Incorporated in 1995, the association represents organizations that are involved or interested in all aspects of geosynthetic installation. There are three membership categories available.

- Installer Members – Any organization engaged in the installation of geosynthetics is eligible to become an Installer member of IAGI.

- Associate Members – Any organization not engaged in the installation of geosynthetics but who is otherwise associated with the industry (e.g., resin supplier, extruder, equipment supplier, and consultant) is eligible to become an Associate member of IAGI.
- Affiliate Members – Any organization not engaged in the installation of geosynthetics but interested in being allied with the geosynthetics installation industry is eligible to become an Affiliate member of IAGI. This non-voting category provides informational access to IAGI’s activities.

Note 7: As a compliment to certified installers (i.e., CQC) it should be mentioned that a certified inspectors program (i.e., CQA) is also available; see www.geosynthetic-institute.org/certification.htm.

6.2.2 Taped Geomembrane Edges – It is universally agreed that the area to be bonded for a successful geomembrane seam must be clean and dry. In field installation, however, this is oftentimes difficult to achieve. Figure 3a and 3b show unprotected seaming areas being cleaned and dried. One method of safeguarding the sheet to assure dryness and cleanliness in the area to be bonded is to have upper and lower surfaces protected by a thin polyethylene strip, approximately 150 mm (6.0 in.) wide, applied before factory shipment to the site. The strips are electrostatically bonded to the sheet edges and are easily removed, that said the strips are not removed until immediately followed by the wedge welding device doing the product seaming. See Figure 3c showing a geomembrane with taped edges thereby assuring clean and dry surfaces to be seamed.



(a) Cleaning area for seaming



(b) Drying an area for seaming



(c) Geomembranes with taped edges

Figure 3. Photographs illustrating the advantages of geomembranes with taped edges in advance of field seaming.

6.2.3 Automatic Welding Devices – To consistently have successful field welding of geomembranes, the operator of a hot wedge welder must be constantly aware of three machine settings;

- pressure of the nip rollers,
- temperature of the wedge, and
- rate of wedge movement (speed)

Note 8: A common situation is when a cloud appears and cools the sheets to be seamed. The operator must slow the welding device so as to generate additional energy for an adequate seam to result, and then reset the speed when the cloud passes by. Rather than adjust these settings manually there are automatic welders which adjust as conditions change.

An automatic welding device, see Figure 4, senses the geomembrane sheet temperature and then automatically adjusts for the changed condition. Even further, automatic welders have data storage in their on-board computers which monitor and record speed, temperature and pressure so as to have a permanent record of conditions along every station of field seam locations, see EPA/600/R-93/112 for a conference proceedings in this regard.

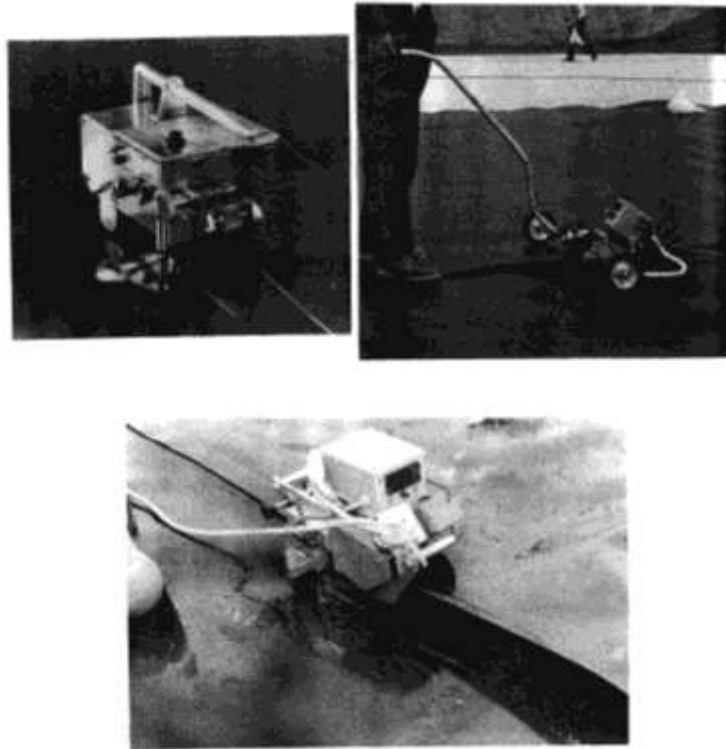


Figure 4. Examples of automatic field welding devices.

6.2.4 Complimentary Nondestructive Testing – There are several nondestructive seam test methods that can be used to supplement the air channel test mentioned previously. They are based on passing ultrasonic (US) or infrared (IR) energy through the seamed area. A good seam will pass the energy very adequately, while a poor seam will intercept the energy and be indicated accordingly. Figure 5 shows the ultrasonic technique. The infrared method is similar with the exception of the energy type being generated and received.

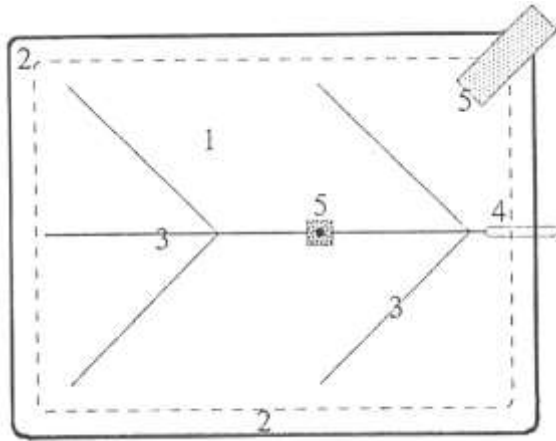
Note 9: While technical papers have been written on each method (Lord, et al. 1986, and Peggs, et al., 1994) their use in practice has been limited to date as a research activity.



(a) Laboratory calibration



(b) Ultrasonic field monitoring



Plan View of Geomembrane Lined Site

Notes:

- 1 = flat floor
- 2 = corners and edges
- 3 = under drainage pipes
- 4 = pipe penetrations
- 5 = other (access roads, temporary storage, concrete structures)

Location of Holes

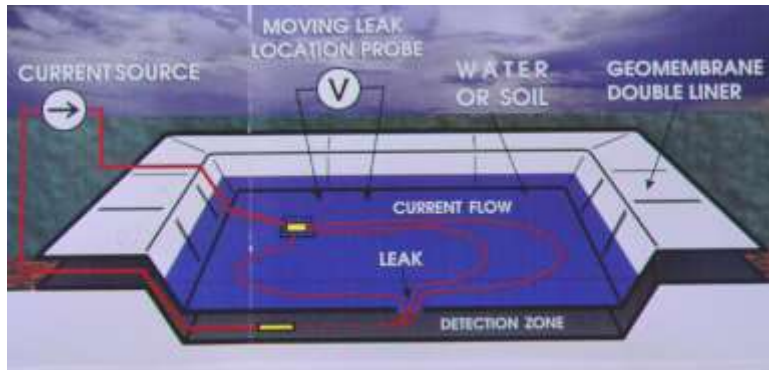
No. of Holes	Flat Floor (1)	Corners and Edges (2)	Under Drainage Pipes (3)	Pipe Penetrations (4)	Other (5)
4194	3261	395	165	84	289
100%	77.8%	9.4%	3.9%	2.0%	6.9%

Cause of Holes vs. Size of Holes

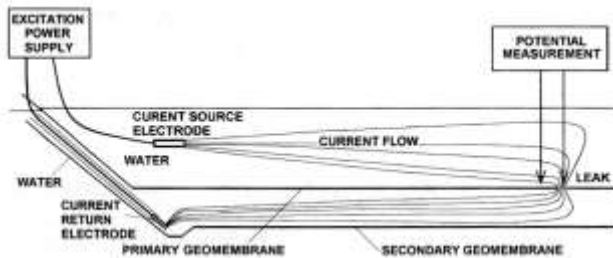
Size of Holes (cm ²)	Stones	%	Heavy Equip.	%	Welds	%	Cuts	%	Worker Directly	%	Total
<0.5	332	11.1	-	-	115	43.4	5	8.5	195	-	452
0.5-2.0	1720	57.6	41	6.3	105	39.6	36	61.0	105	84.4	2097
2.0-10	843	28.2	117	17.9	30	11.3	18	30.5	36	15.6	1044
>10	90	3.0	496	75.8	15	5.7	-	-	-	-	601
Amount	2985		654		265		59		231		4194
Total	71.17%		15.59%		6.32%		1.41%		5.51%		100%

Figure 6 – Results of electrical leak location surveys from 300 sites, ref. Nosko and Touze-Foltz (2000).

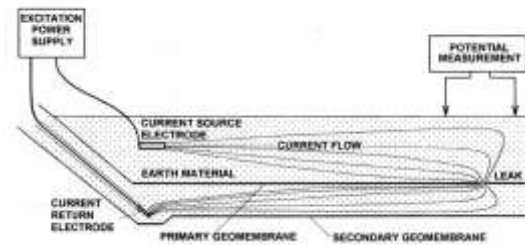
The concept of the ELL method is to use a high voltage (albeit low amplitude) DC power source where the cathode (-) is grounded in moisture beneath the geomembrane (or the lower part of a conductive geomembrane if so provided) and the anode (+) is in water above the geomembrane; see Figure 7a. A technician with an indicator attached to a voltage meter will receive a signal when a hole in the geomembrane is located. As indicated by the various ASTM standards there are several options as to when to use the technique. Figure 7b shows the geomembrane exposed while Figure 7c has the geomembrane backfilled with about 300 mm (12 in.) of soil (in this case leachate collection sand or gravel). Figure 7d is a mosaic of various field surveying projects.



(a) Concept of ELL method



(b) Water covering geomembrane



(c) Soil covering geomembrane



(d) Examples of ELL surveys (Photos. compl. of TRI)

Figure 7. The Electric Leak Location (ELL) Method.

Note 10: There are courses regularly given on the various ELL methods (water covered, soil covered, water puddled and conductive layer sparking) as well as a certification program for personnel performing such surveys. See www.tri-environmental.com in this regard.

Using the ELL survey actual leaks in the installed geomembrane are designated by markers or stations and then repaired accordingly. Repair is invariably by an extrusion welded patch as shown in Figure 2b. Using the ELL method as indicated in Figure 1, there is no routine destructive test sampling recommended. However, there are some destructive samples and testing that should be considered. Situations in this regard are as follows:

- destructive testing of trial, or test, seams
- tests near seam ends, e.g., the anchor trenches
- tests where ever the CQA personnel direct

Note 11: In light of improvements in field seaming (both personnel and equipment) over the decades since the one sample is 150 m (500 ft.) interval was developed **and** the fact that the majority of leaks are in the sheet, this Track 3 of the practice appears to be compelling. While there are obstacles to overcome, e.g., existing state EPA regulations, less reliance on copious amounts of seam shear and peel tests, additional costs over current practices, who pays for such service, etc., it is felt that the ELL method is the way-forward for assessing the field integrity of geomembrane seams and sheet.

7. Summary

This practice focused on assessing the field integrity of geomembrane seams and sheets. It begins with the assumption that the geomembranes have been seamed using the dual track hot wedge method and have successfully passed the prescribed air channel test specification. At that point either destructive and/or nondestructive testing can begin.

Three tracks as illustrated in Figure 1, are described. *First* is to take destructive tests at the historical interval of one sample per 150 m (500 ft.). Rather than keep this interval throughout the project, the interval can be increased or decreased as laboratory testing progresses. There are two such standardized methods: attributes and control charts. In this manner good seaming can be rewarded and poor seaming penalized.

The *second* track is to begin the project at a greater interval, e.g., one sample per 225 m (750 ft.) if some type of “value added” to the seaming aspect of the project is indicated. Such actions as certified welding technicians, taped geomembrane edges, use of automatic welding machines and complimentary nondestructive testing using ultrasonics and infrared were described.

The *third* track described the ELL method which does a post-installation survey investigation for leaks in both seams and sheets. No routine sampling was recommended, however, destructive tests on trial seams, ends of the geomembrane rolls and as CQA directed, should be considered. The method can be deployed after initial backfilling of the seamed geomembrane which directly challenges the care of the backfilling operation.

It is this third track which is felt to be the way-of-the-future. This is rationalized since seam destructive failure rates are low (certainly in comparison to historical data) and it appears that sheet failure holes, tears, and rips are more prone to occur particularly after the geomembrane has been soil covered. These sheet failures come as either a few number of large holes (bulldozer gauges) or many small holes (stones above or below the geomembrane). Since the ELL method is currently performed by many organizations and the technicians performing the survey can be certified, the recommendation for its use is unequivocal.