Pilot Project and Field Study: Data and Quality-Based Geomembrane Field Seaming Evaluation for CCR Projects

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Abstract

The authors summarize the background of long-established geomembrane destructive seam sampling approaches and outline an alternative using data and quality-based geomembrane field seaming techniques. Furthermore, the authors present the data and quality-based geomembrane field seaming framework as implemented on a pilot project and field study evaluating threshold welding parameters.

Destructive seam testing generally demonstrates that seams meet specification requirements, leading many to question the need to cut quality geomembrane seams. The Geosynthetics Research Institute (GRI) published White Paper #3 in 2003 which outlined several elements to be considered as a basis for reducing destructive sampling. Among these elements are geomembrane welding machines equipped with on-board data acquisition systems measuring temperature, speed, and welding pressure, leak location testing, certified welding technicians, and taped geomembrane edges.

Energy companies nation-wide are closing ash ponds in place with geosynthetic cover systems or by removal to new geosynthetic-lined landfills. Ash basin closure projects will rely on thousands of acres of polyethylene geomembrane (high-density or liner-low density) and millions of linear feet of geomembrane seams. Long-established geomembrane design and installation construction quality assurance (CQA) practices require geomembrane destructive seam sampling and testing at a frequency of one sample per 500 lineal feet. By pinpointing destructive seam sampling locations based on installation data, the data/quality-based geomembrane field seaming framework has the potential to reduce geomembrane installation costs while improving seam quality.

Geomembrane Seaming Destructive Sample Origins

Geomembranes are widely used in waste and water containment applications. Robust and established geomembrane construction quality assurance (CQA) and construction quality control (CQC) programs are implemented to confirm both the manufactured material and its installation quality. Geomembrane seam integrity and continuity is important to maintaining containment. Seam quality is vulnerable to environmental contamination (from soil and moisture) and dependent on welding equipment function and operator skill. Therefore, geomembrane installation and especially seaming is rigorously documented, monitored, and tested both non-destructively and destructively. Because practice consistently shows that the vast majority of seam destructive test results meet project requirements, many question the destructive sampling and testing need.

The desire to reduce the destructive seam sampling frequency is documented in environmental containment lining literature since the mid-1980s and is often raised in geomembrane installation conversations. The practice of cutting destructive samples to test the seam strength at a frequency of one sample for every 500 ft (152 m) of installed seam has become standard industry practice. This standard originates from work by Wright et al. in 1987 after strong industry and regulatory desires to standardize geomembrane installation CQA and CQC practices.

In 1986, the US EPA produced a technical guidance document related to construction quality assurance for hazardous waste land disposal facilities that outlined a variety of sampling frequency strategies in detail including the judgement method, statistical sampling, and block sampling among other approaches. Their conclusion shows the state of practice at the time: Until more information is available, the selection of appropriate sampling strategies should be conducted with the guidance of knowledgeable engineers and statisticians. (Northeim & Truesdale, 1986, p. 55).

In 1987, Thomas Wright authored the Manual of Procedures and Criteria for Inspecting the Installation of Flexible Membrane Liners in Hazardous Waste Facilities (Wright et al.) under contract with the Hazardous Waste Engineering Research Laboratory of the US EPA. This appears to be the origin of the 1 seam sample in 500 ft (152 m) frequency and subsequent articles on the topic refer to this work as the industry standard for installation practices and testing. Interestingly, the actual recommendation in the text refers to a minimum of one test per seaming crew per day and only taking destructive samples when there is insufficient number of CQA inspectors to observe each seaming crew fulltime and/or when the results of testing nondestructive samples indicate poor seam quality. Review indicates that literature of the time points to using judgement and performance of the installation crew to base sampling frequency on a project-by-project basis. Wright's work in 1987 only states that one test every 500 ft (152 m) of seam is "normally required" (Wright et al.) and is not an absolute.

Considering current day practices, the industry, its products, and its installation methods are much more mature. However, the concept of using judgement and adjusting seam sampling based on performance has been widely replaced by prescribed values. The State of Kentucky for example has codified a minimum of one (1) test per every 500 ft (152 m) of seam length (Specific Synthetic Liner Requirements 401 K.A.R. 48:080, 2018).

A geomembrane installation cannot be completed without some number of repairs due to welder burnouts, 'tee' seams, or non-destructive test failures among other normal installation conditions. However, randomly cutting destructive seam samples based on a seaming distance may add unnecessary geomembrane holes and, if a deficiency is found, there is no data to indicate its extent. At best, a destructive sample/test passes and confirms that it was not needed in the first place. At worst, a seam is subjected to several additional destructive samples/tests to try to identify the extents of the failing seam. Additionally, there may be areas that pass a nondestructive (air channel pressure test) but could not have achieved the required seam strength. In the absence of data that tracks the entire seam length, there is no way to know if there are failing seam areas not captured through random destructive sampling/testing.

GRI has attempted several times to question why, with better products, manufacturing technology, installation methods, and equipment that we appear to be stuck with this prescribed destructive sampling and testing standard that replaces a superior double-track fusion weld with an inferior extrusion welded patch. GRI White Paper #3 published in 2003 documents the industry advancements since 1987 and advocates for a minimum frequency of one destructive test per 1,000 ft (305 m) of seam and then adjusting the frequency using a table of attributes or control charts (GM 14 and GM 20, respectively, were developed specifically to address these methods) to open the testing frequency for good performance and close the testing frequency for poor performance. They argued that by including new (for 2003) methods such as requiring certified welding technicians, taped geomembrane edges to limit seam contamination, automated welders and infrared or ultrasonic testing, then the control chart could be used, as illustrated in Figure 1. However, they also infer that by adding ELL surveying, no routine destructive sampling should be needed (Koerner & Koerner, 2003).

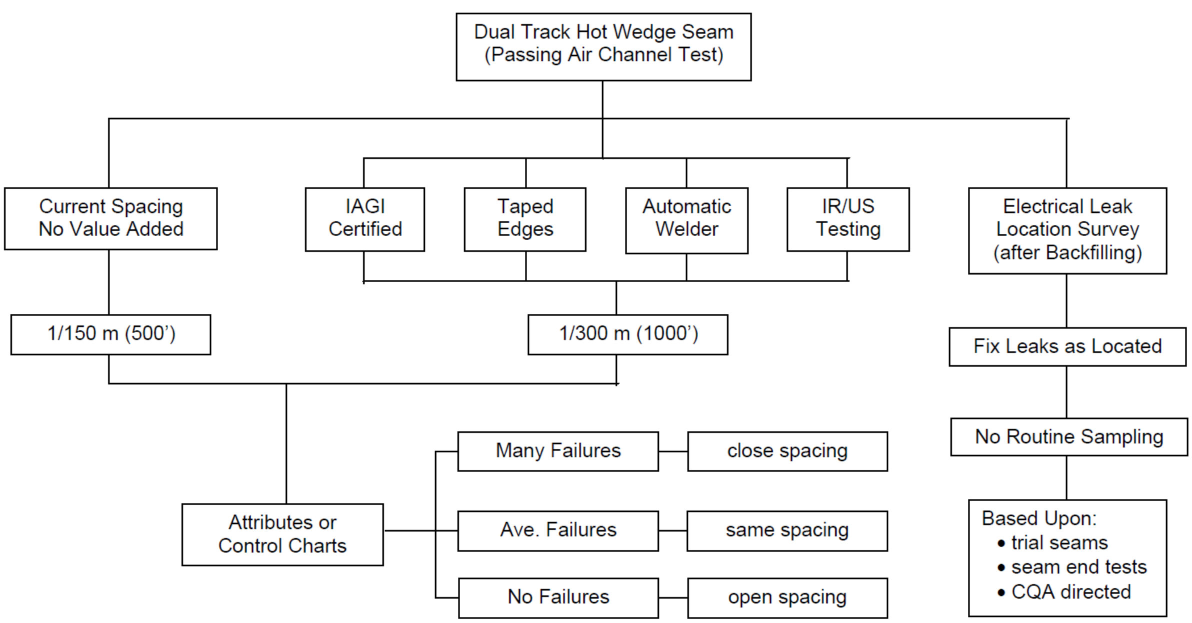

Figure 1: Suggested Strategy for Destructive Test Sampling (from *GRI White Paper #3* by Koerner & Koerner, 2003).

Pilot Project and Field Study Evaluation - Background

The authors of this paper had the opportunity to put GRI White Paper #3 into practice and aim for destructive testing only as the data indicates a need (very similar to the 1980s concept of CQA testing through judgement) by requiring certified welding technicians, taped geomembrane edges, and automated welding technology to reduce as much as practical seam failures due to inexperience or environmental contamination. The automated welding technology was specified to gather data continuously throughout seaming to pinpoint potential seam failure areas. In addition, the project required ELL survey to confirm the geomembrane installation integrity.

The pilot project and field study was a small, 0.2-acre (0.08 hectare) leachate pond at a privately owned industrial landfill facility. The leachate pond was constructed in 1992 with a single 60 mil (1.5 mm) HDPE geomembrane liner and due to the age, damage from periodic cleaning of sediments and the original gravity discharge liner penetration, the owner wanted to replace the liner and pumping system to support continued landfill operations. The owner elected to build a double-liner system with leak detection to alleviate concerns of potential groundwater impacts related to the legacy pond.

Wood Environment and Infrastructure Solutions, Inc. (Wood) partnered with the owner, North Carolina Department of Environmental Quality Solid Waste Section, Chesapeake Containment Systems, Inc. (CCS) and Agru America to develop and permit the project specifications, materials, means, and methods for completing the work.

Data and Quality Based Geomembrane Seaming – Design and Specifications

Wood designed the project preparing construction drawings, technical specifications and the CQA Plan. Technical specifications for the 60 mil (1.5 mm) HDPE geomembrane included four key differences from a standard geomembrane specification including:

1. Requiring International Association of Geomembrane Installers (IAGI) certifications for welding technicians and installation companies;
2. Requiring taped geomembrane edges to limit seam contamination;
3. Requiring the use of data acquisition welding (DAW) machines to continuously monitor double-track fusion seaming temperature, speed, and pressure; and
4. Requiring ELL survey to be performed on the secondary liner to evaluate liner integrity of the last barrier between the pond and the environment.

The technical specifications required fusion welding machines equipped with data acquisition capabilities to measure, record, and display seaming temperature, speed, and pressure as well as displaying voltage. The technical specifications defined the following required tolerances for each seaming parameter:

- Target temperature ± 40° F (4.4° C)
- Target speed ± 0.5 ft/minute (0.15 m/minute)

- Target pressure ± 20 lbs force (89 N)

Consistent with ordinary geomembrane installation, the geosynthetic installer established the target seaming temperature, speed, and pressure appropriate for the geomembrane material and ambient weather conditions.

The technical specifications and CQA Plan defined procedures for Data/Quality-Based Field Seam evaluation instead of prescribing destructive seam sampling and testing at a frequency of one sample/test per 500 ft (152 m). The Data/Quality-Based Field Seam evaluation requirements stated that:

- Destructive test samples shall not be collected at a prescribed frequency.
  - Destructive test samples will be collected based on review of geomembrane seam DAW Reports where temperature, speed, and pressure values were outside of the defined tolerance.
  - The CQA Engineer/personnel may elect to collect destructive test samples based on visual observation of seaming operations and/or observed seam quality.
- The geosynthetics installer shall submit geomembrane DAW Reports to CQA personnel at the end of each working day or at the latest the beginning of the next working day.

Data and Quality Based Geomembrane Seaming – Implementation

The owner contracted Sequoia Services, LLC (Sequoia), of Greensboro, North Carolina as the general contractor. Sequoia subcontracted CCS of Statesville, North Carolina to install geosynthetics. The liner system was installed over the course of one week in early December 2020 and consisted of approximately 0.2 acres (0.08 hectare) of secondary geomembrane overlain by 0.2 acres (0.08 hectare) of primary geomembrane. Agru America produced the 60 mil (1.5 mm) double-sided textured HDPE geomembrane with smooth edges for seaming. The geomembrane was fabricated with a 6 inch (15.2 cm) wide film (tape) adhered to the geomembrane smooth edge as shown in Figure 2. Tape was applied on the top edge of one side of the roll alternating to the bottom edge on the opposite side of the roll so that top and bottom edges matched up when the geomembrane was deployed. Welding technicians removed the tape immediately ahead of the welding machine thereby exposing fresh and clean geomembrane surfaces for seaming as shown in Figure 3.

Figure 2: Geomembrane with taped edge.

Figure 3: Geomembrane seaming in progress – tape removal (right) ahead of seaming (left).

CCS used Leister GEOSTAR G7 LQS double-track fusion wedge welding machines to seam geomembrane. Geomembrane installation began with trial seams conducted in the morning and after lunch break before beginning production seaming. Geosynthetic installer personnel established and set the target seaming temperature, speed, and pressure appropriate for the conditions that day; and set the specified parameter tolerances in the welding machine. In addition, the geosynthetic installer set the data recording frequency to one recording every 4 inches (10.2 cm). It is noted that if a defined threshold was exceeded that the machine recorded data on a 2-inch (5.1 cm) frequency.

CCS seamed approximately 520 lineal ft (158 m) of double-track fusion seam on the primary geomembrane and approximately 550 lineal ft (168 m) on the secondary geomembrane. The welding machine with its visual display is shown in Figure 4. In addition to the machine display, the geosynthetic installer CQC personnel monitored seaming using a tablet PC (connected to the welding machine by Wi-Fi) as shown in Figure 5.

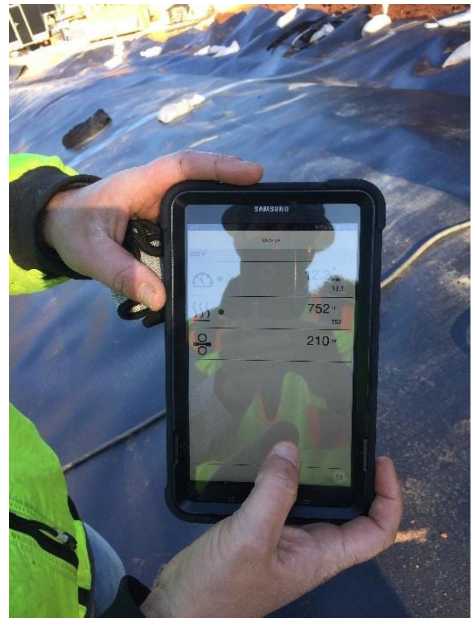

Figure 4: Data Acquisition Welding machine with visual display showing speed, temperature, and pressure.

Figure 5: Tablet PC connected to the Data Acquisition Welding machine displaying seaming parameters.

Each welding machine automatically assigned sequential seam numbers (e.g., 1, 2, 3), therefore the first trial seam began with seam number 1 and production seams started with the next sequential seam number after trial welding (e.g., 3 or 4) depending on the number of trial seams prepared. At select times during the day, the geosynthetic installer transmitted DAW Reports electronically to CQA personnel in portable document format (.pdf). DAW Reports were comprised of the following information:

1. Seam Summary Record: One-page report showing four seams (per summary record) including project information, welding machine make/serial no., seam number, seam start and end times, and the set and measured temperature, speed, and joining force (referred to as pressure) at the seam start and end times (Figures 6 and 7).

Welding record sheet for overlap welds with a testing channel		12/3/2020	No. 7
Construction project		Sealing sheet	NA
Installation company	n/a	Manufacturer	AGRU
Operator	AV	Nom. thickn. [mm]	60 MS
Welding machine	GEOSTAR G7 LQS	Raw material	HDPE
Inventory number	LG2007	Layer	n/a
Serial number	2004241667		

Weld number	4 P4/P5		5 P3/P4		6 P5/P6		7 P5/P6	
Panel number	n/a		n/a		n/a		n/a	
	Start	End	Start	End	Start	End	Start	End
Time	11:48 AM	11:55 AM	12:02 PM	12:09 PM	12:14 PM	12:15 PM	12:20 PM	12:23 PM
Weather conditions								
General (clouds / winds)	n/a		n/a		n/a		n/a	
Air temperature [°F]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rel. air humidity [%]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Figure 6: Data Acquisition Welding Report – Seam Summary Record information (top half).

Welding parameters									
Heated wedge temp. [°F]	Setting	752	752	752	752	752	752	752	752
	Measurem.	745	752	747	752	745	756	750	752
Speed [ft/min]	Setting	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
	Measurem.	12.1	12.2	12.0	12.1	12.1	12.1	12.0	12.2
Joining force [lbf]	Setting	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Measurem.	212	209	204	212	213	169	211	192
Weld specimen									
Test weld	No.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sample from the weld	No.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Remarks									

"Cold" joining pressure = 280 lb/ft

Base-line seaming parameters: T = 752, S = 12.1 ft/min, P = 280 lb/ft
Tolerances: T +/- 40, S = +/- 0.5 ft/min, P = +/- 20 lb/ft
Seaming joining pressure ~ 210 lb/ft; Therefore thresholds set at Low = 190 lb/ft; High = 230 lb/ft

Date / Signature	Date / Signature	Date / Signature

Figure 7: Data Acquisition Welding Report – Seam Summary Record information (bottom half) showing the set and measured seaming parameters at the start and end of each seam.

2. Graphical Report: One page showing the temperature, speed, and pressure plotted versus the data measurement position (distance) and color coded to visually identify out of tolerance seaming parameters (Figure 8).

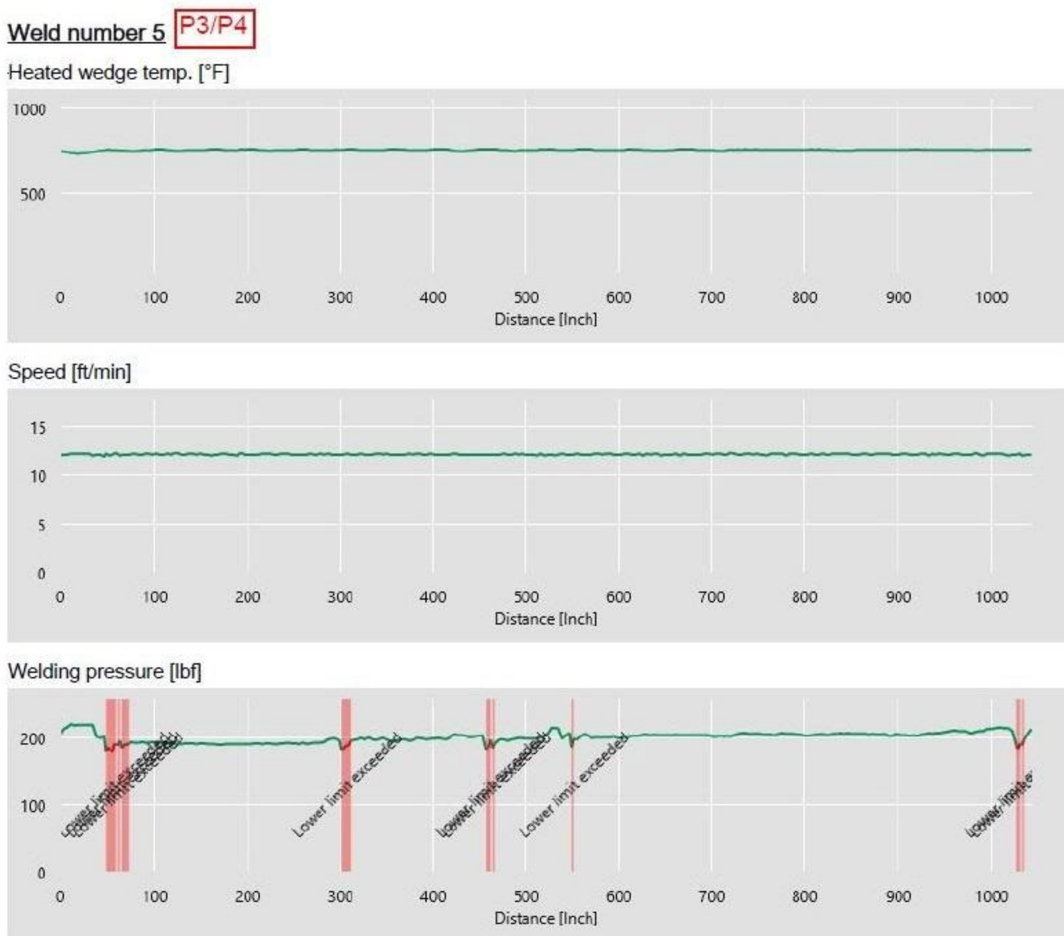

Figure 8: Data Acquisition Welding Report – Graphical Report showing the temperature, speed, and pressure plotted versus the data measurement position (distance).

3. Detailed Report: Multiple-page seam record reporting each data measurement position (distance), temperature, speed, pressure, latitude, and longitude. Out of tolerance seaming parameters were reported in red text to visually distinguish them. The minimum and maximum temperature, speed, and pressure as well as the specified welding limits (tolerances) are summarized at the end of each detailed report (Figure 9).

Records Weld number 5					
Distance [Inch]	Heated wedge temp. [°F]	Speed [ft/min]	Joining force [lbf]	Latitude	Longitude
39.40	745	12.1	201	35.415963	-80.947630
43.30	748	12.1	199	35.415963	-80.947630
47.20	750	11.9	202	35.415964	-80.947631
49.20	750	12.2	178	35.415964	-80.947631
51.20	754	12.2	185	35.415964	-80.947632
53.10	754	12.0	186	35.415964	-80.947633
55.10	752	12.1	181	35.415964	-80.947633
57.10	752	12.1	178	35.415965	-80.947634
59.10	750	12.0	189	35.415965	-80.947634
61.00	750	12.3	190	35.415965	-80.947634

Figure 9: Data Acquisition Welding Report – Detailed Report showing each data measurement position (distance), temperature, speed, joining force (pressure), latitude, and longitude.

Data and Quality Based Geomembrane Seaming – Evaluation

CQA Personnel reviewed DAW Reports in conjunction with non-destructive seam test results and field observations. Fusion seams were non-destructively tested using the air-channel method (ASTM D5820) consistent with standard practices and technical specification/CQA Plan requirements. Non-destructive test results indicated all seams passed test requirements. Reviewing DAW Reports indicated that seaming speed and temperature remained stable, constant, and were within specified tolerances. Reviewing DAW Reports indicated that seaming pressure fluctuated above and below specified tolerances.

During trial welding, personnel observed that the welding machine “set” pressure, before the machine was clamped onto the geomembrane, was higher than the “welding” pressure displayed after the machine was clamped onto the geomembrane. As shown by CQA team comments to the DAW Report seam summary in Figure 7, the “welding” pressure was approximately 70 lbf (311 N) less than the “set” pressure. Therefore, the seaming pressure tolerances set in the welding machine were adjusted to account for the set-to-welding seaming pressure change.

Where DAW Reports indicated seaming parameters outside of the defined tolerances, CQA personnel located and observed the seam quality. Acceptable seam quality was based on observing consistent welding machine track indentations, straight alignment, consistent geomembrane surface appearance, and cleanliness. Questionable seam quality was based on observing inconsistent and shallow welding machine track indentations, misalignment, blistered/melted surface, and cleanliness. DAW Reports and observations indicated that the majority of out of tolerance data were low pressures recorded at anchor trenches, seam ends, and wrinkles (Figure 10); and high pressures recorded at geomembrane tee seams. Geosynthetic installer and CQA personnel attributed low pressures to technicians holding the welding machine by its handle and lifting, guiding, or directing the machine across anchor trenches and wrinkles. High pressure records at tee seems were attributed to the welding machine passing over three layers of geomembrane.

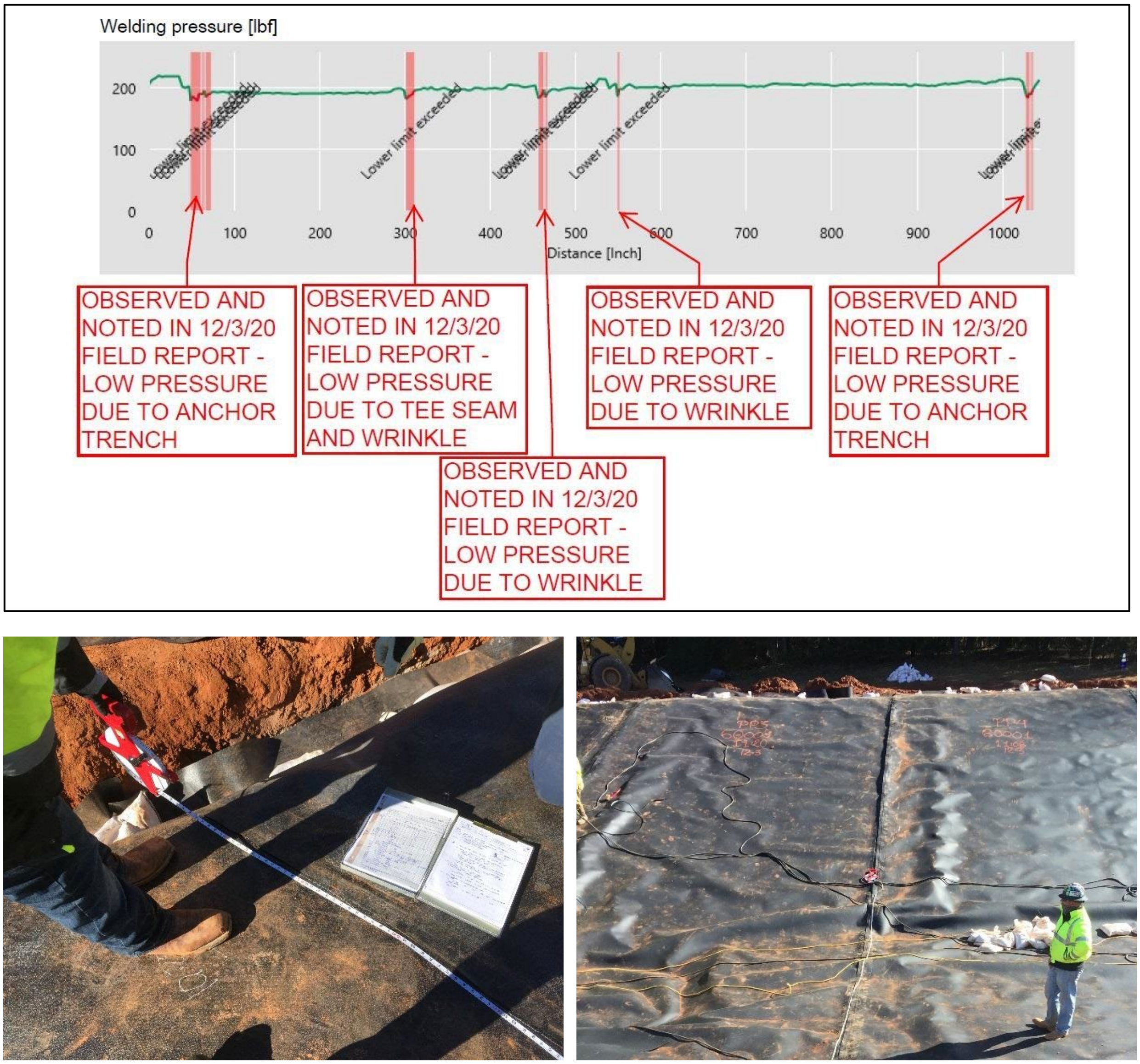

Figure 10: Top shows graphical pressure report of out of tolerance pressure readings with CQA location descriptions and explanations. Photo on the bottom left shows a typical anchor trench location recorded with low pressure; photo on the bottom right shows the location of a wrinkle that recorded low pressure.

Some out of tolerance data resulted from the pressure tolerances not being set correctly during trial seaming. For example, some seaming was completed with the pressure tolerance erroneously set to +10/-30 lbf (+44.5/-133.4 N); or not set at all (during the initial welding). In these cases, CQA personnel manually reviewed the DAW Reports to evaluate seaming parameters.

Compiled out of tolerance seaming pressure data is summarized in Table 1 and describes the location characteristics and the final disposition of each occurrence. The vast majority of out of tolerance pressure readings were attributed to the physical location where the welding machine was lifted by its handle resulting in a low pressure. Based on the data, passing non-destructive test results, and the physical location, 86 percent of the out of tolerance seams were determined to be acceptable; 10 percent were tee seams that were patched as part of ordinary installation; and the remaining 4 percent were true seam defects that were visually obvious, would not have passed non-destructive testing, and were repaired by patching.

Table 1: Seaming Pressure Out-of-Tolerance Summary

Description	Quantity	Frequency %	Disposition
Anchor Trench	22	31	Acceptable
Seam Start/End	3	4	Acceptable
Seam Start/End - Patched	8	11	Acceptable
Wrinkle	5	7	Acceptable
T Seam	7	10	Patched
Burnout	2	3	Patched
Off Track	1	1	Patched
Upper Limit Exceeded - Accepted by Visual and NDT	4	6	Acceptable
Lower Limit Exceeded - Accepted by Visual and NDT	19	27	Acceptable
Total	71	-	-

Based on review of DAW Reports, passing non-destructive seam test results, the locations of out of tolerance recordings, and visual seam observations the CQA Engineer concluded that destructive seam sampling and testing was not necessary. Specific out of tolerance seam locations of concern included wrinkles, two burnouts (at one location), and one off-track seam. The wrinkle locations were accepted based on visual seam quality and passing non-destructive test results. The burnout and off-track seam locations were patched as part of ordinary installation methods.

Data and Quality Based Geomembrane Seaming – Seaming Parameter Sensitivity Analyses

Aside from geomembrane production seaming stakeholders conducted a welding parameter sensitivity analyses to evaluate seam performance over a range of seaming temperature, speed, and pressures. Prior to production seaming, Wood prepared a testing plan with a strategy of beginning from the baseline temperature, speed, and pressure then holding two parameters constant while incrementally varying the third parameter. Seam performance was evaluated through peel testing, shear testing, and visual observation.

Because recorded production seaming temperature and speed were constant and did not result in out of tolerance measurements, the sensitivity analysis focused on varying the seaming pressure. Furthermore, because recorded production seaming and experience indicated that higher pressures ordinarily do not negatively impact seam strength the sensitivity analysis focused on low seam pressures. Results indicated that seaming pressures reduced by three times the project pressure tolerance (3 x 20 lbf = 60 lbf) (3 x 89 N = 267 N) resulted in peel and shear test results similar to the baseline parameters and good visual seam quality.

Unfortunately, due to project time constraints and the primary focus of completing the leachate pond liner system the seaming parameter sensitivity analyses did not establish the upper and lower bound limit temperature, speed, and pressure thresholds.

Conclusions and Recommendations

Some have questioned the need and value of long-established industry standard geomembrane design and installation CQA practices requiring geomembrane destructive seam sampling and testing at a frequency of one sample per 500 lineal ft (152 m). Practice consistently shows that the vast majority of destructive test results pass project requirements.

The authors had the opportunity to put GRI White Paper #3 into practice through this pilot project and field study. GRI White Paper #3 aims for destructive testing only as the data indicates a need by using: certified welding technicians to mitigate inexperience; taped geomembrane edges to reduce seam failures due to contamination; and automated welding technology to measure and record seaming parameters. In addition, the geomembrane installation was non-destructively tested using ELL survey to confirm its integrity.

The pilot project and field study consisted of installing a leachate pond double-liner system. Though the project was small, (0.2 acres or 0.08 hectares), in comparison to many landfill, mining, or liquid containment projects it proved to be a good size for a data and quality-based geomembrane seaming pilot. The project yielded valuable lessons learned that are directly relevant to more common larger projects.

Based on the pilot project and field study results the authors make the following conclusions and recommendations:

- Seaming temperature and speed were constant throughout the project and did not exceed specified tolerances.
- The seaming joining force, referred to as pressure herein, varied:
    - 71 out of tolerance occurrences were recorded.
    - 68 (96%) of these occurrences were deemed acceptable based on their location, observed quality, and passing non-destructive test results.

  - The welding machine “set” pressure was higher than the “welding” pressure measured after the machine was clamped onto the geomembrane by approximately 70 lbf (311 N). Therefore, the pressure tolerance set in the welding machine must be based on the observed “welding” pressure.
  - Seaming evaluation results (conducted aside from production seaming) showed that a pressure tolerance up to ± 60 lbf (267 N) did not affect seam quality based on peel and shear test results. Therefore, the authors recommend changing the pressure tolerance at a minimum to ± 40 lbf or a maximum of ± 60 lbf (178 to 267 N).

- The following installation logistics recommendations are made:
  - The installer must be aware of and plan for the direction of geomembrane panel deployment in order to match the tape on the top and bottom edges of the geomembrane.
  - CQA/CQC must be careful to double check seaming parameter tolerances set in the welding machine during trial welding and before production seaming begins.
  - The welding machine seam identification number (e.g., 1, 2, 3,) must be manually matched with the CQA/CQC seam identification number (e.g. P3/P4) on DAW Reports.

The authors are confident that the data and quality-based geomembrane seaming pilot and field study resulted in a higher quality geomembrane installation relative to standard industry practices. Both installation time and costs were reduced because the data and quality-based geomembrane field seaming framework resulted in no destructive seam sampling/testing. However, the pilot project offered only a small sampling and evaluations on larger projects are warranted to reach a more definitive conclusion.

Though the potential cost and time savings exist they were not quantifiably verified. Taped-edge geomembrane, DAW welding machines, and ELL survey increased costs. Though additional CQA effort was required to evaluate out of tolerance seam data, this may be offset because installation and CQA effort to complete traditional destructive sampling/testing was not required. The authors also note that competitive bidding may be limited because there are limited geosynthetic installers using DAW welding machines and manufacturers making taped-edge geomembrane.

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