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QUALITY ASSURANCE AND QUALITY CONTROL PLAN FOR INSTALLATION OF AN ENGINEERED CAP USING HIGH DENSITY POLYETHYLENE LINER (HDPE)

Kuhlman Electric Corporation
Crystal Springs, Mississippi

Prepared for

BorgWarner Inc.

January 2002

GeoEnvironmental Associates, LLC | MARTIN & SLAGLE

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This Quality Assurance and Quality Control (QA/QC) Plan addresses the installation of an engineered cap over soils containing polychlorinated biphenyls (PCBs) in excess of 25 parts per million (ppm) and less than 100 ppm which may remain on-site following completion of remediation at the Kuhlman Electric Corporation (KEC) in Crystal Springs, Mississippi. The remediation is described in the *"Remediation Work Plan for Kuhlman Electric Plant Site"* dated November 2001.

Federal regulation 40 CFR 761.61(a)(4)(B)(*3*) regarding cleanup levels for this project requires a cap meeting technical requirements under paragraphs (a)(7) of the same section to be installed over any material with concentrations of PCBs ranging between 25 and 100 ppm. The technical requirements specify a cap consisting of concrete or asphalt a minimum of 6 inches thick which will "prevent or minimize human exposure, infiltration of water and erosion".

The areas within the KEC facility designated for caps are parking areas and driveways which are heavily traveled by trucks and heavy equipment. The concrete and asphalt surfaces, by their natures, will crack and shift under heavy truckloads and varying weather conditions causing failure of the cap. In order to maintain the integrity of the cap against damage from vehicular traffic, a layer of impervious, 60-mil HDPE will be installed beneath the driving surfaces and the compacted subgrade for the driving surfaces. The impervious HDPE barrier will prevent or minimize human exposure to, infiltration of water into, and erosion of contaminated soil left in place on the KEC property regardless of the condition of the asphalt or concrete surface. Following is a

material specification, a description of the installation process, and the QA/QC measures to be taken by the manufacturer and installation contractor.

A. MATERIALS

1. The geomembrane shall be high-density polyethylene (HDPE).
2. The HDPE material shall be supplied in rolls a minimum of 23.0 feet seamless width. The thickness shall be 60 mils.
3. Gasket material shall be neoprene, closed cell medium, ¼ inch thick, 2 inches wide with adhesive on one side, as supplied by Poly-Flex, Inc. or other compatible gasket materials as required.
4. Metal battens or bandings and hardware shall be stainless steel.
5. Water cut-off mastic shall be Neoprene Flashing Cement as supplied by Poly-Flex, Inc. or equal.
6. Sealant shall be General Electric Silicone, RTV 103, or equal.
7. The geomembrane rolls shall meet the requirements included in Section 2 of the manufacturer's product specifications attached to this document.

B. INSTALLATION

The following specifications are based on manufacturer's specifications and QA/QC requirements, and recommendations made in a letter by the consulting firm of Burns Cooley Dennis, Inc., Geotechnical Consultants. Copies of the HDPE manufacturer's QA/QC plan and the recommendation letter are attached to this document. Following excavation of contaminated soil and confirmation sampling for PCBs, any soil designated to remain on-site with PCB concentrations greater than 25 ppm and less than 100 ppm shall be capped in place by the following method.

1. A geomembrane consisting of the materials described in Section A of this document shall be placed over any soil areas determined by confirmation sampling to be contaminated with 25 ppm to 100 ppm PCBs, and which are

designated to remain on-site. A minimum of 3 feet of vertical distance shall be maintained between the new asphalt or concrete paving and the top of the geomembrane. The membrane shall extend a minimum of 3 feet beyond the lateral edge of contaminated soil as determined by sampling results.

2. The geomembrane shall be handled and stored on-site as described in Section 5 of the attached manufacturer's product QA/QC plan.
3. Field installation of the geomembrane shall be conducted in accordance with Sections 6 through 12 of the attached manufacturer's product QA/QC plan.
4. Main seam welds e.g. seaming large sheets together, shall be fusion welded during installation. Patches shall be extrusion welded to the main sheets. All welding shall be done in accordance with Sections 10 and 11 of the manufacturer's product QA/QC plan.
5. Backfilling over the geomembrane shall be done only after all testing of the geomembrane and seam is completed and approved by the field inspector.
6. Soils consisting of compacted select fine-grained silty clays (CL) or sandy clays (CL) shall be placed above the geomembrane. All soils shall meet the minimum physical characteristics, compaction, and admixture requirements, and shall be placed as stated in the attached recommendation letter. Field density testing of compacted soil placed over the geomembrane shall be conducted at intervals as determined by Kuhlman's geotechnical engineer.
7. The fine-grained silty clay soil shall be placed and compacted to an elevation specified by the design drawings issued by Usry Architects, P.A. for construction of the plant expansion. The subgrade supporting paving shall be prepared per the drawings and specifications, and either 6 inches of concrete or 8 inches of asphalt shall be placed above all capped areas per the architect's drawings and engineer's recommendations (Refer to attached recommendation letter).
8. Following installation of the finished asphalt or concrete wearing surface the location of the capped area shall be outlined on the pavement surface with a permanent, durable paint.

C. FIELD TESTING

1. Seams shall be non-destructively tested in the field for separations or holes that might allow leakage of moisture into the subgrade. Test procedures for vacuum box testing of extrusion welds are included are included in Section 13.1.1. of the manufacturer's product QA/QC plan. Test procedures for pressure testing of fusion welds are included in Section 13.1.2.
2. Destructive testing of seams shall be done in accordance with Section 13.2 of the manufacturer's QA/QC plan.
3. Procedures for inspection and repairs are included in Section 13.3 of the manufacturer's QA/QC plan.
4. The field inspector shall approve the installation of HDPE liner material in each cap area prior to placement of structural fill over the geomembrane.
5. Compacted backfill placed over the installed geomembrane shall be accomplished in accordance the procedure stated in Section 13.3.4 and tested in accordance with the plant expansion project specifications as determined by the project geotechnical engineer.
6. Asphalt and concrete testing shall be conducted in accordance with the plant expansion project plans and specifications.

BURNS COOLEY DENNIS, INC.

GEOTECHNICAL CONSULTANTS

551 SUNNYBROOK ROAD
RIDGELAND, MS 39157

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POST OFFICE BOX 12828
JACKSON, MS 39236

September 17, 2001

Albert F. Usry, AIA
Usry Architects, P.A.
Post Office Box 2205
Clinton, Mississippi 39060

Project No. 99432-1

Re: Plant Expansion
Kuhlman Electric Corporation
Crystal Springs, Mississippi

Dear Mr. Usry:

This letter is submitted to document our recent discussions with Mr. Robert Martin of Martin & Slagle Geoenvironmental Associates regarding a cap over contaminated soils at certain locations within pavement areas of the referenced project. We have also discussed this matter with you.

Mr. Martin has indicated that a low permeability cap will be required at four different locations in the pavement areas. The location with the largest dimensions (i.e., about 80 ft by 120 ft) will be within a concrete pavement area. The other three locations will have dimensions of either about 40-ft or 60-ft square and will be within asphalt pavement areas. It is our understanding based on discussions with you that the concrete pavement will be subjected to heavy trucks and will consist of 8 in. of unreinforced Portland cement concrete with joints on 15-ft centers. Employee parking areas subjected only to light traffic of automobiles and pickup trucks will be paved with asphalt concrete including 4 in. of bituminous base overlain by 2 in. of surface course materials.

We recommend that the concrete pavement for the facility be directly underlain by a minimum of 4 in. of granular base materials. The granular base is intended to prevent fine-grained soils from pumping up through the joints between the concrete pavement slabs. The concrete-paved areas should be elevated and sloped sufficiently to permit drainage of the granular base. We recommend that the granular base materials conform to the gradation requirements for Class 3 and 4 aggregate presented in the Mississippi Standard Specifications for Road and Bridge Construction (1996 Edition), except the material should have not more than 15 percent fines passing the No. 200 sieve for the total sample. The plasticity characteristics of the aggregate should conform to Group A. The granular base materials should be compacted to not less than 100 percent of standard Proctor maximum dry density (ASTM D 698) at moisture contents within 3 percentage points of the optimum water content.

We recommend a thicker asphalt concrete pavement than previously described for any flexible pavement areas subjected to heavy trucks. In our opinion, that pavement could consist of 8 in. of bituminous base overlain by a 2-in. thick surface course, provided the asphalt concrete pavement

structure is directly underlain by not less than 3 ft of strong nonexpansive subgrade soils with a minimum CBR of 5.

In our opinion, the Portland cement concrete and asphalt concrete pavements will not meet the requirements for low permeability capping materials within the four areas previously mentioned. To create a low permeability cap in those areas, we suggest incorporating a geomembrane in the subgrade. We would recommend that the geomembrane be no closer than 3 ft from the bottom of the pavement structure. The subgrade soils between the geomembrane and pavement structure should consist of compacted select fine-grained silty clays (CL) or sandy clays (CL) having a liquid limit not greater than 45 and a plasticity index in the range of 10 to 24. To be classified as silty clays (CL) or sandy clays (CL) the subgrade fill soils must have more than 50 percent fines passing the No. 200 sieve. We recommend that the subgrade fill soils be compacted from maximum 9-in. thick loose lifts to not less than 95 percent of standard Proctor maximum dry density (ASTM D 698) at moisture contents within 3 percentage points of the optimum water content. A 12-in. thick loose lift should be utilized for the initial lift of fill placed on top of the geomembrane.

Since the geomembrane will essentially be an impervious barrier, surface water entering joints and cracks in the pavement could potentially percolate downward through the subgrade fill soils and perch above the geomembrane. That would cause the fill materials to weaken, resulting in a loss of subgrade support for the pavement. To protect the subgrade soils from softening due to water intrusion, we recommend that the fill materials placed above the geomembrane be treated with lime. For the silty clay (CL) and sandy clay (CL) fill materials, we recommend treatment with 4 to 6 percent hydrated lime by dry weight of soil. Lime treatment should be performed in conformance with Class C lime treatment of Section 307 of the Mississippi Standard Specifications for Road and Bridge Construction (1996 Edition).

We would recommend that the geomembrane consist of high density polyethethylene (HDPE) with a minimum thickness of 60 mils. We also recommend that the HDPE geomembrane be textured on one side (i.e., the side upon which fill is to be placed).

We appreciate the opportunity to be of service. If you should have any questions concerning this letter, please do not hesitate to call.

Very truly yours,

BURNS COOLEY DENNIS, INC.

W. David Dennis, Jr., P.E.

WDD/khh
Copies Submitted: (3)

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

GEOMEMBRANE INSTALLATION QUALITY CONTROL & QUALITY ASSURANCE

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

1. DEFINITIONS

Construction Quality Control (CQC) is a planned system of routine inspections that is used to directly monitor and control the quality of a construction project.

Construction Quality Assurance (CQA) is independent of the CQC and includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of a construction project.

2. PARTIES

This manual references different parties which may be involved in the liner installation process. A successful liner installation depends on the responsible and timely interaction of all involved parties and coordination of all installation, inspection, testing, and documentation.

Owner .....Owner of the property and/or facility; responsible for the final acceptance of the work done on his property/facility.

Designer.....Architectural and/or engineering entity responsible for project planning, design, specifications, and drawings. The designer may also be the project manager.

Project Manager.....Authorized representative of the owner; in charge of project scheduling and coordination of construction activities.

General Contractor.....Prime contractor for the project; may delegate specific tasks in a contractual agreement to one or more subcontractors. The general contractor is sometimes the liner system installer and/or the earthwork contractor.

Liner System Installer .....(Poly-Flex Construction, Inc. or a dealer) subcontractor for the complete installation of the synthetic liner system; must perform according to its contract with the owner or the general contractor.

Liner Manufacturer.....(Poly-Flex, Inc.) manufacturer of the geomembrane from raw material (resin).

Soil CQA Consultant.....Party, independent of the general contractor and the liner installer, in charge of monitoring, testing, inspecting, and documenting all earthwork. Also called soil inspector.

Geosynthetic CQA Consultant ..Party, independent of the general contractor and the liner installer, who monitors, tests, inspects, and documents the installation of all geosynthetic materials, i.e. geomembranes, geotextiles, geonets, and geogrids. Also called third party CQA or liner inspector.

Independent Laboratory.....Testing laboratory unaffiliated with the geosynthetic material manufacturer, installer, or the general contractor for a project.

3. PERSONNEL QUALIFICATIONS

The CQA plan should identify the required qualifications of the CQA officer and the CQA inspection personnel and describe their expected duties.

3.1 Construction Quality Assurance Officer

The CQA officer is assigned singular responsibility for all aspects of the CQA plan implementation. The CQA officer is responsible to the facility owner/operator, and should function independently of the owner/operator, design engineer, and the general contractor. The CQA officer's position within the project's overall organizational structure should be clearly described within the CQA plan.

The CQA officer should possess adequate formal academic training in engineering, engineering geology, or other closely related disciplines. He must also possess sufficient practical, technical, and administrative experience to successfully oversee and implement CQA activities for land disposal facilities. The responsibilities of a CQA officer may require his or her formal registration as a Professional Engineer or equivalent. Because a CQA officer must communicate at all project personnel levels, communication skills of a high order are essential.

3.2 CQA Inspection Personnel

CQA inspection personnel should possess adequate formal training and sufficient practical, technical and administrative experience to successfully execute and document inspection activities. Such personnel must demonstrate knowledge of specific field practices relating to techniques used in the construction of waste land disposal facilities, and of all codes/regulations concerning material and equipment installation, observation and testing procedures, equipment, documentation procedures, and site safety.

3.3 Consultants

Authorities in geology, geotechnical engineering, civil or environmental engineering, or other technical disciplines may be called in from external organizations in the event of unusual site conditions or inspection results. The CQA plan should stipulate in detail the qualifications of such consultants, in the event that it becomes necessary to obtain and use an outside opinion as the basis for a decision implicating construction quality assurance. Consultants should not be used to collect and interpret data when suitable objective observations and test procedures are readily available.

4. MEETINGS

A preconstruction meeting shall be held at the work site prior to commencing the liner installation to discuss work activities, quality control and quality assurance procedure.

A daily meeting shall be held at the work site just prior to commencing the work day. The meeting must include the installer and the liner inspector and will include discussion of both recently completed and imminent activities.

4.1 Preconstruction Meetings

A meeting should be held after the award of the contract and prior to starting the construction of the facility to resolve any uncertainties and review construction objectives. The owner, designer, CQA personnel, general contractor, and the subcontractors should attend this meeting to discuss the following topics:

1. The familiarization of all parties with the site-specific CQA plan and its role relative to the design criteria, plans, and specifications.

2. The responsibilities of each party.
3. The chain of command and communication protocols.
4. The merits of established procedures/protocols for observations and tests (including sampling strategies).
5. The merits of established procedures/protocols regarding construction deficiencies, repairs, and retesting.
6. Methods for documenting and reporting inspection data.
7. Security and safety protocols for the work area.

This meeting should conclude with a walk around the site to review construction material and inspect equipment storage locations. A designated person should document the meeting, and minutes should be distributed to all parties.

4.2 Daily Progress Meetings

A daily meeting shall be held at the work site just prior to commencing the work day. The meeting must include the installer and the liner inspector. The purpose of the meeting is to:

1. Review the previous day's activity.
2. Agree on measurements and specific areas of the previous day's approved work.
3. Review the work schedule.
4. Review work activity and location for the day.
5. Discuss the installer's personnel assignments for the day.
6. Discuss possible problem areas and situations.

5. MATERIAL LOGISTICS

5.1 Transportation

Geomembrane rolls or panels are packaged and shipped in a manner that will protect them from damage. Transportation is the responsibility of the liner manufacturer or the installer.

5.2 Delivery

Off-loading and storage of the geomembrane is the responsibility of the installer, or of the general contractor if delivery precedes the job site arrival of installer personnel. The installer is responsible for replacing any damaged or unacceptable material at no cost to the owner. No off-loading shall be done unless the liner inspector is present. Damage during off-loading shall be documented by the inspector and the installer. All damaged rolls must be separated from the undamaged rolls until the proper disposition of that material has been determined.

5.3 On-Site Storage

Stored geomembrane shall be safely protected against puncture, dirt, grease, moisture, mud, excessive heat and other undesirable conditions.

Geomembrane rolls shall be stored on a prepared smooth surface (not wooden pallets), and shall not be stacked more than two high on soil subgrades. This requirement does not necessarily apply where a concrete pad or warehouse is available for storage purposes.

6. EARTHWORK

The owner or his representative (soil quality assurance inspector) shall inspect the subgrade preparation. Prior to liner installation the subgrade shall be compacted according to the project specifications. Weak or compressible areas which cannot be satisfactorily compacted should be removed and replaced with properly compacted fill. All surfaces to be lined shall be smooth, free of all foreign and organic material, sharp objects, or debris of any kind. The subgrade shall provide a firm, unyielding foundation with no sharp changes or abrupt breaks in grade. Standing water or excessive moisture shall not be allowed. Stones or rocks over $^3/_8$ inch diameter shall not be allowed in the top 6 inches of soil subgrade.

The installer, on a daily basis, shall approve the surface on which the geomembrane will be installed. After the supporting soil surface has been approved, it shall be the installer's responsibility to indicate to the inspector any changes to its condition that may require repair work.

6.1 Vegetation Control

The general contractor, if necessary, shall sterilize the liner installation area using an effective soil sterilant specifically formulated for vegetation present in the area. The sterilant shall not be harmful to the liner and shall be applied according to its manufacturer's recommendations.

6.2 Anchor Trench

The anchor trench shall be excavated to the line, grade, width and depth shown on the construction drawings, prior to liner system placement. The soil inspector shall verify that the anchor trench has been constructed according to construction drawings.

If the anchor trench is located in a clay susceptible to desiccation, no more than the amount of trench required for the base geomembrane to be anchored in one day shall be excavated to minimize desiccation of the anchor trench soils. Slightly rounded corners shall be provided in the trench where the geomembrane adjoins the trench so as to avoid sharp bends in the geomembrane.

7. LINER DEPLOYMENT

The rolls shall be deployed using a spreader bar assembly attached to a loader bucket or by other methods approved by the project engineer.

The liner installer is responsible for the following:

1. Equipment or tools shall not damage the geomembrane by handling, trafficking, or other means.
2. Personnel working on the geomembrane shall not smoke or wear damaging shoes.
3. The method used to unroll the panels shall not score, scratch or crimp the geomembrane, or damage the supporting soil.
4. The method used to place the panels shall minimize wrinkles.
5. Adequate loading (e.g., sand bags or similar items that will not damage the geomembrane) shall be placed to prevent uplift by wind. In cases of high wind, continuous loading is recommended along edges of panels to minimize risk of wind flow under the panels.
6. Direct contact with the geomembrane shall be minimized; i.e., the geomembrane in traffic areas shall be protected by geotextiles, extra geomembrane, or other suitable materials.

7.1 Field Seaming

Approved seaming processes are hot wedge fusion and extrusion fillet welding. On side slopes, seams shall be oriented in the general direction of maximum slope, i.e., oriented down, not across the slope. In corners and odd-shaped geometric locations, the number of field seams shall be minimized.

No base T-seam shall be closer than 5 feet from the toe of the slope. Seams shall be aligned with the least possible number of wrinkles and "fishmouths." If a fishmouth or wrinkle is found, it shall be relieved and cap-stripped.

7.2 Seam Overlap

Geomembrane panels must have a finished minimum overlap of 4 inches for hot wedge fusion welding and 6 inches for extrusion welding.

Cleaning solvents may not be used unless the product is approved by the liner manufacturer.

7.3 Field Seam Testing

Field test seams shall be conducted on the liner to verify that seaming conditions are satisfactory. Test seams shall be conducted at the beginning of each seaming period and at least once each 4 hours, for each seaming apparatus and personnel used that day.

All test seams shall be made in contact with the subgrade. Welding rod used for extrusion welding shall have the same properties as the resin used to manufacture the geomembrane. The test seam samples shall be 10 feet long for fusion welding and 3 feet long for extrusion welding with the seam centered lengthwise. Five specimens shall be cut from each end of the test seams by the inspector. The inspector shall use a tensiometer to test 5 specimens for shear and 5 specimens for peel. Each specimen shall be one inch wide with a grip separation of 4 inches plus the width of the seam. The seam shall be centered between the clamps. The rate of grip separation shall be 2 inches per minute. Test results for seam strength properties shall be the average of five specimens. Four out of five specimens shall pass seam acceptance criteria. Shear and peel tests shall result in Film Tearing Bond (FTB), which is a failure in ductile mode of one of the bonded sheets by tearing prior to complete separation in the bonded area. If a test seam fails to meet field seam specifications, the seaming apparatus and/or seamer shall not be accepted and shall not be used for seaming until the deficiencies are corrected and a successful test seam is achieved.

8. WEATHER CONDITIONS

Liner deployment shall proceed between ambient temperatures of 32° F to 104° F. Placement can proceed below 32° F only after the installer demonstrates to the inspector that the material can be seamed to meet the project specifications. Geomembrane shall not be placed during precipitation or moisture of any type (e.g. fog, rain, dew), or in the presence of excessive winds, as determined by the installation supervisor. Observation of temperature, humidity, precipitation, and wind should be noted to ensure that weather conditions are acceptable prior to liner placement.

9. SEAMING EQUIPMENT AND ACCESSORIES

Approved equipment for field seaming are hot wedge fusion welders and extrusion fillet welders.

1. Hot Wedge Welder, 110 Volt (220 Volt).
2. Extrusion Welder, 220 Volt.
3. 6.5 KW Generator, single-phase with 110/220 Volt Outputs.

10. HOT WEDGE WELDING

10.1 Hot Wedge Welding System

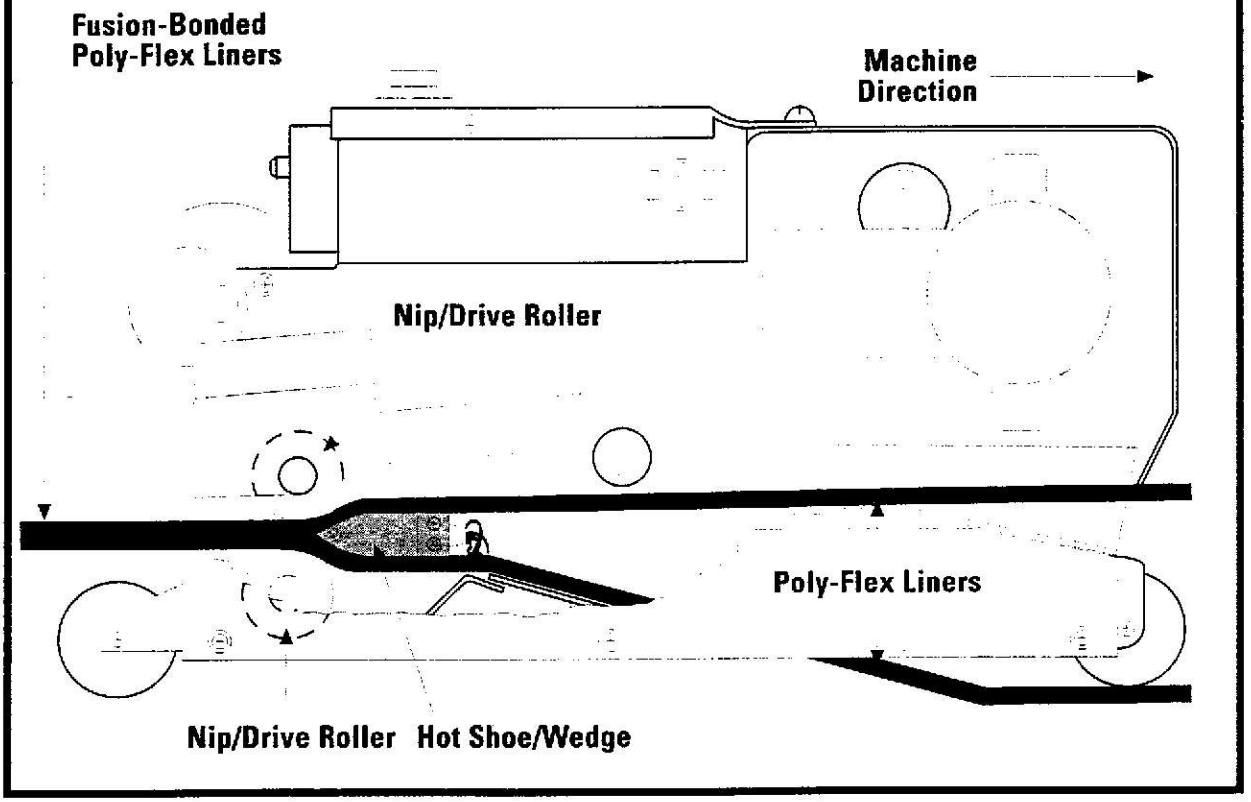
Hot wedge welding represents the primary seaming method for Poly-Flex liners. The hot wedge seaming device is a completely self-contained system. The hot wedge system (Figure 1) produces a bonded seam by running a hot metal wedge between the overlapped area of the Poly-Flex liners. The hot wedge melts the facing surfaces of the two liners and creates a permanent bond between them using controlled heat and pressure. The wedge is square at the leading end and tapered at the trailing end. The heated geomembrane overlaps come together at the tapered end of the hot wedge, under pressure from two nip/drive rollers, and are permanently fused together. Hot air tacking (as employed in extrusion fillet seaming) is not necessary.

The dual hot wedge has a central, canal-like recession along its length. This type of wedge creates a channel in the liner seam between two parallel bonds.

Knurled rollers are used to apply pressure to the sheets where they have just passed over the taper of the hot wedge and been bonded. These rollers should have smooth surfaces and beveled edges.

As the liners pass through the welder, they must contact the full length and width of the hot wedge, or the facing surfaces will not be equally hot. Contour rollers or similar pressure devices, which press the liners against both sides of the hot wedge, must be adjusted so that material of any thickness conforms to the wedge's taper while passing through the welder. Such adjustments should be made while the wedge is cold.

Figure 1 **Hot Wedge Welder**



This seaming method is designed to:

1. Monitor operating temperatures via digital readout.
2. Form uniform bonds by applying uniform and consistent pressure to the seam area.
3. Reduce surface tension and remove surface contamination without grinding, which improves bond strength.
4. Ensure high reliability, which results in consistent seam integrity.
5. Minimize operator error, as the machine is semi-automatic.

10.2 Liner Preparation for Hot Wedge Welding

The following steps shall be taken to prepare the liner for hot shoe seaming:

1. The two liners to be joined must be positioned to create an overlap of 4-6 inches.
2. If the overlap is not substantially wide to contain the wedge, "float" the liner into better position by lifting it high enough to draw air beneath it, guiding it upon this air to an improved position. Avoid dragging the liner, particularly across rough soil subgrades.

3. If the overlap between the liners is excessive, the excess must be trimmed away. This should be done by trimming the lower sheet. If this is not possible and the upper sheet must be trimmed, use a knife with a shielded or hook blade. An unshielded, downward-facing blade cutting from above can easily scratch the liner in a vulnerable location.
4. All cutting and preparation of odd-shaped sections or small fitted pieces must be completed ahead of the seaming operation, so that seaming may be conducted with no interruptions.
5. Before joining the two contiguous liners, make sure they are not excessively scratched, blemished or flawed, and are visually acceptable.
6. If the Plans require panels to be shingled in a particular direction, make sure this is being done.
7. Excessive undulations (waves) along the seams during the seaming operation should be avoided. These occur when the upper and lower sheets have unequal slack between them. This condition can lead to the undesirable formation of "fishmouths," which must be trimmed, laid flat and patched.
8. Polyethylene liners need slack to allow for expansion and contraction caused by weather changes.
9. Sheets which are overlapped and ready for seaming must be clean. If dirty, they must be wiped clean with dry rags.
10. The seam area must be completely free of moisture before the overlapping sheets can be properly seamed. Dry rags can be used to wipe any such moisture from the seam surface. If a sufficient quantity of dry rags is unavailable for this purpose, air blowers can be used.
11. Seaming is not to be performed during rain or snow unless measures are taken to allow the seam to be made on dry liner materials, e.g., within an enclosure or shelter.
12. Seaming is not to be performed when the soil surface beneath the liners is saturated because the hot seaming apparatus will draw moisture into the ongoing seam. Seaming activity on frozen soil is unacceptable for the same reason. Puddled water on the soil's surface beneath the liner is unacceptable.
13. Seaming should be conducted only when ambient temperatures are 32-104° F (0-40° C), unless it can be proven via test strips that good seams can be fabricated at such temperatures.
14. When seaming in cold weather, it is advisable to preheat the sheets with a hot air blower and to conduct seaming activity within a portable tent, to help prevent heat loss. Extra test welds can be used to make any necessary adjustments to the seaming activity.

10.3 Hot Wedge Equipment Preparation

1. A generator must be kept in the proximity of the seaming area with enough extension cord to range the length of the seam. It must either be fitted with rubber tires or be placed on a stable and smooth moveable base, such as an excess of liner, so that no damage will be inflicted upon the liner or subgrade by its movement. The generator's fuel (gasoline or diesel) must be stored off the liner.
2. Surface grinding before application of the hot wedge is not necessary and shall not be done.
3. The hot wedge, or "anvil," should be inspected to see that it is symmetrically balanced and gradually tapered. It is imperative that a wedge has no sharp edges on any surface that contacts the liner during the welding process.
4. The chain drive powering any portion of the welder should be synchronized, properly lubricated, and physically sound.

Contour roller heights are adjustable to allow for varying liner thicknesses. Normal adjustments are made while the welder is at ambient temperature. The procedure is as follows:

1. Insert two material samples into the nip drive rollers.
2. Place two other material samples above and below the wedge.
3. Lock the wedge into its operating position. This is done by shifting the wedge forward, into the clutch of the upper and lower nip rollers.
4. Adjust the contour rollers until they are snug against the liners, which sandwich the wedge.
5. Set the maximum distance that the wedge can move into the nip rollers. Unsecured, the wedge might make direct contact with the nip rollers when the machine has no liner material running through it and damage the machine.
6. The wedge and surrounding rollers are now set for seaming the liner. Remember to disengage the hot wedge from its forward position in the roller apparatus as the machine reaches the end of a seam. This will keep the wedge from advancing into the nip rollers and damaging them.
7. The forward face of the welding machine should be inspected for sharp corners and irregular details which may damage the liner as it advances during the seaming process.
8. Temperature controllers on the wedge device should be set according to liner thickness, ambient temperature, and seaming rate. The "test strip" helps determine these settings. Temperature gauges should be checked for accuracy and repeatability.

10.4 Hot Wedge Seaming Process

Polyethylene liners can be seamed by the hot wedge method, but temperature settings will vary according to the grade of polyethylene used. Typical wedge temperature ranges for hot wedge seaming is as follows:

Liner Type	Minimum[1] °F (°C)	Maximum[2] °F (°C)
HDPE	600 (315)	752 (400)
LLDPE	600 (315)	716 (380)

[1]For dry, warm weather seaming conditions
[2]For damp, cold weather seaming conditions

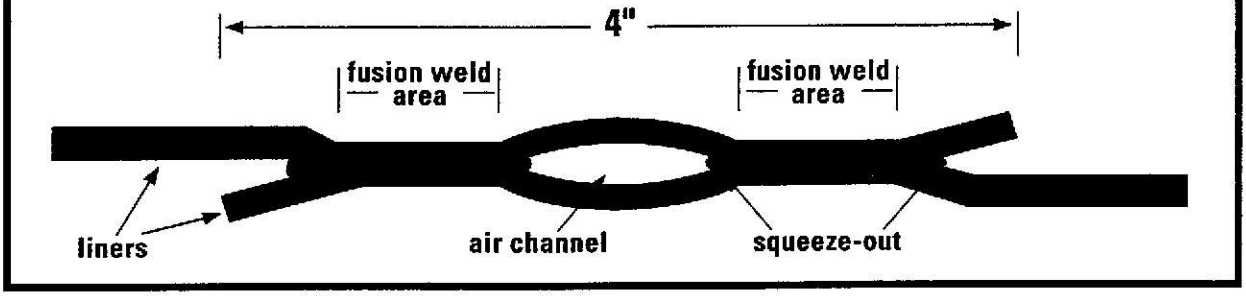
1. The hot wedge system should be properly positioned for making the desired dual (split) seam.
2. Ambient variables such as temperature, cloud cover, and wind speed may make it necessary to adjust the wedge temperature. It may be useful to document wedge temperatures used successfully in a variety of ambient conditions, so that the hot wedge can be more accurately adjusted to new conditions.
3. The drive motor should be off when positioning the welding machine to seam. Guide the overlapped material between the contour rollers and the wedge and into the drive/nip rollers. When the nip rollers engage and the wedge is in position, turn on the drive motor. Move the hot wedge into position and lock it.
4. The operator must constantly monitor the temperature controls, as well as the completed seam passing through the machine. Occasional adjustments in speed may be necessary to maintain a consistent weld.

5. On soft soils, the device tends to "bulldoze" into the ground as it travels, causing soil to enter the weld. A contaminated weld is unacceptable. To avoid this, the operator should slightly lift the front of the machine. Alternatively, a movable base can be used. Strips of geomembrane have proven to be effective materials on which the welder can maintain traction. It is recommended that at least two people work together in making hot wedge seams: one as operator and one as helper.

10.5 After Hot Wedge Seaming

1. A small amount of "squeeze-out" is a reliable indication that proper seaming temperatures have been achieved (Figure 2). The melted polymer will laterally extrude out of the seam area in properly welded seams. An excessive amount of extruded hot melt indicates that excessive heat or pressure, or both, was applied. Reduce the temperature and/or pressure to correct the situation.

Figure 2 **Cross-Section of Dual (Split) Hot Wedge Seam**



2. The 20 mil, 30 mil and 40 mil Poly-Flex liners show a long, low, sinusoidal wavelength pattern in the direction of the seam which indicates a proper weld. If the wave peaks are too close together, machine speed should be increased until a satisfactory pattern appears. The absence of this wavelength pattern indicates that machine speed should be decreased. No wavy pattern will occur on liners thicker than 40 mil due to the inherent stiffness of the thicker liners.
3. Nip/drive roller marks will always show on the surface when using knurled rollers. They should be noticeable to the eye, but just barely to the touch.
4. The hot wedge device has adjustable parts. It is critical that they be checked after a day of seaming. The machine should also be cleaned.

11. EXTRUSION FILLET WELDING

11.1 Extrusion Fillet Welding System

Extrusion fillet welding is used for patches and around details such as pipes and sumps. An extrusion weld is produced by using a 4 or 5 mm diameter welding rod. The welding rod is applied as a "welded bead" at the edge of two overlapped Poly-Flex liners, resulting in an extrusion seam.

11.2 Liner Preparation for Extrusion Fillet Welding

The two liners to be joined must be positioned to create an overlap of at least 6 inches. Follow the same general guidelines as specified for liner preparation for hot wedge welding, page 29 and 30 of this manual.

11.3 Extrusion Equipment Preparation

1. A generator must be kept in the proximity of the seaming area. It must either be fitted with rubber tires, or be placed on a stable and smooth moveable base, such as an excess of liner, so that no damage will be inflicted upon the liner or subgrade by its movement. The generator's fuel (gasoline or diesel) must be stored off the liner.
2. A hand-held electric rotary grinder having a circular disk grinding plate approximately 4.5 inches in diameter and adequate #80 grit paper must be available. Sandpaper coarser than #80, e.g. #60, is not acceptable for smooth liners.
3. A hot air welder capable of 600° C must be available to tack the liner after they are properly positioned.
4. All extrusion fillet seaming devices must be equipped with a properly functioning temperature controller which displays the extrusion temperature.
5. All types of extrusion fillet seaming devices have teflon dies, varied in shape and size, through which the extrudate passes onto the liner. These dies must be inspected for wear, sharp notches and creases, and for their appropriateness to the application at hand.

11.4 Extrusion Fillet Welding Process

1. Surfaces shall be clean and dry.
2. For liners 50 mils and thicker, the upper sheet's leading edge must be ground to a 45° bevel (Figure 3). It is imperative that the sheet be lifted up and away from the lower sheet during the beveling so that no deep gouges are cut in the lower sheet. Beveling should therefore be done before tack welding.
3. A hot air device should be used to "tack" the two sheets together. The hot air gun prepares the seam for the extrusion welder by creating a light bond between the two sheets, securing their position. The hot air gun is not meant to create a primary seam. No heat distortion should be evident on the surface of the upper sheet.
4. The area which is to receive the extrusion bead shall be ground to remove surface contamination and surface tension. Grind marks should not be deeper than 10% of the sheet thickness. Optimally, they should be about 5% of the sheet thickness (Figure 4). The only purpose of grinding is the removal of oxide layers and dirt from the liner surfaces and the roughening of their interface for the extrudate. All material dust generated by grinding the liner sheets must be blown away from the seaming area.
5. Grinding marks should not extend beyond $^1/_4$ inch of either side of the extrudate after its placement. For example, if the final extrudate bead width is 1.5 inches, the width of the grinding trail should not exceed 2 inches.
6. Seaming must take place no more than 10 minutes after grinding, so that surface oxide layers do not reappear where the extrudate must be placed.
7. The welding rod shall be free from dirt, dust, moisture and tangles at all times.

Figure 3 **Beveling Upper Liner**

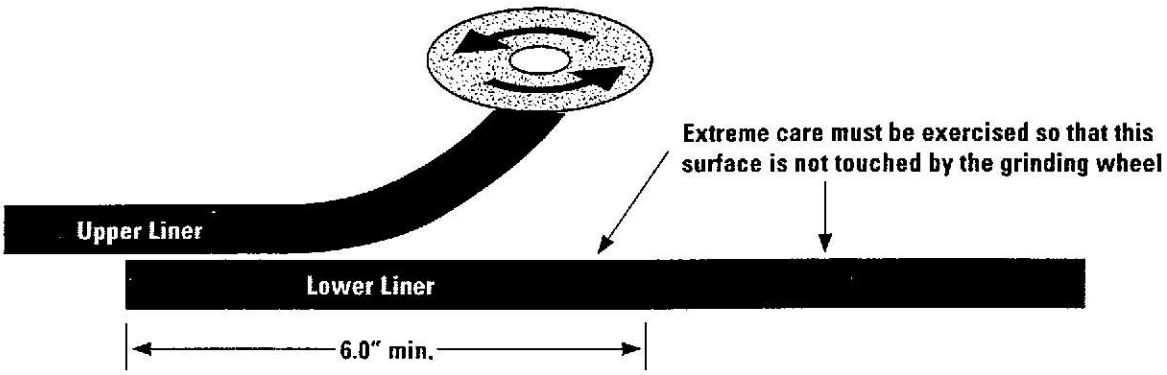
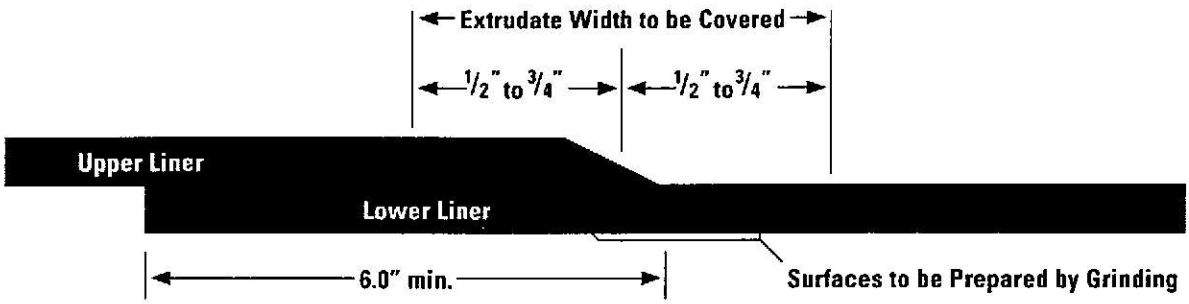


Figure 4 **Grinding Seam Area Prior to Extrustion Fillet Welding**

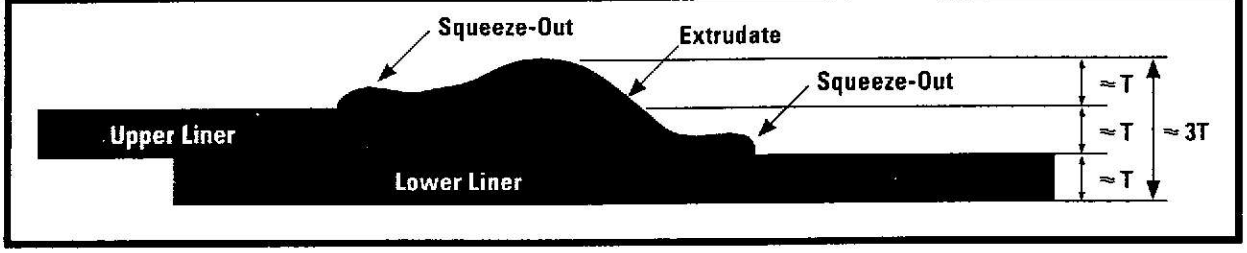


8. The extrusion welder's barrel shall be purged of all heat-degraded extrudate for approximately 30 seconds before starting a seam. This must be done every time the extruder is restarted after two or more minutes of inactivity. The purged extrudate shall not be discharged on the surface of the liner or on prepared subgrade, where it could damage the liner.
9. Molten extrudate is deposited along the overlapped seam. The center of the extrudate passes directly along the edge of the upper liner, at sufficient width to completely cover the edge and most of the outlying grind marks, at least to within 1/4 inch of their extremity.
10. The bottom portion of the welding die shall stay in intimate contact with the sheet surface and conform to various seam angles and configurations.
11. The extrudate should be approximately twice the specified sheet thickness, measured from the top of the bottom sheet to the top or "crown" of the extrudate (Figure 5). Excessive squeeze-out (or "flashing"), as illustrated, is acceptable, if it is equal on both sides and will not interfere with subsequent vacuum box testing. The presence of squeeze-out may indicate that the extrusion die was not

riding directly against the liner, that the extrudate temperature was improper for adequate flow, or that the seaming rate was too slow.

12. Where possible, inspect the underside of the lower liner for heat distortion. This can be done at the end of seams, and wherever samples are cut out of the seam. A slight amount of thermal "puckering" on relatively thin liners (less than 50 mil) is acceptable. It indicates that heat penetrated entirely through the sheet. However, if the underside is greatly distorted, either lower the temperature or increase the rate of seaming. For liners 80 mil and greater, no thermal "puckering" should take place.
13. If the seaming process must be interrupted at mid-seam, the extrudate should trail off gradually, not terminate in a large mass of solidified extrudate. Where such welds are abandoned long enough to cool, they must be ground prior to continuing with new extrudate over the remainder of the seam. Grind where the extrudate trail-off begins. This restart procedure must be followed for patches, pipes, fittings, appurtenances and "T" and "Y" shaped seams.

Figure 5 **Extrusion Fillet Seam Cross-Sections**



11.5 After Extrusion Fillet Seaming

1. A smooth insulating plate or heat insulating fabric is to be placed beneath the hot welding apparatus after usage. The tip die and barrel must not be placed on any liner or other geosynthetic surface, as it is extremely hot and can cause severe damage.
2. The extrudate bead should be visually inspected for alignment, height, and surface texture uniformity. The extrudate should be free of bubbles and pock marks which indicate the undesirable presence of air, water or debris within the extrudate rod or pelletized polymer.
3. Grind marks should not be visible more than $^1/_4$ inch beyond the extrudate. These should be very light and not contain heavy gouges. Grinding is considered excessive when it is deeper than 10% of the liner thickness. It is unacceptable to apply additional extrudate over the original extrusion fillet seam in an area of excessive grinding. A cap strip shall be placed over the entire portion of the seam where excessive grinding is located.

12. UNUSUAL CONDITIONS

Seaming should proceed when ambient air temperature is between 32 -104°F (0-40° C). At temperatures below freezing, special precautions must be taken. Shielding, preheating, increasing extrudate temperature, and/or decreasing the rate of seaming may be necessary. Thawed subgrade moisture in the seam area shall not be tolerated. Frozen irregularities in the subgrade could cause problems. Temperatures outside the given range generally necessitate more frequent testing of trial welds.

High winds, or gusts of wind, always pose problems for liners. After unrolling the liner, the panels must be securely ballasted with sandbags. The seaming process, however, will necessitate the removal of some of the sandbags, which will leave any windward edge vulnerable to wind uplift. Properly orient the overlap to prevent wind uplift. Additional labor may be needed for the sole purpose of removing the sandbags immediately ahead of the seaming operation as it moves along, and immediately replacing them as the welder passes. Any dirt and moisture left behind during the movement of sandbags must be cleaned away.

13. FIELD TEST PROCEDURES

13.1 Non-Destructive Seam Testing

The installer shall non-destructively test every field seam over its full length. All test equipment shall be furnished by the installer.

13.1.1 Vacuum Box Testing

Equipment for testing extrusion seams shall be comprised of the following:

1. A vacuum box assembly consisting of a rigid housing, a transparent viewing window, a soft rubber gasket attached to the bottom, port hole or valve assembly, and a vacuum gauge.
2. Soapy solution in a plastic bucket with a mop.

The following procedures shall be followed by the installer:

1. Excess sheet overlap shall be trimmed away.
2. Wet a strip of geomembrane approximately 12 inches by the length of box with the soapy solution.
3. Place the box over the wetted area and compress.
4. Create a vacuum of 3 - 5 psi.
5. Ensure that a leak tight seal is created.
6. For a period of approximately 15 seconds, examine the geomembrane through the viewing window for the presence of animated soap bubbles.
7. If no animated bubbles appear after 15 seconds, close the vacuum valve and open the bleed valve, move the box over the next adjoining area with a minimum 3 inches overlap and repeat the process.
8. All areas where animated soap bubbles appear shall be marked, repaired and then retested.

The following procedures shall apply to locations where seams cannot be non-destructively tested.

1. If the seam is accessible to testing equipment prior to final installation, the seam shall be non-destructively tested prior to final installation.
2. If the seam cannot be tested prior to final installation, the seams shall be spark tested according to the spark tester manufacturer's procedures.

13.1.2 Air Pressure Testing (For Double Fusion Seams Only)

Equipment for testing double fusion seams shall be comprised of the following:

1. An air pump equipped with pressure gauge capable of generating and sustaining a pressure between 25 and 30 psi.
2. A pressure gauge equipped with a sharp hollow needle.

The following procedures shall be followed by the installer:

1. Seal one end of the seam to be tested.
2. Insert needle or other approved pressure feed device through the sealed end of the channel created by the double wedge fusion weld.
3. Seal the other end of the channel.
4. Energize the air pump to a pressure between 25 and 30 psi, close valve, allow 2 minutes for the injected air to come to equilibrium in the channel, and sustain pressure for approximately 5 minutes.
5. If pressure loss exceeds 4 psi, or pressure does not stabilize, locate faulty area, repair and retest.
6. If pressure does not drop below the acceptable value after five minutes, cut the air channel open at the opposite end from the pressure gauge. The air channel should deflate immediately indicating that the entire length of the seam has been tested.

13.2 Destructive Seam Testing

Destructive seam testing should be minimized to preserve the integrity of the liner. The installer shall provide the inspector with one destructive test sample per project specifications (usually once per 500 feet of seam length) from a location specified by the inspector.

13.2.1 Sampling Procedure

In order to obtain test results prior to completion of liner installation, samples shall be cut and marked by the installer as the seaming progresses. The installer shall also record the date, location, and pass or fail description. All holes in the geomembrane resulting from obtaining the seam samples shall be immediately repaired and vacuum tested.

13.2.2 Size and Disposition of Samples

The samples shall be 12 inches wide by 36 inches long with the seam centered lengthwise. The sample shall be cut into three equal-length pieces, one to be given to the inspector, one to be given to the owner's representative and one to the installer.

13.2.3 Field Laboratory Testing

The inspector shall test ten 1 inch wide specimens from his sample, five specimens for shear strength and five for peel strength. To be acceptable, four out of the five specimens must pass.

13.2.4 Independent Laboratory Testing

The owner, at his discretion and expense, may send seam samples to a laboratory for testing. The test method and procedures to be used by the independent laboratory shall be the same as used in field testing.

13.2.5 Procedures for Destructive Test Failure

The following procedures shall apply whenever a sample fails the field destructive test:

1. The installer shall cap strip the seam between the failed location and any passed test locations.
2. The installer can retrace the welding path to an intermediate location (usually 10 feet from the location of the failed test), and take a sample for an additional field test. If this test passes, then the seam shall be cap stripped between that location and the original failed location. If the test fails, then the process is repeated.
3. Over the length of seam failure, the installer shall either cut out the old seam, reposition the panel and reseam, or add a cap strip.

13.3 Defects and Repairs

All seams and non-seam areas of the geomembrane shall be inspected by the inspector for defects, holes, blisters, undispersed raw materials, and any sign of contamination by foreign matter. The surface of the geomembrane shall be clean at the time of inspection.

13.3.1 Evaluation

Each suspect location in seam and non-seam areas shall be non-destructively tested as appropriate in the presence of the inspector. Each location that fails the non-destructive testing shall be marked by the inspector, and repaired accordingly.

13.3.2 Repair Procedures

1. Defective seams shall be cap stripped or replaced.
2. Small holes shall be repaired by extrusion welding. If the hole is larger than 1/4 inch, it shall be patched.
3. Tears shall be repaired by patching. Where the tear is on a slope or an area of stress and has a sharp end it must be rounded prior to patching.
4. Blisters, large cuts and undispersed raw materials shall be repaired by patches.
5. Patches shall be done by extrusion welding. The weld area shall be cleaned no more than 10 minutes prior to the repair. No more than 10% of the thickness shall be removed by grinding. Welding shall commence where the grinding started and must overlap the previous seam by at least 2 inches. Reseaming over an existing seam without regrinding shall not be permitted. The welding shall restart by grinding the existing seam and rewelding a new seam.

Patches shall be round or oval in shape, made of the same geomembrane, and extend a minimum of 6 inches beyond the edge of defects. All patches shall be of the same material and thickness as the geomembrane.

13.3.3 Verification of Repairs

Each repair shall be non-destructively tested. Repairs that pass the non-destructive test shall be taken as an indication of an adequate repair. Failed tests indicate that the repair shall be repeated and retested until passing test results are achieved.

Daily documentation of all non-destructive and destructive testing shall be provided to the inspector by the installer. This documentation shall identify all seams that initially failed the test and include evidence that these seams were repaired and successfully retested.

13.3.4 Cover Soil Placement

The earthwork contractor shall place the soil cover layer over the liner system on a daily basis as soon as a lined area of the facility has been completed and accepted by the owner.

Extreme care shall be taken by the earthwork contractor not to damage the liner system during the cover soil placement. A minimum of 12 inches of cover soil is needed prior to placing any earth-moving machinery over the liner system. The soil and rock particles of the cover material shall be of such size and shape as not to damage the liner. The upper particles' size limit is usually $^{3}/_{8}$ inch. Angular or sharp rock fragments are not allowed.

The earthwork contractor should conduct a test on the job site simulating field subgrade, liner system, and cover soil placement. The earthwork contractor should use the proposed method of cover soil placement and equipment to verify the integrity of the liner. The liner installer is not responsible for damage to the liner as a result of using unsuitable cover material or improper methods of cover placement over the liner. That is the responsibility of the earthwork contractor.

Cover soil shall be placed on side slopes from the bottom to the top of the slope. During the cover soil placement, the driver shall not make sharp turns or sudden starts and stops. The machinery speed shall be slow. Frozen soils are not to be used as cover material unless screened prior to placement.

Cover soils shall be placed during the coolest time of the day to prevent folds in the liner. Special techniques shall be implemented to isolate small liner ripples and prevent the liner from folding over itself during cover soil placement.

13.3.5 Pipe Penetrations

Pipe boots should be isolated from the seasonal effects of liner expansion and contraction. Such penetrations should allow for reasonable access for extrusion welding and testing equipment.

14. BACKFILLING OF ANCHOR TRENCH

Unless otherwise specified, the anchor trench shall be backfilled and compacted by the earthwork contractor. Trench backfill material shall be placed and compacted according to project specifications.

Care shall be taken when backfilling the trenches to prevent any damage to the geomembrane.

15. GEOMEMBRANE ACCEPTANCE

The liner installer shall retain ownership and responsibility for the liner until installation is finished and verification of the adequacy of all field seams and repairs, including associated testing, is complete, at which time the owner shall accept the liner and assume ownership and full responsibility for it.

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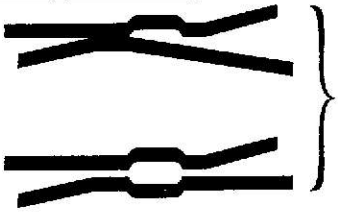
Locus-of-Break Codes and Descriptions of Breaks for Dual Wedge-Weld Seams*

Type of Break	Code	Break Description	Classification
	AD	Adhesion Failure. Complete separation on one or both sides of the air channel.	Non-FTB
	BRK	Break in Sheeting.	FTB
	SE-1	Break at outer edge of seam. Break can be either top or bottom sheet.	FTB
	SE-2	Break at inner edge of seam.	FTB
	AD-BRK	Break in first seam after some adhesion failure. Break can be either top or bottom sheet.	FTB

*Henry Haxo, Matrecon Inc., Alameda, CA.
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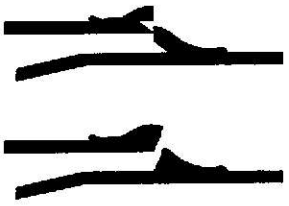
Locus-of-Break Codes and Descriptions of Breaks for Extrusion Fillet-Weld Seams*

Type of Break	Code	Break Description	Classification
	AD-1	Failure in adhesion. Specimens may also delaminate under the bead and break through the thin extruded material in the outer area.	Non-FTB
	AD-2	Failure in adhesion.	Non-FTB
	AD-WLD	Break through the fillet. Such breaks range from those that start at the edge of the top sheet to those that run through the fillet after some adhesion failure between the fillet and the bottom sheet.	FTB
	SE-1	Break at seam edge. Specimens may break anywhere from bead/outer area edge to the outer area/buffed area edge. (Applicable to shear tests only.)	FTB
	SE-2	Break at seam edge. Specimens may break anywhere from bead/outer area edge to the outer area/buffed area edge.	FTB
	SE-3	Break at seam edge. (Applicable to peel tests only.)	FTB
	BRK-1	Break in sheeting. A "B" in parenthesis after the code means the specimen broke in the buffed area. (Applicable to shear tests only.)	FTB
	BRK-2	Break in sheeting. A "B" in parenthesis after the code means the specimen broke in the buffed area.	FTB
	AD-BRK	Break in sheeting after some adhesion failure between the fillet and the bottom sheet. (Applicable to peel tests only.)	FTB
	HT	Break at the edge of the hot tack for specimens which could not be delaminated in the hot tack. (Applicable to shear tests only.)	FTB

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