FLEXIBLE GEOMEMBRANES (other than HDPE)

SPECIFICATION FOR THE SUPPLY, PANEL FABRICATION AND FIELD INSTALLATION OF

FLEXIBLE GEOMEMBRANE LINERS BASED ON

POLYPROPYLENE, PVC, EI ALLOY

AND SIMILAR NON-CRYSTALLINE MATERIALS.

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Further Information

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1. SCOPE OF WORK

The Scope of Work covered by this Specification is that required for the supply and installation of a flexible membrane liner system using a Polypropylene, PVC , EIA or other non-crystalline thermoplastic flexible membrane liner. This is a flexible membrane based on polypropylene which offers greater flexibility and multiaxial tension capability as well as freedom from environmental stress cracking.

Specific work items include:

- Preparation, inspection and acceptance of subgrade surfaces prior to placement of the flexible membrane liner.
- Supply and installation of all associated geosynthetic materials, geotextiles and geonets, leak detection systems, pipe penetrations, materials, anchors, anchor trenches and other ancillary materials and services necessary to complete all liner and floating roof systems described herein.
- Supply of all flexible membrane liner materials including provision of QA/QC certificates for raw materials and materials manufacture.
- Supply of all approved flexible membrane liner welding and QA/QC test apparatus and equipment.
- Provision of all flexible membrane liner proposed layout drawings (Shop Drawings) for approval by the Superintendent.
- Factory fabrication of flexible membrane liner into panels as set out on the proposed layout drawings including all packaging and wrapping and provision of QC/QA documentation.
- Deployment, welding, testing and commissioning of all flexible membrane liner, geotextiles, geonets and all other items and materials associated with this Specification including provision of QC/QA documentation.

2. STANDARDS

The following Standards are applicable to the materials and works covered by this Specification and shall be deemed to form part of this Specification as applicable.

ASTM D 413	Tensile Properties strip tensile test
ASTM D 570	Moisture Content
ASTM D 638	Strip Tensile Properties – Plastics (> 1 mm)
ASTM D 696	Thermal Shrinkage
ASTM D 882	Strip Tensile Properties – Plastics (< 1mm)
ASTM D 751	Coated Fabrics - Thickness, Grab Tensile, Strip Tensile, Peel Adhesion, Seam Strength, Hydrostatic Resistance and Blocking Resistance
ASTM D 1004	Tear Strength
ASTM D 1149	Ozone Resistance
ASTM D 1204	Dimensional Stability
ASTM D 1505	Density
ASTM D 1693	Stress Crack Resistance
ASTM D 1822	Impact Resistance
ASTM D 3083	Resistance to soil burial
ASTM D 4632	Grab Tensile – Geotextiles
ASTM D 4716	Transmissivity (longitudinal)
ASTM D 4833	Puncture Resistance
ASTM D 4885	Tensile Properties - Wide Strip Test
ASTM D 5199	Thickness - Optical Method
ASTM D 5397	Stress Crack Resistance (NCLT)
ASTM D 5617	Multiaxial Deformation
ASTM E 228	Coefficient of Thermal Expansion
ASTM G 26	UV Exposure - Xenon Arc
AS 3706.1 – 1990	Unit mass, thickness and general properties
AS 3706.2 – 1990	Wide strip tensile strength
AS 3706.3 – 1990	Trapezoidal tear strength
AS 3706.4 - 1990	C.B.R. Burst
AS 3706.5 - 1994	Drop Cone
AS 3706-7 - 1990	Pore Size - Geotextiles
AS 3706-9 - 1990	Permittivity
AS 3706-10 - 1990	Transmissivity (Radial)

3. CONTRACTOR

3.1 Contractor's Experience

The flexible membrane liner contractor shall demonstrate evidence of ability and experience to supply and install the nominated materials to the standards demanded in this specification. Details of experience must be provided and failure to demonstrate prior use and experience with the specified materials or similar materials shall be grounds for rejection.

The panel fabrication shall be carried out by an experienced firm customarily engaged in factory fabrication of individual widths of flexible membrane liner roll stock into large panels. The flexible membrane liner fabricator shall provide all necessary details relating to key personnel to demonstrate their experience in all facets of the flexible membrane liner panel fabrication including membrane inspection and acceptance, membrane deployment, thermal welding and the administration of quality assurance programs.

The panel deployment and field welding shall be carried out by an experienced firm accustomed to the deployment and field welding of large panels of flexible membrane liner. The flexible membrane liner installer shall provide all necessary details relating to key personnel to demonstrate their experience in all facets of the flexible membrane liner installation including subgrade preparation, inspection and acceptance, membrane deployment, thermal welding and the administration of quality assurance programs.

The flexible membrane liner contractor shall be required to register all key personnel, all welding plant and testing equipment prior to commencement and no changes to the registration list will be permitted without prior approval by the Superintendent.

3.2 As Constructed Drawings

Throughout the progress of this contract the flexible membrane liner contractor shall maintain an up-to-date set of progressive "As-Constructed" drawings detailing all elements of the flexible membrane liner layout including anchorage, flexible membrane liner roll numbers, location of all primary and secondary welds and all areas tested and repaired.

On the completion of the works the flexible membrane liner Lining contractor shall issue a complete set of "As-Constructed" drawings detailing all of the above data.

4. QUALITY MANAGEMENT SYSTEM

The whole of the works shall be subject to a Quality Assurance / Quality Control system that includes the following elements:

- A Manufacturers Quality Assurance program that includes raw materials control, process control and finished product control in accordance with the requirements of AS/NZS ISO 9002 - 1994.

- A Fabrication Quality Assurance program that includes deployed membrane inspection, welding process control and non-destructive and destructive testing in accordance with the requirements of AS/NZS ISO 9002 - 1994

- A Field Installation Quality Assurance program that includes deployed membrane panel inspection, welding process control and non-destructive and destructive testing in accordance with the requirements of AS/NZS ISO 9002 - 1994

The contractor is to provide full details of these programs to the Superintendent prior to the commencement of the work.

At each stage of the work the contractor is to nominate a person who is to act as QA/QC officer and who shall coordinate all testing and shall retain all results, reports and certificates as they are generated for that section of the work.

5. FLEXIBLE MEMBRANE LINER

5.1 Flexible Membrane Liner Material

The flexible membrane liner is to be a flexible geomembrane manufactured from a non-crystalline thermoplastic material such as:

- Flexible polypropylene (FPP) based on the Catalloy polymerisation process with a suitable stabiliser package based on HALS to give the required UV stability.
- Polyvinyl chloride (PVC) with suitable plasticiser and stabiliser packages. PVC will normally require some form of covering in order to give the service life required under UV exposure.
- Ethylene Interpolymer alloy on a PVC base

The flexible membrane liner may be based on a plain (unreinforced) material or it may be based on materials reinforced with suitable high tensile polyester scrim reinforcement.

5.1.1 Plain (Unreinforced) Flexible Membrane Liner Material

Unreinforced Flexible Membrane Liner is to be made by a single pass calendering or extrusion which may require a subsequent lamination process to achieve the desired thickness. The finished flexible membrane liner is to be uniform in colour, thickness and surface appearance and is to provide exceptional flexibility, seaming capability, multiaxial elongation and puncture resistance characteristics.

The flexible membrane liner properties shall comply with the test result listing provided under Appendix A.

5.1.2 Reinforced Flexible Membrane Liner Material

Reinforced Flexible Membrane Liner is to be made by a calendering and lamination or a co-extrusion or a spread coating process which incorporates a woven polyester reinforcing scrim between two layers of the polypropylene liner material. The finished flexible membrane liner is to be uniform in colour, thickness and surface appearance and is to provide exceptional flexibility, seaming capability , dimensional stability and puncture resistance characteristics. There is to be no evidence of incomplete lamination or channeling around the reinforcement.

The flexible membrane liner properties shall comply with the test result listing provided under Appendix B.

5.2 Flexible Membrane Liner Delivery and Acceptance

The flexible membrane liner materials shall be provided in rolls with a minimum seamless width of 2 metres. Each roll shall be labeled so as to provide the following identifying data:

- Product Description
- Roll Number
- Batch Number / Order Number
- Width
- Thickness
- Roll Length

This information must be provided prior to or with delivery of all materials to the panel fabrication premises or to the construction site. All materials for these works shall be certified prior to installation by the manufacturer's laboratory test reports.

The tests to be used for these reports will be as set out in the Quality Assurance documentation as presented by the contractor and approved by the Superintendent as complying with this specification. These tests may, at the Superintendent's discretion be supplemented by additional independent laboratory testing.

On taking delivery of materials and after unrolling and spreading out the flexible membrane liner sheet and aligning same, the entire surface area of each and every roll shall be inspected to ensure that there are no tears, abrasions, indentations, cracks, thin spots, or other faults in the material.

The formulation and manufacture shall be uniform such that all properties detailed within the specification will be met at all times.

The materials shall be free from surface folds, holes, blisters, undispersed raw materials and any sign of contamination by foreign matter. Manufacturing process irregularities which present irregular thickness and imperfections that will not provide even stress distribution throughout the sheet will be rejected and replaced.

5.3 Transport and Handling

Materials shall be stored at the factory or on site in an area approved by the Superintendent.

The flexible membrane liner contractor shall be responsible for all freight, transportation to site and handling and storage on site, including site security.

Materials shall be stored in such a manner that no surface irregularities or other influences will apply point loads, abrasions, cuts or distortions or other forms of damage to the rolls.

No more than two rolls of flexible membrane liner shall be stacked one on top of the other. The Superintendent may direct the flexible membrane liner contractor to make adjustments to the stored materials if evidence of damage is observed. Any defects or damage detected shall be repaired to acceptable standards or totally replaced by the flexible membrane liner contractor.

6. SITE PREPARATION

6.1 Subgrade Preparation

All subgrade surfaces over which the flexible membrane liner materials shall be placed, shall be prepared to the appropriate standards. It is the responsibility of the flexible membrane liner contractor to formally accept all surfaces prior to the application of the flexible membrane liner materials. The flexible membrane liner contractor shall inspect the prepared subgrade for each area with the Superintendent who will jointly sign a form to signify acceptance and takeover of a particular area. Transfer to the flexible membrane liner contractor of responsibility for maintenance of the subgrade and subsequent performance of the membrane in that area shall occur with the provision of such written acceptance.

In general, all prepared subgrade surfaces shall consist of a flat, smooth, compacted surfaces free of rocks or other foreign matter. The subgrade and surface shall consist of an existing concrete surface with any loose rocks and other particles having a maximum particle size of 8mm for reinforced flexible membrane liner material and 16 mm for unreinforced flexible membrane liner material. This surface shall contain no angular, sharp or pointed material or edges.

The surface shall provide a firm unyielding foundation for the flexible membrane liner with no sudden, sharp or abrupt changes or breaks in the grade. No standing water or excessive moisture shall be allowed. Surfaces to be lined shall be flat within tolerances of +/- 100mm over any 5 metres. Particular caution is to be taken with concrete channels built in clay soils with a high water table where pore water pressure changes are likely to induce movement.

Any area of sub-grade not meeting these standards shall be brought up to standard before proceeding with membrane deployment. Alternatively the superintendent may authorise the use of a geotextile underlay as set out below without diminishing the responsibilities of the parties in relation to subgrade approval and acceptance.

6.2 Surface Maintenance

Having accepted the subgrade finish, it shall remain the responsibility of the flexible membrane liner contractor to maintain the subgrade in an approved condition during the period of construction and immediately prior to the application of the geotextile if required and the flexible membrane liner lining system.

All costs associated with the reinstatement of previously prepared subgrade will be borne by the flexible membrane liner contractor.

6.3 Anchor trenches

All anchor trenches shall be excavated to line and level as indicated on the drawings. They shall be set back a minimum of 1 m from the crest of any slope. After the flexible membrane liner is placed they shall be backfilled with excavated spoil with water added if appropriate to assist with compaction. Compaction shall be as set out on the drawings with at least 85% of standard compaction required for liner anchorage.

6.4 Anchorage Beams

Anchorage beams if required shall be constructed in plain or reinforced concrete to the lines and levels set out on the drawings with either cast-in bolts or drilled anchors. The surface finish shall be a smooth steel trowel surface with no rough edges or protrusions.

Care shall be taken to protect the threads of embedded bolts and to protect the flexible membrane liner from protruding bolts.

6.5 Geotextile Materials

A geotextile material may be required in order to provide protection for the flexible membrane liner from rough or jagged elements in the subgrade or to provide underliner drainage or gas venting. Such geotextile shall be selected as appropriate for individual cases.

It shall remain the responsibility of the flexible membrane liner contractor to install the geotextiles in a manner such that the sub grade or other surfaces do not become disturbed and such that the composite lining system is not adversely affected either during construction or during the life of the facility. Where such disturbance does occur, the flexible membrane liner contractor shall reinstate the area to conform with the requirements of this Specification.

The geotextile shall always be ballasted and anchored within anchor trenches or by using sand filled ballast bags or similar, to ensure that the geotextile is not displaced or uplifted by wind or other cause.

7. CONSTRUCTION PANEL LAYOUT

The flexible membrane liner contractor shall submit for approval a detailed drawing clearly defining the total panel layout, all primary welds, all secondary welds, corner arrangements, weld crossover, offsets and base to embankment weld locations for approval by the Superintendent. Any changes, deviations, tests, repairs and other construction data can only be made with the written approval of the Superintendent and shall be fully detailed on "as constructed" drawings.

The liner and weld layout shall take account of the following requirements:-

- No horizontal field welds shall be permitted within the slope area and due care and attention shall be given to ensuring that welds shall be running directly up the embankment slopes. In corners of ponds it shall be permitted to have short field seams of no more than 2 m running at close to horizontal.

- The flexible membrane liner and the geotextile shall terminate on the bottom of the anchor trench located at the top of the embankment. The slope lining shall enter the base of the reservoir a minimum of 1.5 metre from the toe into the base before any perimeter base welds are permitted.

- Crossover or T - joint welds must be offset a minimum of 300 mm to avoid multi-layer weld lapping.

- Individual panels of flexible membrane liner materials shall be supplied in dimensions to suit the approved layout. The materials shall be in continuous sheets down slopes or across the base and shall be overlapped over adjacent membrane sheets by a minimum of 50mm or to an additional width as demanded by the type of welding equipment to be employed.

The flexible membrane liner contractor will be responsible for making any allowances considered necessary to accommodate predictable differential settlements of the subgrade, and/or variations in temperature. In particular, allowances shall be made to accommodate the ultimate thermal movement for the membrane during the coldest periods in the region.

8. GEOMEMBRANE PANEL ASSEMBLY

8.1 Fabrication

The highly flexible membrane liner materials covered by this specification are typically less than 1 mm thick and quite flexible. As such they lend themselves to pre-fabrication of panels which reduces the on-site welding requirements. Pre-fabrication in an appropriately prepared area helps to eliminate some of the difficulties and uncertainties associated with field installation work.

8.1.1 Fabrication Area

Fabrication shall be carried out in a factory environment which provides protection from winds and weather changes. Basic requirements are a large flat area with a geomembrane liner deployment device. Enhancements may include overhead gantry cabling, vacuum slot restraint and mechanical handling aids.

Because the floor is normally concrete care should be taken to remove any loose stones that may damage the liner material.

8.1.2 Visual Inspection of Liner

The liner and seam areas shall be subject to 100% visual inspection during the course of the material deployment and fabrication.

8.2 Seam Welding

8.2.1 Seam Welding Methods

Seaming shall be by heat fusion methods. Solvent welding or adhesives shall not be permitted. Heat fusion (hot wedge and hot air) facilitates weld quality confirmation by destructive and no-destructive methods.

The two preferred methods in use are:

(a) Automatic travel hot wedge or hot air welding by machines which enable the operator regulate the temperature of the air stream or wedge and to regulate the speed of welding to ensure adequate fusion without excessive melting or burn-through. Such machines may provide single welds or a double weld separated by an air gap for weld integrity testing.

(b) Extrusion Fillet Welding by hand held extrusion welding machines. The weld formed shall be a single fillet weld or created by laying a molten bead of the same polypropylene material over the interface of the two faces to be joined. This shall only be used for patching, curves and other welds not accessible to the automatic machines and is not used for PVC or EIA materials.

(c) Manual hot air welding using a hot air gun and roller. This shall only be used for patching, curves and other welds not accessible to the automatic machines.

The welding equipment shall have all controls of temperature and speed functioning properly and these functions are to be confirmed by a calibration certificate not more than 180 days old.

8.2.2 Seaming Procedures

The seaming methods for the major welding methods are:

- Automatic welds. The panel edges shall be aligned with an overlap of approximately 50 - 100 mm as appropriate for the welder in use. The welder shall be positioned and drive engaged to set the welder in motion. The welder is be steered and controlled continuously by the operator.

- Manual Hot Air Welds. Patches are to be cut with a minimum overlap of 150 mm and tacked into place. The hot air gun is inserted and a rear tack weld made to form a pocket to trap the hot air. The material is then rolled down progressively working towards the outside of the pocket to achieve a continuous wrinkle free weld.

Any proposal to use other welding methods shall be subjected to a review of effectiveness and performance by the Superintendent whose decision shall be final.

The liner is pulled from the roll and positioned with appropriate overlap for the welder in use. The welders are positioned with the membrane inserted and the drives engaged. An operator steers and controls each weld continuously to ensure proper tracking and allow constant observation of the liner and the weld as it is made.

8.3 Non destructive Seam Continuity testing

It is important that non-destructive seam testing proceed continuously as the installation is carried out. Delay of testing until the work is nearly complete is entirely unsatisfactory.

8.3.1 Concept

Non destructive testing of welded seams is carried out to ensure continuity of the seams and 100% of the seams shall be tested in this way. These procedures are not intended to provide information about seam strength.

The air pressure test method shall be used for all seams produced with this seaming method and the other non-destructive methods shall be used for all other seams.

8.3.2 Vacuum Testing

For vacuum testing a box with a transparent top, neoprene rubber base seal and a connection to a suitable vacuum device is required. A soapy solution is applied to the geomembrane surface, the vacuum box positioned and a vacuum of 35 kPa drawn on the box. After observation for bubbles for 10 seconds the vacuum is released and the process repeated on the next piece of seam with a suitable overlap to ensure continuity. For very flexible membranes a restraining grid may be required at the base of the vacuum box.

Vacuum testing of seams shall be reported on the appropriate daily report form as set out in the quality plan.

8.3.3 Manual Probe Testing

This requires a blunt tipped probe such as a screwdriver or circlip remover. The probe is gently and systematically used to feel the weld bead and ensure continuity along its length.

8.3.4 Air pressure testing

Air pressure testing takes advantage of the capacity of some wedge and hot air welders to produce two continuous welds with an air gap between them. An internal pressure is applied to this gap and the weld accepted if no loss of pressure occurs. The applied pressure is normally 200 kPa and the testing period 5 minutes. Pressure gauges are required at each end of the weld to ensure continuity - alternatively the seal can be released at the end without a gauge and the pressure drop observed to ensure continuity.

An alternative method is to pressurise the gap as the weld is being made and to observe the continuity of the air channel as the weld is being made.

Pressure testing of seams shall be reported on the appropriate daily report form as set out in the quality plan.

8.3.5 Failed Weld Procedure

Should a weld fail a vacuum box or probe test the area is marked for subsequent repair or patching. Should a weld fail a pressure test it is necessary to progressively halve the length of weld tested in order to eventually isolate the defective portion.

8.4 Destructive Testing of Seams

It is important that destructive seam testing proceed continuously as the installation is carried out. Delay of testing until the work is nearly complete is entirely unsatisfactory.

8.4.1 Concept

The purpose of destructive seam tests is to:

(a) evaluate the consistency of welds produced by an operator dependent procedure.

(b) provide a check on the strength and integrity of the welds as produced in practice.

8.4.2 Frequency and Location

Destructive seam samples are to be taken from the work at random at locations selected by the Superintendent or his representative based on a distribution of one destructive sample for every 1000 linm of seam. These are to be in addition to destructive samples provided from welder start-up tests which are to be provided at each resumption of work after a break provided that there are two start up welds sample tests per day.

If agreed destructive sampling may be based on test pieces produced at the beginning or end of a weld run with machine settings and other factors as for the production weld.

8.4.3 Sampling Procedure

The weld samples shall be at least 1m long and 0.6 m wide with the seam in the centre. The sample shall be assigned a number and its location will be noted on the report form for destructive testing and will also be noted on the as-built drawing.

The sample shall be divided into three equal sections for use as follows:

(a) the first shall be used to provide 6 No 25 mm wide nominal weld strips for field testing in peel and shear.

(b) the second is to be retained by the Superintendent for laboratory testing duplicating the field testing.

(c) the third is to be archived for reference in case of dispute or other future incident

8.4.4 Factory Laboratory or Field Testing

The sample shall be cut on site to provide 6 No 25 mm wide nominal weld strips for field tensiometer testing in peel. Weld acceptance shall be the basis of Film Tear Bond criteria as per Appendix C. If suitable equipment is available the samples may be die cut to evaluate seam strength in shear tests as per the criteria in section 8.4.5.

8.4.5 Independent Laboratory Testing

The sample is used at the Superintendent's discretion to provide 6 No. 25 mm samples die cut in the laboratory for testing in peel and shear duplicating the field testing. Acceptance criteria shall be Film Tear Bond as per Appendix C and achievement of 80% of sheet ultimate tensile strength in shear mode.

8.4.6 Failed Weld Procedure

In the event of failure of a field destructive test sample in either field or laboratory testing two further samples shall be taken 5m each side of the failed sample. If both these samples pass testing the weld between them shall be patched and the seam accepted. If one or both fail, further samples at 5 m intervals shall be taken until a passing sample is obtained.

Alternatively the fabricator may choose to cut out a failed weld and replace it entirely.

8.5 Panel Storage and Delivery to site.

8.5.1 Panel packing and marking

The panels shall be concertina folded and then rolled or folded to facilitate deployment at site. The panels shall be marked with the panel number as per the panel layout drawing and be marked to indicate directions for deployment.

8.5.2 Panel storage and delivery

Panels shall be stored on pallets with suitable cover if outside to provide protection from weather and UV exposure. Particular care is to be taken with packing and protective wrapping to prevent rubbing of membrane edges or folds against container walls or other surfaces.

The Superintendent shall approve site storage space in a location (or several locations) such that on-site transportation and handling are minimised. Storage space should be protected from theft, vandalism, passage of vehicles, and be adjacent to the area to be lined.

8.5.3 Reporting

Reporting on panel fabrication including non-destructive and destructive QC sampling and testing shall be on a form provided for each panel with any relevant observations about the liner or the welding processes.

9. GEOMEMBRANE FIELD INSTALLATION

9.1 Geomembrane Panel Placement

Immediately prior to the installation of the geomembrane the subgrade shall be inspected by the Installer and the Superintendent. If the surface is acceptable this shall be indicated on the form provided for this purpose. If the surface is not acceptable this shall be indicated on the same form with an appropriate action and re-inspection plan.

The integrity and stability of the subgrade including any surface water management is the responsibility of the Superintendent and the relevant consultants and contractors. Geomembranes are relatively impervious barriers only and should not be relied upon to provide any structural assistance to the containment structure. Acceptance by the installer of a part of the subgrade applies to the area nominated and may not apply to the whole site.

9.1.1 Field Panel Identification

At the time of fabrication each panel shall be given a panel number as indicated on the panel layout drawing and panels shall be deployed as noted on that plan. Any changes to these numbers shall be noted on the panel layout report and appropriate changes shown on the geomembrane liner as-built drawing.

9.2 Field Panel Location

Field panels are to be installed at the location indicated on the panel layout out plan unless modified as a result of field conditions. Any modifications are to be noted on the Field Deployment Report and adjustment made to the as-built drawings.

9.2.1 Installation Schedule

Field panels may be deployed and welded:

(a) progressively one panel at a time or,

(b) a number of panels may be deployed prior to welding in order to maximise coverage of prepared subgrade.

Whichever approach is chosen adequate temporary ballast such as sand bags shall be provided for protection against wind effects. Only those panels should be deployed that can be welded on that same day.

Field panel deployment shall be recorded daily on the report for that purpose.

9.2.2 Weather Conditions

Welding is not to take place during precipitation, in the presence of excessive atmospheric moisture (fog and dew) or excessive winds. Care should also be taken with extremes of hot or cold ambient temperature conditions that make controlled welding temperatures difficult. Weather conditions are to be recorded on the Daily Report.

9.2.3 Placement Method

The method employed to deploy and place the geomembrane shall be chosen to ensure that no damage is caused to the geomembrane or to the subgrade by handling, trafficking, excessive heat, leakage of hydrocarbons, dragging of liner, crimpling or wrinkling. Smoking, unsuitable footwear and other sources of possible damage are to be prevented.

If necessary protective layers of soil and/or geotextile shall be placed to protect the geomembrane in trafficked areas.

9.2.4 Damage

The installer is to inspect each panel after placement for possible defects or damage. Any damaged areas are to be marked and repaired using procedures established in accordance with section 9.4.

9.3 Field Seaming

9.3.1 Seam Layout

Field seams shall be indicated on the panel layout drawing. Any variation to this seaming layout shall be indicated on the daily welding report and adjustments made to the as-built drawings. Seams shall be identified by a numbering system compatible with the panel identification numbering system.

Seams are to oriented down any slope rather than across it. Any cross slope weld is to be at least 1.5m from any change of plane.

9.3.2 Seaming Equipment and Materials

Seaming shall be by heat fusion methods. Solvent welding or adhesives shall not be permitted. Heat fusion (hot wedge and hot air) facilitates weld quality confirmation by destructive and no-destructive methods.

The preferred methods in use are:

- Automatic travel hot wedge or hot air welding by machines which enable the operator regulate the temperature of the air stream or wedge and to regulate the speed of welding to ensure adequate fusion without excessive melting or burn-through. Such machines may provide single welds or a double weld separated by an air gap for weld integrity testing.

- Extrusion Fillet Welding by hand held extrusion welding machines. The weld formed shall be a single fillet weld or created by laying a molten bead of the same polypropylene material over the interface of the two faces to be joined. This shall only be used for patching, curves and other welds not accessible to the automatic machines and is not used for PVC or EIA materials.

- Manual hot air welding using a hot air gun and roller. This shall only be used for patching, curves and other welds not accessible to the automatic machines.

The welding equipment shall have all controls of temperature and speed functioning properly and these functions are to be confirmed by a calibration certificate not more than 180 days old.

Any proposal to use other welding methods shall be subjected to a review of effectiveness and performance by the Superintendent whose decision shall be final.

9.3.3 Seam Preparation

Prior to any welding the panels are to be aligned with appropriate overlaps for the equipment in use and no wrinkles or kinks. The surfaces to be welded shall be clean and dry.

9.3.4 Weather Conditions

Field welding quality is impacted by excesses of high or low ambient temperature and by excessive wind.

Specific field conditions, geomembrane sheet thickness and other factors shall influence the limits of acceptable atmospheric conditions but welding outside of the range 0 deg C to 40 deg C is likely to be difficult and unreliable. Excessive wind shall create difficulties in maintaining panel alignment as ballast is removed for welding such that continuing work is impracticable. Care needs to be taken that wind chill factor is not reducing welding temperature such that fusion is inadequate or that excess heat is being used to overcome wind chill.

9.3.5 Trial (Pre-weld) Seams

Trial seams shall be made on off-cut or fragment pieces of liner in order to verify that adequate seams can be produced by the chosen equipment and settings in the prevailing conditions. It is important that the conditions under which these seams are made reflect the actual conditions influencing the seam welding. Frequency of trial seams shall be based on any resumption of work after a break or any change in conditions but shall not be less than twice per day per machine and/or operator.

The seams shall be at least 1 m long with adequate 'tails' each side of the weld for testing. Test samples shall be cut from the weld approximately 25 mm wide and these shall be tested in shear and peel using a field tensiometer. The specimens shall pass or fail according to film tear bond criteria set out in Appendix C. If two out of three test samples should fail the trial weld is to be rejected, and changes made to welding conditions to produce a trial weld with two out of three samples passing.

Trial (Pre-weld) seams production and testing is to be recorded on the appropriate form.

9.3.6 Seaming Procedures

The seaming methods for the major and preferred welding methods in use are:

- Automatic welds. The panel edges shall be aligned with an overlap of approximately 50 mm as appropriate for the welder in use. The welder shall be positioned and drive engaged to set the welder in motion. It may be desirable to have a drag sheet of liner material placed under the welder and dragged along to provide a smooth surface for the welder to roll on. The welder is steered and controlled continuously by the operator. Should any 'fishmouths' occur they are to be slit and patched. T-joints are also to be patched. Welding is to extend at least 500 mm beyond the crest and into the anchor trench.

- Manual Extrusion Welds. The panel edges shall be aligned with an overlap of approximately 100 - 150 mm and a hot air tack weld laid in the overlap to stop the overlapped sheet from shifting. The surfaces shall be thoroughly cleaned and dried. The extruder shall be purged of any preheated extrudate and the weld bead shall be laid carefully along the line of the edge of the top sheet such that the fillet is evenly distributed between the two sheets.

- Manual Hot Air Welds. Patches are to be cut with a minimum overlap of 150 mm and tacked into place. The hot air gun is inserted and a rear tack weld made to form a pocket to trap the hot air. The material is then rolled down progressively working towards the outside of the pocket to achieve a continuous wrinkle free weld.

Any proposal to use other welding methods shall be subjected to a review of effectiveness and performance by the Superintendent whose decision shall be final.

9.4 Non destructive seam continuity testing

It is important that non destructive seam testing proceed continuously as the installation is carried out. Delay of testing until the work is nearly complete is entirely unsatisfactory.

9.4.1 Concept

Non destructive testing of welded seams is carried out to ensure continuity of the seams and is to be applied to 100% of the field seams. The procedures are not intended to provide information about seam strength.

The air pressure test method shall be used for all seams produced with this seaming method and the other non-destructive methods shall be used for all other seams.

9.4.2 Vacuum Testing

For vacuum testing a box with a transparent top, neoprene rubber base seal and a connection to a suitable vacuum device is required. A soapy solution is applied to the geomembrane surface, the vacuum box positioned and a vacuum of 35 kPa drawn on the box. After observation for bubbles for 10 seconds the vacuum is released and the process repeated on the next piece of seam with a suitable overlap to ensure continuity. For very flexible membranes a restraining grid may be required at the base of the vacuum box.

Vacuum testing of seams is reported on the appropriate daily report form.

9.4.3 Manual Probe Testing.

This requires a blunt tipped probe such as a screwdriver or circlip remover. The probe is gently and systematically used to feel the weld bead and ensure continuity along its length.

9.4.4 Air pressure testing

Air pressure testing takes advantage of the capacity of some wedge and hot air welders to produce two continuous welds with an air gap between them. An internal pressure is applied to this gap and the weld accepted if no loss of pressure occurs. The applied pressure is normally 200 kPa and the testing period 5 minutes. Pressure gauges are required at each end of the weld to ensure continuity - alternatively the seal can be released at the end without a gauge and the pressure drop observed to ensure continuity.

An alternative method is to pressurise the gap as the weld is being made and to observe the continuity of the air channel as the weld is being made.

Pressure testing of seams is reported on the appropriate daily report form.

9.4.5 Failed Weld Procedure

Should a weld fail a vacuum box or probe test the area is marked for subsequent repair or patching. Should a weld fail a pressure test it is necessary to progressively halve the length of weld tested in order to eventually isolate the defective portion.

9.5 Destructive testing of Seams

It is important that destructive seam sampling and testing proceed continuously as the installation is carried out. Delay of testing until the work is nearly complete is entirely unsatisfactory.

9.5.1 Concept

The purpose of destructive seam tests is to:

(a) evaluate the consistency of welds produced by an operator dependent procedure.

(b) provide a check on the strength and integrity of the welds as produced in practice.

9.5.2 Frequency and Location

Destructive seam samples are taken at random at locations selected by the Superintendent or his representative based on a distribution of one sample for every 300 linm of field seam. They are to be taken in addition to the start-up seam samples set out elsewhere in this document.

Location of destructive seam test samples shall be recorded on the appropriate form and shown on the as-built drawings.

9.5.3 Sampling Procedure

The weld samples shall be at least 1m long and 0.6 m wide with the seam in the centre. The sample shall be assigned a number and its location shall be noted on the report form for destructive testing and shall also be noted on the as-built drawing.

The sample shall be divided into three equal sections for use as follows:

(a) the first shall be used to provide 6 No 25 mm wide nominal weld strips for field testing in peel.

(b) the second is to be retained by the Superintendent or Geosynthetic Quality Assurance Consultant for laboratory testing.

(c) the third is to be archived for reference in case of dispute or other future incident

9.5.4 Field Testing

The sample shall be cut on site to provide 6 No 25 mm wide nominal weld strips for field tensiometer testing in peel. Weld acceptance shall be the basis of Film Tear Bond as per Appendix C. and results shall be reported on the appropriate form.

9.5.5 Laboratory Testing

The sample is used to provide 6 No. 25 mm samples die cut in the laboratory for testing in peel and shear as set out in Appendix C. Acceptance criteria shall be Film Tear Bond as per Appendix C and achievement of 90% of sheet ultimate tensile strength in shear mode.

9.5.6 Failed Weld Procedure

In the event of failure of a field destructive test sample in either field or laboratory testing two further samples shall be taken 5m each side of the failed sample. If both these samples pass testing the weld between them shall be patched. If one or both fail further samples at 5 m intervals shall be taken until a passing sample is obtained and the intervening weld shall be regarded as defective and be repaired.

9.6 Defects and Repairs

Any defects that require repair shall be patched providing a minimum overlap of 150 mm for manual welding as per clause 9.3.6. If a patch or cap is large enough it is permissible to trim the liner to enable the use of the automatic welder if desired.

9.6.1 Identification

All repairs and patches are to be allocated a number and details are to be noted on the seam welding report and on the as-built drawings

9.6.2 Verification of Repairs

All repairs and patches are to be subject to non destructive testing as set out in section 9.3.7.

9.7 Penetrations and other 'Specials".

Termination of the liner and penetrations at sumps and pipes cannot normally be tested by destructive or non destructive methods yet they can be a critical weak link in the effectiveness of the geomembrane liner. They are therefore technique and workmanship dependent and the following procedures are to be followed:

- the precise technique shall be discussed at a site meeting and drawn on paper before commencement.

- the work shall be observed by the Superintendent or other informed party who shall probe test the welds if appropriate prior to approval.

- Consideration in critical work should be given to the incorporation of earthing mechanisms to facilitate high voltage spark testing.

For pipe terminations in existing work the preferred method is a fabricated 'boot' which is fitted over the pipe and welded to the body of the membrane. A stainless steel clamp or hose clip is then fitted over the pipe and boot and silicon rubber is used to prepare the pipe surface.

For liner system termination on relatively flat concrete surfaces a batten system with a closed cell neoprene or similar foam rubber strip is to be used. The batten is normally stainless steel 50 mm x 6 mm (although thinner angle section can be used) and the bolts are at 150 mm centres. The batten is placed over the liner edge and the foam strip is compressed between the liner and the concrete. Silicon rubber or other preparation is to be used to improve the finish of the concrete.

9.8 Anchor trench Backfilling

Anchor trench backfilling shall be the responsibility of the membrane liner contractor. Care shall be taken in backfilling to ensure that the trench has not been softened by standing water and that the backfill material contains no rocks etc likely to damage or tear the liner.

Care should be taken with backfilling and ambient temperatures to avoid excess tension or 'bridging' in the liner on cooling.

9.9 Soil Cover and other Materials

Soil cover shall be fine grained material such as sand particularly if traffic is to operate over the lined area. A geotextile layer can provide cushioning against possible puncture but care should be taken on slopes because of the possible reduction in friction angles.

Normally soil cover of 300 mm is adequate for short term construction traffic by light equipment. For prolonged or heavier traffic cover of 500 mm or more may be preferable. These considerations will vary with the details of the materials and the techniques selected for the cover material placement.

For more critical work consideration should be given to independent observation of the backfilling process.

10. RECORDS

The QC/QA records shall comprise all of the forms listed in the Quality Plan in addition to the as-built drawings. The installation shall prepare two bound copies of these documents and provide them to the superintendent prior to the release of a final certificate for the work.

The finished installation shall be accepted by the superintendent as complete when the following documents have been assembled:

- Manufacturers material tests certification
- Fabrication and Field Installation QC/QA records as set out above

The superintendent may also require a final site inspection prior to final acceptance of the work. This inspection may give rise to a list of minor works and maintenance items that shall not impede acceptance. Acceptance may be held back in the event of major work items incomplete or major defects.

Appendix A.

TYPICAL SPECIFICATIONS UNREINFORCED MATERIALS

PROPERTY	TEST METHOD & CONDITIONS	PVC 1.0 mm thick	POLYPROPYLENE 1.0 mm thick
Thickness (min)	ASTM D5199 Optical Method	1.0 mm +/- 7%	1.0 mm +/- 7%
Breaking load (min	ASTM D882 Method A	14 MPa	15.0 MPa
Elongation at break (average)	ASTM D882 Method A	250 %	700 %
Tear strength (min)	ASTM D1004	47 N/mm	50 N/mm
Puncture Resistance (min)	ASTM D 4833	Not Quoted	225 N
Hydrostatic Resistance	ASTM D751 Method A	814 kPa	650 kPa
Seam peel adhesion strength (25 mm wide strips)	ASTM D413 Per Annexure A of NSF 54	45 N/25 mm	89 N/25 mm
Dimensional Stability	ASTM D1204 82 deg C / 1 hr.	+/- 3%	+/- 1.0 % max
Coefficient of Thermal Expansion	ASTM E228	15 x 10-5 cm/cm/^{o}C	12 x 10-5 cm/cm/^{o}C
Water Extraction	ASTM D 1239	0.35 % max	N.A.
Volatile Loss	ASTM D 1203 Method A	0.5 % max	N.A.
Ultra Violent Light Resistance	Emmaqua	Not Quoted	3 million Langleys no damage
Ultra Violent Light Resistance	ASTM G26 Xenon Arc 80 deg C	Not Quoted	6000 hrs - pass

These results are drawn from manufacturers published information. The reader should refer to current information from the manufacturer(s) under consideration before use.

Appendix B.

TYPICAL SPECIFICATIONS
REINFORCED MATERIALS

PROPERTY	TEST METHOD & CONDITIONS	EIA-R 1.14mm thick (eg. SEAMAN XR-5)	REINFORCED POLYPROPYLENE 1.14 mm thick
Thickness (min)	ASTM D5199 Optical Method	1.02 mm	1.04 mm
Breaking load (min	ASTM D751 Method A – Grab Test	2.1 kN	1.1 kN
Elongation at break (average)	ASTM D751 Method A – Grab Test	~25% (from graph)	22 %
Wide Strip Breaking Load and Elongation	ASTM D4885 200 mm strip	Not Quoted	5.76 kN & 26%
Tear strength (min)	ASTM D751 Method B	0.56 kN	0.24 kN
Puncture Resistance (min)	FTMS 101C	0.62 kN Method 2065	0.93 kN Method 2031
Hydrostatic Resistance	ASTM D751 Method A	3.4 MPa	1.72 Mpa
Ply adhesion (min)	ASTM D413 Machine method	67 N/25 mm	67 to 89 N/25 mm
Bonded seam strength (min) (100/25 mm grab test)	ASTM D751 Per Annexure A of NSF 54	1.42 kN	0.89 kN
Seam peel adhesion strength (25 mm wide strips)	ASTM D413 Per Annexure A of NSF 54	78 N/ 25mm	89 N/25 mm
Dimensional Stability	ASTM D1204 82 deg C / 1 hr.	2.0 % max	1.0 % max
Coefficient of Thermal Expansion	ASTM E228	1 x 10-6 cm/cm/^{o}C	2 x 10-6 cm/cm/^{o}C
Ozone Resistance	ASTM D1149 3 ppm @ 40^{o}C	no effect	no effect
Ultra Violent Light Resistance	Emmaqua	3 million Langleys no damage	3 million Langleys no damage
Ultra Violent Light Resistance		8000 hrs - pass Carbon Arc Weatherometer	6000 hrs - pass ASTM G26 Xenon Arc 80 deg C

These results are drawn from manufacturers published information. The reader should refer to current information from the manufacturer(s) under consideration before use.

Appendix C

FILM TEAR BOND WELD SAMPLE TEST CRITERIA.

The basic aim of laboratory testing of weld samples is to ensure that the welds are capable of effectively transmitting tensile forces that may be imposed on the liner. Tensile testing is carried out using both a shear mode and a peel mode to establish the minimum strength across the weld and to ensure that the weld has achieved a sound bond.

Both tests use the same method based on ASTM D4437 for field seams and ASTM D 4545 for factory seams using a 25 mm wide specimen and a testing speed of 50 mm per minute. Adequate curing or conditioning time shall be allowed to ensure that the test results are not influenced by residual heat or other temporary factors.

For the peel test the criteria is based upon the mode of failure. The desired mode is a Film Tear Bond (FTB) which requires that the weld face not peel apart and that the weld fail by necking and elongation in other parts of the specimen. In the case of reinforced materials the desired failure mode is by peeling of the material from the reinforcing scrim.

For the shear test the mode of failure is noted but is not critical. Pass criteria is that the ultimate tensile strength of the weld should exceed 80% of the ultimate tensile strength of the base material. The purpose of this test is to ensure that welds which meet the FTB criteria in peel mode do not suffer from a weakening of the parent material in the region adjacent to the weld.