BEST PRACTICE GUIDELINES

GEOMEMBRANE SYSTEMS

FOR THE REHABILITATION OF

CONCRETE LINED IRRIGATION

CHANNELS

January 1999

1. Overview

Geomembrane liner systems are commonly used for containment of solid and liquid hazardous materials, for waste water and process liquid containment as well as for water supply storage. There is also a growing use of floating membrane cover systems for water supply protection as well as for odour control and gas harvesting from waste water systems. This document is directed towards the special needs of geomembrane liners used as internal liners in old and new concrete lined channel water transport structures.

The geomembrane materials are usually part of a system which can be simple or complex in order to contain liquid materials or to prevent ingress of liquid materials. The liner system may be as simple as a prepared base and the liner or it may be as complex as systems comprising primary, secondary and even tertiary liners complete with drainage systems above and below and leak detection and collection systems between the liners.

These geomembrane materials are merely thin barriers of very low permeability material and they offer very little structural capacity. Thus they require appropriate structural support and careful treatment to give results that live up to expectations. An overview is given of the theoretical and practical properties that are desirable in geomembranes with an assessment of how well the available geomembranes achieve this seemingly impossible marriage of disparate properties.

Although they can assist with shear forces on slopes the geomembrane materials are not competent structural members and require a suitable supporting material to be effective. There are materials that can sustain higher shear forces and others that can accommodate movement with less likelihood of rupture. Some of the geomembrane materials require a very good smooth surface to support them whilst others are able to accommodate rougher surfaces without loss of effectiveness.

One of the most important questions a potential geomembrane user must ask relates to the degree of effectiveness which is required. To achieve a geomembrane which absolutely does not leak is difficult if not impossible and a realistic understanding of the consequences of minor leakage can be a key factor in achieving the desired outcome.

This set of documents relating to the use of geomembrane systems for concrete lined channels is in three parts:

a) An outline of geomembrane liner types and characteristics (this section)
b) Specification for a HDPE liner.
c) Specification for a flexible liner such as PVC or polypropylene.

These specifications and other documents are standard documents intended for guidance for standard projects. Review of the intended membrane choice and construction details and documentation by an experienced geosynthetic engineer is always prudent.

2. Issues to be Considered

2.1 Performance Needs

There are a range of performance parameters or attributes that are important to geomembrane installations in channels and these are outlined below.

2.1.1 Durability.

The durability of a membrane to survive in the environment in which it is used is of paramount importance. The polymer nature of most geomembranes will mean that there are some potential problems with liquids such as hydrocarbons and solvents as well as strong acids and bases. The geomembranes are generally exposed to the direct sunlight either permanently or during construction and initial use and resistance to damage by UV light can be an important consideration.

There are also issues related to brittle cracking due to thermal effects or Environmental Stress Cracking and the combination of these effects with thermal expansion and contraction.

2.1.2 Mechanical Performance.

Mechanical performance will normally mean tensile performance but simple tensile tests can be misleading and for many applications consideration must be given to other factors such as modulus and elongation capacity in both simple tensile mode and in multiaxial mode. Very often the forces on a geomembrane may be such that resistance is futile and survival as an effective barrier is achieved by the capacity to give and accept deformation without rupture or excessive thinning. In the case of existing channels in clay soils the introduction of a liner can dramatically change the moisture content of the surrounding soil giving rise to significant soil and structural movement.

There is also the question of low stress brittle cracking in HDPE which may be exacerbated by chemical contact. Other membranes have very low modulus and low tensile capacity in isolation and these are often provided in a multilayer reinforced form with a high tensile polyester scrim when better tensile performance is required.

Another peculiar issue to channels and small reservoirs is the lack of protection from animal and human entry and the potential for physical damage by puncturing by animal hoofs or even vandalism.

2.2 Important Properties

2.2.1 Tensile Properties

High tensile strength at low elongation are very useful properties for geomembranes but for most geomembranes used in environmental and hydrotechnical applications the capacity of a membrane to resist the forces of larger scale soil movements has little chance of being adequate. With such movement the membrane will survive and retain its integrity if it is able to elongate with minimal thinning and thereby maintain an effective barrier.

Some membranes such as HDPE can also be subject to brittle Environmental Stress Crack failure at low stresses especially with chemical exposure.

This means that every effort must be made to minimise the load and stresses applied to a membrane. This will generally require a firm well prepared substrate to support the membrane and may also require a protective geotextile cushion.

Figure 1 illustrates comparative strip tensile and multiaxial strain characteristics and Figure 2 shows some multiaxial burst (500 mm dia) response curves.

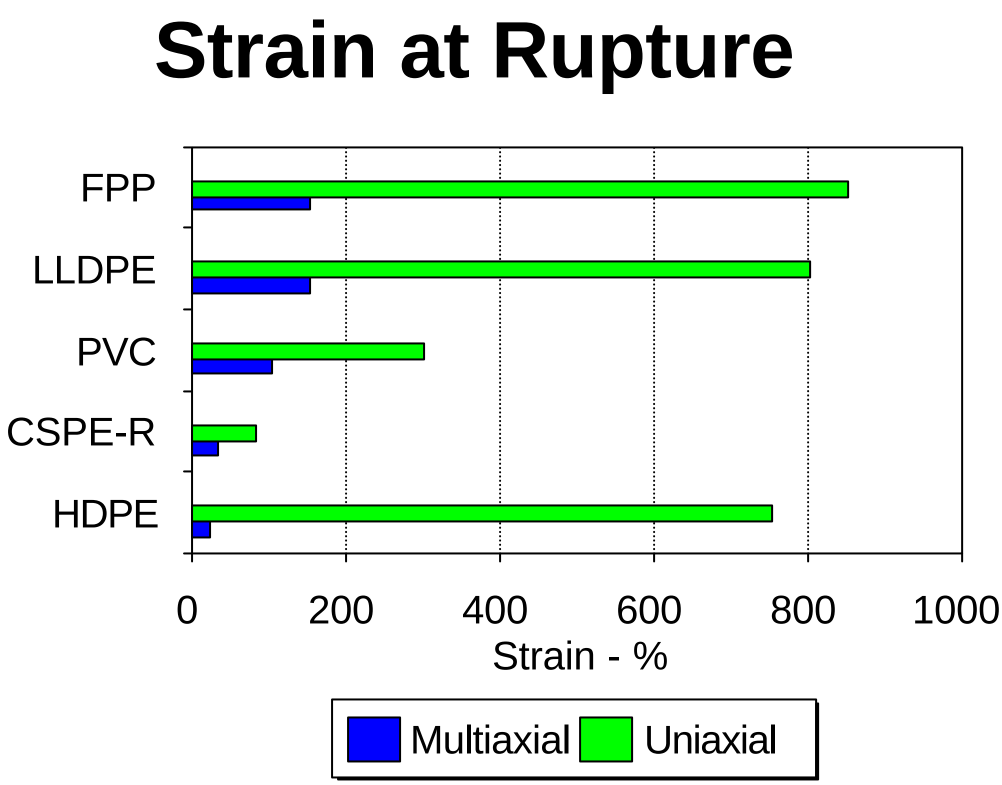

Figure 1

A common and misleading argument is based on the use of tensile test results to show that a particular membrane has a high elongation factor and therefore a high survival capacity. Several materials which behave very well in simple tensile tests actually behave quite poorly in multiaxial or large scale burst type tests which do more to simulate real out of plane loading circumstances such as may occur with subgrade subsidence. When designing critical liner systems in HDPE it is common to pursue a factor of safety of around 4 against ultimate elongation in order to negate the effects of stress cracking. This means that for a material such as HDPE the available elongation for local surface effects, thermal effects and local deformation is around 5% whereas for a material such as PVC or FPP the available elongation is in excess of 20%.

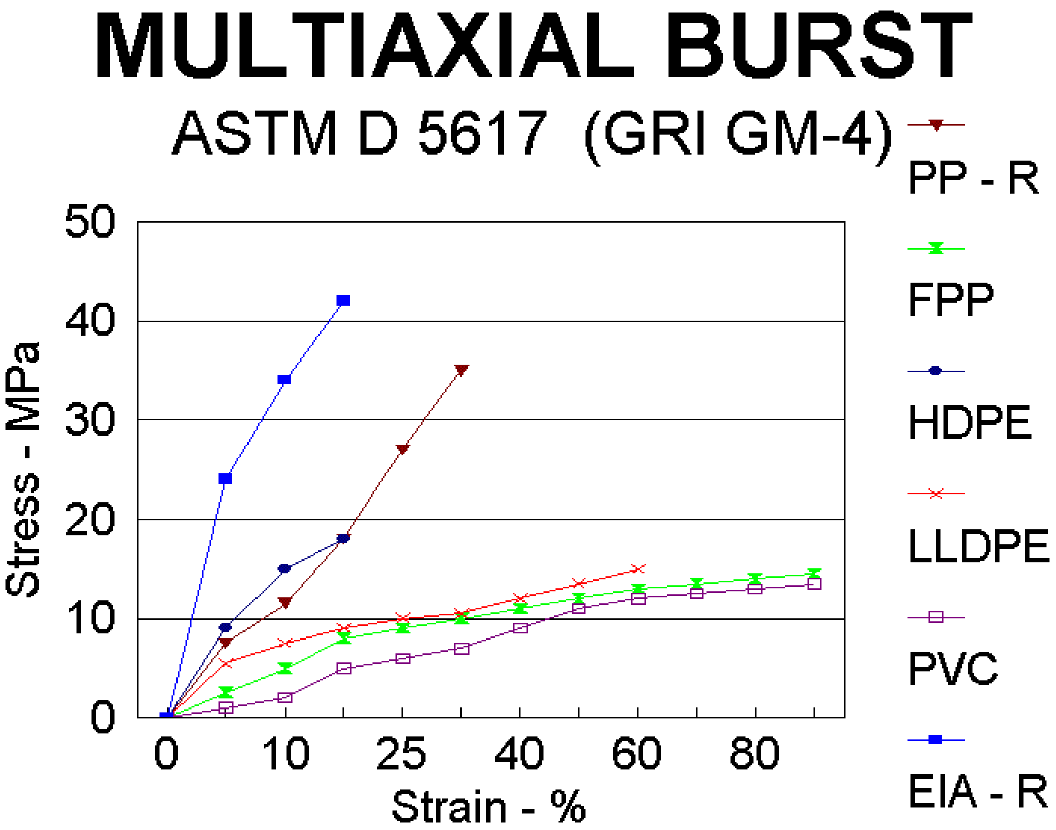

Figure 2

2.2.2 Thermal Effects

A geomembrane on a channel face may be exposed to significant levels of UV radiation generating quite high temperatures sometimes in excess of 60^{o}C. These higher temperatures are normally seen in membranes with black surfaces. When the channel is running full of water the membrane is protected but not when the channel is empty. The variation in temperature during the daily cycle can also be quite high with a range of 40^{o}C quite common.

The table below sets out the coefficients of thermal expansion for several typical membrane types as well as a typical expectation for thermal expansion in a channel situation.

Material	Thermal coefficient of expansion	Increase in length over 10 metres for a 40 ^{o}C temperature rise
HDPE	2 x 10^{-4} cm/cm/^{o}C	80 mm
FPP Unreinforced (PVC is similar)	12 x 10^{-5} cm/cm/^{o}C	48 mm
FPP Reinforced	2 x 10^{-6} cm/cm/^{o}C	0.8 mm

These thermal expansion and contraction effects can be significant in long term exposed applications where a monolithic membrane can expand down slopes and not return fully on cooling due to surface friction and associated effects. These conditions will give rise to a gradual build up of stress at the crest of the slope which will release by creep and possible necking or, in the case of HDPE, is likely to give rise to brittle stress cracking. Such effects do not occur with reinforced membrane structures.

2.2.3 Puncture Resistance

In these channels there are two potential modes of puncturing the membrane. One is by hydraulic pressure on the membrane over a rock or other sharp object and the other is by an object such as an animal hoof as it tries to get out from the channel.

Set out in Figure 3 is a comparison of puncture strengths for geomembranes. These results are based on a cone penetration test which determines the cone height at which the membrane can survive at a standard pressure. Unfortunately this data relates to perpendicular puncture pressure rather than local point puncture or tearing from a hoof or similar.

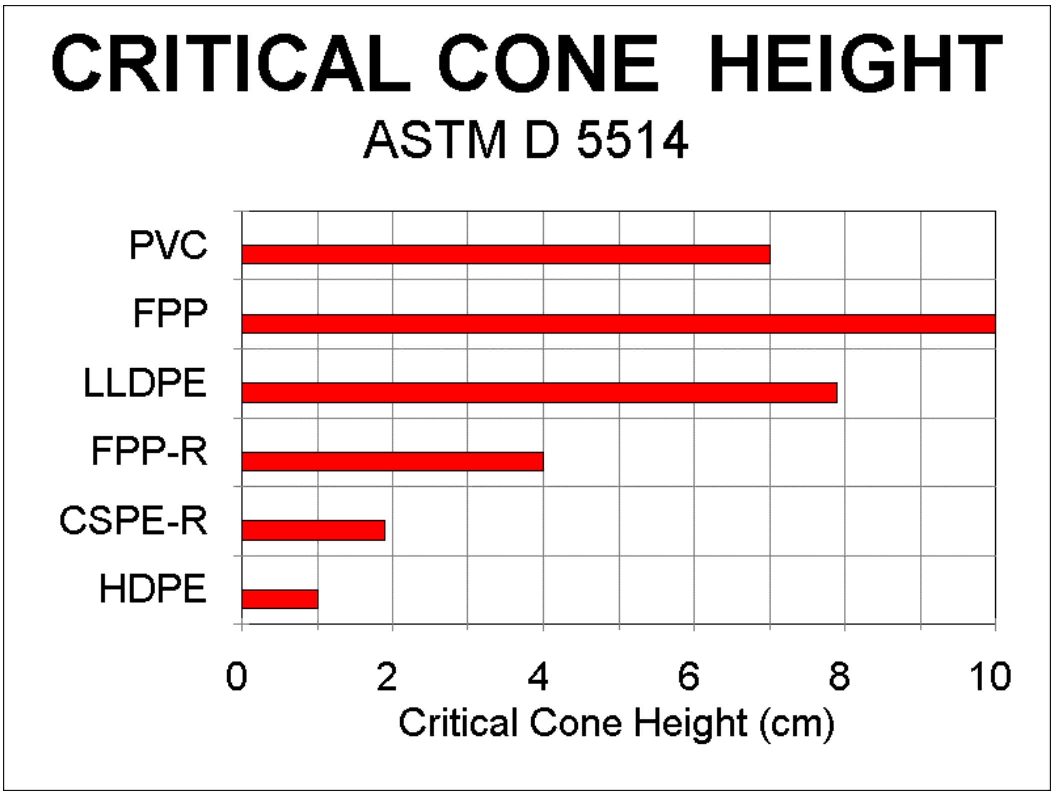
CRITICAL CONE HEIGHT
ASTM D 5514
PVC
FPP
LLDPE
FPP-R
CSPE-R
HDPE
0
2
4
6
8
10
Critical Cone Height (cm)

Figure 3

3. Material Types & Method Details

3.1 Material Types

In discussing the different types of geomembrane materials that are available the terms and descriptions that are in common use will sometimes be recognised by polymer chemists and others as being less than strictly correct. These common terms are used below since the aim here is convey meaning and understanding to engineers using the materials who are perhaps more familiar with construction using soils, steel or concrete. The following are the more common types of geomembrane and a descriptive tabulation of properties is given in Appendix A.

3.1.1 Polyethylene. (HDPE)

The most common form of polyethylene used for liners is known as high density polyethylene (HDPE) and is very similar to the material used in black polyethylene pipes. Strictly speaking it is based on a medium density resin but the addition of carbon black tends to increase the density. It has a very strongly crystallised structure which contributes to its broad chemical resistance and excellent UV resistance for which it is well known. However it is less well known for its lack of flexibility, its high coefficient of thermal expansion and its brittle behaviour particularly in developing brittle stress cracking at low stresses.

The base polymers have been developed to improve the Environmental Stress Crack performance considerably in recent years but this is still an area worthy of great care in design and seaming especially in the areas around extrusion fillet welds.

HDPE seaming has embraced the hot wedge automatic welder which produces dual fusion track seams with great reliability and efficiency that can be readily tested by the air pressure test. These seams still require significant attention to seaming hygiene but are less operator dependent and create a less influential heat affected zone. The older extrusion fillet welding method which creates a large heat affected zone is still used mainly for details such as connections, T-junctions and patching. It requires skilled operators for effective repair work in service.

Polyethylene has also appeared in more flexible forms based on very low density (VLDPE), medium density (MDPE) and linear low density materials (LLDPE). Whilst these have had some advantages in mechanical behaviour there have been some disadvantages with the compromised durability and chemical resistance from the less crystalline structure, as well as problems developing seaming systems.

Very low cost and thin MDPE membranes are commonly used under concrete slabs as moisture barriers. These usually have taped joints and are systems that might be considered as a low cost alternative under cover such as shotcrete or similar.

3.1.2 Polyvinyl Chloride. (PVC)

The basic structure of polyvinyl chloride is quite brittle and the material we see used as a geomembrane achieves its soft flexible structure by the extensive use of additives known as plasticisers. It is the presence and potential mobility of the plasticisers that make PVC susceptible to contact with various chemicals and to exposure to UV radiation. All of these influences can lead to loss of plasticiser and a reversion to the brittle behaviour. If these influences can be avoided or controlled, then PVC remains the most flexible and workable membrane of all.

In many cases it will be necessary to cover PVC with soil, shotcrete, interlocking blocks or other cover material in order to provide protection from UV radiation and if this cover is needed for mechanical protection PVC may well be a very good choice.

PVC geomembrane seaming was formerly carried out by chemical bonding using solvent based systems but recent years have seen PVC applicators embracing thermal fusion welding using both hot air and hot wedge methods. Thermal seaming of PVC is still not yet universal in the way it is with HDPE and reasonable seams can be obtained with hand held equipment.

3.1.3 Chlorosulphonated Polyethylene (Hypalon or CSPE)

CSPE is based on the use of chlorine and sulphur to modify and soften the polyethylene structure in order to make the material more workable and facilitate seaming. CSPE geomembranes are always scrim reinforced for dimensional stability.

When fresh it is amenable to seaming by both solvent bonding and thermal methods but it crosslinks or cures with exposure such that normal welding becomes more difficult and in fact impossible after one year. Once cured, modifications or repairs must be carried out using two part solvent based adhesives with extensive abrasion and solvent scrubbing of the seam area. The solvent bonded field seams also tend to suffer a decline in strength after a number of years primarily due to polymer softening and scrim pullout.

CSPE provides very good chemical resistance and excellent UV exposure performance and it has provided good service in the past for floating membrane cover structures.

3.1.4 Polypropylene

Flexible Polypropylene (FPP) has developed as a result of recent polymer catylisation developments that have enabled flexible polypropylene sheets to be produced by extrusion or calendering. They are provided in both unreinforced and reinforced form and provide a choice in terms of tensile behaviour. The unreinforced polypropylene membrane materials are typically very flexible with excellent elongation capability. The reinforced materials have low elongation but also have very low coefficients of thermal expansion.

Seaming of FPP is very easy using thermal methods on both old and new sheet. The resistance to common chemical exposures is quite good as is the UV performance for properly stabilised polymer packages.

3.1.5 Ethylene Interpolymer Alloy (XR-5 or EIA)

EIA geomembranes are an alloy of PVC resin with a special ethylene interpolymer (EI) which results in a flexible plasticiser free material. EIA geomembranes maintain the advantages of PVC but have a high degree of durability and chemical resistance especially in relation to hydrocarbons and extreme temperatures.

As a thermoplastic material EIA can be thermally bonded using the conventional thermal welding techniques. EIA has some excellent applications experience in high UV exposed solar ponds as well as hydrocarbon containment and in biogas collection covers.

3.1.6 Geosynthetic Clay Liners

Geosynthetic Clay Liners (GCL) are a factory produced product which make use of bentonite clay as the sealing layer usually encapsulated by two geotextile layers for containment during handling and installation. Their effectiveness is dependent on the bentonite clay swelling when hydrated and forming an impervious barrier. As a result they also depend on the geotextile and a suitable confining load preventing loss of the bentonite gel. Normally a soil cover in the order of 200 to 300mm thick will be required over the GCL to provide the confining pressure.

3.1.7 Bituminous Membranes

There is a developing practice of road base seals using bitumen impregnated geotextiles and these techniques could be adapted to channel work particularly when a relatively inexpensive membrane is required to go under shotcrete or similar cover.

The principle is to fill the voids of a thick non-woven geotextile with a bituminous material such that an impervious membrane is formed. The process involves an initial tack coat into which the geotextile is placed. The bitumen is normally a cut bitumen (not emulsion) with or without rubber additives and a polyester geotextile is often used because of the higher melting point.

Shotcrete adheres very well to these geotextiles such that a system could be developed with a bitumen tack coat, geotextile and shotcrete to develop a composite liner or repair system.

3.2 Economic Factors In Geomembrane Selection

For all except simple prefabricated drop-in liners the actual geomembrane material contributes a relatively small component of the overall cost of the system. Other contributing factors include surface preparation, protection and drainage mediums and the ultimate cover layers. Attempts to reduce project costs by simple reduction in geomembrane cost may be ineffective and result in poor performance.

In order to achieve economic and satisfactory barrier systems it will be preferable to look closely at geomembrane performance against cost and to compare the total costs of systems which include factors for surface preparation cost, protection and cover layers (if necessary) as well as factors for installation and QA/QC which may be easier with some materials. In many cases a better performing yet more expensive geomembrane can justify its selection because it can perform with less rigorous surface preparation and lesser degrees of protection.

There is also the question of suitable thickness in the different types of membrane. The suppliers of FPP and PVC membranes have argued that their product can be used successfully in much thinner gauges than is required for HDPE and have pointed to the puncture test and elongation results as evidence of this. This argument has a lot of merit in terms of puncture over rocks or substrate movement and a practice has developed of using a thickness ratio of 0.5 to 0.67 for FPP against HDPE.

A broad evaluation of geomembrane material costs for roll goods of similar thickness is given in the table in Appendix A.

3.3 Other Considerations

A geomembrane is by definition a flexible impervious barrier and the majority of geomembrane materials are less dense than water and therefore float unaided. Whilst this can be an advantage for some applications it can give problems if water is able to get under the geomembrane from ground water or other sources.

If there is a possibility of water accumulating under the membrane then there are a number of issues to be considered:

- Will the water affect the surrounding soil structure and therefore the stability of the channel structure itself?
- Is there a need for some kind of drainage or pressure relief system?
- Is there a need for some kind of ballasting system over the liner? An example of this is the large scale lined channels recently built in Pakistan using flexible membranes with geotextiles and interlocking brick ballast.

Consideration of all of these issues becomes a complex exercise and simple geomembrane comparisons are of little assistance.

4.0 Installation Considerations

Geomembranes are thin impermeable barriers with little or no structural strength and require a suitable substrate. The brittle cracking potential of HDPE will also require a very smooth surface with no substantial cracks or other imperfections. Seaming of geomembranes is also ineffective under wet conditions.

Geomembranes are lightweight and are manufactured in a large variety of roll and panel sizes which makes them easy to deploy over large areas. The effectiveness of geomembranes has been greatly enhanced by the advent of better and more positive seaming methods which are often based on the application of controlled heat by a hot wedge or by hot air. It is possible now to produce seams which can reflect the underlying strength of the geomembrane material and which can be readily verified by inspection and testing. Methods such as the dual fusion track seam with an air gap have enhanced the capacity to check the quality of the seaming work quickly and effectively on a broad scale.

Thermal stability and local climatic conditions will also have an impact on the geomembrane installation. Ambient temperatures of 30^{o}C can give rise to surface temperatures of 60^{o}C on the surface of black HDPE and this gives rise to major problems with thermal expansion and contraction both during construction and in service. In some cases it may be necessary to carry out installation works at night to avoid these effects.

It is still a necessity for proper quality control sampling and testing of the weld process to be implemented along with constant inspection to ensure cleanliness and proper control of the seaming process. There is also the question of seaming methods for detail areas and methods for sealing the membrane to concrete structures or at other termination points.

Another factor is the ability to have local, unfamiliar people carry out satisfactory repairs to the geomembrane in service. For some membranes this can be a simple process with hand held equipment whilst for others it may be more complex.

In addition, the natural flotation of a geomembrane may impact on its function in service and may also impact on the available installation methods if the facility is full of water for example. One may wish to float the material into position and in other cases one may prefer that it sinks readily without ballasting.

5. Summary & Recommendations

The perfect geomembrane for all applications does not exist and the performance of different types of geomembrane can vary widely and a material that is well suited to one application may not be well suited to another. It is also very possible that a liner type that appears to offer an economic advantage may not be advantageous at all when all of the associated factors are taken into account.

Care should be taken in selecting a material to look at the real performance requirements of the application and to review all of the associated aspects involved with the use of a particular material.

In the majority of cases lining over existing concrete lined channels will lead to the use of HDPE without other cover based largely on economic considerations. In cases where the concrete substrate is in poor condition or thermal expansion is a concern materials such as reinforced PP may be an option. In other cases local factors (e.g. cattle) may dictate a cover layer and membranes such as PVC or unreinforced PP will be of interest.

6. References

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Further Information

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A FLEXIBLE MEMBRANE LINER COMPARISON

ATTRIBUTE	HDPE	LLDPE	PVC	EPDM	EIA	CSPE -R	FPP	GCL
GENERAL CHEMICAL EXPOSURE	Excellent	Good	Fair	Good	Excellent	Excellent (when cured)	Excellent	Fair
HYDROCARBON EXPOSURE	Good	Good	Fair	Good	Excellent	Good (when cured)	Good	Poor
WEATHERING (UV EXPOSURE)	Excellent	Fair	Poor	Excellent	Excellent	Excellent (when cured)	Excellent	Poor
THERMAL STABILITY	Poor	Poor	Good	Excellent	Good	Excellent	Good - excellent when reinforced	Good
TENSILE PERFORMANCE	Good	Good	Good	Good	Excellent	Excellent	Good - excellent when reinforced	Good
UNI-AXIAL ELONGATION PERFORMANCE	Excellent	Excellent	Good	Good	Fair	Good	Excellent	Fair
MULTI-AXIAL ELONGATION PERFORMANCE	Poor	Excellent	Excellent	Good	Fair	Good	Excellent	Fair
PUNCTURE PERFORMANCE	Fair	Excellent	Excellent	Good	Excellent	Good	Good	Good
INSTALLATION DAMAGE RESISTANCE	Fair	Fair	Excellent	Excellent	Good	Good	Excellent	Good
SEAMING METHODS	Thermal/ Excellent	Thermal/ Excellent	Thermal or solvent bonding/ Good	Tape seams/ Good	Thermal/ Excellent	Thermal or solvent bonding / Good	Thermal/ Excellent	Laps only
REPAIR IN SERVICE	Good	Good	Good	Good	Good	Poor - requires adhesives	Excellent	NA
STRESS CRACKING	Fair	Good	Does not occur	Does not occur	Does not occur	Does not occur	Does not occur	Does not occur
FLEXIBILITY IN DETAILING	Fair	Excellent	Good	Good	Good	Good	Excellent	NA
ROLL GOOD COST	Low	Low/medium	Medium	Medium/high	High	High	Medium	Medium