Current developments and trends for water reservoir renovation with geosynthetics

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ABSTRACT: This paper will describe developments and trends that have been observed since the 10 ICG in Berlin where the same authors presented a paper titled "Material Selection For Reservoir Floating Covers". The paper is based on work carried out for several recent projects where facility owners are discovering a need to look at new trends and developments in both the geomembrane liner systems used for these facilities and the geomembrane materials being used for floating covers. Along with these material selection trends there have been design trends partly driven by the material choices and partly driven by operation, access and safety issues. Free access for personnel performing maintenance on these covers has been more restricted in recent years resulting in walkway and stormwater management trends that involve interesting compromises in design and reconstruction.

Keywords: water reservoirs, geomembrane liners, floating covers

1 INTRODUCTION

This paper discusses the geosynthetic related issues of water supply reservoir renovation projects involving design and installation of new liner systems and floating cover systems. It will briefly discuss some of the geotechnical, hydraulic and operational issues that can be involved.

2 THE RESERVOIR

Renovation of existing water supply reservoirs requires consideration of some of the design and operational consequences that will occur.

2.1 *One reservoir or two?*

There is a growing recognition of the health and safety issues associated with workers traversing floating covers for maintenance purposes. One way of addressing this with larger reservoirs is to create two adjacent reservoirs such that one can be emptied for maintenance whilst the other remains operational.

This requires a dividing wall or dam embankment section that will remain stable under all conditions and in many cases there is more flexibility in using rockfill in favour of compacted clay, both of which require an impervious cut-off. In most cases this will also require new inlet, outlet, overflow and scour structures for each of the two basins as well as interbasin connections.

2.2 *Embankments - saturated or drained?*

Many of these older reservoirs were built as cut and fill using questionable quality local clayey materials and then were subsequently renovated by the introduction of geomembrane liners and possibly floating covers.

In many cases these liners have deteriorated or suffered damage such that they have been leaking for some time and the embankments are effectively saturated. If a new quality liner system is installed, the embankments will drain and possibly consolidate with subsequent movement that can be difficult to predict. This requires careful choice of a liner system and connection details that can accommodate this movement.

2.3 *Old Geosynthetic Materials*

The first impulse is to remove the old geosynthetics, prepare the subgrades and start anew. However for liners installed 20-30 years ago there may be poor subgrade conditions beneath the existing liner including remnants of beaching or soils that are difficult to work with after rainfall.
Under these circumstances keeping the existing geosynthetic materials in place may provide additional and more cost effective protection to the new liner materials. Care needs to be taken with compatibility - for example an old bituminous liner may not be compatible with many polymeric materials. Additionally, the old lining system will need to be breached in order to prevent accumulation of water or air between the old and new lining system.

3 THE LINER SYSTEMS

3.1 *HDPE and LLDPE alternatives*

Due to the fact that the HDPE polymer material is changing and there have been many developments in LLDPE there are now multiple choices for polyethylene liner materials in addition to conventional materials such as CSPE and fPP or fPP-R. There is also a growing trend towards the use of liner underdrainage systems to facilitate better performance and better monitoring.

Based on design details, cost and effectiveness for most projects there are currently trends to consider materials to include polyethylene geomembranes, be they HDPE, LLDPE, RPE or improved versions thereof as they are all inert and suitable for potable water.

Table 1 shows a progression of key properties of HDPE geomembranes over recent time. It can be seen that the basic strength properties of HDPE materials have not changed much over the years but newer polyethylene resins have seen considerable improvement in multiaxial burst and durability properties. This makes modern HDPE much more flexible and forgiving of subgrade movements which is excellent for the water supply sector. However there may be a need for more caution in the mining sector if chemical exposure is involved.

The more flexible polyethylene materials are based on LLDPE and there is what the manufacturers are calling a "Fortified" material with enhanced durability properties. Table 2 compares the properties of interest (from Sadlier 2017). Both the 'Enhanced' HDPE and the 'Fortified' LLDPE materialsare available from several suppliers so commercial competition is active.

It should be noted that there have been some recent undocumented reports of the "Fortified" LLDPE blistering as a result of contact with strong chlorinated water. These may be isolated incidents but it would be prudent to be cautious with both these newer PE materials until more is known or compatibility testing is completed.

Table 1. A comparison of key properties of HDPE materials over time. (from Sadlier 2017)

Property	**Test Method ASTM**	**GM 13 Value (1999)**	**GM 13 Value (2016)**	**“Enhanced” HDPE (2017)**
Tensile Properties (min. ave.)	D 638 Type IV or D 6693 Type IV			
• yield stress		22 kN/m.	22 kN/m.	23 kN/m.
• break stress		40 kN/m.	40 kN/m.	43kN/m.
• yield elongation		12%	12%	12%
• break elongation		700%	700%	700%
Tear Resistance (min. ave.)	D 1004	187 N	187 N	187 N

Puncture Resistance (min. ave.)	D 4833	480 N	480 N	534N
Stress Crack Resistance	D 5397	200 hr.	500 hr.	1000 hr. plus
Multiaxial bursting elongation at burst	D 5617	Not in GM13 ~15%	Not in GM13 ~15 to 20%	45%
Oxidative Induction Time	(OIT)			
(a) Standard OIT	D 3895	100 min.	100 min.	130 min.
(b) High Pressure OIT	D 5885	400 min.	400 min.	700 min. plus

Table 2. LLDPE and 'Fortified' LLDPE. (from Sadlier 2017)

Tested Property	**Test Method**	**Unit**	**LLDPE to GRI GM17**	**Fortified LLDPE**
Density	ASTM D1505	g/cm (Min)	<0.939	<0.939
Tensile	ASTM D6693	N/mm (width)	40	44
Tensile Elongation	Break – no yield	%	800	1000
Tear Resistance	ASTM D1004	N	150	156 N
Notched Constant Tensile Load	ASTM D5397	hrs	N/A for LLDPE	1000 hrs
Puncture Resistance	ASTM D4833	N	370	400
Multi-Axial Tensile	ASTM D5617	%	30	80
Strength Retained after 30,000 Hrs	ASTM D4329 QUV exposure	%	Not listed	90%
Oxidation Induction Time (OIT)	ASTM D3895	min	> 100	> 100
High Pressure Oxidation Induction Time (HPOIT)	ASTM D5885	min	>400	2000 min

Other materials such as non-reinforced polypropylene (fPP) or potable water PVC can also be used for liner systems as can reinforced materials such as RPE,fPP-R and CSPE (Hypalon).

On a recent project, the old liner system on the slopes was a flexible polypropylene (fPP-R) liner with a geocomposite drain under it. This old liner system was kept in place and a new liner system comprised of a 1.5 mm thick “Fortified” LLDPE geomembrane over a geocomposite drain was installed. The LLDPE liner was installed with conventional hot wedge and extrusion welding and non-destructive and destructive QC testing in the normal way. On subsequent filling the target design leakage rates of 0.25 L/hectare/minute under approximately 7 m of hydraulic head were quite readily achieved.

3.2 *Seaming*

One of the advantages of the new non-reinforced polyethylene materials is that they can be thermally fusion welded by hot wedge/hot air with an air gap for non-destructive continuity testing of the seams similar to non-reinforced fPP and PVC. This allows for conventional QC and CQA testing as in waste disposal or mining projects. This option is not available for scrim reinforced materials.

4 THE COVER SYSTEMS

4.1 *Material selection and properties*

Flexible reinforced polypropylene (fPP-R) has been installed for many cover systems worldwide over the last 15-20 years and the older materials are actually performing better than the newer materials. Most recently the materials used in Australia have suffered from a loss of oxidation resistance such that the effective service life has been reduced to 10-15 years and there has been difficulty in welding the aged material for repairs. There were reports of problems with chlorinated water in North America and several failures in Australia were in covered reservoirs with no UV exposure but with various active oxidizing agents in the sludges generated by the water.

GRI GM18 (2011) increased the required UV Resistance test for fPP-R to 20,000 hrs and several manufacturers are offering material that meets this requirement. Whilst this would appear to answer the durability issue we are not aware of a project using the 'new' fPP-R and in particular the repair welding experience of the aged material.

Even with the 'new' GRI GM18 specification with extended UV testing requirements the performance of fPP-R has disappointed many facility owners and they are looking to other options. Some returned to using CSPE (Hypalon) and tried to work through the issues of using solvent based adhesives for repairs. Others have looked to 'new' materials such as the PVC/EIA materials which are based on reinforced PVC with proprietary ketone ethylene ester (KEE) polymeric plasticisers which enable the possibility of long term flexible performance under exposed conditions.

Currently there is a source for confusion with the marketing gurus seeking to hide the PVC origins of the PVC/EIA materials by calling them "Elvalloys" or "Ethylene Interalloys”. Previous versions of PVC in North America and Australia were often very thin and used liquid fatty acid plasticisers with poor exposed durability. The current materials tend to be PVC based with a KEE elvalloy plasticiser with thicknesses of 1.14 mm or more often 1.5 mm for reinforced materials based on European practice which the North American manufacturers regard as a new development.

Currently there are no reliable sources for quality polyester reinforced flexible PE materials (RPE) based on LLDPE resin and although a “Fortified” LLDPE has been used for some covers in Australia we hold the view that a flexible reinforced material is better from a design perspective where continuous hinging or flexing of the material is required for a water reservoir cover.

CSPE (Hypalon) can be very durable because it cures in air but this curing makes it progressively more difficult to weld aged material. There have been some major problems on recent projects in Australia when there were delays due to delivery and storage conditions which allowed ageing of the CSPE beyond its usable date for weldability. Once the material has aged and cured then seams must be made with adhesives that include solvents such as Xylene. The adhesive solvent residuals must be effectively dealt with by air or water flushing. It should be noted that shipping times dictate that CSPE in Australia is often 10-12 weeks old which is much older than typical use of CSPE in North America.

There is also some confusion in the market with a manufacturer producing a 1.5 mm thick PVC/EIA material that has an enhanced reinforcement compared to what has been or is traditionally used as shown in Table 3. It should be noted that this additional tensile strength is not a design requirement for most covers and in practice the extra strength is not achieved across the seams.

Table 3. Comparison of 'Typical' reinforced materials with one with stronger reinforcement

Properties	**ASTM Method**	**Special Reinforced Material**	**Typical Reinforced Materials**	**Comment**
Thickness – min	D751	1.5 mm ±5%	1.5 mm ±5%	
Tensile Strength at Yield	D751A	1800 N	>1100 N	Reflective of stronger reinforcement
Tear Resistance	D751	> 600 N	350 N	Reflective of stronger reinforcement
Seam Peel Adhesion	D751	>87N/ 25mm	>87 N/25 mm	Additional strength not achieved in seams
Seam Shear Strength (Grab)	D7749	>930N	>1100 N	Additional strength not achieved in seams

Their PVC origins of the PVC/EIA material in some cases has given rise to an odour and water taste issue which appears also to be best dealt with by air venting. This puts both the PVC/EIA and CSPE effectively on the same footing with regard to taste and odour management.

Many of the manufacturers have certification to Australian Standard AS4020 which includes a taste and odour evaluation by a tasting panel after water immersion but there seems to be some inconsistency with this subjective test procedure.

4.2 *Cover system design*

4.2.1 *Ballasting and floats*

The PVC/EIA and CSPE especially at 1.5 mm thick are heavier than typical 1.14 mm fPP-R which will float without assistance. With fPP-R there was a trend to reduce the size and weight of the cover tensioning ballast and also reduce the size of the matching floats. When designing with PVC/EIA and CSPE there is a need to return to the more traditional sizes for these components.

4.2.2 *Sumps and pumps*

It has become traditional to use floating sump baskets that do not actually reach to the bottom of the trench formed by the ballast at full water level. This means that all of the water in the trench is not removed but the trench tends to close at the top such that the water in the trench is not accessible to birds, vermin and insects.

The floating sumps are normally fitted with a submersible pump with automated level controls. Tubular level control units with no moving parts are less likely to foul than float switches or similar but these tubular level controls are not available on larger pumps.

On smaller reservoirs where the suction head is not high there is an option to use off cover pumps with a header tank to prime the suction line as shown in Figure 1. These systems usually require manual activation with automatic shutdown.

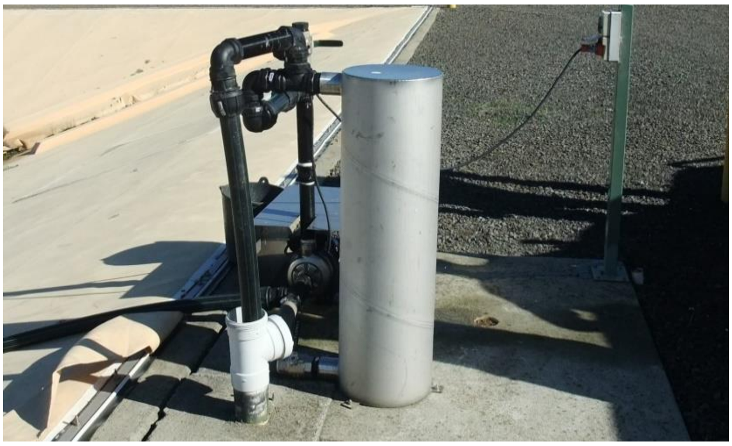

Figure 1. An off-cover pump arrangement. The pump discharges to the header tank which overflows to a drain.

4.2.3 *Access and walkways impact on design*

Management of health and safety for personnel performing maintenance tasks on floating covers has led for a demand for additional and larger walkways. However, these walkways compromise surface water management because they can restrict the movement of surface water.

One way of reducing this impact is to provide discontinuous walkways with drainage gaps between the float elements such that personnel can easily step over the gaps. In practice this might require supplementary ballast in the gaps. Another method is to position the access hatches fairly close to the tensioning floats on either side of the ballast and to make the floats on one side wider with non-skid surfaces for walkways. This can avoid having a separate walkway to every access hatch.

4.3 *Assembly and fabrication*

4.3.1 *Seaming*

Typical automatic seaming methods for the PVC/EIA and CSPE materials are hot wedge and hot air but solid rather than airgap seams are made so that air pressure testing is not used. Air lance testing is the main non-destructive testing method based on the guidelines provided by the Fabricated Geomembrane Institute.

For T-joints and other patches extrusion welding as used on the polyethylene materials is not very satisfactory on the PVC/EIA or the CSPE materials. With the PVC/EIA materials very good seams can be achieved with a hot air gun and a hand roller with the appropriate technique. Whilst hand welding can be effective on CSPE most installers prefer to use the bodied solvent adhesive for patches.

Prefabrication of panels can be useful especially on larger projects or narrower rolls but care must be taken in designing the system so that damage does not occur during transport or deployment.

4.3.2 *Quality control and testing*

The quality control systems for these materials include well known procedures such as trial welds, destructive seam tests (taken from weld overruns where possible) and non-destructive examination using air lance, vacuum box or even a manual probe.

Seam testing makes fairly uniform use of peel tests using 25 mm strips with 25 mm jaws either in the field or in the laboratory with considerable emphasis on failure mode by film tear bond where the bonded coating is pulled off the reinforcement with preferably no peeling of the bonded coatings.

However shear testing is less consistent with some preferring 25 mm strips with 25 mm jaws and others preferring a 50 mm or 100 mm or even a standard 150 mm wide strip in the same 25 mm jaws. With good seams these wider specimens tend to generate jaw failures such that an actual seam failure is a bad sign. Others prefer to perform a wide width test (200 mm specimen and 200 mm jaws such as the ISO 10319 in the laboratory since this generates useful engineering information. Whilst the 25 mm strip is preferable since it requires smaller samples from the work there needs to be testing to establish a correlation with the wider tests.

4.3.3 *Cut edges*

Manufacturers have been seeking to limit the wicking of water into the reinforcing scrim but it is still common practice to seal off cut edges especially on the underside of a cover. Most will provide a paint or paste compatible with the polymer coatingbut some will only provide an extrusion rod which is more difficult to apply. Whatever the method, it is imperative that any cut edges or cross lap seams be fully encapsulated to prevent any potential for wicking.

5 COMMISSIONING

5.1 *Cover inflation*

In recent years with many covers being built using fPP-R with good quality systems the practice of inflating covers was in decline. But with the recent trend to using PVC/EIA or CSPE materials there is a potential need to deal with odour and associated water taste. Inflation and associated air ventilation has proven to be a good way of dealing with odour issues in particular. Additionally, inflation is usually carried out with ballast system remaining grounded for the most part to reduce the possibility of damage during wind events.

5.2 *Final trimming*

When reservoirs with floating covers are first filled with water there is a need to observe the cover behaviour through a number of weather and wind cycles that can affect the movement of surface water on the cover. Normal practice to have lengths of supplementary sand filled ballast tubes that can be placed to fine tune the cover and control water behaviour as required.

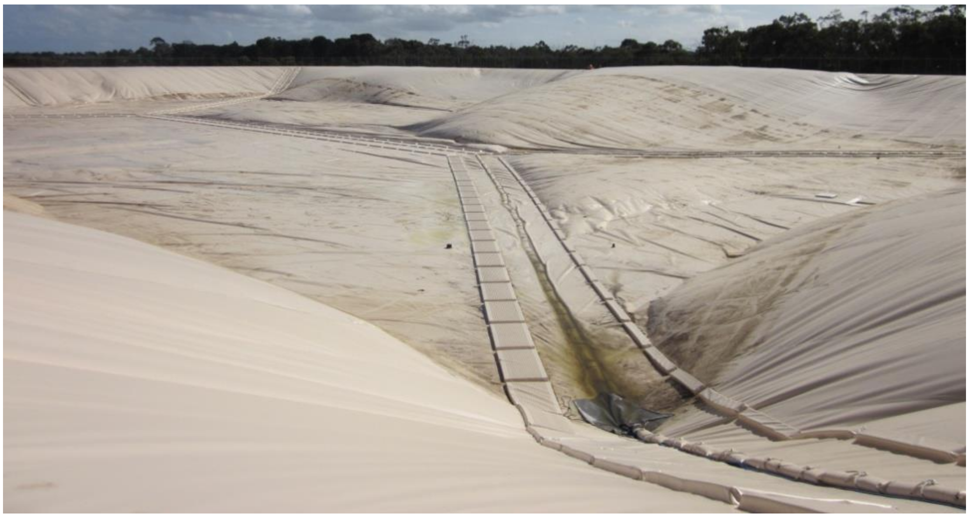

Figure 2. A partially inflated cover with wider floats as walkways on one side of the ballast

6 SUMMARY

Materials used in the design, construction and operation of potable water reservoirs for not only bottom lining systems but also floating cover systems have changed and are evolving into more technically acceptable polymeric geomembranes specific to this end use. It is evident that as this part of the geosynthetics industry grows, more project or design specific materials will and/or are being developed and introduced to the market. The development of new materials and methods will greatly improve the potable water containment industry and provide increased protection for health and the environment.

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