E3S Web of Conferences **569**, 24001 (2024) https://doi.org/10.1051/e3sconf/202456924001
GeoAmericas 2024

Use of HDPE geomembranes as alternative to the use of concrete for channels lining in remote areas

Andrés León[1*] , *Felipe* Cornejo[2†] *and Daniel* Zúñiga[3‡]

[1]Chair, IGS Chile. CEO, Axios Engineering SpA, Chile.
[2]Project Civil Engineer, Axios Engineering SpA, Chile.
[3]Geotechnical Engineer, Axios Engineering SpA, Chile. MSc Candidate in Seismic and Geotechnical Engineering, University of Chile.

Abstract. The use of high-density polyethylene (HDPE) geomembranes as channels linings for water transportation is an effective solution that offers numerous advantages over traditional concrete lining systems. This paper evaluates the use of these geomembranes as lining system for diversion channels for a photovoltaic power plant in the II Region of Antofagasta, Chile. The study consisted of the analysis of advantages and limitations of using geomembranes as channels linings for water transportation, compared to traditional concrete lining. Additionally, it is described the main recommendations for proper installation and maintenance of the geomembranes to ensure their effectiveness and durability over time. To ensure optimal performance, the hydraulic design of the geomembranes considered parameters such as water velocity and flow rate, slope, and cross-sectional area of the channel. Structural design factors such as impact resistance, rupture resistance, and erosion were also considered. The study concludes that HDPE geomembranes are an efficient solution for water channels lining, guaranteeing safe and long-lasting water retention. Flexibility, adaptability to terrain irregularities, simple transportation and installation are some of the main advantages of geomembranes. Additionally, geomembranes have long-term durability, resistance to low and high temperatures, and are an optimal solution for remote areas with logistical difficulties.

1 Introduction

The use of waterproof lining for channel surfaces can, in some cases, represent challenges in terms of cost, material availability, and capacity. Therefore, achieving optimal utilization of the water resources conveyed by channels is crucial for such projects.

This paper presents a case study of a stormwater management project associated with a ditch system for a photovoltaic technology-based power generation plant located near the

* Andrés León : andres.leon@axiosingenieria.cl
† Felipe Cornejo : felipe.cornejo@axiosingenieria.cl
‡ Daniel Zúñiga : daniel.zuniga@axiosingenieria.cl

Salar de Atacama in the north of Chile. These structures capture runoff rainwater from contributing watersheds in the area. At the beginning, the project considered channels designed to be lined with concrete, but a study was requested to implement and validate a solution involving channels lined with high-density polyethylene (HDPE) geomembrane as a replacement. This change was made to avoid the use of concrete due to the logistical challenges and costs associated with the project's location.

2 Design considerations

Geomembrane is a plastic laminate manufactured from high-density polyethylene with a high molecular weight. It exhibits high resistance to ultraviolet radiation and high tensile strength. It is used as an impermeable barrier against the penetration of water, chemicals, petrochemicals, solid waste (both industrial and municipal), in mining, as well as for the storage, preservation, and treatment of water. Geomembranes are also used in aquaculture and can be applied over various substrates, such as soil, sand, concrete, or steel.

The use of geomembranes for channels lining used in water conveyance offers an effective alternative to traditional concrete lining systems, which are prone to cracking due to their excessive rigidity, leading to significant water losses and erosion around the cracks, ultimately causing system failure. Table 1 below presents a comparison of properties between concrete and geomembrane lining [1].

Table 1. A comparative summary between concrete and geomembrane lining [1].

Concrete Lining	Geomembrane lining
Roughness of 0,13	Roughness of 0,01
20-year useful life	30-year useful life
	High chemical and weather resistance

If a well-constructed concrete channel is considered, with a new lining and then the same channel is reevaluated after years of use without proper maintenance, its roughness could increase until the channel can transport only 32% of its potential capacity. This would not be the case with geomembrane, as it maintains its properties over time.

2.1 Geomembrane Lining Parameters

2.1.1. Manning's Coefficient

For calculating the flow capacity of a channel, it is essential to establish a value for the coefficient of roughness. The lower this value is, the greater the hydraulic capacity of the channel would be, and therefore, the greater the volume it can transport.

The Manning's equation is the most recognized method for determining the capacity of pipes and channels for gravity flow installations. It serves as the foundation for hydraulic design considerations for high-density polyethylene (HDPE) lined channels. In Fig. 1, values of Manning's "n" (roughness coefficient) are presented [2-7].

Material	Manning n	Material	Manning n
Natural Streams		*Excavated Earth Channels*	
Clean and Straight	0.030	Clean	0.022
Major Rivers	0.035	Gravelly	0.025
Sluggish with Deep Pools	0.040	Weedy	0.030
		Stony, Cobbles	0.035
Metals		*Floodplains*	
Brass	0.011	Pasture, Farmland	0.035
Cast Iron	0.013	Light Brush	0.050
Smooth Steel	0.012	Heavy Brush	0.075
Corrugated Metal	0.022	Trees	0.15
Non-Metals			
Glass	0.010	Finished Concrete	0.012
Clay Tile	0.014	Unfinished Concrete	0.014
Brickwork	0.015	Gravel	0.029
Asphalt	0.016	Earth	0.025
Masonry	0.025	Planed Wood	0.012
		Unplaned Wood	0.013
Corrugated Polyethylene (PE) with smooth inner walls [a,b]			0.009-0.015
Corrugated Polyethylene (PE) with corrugated inner walls [c]			0.018-0.025
Polyvinyl Chloride (PVC) with smooth inner walls [d,e]			0.009-0.011

Fig. 1. Manning's "n" coefficient for open channels and pipes.

When considering an HDPE lining, the values correspond to corrugated polyethylene (PE) with smooth interior walls, with a Manning's "n" ranging between 0.009 and 0.015. To choose an appropriate value, the texture of the geomembrane should be considered, selecting a higher value for textured geomembranes or a lower value for smooth geomembranes.

On the other hand, both tests conducted at the Water Research Laboratory of Utah State University and Koerner (2005) [8] demonstrate that the minimum Manning's "n" values for corrugated HDPE pipes with smooth interior linings are less than 0.010. To accommodate real field conditions and incorporate a safety factor, Advanced Drainage Systems (ADS) recommends using a Manning's "n" value of 0.012 for corrugated HDPE products with smooth interior linings.

2.1.2. Slopes of the channel walls

To ensure that the HDPE geomembrane is not affected by shear stresses, caused by the fluid flow over it, it is essential to define a slope with a maximum inclination of H:V = 1:1. However, in steeper slopes (H:V = 2:3), it is recommended to add a geotextile or geocomposite to provide support and protection to the geomembrane. The recommendation also depends on the preparation of the base, as steeper slopes make it challenging to provide a compacted and smooth surface free of loose and protruding materials that could damage the geomembrane. That's why it is also recommended to work with slopes that allow for compaction and, where possible, to place a soil liner as a support bedding.

2.1.3. Durability

According to ADS [2], in a drainage system, adverse conditions that challenge the durability of the materials involved can be encountered in the soil, the air, and the effluent. The primary aspects of durability in gravity flow applications include:

- Corrosion,
- Mechanical strength
- Erosion (abrasion) of effluent
- Effects of weather conditions such as sub-zero temperatures, freezing/unfreezing cycles, or exposure to ultraviolet radiation

2.1.3.1. Corrosion

Plastics, including polyethylene and polypropylene, are some of the most inert materials in the current market for rainwater drainage. They are highly resistant to the effects of abrasives and are immune to galvanic corrosion. The choice of joint material is also a critical consideration for projects involving chemical substances or unusual concentrations of chemicals. Some chemicals can have a negative effect on the joint material, such as high concentrations of hydrocarbons. In environmental conditions where a standard joint material is not suitable, alternative joint materials should be provided to meet the majority of the project's requirements.

2.1.3.2. Shear Strength Resistance

To verify that the base material has the appropriate tensile strength for a specific application, the HDPE base material undertakes a frequent join strain test. All the necessary tests for property verification and their permissible values are detailed in the GRI-GM13 standard [9] from the Geosynthetic Institute. Table 2 displays the minimum required strength properties as mandated by the standard for each type of smooth HDPE geomembrane thickness.

Table 2. Properties of Smooth HDPE Geomembrane Strength per GRI-GM13

Properties	**Test Method**	**Test Value**							**Testing Frequency (minimum)**
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness - (min. ave.) - mm · lowest individual of 10 values - %	D5199	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	per roll
Formulated Density (min. ave.) - g/cc	D 1505/D 792	0,940	0,940	0,940	0,940	0,940	0,940	0,940	90,000 kg
Tensile Properties (1) (min. ave.) · yield strength - kN/m · break strength - kN/m · yield elongation - % · break elongation - %	D 6693 Type IV	11 20 12 700	15 27 12 700	18 33 12 700	22 40 12 700	29 53 12 700	37 67 12 700	44 80 12 700	9,000 kg
Tear Resistance (min. ave.) - N	D 1004	93	125	156	187	249	311	374	20,000 kg
Puncture Resistance (min. ave.) - N	D 4833	240	320	400	480	640	800	960	20,000 kg
Stress Crack Resistance (2) - hr.	D 5397 (App.)	500	500	500	500	500	500	500	per GRI GM-10
Carbon Black Content (range) - %	D 4218 (3)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	9,000 kg
Carbon Black Dispersion	D 5596	note (4)	note (4)	note (4)	note (4)	note (4)	note (4)	note (4)	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) (5) (a) Standard OIT - min. — or — (b) High Pressure OIT - min.	D 8117 D 5885	100 400	100 400	100 400	100 400	100 400	100 400	100 400	90,000 kg
Oven Aging at 85°C (5), (6) (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 8117 D 5885	55 80	55 80	55 80	55 80	55 80	55 80	55 80	per each formulation
UV Resistance (7) (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs (9)	D 7238 D 8117 D 5885	N. R. (8) 50	N.R. (8) 50	N.R. (8) 50	N.R. (8) 50	N.R. (8) 50	N.R. (8) 50	N.R. (8) 50	per each formulation

Notes:
(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction Yield elongation is calculated using a gage length of 33 mm Break elongation is calculated using a gage length of 50 mm
(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
(3) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.
(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views: 9 in Categories 1 or 2 and 1 in Category 3.
(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90-day response.
(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(9) UV resistance is based on percent retained value regardless of the original HP-OIT value

Along with shear strength values, the elongation properties at 12% for elastic conditions and 700% at rupture are also included, demonstrating a high resistance to material deformation.

2.1.3.3. Erosion

The Saskatchewan Research Council conducted laboratory research on various materials to quantify the level of wear expected from controlled abrasive applications [10], using velocities of 7 fps (2.1 m/s) and 15 fps (4.6 m/s). The study's results for 15 fps (4.6 m/s) velocities were extrapolated to obtain wear rates on an annual basis, as shown in Table 3.

Table 3. Wear Rate by the Saskatchewan Research Council.

Material	Wear Rates (mm/yr)			
	Coarse Sand (30 mesh)		**Fine Sand (48 mesh)**	
	@7 fps	@15 fps	@7 fps	@15 fps
Steel	0.65	1.81	0.04	0.2
Aluminum	1.81	7.48	0.14	0.86
Polyethylene	0.06	0.46	nil	0.06

2.1.3.4. Sub-zero Condition

Extreme cold conditions can cause some plastic drainage products to become brittle. This results in challenging installations due to the precautions that must be taken to avoid damaging the geomembrane.

Industry standards typically test HDPE at temperatures of 4°C or lower. The minimum working temperature for polyethylene is around -40°C. Polyethylene can withstand continuous freezing temperatures without becoming brittle, and it does not require additional safeguards during installation.

2.1.3.5. High Temperatures

The combination of direct sunlight and high ambient temperatures can cause black polyethylene to absorb heat. Generally, the maximum working temperature for polyethylene geomembranes is 60°C (140°F), although it also depends on the chemicals present in the transported solution. For any plastic material, an increase in temperature reduces its rigidity; besides that, a decrease in temperature increases its rigidity.

In areas with significant temperature variations, lateral or longitudinal displacement due to thermal contraction can occur, potentially causing joints to open as the geomembrane cool down. Due to the thermal expansion coefficient for polyethylene (6.5x10-5 inches), precautions should be taken against contraction in applications where there is an extreme temperature gradient between the geomembrane and the surrounding conditions. This is especially critical for exposed installations.

2.1.4. Speed Control

Higher flow velocities help prevent sediments in stormwater from depositing along the bottom of the channel. Reducing sediment can also lower maintenance frequency and ensure that hydraulic function continues throughout its service lifecycle [11]. However, these velocities must be maintained within the maximum performance limits of the channel and associated installation to avoid compromising the channel's capacity.

2.1.4.1. Minimum Velocity

Sediments can reduce the capacity of a stormwater channel over time, potentially disabling the channel until the system is cleaned. This is a costly and time-consuming task, making it essential to take preventive measures during the design phase.

To minimize potential issues, flow should be maintained at a minimum self-cleaning velocity. According to ADS, a commonly accepted self-cleaning velocity for storm and sanitary sewers is 3 fps (0.9 m/s). In every design, a final check should be performed to compare the expected velocity with the self-cleaning velocity [10].

2.1.4.2. Maximum Velocity

High flow velocity can also create problems if is not properly considered. According to ADS, high velocity is considered around 12 fps (3.7 m/s), but it can vary based on site-specific conditions, where in other applications, 15 fps (4.6 m/s) has been considered.

In the case of very high velocities (> 5 m/s), there are alternative methods to reduce velocities in channels, such as the installation of HDPE geocells. These are a set of strips connected by a series of ultrasonic welding cords, which, when interconnected, form walls of a "cell confinement" structure similar to a beehive. These cells can be filled with various substrates like vegetation, soil-cement, gravel, mortar, or concrete, depending on the specific control requirement.

2.1.5. Geomembrane Installation and Maintenance.

The surface to be covered should be as smooth as possible, free from sharp objects, angular stones, or roots that could tear the geomembrane. It should not have excessive moisture or dirt, and the terrain must be stable and firm.

The geometry and size of the channel are important in determining the installation method. Long, straight sections should be installed lengthwise to minimize the number of joints, and in the case of transverse installation, appropriate downstream overlaps should be made.

Geomembranes are unrolled without tension and should be overlapped. The overlap depends on the welding machine to be used (4 cm to 10 cm). Machines that create a channel for control require an overlap of 8 cm to 10 cm. For extrusion welding, the maximum overlap is 4 cm [9].

2.1.5.1. Maintenance

The maintenance aspects of a geomembrane are related to the integrity of the waterproofing system and ensuring there are no leaks. In the case of exposed channels, maintenance is associated with preserving the transport capacity for which they were designed. Specifically, it involves preventing excessive sediment accumulation or the entry of external materials into the channels.

3 Conclusions

The use of geomembranes for lining channels used in water transportation is an effective solution to replace traditional concrete lining systems. Concrete linings are susceptible to cracking due to their excessive rigidity, leading to significant water losses and erosion around the cracks, which can ultimately result in system failure.

The use of geomembranes offers several advantages that can be beneficial. Their high flexibility and strength allow geomembranes to adapt to the irregularities of the terrain. They are also easy to transport, apply, and handle.

The use of geomembranes extends the lifetime of installations, offering a durability of more than 30 years. Their high impermeability ensures water retention. With their high flexibility at low temperatures (-40°C) and resistance to high-temperature areas, geomembranes become an optimal solution for isolated areas with challenging access.

Channels with this type of lining make cleaning and maintenance easier. It is essential to ensure a minimum self-cleaning velocity of 0.9 m/s to prevent sediment accumulation. On the other hand, when high velocities are present, especially when transporting abrasive effluents, durability issues may arise. In such cases, it is recommended to use textured geomembranes to increase roughness or install geomembranes with a thickness of 2.0 mm or more to reduce wear from particle drag. If reducing maximum velocities is not possible, there is an alternative option for lining, which involves the installation of HDPE geocells or bituminous BGM geomembranes.

To achieve greater stability against ultraviolet radiation, it is recommended to install geomembranes with greater thickness (1.5 - 2.0 mm). Additionally, considering geomembranes with additives that make the exterior side of the geomembrane white can help reduce the absorption of solar light and, consequently, minimize expansion when exposed to sunlight.

In areas exposed to strong wind conditions, it's important to consider additional anchoring methods to prevent the geomembrane from being affected. This can include using sandbags during installation and monitoring during its operation to ensure its stability.

Outdoor temperature should be considered during installation and welding of geomembranes. In periods of high temperatures, the geomembrane can undertake significant elongation, leading to the formation of wrinkles. Therefore, in warm climates, it's recommended to conduct welding operations in the early morning when the geomembrane has cooled down overnight and is in a contracted state.

References

1. Rinel Abreu Morrobel y Ángel Alfonso Lara Vargas. Análisis Comparativo de Canales Tradicionales VS Canales Revestidos Con Geomembrana de Polietileno en Secciones Trapezoidales. Trabajo de Grado para la Obtención del Grado de Ingeniero Civil. 2015.
2. Barfuss, Steven and J. Paul Tullis. Friction factor test on high density polyethylene pipe. Hydraulics Report No. 208. Utah Water Research Laboratory, Utah State University. Logan, Utah. 1988.
3. Barfuss, Steven and J. Paul Tullis. Friction factor test on high density polyethylene pipe. Hydraulics Report No. 208. Utah Water Research Laboratory, Utah State University. Logan, Utah. 1994.
4. Bishop, R. R., and R.W. Jeppson. Hydraulic characteristics of PVC sewer pipe in sanitary sewers. Utah State University. Logan, Utah. September 1975.
5. Neale, L. C., and R.E. Price. Flow characteristics of PVC sewer pipe. Journal of the Sanitary Engineering Division, Div. Proc 90SA3, ASCE. pp. 109-129. 1964.

6. Tullis, J. Paul, R.K. Watkins, and S. L. Barfuss. Innovative new drainage pipe. Proceedings of the International Conference on Pipeline Design and Installation, ASCE. March 25-27, 1990.
7. Advanced Drainage Systems (ADS) Inc. Drainage Handbook. 2015.
8. Koerner, R.M. Design with geosynthetics, ed. 5th., 2005.
9. Geosynthetic Institute. GRI - GM13 Standard Specification. 2019.
10. Haas, D.B. and Smith, L.G., Erosion Studies, Saskatchewan Research Council, E75-7, Sept. 1975.
11. Corrugated Plastic Tubing Association, Abrasion Resistance of Polyethylene and Other Pipes (Sacramento, CA, 1989).
12. Tisinger, L.G. & Giroud, J.P. (1993). The Durability of HDPE Geomembranes. Geotechnical Fabrics Report.