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Introduction

This manual contains information on lining systems using **Firestone EPDM Geomembranes**. Apart from general recommendations on the use of the Geomembrane, it also gives information on site preparation and excavation works.

At first sight, the design and the execution of a hydraulic construction may look simple. For this reason, the contractor, the designer and the builder may be in for a rude awakening if all the parameters regarding the design and the installation are not taken into account.

Generally, for simple projects, the design may be carried out by the owner or the contractor.
However, in the case of larger ponds the problem is often considerably more complex, and the contractor should request the advice of a specialist in hydraulic structures. The specialist should be able to answer specific questions on excavation, drainage, protection of the liner, etc.

Before initiating any project, a study of the site should be carried out for the purpose of obtaining correct information regarding :

- *Nature of the soil*
- *Presence of cavities (chalk rocks, chalky soil,...)*
- *Depth and variation of the groundwater level*
- *Presence of gases in the soil (peat, organic matter,...)*
- *Risk of differential settling (poorly consolidated soil, recent backfill,…)*
- *Risk of internal erosion (karst soil, sand,...)*

In any case, the rules of soil mechanics must be complied with in order to ensure the stability of the support and consequently, a durable lining system. All these subjects are covered in the first part of this manual.

The second part of this manual deals with the installation of the Firestone Geomembrane System. This section covers site preparation, compaction of the soil, installation of the drainage, installation of the Geomembrane, splicing , jointing and execution of details.

Finally, the manual is completed with 3 attachments dealing respectively with :

- *Attachment 1 : Technical data sheets*
- *Attachment 2 : Installation tools*
- *Attachment 3 : Chemical resistance chart*

The Firestone Geomembrane must be installed by an authorized Firestone contractor in accordance with Firestone's specifications. It is also essential that all regulations and codes are complied with.

1 • Design

1.1. Field of application

The recommendations in this manual mainly apply to decorative and landscape ponds, agricultural ponds, canals and other water features.

Applications where gas generation or hydrostatic pressure might disturb the function of the Firestone Geomembrane must be avoided, as well as projects where the Geomembrane could be in contact with chemical substances that could affect the Geomembrane.

1.2 Geomembrane selection

The Firestone Geomembrane is a synthetic rubber membrane. The panels are assembled in the factory prior to vulcanization, in order to limit on-site splicing. The rubber sheets are folded and packed on 3,30 m long cores. Each roll is labelled with the brand name, thickness, dimensions, date and production lot, as well as an arrow indicating the direction for unrolling.

The sheets are available in the following ticknesses and sizes :

- *thickness (mm) : 1,02 - 1,14 - 1,52*
- *width (m) : 3,05 - 6,10 - 7,62 - 9,15 - 12,20 and 15,25*
- *length (m) : 30,50 - 45,75 and 61,00*

The 1.02 mm thick Firestone EPDM Geomembrane is specifically designed for decorative pond applications. It is commercialized under the trade name **Firestone Pond Liner™**.

Because of its specific formulation and production process, **only the Firestone Pond Liner™ membrane is guaranteed to be compatible with aquatic life** in accordance with testing reports published by the Water Research Centre in the UK.

1.3 Site selection

When selecting the construction site, several elements must be considered to ensure long-term performance of the lining system and to avoid any future problems. Site selection is the responsibility of a specialist engineer.

The following is a general overview of a few of the critical site selection parameters which should be investigated:

1.3.1 Nature of the soil

A thorough investigation of the site must be carried out in order to ensure underlying soil stability under all circumstances.

The type of soil, permeability and thickness of the geological strata under the Geomembrane must be known. The table below outlines some risks associated with general soil type:

Soil Type	Risk	Solution
• Compressible (peat, fine sand, ...)	• Considerable gas generation • Pressure under the Geomembrane	• Gas drainage • Slope must be adapted to facilitate gas drainage
• Loose backfill	• Settling • Over-consolidation of the backfill materials	• Appropriate compaction
• Soil containing organic matter (old sugar or paper industry ponds, landfill)	• Fermentation • Pressure under the Geomembrane (gas)	• Gas drainage
• Soil with internal erosion hazard (backfill material containing waste, limestone-type soil, gypsum chalk)	• Dissolution of the soil by liquid in case of a leaking system • Collapse caused by eroding water circulation	• Change sites or provide a good geological assessment in order to find cavities, if any • Special compaction or double waterproofing layer
• Volcanic soil (soft clay, compressible silt)	• Absorption capacity • Differential settling provoking tearing of the Geomembrane at the splices	• An intermediate layer • Particular drainage and special compacting around the details

1.3.2 Groundwater level

If the groundwater level is higher than the bottom of the water feature, the Firestone Geomembrane System will be subject to hydrostatic pressure. Also, air may be entrapped, causing gas pressure if the ground water level rises.

For this reason, the depth of the groundwater level must be known (both the average level and the extreme level). If the groundwater level exceeds the level, the Geomembrane risks being lifted and the functioning of the gas drainage system can be disturbed. In this case, an appropriate drainage system under the Geomembrane must be provided. Groundwater drainage systems must be designed by the project engineer.

1.4. Site geometry

1.4.1 Bottom

A fall of 2 % is recommended for the following reasons:

- *Correct operation of the drainage system*
- *Easy maintenance of the pond (if unprotected)*
- *Positive gas movement*

The fall becomes more important the larger the pond surface, and must be adapted to the calculated settling level.

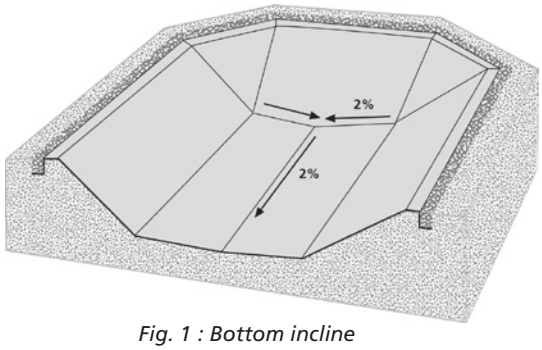

Fig. 1 : Bottom incline

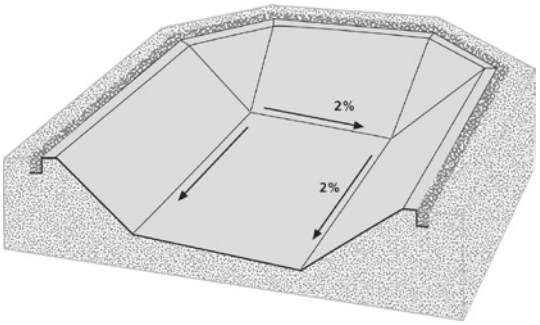

Fig. 2 : Bottom incline

1.4.2 Embankment incline or side slopes

Stability of the embankment is a geotechnical issue. The presence of groundwater and the nature of the soil play an important part in the stability of the embankment. The Firestone Geomembrane must not be used to provide stability of the embankment.

The stability study must deal with the following:

- *Stability of the drainage system and of other layers between the bottom of the pond and the Geomembrane*
- *Effects of waves*
- *Consequences of rapid drop in water level*
- *Consequences of excessive leakage*
- *Stability of the Geomembrane protection layer, if any*
- *Ease of installation*

If no slope stability study is carried out, the contractor shall provide a minimum slope of 2/1.

If the height of the embankment above the base of the pond is between 5 and 10 m, a slope of 3/1 is recommended.

The values mentioned in the table below may be used as a general guide. These values are given according to the nature of the soil. They should be considered with extreme care for the reasons mentioned above.

Nature of soil	Incline
Clay soil	2,5 H/1 V
Clay and sandy soil	2-3 H/1 V
Sandy gravel	2 H/1 V
Soft rock	1,5 H/1 V

1.4.3 Embankment crest (top of the slope)

The embankment crest must have a minimum width of :

- *1,0 m for installation of anchor trench*
- *3,0 m if machines or vehicles are used during the construction and operation of the water feature*

If such width cannot be obtained, alternative anchoring methods must be used. Also a slight incline of 1% towards the outside of the pond is recommended for drainage.

1.4.4 Maximum length of the pond

Waves created by the wind or by boats cause an impact on the side slopes. The greater the length of the pond in the direction of the prevailing winds and the steeper the slope of the embankment, the stronger the wave action will be.

Wave impact can be reduced by :

- *Building a smaller but deeper pond*
- *Selecting another shape, with a shorter dimension in the direction of the prevailing winds*
- *Building several smaller ponds, instead of one large pond*

According to the specific height of the waves, the nature of the soil and the slope of the embankments, we recommend the following :

- *Protection of the Geomembrane adapted to the incline (concrete, riprap, soil cover)*
- *Adequate anchoring of the Geomembrane*
- *Adequate compacting of the soil*
- *A geotextile protection under the Geomembrane*

1.4.5 Maximum liquid level

The higher the liquid level in the pond, the higher the hydrostatic pressure. The risks of the substrate layer settling and the Geomembrane tearing are also higher. Even considering the considerable elongation at break properties of the Firestone Geomembrane, cavities may be present in the soil that could cause the Geomembrane to be perforated, especially if the soil contains gravel. To avoid this risk, a fine grained intermediate layer of sand or clean soil and/or the installation of a geotextile underlayment is recommended.

1. 5 Soil preparation

1.5.1 Natural soil

The support (the soil layer in immediate contact with the sheet) must be clean, smooth, compacted, free of aggressive angle changes, stones and small cavities. This layer must also be able to compensate for the differential settling of the soil and to facilitate the installation of the drainage system when required.

The support may be realized in various ways :

- *Excavated pond base after removing stones, rocks, vegetation etc., followed by smoothing and compacting*
- *Backfill layers with controlled particle size which are compacted (sand, stable earth,...)*

Vegetation

All plant growth must be removed from the base prior to compaction in order to avoid any gas generation and compression of the base. According to the conditions, the use of a durable weed killer is recommended. The weed killer must not contain any components which might affect the Lining System.

Compaction

The Geomembrane support must be optimally compacted (to a density between 85% and 95% of the normal Proctor Optimum), either by natural or by mechanical compacting. The compaction at the crest of the embankments must be carried out with the utmost care.

(Note : The Proctor Optimum value corresponds to a state of soil equilibrium between consolidation and swelling.)

Geotextile

Installation of a geotextile between the support and the Geomembrane is recommended. It is an absolute necessity on embankments where deposition of an additional support layer is often difficult. Depending upon the nature of the soil, the weight of the geotextile may vary between 200 and 500 g/m^2.

When the geotextile also has a drainage function, it must be checked for sufficient transmissibility. In such cases, draining geotextiles must be used. Consult the manufacturer of geotextiles for advice.

1.5.2 Hard substrates (concrete, treated soils,...)

On hard substrates such as concrete, it is always necessary to install a protection layer, unless the Geomembrane is fully adhered. On a bituminous support (bituminous concrete, bitumen emulsion stabilized soil), a geotextile of at least 300 g/m^2 must be used.

1.5.3 Soil around concrete structures

The Geomembrane fixed to a concrete structure must absorb any stress caused by soil movements. Therefore, compaction of the natural soil around such structures must be performed with particular care, to limit settling as much as possible. Backfill material around the structure must be compacted to 95% of the normal Proctor Optimum.

1.6 Drainage system

The need for a drainage system depends on local site conditions such as the presence of clay in the soil. In all cases where liquid or gas may cause an instability of the soil, the amount of water in the soil must be limited. This can be done by means of a specific drainage system, or eventually a double lining system with a drainage layer between the two Geomembranes.

1.6.1 Application criteria

The application of a drainage system is not required, if the permeability of the supporting layer exceeds 10^{-4} m/s, or if no gas or water pressure is anticipated. However, in many cases, the presence of a drainage layer allows the rapid detection of leaks.

Water/Gas drainage is always required under the following conditions :

- *When water flows are possible under the Geomembrane, namely in soils where erosion can be possible (karst soil, ...)*
- *Soils containing organic matter (gas generation)*
- *Embankments containing clay (stability when emptying,..)*
- *Whenever variations of the groundwater level can be anticipated*
- *Whenever the Geomembrane is not fixed and can move (wind,...)*
- *Pond containing organic matter*

The figure below summarizes the main causes of pressures under a Pond.

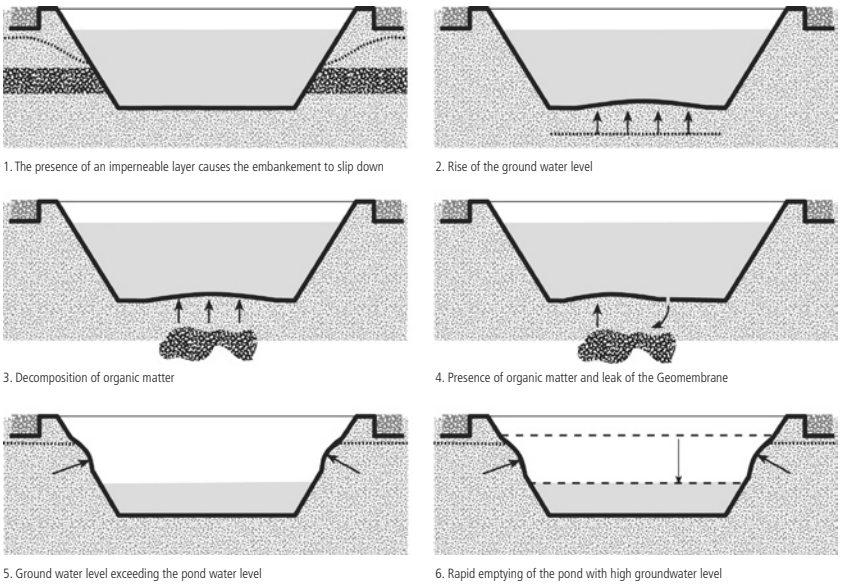

Fig. 3 : Some causes of excessive pressure

1.6.2 Water drainage

Water drainage and gas drainage are often combined. For this reason, a slope of 1 to 2% of the base towards the embankment is recommended.

The water drainage may be implemented by means of one of the following:

- *A layer of permeable material with a minimum thickness of 100 mm*
- *A permeable geosynthetic material*
- *A network of drainage ditches linked to each other covered with a permeable geotextile or a thin layer of permeable material*

In order to prevent the drain blockage, a natural or synthetic filter must be installed between the soil and the drainage layer. Rules for correct filter operation must be complied with. Water must be collected by a network of pipes placed at the lower points of the pond. For larger structures, a compartimentilized drainage network is recommended to facilitate leak detection.

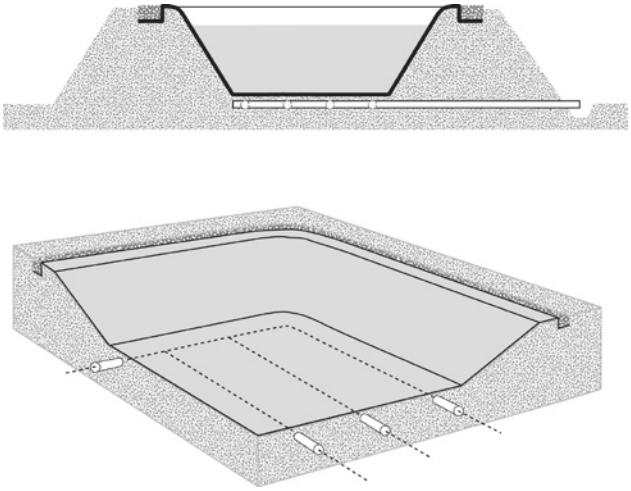

Fig. 4 : Water drainage

Size and gradient of the water drainage system depends on the following factors:

- *Leak flow rate that is acceptable*
- *Flow rate of water coming from outside the pond*
- *Maximum pressures that are acceptable under the Geomembrane*

For smaller projects, the use of perforated drain pipes with a diameter of 60 mm or flat drains is recommended. For larger structures, the size and the density of the network, as well as the compressive strength of the drain pipes must be carefully calculated. Consult the manufacturer for advice.

1.6.3 Gas drainage

The application of perforated pipes is recommended in less permeable soils. A sand bed (or a similar material), a geotextile, or some other permeable geosynthetic material must be placed between the pipes.

A flat synthetic drainage system can be used as an alternative.

Any direct contact between the Geomembrane and abrasive surfaces of the drainage systems must be avoided.

Gas vents are always located at the higher points of the embankment and must be protected by a cap.

Gas drainage must always be designed in such a way that flooding is avoided. All gas drainage systems need to be combined with water drainage.

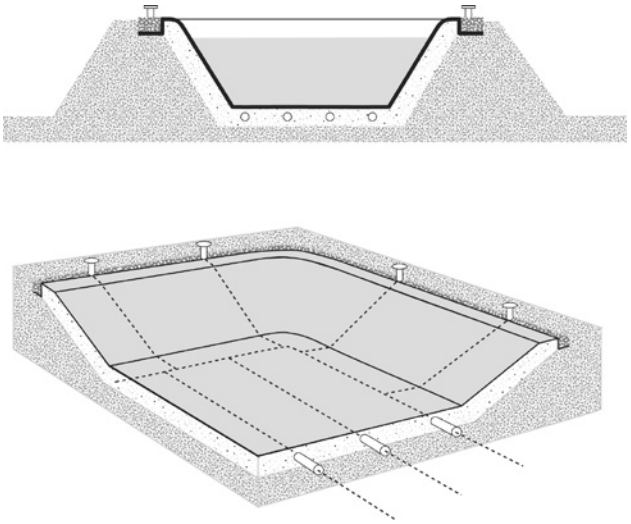

Fig. 5 : Gas drainage