Waterproofing of Reservoirs and Similar

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1. INTRODUCTION

1.1. Scope of the Work

The estimated reserve of water is 1.500 billion m², but only 0,3 % is usable fresh water. 97,3 % of the water is salty, 2,15 % appears as polar or glacier bound water, 0,65 % is in the ground water table or shows up as water on the surface. Around 12 millions of people die yearly due to lack of potable water.
These numbers are a clear sign telling us it is time to act : too much water is wasted and polluted without reason, water which could save human lives.
A very effective method to conserve water is to build water basins for multiple uses. Besides being a reserve for water and other liquids, it can also be used to gain electric energy. The water can be used as drinking water or water for irrigation, all purposes that save lives.
These type of constructions are frequently built in areas with porous underground. Water can disappear through the ground, through the side walls and in case of Storage Lakes through the dam as well.
There are technical solutions to avoid loss of water. One very effective method is the installation of water proofing membranes. There are different possibilities to use such membranes. One of the most convenient membranes is the thermoplastic membrane. The best known thermoplastic membranes are PVC-P, PP and PE in different densities.

1.2. Products of RENOLIT

RENOLIT presents a large offer of suitable plastic sheeting to carry out the waterproofing of water basins and similar projects:

- RENOLIT ALKORPLAN PVC-P geomembranes
- RENOLIT ALKORTENE PE geomembranes
- RENOLIT ALKORTOP PP geomembranes

The following type of projects can be carried out with the above mentioned products:

- Irrigation basins
- Artificial lakes
- Fire fighting ponds
- Drinking water basins
- Waste disposals for different waste (basic waterproofing as well as cover)
- Canals
- Retention basins for all kind of liquids (rainwater, chemical products and similar)
- Floating covers
- Dams

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1.3. Requirements on the waterproofing materials

The quality of the waterproofing depends on:

- choice of geomembrane
- waterproofing system including the preparation of the ground
- way of carrying out the work (ground, drainage, waterproofing system, protection).

1.3.1. Water tightness

Depends on the definition of geomembrane (product group, thickness) in order to withstand all influences (pressure, condition of ground).

1.3.2. Flexibility

This question has to be taken into consideration during projecting. Depending on the form, angles and settlements of the construction the type of membrane has to be chosen accordingly.

1.3.3. Chemical resistance

The waterproofing has to be resistant against the chemical influence of:
- stocked material
- pollution rising from the ground due to the changing water levels of the water table.

1.3.4. Compatibility with the drinking water

In case the waterproofing has to serve in connection with drinking water the geomembrane has to correspond to the national standards.

1.3.5. Geography

The described waterproofing systems are suitable for all geographical regions and climate zones. In any case it is recommended to ask for technical advice from the technical team of RENOLIT concerning questions of choice of material, situation concerning UV radiation or cold temperatures.

2. GEOMEMBRANES OF RENOLIT

2.1. Geomembranes RENOLIT ALKORPLAN

The type RENOLIT ALKORPLAN represents all geomembrane of soft, homogeneous and reinforced PVC-P.

2.1.1. References of Geomembranes RENOLIT ALKORPLAN

- 35052, drinking water geomembrane. Light grey or dark grey. Homogeneous and reinforced with protection against UV radiation.
- 35254 PES, reinforced geomembrane for dams, floating cover and hydraulic works. Light grey or dark grey with protection against UV radiation.
- 35053, geomembrane for hydraulic works. Light grey or dark grey. Homogeneous without protection against UV radiation.
- 35054 / 35254, geomembrane for hydraulic works. Light grey or dark grey. Homogeneous with protection against UV radiation.
- 02339 geomembrane for hydraulic works, homogeneous with protection against UV. Dark grey or black.
- 35038, geomembrane resistant against temporary influences of hydro carbonates and can be applied directly in contact with bitumen (non UV resistant). Black.

The above mentioned geomembranes can also be produced:

- With reinforcement (polyester grid or glass fibres).
- Fleece backed with PES (polyester) or PP (polypropylene) geotextile.

The mechanical characteristics can change due to the reinforcement and/or the fleece backing.

2.1.2. Properties

RENOLIT ALKORPLAN geomembranes are PVC-P soft membranes, calendared or extruded, rolled into a hard box, with a width of 2,05m.

- No point of yield will be reached before breaking: after elongation under stress, PVC-P is able to relax and adapt to the ground.
- High performance concerning bi-directional deformation due to their elasticity (>170%).
- Very high resistance against hydrostatic puncture (>950 kPa/mm).
- High puncture resistance.
- Good resistance against chemicals like acid bases and salts, aging, roots and environmental influences.
- PVC-P Geomembranes resist permanent contact of pH levels between 2 and 10.
- Geomembrane without UV protection can resist 1 month in direct exposition to UV radiation without loosing its mechanical characteristics.
- UV protected geomembranes may be used for permanent exposition to sunlight.
- Very good weld ability with hot air hand welder (type Triac) and automatic machine (hot wedge and/or hot air), even after many years of use, with a large window of temperature and speed.
- Limited thermal dilatation : 1.5 10-4 cm/cm/°C
- Very good angle of friction (+- 28°).

2.1.3. Characteristics

See technical data sheets.

2.2. Geomembranes RENOLIT ALKORTOP

This type of geomembrane is made of Polypropylene, flexible

2.2.1. References of RENOLIT ALKORTOP geomembranes

- 03550, homogeneous geomembrane, black, extruded, 5.80 m and
- 6.00 m width.
- 35080, homogeneous geomembrane, grey, calendared, 2.10 m width.
- 35086, reinforced geomembrane with Polyester grid, grey, calendared, 2,10 m with, UV resistant.
- 35087, reinforced geomembrane with glass fiber, grey, calendared, 2,10 m width, non UV resistant.

2.2.2. Properties

Geomembranes made of flexible PP, homogeneous or reinforced.

- FPP is less flexible than PVC-P.
- A pseudo yield point can be observed after a certain elongation of the material (+-40%).
- Homogeneous geomembranes show good performance concerning bi-directional deformation due to their relative flexibility, especially in cold temperatures.
- Good chemical resistance.
- Medium hydraulic puncture resistance (600 kPa/mm).
- FPP can be welded with hot air and hot wedge automatic machines and with hot air hand welder, with a narrow window of temperature.

2.2.3. Characteristics

See technical data sheet.

2.3. Geomembranes RENOLIT ALKORTENE

This type of geomembrane is made of Polyethylene (PE)

2.3.1. References of AKLORTENE geomembranes

- 00251, geomembrane HDPE, black
- 00274, geomembrane LDPE black

2.3.2. Properties

Geomembranes made of PE, extruded, black.

- High resistance against chemical influence, especially hydro carbonates acids and bases.

- Poor resistance against active oxygen.
- Capability of deformation is reduced due to its low flexibility, especially on uneven and rough ground.
  To initiate an elongation of the material, important power has to be applied due to its stiffness. After an elongation of around 8% (one-direction) the point of yield is reached and the material starts to flow. The elongation happens at the weakest point of the material till it breaks. Durng its flowing state HDPE is very sensitive to any mechanical influence.
- Medium hydraulic puncture resistance (675 kPa/mm).
- Poor friction angle (+- 18°)
- High thermal dilatation (+- 2.6 10-4 cm/cm/°C)
- PE-HD has to be welded by hot air or hot wedge welding machines with high pressure. Details have to be welded by extrusion. It is not possible to weld this material by hand with hot air.

2.3.3. Characteristics

See data sheets

2.4. Accessories

Geomembranes are the most important part of a waterproofing system. To make it function in a correct way different accessories complete the whole system, depending on the kind of construction that will be water proofed. All accessories have to be compatible with the used geomembrane.
The following accessories are part of such a system:

- o Protection layer (geotextile, plastic sheeting made of regenerates and similar)
- o Drainage layer (all kind of geo-grids)
- o Fixation elements (laminated metal sheet, water stop, stainless metal plates, anchor and more)

2.5. RENOLIT Production

The whole production procedure including the management and the purchase of raw materials has to conform to the demands of ISO 9001.
The control of production starts with the supply of raw material before proceeding to the laboratory responsible for the mixing of the compound, then continues through production, the logistic department, and also the management team.
After passing through the mixing and melting unit the compound is transported to the calendaring or extrusion unit. After going through numerous calendaring drums the final membrane, controlled by many electronic devices for thickness, heat and speed is extracted and rolled up.
The production of geomembranes suitable for drinking water has to be carried out

under great care. The mixing unit has to be completely emptied and cleaned of rests of recent production, in order not to influence the quality of the geomembrane.
A PES reinforced geomembrane is produced on laminating machinery where the Polyester grid is introduced between two layers of geomembrane. Exact heat and pressure are important to receive a perfect lamination between the 2 layers of geomembrane and the Polyester grid.

2.6. Geomembrane recommended

RENOLIT group manufactures and markets a complete range of PVC-P, PE or PP geomembranes in response to a wide variety of applications. Experience has shown that the PVC-P geomembrane is the most suitable for waterproofing of hydraulic structures due to its excellent deformability, which allows it to adapt to all forms of support, its puncture resistance, weld ability, resistance to UV and durability: RENOLIT ALKORPLAN 35054 & 35254.
If necessary, the geomembrane is also available with a special formulation for storage of potable water: RENOLIT ALKORPLAN 35052.
In addition, this geomembrane can be laminated with a geotextile in polyester or polypropylene (up to 700 g/m²) and receive a reinforcement grid made of polyester or glass.

3. INSTALLATION OF LINING

3.1. Conception of the Waterproofing System

It is necessary to study the exact conditions under which the waterproofing system has to be installed and has to work. Different parameters can lead to a malfunction of the system. Therefore the geological and geo-technical conditions have to be investigated on site.

In general the waterproofing system consists of:

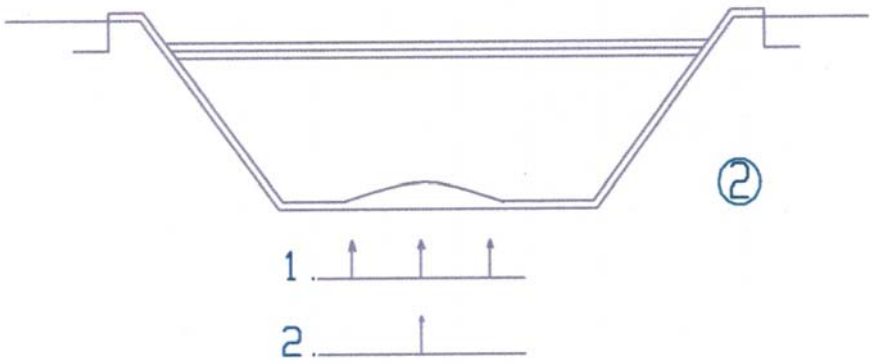
- Support
  - Drainage layer
  - Protection layer
  - Filter layer
- Waterproofing layer
- Protection
  - Synthetic protection
  - Mineral protection
  - Combination

3.2. Preparation of the Support

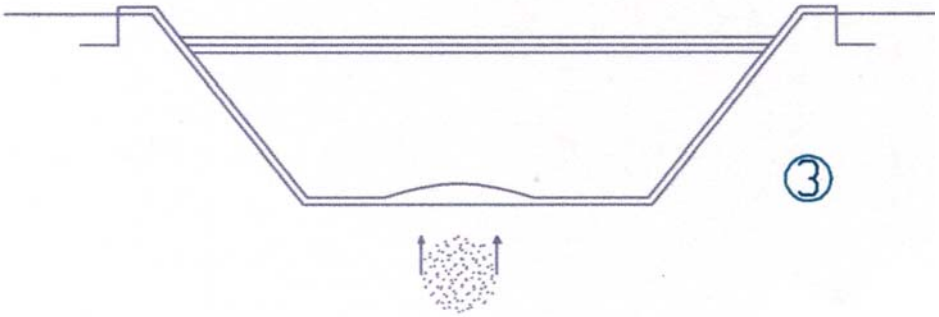
3.2.1. Quality of soil

The quality of soil is of importance. Investigation should be made concerning the existence of gas and organic material in the soil. It could be possible that drainages to evacuate developing gas underneath the waterproofing system have to be installed. There are multiple reasons for sub-pressure under the waterproofing system which can cause a failure of the waterproofing system:

An impermeable layer and a raising water table due to heavy rainfalls can lead to negative pressure.



Pressure due to gas and a permeable layer with rising water from the water table can lead to damages.



Dissolution of organic material below the waterproofing system can lead to sub-pressure underneath the water proofing system

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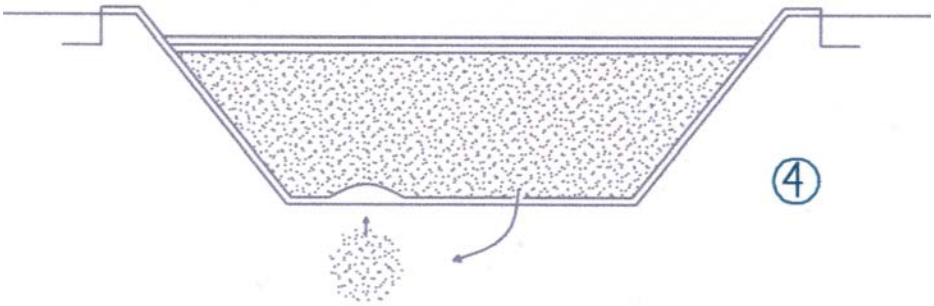
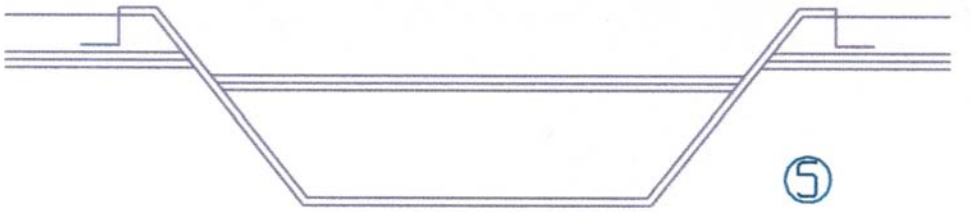
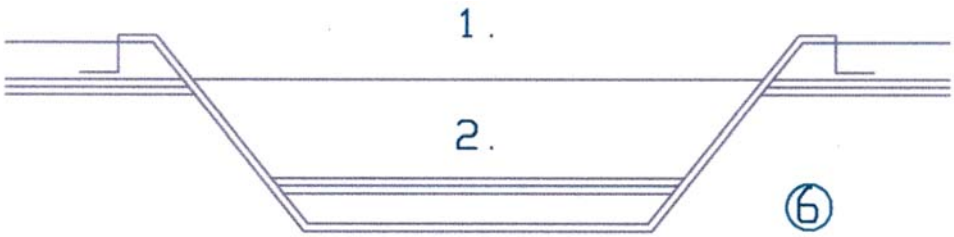


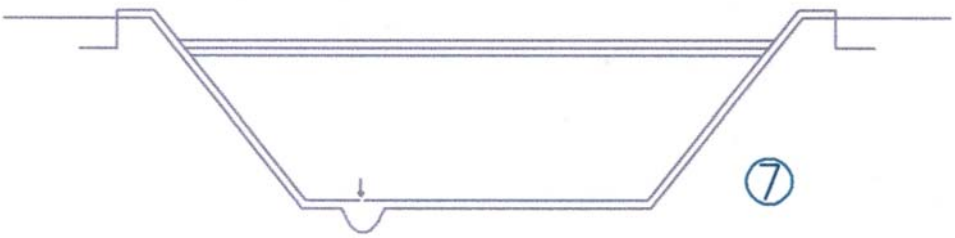
Leak under a lagoon of a liquid laden with Organic Material



A higher water table than the water level in the lagoon provokes sub-pressure.



Rapid emptying of the lagoon in equilibrium with the outside in the period of service.



Localized subsidence as a result of a leak.

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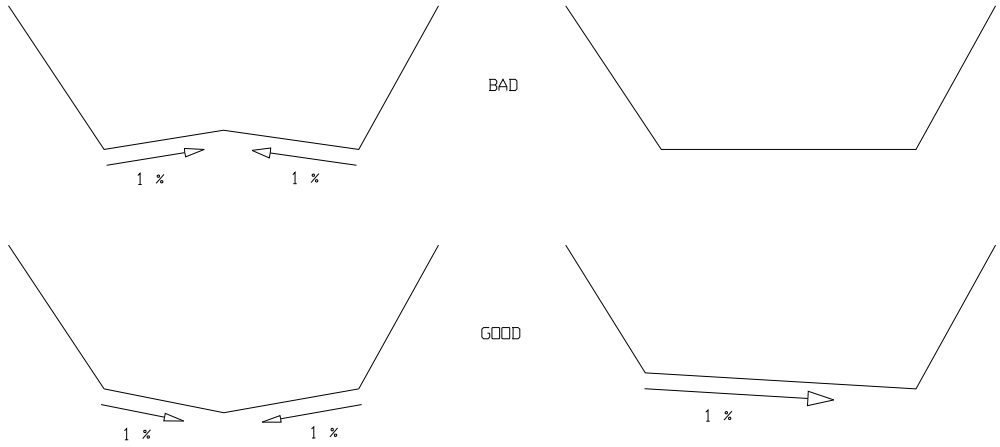
3.2.2. Geometry

3.2.2.1. Bottom

In order to have a good functioning of the drainage and to simplify the cleaning of the basin after emptying a minimum inclination of 1 % should be built.



3.2.2.2. Slopes

The slopes have to be built in such a way in order to be stable on their own. The waterproofing system may not have any stabilising function. In most cases the inclination of the slope has to be below 45° (1/1) for the following reasons:

- Elongation of the geomembrane due to its weight could lead to flowing and gliding.
- Instability of the drainage layer and/or the protection layer consisting of gravel, concrete slabs.
- Quick emptying of the basin can lead to instability of the slope.
- Work on the steep slopes.

3.2.2.3. Top area

The dimension of the top area has to be large enough to allow:

- correct fixation of the waterproofing system
- circulation of traffic during and after installation of waterproofing system.
- Special rules for application of PE geomembranes.
- Radius between slope and bottom has to be large enough to avoid local stress of the geomembrane (German standard DVS 2225 prescribes a radius of 1m with the use of a geomembrane of 2,5 mm).

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3.2.3. Drainage

The drainage has to ensure the release of liquids and gas under the geomembrane.

It is recommended to create a slight inclination (1% min.) towards the slope in order to evacuate enclosed air and gas at the first filling of the basin.

A study before starting the project should be done concerning the drainage, as any mistakes during the work can lead to important failures of the waterproofing system.

Drainage of the water/gas should be taken into account under the following circumstances:

- when the liquids or solids stored are pollutants or toxic
- when the liquid stored contains organic matters
- when the soil under the waterproofing system contains organic matters
- when the soil is karstic or susceptible to internal erosion
- when the lagoon is subject to rapid tidal rises
- when temporary groundwater can develop under the geomembrane
- to avoid the lifting of the geomembrane through wind action.

3.2.3.1. Gas drainage (in case it is necessary)

In general, perforated pipes of 60 to 80 mm diameter will be used, placed approximately every 20 m (reduced to 10 m if the underlying soil is relatively impermeable and in the event of an expected significant emission of gas).

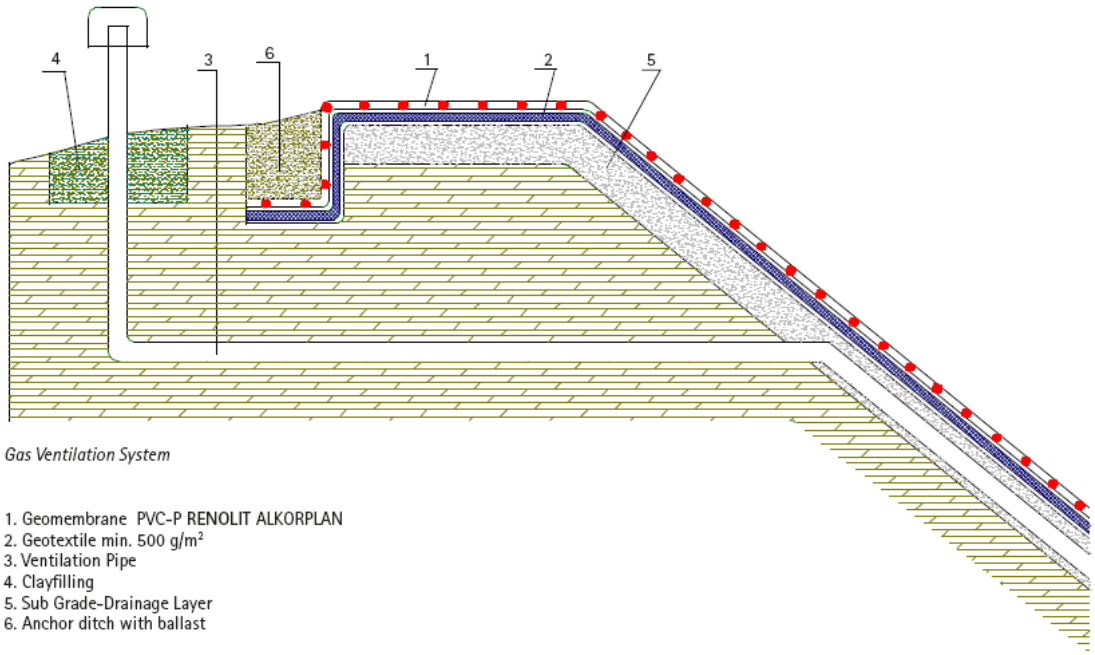
The drainage pipes are not in direct contact with the geomembrane, they are placed in a gas permeable layer (drainage layer or drainage trench), which consists either of granulates with sand (at least 60 %) or a transmissive geotextile.

These pipes can be replaced by strips of geo-spacers placed directly on the support.

The outlets of the gas drains are installed at the highest points and equipped with protected chimneys. The output section must be horizontal, and never facing the wind.

In each case, it is necessary to design the gas drainage in such a way that these drains never get filled with water: it must therefore be associated with liquid drainage.

In addition, the form of bottom of the basin should allow evacuation of the air imprisoned under the geomembrane during installation (slope allowing venting to the outside).



Gas Ventilation System

1. Geomembrane PVC-P RENOLIT ALKORPLAN
2. Geotextile min. 500 g/m²
3. Ventilation Pipe
4. Clayfilling
5. Sub Grade-Drainage Layer
6. Anchor ditch with ballast

3.2.3.2. Drainage of water

The drainage of water can be carried out as follows:

- Layer of granulates in a thickness of 10 cm with minimum of 60 % sand, 0,5 < D < 5 mm. A synthetic separation layer (filter) has to be placed between the ground and the drainage layer.
- A net of drainage ditches has to be installed in order to collect the upcoming liquids. The drainage pipes are covered with a transmissive geotextile to avoid a collimating of the pipes due to fine granulates.
- Geosynthetic drainage in combination with drainage pipes.

3.2.3.3. Collectors and outlets

All liquids are guided into the collectors, leading to outlets where they are evacuated through gravity. If an evacuation with gravity is not possible it has to be done with the help of a pump. In this case a well has to be constructed at the lowest point, containing an automatic pump. This well has to be controlled frequently. It also serves as a control for the functioning of the waterproofing system.

It is recommended to construct such a control well in case the stocked liquids have polluting effects.

For large projects, it is recommended to compartmentalize the drainage system with separate outlets for each area to help locate leaks.

3.2.3.4. Dimensioning of drainage

To measure the dimension of the drainage the following has to be taken into consideration:

- quantity of liquids rising behind the geomembrane
- quantity of liquid in case of a failure of the geomembrane
- the maximal negative pressure in case of a quick emptying of the basin or a failure of the waterproofing system.

Depending on the hydrogeological context, an additional drainage system outside the work may be indispensable.

In small projects half perforated pipes with a diameter of 125 mm in combination with bands of geo-spacer in 0,2 m to 0,5 m width are used in general. For big projects the drainage system has to be measured following the actual situation.

Drainage pipes under waterproofing

3.2.4. Sub grade

The surface has to be smooth, without sharp stones, vegetation and well compacted to avoid relative settlements. It should be able to provide drainage under the water proofing system to avoid negative pressure. This can also be effectively achieved with the help of drainage pipes which are embedded into the sub grade.
The following picture shows the different layers under the waterproofing:

Project of Barlovento: 1st drainage layer of 8/40
Separation layer geotextile 500 g/m² - 2nd drainage layer of 0/6

3.3. Installation of the waterproofing layer

3.3.1. The waterproofing system

After exactly determining the parameters of the soil and the sub grade the waterproofing system can be chosen.
In general the waterproofing system consists of:

- Separation or/and protection layer:
  Geotextile of min 500 g/m² will be placed on the prepared sub grade (drainage layers). Its task is to protect and to separate the geomembrane from the sub grade. In case the last layer under the geomembrane consists of sand, precautions have to be taken during the welding of the geomembrane to avoid pollution of the welding zone (Strip of geomembrane placed under the actual welding zone and pulled in direction of the welding process following the progress of the welding).
- Geomembrane :
  The choice of the geomembrane should be done following the task the geomembrane should fulfil (PVC-P, PP or PE)
- Protection layer:
  It is recommended to protect the waterproofing system. There are different influences possibly damaging the system like waves, rapid emptying of the water, UV-radiation on the exposed part, vandalism. Depending on the steepness of the slope this protective layer can be composed of mostly a combination of geotextile and a solid protective layer as Rip Rap, sand, shotcrete and more (sometimes there is no exterior protection, in this case the geomembrane has to be specially made to safely withstand the existing influences).

3.3.2. Installation of geotextile

The geotextile can be produced in different widths. Depending on the construction the width could be important. For large surfaces the maximum width (up to 8 m) should be used. It may be useful to combine 2 different widths in order to cover the whole project. It is difficult to cut the geotextile therefore some smaller rolls can lighten the work.

Placing of geotextile

3.3.3. Installation of the geomembrane

3.3.3.1. Prefabrication of panels

For large surfaces it is recommended to prepare large panels. This especially concerns PVC-P geomembranes which are produced in widths of 2,05 m. At the prefabrication stage, panels of any size can be produced.

The advantages of prefabrication are as follows:

- Quality of welding is very high as the conditions in prefabrication do not change.
- Reduction of cost compared with welding on site
- Reduction of working time as prefabrication can start before installation on site.
- Reduction of welding on site, therefore failure of welding on site reduced.
- Reduction of testing time.

To be able to produce in prefabrication it is necessary that:

- engines on site are available to place the panels without destruction

- design an exact assembling plan following the condition of the site.

The welding has to be carried out with an automatic welding machine. It is recommended to use a machine with double welding in order to be able to control the welding with air pressure. In case of a simple welding seam it is recommended to control with an iron pipe (opening about 3,0 mm) with air pressure.
The panels are folded in case of minor thickness of geomembrane or rolled onto a large mandrin for more important thickness. To avoid destruction of the panels they have to be packed for the transport to the site.

3.3.3.2. Assembling of panels

The assembling is carried out following the installation plan. The prefabricated panels are numbered to help with the installation and also for clear identification of the panels.
In general the size of panels is between 200 m² to 1.000 m² depending on:

- Thickness of geomembrane
- Means of manipulation in the prefabrication as well as on site
- Accessibility and configuration of site
- Way of folding panels

For PP and PE in most cases it is not necessary to prefabricate panels as the production width can be superior to 5 m.

3.3.3.3. Installation on site

a. Placing of geomembrane

- The installation of the geomembrane of the prefabricated panels can only be executed if all works concerning the sub grade (layers of granulates, separation layer, drainage) are completely finished and approved by the responsible site engineer.
- The geomembranes are unrolled without tension and have to be overlapped. The overlap depends on the used welding machine (4cm to 10 cm). Machines creating a control channel demand an overlap between 8 cm to 10 cm. For extrusion welding an overlap of 4 cm is the limit.
- Outside temperature has to be taken into consideration. During periods of high temperature the elongation of the geomembrane can be important. In hot climates therefore it is recommended to carry out the welding operation early in the morning when the geomembrane has cooled down from the previous night.

Thermal dilatation of different materials:
PVC-P: 1.0 10-4 cm/cm/°C (Displacement: 48 cm for 100 m and 50°C change)
HDPE: 2.4 10-4 cm/cm/°C (Displacement: 120 cm for 100 m and 50°C change)
Reference : Congdon, 1998

Unrolling and placing of geomembrane

b. Welding on site

The quality of welding depends on following parameters:

- Cleanness of the welding area (cleaning with a dry and clean cloth)
- Good adjusting of the machine (temperature, speed and pressure)
- Qualification of personnel.

The used machines are hot wedge or hot air machines. This type of machine is suitable for all kinds of materials (PVC-P, PP, PE). Hand welding for the execution of details, connections at the end of panels, based on hot air can only be applied with PVC-P and PP. Extrusion welding is the common technique for the execution of details for PE geomembranes

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Welding with hot air and double seam

c. Action of wind

The geomembrane has to be ballasted after installation. Wind can displace and lift the panels. In general sand sacks or old tyres are used as ballasting material.

In case of a protected system it is recommended to execute the protection works after the complete control of the executed section.

3.3.4. Anchorage of the waterproofing system on the crest of the construction

In general the waterproofing system will be anchored in a ditch. The ditch should be immediately refilled as the lining system is introduced into the ditch. The dimension of the ditch depends on the length of the slope.

Other fixations are possible (Stainless steel plates in connection with concrete structures)

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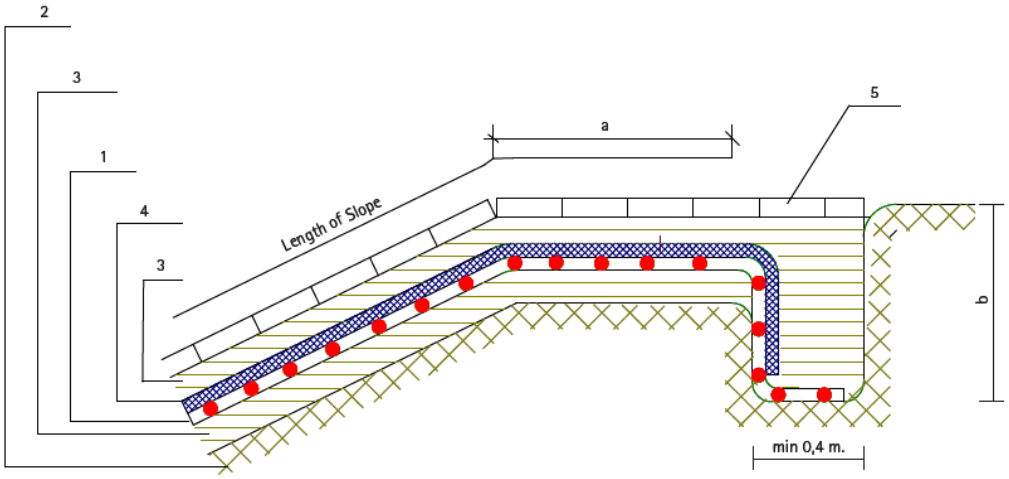


Dimension of Anchor Ditch (Principal Drawing)

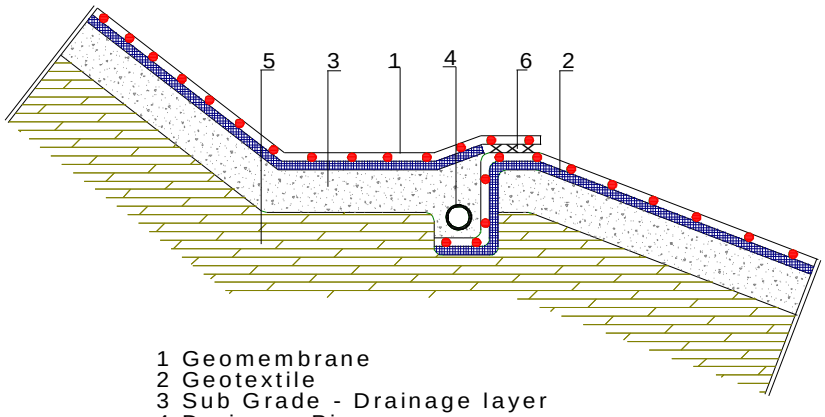
1. Geomembrane RENOLIT ALKORPLAN
2. Compacted Subsoil
3. Sand as Protection Layer
4. Geotextile
5. Concrete Slabs

Length of Slope	a	b
< 10 m	> 0,5 m	> 0,5 m
10 - 40 m	> 0,8 m	> 0,6 m
> 40 m	> 1,0 m	> 0,8 m

3.3.5. Intermediate fixation of the lining system

Depending on the construction intermediate fixations could be necessary. In case of very long slopes it is recommended to foresee such a fixation in order to reduce the stress on the membrane due to wind forces.

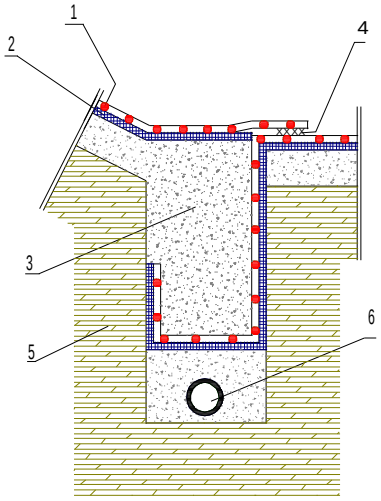
Intermediate Fixation



1 Geomembrane
2 Geotextile
3 Sub Grade - Drainage layer
4 Drainage Pipe
5 Compacted Underground
6 Welding

3.3.6. Anchorage of the water proofing system on the bottom of the construction

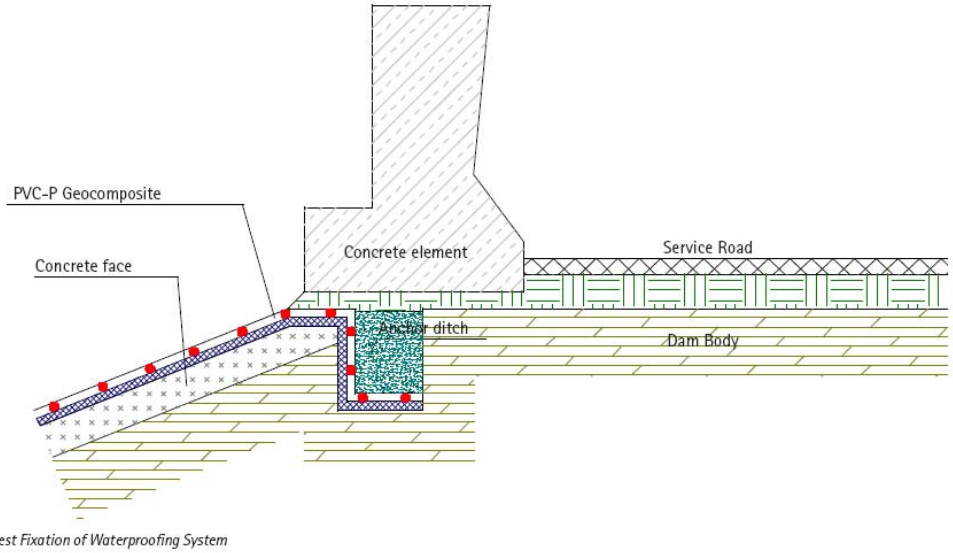
Fixation on the Bottom



1 Geomembrane
2 Geotextile
3 Sub Grade - Drainage Layer
4 Welding
5 Compacted Underground
6 Drainage Pipe

3.3.7. Anchorage in combination with a concrete structure

It is no always possible to find adequate anchorage in a ditch. If there is a service road these concrete structures are often used. In such a case a possible termination of the lining system could be done as shown in the following drawing:



Crest Fixation of Waterproofing System

3.3.8. Ventilation system

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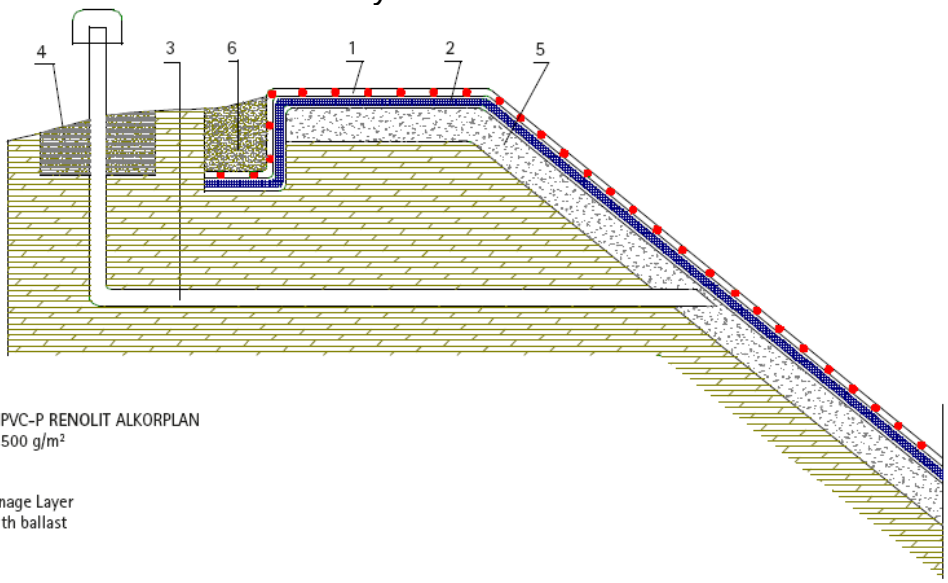
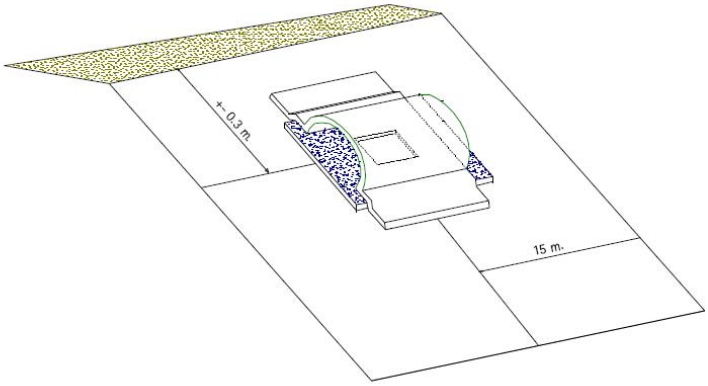
Wind has an important influence on a loosely laid waterproofing system. Especially in basins with high changing water levels (irrigation basin) the exposed part of the membrane could suffer under the wind. Therefore it is recommended to install a ventilation system:



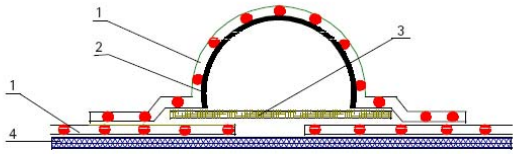
1. Geomembrane PVC-P RENOLIT ALKORPLAN
2. Geotextile min. 500 g/m²
3. Ventilation Pipe
4. Clayfilling
5. Sub Grade-Drainage Layer
6. Anchor ditch with ballast

Another type of ventilation system is shown in the following drawing:



Ventilation System with Half Pipe of PVC-P

1. Geomembrane PVC-P RENOLIT ALKORPLAN
2. Half pipe of PVC-P
3. GEOGRID as protection
4. Geotextile PP



A ventilation system is not necessary if protection of the waterproofing system is provided.

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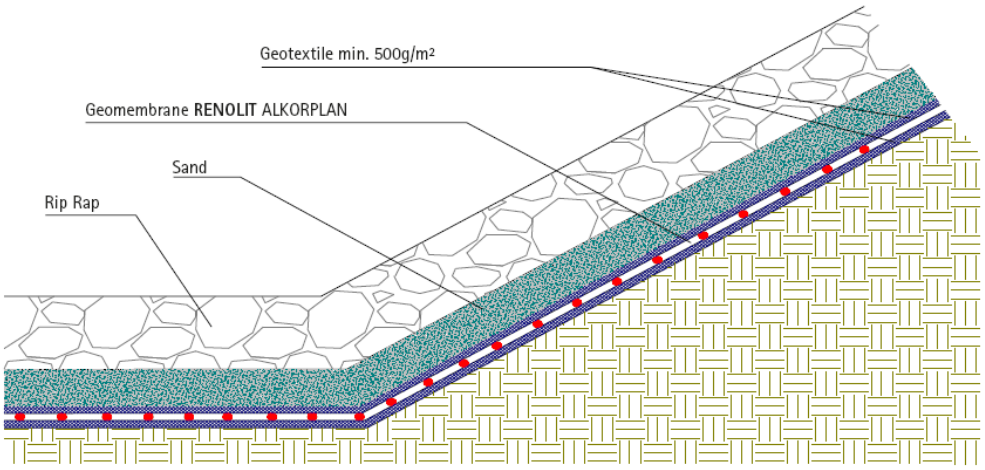
3.4. Protection of the waterproofing system

Protection against mechanical influences is a warranty for a long-lasting waterproofing system. Therefore for the following reasons a protection of the waterproofing system should be installed:

- in canals with a speed of water > 1 m/sec
- in areas of the project with speed of water > 1 m/sec
- against floating objects
- in areas with an access ramp
- on lakesides of artificial bathing lakes
- against wind, ice, waves.
- on the bottom if cleaning with engines is intended
- against vandalism.
- against the influence of UV radiation in exposed zones

3.4.1. Protection with granulates

The study of the stability of the protection depends on the complete knowledge of the characteristics of all used materials, granulates or synthetic, that are going to be used. Especially the friction angle between the different faces may change in an important way with the type of geomembrane, the geotextile and the granulation.. Therefore it is recommended to carry out trials on site to find out the best combination.



Protection with Rip Rap

The thickness of the geomembrane and the weight of the geotextile depend on:

- type of geomembrane
- granulation and angle of the ground
- granulation and angle of the sub grade
- created forces during the execution of protection layer
  These forces depend on:

- thickness of protection layer placed directly onto the waterproofing system
- type of engine used for the placement of the protection layer.

Unloading of protection material with truck

Distribution of material with bulldozer

Distribution with loader

Distribution with excavator

3.4.2. Protection with concrete:

For slopes where no stability with granulates can be achieved (angle of friction too low) a protection with concrete has to be done.

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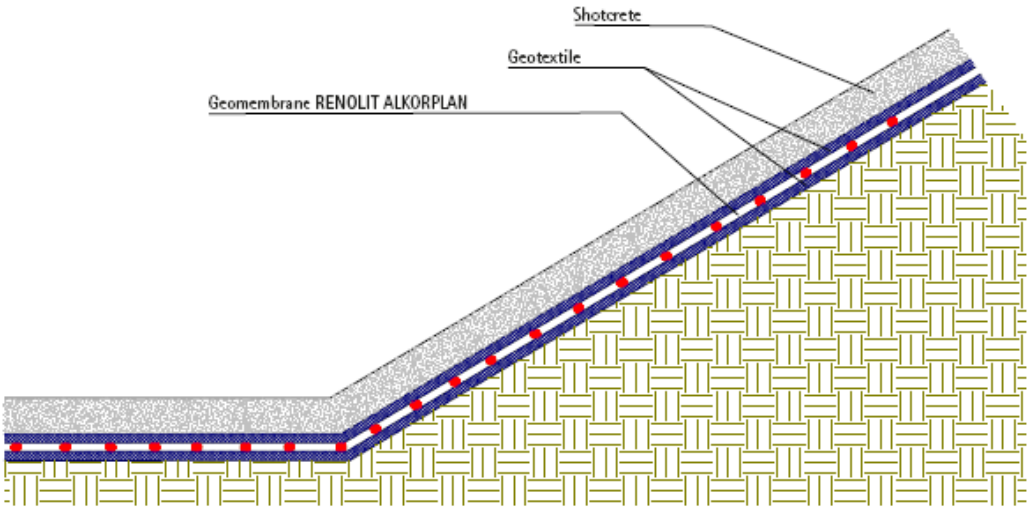
Protection with concrete:

For slopes where no stability with granulates can be achieved (angle of friction too low) a protection with concrete has to be carried out.



Waterproofing System with Shotcrete as Protection

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4. CONSTRUCTION QUALITY CONTROL MANUAL

This manual addresses the quality Control Program to ensure the quality of workmanship and the installation integrity of geomembranes and other geo-synthetic products.

4.1. Material Delivery

A representative should be present, whenever possible, to observe and assist in the material delivery and unloading on site. The representative is to note any material received in a damaged state and to remove any necessary conformance samples. Upon mobilisation to site a representative shall:

- Verify the equipment used on site is adequate and does not risk damage to the geocomposite or other materials.
- Mark rolls or portions of rolls which appear damaged.
- Verify that storage of materials ensure adequate protection against dirt, theft, vandalism, and passage of vehicles.
- Ensure that rolls are properly labelled and that labelling corresponds with QC documents.
- Complete roll numbers, date of production, roll size and any damage due to transport will be noted in the Material Delivery Checklist.

4.2. Geomembrane Installation

The general contractor shall be responsible for preparing the concrete surface suitable for installation of the liner unless specifically agreed otherwise.

4.2.1. Panel Layout

Before laying out the liner, drawings shall be produced to indicate the panel configuration and general location of field seams for the project.

4.2.2. Identification

Each panel used for the installation will be given a number which correlates with a batch or roll number. This panel identification number should be registered on the panel placement form, which will be used when required. Following a plan, given by the contractor, showing the straight sections of the canal to be in condition to identify these specific rolls for controlling, identifying and deliberating for the prefabrication works.

4.2.3. Field Panel Placement

4.2.3.1. Weather conditions

Geomembrane layout will generally not be done during bad weather, i.e. rain, in the presence of excessive moisture, in an area of

standing water, or during high winds.

4.2.3.2. Location

The installer will attempt to install field panels as indicated on the layout drawing. If the panels are layed out at a location other than that indicated on the layout drawings, the revised location will be noted in the field.

4.2.3.3. Damage repairs

Any area of a panel seriously damaged will be marked and repaired in accordance with Paragraph 2.4 of this document.

4.2.4. Geomembrane Field Seaming

4.2.4.1. Personnel

All personnel performing seaming operations shall be trained in the operation with the specific seaming equipment used and will qualify by successfully welding a test seam as described in Paragraph 2.6

4.2.4.2. Equipment

a) Welding in Prefabrication

Before starting the daily welding work a trial has to be carried out in order to regulate the welding equipment with regards to important parameters such as temperature and welding speed. The used welding machine is a device applied for lining works on flat roofs (Type Leister Variant or X 10). The welding machine produces simple seams.

b) Welding on site with hot wedge welding machine

This type of machine delivers welding with testing canal. It is used for the assembly of the geomembrane and the prefabricated panels.

c) Hand Welding

T-joints, transversal strips, connection of geomembrane of the slopes with bottom elements in curved areas, and details have to be carried out by hand welding. Recommended device is a hot air hand welder from the company Leister. Hand welding with hot air only can be used in connection with PVC-P and PP geomembranes. PE geomembranes will be welded with the help of an extrusion welder.

4.2.5. Seam preparation

The overlapping of the geomembrane has to be done in such a way that a safe welding with the machine is guaranteed as well as ensuring a welding of 30 mm for simple welding, and 40 mm for the double welding.

Clean the seam area prior to seaming to ensure the area is clean and free of

moisture, dust, dirt, and debris of any kind.
Adjust the geomembrane (panels) so the seams are aligned with the fewest possible number of creases.

4.2.6. Trial welding

Every working day - before starting seaming works - the machinery has to be checked and adapted following the daily circumstances (temperature, air humidity). This is done through daily trials to determine the speed and temperature of the welding equipment, for the hot wedge machine this also includes pressure applied to the seam. These parameters should not change throughout the day unless the weather conditions change considerably.

Trial Welding

4.2.7. Samples Procedure

Cut 2cm off a 2,5 cm wide specimen and proceed to carry out a peeling test with a field traction device. The welding may not separate; the specimen must show the break of the material.

Testing device and testing specimen

4.2.8. Seaming Documentation

The welding technicians have to fill out all important parameters into the form of seam control:

- outside temperature in the morning, at noon an in the evening;

- data like welding temperature, pressure and speed of the machine determined through the daily testing procedure (controlled through peeling test and tear resistance);
- time welding work started and ended;
- numbers of the seam;
- data of the welding result after testing (reduction of pressure after 15 minutes of testing);
- destructive tests of welding seam (peeling test and tear resistance);
- repair measurements if seams do not pass the test;
- signature of representative of the client and the installer.

4.3. Seam Testing – Geomembrane

4.3.1. Control of seams executed in prefabrication

4.3.1.1. Double seams

Double seams are controlled through air pressure. The air canal has to be closed on both sides of the testing distance. A testing needle (e.g. type Leister) is introduced into the testing channel. The needle has a conical form to avoid the evacuation of the air under pressure. During the testing time the needle may not be removed or manipulated. The applied testing pressure depends on the thickness of the geomembrane and the outside temperature. The testing has to be carried out after one hour of carrying out the welding. The applied pressure may not decrease by more than than 20 % for PVC-P geomembranes and ?to % for PE geomembranes.

4.3.1.2. Simple seams

In case of single seams, a steel pipe connected to a compressor with a diameter of 3 to 4 mm is drawn along the seam under an air pressure of 5 bars. This kind of testing is only suitable for flexible geomembranes not for PE. Leakages are immediately detected through the developing air bubble due to the applied air pressure.

4.3.2. Control of double seam on site through air pressure

See point **4.3.1.** Control of seams executed in prefabrication.
After successful testing, a patch of geomembrane has to be welded over the penetration hole of the testing needle. The testing data will be noted again in the testing document.

4.3.3. Control of hand welding

Follow the procedure of control of seams described under Paragraph **4.3.1.2.** Simple seams. Repair patches and short hand seams are easyly controlled with a vacuum bell.

4.3.4. Repair of detected leakage

The detected leakages have to be repaired with homogeneous geomembrane patches. This welding has to be tested following the procedure mentioned under **4.3.3.** Control of hand welding.

4.3.5. Destructive testing (Pealing test)

The purpose of destructive testing is to determine and evaluate seam strength. These tests require direct sampling and thus subsequent patching. Therefore destructive testing should be held to a minimum to reduce the amount of repairs to the geomembrane.

- Depending on the size of the project it will be determined after how many meters of welding a pealing test has to be executed. A test sample will be extracted by noting date, time and location.
- Destructive samples should be taken and tested as soon as possible after the seams are welded but not before one hour in order to receive test results in a timely manner.
- All destructive test locations with pass/fail designation will be marked on the geomembrane with permanent mean streak markers.

Testing method:
The material has to break outside of the welding area. The following values are recommended:

- PVC-P and PP geomembranes: > 4 N/mm for machine welding
  > 3,5 N/mm for hand welding
- PE geomembranes > 15 N/mm

5. CONCLUSION

The waterproofing of dams, canals and lagoons is a highly technical work. Only experts are allowed to carry out the welding works.
The technical support from the side of RENOLIT Ibérica S.A, starting already at the design of the project till the end of the waterproofing works is a guarantee of delivering a successful work. The experience is high and is an advantage for the client. Many projects have been successfully carried out in the past as shown from our long list of references.

Upper lake for Hydraulic power plant of Afourer in Morocco

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