



Rely on it.

Waterproofing of tunnels under infiltrating water

RENOLIT ALKORGEO

Underground
structures



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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 the waterproofing of tunnels due to its excellent mechanical properties and its durability in accordance with the expected lifetime of the building: RENOLIT ALKORPLAN 35034 – 35036 – 35041. In addition, this geomembrane can be laminated with a geotextile in polypropylene (up to 700 g/m²) for bonded applications, and receive a reinforcement grid made of polyester or glass.

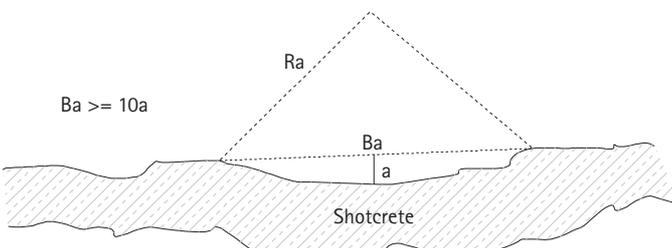
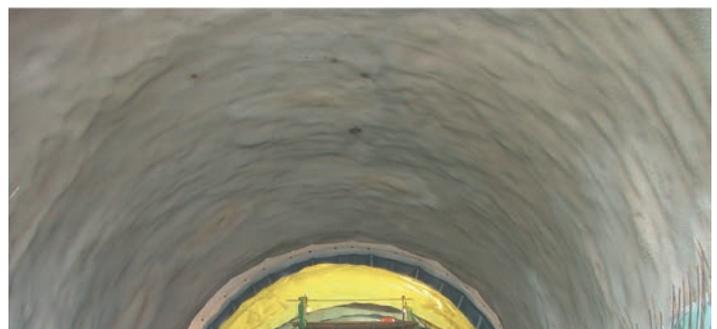
Conception of the waterproofing

Components

- Geotextile minimum 500 g/m² Polypropylene (no Polyester), depending on the surface.
- Geomembrane of homogenous thermoplastic material like PVC-P, TPO min. 2.0 mm thick, transparent (French prescription) or with signal layer.
- Fixing elements.
- Reinforcement strips to protect the geomembrane in the area where shuttering for concrete shell finishes.
- Protection geomembrane (French prescription).
- Anchors if necessary to hold the reinforcement of the inside concrete shell.
- Water stops (mainly for tunnels under water pressure).
- Injection device (mainly for tunnels under water pressure).

Support

The surface of the support has to be as flat as possible, the used granulates should not be greater than 16 mm. The geometry of the surface ($Ba > 10a$) should be followed to avoid possible folding of the geomembrane after the concrete is poured (see drawing of the geometry recommended by Austrian standard HEFT 3659). An irregular surface of the support can lead to folds of the geomembrane during concreting of the inside shell what could harm the waterproofing.



Definition of underground

Installation of the bottom drainage

The so called umbrella tunnels (Waterproofing system only in the vault – no water pressure) need drainage at the bottom of the tunnel in order to evacuate infiltrating or temporary water. A good technical solution has to guarantee that the water will not infiltrate between the waterproofing system and the inside concrete shell.

Installation of the waterproofing system

Before starting the installation, the installer has to confirm that the surface of the support follows the specification.

The scaffolding for the installation of the lining system can be built on to the slab of the tunnel. Depending on the type of scaffolding used, the geotextile and the geomembrane will be installed from one side of the tunnel to the other (use of hydraulic scaffolding) or from the highest point of the tunnel to both sides (manual scaffolding).

The hydraulic scaffolding is costly but makes for more comfortable working conditions for the installer. It has to be adjusted following the geometry of the tunnel.

The geotextile will be positioned on the steel bar of the moving basket, where it will be unrolled automatically when lifting the basket. The geotextile will be fixed with the fastening roundels to which the geomembrane will be welded in the second turn of the basket. After having fixed both items the scaffolding can be moved and put into position for the next placement of waterproofing system.

The use of conventional scaffolding means hard work. First the rolls of geotextile are brought to the highest level of the scaffolding, and fixed to the shotcrete surface with the roundels. Then the geomembrane is unrolled on top of the scaffolding, and spot welded to the fixation roundels starting from the highest point of the vault.

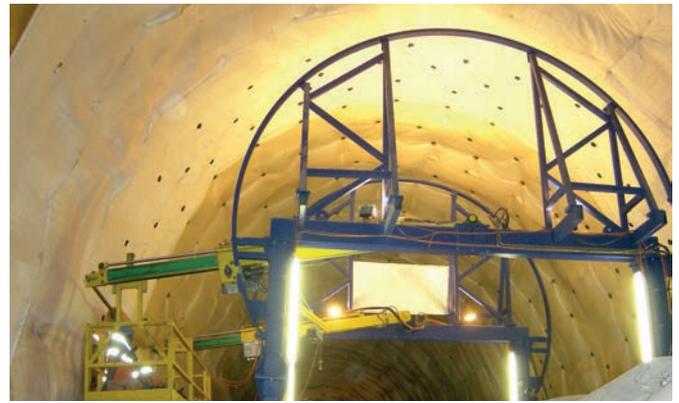
The geomembranes are welded together with automatic welding machines producing a seam with testing canal.

Installation of the Geotextile

The geotextile will be fixed with fixation roundels: in the wall area about 2 pieces per m^2 , on the vault 3 pieces per m^2 . The fixation elements have to be fixed on the deep spots of the shotcrete surface to avoid elongations of the geomembrane during pouring of the concrete shell (the geomembrane will be welded to these fixing roundels).

The geotextile is lifted to the scaffolding, unrolled and fixed with the fixation roundels to the shotcrete surface. The geotextile has to have an overlap of minimum 10 cm. The geotextile will be fixed completely over the surface of the daily planned work.

In areas of severe irregularities it is recommended to double the geotextile.



Hydraulic scaffolding on wheels



Scaffolding for manual installation



Fixation of the geotextile

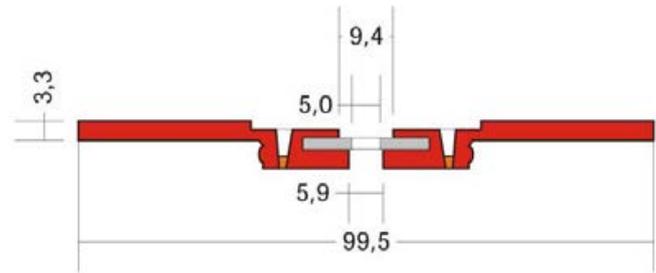


Fixation of the geomembrane by spot welding

Fixation roundels

The task of the fixation roundel is on the one hand to fix the geotextile to the shotcrete surface by shot nails, and on the other hand to serve as a welding surface in order to fix the geomembrane to the tunnel. The roundel is composed of the same material as the geomembrane to ensure compatibility between the materials. It is recommended to use "knock-out" roundels, in the rare case of pressure due to infiltrating water.

Example of flat PVC-P roundel with knock-out system, with a steel washer:



Installation of the Geomembrane

The manufacturer of geomembranes has to produce the correct length of geomembrane following the indications of the installer, which corresponds to the perimeter of the tunnel to be waterproofed. Besides the indicated length a middle mark will be applied as well as a line on one side of the membrane at a distance of 5 to 8 cm. The middle mark shows the installer where he has to fix the membrane to the highest point of the vault (manual scaffolding), the side line indicates the necessary overlap for the welding.

The installer unrolls the geomembrane on top of the scaffolding, welds it to the fixation roundels on the highest point of the vault and proceeds with this work downwards until the whole geomembrane is attached to the fixation roundels.

In this way the daily quantity of geomembrane will be attached to the tunnel surface. Returning the scaffolding to the beginning of the newly fixed membranes, the geomembranes are welded together, with the help of welding machines, producing a double seam with testing canal.

The installer has to take care that the machine is well adjusted concerning temperature, speed and pressure. Therefore it is crucial to adjust the machine through trial welding every day before starting the initial welding works.

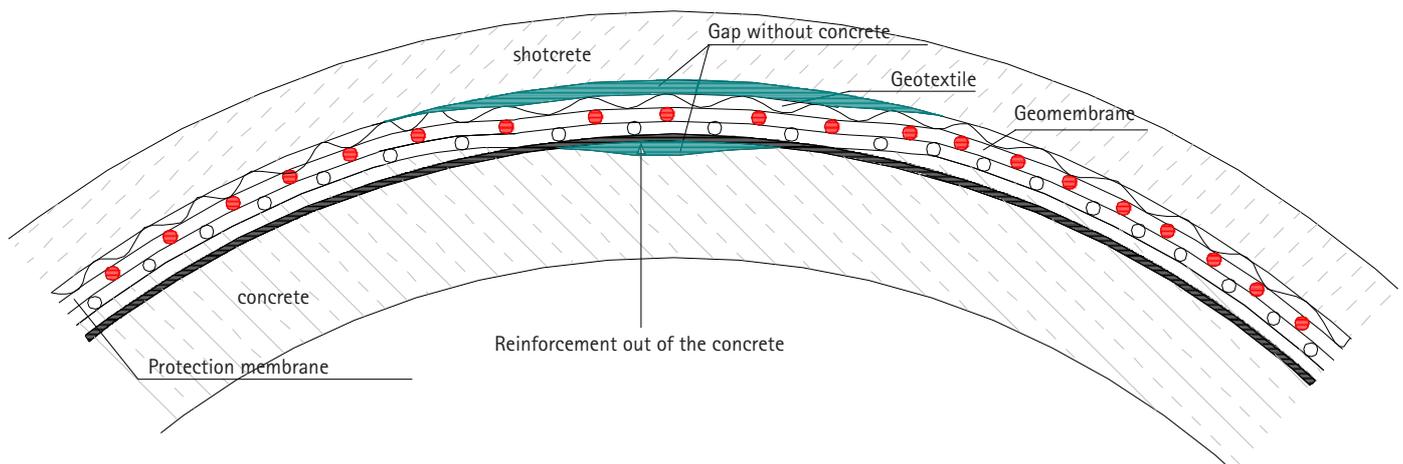
Reinforcement strip

Shuttering units for the inside concrete are, in general, between 8 to 12 m. At the end of the shuttering unit a head shuttering has to be placed. The placement of this head shuttering, consisting of small boards, is a great danger for the waterproofing system. During the fixing of the boards the geomembrane could get damaged. Therefore a protection strip of about 50 cm is placed onto the geomembrane at the end parts of the shuttering unit in order to strengthen the lining system.

Concrete for the vault

The concrete procedure will put some strain onto the geomembrane, causing it to elongate due to the weight of the concrete. Experiences in the past have shown that, depending on the surface of the shotcrete and the way the lining system is installed folds can occur when the concrete is poured. A smooth surface of the shotcrete guarantees less folds in the geomembrane.

The peak of the vault has to be treated with great care. After having poured the concrete, it starts to settle and leaves a gap on top of the vault. Precautions have to be taken to close this gap by injecting cement after the concrete has settled. The steel bars have to be embedded completely in the concrete as well as the anchors of the water stoppage (if present).

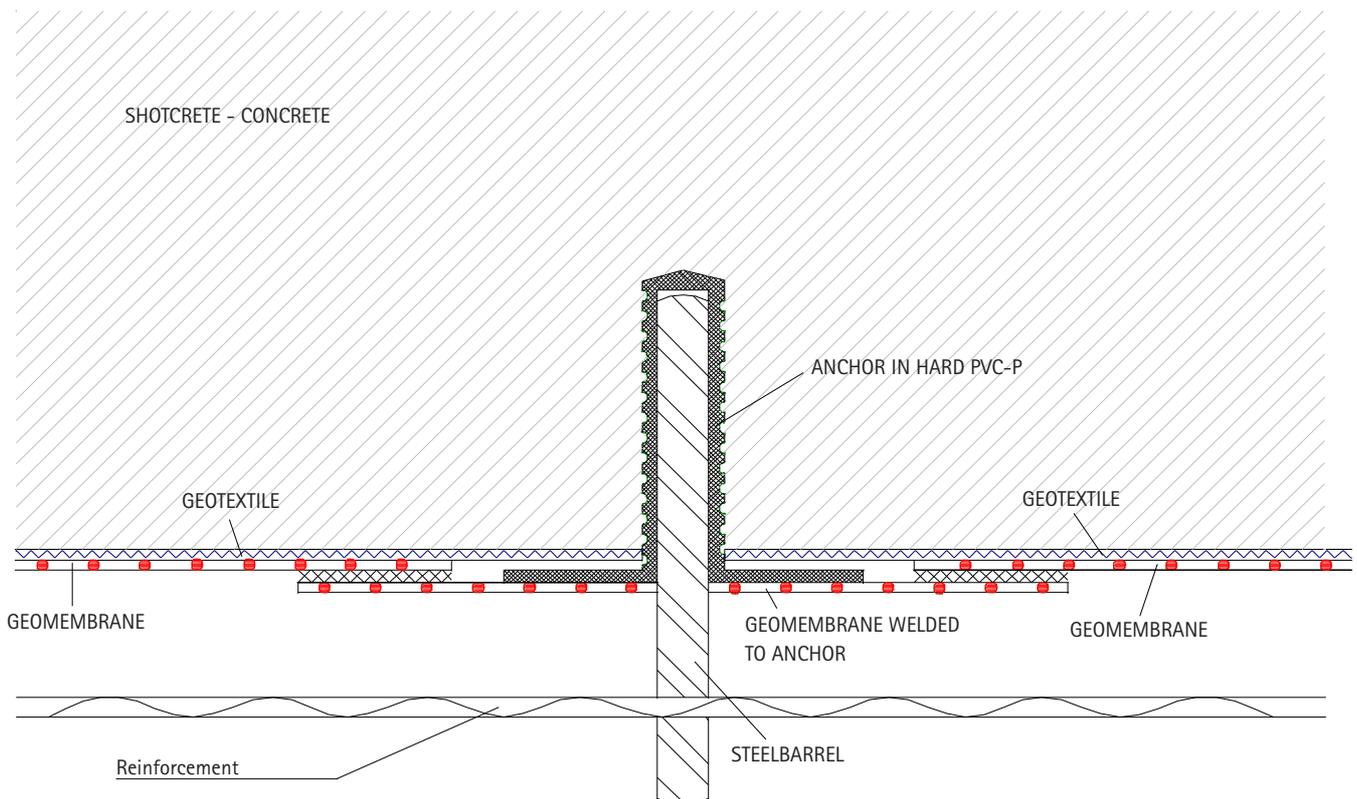


Anchors for reinforcement steel

The installation of the reinforcement steel is one of the most important dangers to the lining system. In the vault the geomembrane is usually not protected and therefore it is exposed to the danger of being perforated during the reinforcement works. The steel bars have to be placed at a certain distance to the lining system. In the case that there is not a self carrying reinforcement, it is highly recommended to use anchors on which the reinforcement bars are fixed onto, at the correct static distance. Such anchors can carry loads of over 30 kN depending on the quality of the shotcrete.

This type of anchor is a completely closed system, water is unable to enter between the lining system and the inside concrete shell. The anchor exists of a hard PVC-P tube with a flange, on which the PVC-P geomembrane is welded. After having installed the geomembrane, a hole is drilled into the shotcrete through the geomembrane. The PVC-P tube is bonded into the borehole. The soft PVC-P flange is welded to the geomembrane.

Into the PVC-P tube a steel pin is introduced in order to fix the reinforcement steel of the inside concrete shell.



Watertight Hard PVC-P Anchor

Compartment system

Water stops are mainly used in tunnels with water pressure. The water stop divides the lining system into compartments which limits the spreading of the infiltrating water, in case of leakage. In combination with an injection system a repair of a leaking compartment can be done without damaging the geomembrane, and at a reasonable cost.





Bonded system

The latest development in tunnel waterproofing is the employment of bonded waterproofing systems. Overall tunnels are becoming longer with the development of high speed trains. These tunnels are constructed with TBM machines where the geology permits it and where the profile of the excavated zone is regular. Tübbing are placed to the shotcrete and make a perfect surface to bond the geomembrane onto.

For such an application a geomembrane with a laminated PP fleece is the correct material to achieve a water tightness of the construction. Special machines were developed for the installation of the geomembrane. They have a cleaning, brushing and a bonding unit and can be managed with only three people. The performance with such an installation machine is much higher than with a conventional installation method.

RENOLIT is able to offer the right geomembrane for this application.



Installation geomembrane with glue

Material

Geomembrane

The choice of the geomembrane should be done following the task the geomembrane should fulfil (PVC-P, PP or PE).

PVC-P Geomembranes are the most suitable material for the waterproofing of tunnels and foundations due to their excellent mechanical performance and their good chemical resistance. During the past 40 years all kind of PVC-P geomembranes have been made, and in view of the existing standards in Europe two types have finally conquered this difficult market.

In the German spoken countries the "signal layer" geomembrane (bicolour) entered all important standards.

In France and other Mediterranean countries the translucent geomembrane was the convincing one as the suitable material for this important sector as a waterproofing material.

System with signal layer

The target of the "signal layer" geomembrane is to detect failures and leakages through a very thin signal layer. The signal layer should be a bright coloured thin upper-layer (less than 0,2 mm in DS 853) so that the dark colour of the geomembrane underneath can be seen in case of any mechanical impact to the material.

The signal layer geomembrane can be produced in two ways :

- By calendaring a 0.2mm thin signal layer to be laminated with the geomembrane.
- By printing.



Translucent system

The use of a translucent geomembrane allows for a very good visual control of the welding (continuity + burning).



Control with colour liquid

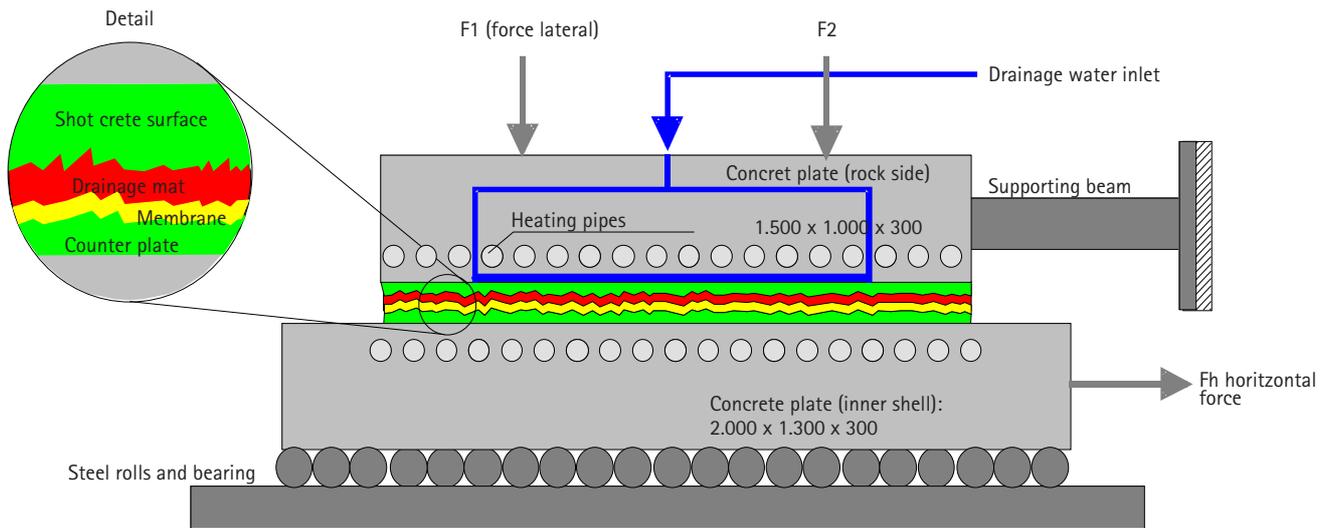
This picture shows visually that the welding is of good quality as the welding is more translucent than the area of the testing canal, but the black traces in the beginning of the welding tell that the temperature was very high, or the hot wedge not properly cleaned. In such a case a special investigation of the quality of welding in this area can be done immediately. With an opaque geomembrane such defaults never show.

The double welding can be controlled with air pressure as well as with coloured liquids. The advantage of this method is to detect immediately the place where the welding has failed.



Resistance of PVC-P RENOLIT ALKORPLAN geomembrane under pressure:

- Intense tests for the St.Gotthard tunnel in Switzerland (Project of NEAT) showed the high shear/compression resistance of translucent PVC-P membrane RENOLIT ALKORPLAN (type 35036 2mm thick), 35036 2mm thick, even under high pressure :
 - Load of 2Mpa.
 - Horizontal movement of 3mm.



Cross-section of the compression/shear set-up with heating and drainage capability, the top plate (fixed) corresponds to the shotcrete surface of the outer tunnel shell

source : The Sealing of Deep-seated Swiss Alpine Railway Tunnels – New Evaluation
 Procedure for Waterproofing Systems – NEAT AlpTransit

- The German laboratory SKZ showed that the PVC-P geomembrane RENOLIT ALKORPLAN 35041 2mm behaved very well under pressure (EN ISO 604):
 - Compressive stress, at 20% compression, is 13.3 MPa, when a minimum of 2.5 MPa is required.
 - Compression, at 2.5 Mpa compressive stress, is 7.5%, when a maximum of 20% is required.
- The French Institute CETE showed that the waterproofing system composed of geotextile 700g/m² + geomembrane RENOLIT ALKORPLAN 35036 2mm + protection layer RENOLIT ALKORPLAN 35020 1.9mm offers a dynamic puncture resistance higher than 8.5J (fascicule 67 titre III of C.C.T.G.).

Geotextile

Product

The geotextile has to be of Polypropylene fibers, short fibers mechanically fixed or long fibers. Polyester geotextile has to be avoided because of hydrolysis of polyester due to alkalinity of concrete. The freshly applied concrete attacks the Polyester geotextile and after a certain time the geotextile dissolves completely.

Water stops

Water stop for Expansion joint

This water stop is placed in all dilatations of the construction. In case of important movements of the construction the middle bulb is able to break in the thin part on the bottom to follow the movements without losing water tightness.

Water stop for Normal joint

They are used to create the compartment system.

Injection devices

- Two different injection systems are available:
- injection pipe
 - injection tube

Scaffolding

Simple Scaffolding

In general, simple scaffolding is used, running on rails or on wheels. The scaffolding consists of stable elements which can be transported easily and allows adaptations following the dimensions of the tunnel.

Hydraulic Scaffolding

This is a more sophisticated scaffolding consisting of a hydraulic basket that turns from side to side.

Welding tools

Automatic hot wedge welding machine

This kind of machine works with an electric heated wedge. Above and underneath the wedge there are two pressure rolls which are both independently motorized. The hot wedge is guided between the overlapped geomembranes; the two pressure rolls move the machine at a specific speed. Temperature, pressure and speed are adjusted before executing the final welding.

The machine is completely electronically guided. When the outside temperature changes the electronic guidance adjusts the temperature accordingly. Tests have shown that welding executed by a hot wedge automat delivers nearly always a 100% good result.

Automatic hot air welding machine

The machine is a combination of hot wedge and of hot air automatic welding machine. The hot air temperature, the pressure, and the speed welding are adjustable in a step less way and are electronically controlled.

Hand welder

The hand welder works with hot air and is indispensable on an underground project. All details have to be done with this well known device.





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