



*Rely on it.*

Waterproofing of tunnels under water pressure

# RENOLIT ALKOR GEO

Underground  
structures



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## Underground structures



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## Geomembrane recommended

RENOLIT group manufactures and markets a complete range of PVC, PE or PP geomembranes in response to a wide variety of applications. Experience has shown that the PVC geomembrane is the most suitable for 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/m<sup>2</sup>) for bonded applications, and receive a reinforcement grid made of polyester or glass.

The waterproofing system with PVC geomembrane RENOLIT ALKORPLAN offers maximum security against differential settlement, and risk of perforation due to concrete reinforcement.

In addition, in the event of any damage occurred to the geomembrane, it offers the possibility to achieve a system to repair any leaking, with no perforation of the concrete shell.

## Concept of the waterproofing system

### Components

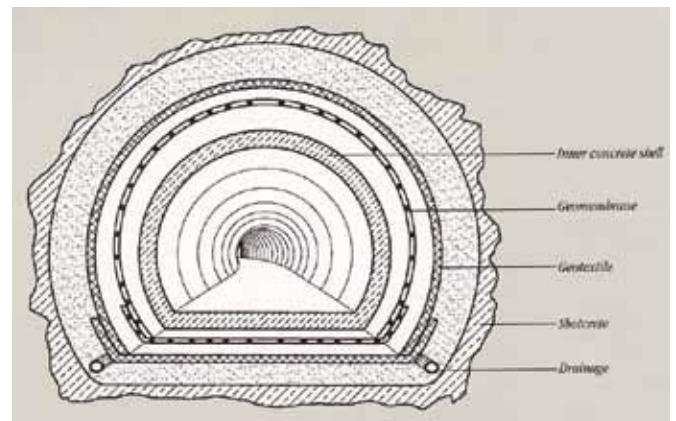
The waterproofing of a tunnel is a loose laid system. In case of a leakage, the water is able to enter between the geomembrane and concrete shell and will look for the weakest point of the concrete structure. In general it is the joint between 2 concrete blocks. In the complexity of the waterproofing, the possibility of leaks occurring after installation of the waterproofing system must be considered. Therefore it makes sense to plan the waterproofing system in such way that a repair is possible after finishing the construction, without perforating the concrete, and without damaging the waterproofing system.

This can be achieved through joint two methods:

- The first one is to create compartments with water stops to limit the spreading of the infiltrating water over an important length of the tunnel.
- The second one, is to place injection devices to have the possibility to repair leakages after having poured the concrete.

Components of the waterproofing system:

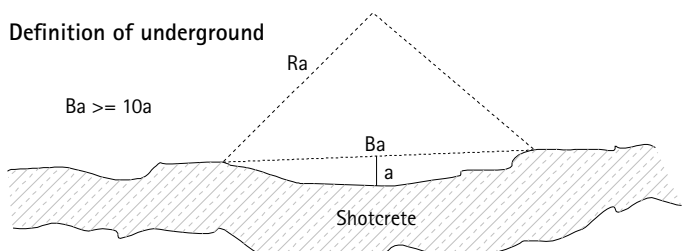
- Geotextile minimum 500 g/m<sup>2</sup> Polypropylene (no Polyester), depending on the surface.
- Geomembrane of homogenous thermoplastic material like PVC, TPO, min 2,0 mm, transparent (French prescription) or with signal layer.
- Fixing elements.
- Reinforcement strips to protect the geomembrane in 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
- Injection device



### Support

The surface of the support has to be as flat as possible, the used granulate should not be greater than 16 mm. The geometry of the surface ( $Ba \geq 10a$ ) 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



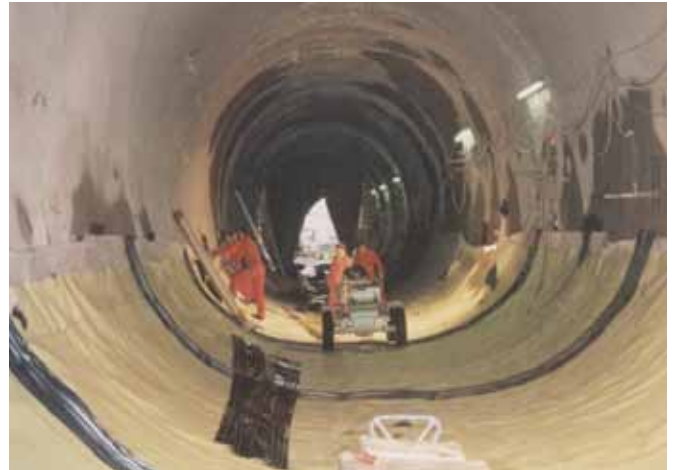
## Installation of the lining system to the bottom of the tunnel

### Installation of the Geotextile

After inspection of the shotcrete surface the geotextile will be placed to the bottom area. The overlap has to be sufficient to assure protection of the geomembrane at any place of the tunnel (minimum 10cm).

### Installation of the Geomembrane

The geomembrane will be placed and welded together with an automatic welding machine. Wherever a T-Cross occurs the geomembrane has to be adapted at the edges to guarantee a correct welding. The geomembrane should be cut in an inclined way to allow the welding automat to produce welding without failure. When laying out the geomembrane T-crosses should be avoided as much as possible as there is the danger of capillaries.



*Installation of membrane at the slope*

### Water stops

The water stop divides the lining system into compartments which limits the spreading of the infiltrating water. In combination with an injection system a repair of a leaking compartment can be carried out without damaging the geomembrane as well as keeping the cost at a reasonable level. To install the water stop, the best way is to weld it directly to the geomembrane outside of the tunnel under good conditions with a welding automate for roofing (single welding). This prefabricated geomembrane is then welded onto the next geomembrane with an automatic welding machine with double seam. This technology allows a perfect welding of the system.



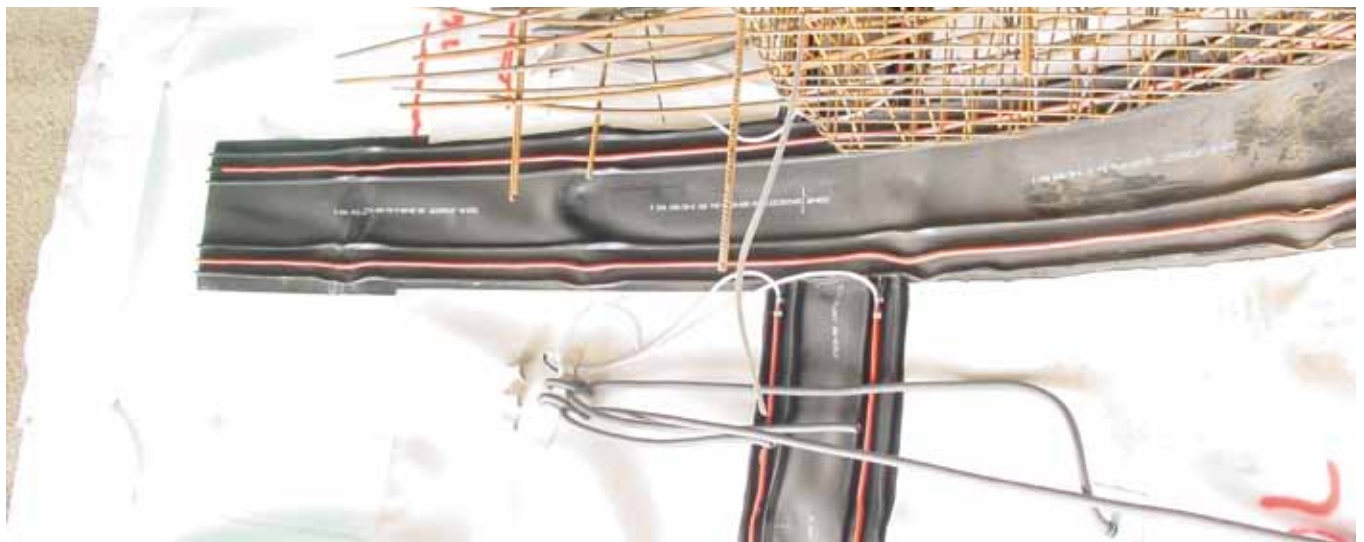
*Geomembranes with welded water stops produced in prefabrication*

### Injection pipes

The injection pipes can be placed in the corners of the compartment and, depending on the size of the compartment also in the middle. It is recommended to use water stops with an integrated injection tube as it is important to ensure the water tightness in the joints. The injection pipes also fulfill the task of a detection system. In case of a leakage the water will exit at the injection pipes, therefore they are also very helpful as control devices after having poured the concrete on the slab.



*Vacuum*



*Waterstops with integrated injection tubes*

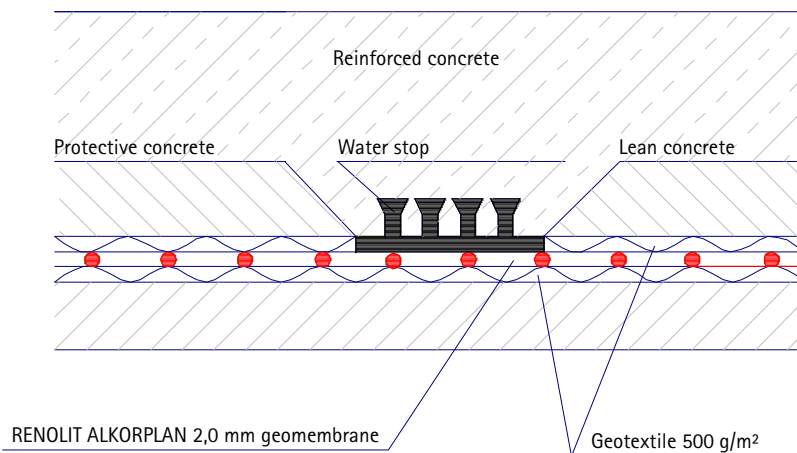


## Pending connection to the vault

The waterproofing system at the bottom must overpass the construction of the bottom concrete far enough to guarantee a safe connection with the waterproofing of the vault. The geomembrane and the geotextile will be provisionary fixed to the shotcrete. It is very important to protect this area very careful. The reinforcement bars - sticking out of the slab to be connected with the reinforcement bars for the vault - endanger the waterproofing system.

## Protection of Waterproofing system on the bottom slab

When the waterproofing system is installed, it has to be covered with a geotextile and a protective concrete of about 10 cm. The areas of water stop must stay free in order to be embedded in the concrete of the slab to be able to fulfill their task.



*Water stop of bottom slab*

## Concrete of slab

The reinforcement works can be executed and also the pouring of the concrete of the slab. The protective concrete should ensure that no damage can harm the waterproofing system through the shuttering of the concrete slab.



## Installation of the lining system to the vault of the tunnel

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

### Scaffolding

The scaffolding for the installation of the lining system can be placed on the slab of the tunnel. Depending what kind of scaffolding will be 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).



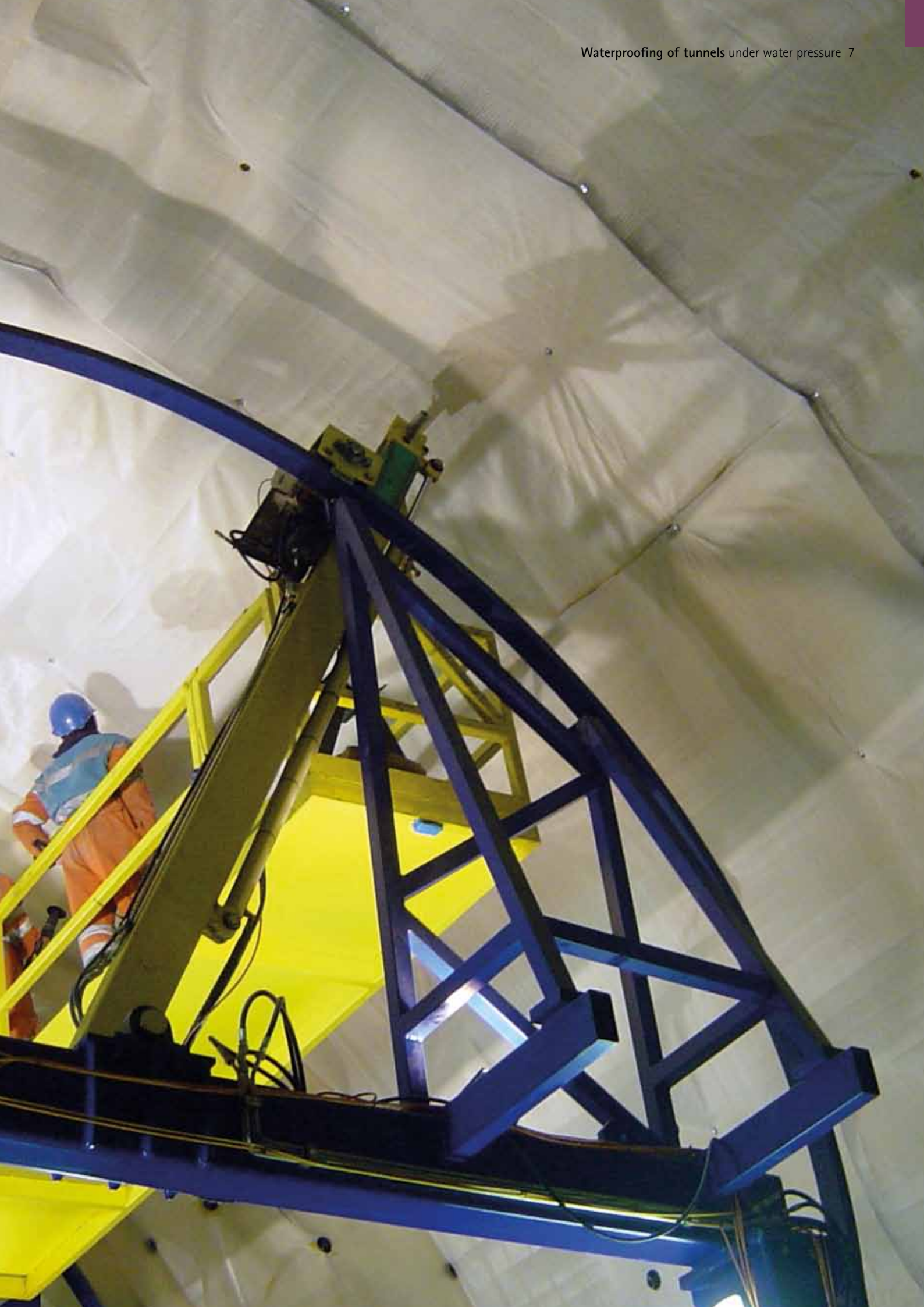
*Hydraulic scaffolding*

The hydraulic scaffolding is costly but of course allows for a more comfortable working condition for the installer. It has to be adjustable 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 with the lifting of 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 move on to get into position for the next placement of the 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 at 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<sup>2</sup>, on the vault 3 pieces per m<sup>2</sup>. 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 important irregularities it is recommended to double the geotextile.



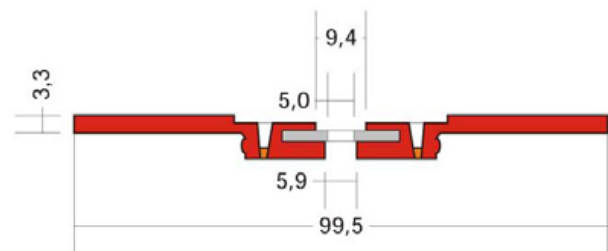
Fixation of the geotextile



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, on the other hand to serve as a welding surface in order to fix the geomembrane to the tunnel. The roundel is of the same composition of material as the geomembrane to assure compatibility between the materials. In case of high pressure behind the geomembrane, the "knock-out" zone of the roundel prevents the fixation to fall down behind the geomembrane, which could lead to damage of the waterproofing. Example of flat PVC roundel with knock-out system, with steel washer:



Section

## Installation of the Geomembrane

The producer of geomembrane has to produce the geomembrane in the correct length following the indications of the installer, which corresponds to the perimeter of the tunnel to be waterproofed. Beside 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 from the top of the scaffolding, welds it to the fixation roundels on the highest point of the vault and proceeds with this work downwards till the whole geomembrane is attached to the fixation roundels.

In this way the daily quantity of geomembrane will be attached to the tunnel surface.

Coming back with the scaffolding to the beginning of the newly fixed membranes, the welding procedure may start.

With the help of welding automats, producing a seam with testing canal, the geomembranes are welded together.

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.







## Water stops

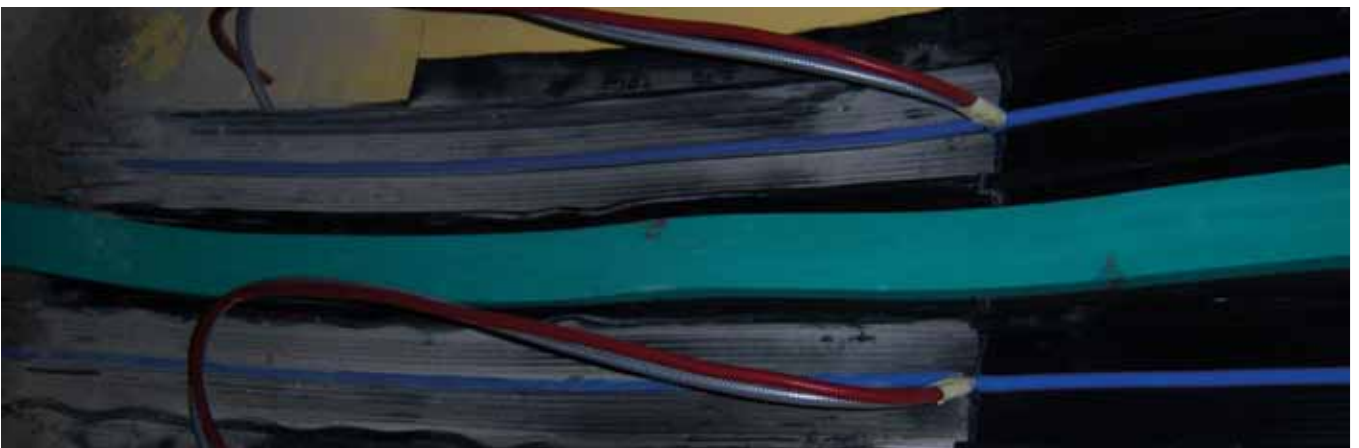
As for the slab, it is preferable to weld the water stops during prefabrication onto the membrane strips. Having brought all geomembranes into position, the connection to the prefabricated strips of geomembrane with water stops has to fit exactly with the necessary overlap for the welding.

## Injection pipes

The injection pipes have to be placed on the correct positions, on both sides of the vault.

## Reinforcement strip

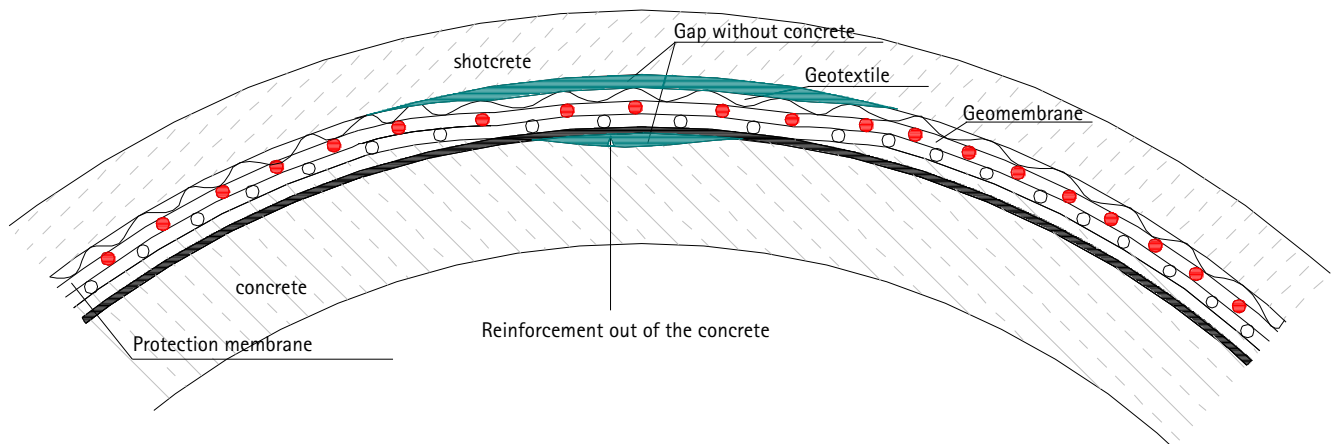
Shuttering units for the inside concrete are, in general, between 8 to 12 m. At the end of the shuttering unit a head shuttering has to be placed. The placement of this shuttering, consisting of small boards, is a great danger for the waterproofing system. During the fixing of the boards the geomembrane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



## Concrete for the vault

Throughout the concrete procedure a strain will be applied to the geomembrane, provoking a slight elongation due to the weight of the concrete. Experiences in the past have shown that, depending on the surface of the shotcrete and the way of installation of the lining system, folds can appear due to the pouring the concrete. A smooth surface of the shotcrete guarantees less folds in the geomembrane.

The peak of the vault has to be done 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 stop (if present).



Top of the Vault  
French Waterproofing System

## Anchors for reinforcement bars

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 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 case of a not self carrying reinforcement it is highly recommended to use anchors on which the reinforcement bars are fixed at a correct static distance. Such anchors are able to hold loads of over 30 kN depending on the quality of the shotcrete.

This type of anchor is a complete closed system, water is unable to enter between the lining system and the inside concrete shell.

The anchor consists of a hard PVC tube with a flange, on which the PVC geomembrane is welded on.

After having installed the geomembrane, a hole is drilled into the shotcrete through the geomembrane. The PVC tube is bonded into the borehole. The soft PVC flange is welded to the geomembrane. Into the PVC tube a steel pin is introduced in order to fix the reinforcement steel of the inside concrete shell.

## Bonded system

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

For such 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 directed with only 3 men. The performance with such an installing automat is much higher as with the 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 needs to fulfil (PVC, PP or PE).

PVC 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 geomembranes were formulated and due to the existing standards in Europe two types finally conquered this difficult market.

In the German spoken countries the "signal layer" geomembrane (bicolour) became the chosen one.

In France and other Mediterranean countries the translucent geomembrane was chosen as the suitable material for this important sector as 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.

RENOLIT ALKORPLAN 35041 : PVC-P Geomembrane for tunnels and basement works with calendared signal layer.

- The signal layer is produced by calendaring / lamination in order:
- to have a signal layer in a thickness less than 0.2mm (as required by DS853 and ZTV tunnel)
- to have perfect control over the thickness of the entire surface.

### Translucent system

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

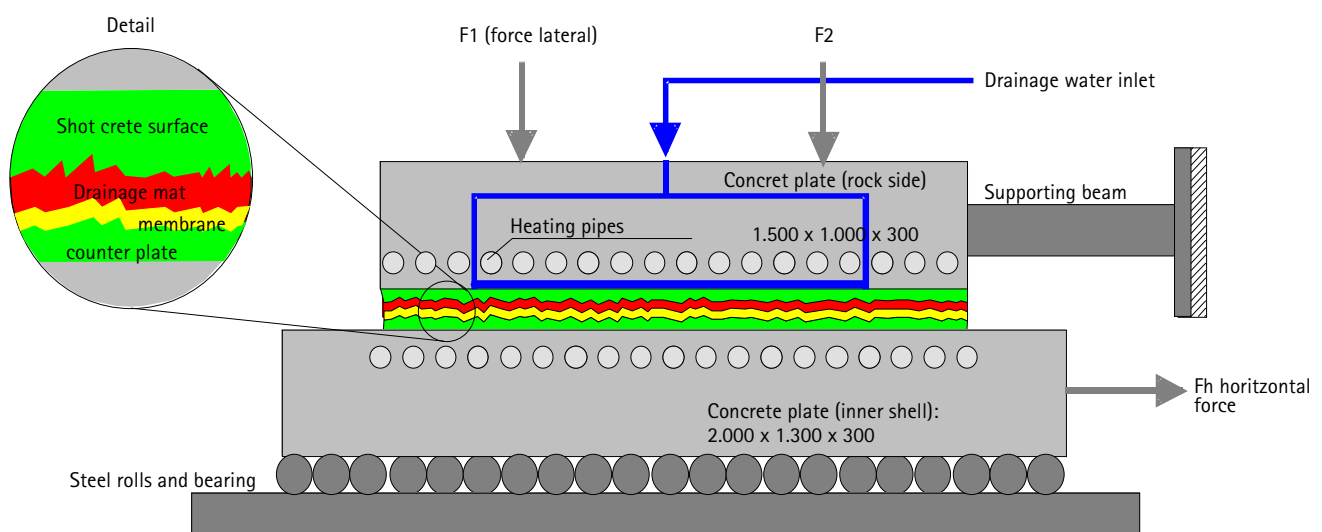


This picture shows visually that the welding is of good quality as the welding is more translucent than the area of the testing canal, but the black traces at the beginning of the welding show that either the temperature was very high, or the hot wedge not properly cleaned. In such a case a special investigation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

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

### Resistance of RENOLIT ALKORPLAN PVC geomembrane under pressure

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



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

Figure7: Schematic 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

## 12 Waterproofing of tunnels under water pressure

- The German laboratory SKZ showed that the translucent PVC geomembrane RENOLIT ALKORPLAN 35041 2mm thick had an excellent behavior 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 by a geotextile 700g/m<sup>2</sup> + 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 dissolved 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

In addition to the water stops, injection devices are welded punctually to the geomembrane. The task of the injection devices is to provide the possibility to inject liquid waterproofing materials in order to close the eventual leakage of the geomembrane. These liquids or resins are based mostly on two components acrylate or polyurethane. The injection devices go through the concrete shell and are always reachable in case of failure of the waterproofing system. The injection work is a difficult task and has to be carried out by experts. The injection resin has to be pressed through the injection pipes between the geomembrane and the inside concrete. Very important is the mixture of the 2 components resin as it has to stay liquid long enough to spread over the whole surface of the compartment on the one side, and on the other side it has to harden quickly so it does not get evacuated by infiltrating water.

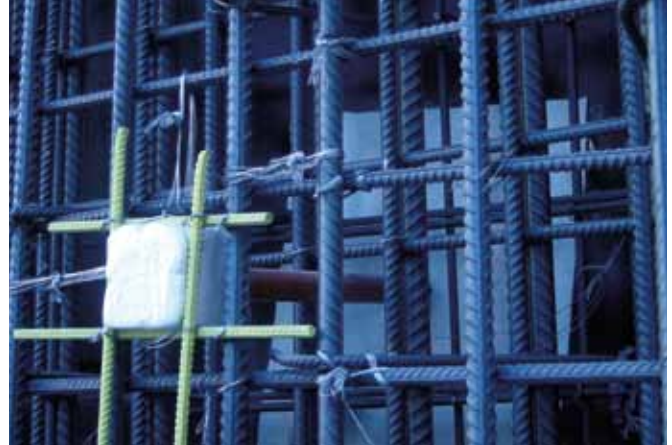
Two different injection systems are available:

- injection pipe
- injection tube

### Injection pipe

The injection pipe is a hose on which a PVC tube will be welded through THF. One has to ensure that the tube can resist a pressure of at least 6 to 8 bars. No metallic device will be used to avoid the danger of perforating the geomembranes.

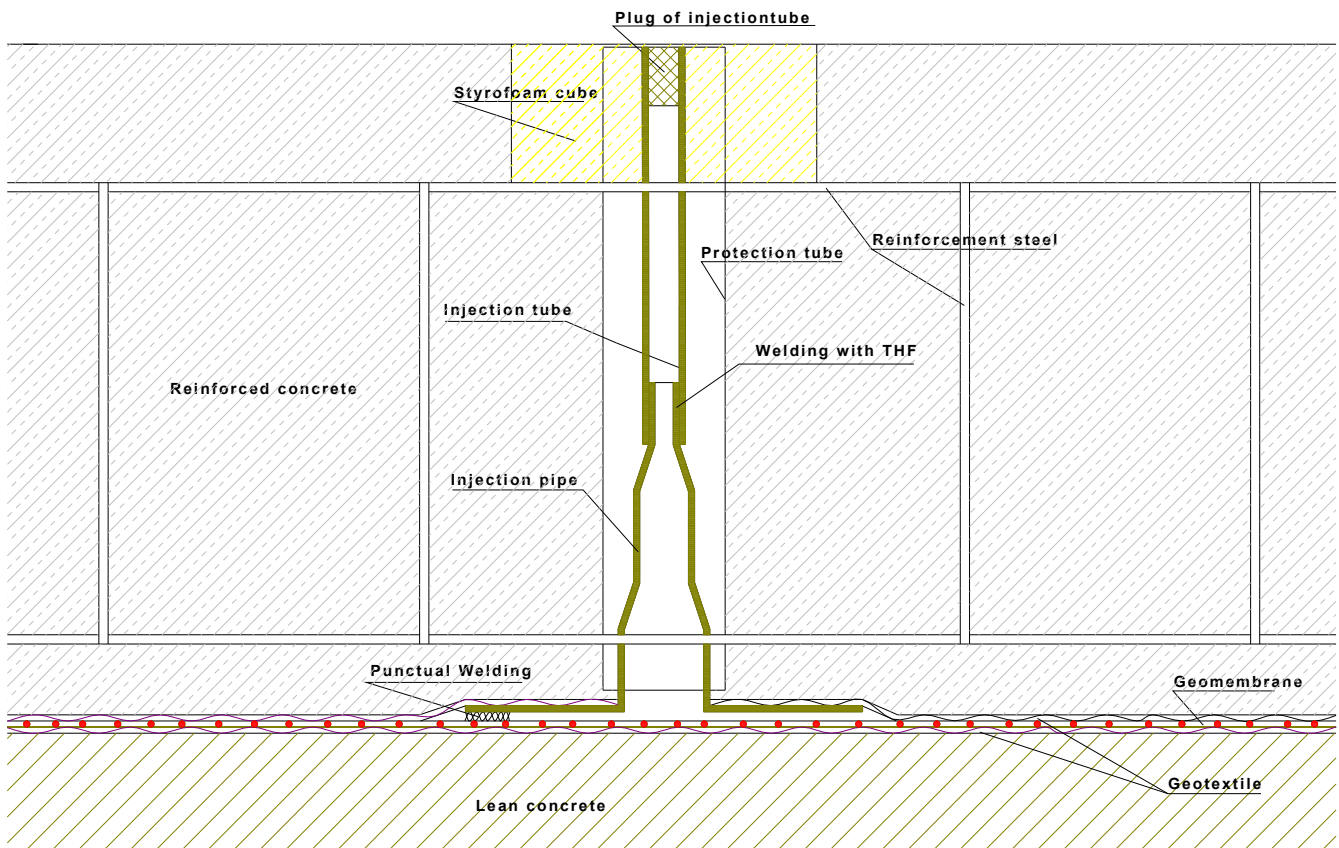
The exit piece of the injection pipe has to be integrated in a safe device of the surface of the concrete.



Protected inlet of Injection Pipe

### Injection tube

Alternative injection device : injection tubes punctually welded to the geomembrane that open when the resin is injected under pressure.



Installed Injection Pipe spot welded to the Geomembrane



## 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

A more sophisticated scaffolding is one with a hydraulic basket turning from one side to the other.

## 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 advance the machine at the determined speed. Temperature, pressure and speed are adjusted before executing the final welding. The machine is completely electronically guided. By changing outside temperature the electronic guidance adjusts the temperature following the conditions.

### Automatic hot air welding machine

The machine is a combination hot wedge / hot air automatic welding machine. The hot air temperature, the pressure, and the speed welding are adjustable in 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.



*Automatic hot wedge welding machine*



*Automatic hot air welding machine*





*Rely on it.*

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