Waterproofing of Tunnels under Water Pressure

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RENOLIT

1. INTRODUCTION

1.1. General

The use of PVC-P geomembranes as a waterproofing for tunnels under water pressure is a sophisticated and safe technology to protect the construction against destructive influences of the water.

Depending on the appearance of the water (humidity, temporary water pressure, permanent water pressure) the lining system has to be adapted. This is expressed in the thickness of the geomembrane and a system of control and repair. Under the influence of permanent water pressure a minimum thickness of 2,0 mm of the geomembrane has to be used.
This technical description explains the use of RENOLIT geomembranes for the waterproofing.

1.2. Products of RENOLIT

RENOLIT offers a large range of suitable plastic sheeting to carry out the waterproofing of tunnels:

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

1.3. Requirements of the waterproofing materials

The quality of the waterproofing depends on:

- choice of geomembrane
- waterproofing system including the preparation of the underground
- how the work is carried out (ground, drainage, waterproofing system, protection).

1.3.1. Water tightness

Water tightness depends on the definition of geomembrane (product group, thickness) in order to be able to withstand all influences (e.g. pressure, condition of the ground).

1.3.2. Flexibility

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

1.3.3. Chemical resistance

Pollution of the ground and ground water.

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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

- 35041, non-reinforced geomembrane, opaque, dark grey with thin yellow signal layer (bi-colour) to prevent any mechanical damage.
  Conform to specification as SIA V280, RVS 8T, DS 853, HEFT 365.
- 35034, non-reinforced geomembrane, opaque, light green (single colour).
  Conform to specification as RVS 8T, HEFT 365;
- 35036, non-reinforced geomembrane, translucent (>70%).
  Conform to specification as fascicule 67 titre III CETE Lyon, NEAT ;
- 35020, non-reinforced PVC-P protection layer.
  Conform to specification as fascicule 67 titre III CETE Lyon.
- 35038, non-reinforced geomembrane, opaque, dark grey, resistant against temporary influences of hydro carbonates and can be applied directly in contact with bitumen.

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, enrolled on hard box, width of 2,05m.

- No point of yield will be reached before breakage : after elongation under stress, PVC-P is able to relax and to adapt to the underground.
- 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, against aging and against 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 exposure to UV radiation without loosing its mechanical characteristics.
- 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

2.1.3. Characteristics

See technical data sheets.

2.2. Geomembranes RENOLIT ALKORTOP

This type of geomembrane is made of flexible Polypropylene.

2.2.1. References of RENOLIT ALKORTOP geomembranes

- 35080, homogeneous geomembrane, grey, 2.05 m large

2.2.2. Properties

Geomembranes made of flexible Polypropylene (FPP), 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. 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. 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, …)
- o Fixation elements (laminated metal sheet, water stop, stainless metal plates, anchor and more)
- o compartment and injection devices to be able to control and repair the waterproofing after pouring concrete (water stops, injection pipes, …)

2.4. 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 materials, before proceeding to the laboratory, responsible for the mixing of the compound, then it passes through production, the logistic department, as well as the management department.
After going 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.
The signal layer geomembrane (35041) is produced on extrusion/laminating machinery where the thin signal layer is laminated on dark grey geomembrane. Exact heat and pressure are important to receive a perfect lamination between the 2 layers of geomembrane.

2.5. 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 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.
The waterproofing system with PVC-P 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.

3. CONCEPT OF THE WATERPROOFING SYSTEM

3.1. Components

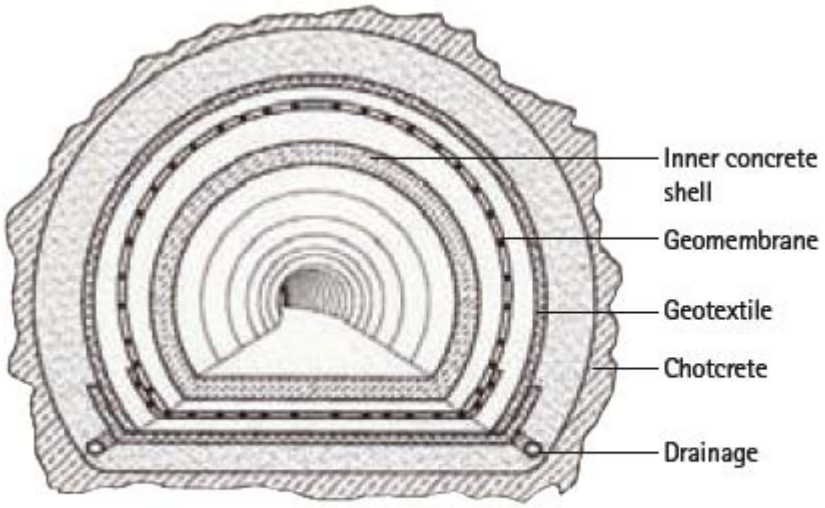
The waterproofing of a tunnel is a loose laid system. In case of a leakage, the water is able to enter between the geomembrane and concrete shell and will look for the weakest point of the concrete structure. In general it is the joint between 2 concrete blocks.
In the complexity of the waterproofing, 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/m² Polypropylene (no Polyester), depending on the surface.
- Geomembrane of homogenous thermoplastic material like PVC-P, 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

3.2. Support

The surface of the support has to be as flat as possible, the used granulate should not be greater then 16 mm. The geometry of the surface (Ba ≥ 10 a) should be followed to avoid a possible folding of the geomembrane after the concrete is poured. (see drawing of geometry).
The surface is a very important item because it is responsible for the lining system to adapt well to the surface after pouring the concrete of the inside shell. In case

the surface is very irregular, folds in the membrane will occur. In tunnels with water pressure these folds can lead to failures of the lining membrane.

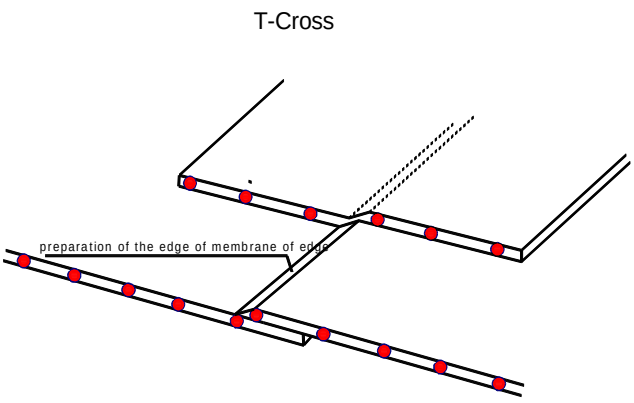
4. INSTALLATION OF THE LINING SYSTEM TO THE BOTTOM OF THE TUNNEL

4.1. 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).

4.2. 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.



Prepared seam for T-cross

4.3. 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
stem.

Geomembranes with welded water stops produced in prefabrication

The width of the prefabricated geomembrane with water stop can be the same width as the normal geomembrane (2,05 m in general).

4.4. 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.

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.

Reinforcement bars endanger geomembrane

Head shuttering of the concrete unit

4.5.

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.

4.6. 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. In case the protective concrete is not strong enough, precautions have to be taken to avoid damage to the geomembrane.

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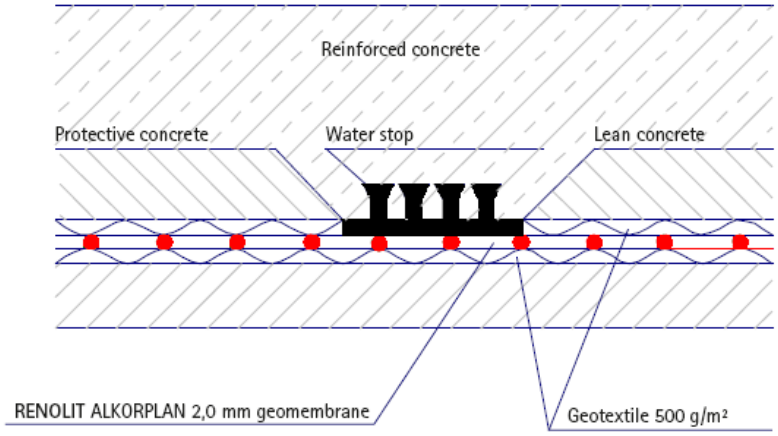

Water stop of bottom slab

5. 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.

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).

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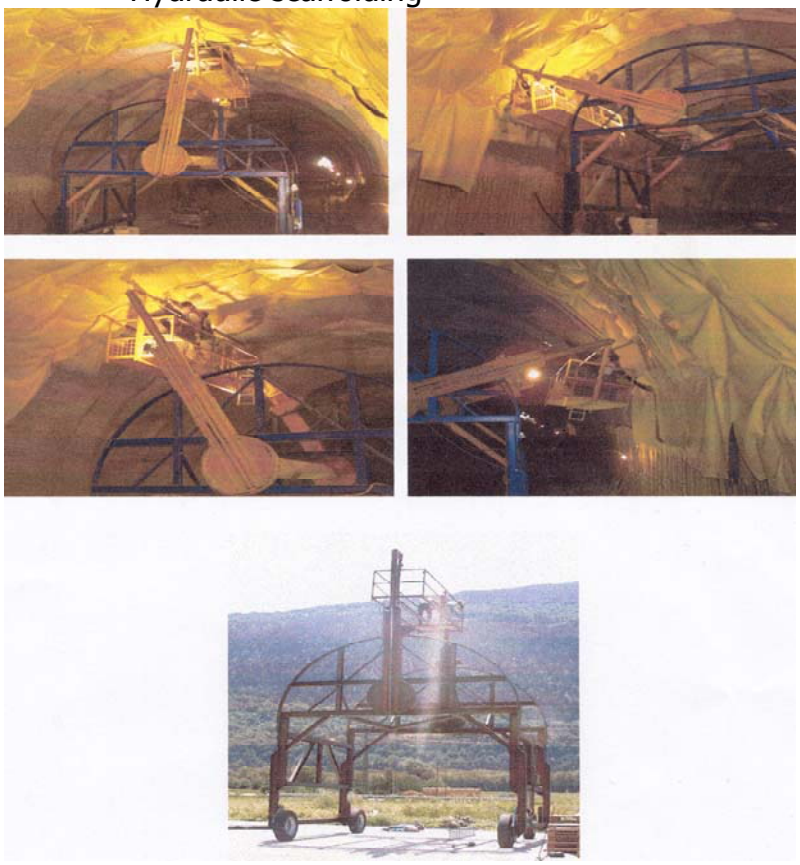
Hydraulic scaffolding



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.

Conventional scaffolding

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.

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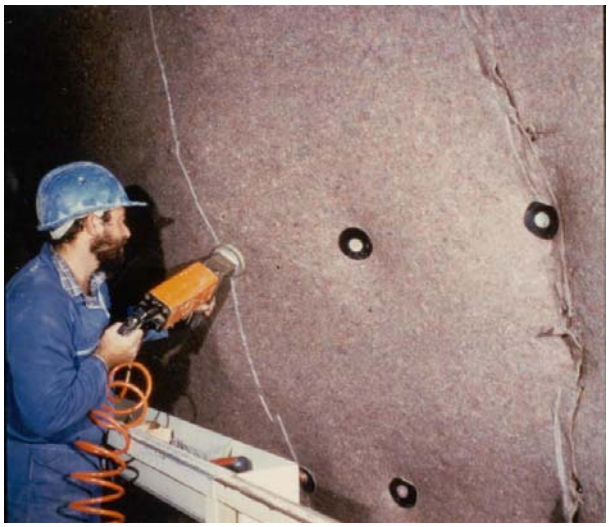
5.1. Installation of the Geotextile

The geotextile will be fixed with fixation roundels: in the wall area about 2 pieces per m², on the vault 3 pieces per m². 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

5.2. 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-P roundel with knock-out system, with steel washer:

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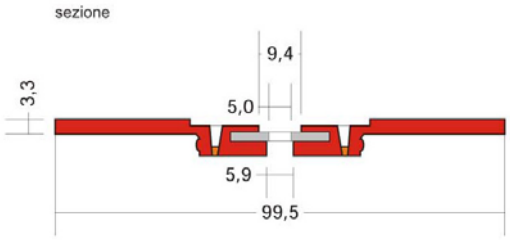


5.3. Installation of the Geomembrane

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 on 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.

5.4. Water stops

As for the slab, it is preferable to weld the water stops during prefabrication onto the geomembrane 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.

5.5. Injection pipes

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

5.6. Reinforcement strip

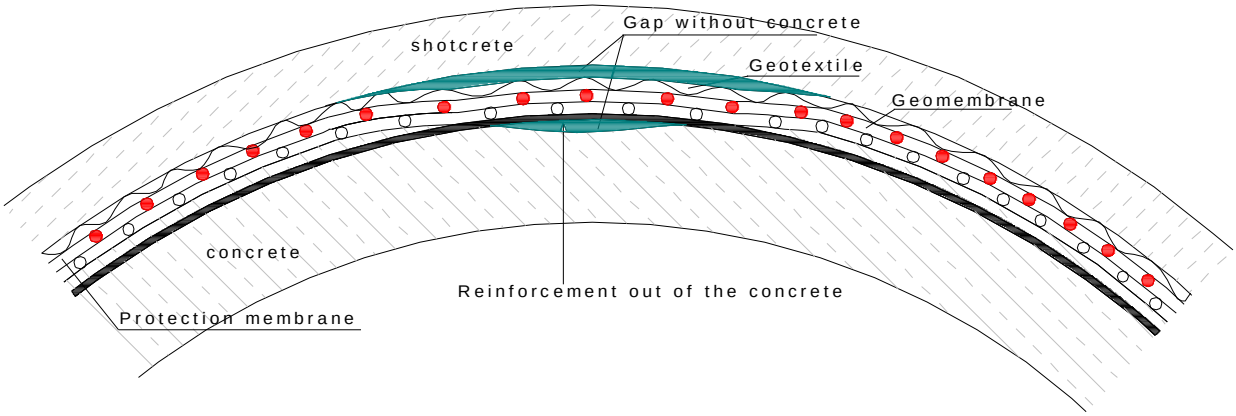
Shuttering units for the inside concrete are, in general, between 8 to 12 m. At the end of the shuttering unit a head shuttering has to be placed. The placement of this shuttering, consisting of small boards, is a great danger for the waterproofing system. During the fixing of the boards the geomembrane 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.

5.7. 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



5.8. 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-P tube with a flange, on which the PVC-P geomembrane is welded on.
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.

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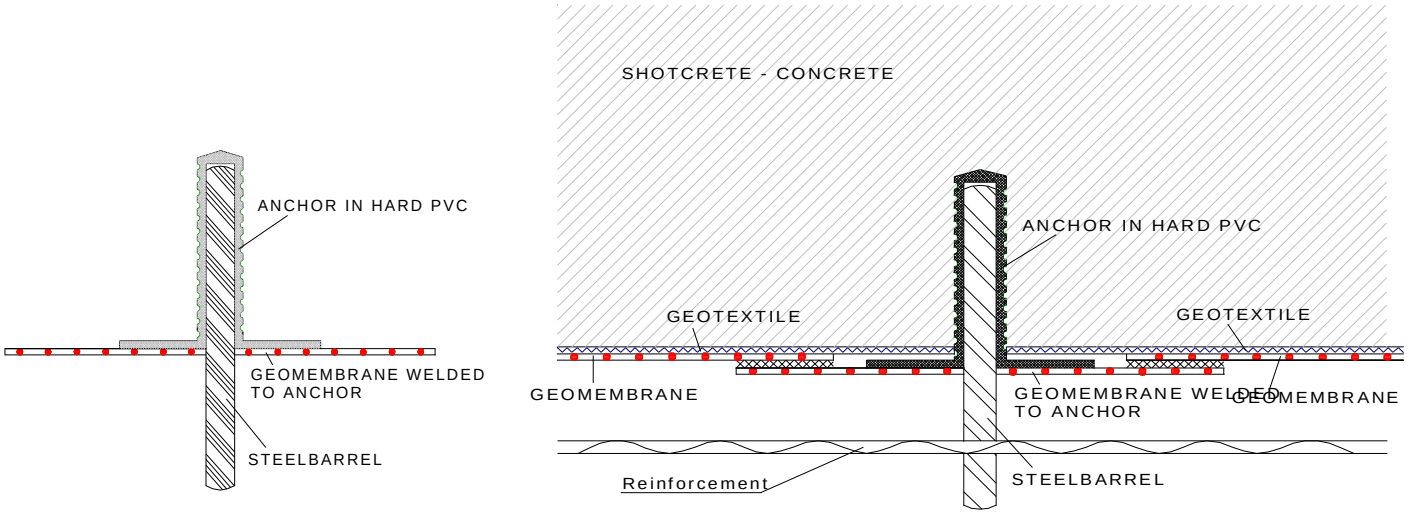
Watertight Hard PVC Anchor



5.9. Bonded system

The latest development in tunnel 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.

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Installation Automat for bonded system

6. MATERIAL

6.1. Geomembrane

The choice of the geomembrane should be done following the task the geomembrane needs to 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 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.

6.1.1. System with signal layer

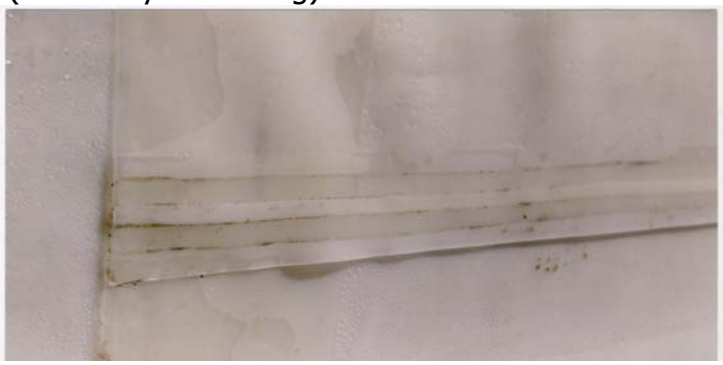
The target of the "signal layer" geomembrane is to detect failures and leakages through a very thin signal layer. The signal layer should be a bright coloured thin upper-layer (less than 0,2 mm in DS 853) so that the dark colour of the geomembrane underneath can be seen in case of any mechanical impact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

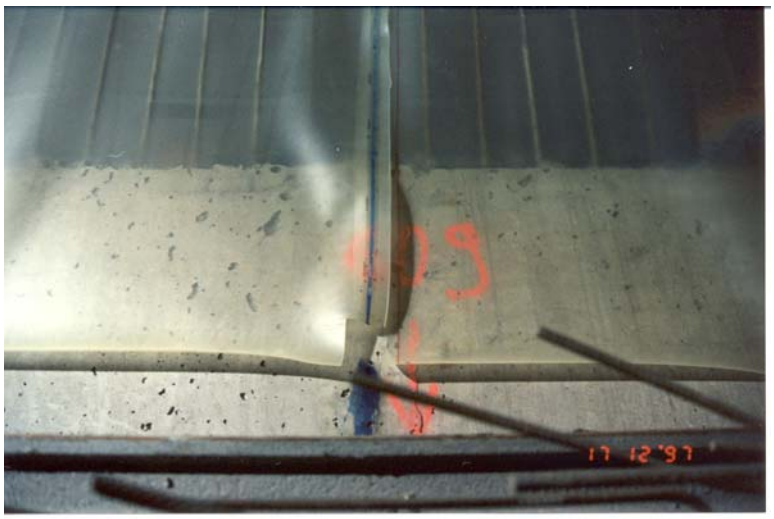
6.1.2. Translucent system

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.

control with colour liquid



6.1.3. Resistance of RENOLIT ALKORPLAN PVC-P 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-P membrane **RENOLIT** ALKORPLAN (type 35036 2mm thick), even under high pressure:
  - Load of 2Mpa

- Horizontal movement of 3mm

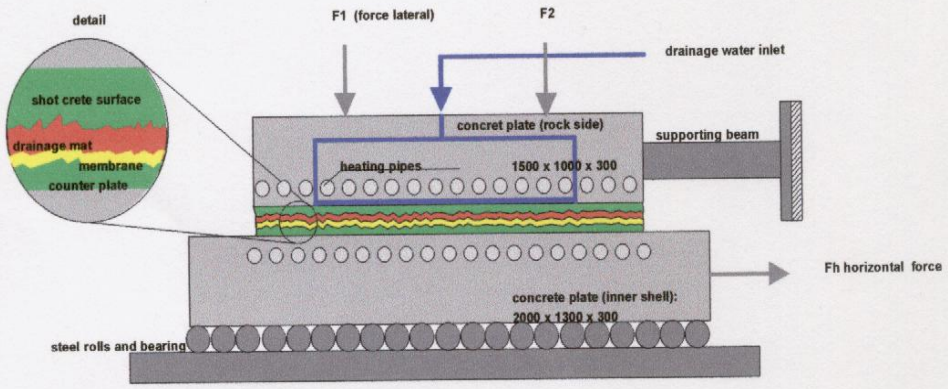


Figure 7: Schematic cross-section of the compression/shear set-up with heating and drainage capability, the top plate (fixed) corresponds to the shotcrete surface of the outer tunnel shell

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 translucent PVC-P 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/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.)

6.2. Geotextile

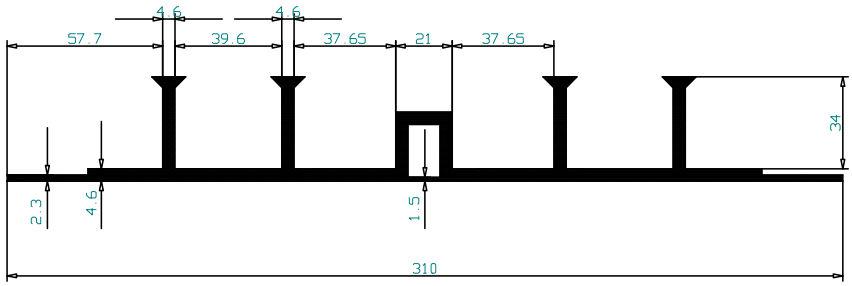
The geotextile has to be of Polypropylene fibers, short fibers mechanically fixed or long fibers. Polyester geotextile has to be avoided because of hydrolysis of polyester due to alkalinity of concrete. The freshly applied concrete attacks the Polyester geotextile and after a certain time the geotextile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

6.3. Water stops

6.3.1. 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 loosing water tightness.

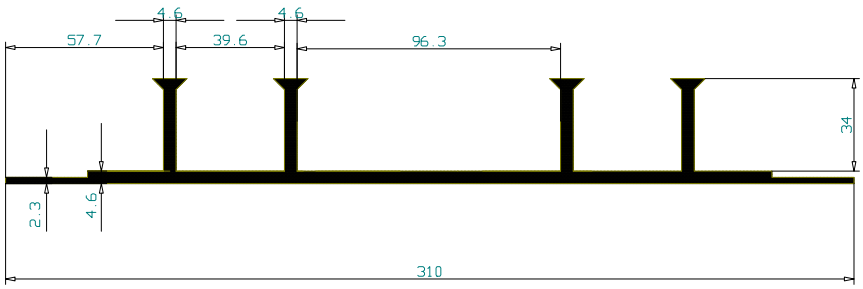
DILATION WATER STOP 30/3/4



6.3.2. Water stop for Normal joint

They are used to create the compartment system.

WATER STOP 30/3/4



6.4. 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.

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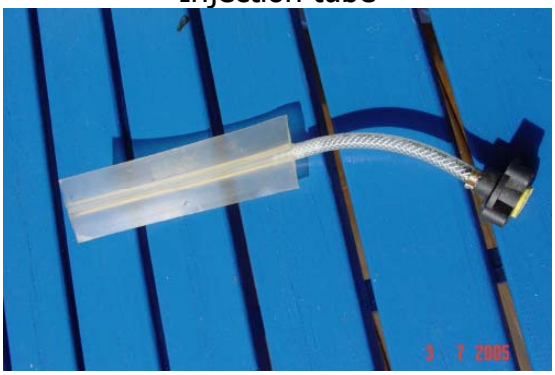
Two different injection systems are available:
- injection pipe
- injection tube

Injection pipe

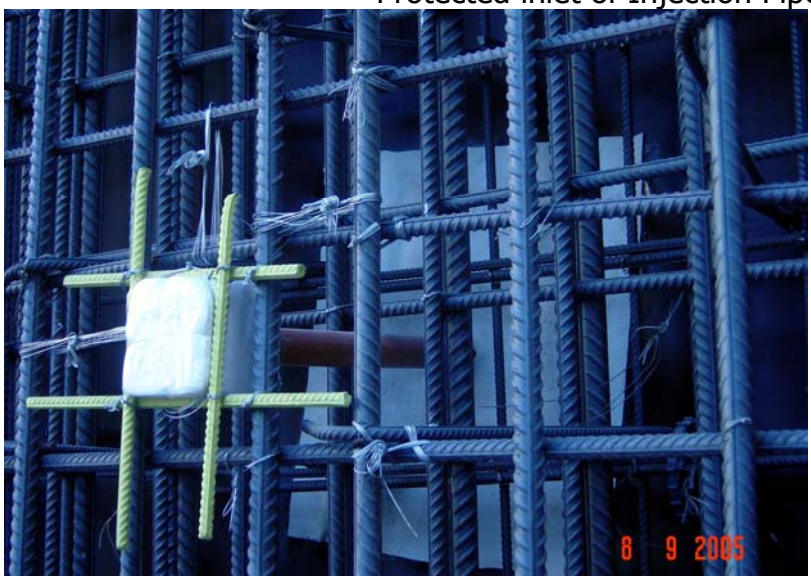
Injection tube



6.4.1. Injection pipe

The injection pipe is a hose on which a PVC-P 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



Installed Injection Pipe spot welded to the Geomembrane

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6.4.2. Injection tube

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

6.5. Scaffolding

6.5.1. 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.

6.5.2. Hydraulic Scaffolding

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

6.6. Welding tools

6.6.1. 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 wedge welding machine

6.6.2. 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.

Automatic hot air welding machine

6.6.3. 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.

7. CONTROL AND TESTING OF WATERPROOFING

The whole waterproofing work has to be controlled carefully because the smallest leakage can lead to heavy problems in the future, therefore every seam executed on site or in prefabrication has to be tested.

7.1. Control of double seam through air pressure

The machine welding is produced with a so-called testing canal. After having finished the welding work the seams have to be tested through air pressure or through a coloured liquid which also has to be introduced under pressure into the canal.
The air canal is 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.
The pressure has to be 2 bars and may not reduce more than 20 % due to the elongation capacity of the PVC-P material, within 15 minutes, up to an exterior temperature of 30°C.
In case of a failure the pressure will go down.
In case of testing with coloured liquid, the leakage of the welding can be detected immediately as it will pour out of the leakage of the welding.
In case of a defect welding, it has to be repaired carefully way by hand welding.
After successful testing, a patch of PVC-P has to be welded over the penetration hole of the testing needle.

Every single welding has to be tested in this way by noting the time, the date, and the pressure at the beginning and at the end of the test.
That information will be written into a daily protocol, which has to be signed by the control engineer, the contractor and the installer.

Control devices

Control by coloured liquid

Double seams control

7.2. Control of hand welding

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.
Leakages are immediately detected though the developing air bulb due to the applied air pressure.

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8. CONCLUSION

The installation of waterproofing systems in tunnels under water pressure is a sophisticated piece of engineering. Only a precise installation can lead to success. The slightest mistake will allow water to enter between the geomembrane and the inside concrete shell.
The installer cannot be the only one responsible for the success of a waterproofing system under such circumstances, there are too many risks for damage after he has finished his work.
The contractor has the duty to execute his works in the same professional, careful way as the installer to deliver a dry tunnel.
This is a difficult task and failures in the lining system can happen. Therefore a repair system is foreseen from the beginning through to the integration of the compartment system with injection pipes. It delivers a realistic chance to close any leakages in the waterproofing system.

The range of geomembranes of RENOLIT for the tunnel lining is complete and offers you the correct material for the right application:

- RENOLIT ALKORPLAN 35034 opaque geomembrane following RVS 8T- Austria
- RENOLIT ALKORPLAN 35036 translucent geomembrane with Avis Technique – France
- RENOLIT ALKORPLAN 35038 black geomembrane resisting to bitumen
- RENOLIT ALKORPLAN 35041 geomembrane with signal layer following RVS 8T, DS853

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