Waterproofing of Foundation

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1. INTRODUCTION

1.1. General

To use synthetic geomembranes as a waterproofing for foundation is a sophisticated and safe technology to protect the construction against the destructive influences of water.

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

1.2. Products of RENOLIT

RENOLIT presents a large offer of suitable plastic sheeting for the waterproofing of foundations :

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

1.3. Requirements on 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 (underground, 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 underground).

1.3.2. Flexibility

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

1.3.3. Chemical resistance

Pollution of the ground and ground water.

2. GEOMEMBRANES OF RENOLIT

2.1. Geomembranes RENOLIT ALKORPLAN

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

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

The mechanical characteristics 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 in a hard box measuring 2,05m wide.

- No point of yield will be reached before breaking : 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 acids bases and salts, against aging and against environmental influences.
- PVC-P Geomembranes resist permanent contact of PH between 2 and 10.
- Geomembrane without UV protection can resist 1 month in direct exposition 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 out 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. Geomembranes RENOLIT ALKORTENE

This type of geomembrane is made of Polyethylene (PE)

2.3.1. References of RENOLIT ALKORTENE 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 their low flexibility, especially on uneven and rough ground.
  To initiate an elongation of the material, a lot of power has to be applied

due to its stiffness. After an elongation of around 8% (one-direction) the point of yield has been reached and the material starts to flow. The elongation happens on the weakest point of the material until it breaks. In the 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. All accessories have to be compatible with the geomembrane being used.
The following accessories are part of such a system:

- Protection layer (geotextile, plastic sheeting, ...)
- Fixation elements (laminated metal sheet, water stop, stainless metal plates, anchor and more)
- compartment and injection devices to be able to control and repair the waterproofing after pouring concrete (water stops, injection pipes, ...)

2.5. RENOLIT Production

The whole procedure of production including the management and the purchase of the raw material has to conform to ISO 9001.
The control of production starts with the supply of raw material, then it goes to the laboratory, responsible for the mixing of the compound, then production, then logistic department and finally reaches the management department.
After the mixing and melting unit the compound is transported to the calendaring or extrusion unit. After passing through numerous calendaring drums the final membrane, controlled by many electronic devices for thickness, heat and speed is extracted and rolled out.
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.

2.6. 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 foundations due to its excellent mechanical properties, handling and durability.
Its high resistance to puncture is valuable to withstand the mechanical aggression caused by the implementation of backfill and to resist high pressure carried out on the geomembrane by the weight of the building : RENOLIT ALKORPLAN 35034 – 35036 – 35041.
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. Foundation Slab

- lean concrete
- geotextile of 500 g/m²
- PVC-P geomembrane of 2,0 mm (1,5 mm)
- Geotextile of 500 g/m²
- PE sheet of 0,25 mm as gliding layer
- Protective concrete

As a control and repair system water stops and injection pipes are installed.
The surface of the control areas should not be larger than 100 m² of the foundation slab.
The foundation slab has to be separated through water stops from the wall section.

3.2. Vertical Faces

3.2.1. Vertical faces with working space

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- geotextile 500 g/m²
- PVC-P geomembrane 2,0 mm (1,5 mm)
- geotextile 500 g/m²
- protection layer (card board, concrete blocks)
- backfill

3.2.2. Vertical faces without working space

- retaining wall
- separation layer (e.g. Styrofoam 4 cm or similar)
- geotextile 500 g/m²
- PVC-P geomembrane 2,0 mm (1,5 mm)
- Geotextile
- concrete wall

The same control and repair system is used as for the slab. The water stops are placed in the joint or just near the joint between the slab and the wall. The surface of control areas has to be determined following the situation on site.

4. INSTALLATION OF THE WATERPROOFING SYSTEM

4.1. Waterproofing with working space

4.1.1. Lining of the bottom slab

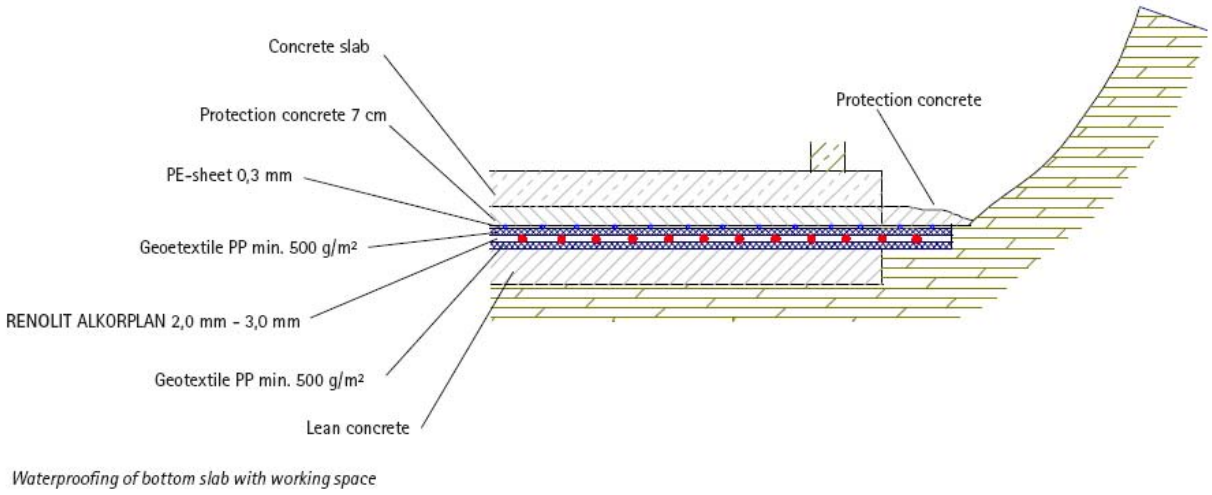
Once the lean concrete has been poured, the lining system has to be installed, consisting of:

- Geotextile PP minimum 500 g/m²,
- Geomembrane of PVC-P of a thickness, of at least 1.5 mm
- Protection layer which can be a PVC-P sheet of 1,5 mm to 2,0 mm (RENOLIT ALKORPLAN 35020) or a geotextile of minimum 500 g/m². It is absolutely recommended to put a PE-sheet on top of the geotextile in case this material is chosen as a protection layer, to achieve a gliding between the lean concrete and the concrete slab. Besides the PE sheet avoids the penetration of liquid cement into the geotextile.

This protection layer is installed outside the water stops (if any), which must remain free.

- At the end a last layer of protective concrete has to be poured. In case of using water stops the concrete should not be poured over them, otherwise the compartment system will not work.

Execution of Protective Concrete



Waterproofing of bottom slab with working space

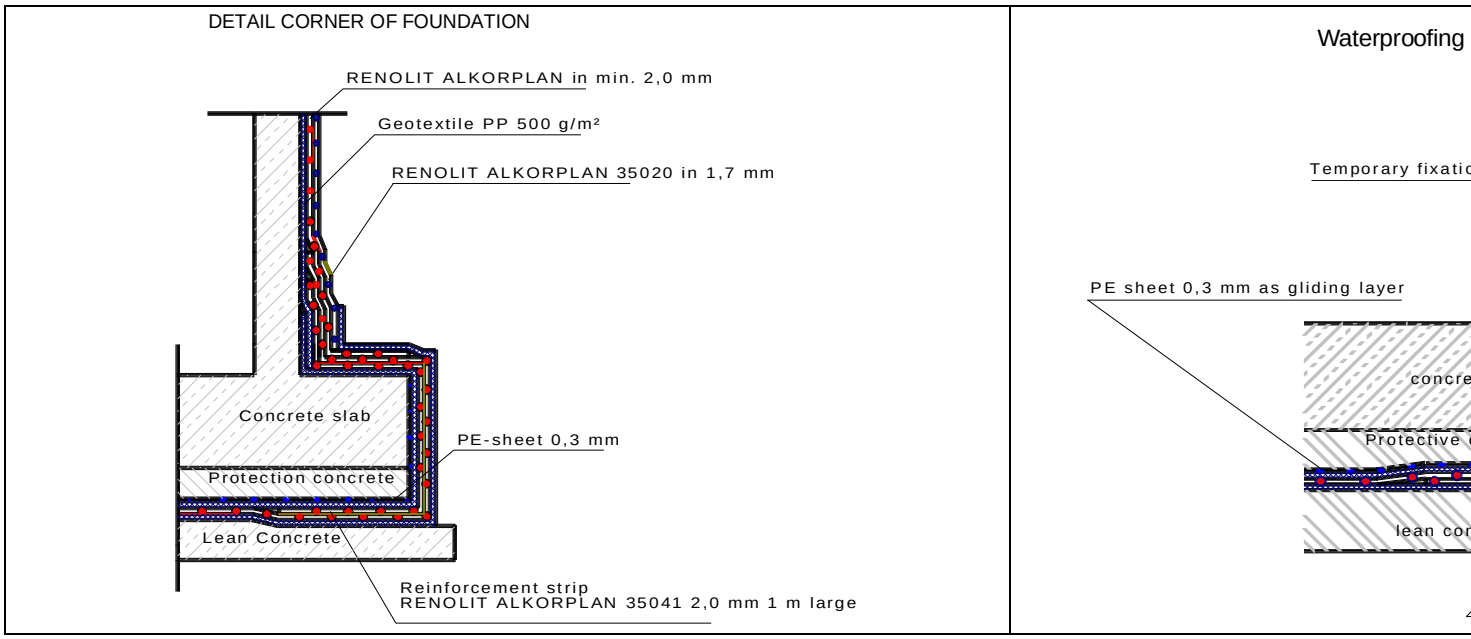
Excavation with working space

4.1.2. Lining between Slab and Wall

The lining system is over passing the concrete slab on each side, in order to connect the waterproofing system of the wall. The waterproofing system - over passing the bottom slab - has to be protected (e.g. porous concrete) until the walls are constructed.

Depending on its height, the vertical wall will be constructed in stages. After finishing the concrete works of the wall (first section), the protective concrete (shown in the drawing above) will be removed, the connection between waterproofing system slab and the wall can be executed.

A very sensitive point for the lining is the change from horizontal slab to vertical wall. Local pressures at the corners mean serious stress; therefore it is very important to place the lining with great care.



Lining between Slab and Wall

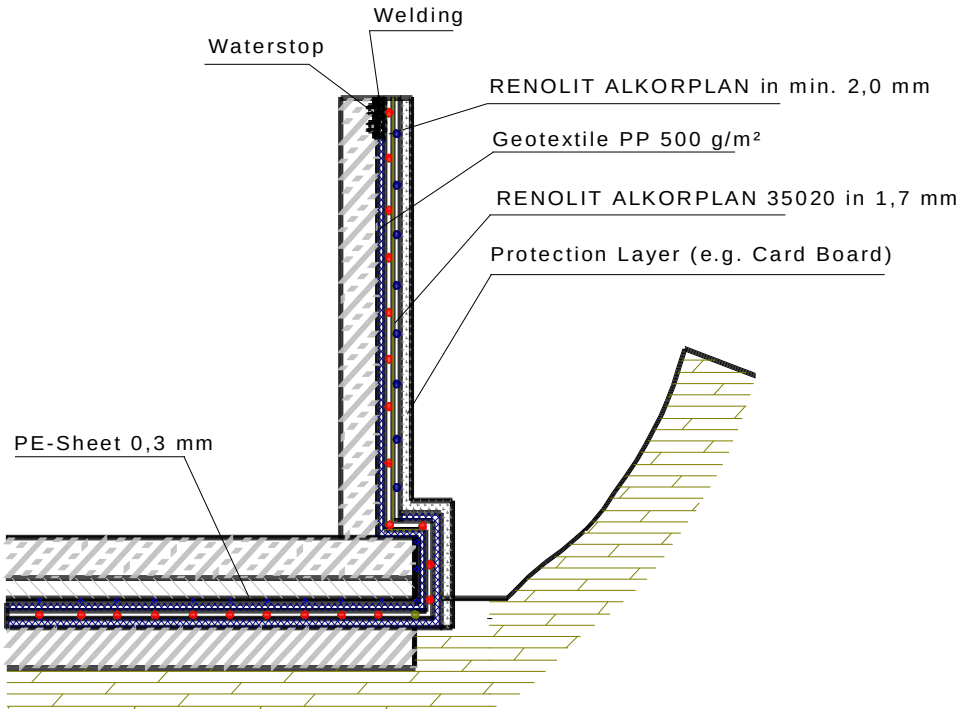
4.1.3. Lining of Vertical Faces

The fixation on top of the wall can be done in different ways. There is the possibility of placing a water stop into the upper side of the shuttering. After the concreting the shuttering is removed, the water stop cleaned and the membrane welded to the water stop. This is for sure a good technical solution and creates in addition a compartment system.

In case the backfill follows the concrete works of each wall section the waterproofing will be fixed temporarily.

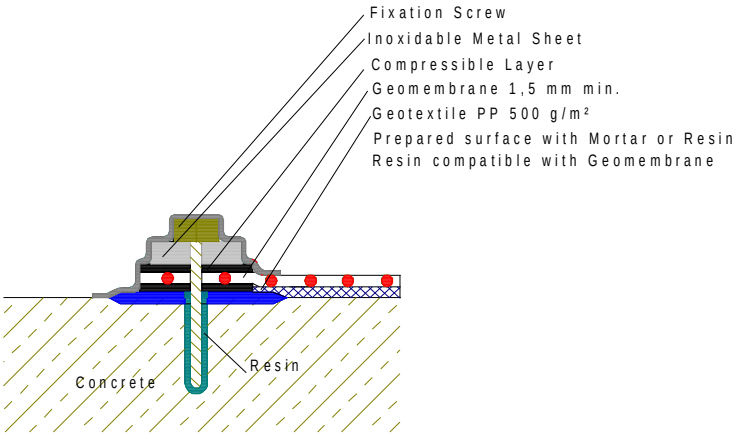
To continue the waterproofing work, the backfill is brought to the desired height and the concrete of the next section of wall is executed. After the shuttering of this section is removed the waterproofing follows. The temporary fixation underneath will be removed and the geomembrane welded to the fixation to guarantee water tightness.

WATERPROOFING OF THE WALL



System of the wall

Mechanical Fixation of Waterproofing System



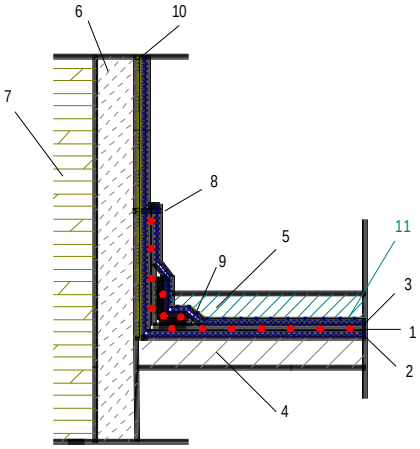
4.2. Waterproofing without working space

4.2.1. Lining of the Bottom Slab

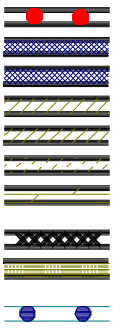
Waterproofing of Foundation

The execution of the waterproofing of the bottom slab without working space is similar to the one with working space, besides the connection point for the wall lining. The waterproofing has to be fixed temporary to the retaining wall at a specific height (minimum 30 cm) to guarantee a safe connection with the waterproofing of the wall. The temporary fixation has to be removed before continuing with the concreting of the vertical faces. A geotextile has to be placed between the retaining wall and the geomembrane.

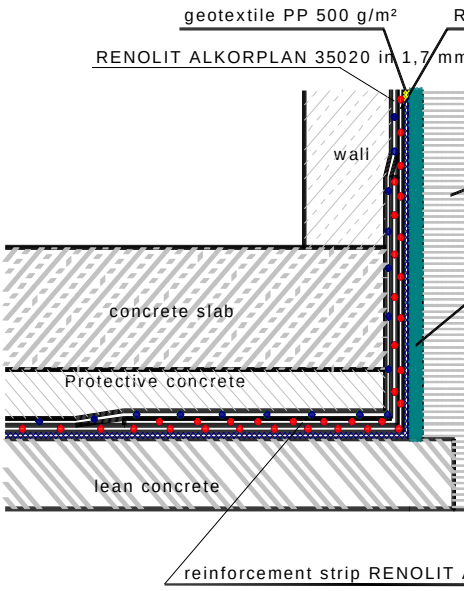
STANDARD - DESIGN FOUNDATIONSLAB - WALL



1 RENOLIT ALKORPLAN 35041 2,0 mm
2 Geotextile 800 g/m²-500 g/m²
3 Geotextil 500 g/m²
4 Lean concrete
5 Protective concrete
6 Shotcrete
7 Retaining wall
8 Temporary fixation
9 Welding seam
10 Separation Layer
11 PE Foile 0,3 mm



Waterproofing of foundation without working sp



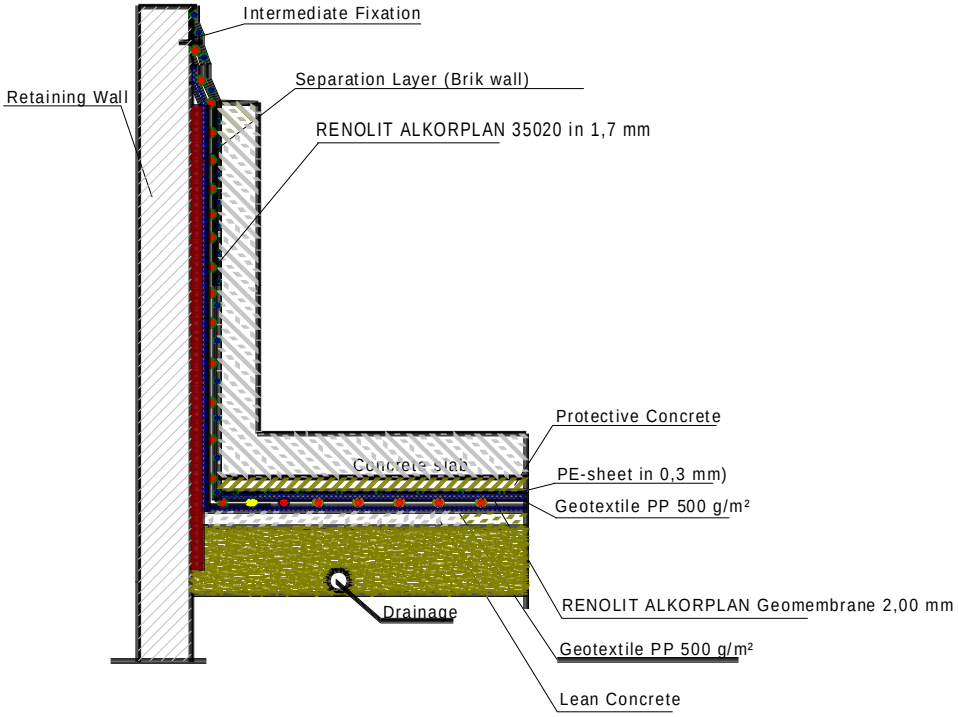
Execution of the lining system between slab and wall

4.2.2. Lining of Vertical Faces

The waterproofing works are carried out before the concrete works of the walls. The waterproofing has to be brought to the height of the next concrete section of the walls and fixed intermediate over this level on the retaining wall. When the lining works continue, the temporary fixation is removed, the next part of the lining system welded to the installed membrane and placed over the vertical surface of the next section. If the construction continues in this way, the described method will be repeated (Sketch without water stops).

Waterproofing of Foundation

Intermediat Fixation of the Lining System



Intermediate Fixation of Waterproofing

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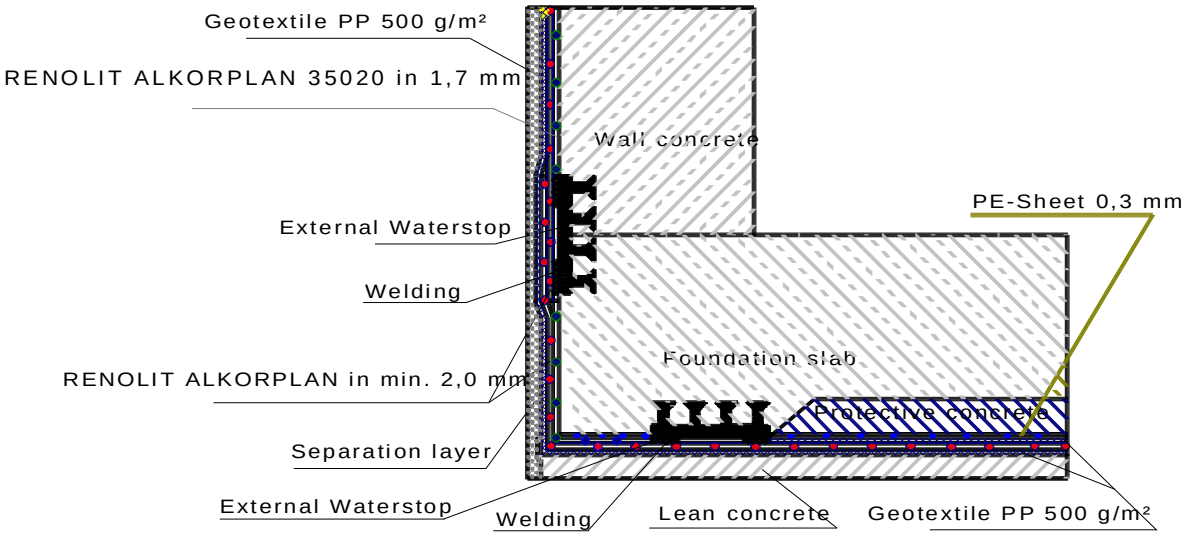
4.3. Compartment system

This system helps to limit the repair works in case of damage. The water stop, welded to the geomembrane, divides the lining system into compartments which limits the spreading of the infiltrating water. The surface of one compartment should not be greater than 100 m².
The anchors of the water stop have to be well embedded into the concrete in order to stop the water from spreading from one compartment to the other.
The PVC-P water stops are welded to the geomembrane (with welding automate for horizontal surfaces).
Through these compartments the leakage area can be precisely determined to a certain limited surface.
In combination with an injection system, the repair of a leaking compartment can be carried out without damaging the geomembrane as well as keeping the cost at a reasonable level.
Depending on the joints (working joints or dilatation joints) an external water stop or an expansion water stop has to be used.

Protected Slab with exposed Water Stops

Waterproofing of Foundation

Foundation slab - Wall



Execution of lining system with external water stops

Dangers of mechanical impact to Waterproofing system

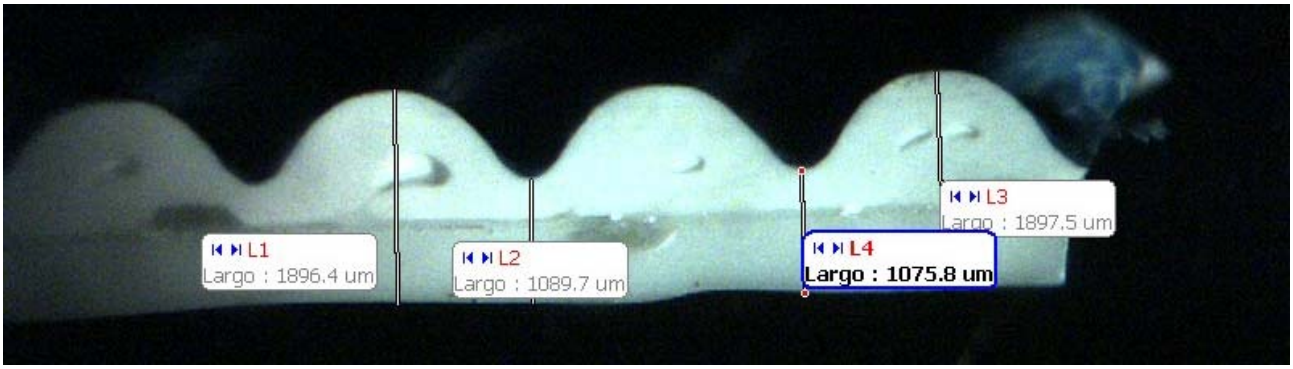
4.4. Double Layer System for special Applications

Waterproofing of Foundation

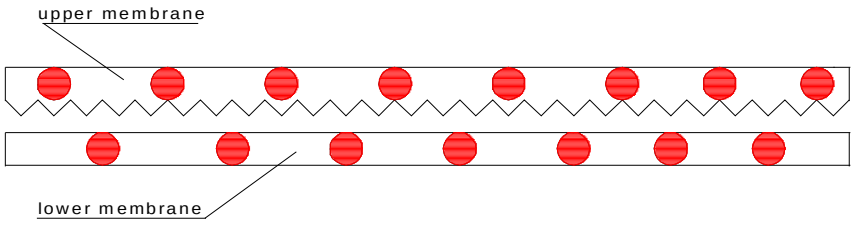
Constructions in high pressure ground water need very secure waterproofing. Such buildings can be nuclear power stations, hospitals, storing isotope materials, banks with safes, park decks and also tunnels at important depths.
For such buildings a single layer waterproofing might not be sufficient as it has to be taken into consideration that the waterproofing membrane could be damaged during the reinforcement and concrete works.
Therefore a controllable and repairable waterproofing system should be applied in such cases.

A possible controllable and repairable waterproofing system is the double layer system. A common and a structured geomembrane are placed one over the other, and they are welded together on all sides to create a closed compartment. Vacuum of each compartment controls its waterproofing. A structured geomembrane allows having space between the two layers. In case of a failure in one of the geomembranes the vacuum will break down. Due to the structured geomembrane the injection material for repair can distribute easily over the whole surface between the 2 layers.

Picture of structured membrane allowing empty space between the two layers



System of Double Layer with structured geomembrane



Advantages:

- By using two layers of geomembrane the risk of damage is highly reduced. In case of damage, in most cases only one layer will be affected which means that there is still one remaining layer left which is fully functioning.

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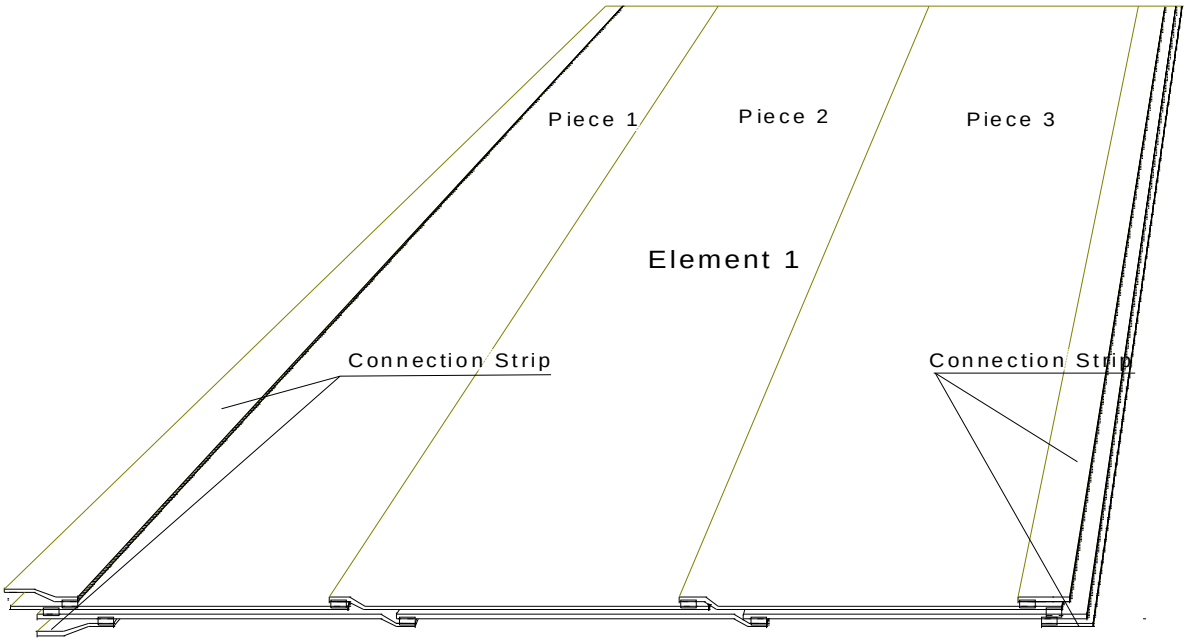
- In the worst case where both geomembranes are damaged there is still the possibility of repair through the injection system with liquid waterproofing material (PU, Acrylic).
- The injection pipes allow in one hand to control the waterproofing of the double layer system (vacuum), and, in the other hand, to repair it without destroying the concrete (injection).

4.4.1. Prefabrication

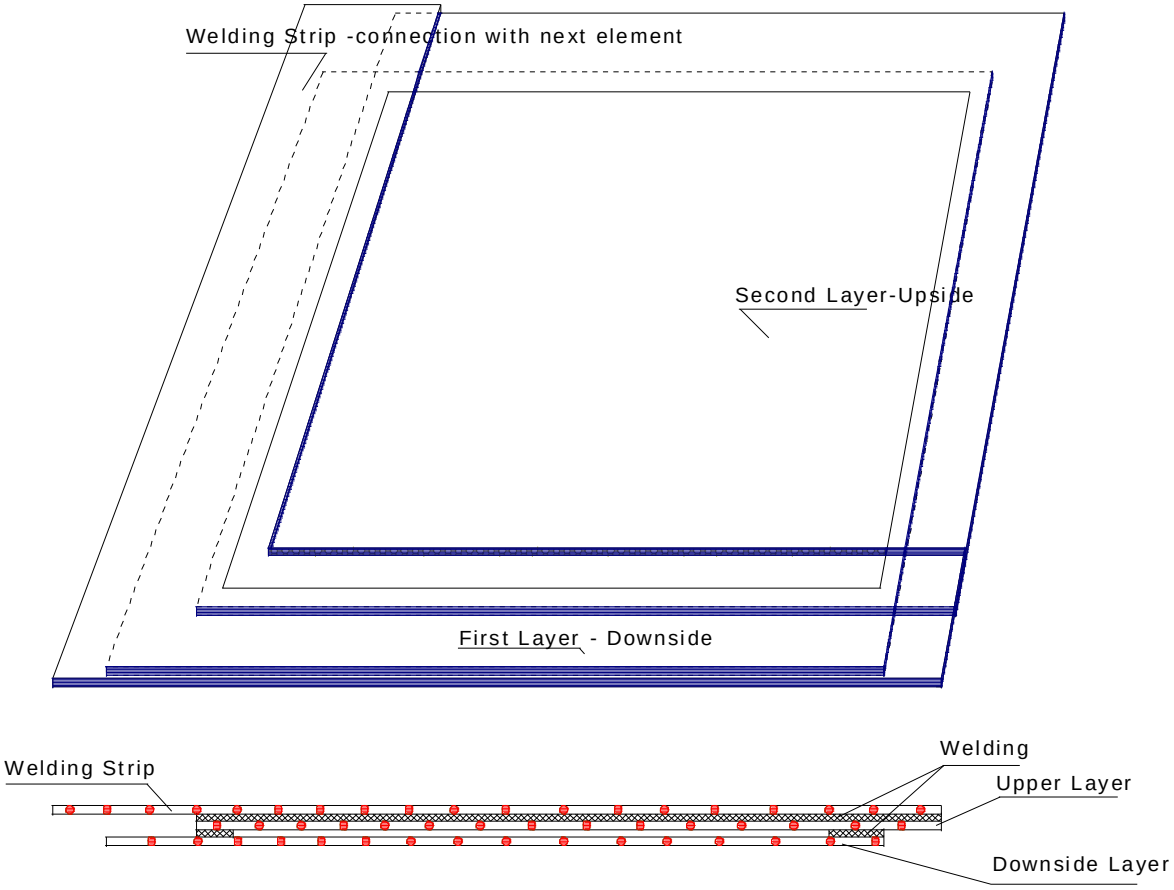
Depending on the size of the construction of prefabricated elements, consisting of an upper structured geomembrane and a normal lower geomembrane, these are welded together in a clean and dry surrounding. The upper geomembrane will be placed at a distance of around 20 cm parallel to the lower geomembrane. This overlap is needed to create the connection to the next double layered piece.
One has to ensure that also the connection area of the elements has got the possibility of being controlled and injected. For this reason strips of geomembrane have to be welded onto the geomembrane at both borders of the prefabricated element.



In case elements have to be connected from both head sides of a prefabricated element, the upper membrane will be placed at a distance of 20 cm inward from the head side of the lower element.

Waterproofing of Foundation

Prefabricated Element



4.4.2. Control and Injection system:

This system helps to control the quality of welding and to detect leakages. At the same time it can be used as a repair system.

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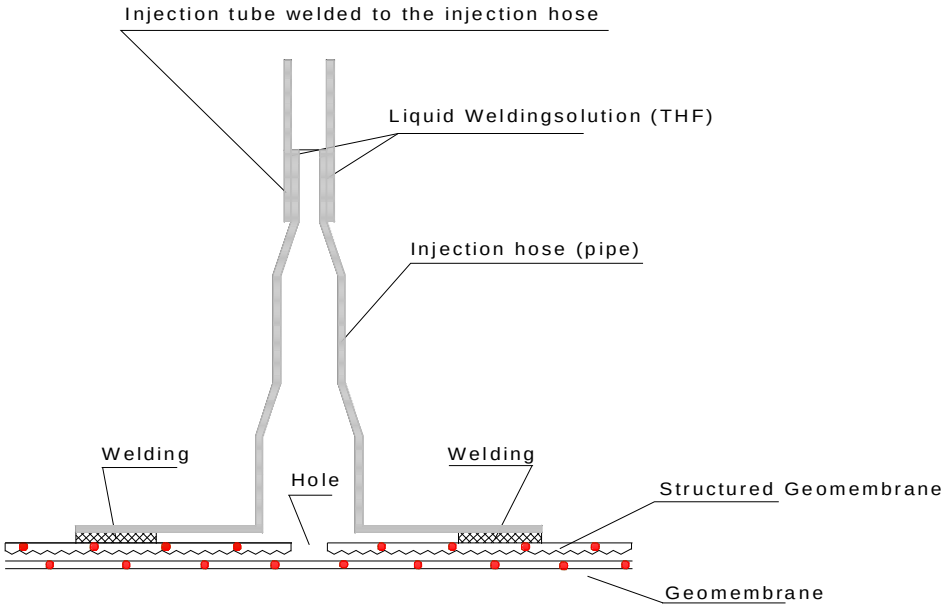
Injection and Control Device
System with structured geomembrane

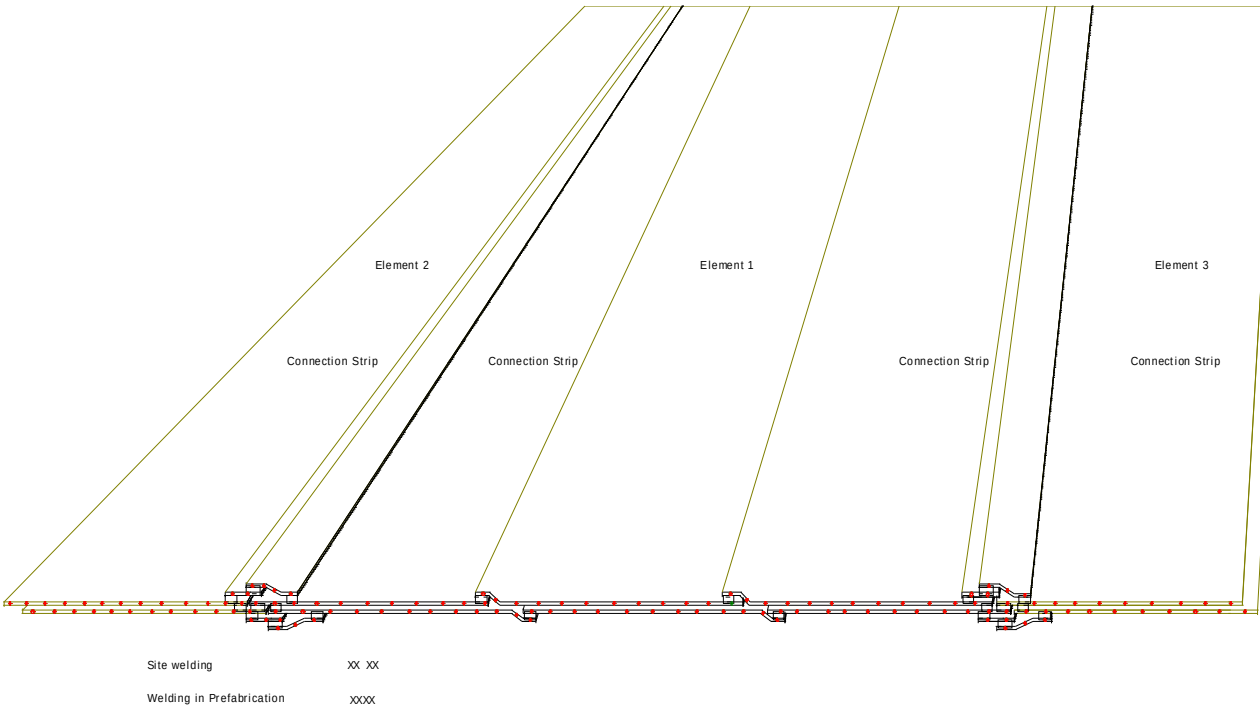


The injection pipe can have different forms depending on the product. A small hole is cut into the upper geomembrane and the injection pipe welded onto. Injection pipes can be welded to the elements already during prefabrication but also on site – depending on the structure that will be lined. When such systems are applied in tunnels it is recommended to install the injection pipes during prefabrication, then the vacuum test has to be executed to control all weldings. In case one welding is not correct it will not be possible to create the vacuum. Due to the vacuum, both geomembranes stick together and the elements can be installed to the vault as a single layer system. On site the injection tubes are welded to the injection pipe by THF.

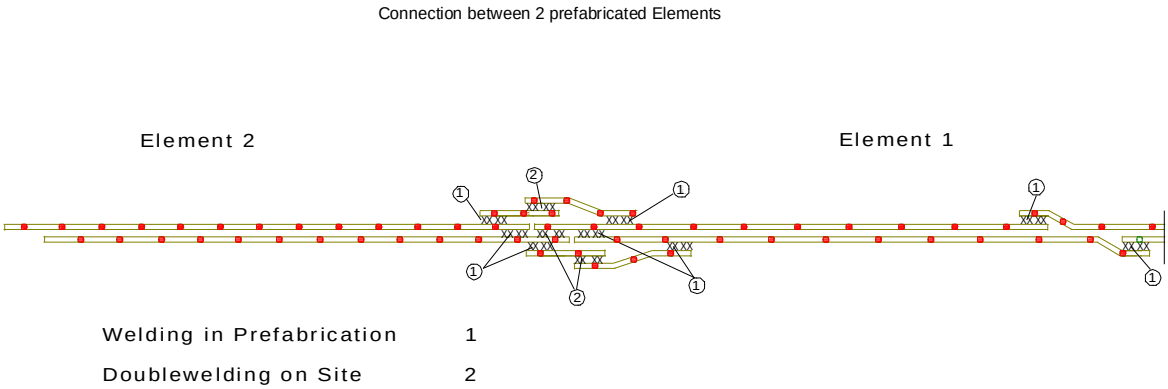
4.4.3. Connection of the prefabricated elements on site.

The prefabricated elements are placed into the correct position on site and welded together. All weldings on site, apart from the details should be welded with a welding automate.

Waterproofing of Foundation



Detail of Connection between elements:



After the connection of all elements the concrete can be poured over the waterproofing system.
The injection tubes can be guided to a central box connected to vacuum gauges in order to control the functioning of each element.

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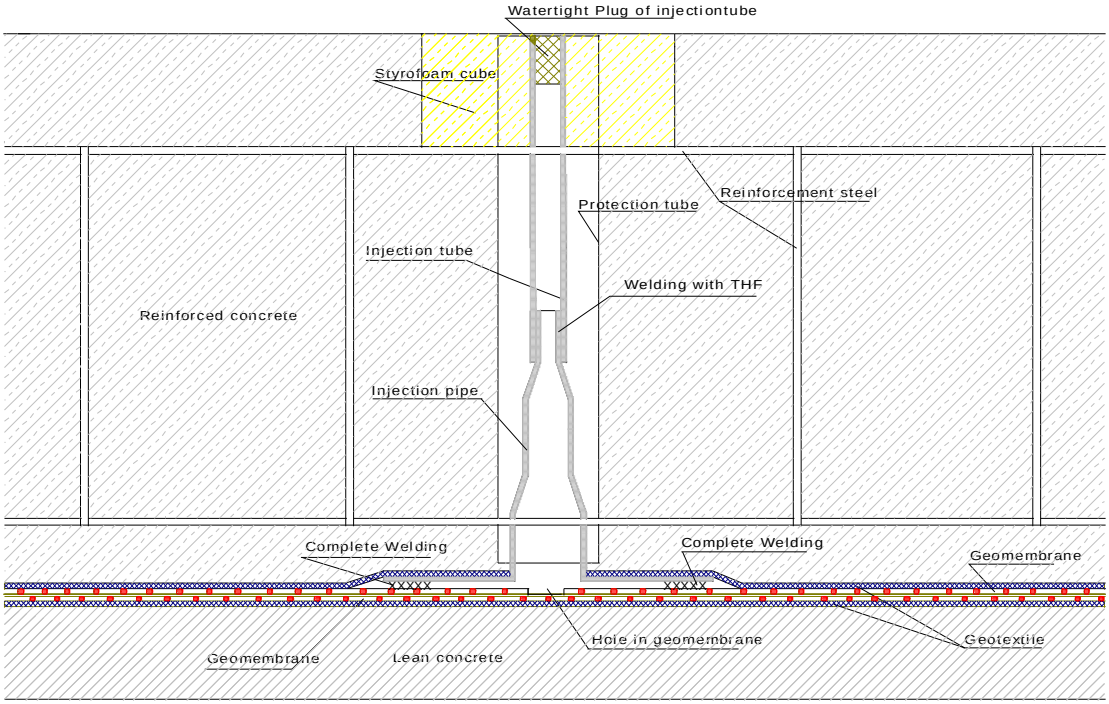
Injectionsystem for double laid Waterproofing



4.4.4. Repair

In case of a fault the vacuum of the prefabricated element will break down. It can happen when only one layer of the 2 geomembranes is damaged or if a welding is incorrect. With the injection pipes it can be controlled which of the both layers is damaged as water will appear through the injection tubes.
In case of leakage in the upper layer, no water will enter but the vacuum will break down. That means the waterproofing is still working but only with one layer of geomembrane and therefore there is no reason to make any repairs.
If both layers are damaged the space between the two layers of geomembrane has to be injected. The repair in general is done by injecting acrylic, PU or water tightening cement.
The injection work has to be carried out by a specialist as it is a very sensitive work. The ideal mixture (viscosity), the force of pressure and the speed of the injection has to be coordinated carefully. On the one hand the injection material has to flow easily through the whole space between the 2 layers of membrane to fill the damage, and on the other hand it should not be too liquid in order to be washed out by incoming water. The viscosity of the injection material has to be determined with great precision.

5. MATERIALS

5.1. Geomembrane

The choice of the geomembrane depends on 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 kinds of PVC-P geomembranes have been created and seen the existing standards in Europe two types 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 for this important sector, as a waterproofing material.

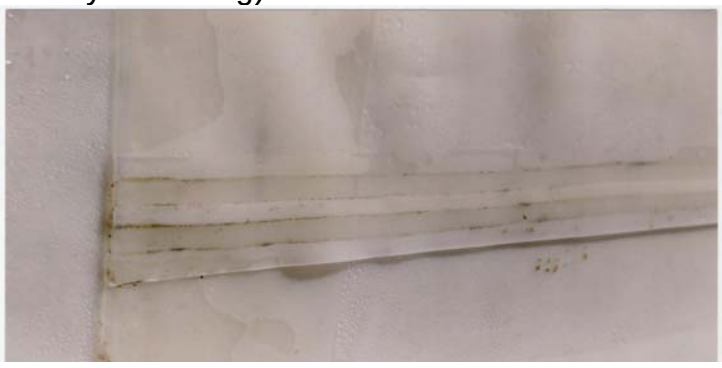
5.1.1. System with signal layer

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 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.

5.1.2. Translucent system

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



This picture shows 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 the temperature was very high, or the hot wedge not properly cleaned. In such case a special investigation of the welding

quality 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 as with coloured liquids. The advantage of this method is to detect immediately the place of the welding failure.

5.1.3. Resistance of 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 translucent PVC-P membrane RENOLIT ALKORPLAN (type 35036 2mm thick), even under high pressure:
  - Load of 2Mpa
  - Horizontal movement of 3mm

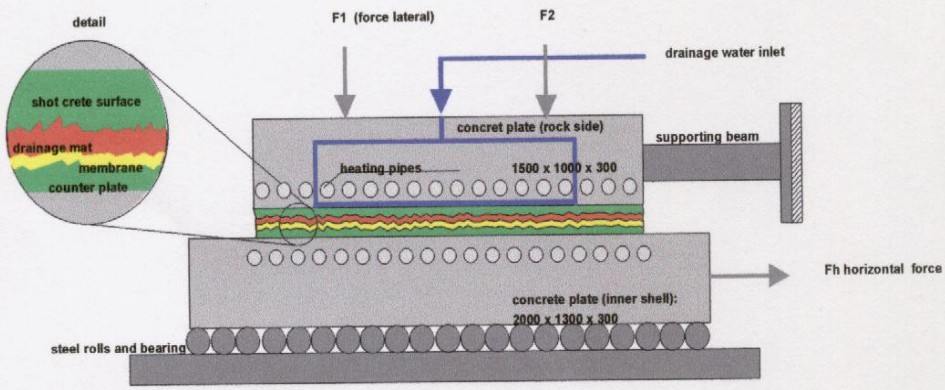


Figure 7: Schematic cross-section of the compression/shear set-up with heating and drainage capability, the top plate (fixed) corresponds to the shotcrete surface of the outer tunnel shell

ref : The Sealing of Deep-seated Swiss Alpine Railway Tunnels
New Evaluation Procedure for Waterproofing Systems
P. Flüeler, Ch. Löwe, M. Farshad, P. Zwicky, H. Böhni

- The German laboratory SKZ showed that the PVC-P signal layer geomembrane RENOLIT ALKORPLAN (type 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 of 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.).

5.2. Geotextile

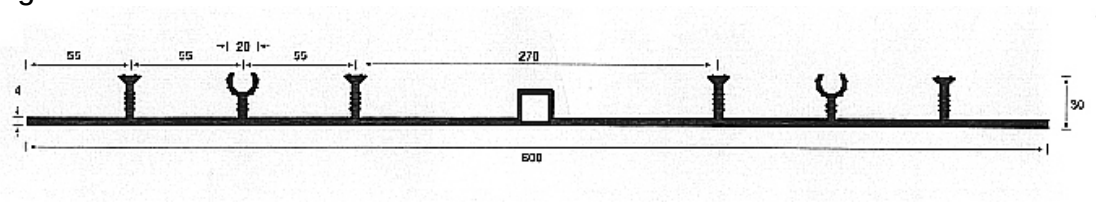
The geotextile has to be of Polypropylene fibers, short fibers mechanically fixed or long fibers. Polyester geotextile has to be avoided because of hydrolysis of polyester due to the alkalinity of concrete. The freshly applied concrete attacks the Polyester geotextile and after a certain time the geotextile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

5.3. Water stops

It is recommendable to use water stops with integrated injection tube as it is important to assure the water tightness in the joints.

5.3.1. Water stop for Expansion joint

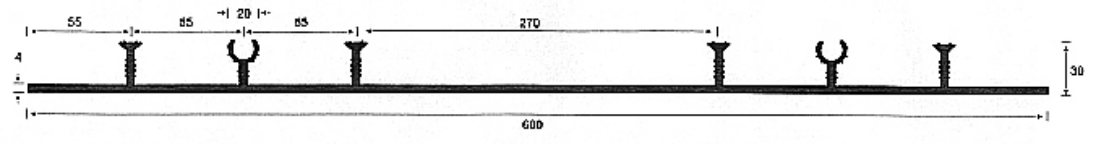
This water stop is placed in all dilatations of the construction. In case of important movements of the construction the middle bulb is able to break in the thin part on the bottom to follow the movements without loosing water tightness.



example of water stop for expansion joint following DS 853

5.3.2. Water stop for Normal joint

They are used to create the compartment system.



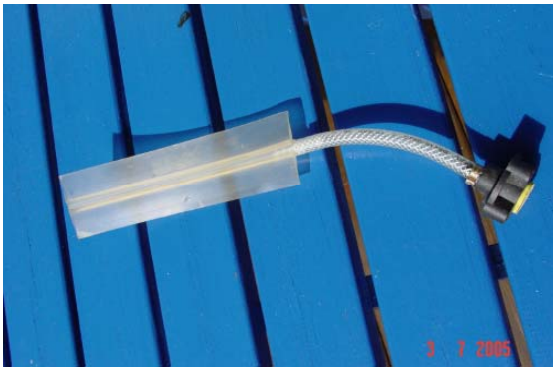
exemple of normal water stop following DS 853

5.4. Injection devices

In addition to the water stops, injection devices are welded punctualy to the geomembrane. The task of the injection devices is to provide the possibility to inject liquid waterproofing materials in order to close an eventual leakage of the geomembrane. These liquids or resins are based mostly on two components acrylic 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

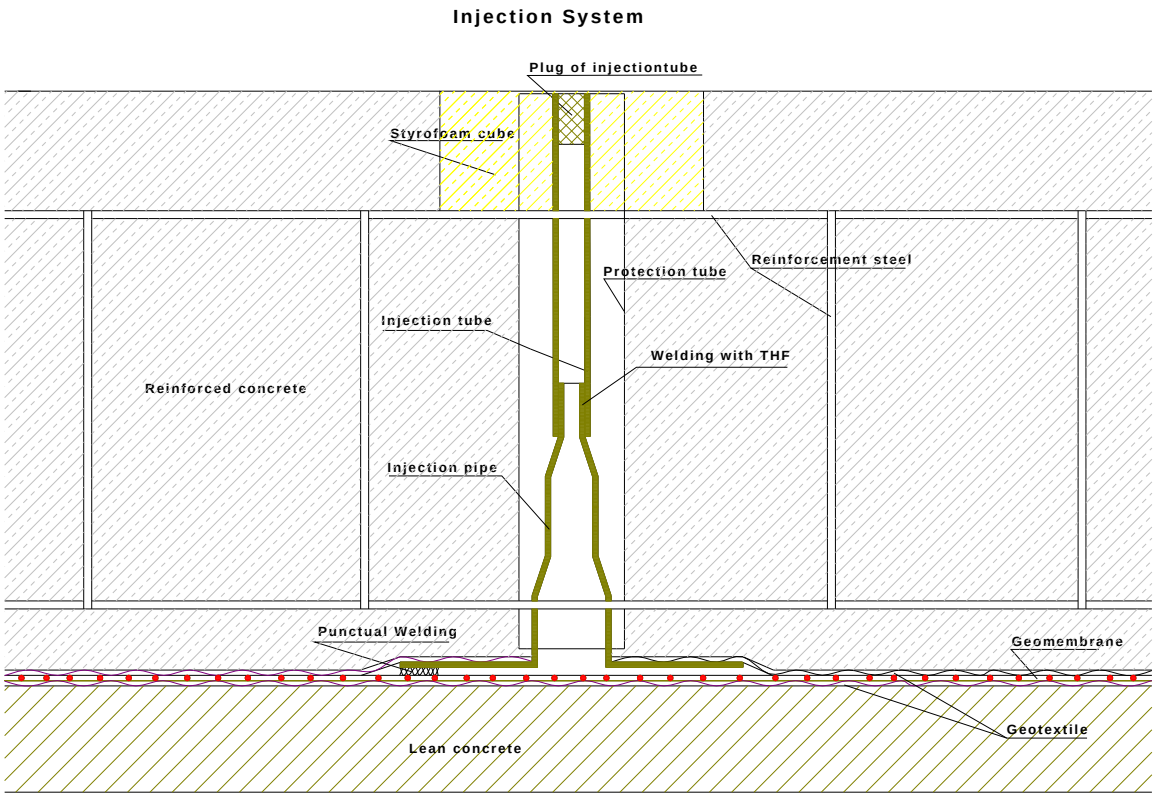
Injection pipe



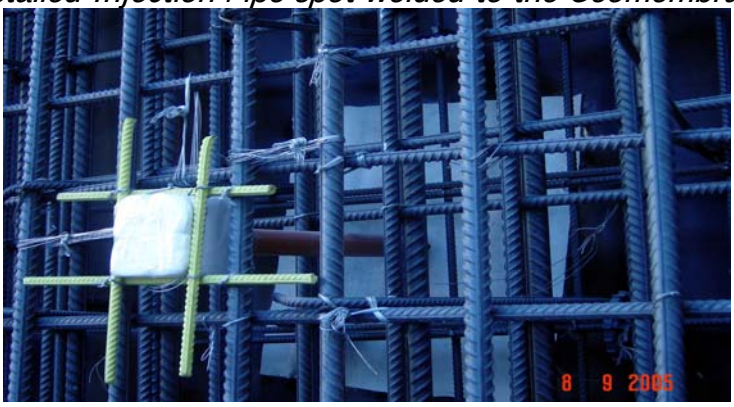
Injection tube

5.4.1. 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 into a safe device of the surface of the concrete.



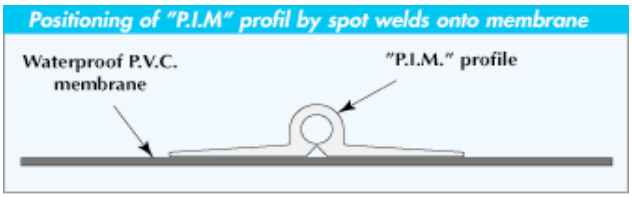
Installed Injection Pipe spot welded to the Geomembrane

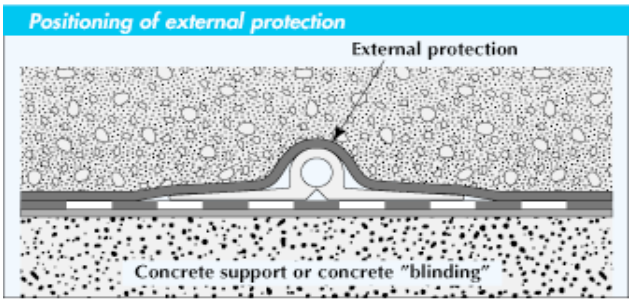


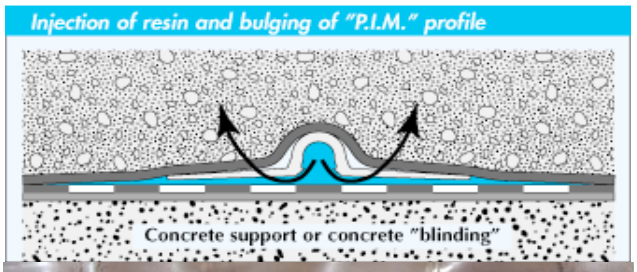
Protected inlet of Injection Pipe

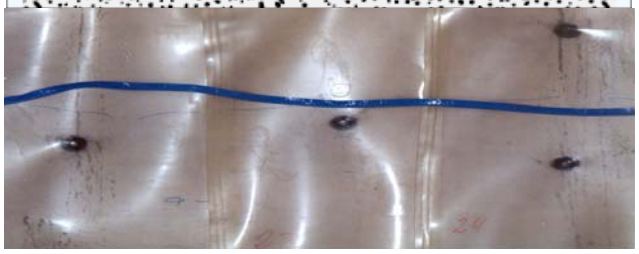
5.4.2. Injection tube

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









Injection tube welded to geomembrane

5.5. Welding tools

5.5.1. Automatic hot wedge welding machine

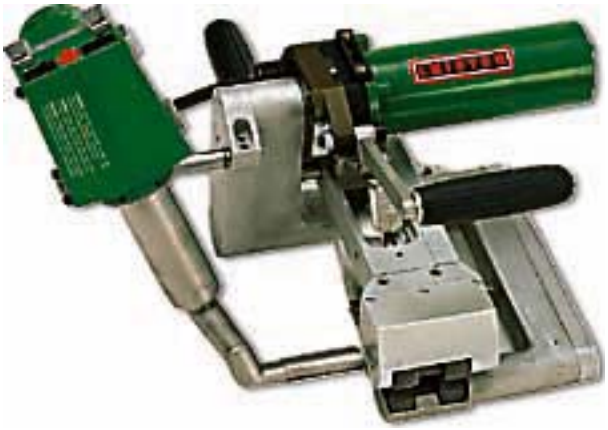
This kind of machine works with an electric heated wedge. Above and underneath the wedge there are the two pressure rolls which are both independently motorized. The hot wedge is guided between the overlapping geomembranes; the two pressure rolls advance the machine at the determined speed. Temperature,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

The machine is completely electronically guided. In case the outside temperature is changing the electronic guidance adjusts the temperature following the conditions.

Automatic hot wedge welding machine

5.5.2. 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

5.5.3. 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.

6. CONTROL AND TESTING OF WATERPROOFING

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

6.1. 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 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 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 carefully repaired 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

Double seam control

6.2. 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 bubbles due to the applied air pressure.

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7. CONCLUSION

The installation of waterproofing systems in foundations 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 person responsible for the success of the waterproofing system under such circumstances, too many risks for damage exist 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 foundation.
This is a difficult task and failures in the lining system can happen. Therefore a repair system is foreseen from the beginning with the integration of the compartment system with injection pipes. This delivers a realistic chance to close any leakages in the waterproofing system.

Installation of Water Stops and Execution of Protective Concrete