Flexible Waterproofing of Tunnels with Sikaplan® Membranes
Flexible Waterproofing of Tunnels with Sikaplan® Membranes

Road Tunnels
Rail Tunnels
Metro Tunnels
Water Tunnels

Birmensdorf/Switzerland
Open cut construction with Sikaplan® WT 1200-30C

Lötschberg/Switzerland
Drill and blast construction with Sikaplan® 14.6 NEAT

NBS Frankfurt – Köln/Germany
Emergency exit shaft with Sikaplan® WT 2200-31HL2 and Waterstop MP AF 600/35

DMRC/India
Open cut construction with Sikaplan® WP 1100-20HL
Degree of Watertightness
(According to Pre Norm SIA 272)

Tunnels are built with a service life of over 100 years, which means that standards for tunnel construction must be high, in particular those involving sealing and waterproofing systems.

**Class 1**  
Completely dry  
No moist parts on the dry part of the tunnel surface permitted.

**Class 2**  
Dry to slightly moist  
Single failing parts permitted. No dropping water on the dry part of the tunnel surface permitted.

**Class 3**  
Moist  
Partly limited moisty parts and single dropping parts on the dry part of the tunnel surface permitted.

**Class 4**  
Moist to wet  
Moisty parts and dropping parts permitted.

A tunnel seal has the task of protecting the tunnel construction against damage resulting from moisture or the unintentional entry of water as well as the danger posed by aggressive water or soils and the effects of chemicals.

Thus the reliable functioning of a seal is of particular significance in the case of traffic tunnels, which are not easily accessible for all subsequent repairs after the construction in seepage water and especially when located in a pressure water zone. If ground-water infiltrates, it can cause damage, restrict tunnel service, or create a traffic hazard.

With respect to the overall demands made on sealing tunnels, it is essential to remember that essentially a sealing system has to be selected and planned in order to represent the optimal solution with regard to the given requirements pertaining to its intended use on the one hand, and the technically and economically acceptable possibilities on the other.

**Waterproofing Drainage Concept**

The tunnel can be built as a non-draining structure with a watertight all-round seal. After the construction is finished there is no need to divert underground water and therefore no permanent negative influence of the water level or water balance.

The decision not to permanently divert the prevailing underground water into a drain system makes it necessary, for the construction and the seal, to be designed to cope with water pressure. Permanently drained tunnels carry off the prevailing underground water, usually collected at the edges of the floor or feet of the vault, so that the tunnel shell is relieved.

**Draining**
Evacuation of Mountain Water
- Less lining costs
- Reduction of concrete thickness
- Allows tunneling under extreme conditions
- Higher maintenance cost
- Permanent drainage concept
- Traffic interruption during maintenance work

**Holding Water Head**
Mountain Water Displacement
- Higher lining costs
- Construction has to consider the water pressure
- Lower maintenance cost
- No influence of water table after construction
- Environmentally friendly
- Higher level of waterproofing system
- Reduction of ground settlements

Thus the reliable functioning of a seal is of particular significance in the case of traffic tunnels, which are not easily accessible for all subsequent repairs after the construction in seepage water and especially when located in a pressure water zone. If ground-water infiltrates, it can cause damage, restrict tunnel service, or create a traffic hazard.

With respect to the overall demands made on sealing tunnels, it is essential to remember that essentially a sealing system has to be selected and planned in order to represent the optimal solution with regard to the given requirements pertaining to its intended use on the one hand, and the technically and economically acceptable possibilities on the other.
Influences on Waterproofing in Tunnels

During the Construction

The waterproofing system in a tunnel is composed of a combination of many factors and influences. Therefore the characteristics of the membranes are very important.

- Geostatistical forces
- Temperature
- Area load
- Water
- Puncture load
- Reinforcement
- Fire

After the Construction

- Hydraulic pressure
- Dynamic forces
- Soluble components + O2 caused clogging + sintering process of the drainage pipe.
- High water flushing
- Concrete, Traffic, Bulk-head
- Reinforcement
- Area load
- Puncture load
- Fire

Aggressive water
- Sulphate water
- Chloride water
- Soft water with low calcium content

Settlements
- Fire

Puncture load
- Reinforcement
- Area load
- Water
- Puncture load
- Faulty inner concrete areas

Temperature
- Fire

Puncture load
- Reinforcement
- Area load
- Water
- Puncture load
- Faulty inner concrete areas

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Temperature
- Fire

Puncture load
- Reinforcement
- Area load
- Water
- Puncture load
- Faulty inner concrete areas

Temperature
- Fire
Systems for Waterproofing

Systems for waterproofing structures built with open cut construction techniques, exposed to hydrostatic pressure and groundwater that is chemically aggressive to concrete.

**Membrane Laying Systems**

According to the required degrees of watertightness - a tunnel structure has to be waterproofed. There are a number of possible solutions depending on the ground and substrate conditions, the water pressure and the water and design concept.

### Drained

**Evacuation of water (seepage water)**

**Water displacement (pressurized water)**

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Water concept</th>
<th>Hydrostatic pressure above invert</th>
<th>Sealing system</th>
<th>Concrete aggressive water</th>
<th>Additional measures</th>
<th>Sika Membrane System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Draining</td>
<td>without water stop</td>
<td>flexible</td>
<td>Waterproofing membrane 3 mm</td>
<td>no  no  no</td>
<td>Sika Membrane System</td>
</tr>
<tr>
<td>2</td>
<td>Evacuation of mountain water</td>
<td>with mountain water stop</td>
<td>rigid</td>
<td>Watertight concrete</td>
<td>yes  no  no</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Holding water head</td>
<td>without water stop</td>
<td>flexible</td>
<td>Waterproofing membrane 3 mm</td>
<td>no  no  no</td>
<td>Sika Membrane System</td>
</tr>
<tr>
<td>4</td>
<td>Holding water head</td>
<td>with mountain water stop</td>
<td>flexible</td>
<td>Waterproof concrete + Watertight membrane 3 mm</td>
<td>no  yes  yes</td>
<td>Sika Membrane System</td>
</tr>
<tr>
<td>5</td>
<td>Holding water head</td>
<td>with mountain water stop</td>
<td>rigid</td>
<td>Watertight concrete</td>
<td>yes  no  no</td>
<td>Sika Membrane System</td>
</tr>
</tbody>
</table>

### Holding the Head of Water (un-drained)

**Evacuation of water**

**Water displacement**

<table>
<thead>
<tr>
<th>Nr.</th>
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<tr>
<td>1</td>
<td>Draining</td>
<td>without water stop</td>
<td>flexible</td>
<td>Waterproofing membrane 2 mm</td>
<td>no  no  no</td>
<td>Sika Membrane System</td>
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<td>2</td>
<td>Evacuation of mountain water</td>
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<td>rigid</td>
<td>Shotcrete</td>
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</table>

**Suitable products**

- Sika® FlexoDrain
- Sikaplan® WT Tundrain PE
- Sikaplan® WP Disc
- Sikaplan® WT Disc
- Sikaplan® WP
- Sika® Waterbar: WT AF-40/6 MP
- Sika® Waterbar: WT AF-50/6 MP
- Sika® Waterbar: WP AR-40/6 PVC Inject
- Sika® Waterbar: WP AR-50/6 PVC Inject
- Sikaplan® WP Protection sheet
- Sikaplan® WT Protection sheet
- Sika® Dilatoc®, type E/ER sealing strips
- Sika® Dilatoc®, type E/ER sealing strips
- Sika® Combiflex® sealing system
- Sika® Combiflex® sealing system

Minimum recommendation of shotcrete evenness in connection to the membrane laying system

- 1 : 5
- 1 : 10

Minimum recommendation of shotcrete evenness in connection to the membrane laying system

- 1 : 10 – 1 : 15

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**Systems for Waterproofing Structures Built with Tunnelling Techniques, Exposed to Hydrostatic Pressure and Groundwater that is Chemically Aggressive to Concrete.**

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- Sika® Waterbar: WT AF-50/6 MP
- Sika® Waterbar: WP AR-40/6 PVC Inject
- Sika® Waterbar: WP AR-50/6 PVC Inject
- Sikaplan® WP Protection sheet
- Sikaplan® WT Protection sheet
- Sika® Dilatoc®, type E/ER sealing strips
- Sika® Dilatoc®, type E/ER sealing strips
- Sika® Combiflex® sealing system
- Sika® Combiflex® sealing system

Minimum recommendation of shotcrete evenness in connection to the membrane laying system

- 1 : 5
- 1 : 10 – 1 : 15
Flexible Waterproofing with Sikaplan® Membrane Systems

Drill-and-blast Excavation with Drainage

- Drainage pipe with gravel package
- Invert drainage with gravel
- Sika® FlexoDrain for preliminary waterproofing
- Geotextile or drainage mats for draining and levelling out
- Polymer waterproofing membranes Sikaplan®
- Manholes for inspection and cleaning
- Separation layer

Mountain Water flows without head of pressure into the drainage
No accumulation of water
Sikaplan® WP drainage angle

TBM driving with Drainage

- Drainage pipe with gravel package
- Tubbing segments ring gap and segment joints (hollow space for drainage)
- Protective geotextile as levelling layer
- Polymer waterproofing membrane Sikaplan®, protective membrane in the invert and shuttering zone
- Manholes for inspection and cleaning

Mountain water flows without head of pressure into the drainage
No accumulation of water
Loose-Flange construction

Drainage of Mountain Water / Not holding a Head of Water / Drill-and-blast Excavation

- Drainage pipe with gravel package
- Invert drainage with gravel
- Sika® FlexoDrain for preliminary waterproofing
- Geotextile or drainage mats for draining and levelling out
- Polymer waterproofing membranes Sikaplan®
- Manholes for inspection and cleaning
- Separation layer

Mountain water flows without head of pressure into the drainage
No accumulation of water
Sikaplan® WP drainage angle

Mountain Water Displacement / Holding the Head of Water / Drill-and-blast / TBM Excavation
Flexible Waterproofing with Sikaplan® Membrane Systems

Drill-and-blast / TBM Excavation

1. Sika® FlexDrain for preliminary waterproofing
2. Substrate
3. Levelling layer
4. Sikaplan™ membrane
5. Partitioning with Sikaplan™ Waterbars, injectable
6. Sikaplan® control socket
7. Sikaplan® protection sheet
8. Drainage during construction
9. Groundwater relief socket
10. Construction phase drainage, possibly with groundwater relief drains filled by cement grout after structural completion
11. Polymer waterproofing membrane Sikaplan® with geotextile
12. Waterproofing membranes Sikaplan® with knops-embossed surface (knops height: 0.3 mm, knops area: < 30% of membrane surface)
13. Polymer waterproofing membrane Sikaplan®, protective membranes in invert, shuttering and reinforcement steel zones
14. Segmental weld of double layer membranes
15. Connection point for vacuum test and injection
16. Groundwater relief drain

Mountain Water Displacement / Holding the Head of Water / Drill-and-blast / TBM Excavation

Sika

McMaster-Carr

Flexible Waterproofing with Sikaplan® Membrane Systems

Open Cut Tunnel

Drainage of Mountain Water / Not holding a Head of Water / Drill-and-blast / TBM Excavation

- Sikaplan® protection sheet
- Sikaplan® membrane
- Levelling layer/Geotextile
- Levelling grout
- Filter (gravel)
- Drainage pipe
- Concrete foundation
- Substrate
- Excavated surface

Mountain Water Displacement / Holding the Head of Water / Open Cut Tunnel

- Sika Dilatec®, joint sealing system or Sikadur® Combiflex®
- Levelling layer/Geotextile
- Sikaplan® membrane
- Sikaplan® protection sheet
- Levelling grout
- Steel sheet piling
- Partitioning with Sikaplan® waterbars, injectable
- Protective concrete layer
- Substrate
- Excavated surface
- Levelling layer/Geotextile
Flexible Waterproofing

Sika offers a wide range of different waterproofing systems according to the required degrees of watertightness and to the individual project conditions. A tunnel structure has to be waterproofed either by drainage system by waterstop system or by active control system for highest demands with double layer waterproofing, controlled by vacuum.

**Drainage of water, not holding a head of water**

**Drainage system**
Single-layer polymer waterproofing membrane with geotextile or drainage mats or open tubbing segment joints

**Displacement of water, holding the head of water**

**Waterstop system**
Single-layer polymer waterproofing membrane with partitioning

**Evacuation of leak-water system**
Double-layer polymer waterproofing membrane with knobs or with an intermediate drainage layer and partitioning

**Active control system**
Double-layer polymer waterproofing membrane with injection space and partitioning with compartments; ability to actively test the waterproofing seal

Rigid Waterproofing

**Waterproof Concrete and Joint Sealing**

Sika ViscoCrete® SCC technology and Sika®-I capillary pore blocking technology.

Sika® Waterbars, Sika® Injectoflex, SikaSwell®, Sikadur®-Combflex, Sika® Dilatec® and Sikaflex® sealants are used for watertight joints.

**Thin-shell Waterproofing**

**Tunnel rehabilitation**
Sika waterproofing gunites are high-performance waterproofing systems requiring only little space. They are used for restoration and waterproofing work in the field of rehabilitation of existing tunnels.

**New Tunnels**
The outstanding waterproofing capacity of SikaCem-Gunit® 143 allows using high-durability thin-shell waterproofing linings also for new tunnels. The quick-setting gunite can be applied onto wet substrates. The polymer content of SikaCem-Gunit® 143 maximizes durability-relevant qualities such as freeze-thaw-deicing salt resistance and sulphate resistance while reducing the E-modulus. For special applications, fibre-reinforced types of the waterproofing gunites can be supplied on request.
Considering the application of waterproofing membranes in tunnels, the long time experience of sealing, the practical welding behaviour, the economics and the technical characteristics of the wide plastic range, in general two of them have convinced: Advanced plasticized PVC and high flexible TPO (FPO) with an E_{50-modul} < 65 N/mm². Important for the material specification and test procedures: PVC-P and TPO are completely different materials, with different material characteristics and behaviour.

### Raw Material

Material-related properties of tunnel sealing materials made of thermoplastics (PVC-P) and thermoplastics elastomers (polyolefine elastomers/TPO) for permanent waterproofing.

#### PVC-P

- **Easy and reliable joint technology (hot air/adhesive)**
- **Long experience (more than 50 years)**
- **Optimal stiffness and material behaviour (elastic behaviour)**
- **Self extinguishing (approx. 21 MJ/kg)**
- **High resistance to mechanical impact**
- **Aging through plasticiser loss**
- **Affected by cold (depending on the plasticiser)**

#### FPO

- **Thermal and chemical resistance**
- **Service life**
- **Low smoke behaviour**
- **Good welding properties due to advanced FPO-recipes**
- **Environmental stress corrosion cracking (depending on the flexibility/crystallization)**
- **Fire behaviour (approx. 40–45 MJ/kg)**
- **Aging through thermal oxidation process**
- **Less flexibility**

### Ancillary Products

#### Sika® Waterbar, PVC and FPO based types

- **Sika® Waterbar type AR (PVC)**
- **Sika® Waterbar type DR (PVC)**
- **Sika® Waterstop type MP AR (FPO)**
- **Sika® Waterstop type MP DF (FPO)**

Compartment in invert and arch of tunnels, raw material compatible with the waterproofing membrane.

#### Sikaplan® WP/WT protection sheets

- **Sikaplan® WP Protection sheet (PVC)**
- **Sikaplan® WT Protection sheet (TPO)**

#### Sika®-Combiflex® joint sealing system

- **Sika®-Combiflex® tape**
- **Sika®-Combiflex® joint sealing strips**

#### Sikadur® -31 (EP adhesive)

- **Sikadur®-31 (EP adhesive)**

For compartments and terminations with FPO membranes.

#### Sikadur® Dilatec®, type E / ER joint sealing strips

- **Sikadur® Dilatec® E-220 for expansion joints**
- **Sikadur® Dilatec® ER-350 for waterproofing terminations**
- **Sikadur®-31 (EP adhesive) for compartments and terminations with FPO membranes**

#### Sikaplan® Control and injection flange

- **Sikaplan® WP/WT injection Flange**
- **Sikaplan® WP/WT Control socket**
- **Sikaplan® W PU-control pipe**
- **Sikaplan® W PU-control tube**

For an integrated prophylactically injection system for possible repair work, for injection of fine cement and chemicals and for vacuum control.

#### Sikaplan® WP/WT laminated metal

- **Sikaplan® WP/WT disc fixing element**
- **Sikaplan® WP/WT Trumpet Flange**
100 Years Service Life?!
Long Term Testing according to the NEAT-standard

During the last decade, different waterproofing materials have been studied and tested in tunnel applications, mainly in Switzerland and Germany.

The materials are based on polyolefines compounds (PE and PP) or polyvinyl chloride (PVC-P). A comprehensive evaluation procedure was performed for two particularly long tunnels through the Swiss Alps based on requirements established by Alp Transit Gotthard AG and BLS Alp Transit AG.

Schematic of the pressure vessel with test specimens vertically arranged in oxygen-enriched water.

As many systems and products did not meet all of the stringent requirements, the most promising systems were then optimized and re-evaluated.

The result of this evaluation and these test procedures clearly showed that Sika products based on PVC-P and polyolefine compounds could fully meet the defined requirements for the waterproofing systems (EMPA-Report).

Ageing Behaviour

In this part of the evaluation, the components of the waterproofing systems were exposed for 24 months without mechanical loading to the following media: water circulated at temperatures of 23 °C, 45 °C and 70 °C, alkaline and acidic water at 50 °C, oxygen-enriched water at 70 °C and 3 bar pressure (Roxi-test) and by burying specimens in an environment with both aerobic and anaerobic micro-organisms.

At 5 intervals during the storage, the waterproofing membranes were tested for mass changes, changes in dimension and mechanical puncture strength. An additional series of tests including tensile, thermo-mechanical and thermo-analytical assessment after 3, 6, 12 and 24 months were used to determine the most appropriate properties for a sufficiently complete description of the ageing process (EMPA-Report).

Special influences such as high geothermal heat (45 °C), high pressure of mountain mass, construction, and high expectations for the service lifetime of 100 years had to be considered.

Polymeric products combined to waterproofing systems (membranes PE, PE-copolymer, PVC-P; drainage materials PE, PP, PA, PES) were tested in a 24-month programme. Existing test methods were complemented, e.g. by ageing at elevated temperatures and in oxygen-enriched water at elevated temperatures, respectively, compression creep tests, behaviour under combined lateral compression and horizontal shear, seam and installation tests.

As many systems and products did not meet all of the stringent requirements, the most promising systems were then optimized and re-evaluated.

The result of this evaluation and these test procedures clearly showed that Sika products based on PVC-P and polyolefine compounds could fully meet the defined requirements for the waterproofing systems (EMPA-Report).

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.

Test Application Field – NEAT

The system was installed on a shotcrete surface with variable surface roughness between 3–7 mm and a waviness of 4:1, 7:1 and 15:1. With additional heating during the setting of concrete the temperature in the waterproofing system rose to 55 °C. After completion of the construction the drainage capability was determined. The concrete support shell was then removed and the waterproofing system exposed.

The first installation tests showed that the waterproofing membranes develop regular folds with small radius of curvature during construction. Development of folds in the plane of the waterproofing membrane produces potential failure lines and has thus to avoided in long-term service.

To avoid such folds in the waterproofing membrane and to guarantee a close fit to the shotcrete profile, the Neat committee set strict requirements concerning the quantity and location of fixings points, the grading pressure and the friction between waterproofing membrane and drainage material.

To achieve such a close fit to the shotcrete profile, the flexibility of the waterproofing membrane – described with the section elasticity module between 1 % and 2 % elongation according to DIN EN ISO 527 – is recommended below 70 N/mm².

System 212: Sikaplan 14.6 Neat and PP-drainage (“Wirrgelege”).
System 620: Sikaplan-14.6 Neat Felt 500, Sikaplan PVC-P backed with a PP geotextile and a drainage made of gravel.
System 121: Sarnafi l MP 916 Neat and a PE drainage inclusive slabs.

Test Application Field – NEAT

The system was installed on a shotcrete surface with variable surface roughness between 3–7 mm and a waviness of 4:1, 7:1 and 15:1. With additional heating during the setting of concrete the temperature in the waterproofing system rose to 55 °C. After completion of the construction the drainage capability was determined. The concrete support shell was then removed and the waterproofing system exposed.

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Sikaplan® approved Systems

Schematic of the pressure vessel with test specimens vertically arranged in oxygen-enriched water.
Substrate Roughness/Evenness

To support the excavated space and if necessary also the tunnel front during the excavation of a new tunnel, shotcrete has to be used. In case of a double shell tunnel lining, incorporating a geomembrane, the final shotcrete layer shall be sprayed in a way that no re-profiling with additional shotcrete is necessary to be able to properly fix the geotextile and the membrane respectively. Arch ribs, wire mesh, lattice girder and shotcrete are used for primary support.

All initial shotcrete surfaces are prepared so as to achieve the smoothness and regularity required to preserve the membrane integrity. Additional shotcrete has to be used where required to smooth surface irregularities and meet the criteria below.

In the application field of tunnels, the problem has mainly involved the stiffness of the material and the difficulties of hand welding, particularly in wet and uncomfortable conditions or e.g. in niches, in cross sections, welding of watertops, welding of patches, etc. Arguably, the most important aspect of the waterproofing operation is the welding of the membranes, which has to be carried out very carefully to maintain the continuity of the waterproofing sheet; any failure in the welding will cause leakage in the tunnel, with fatal results if water under pressure is present. The flexibility of a material will be described with the section elasticity module $E_{1-2}$ according to DIN EN ISO 527.

### Requirement of membrane flexibility in connection with shotcrete evenness

<table>
<thead>
<tr>
<th>Evenness of shotcrete</th>
<th>$E_{1-5}$</th>
<th>$E_{1-10}$</th>
<th>$E_{1-15}$</th>
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</thead>
<tbody>
<tr>
<td>Section elasticity module $E_{1-2}$ according to DIN ISO 527</td>
<td>&lt; 20 N/mm²</td>
<td>&lt; 70 N/mm²</td>
<td>&lt; 100 N/mm²</td>
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### Roughness of shotcrete (recommendation according to NEAT/SIA 272)

<table>
<thead>
<tr>
<th>Definition</th>
<th>Requirement</th>
<th>Method of measurement</th>
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<tbody>
<tr>
<td>Roughness</td>
<td>Depth 4–16 mm</td>
<td>Sandfill as per ZTV-SIB measured at Ø 250 mm</td>
</tr>
<tr>
<td>Evenness</td>
<td>Small waves (R ≤ 200 mm)</td>
<td>Manual measurement of substrate at negative form</td>
</tr>
<tr>
<td></td>
<td>Large waves (R ≥ 200 mm)</td>
<td>Measurement of substrate with profilometer</td>
</tr>
</tbody>
</table>

**Waterproofing Sections, with the Membrane Installation on Shotcrete** *(initial lining)*

The surface of the shotcrete should be smooth and even. The shotcrete aggregate shall have a diameter of 4–8 mm. Minimum radius of any unevenness shall be not less than 20 cm. Loose and protruding stones must be removed. The shotcrete shall be cured for at least 24 hours. Steel elements, such as reinforcement bars, steel girders and the heads of rock bolts – as far as not used to hold inner lining structures – shall be covered with at least 5 cm of shotcrete. Running water ingress can be plugged with waterproof mortars (i.e. Sika®-4A admixture) mixed with brand new Portland cement, prior to the initial lining. Heavy water ingress can be collected into PVC half-pipes (i.e. FlexoDrain), mounted by nailing and led into the permanent drainage system. The mounted half-pipe should be covered with at least 5 cm of shotcrete prior to the initial lining installation.
Fixing Technique

The possibility to bridge joints, cracks, fissures and gravel pockets is the big advantage of loose laid (spot-fixed) plastic sealing membranes. Fixing discs (roundels) are installed on the shotcrete surface to provide adequate support and a close fit over the entire shotcrete surface. The waterproofing membrane is laid with the signal layer inside the tunnel and with sufficient slack to prevent overstressing during concreting. New fixing methods come up, e.g. the hook and loop fastener system and the hot-melt system, which allows an automatic installation.

Spotwise welding
- Shotcrete, >5 cm
- Geotextile / Drainage mat
- Fixing discs
- Hot air weld
- Waterproofing membrane Sikaplan

Spotwise hook and loop
- Shotcrete, >5 cm
- Geotextile / Drainage mat
- Fixing disc with hook and loop
- Hot air weld
- Waterproofing membrane Sikaplan fleece-backed

Stripwise adhesive-bonded (e.g. hot melt)
- Tubbing segment concrete (shotcrete)
- Adhesive bead (liquid adhesive)
- Waterproofing membrane Sikaplan fleece-backed

Welding Technique of Membranes

Sikaplan membranes are heat-welded using various methods. The main difference is between welding by hand and welding using an automatic welding machine. The welding method must be adapted to the site conditions and must be suited to the Sikaplan membrane type. Before the membrane is welded, a trial weld and peel test must be carried out. The trial weld serves to check the welder settings and adjust these to suit the site conditions if necessary.

Hand-Welding
- Sika seam surfaces to be welded must be clean and dry (cleaning / seam preparation).
- Adjoining sheets should overlap at least 80 mm.
- Proper hand welding involves three steps:
  1. Tack welding
     Hold the sheets in position.
  2. Pre-welding
     Continuous weld joins the sheets to form a heat pocket. The weld is placed along the back of the overlap, leaving 35 to 40 mm of free material to weld with a 40 mm wide welding nozzle (or 15 to 20 mm for a 20 mm nozzle).
  3. Final welding
     The final weld produces an airtight and watertight seam 10 to 30 mm wide (depending on nozzle width). A Sika pressure roller is applied at a distance of 30 mm in front of the nozzle and parallel to it. The travel of the roller should always extend beyond the welded seam.

Automatic Welding
- Heated wedge automatic welding machines are predominantly used on civil engineering projects.
- The machines are used to weld both the longitudinal and transverse seams.

Heat welding of Sika Waterbars onto the installed Sikaplan® membrane with heated blades
- Butt joints between Sika® Waterbars type A1A4 are made with hot copper blades whilst the waterbar's ends are fixed into special clamps.

Leister PID
- This heated wedge automatic welding machine is used in tunnels, below-ground structures, and hydraulic / water-retaining structures. For membranes 1.5 mm to 3 mm thick, dependent on the material.
- Double seams (widths: 15 mm each plus 10 mm air testing channel) only with automatic welding machines.
- Heat is transferred to the material to be welded by a temperature-controlled heated wedge, heated electrically or by hot air. The machines can be used over any substrate. The use of each machine is described in detail in the relevant user manual.
Seam Inspection after Welding

Testing with compressed Air
The double-wedge machines produce two welded seams at once. At both ends of the double seam the channel between the two welds to be tested is clamped shut and a manometer and needle is installed. A foot-pump or air compressor is then connected to the valve and the appropriate test pressure developed. (The pressure depends on the material and the temperature; see DVS 2225 Part 2 / Test pressure chart.)

The standard test parameters are as follows:
Test duration: 10 minutes; test pressure: 1.5–2 bars, depending on the temperature and membrane thickness. The seam is considered watertight if the initial pressure in the test channel drops by not more than 10% during the test period. The pressure values are recorded, specifically the initial pressure and the final pressure.

Visual Inspection of Seams
After welding, all seams should be visually inspected for good workmanship. Special attention should be paid to T-joints, penetrations, and flashings.

Mechanical Testing of Seams
All hand-welded seams should be mechanically tested once they have completely cooled. For this purpose use a screwdriver (about 5 mm wide, with blunted edges). Apply light pressure to the seam, and do not scratch the membrane. Mechanical testing is not a test for watertightness; it helps detect seams that are not fully welded.

Testing with Vacuum
Vacuum bell over seam area to be tested, build up vacuum with electric pump.

Testing of watertightness for the double-layer system, which is the only waterproofing system which can be tested during any of the construction phases.

Visual Inspection of Seams
After welding, all seams should be visually inspected for good workmanship. Special attention should be paid to T-joints, penetrations, and flashings.

Mechanical Testing of Seams
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Testing with Vacuum
Vacuum bell over seam area to be tested, build up vacuum with electric pump.

Vacuum bell over seam area to be tested, build up vacuum with electric pump.

Acceptance of each section
Visually inspect the waterproofing surface for damage or faults.
Make sure waterstops are clean and free of residue.
Ensure acceptance by construction supervising officer.

Checklist for Waterproofing

Acceptance of substrate
- Make sure the substrate is even, smooth and clean as specified.

Levelling and protective layer
- Are the type, weight, and quality correct?
- Are the lapped seams correct?
- Is the number of fixing points correct?

Sikaplan® membrane
- Are the type, thickness, and quality correct?
- Are lapped seams correct? Field cuts?
- Is the membrane laid without wrinkles?

Welding of the membrane
- Is the welding machine clean (heating wedges)?
- Are temperature, speed, and pressure correctly set?

Checking welds
- Check double-wedge seams with compressed air in accordance with the Installation Manual.
- Check finished hand-welded seams with a screwdriver as recommended.

Transition at invert / vault
- Cut the overlap correctly.
- Bevel edges at T-joints.
- Weld transverse seams with a welding machine.
- Test welded seams with compressed air.

Waterstops
- Check position of the waterstops.
- Check welds with a screwdriver.

Membrane Protective layer
- Are the type, thickness, and quality correct?
- Are welded seams and welds to the waterstops complete?

Acceptance of each section
- Visually inspect the waterproofing surface for damage or faults.
- Make sure waterstops are clean and free of residue.
- Ensure acceptance by construction supervising officer.
Quality

The success of a construction project is determined by the quality of every aspect. Thus quality assurance is especially important. That’s why we are focussed to deliver the following demonstrable characteristics:

Quality Assurance of the Product

- Sika is innovative, uses advanced raw materials, researches intensively, uses modern production methods, ensures the internal monitoring of processes and external monitoring of products. Yet that’s just the start of the long chain of processes a Sikaplan® membrane goes through to ultimately become a customer-tailor-made water-proofing system that protects a tunnel against water.

Material Quality

- Specified and cost-optimized Sika products and systems
- Certified Sika Systems according to NEAT-standard
- High quality and advanced raw material technology for PVC-P and FPO products
- Experienced material know how based on different application fields in tunnels, basements, roofing, pit and ponds, groundwater protection, tank sealing and swimming pools
- Complete material compatible-systems including design and accessories

Quality of the Installation

- Welded seams
  Flawless seams can be welded by hand and/or with automatic welding machines. Seam quality is tested and evaluated according to DVS 2225 Part 2.
- Checklist
  This tool is adapted to the specific conditions of each job. It is one part of quality management on the construction site and serves to reduce sources of errors.
- Field Test Report
  The Field Test Report helps ensure that all tests and inspections are carried out for each tunnel section. The report form also documents readiness for the subsequent concreting.

For more information on working with Sika membranes: The Sika Membrane Installation Manuals describe and illustrate each step of detail work. Sika Installation Manuals for Sikaplan PVC and for TPO membranes are available on request.

Inadequate workmanship or incorrect installation of membrane waterproofing could mean that the structure is not watertight, thus allowing future water ingress. Sika® trained professional contractors and QC on site are always recommended to prevent such defects.
Global Case Studies
Flexible Waterproofing of Tunnels with Sikaplan® Membranes

Project
- Road tunnel Bad Ems/ Germany, 1,600 m, 36,500 m³
- Thermal water up to 55°C incl. 4m corrosive carbonic acid, under pressure

Sika solution
- Waterstop System
- Full round sealing with a 3 mm flexible polyolefine membrane – Sikaplan® WT 1200-30 C – including contraction preventing with glass fleece
- Installation of flexible – membrane compatible – polyolefine waterstops including pre-fabricated cross-joints

Additional products:
- Sikaplan® W FELT PP ZTV 850
- Sikaplan® WT Protection sheet-30H
- Sikaplan® Waterstop MP AF 240/30 (4 anchors)
- Sikaplan® Waterstop MP AF 400/30 (6 anchors)
- Sikaplan® Waterstop MP DF 400/30 (6 anchors)
- Sikaplan® WT Disc grey PE

Products
- Sikaplan® WT 1200-30 C
- Sikaplan® WT 200-30 PE
- Sikaplan® Protection sheet-30H
- Sikaplan® Waterstop MP 6-STEM® AFI 600/35
- Sikaplan® Waterstop MP 6-STEM® AFI 850
- Sikaplan® Control socket 6 mm PE
- Sikaplan® Flexible PP protection pipe
- Sikaplan® WP-control tube
- Sikaplan® WT Disc grey PE

High flexible FPO membranes allow to weld difficult sections of tunnels without cutting.

Project
- Gotthard-Tunnel/ Switzerland, year 1910
- Protection of Electricity against water

Sika solution
- Drainage System
- Improvement of concrete structure with mortar sealing compound

Products
- Sika®-1 waterproofing adhesive for mortars

Project
- NBS-Köln-Rhein Main/ Germany
- 60 m waterpressure

Sika solution
- Active Control System with double membrane layer
  (3+2 mm) & vacuum control
- Using of high flexible FPO membranes (FPO), which allow to weld difficult sections of tunnels without cutting (e.g. cross sections) and therefore to reduce hand-welded seams and vacuum tests
- Installation of flexible – membrane compatible – polyolefine waterstops with integrated injection canals and external gouging hoses

Products
- Sikaplan® WT 2300-32 HL2
- Sikaplan® WT 2200-25 HLE
- Sikaplan® WT Protection sheet-30H
- Sarnafil® Waterstop MP 6-STEM® AFI 600/35
- Sikaplan® W FELT PP RIL 850
- Sikaplan® WT Control socket 6 mm PE
- Sikaplan® W Flexible PP protection pipe
- Sikaplan® WP-control tube
- Sikaplan® WT Disc grey PE

Project
- Ueltlibergtunnel- Birmisdomf/ Switzerland, 4200 m, 36,000 m³
- NATM/ TBM, shotcrete surface, waterhead 50 m (partly)

Sika solution
- Waterstop System with double layer membrane and Drainage System (full round seal)
- Using an innovative injection barrier/compartment system in the area of the horizontal construction joints
- At the interfaces between the different waterproofing drainage concepts (drained/undrained) it was necessary to install a tight sealing ring system “Dammring” between the rock and waterproofing membrane. This detail was solved with a Sikadur Combiflex System

Products
- Sikaplan® WT 1200-30 C – including contraction preventing with glass fleece
- Sikaplan® Waterstop MP 60-6 inject PECO
- Sikaplan® Waterstop AR 40-6 inject PECO
- Sikaplan® Waterstop AR 10-1 PECO
- Sikadur® Combiflex® 2502

Project
- Railway -Gotthard-Tunnel/ Switzerland, year 1910
- Protection of Electricity against water

Sika solution
- Drainage System
- Improvement of concrete structure with mortar sealing compound

Products
- Sika®-1 waterproofing adhesive for mortars
Global Case Studies
Flexible Waterproofing of Tunnels with Sikaplan® Membranes

Project
- Katzenberg tunnel / Germany, cross section, 90 mWS
- Main tunnel with pre-cast-concrete elements/ tubbings (TBM)

Sika Solution
- Waterstop System
  - Using of high flexible TPO membranes (FPO) to guarantee a close fit to the surface profile and to improve the workability/patch-work
  - Installation of flexible – membrane compatible – polyesterine waterstops with four integrated injection canals

Products
- Sikaplan® W FELT PP RL 850
- Sikaplan® WT 2200-32HL2
- Sikaplan® WT 2200-42HL2
- Sarnafil® Waterstop AF-600/34 MP Inject
- Sikaplan® WT Disc grey PE

Project
- Iselberg tunnel / Switzerland
- Full automatically installation with hot-melt on pre-cast concrete elements/ tubbings

Sika Solution
- Drainage System
  - Using a PVC-P-fleece backed (500 g/m², PP) waterproofing membrane
  - To avoid critical peeling process between membrane and fleece caused by water and weight, the lamination between both has to be more than 80 % of the surface
  - Fire behaviour of the membrane 5.1 acc. to SIA V 280, self-extinguishing, caused by high continuously membrane installation without final concrete lining

Products
- Sikaplan® WP 2110-20 HL Felt 500
- Sikaplan® WP 2160-20 HL Felt 500

Project
- Road tunnel N 20.1.4- Birmensdorf-Helfenberg / Switzerland, 130,000 m²
- pressure water

Sika Solution
- Waterstop System
  - Using a PVC-Anchor to fix the reinforcement of inner lining to the outer shell without losing the watertightness in case of membrane penetration

Products
- Sikaplan® WP 2110-30HL
- Sikaplan® WP Protection sheet-40HE
- Sikaplan® WP Anchor 16/200
- Sikaplan® WP Disc 80*10mm yellow

Sarnafil® Waterstop AF-600/34 MP Inject
- Sikaplan® WT Disc grey PE

Project
- AxTransit/NEAT-Gotthard-section Bodio/ Switzerland, year 2007, 16.5 km, 1.8 Mio m²

Sika Solution
- Drainage System
  - Full automatically installation with hook and loop fixing discs
  - Spot-wise fixing technology in combination with a fleece backed PVC-P membrane (200 g/m², PP)
  - Guarantee of a close fit to the shotcrete surface (machined) and therefore improvement of the system quality
  - Waterproofing membrane according to NEAT-Ap Transit requirements

Products
- Sikaplan®-14.6 Neat F 200 Klett (System 216)
Global Case Studies

Sika Experience in Waterproofing for nearly 100 Years

As early as 1920, when the electrification of the railways began, the importance of tunnel waterproofing was recognized. Nowadays, the waterproofing of underground traffic structures is required as a matter of course by specialists. With its quick-setting mortar, Sika not only provided the first lead in the tunnel waterproofing epoch, but was consequently involved most influentially to the present day in the development of new technologies, as the following brief history shows.

1910 Gotthard railway tunnel (CH), waterproofing with pointing mortar Sika®-4, surface waterproofing with Sika®-1
1930 Paris metro, Chaillert-station (F), waterproofing with Sika® mortars
1940 Oberhasli power station (CH), preliminary waterproofing with Sika®-4a
1950 Walensee road, Kernenzer tunnel (CH), isolation of interior tunnel vault with Sika® bitumen felts
1960 Lötschberg base tunnel (CH), waterproofing with Sika® mortars
1968 NBS Köln-Rhein/Main (D), tunnel waterproofing with pointing mortar Sika®-4, Active Control system with Sikaplan® (Sarnafil) FPO
1972 Schönibuchtunnel (D), Herrenberg, waterproofing with Sikaplan® (Sarnafil) mod. TP0 membranes, double welding seam with test canal
1978 Belmont tunnel (CH), waterproofing with Sikaplan® PVC-P tunnel membranes, spot-fastened by the "suspender method"
1980 Metro São Paulo (BR), waterproofing with PVC-P membrane according to SIA V 280 standard
1984 Gubrist tunnel (CH), fully glued Sikaplan® PVC-P, with signal layer and fleece backing
1984 Tunnel Grauff (LUX), waterproofing with PVC-P, fire resistance of 5.1 according to SIA V 280
1990 Katzenberg tunnel (D), 90 m WS, cross section, Sikaplan® (Sarnafil) FPO membranes
1995 Förnsbergtunnel (D), 1st Active Control System with a PVC-P membrane
1999 Tunnel Pianzetta Sierra, A9 (CH), waterproofing with Sikaplan® FPO membrane
2004 Airport Terminal San Gottardo, spot-wise fixing based on Sika® hook and loop technology, Sikaplan® PVC-P Neat fleece-backed and Sikaplan® (Sarnafil) FPO Neat

NBS Köln-Rhein/Main (D), tunnel under water pressure (60 m WS), Active Control system with Sikaplan® (Sarnafil) FPO

Lötschberg base tunnel (CH), waterproofing with Sikaplan® PVC-P

2006 Metro São Paulo (BR), waterproofing with PVC-P membrane according to SIA V 280 standard

Holland Tunnel (S), 120 m WS, cross section, Sikaplan® (Sarnafil) FPO membranes

Ilsbottelunnel (CH), adhesive fixing technology with fully automatic installation, Sikaplan® PVC-P fleece-backed on tubbings

2007 Tunnel Grouft (LUX), waterproofing with PVC-P, fire resistance of 5.1 according to SIA V 280

2007 Katzenberg tunnel (D), 90 m WS, cross section, Sikaplan® (Sarnafil) FPO and new generation of Sika stops

Tunnel chain Perschling and tunnel Wienerwald (AT), adhesive fixing technology with fully automatic installation, Sikaplan® PVC-P fleece-backed on tubbings

1968/69 Viamala, Roflatunnel (CH), preliminary surface waterproofing by machine with SikaShot® (ready-mix concrete/ sprayable membrane).
1971 Furka railway tunnel (CH), preliminary surface waterproofing by machine with SikaShot® (ready-mix concrete/ sprayable membrane).
1972 Gotthard road tunnel (CH), application of frost-resistant concrete with the admixture Plastocrete®
1976 Schönibuchtunnel (D), Herrenberg, water pressure resistant sealing with Sikaplan® (Sarnafil) mod. TP0 membrane, double welding seam with test canal
1978 Belmont tunnel (CH), waterproofing with Sikaplan® PVC-P tunnel membranes, spot-fastened by the "suspender method"
1980 Metro São Paulo (BR), waterproofing with PVC-P membrane according to SIA V 280 standard
1984 Gubrist tunnel (CH), fully glued Sikaplan® PVC-P, with signal layer and fleece backing
1984 Tunnel Grauff (LUX), waterproofing with PVC-P, fire resistance of 5.1 according to SIA V 280
1990 Katzenberg tunnel (D), 90 m WS, cross section, Sikaplan® (Sarnafil) FPO membranes and new generation of Sika stops

Tunnel chain Perschling and tunnel Wienerwald (AT), adhesive fixing technology with fully automatic installation, Sikaplan® PVC-P fleece-backed on tubbings

1995 Förnsbergtunnel (D), 1st Active Control System with a PVC-P membrane

Önsbergtunnel (CH), adhesive fixing technology with fully automatic installation, Sikaplan® PECO fleece-backed, on tubbings

1999 Tunnel Pianzetta Sierra, A9 (CH), waterproofing with Sikaplan® FPO membrane

2004 Airport Terminal San Gottardo, spot-wise fixing based on Sika® hook and loop technology, Sikaplan® PVC-P Neat fleece-backed and Sikaplan® (Sarnafil) FPO Neat

NBS Köln-Rhein/Main (D), tunnel under water pressure (60 m WS), Active Control system with Sikaplan® (Sarnafil) FPO

Lötschberg base tunnel (CH), waterproofing with Sikaplan® PVC-P

2006 Metro São Paulo (BR), waterproofing with PVC-P membrane according to SIA V 280 standard

Holland Tunnel (S), 120 m WS, cross section, Sikaplan® (Sarnafil) FPO membranes

Ilsbottelunnel (CH), adhesive fixing technology with fully automatic installation, Sikaplan® PVC-P fleece-backed on tubbings

2007 Tunnel Grouft (LUX), waterproofing with PVC-P, fire resistance of 5.1 according to SIA V 280

2007 Katzenberg tunnel (D), 90 m WS, cross section, Sikaplan® (Sarnafil) FPO and new generation of Sika stops

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1978 Belmont tunnel (CH), waterproofing with Sikaplan® PVC-P tunnel membranes, spot-fastened by the "suspender method"
1978 Ventilation shaft for Gotthard road tunnel (CH), waterproofing with Sikaplan® PVC-P tunnel membrane, in hardly combustible version and with incorporate signal layer
1984 Gubrist tunnel (CH), fully glued Sikaplan® PVC-P, with signal layer and fleece backing
1984 Tunnel Grauff (LUX), waterproofing with PVC-P, fire resistance of 5.1 according to SIA V 280

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1984 Gubrist tunnel (CH), fully glued Sikaplan® PVC-P, with signal layer and fleece backing
Sika’s Competence in Tunneling

- Rock stabilization with Sika® Injection resins
- Sprayed concrete SikaCem®-Gunite®
- Tubbing/Pre-cast-concrete elements Sika® ViscoCrete® SCC
  Concrete admixture technology
- Wall protection Sikagard®-Wallcoat
- Flexible waterproofing Sikaplan® membrane
- Tubbing/Pre-cast-concrete elements

Specialities
- SikaGrout® mortars
- Sikadur® epoxy adhesives

Joint sealing, crack sealing
- Sikadur®-Combiflex® System
- Sika® Waterbar
- Sikaplan® WP drainage angle
Sika® Injection Technology for Waterproofing Construction Joints or Remedial Works

Solutions for Leaks and Construction Damage

Concrete Damage
Damage can occur to the concrete in many ways but primarily through difficulties in interpreting design aspects, inadequate or untimely compaction, or by accident. Sika produces a full range of concrete repair systems, which are compatible with all Sika waterproofing systems.

Cracks/Honeycombing
The terms “watertight” and “vapour-tight” do not mean “crack-free”. Cracking can always occur in concrete in its plastic or in its hardened state, due to the stresses imposed. These include the internal forces caused by temperature and water content changes. Sika has a complete range of products and systems for the repair of “cracks” and “honeycombing” in water-tight concrete structures.

Waterproofing of damaged Membranes
Repair by injection of damaged waterproofing membranes (single and double layer systems)

Sika® Injection-305
Flexible, very low viscous and quick-setting polyacrylate injection gel for permanent watertight sealing of damaged membranes (single and double layer systems). The material reacts to form a waterproof, flexible but solid gel with good adhesion to both dry and wet substrates.

Compartmentalization Waterbars
To ensure watertight embedding of the anchors, the waterstop system uses injectable cement suspensions. Potential air pockets or minor imperfections in the concrete can be injected with this system, but it is not possible to use the system to fill large voids left by inadequate or incomplete concreting.

Sika® Injection-201
Low-viscous, flexible and solvent-free polyurethane injection resin for permanent waterproof sealing of voids and non-moving cracks in the structure.

Using Curing Agents
Sika® Curing Agents are used as Connection Pieces between the Injection Pump and the Structure. Sika® provides a full Range of Packers for different Applications.

Mechanical Packers
Type MPS
Type MPR
Type MPC
Type SP

Surface Sealing and Waterproofing of Concrete Structures
Remedial surface sealing by curtain injection of surface defects in below ground concrete structures:

Sika® Injection-204
Flexible, very low viscous and very quick-setting polyacrylate injection gel for permanent watertight sealing. The material reacts to form a waterproof, flexible but solid gel with good adhesion to both dry and wet substrates.

Sealing and Waterproofing of Cracks
Closing, sealing and flexible bridging of leaking cracks and honeycombing or voids in new and existing structures:

Sika® Injection-101
Fast-foaming, low-viscous polyurethane injection foam for temporary water-stopping

Sika® Injection-201
Low-viscous, flexible polyurethane injection resin for permanent waterproof sealing

Sika® InjectableCem-190
Two-component injection grout based on microfine cement

Waterproofing of Construction Joints
For sealing construction joints in a watertight structure, Sika provides a full range of products and systems:

Sika® Injection-29
Low-viscous, flexible polyacrylate injection resin with a high solids content

Sika® Injection-201
Low-viscous, flexible polyurethane injection resin for permanent watertight sealing even in wet conditions

Sika® InjectableCem-190
Two-component injection grout based on microfine cement for waterproof sealing of voids and non-moving cracks in the structure

Sika® Injection Pumps and Packers

Single-component Pumps for Polyurethane, Epoxy and Polyacrylate Resins
Sika® single-component injection pumps are universal injection devices suitable for a wide range of applications. They are designed for professional use in crack injection and for the Sika Injectoflex System. The Sika® Injection Pump EL-1, EL-2, Hand-1 and Hand-2 are suitable for Sika polyurethane, epoxy and polyacrylate injection resins.

Mixing and Pumping Equipment for Microfine Cement Suspension
The colloidal mixer Sika® Injection Mixer C-1 is designed for the complete and thorough mixing of Sika® microfine cement suspensions. Sika® Injection Pump MFC-1 is used for the pumping of Sika® microfine cement suspensions. It provides continuous pumping without separation of the suspension.

Compartmental Waterbars
Sika® Injection Packers are used as Connection Pieces between the Injection Pump and the Structure. Sika® provides a full Range of Packers for different Applications.

Mechanical Packers
Type MPS
Type MPR
Type MPC
Type SP

Surface Packers
for low pressure injection, where drilling is not possible

Sika® Injection Pump PN-2C is specially designed for curtain injection. A two-component pump is required for these fast-reacting polyacrylate gels. The individual resin components are introduced to the mixing head separately. The actual mixing process takes place in a static mixer located in the mixing head.
Flexible Waterproofing of Tunnels with Sikaplan® Membranes

Sika is a globally active company in the speciality and construction chemicals business. It has subsidiary manufacturing, sales and technical support facilities in over 70 countries around the world. Sika is THE global market and technology leader in waterproofing, sealing, bonding, dampening, strengthening and the protection of buildings and civil engineering structures. Sika has approx. 12'000 employees worldwide and is therefore ideally positioned to support the success of its customers.

Also available from Sika

Our most current General Sales Conditions shall apply. Please consult the Product Data Sheet prior to any use and processing.

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