Flexible Waterproofing of Tunnels with Sikaplan Membranes
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Road Tunnels
Rail Tunnels
Metro Tunnels
Water Tunnels

**Islisberg/Switzerland**
TBM construction with Sikaplan® WP 2110-20HL and fixing with hot-meld

**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 AFI 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 moist parts and single dropping parts on the dry part of the tunnel surface permitted.

Class 4
- Moist to wet
- Moist parts and dropping parts permitted.

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.

Waterproofing

Drainage Concept

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Sikaplan® WP Drainage angle

Loose- Flange construction in case of water pressure

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 groundwater 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.

During the Construction

Aggressive water
Sulphate water
Chloride water
Soft water with low calcium content
Soluble components + O₂ caused clogging + sintering process of the drainage pipe.
High water flushing
Dynamic forces
Upheaving forces
Geostatistical forces
Settlements
Hydraulic pressure

After the Construction

Aggressive water
Sulphate water
Chloride water
Soft water with low calcium content
Soluble components + O₂ caused clogging + sintering process of the drainage pipe.
High water flushing
Dynamic forces
Upheaving forces
Geostatistical forces
Settlements
Hydraulic pressure

Puncture load
Reinforcement
(Portals/Entrance)
Area load
Concrete/traffic/bulk-head
Water
Puncture load
Substrate
Puncture load
Faulty inner concrete areas

Water

Fire
Systems for Waterproofing

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

<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 (no pressure allowed)</td>
<td>Umbrella</td>
<td>Waterproofing membrane 3 mm</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

Systems for waterproofing structures built with tunnelling techniques, exposed to hydrostatic pressure and ground water that is chemically aggressive to concrete.

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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

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)

### Holding the Head of Water (un-drained)
Water displacement (pressurized water)

<table>
<thead>
<tr>
<th>1. Drainage System</th>
<th>2. Waterstop System</th>
<th>3. Active Control System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose laid, with lateral drainage, without compartments</td>
<td>Loose laid, with compartments made of waterbars</td>
<td>Loose laid, with two membrane layers installed in watertight sectors</td>
</tr>
<tr>
<td>- For waterproofing against ground water, humidity and percolating water</td>
<td>- For waterproofing against water under hydrostatic pressure</td>
<td>- High security of watertightness by vacuum control</td>
</tr>
<tr>
<td>- Requires drainage pipes on the bottom to prevent build up of water pressure</td>
<td>- Compartments injectable in case of leaks in the waterproofing membranes</td>
<td>- Compartments injectable in case of leaks in the waterproofing membranes</td>
</tr>
</tbody>
</table>

### Drained
Evacuation of water (seepage water)

### Holding the Head of Water (un-drained)
Water displacement (pressurized water)

<table>
<thead>
<tr>
<th>Suitable products</th>
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<th>Suitable products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sika® FlexoDrain</td>
<td>Sika® FlexoDrain</td>
<td>Sika® FlexoDrain</td>
</tr>
<tr>
<td>Sikan® WT Tundrain PE</td>
<td>Sikan® W Felt 500 g/m²</td>
<td>Sikan® W Felt 500 g/m²</td>
</tr>
<tr>
<td>Sikan® W 1000</td>
<td>Sikan® W 1000</td>
<td>Sikan® W 1000</td>
</tr>
<tr>
<td>Sikan® W 1010</td>
<td>Sikan® W 1010</td>
<td>Sikan® W 1010</td>
</tr>
<tr>
<td>Sikan® W 2110</td>
<td>Sikan® W 2110</td>
<td>Sikan® W 2110</td>
</tr>
<tr>
<td>Sikan® W 2160</td>
<td>Sikan® W 2160</td>
<td>Sikan® W 2160</td>
</tr>
<tr>
<td>Sikan® W 2200</td>
<td>Sikan® W 2200</td>
<td>Sikan® W 2200</td>
</tr>
<tr>
<td>Sikan® W 50/6 MP Fleeceback</td>
<td>Sikan® W 50/6 MP Fleeceback</td>
<td>Sikan® W 50/6 MP Fleeceback</td>
</tr>
<tr>
<td>Sikan® W Protection sheet</td>
<td>Sikan® W Protection sheet</td>
<td>Sikan® W Protection sheet</td>
</tr>
<tr>
<td>Sikan® Waterbar:</td>
<td>Sikan® Waterbar:</td>
<td>Sikan® Waterbar:</td>
</tr>
<tr>
<td>WT AF-40/6 MP</td>
<td>WP AR-40/6 PVC Inject</td>
<td>WT AF-40/6 MP</td>
</tr>
<tr>
<td>WP AR-50/6 MP</td>
<td>WP AR-50/6 PVC Inject</td>
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<tr>
<td>WT AF-60/6 MP</td>
<td>WT AF-60/6 MP</td>
<td>WT AF-60/6 MP</td>
</tr>
<tr>
<td>Sika® Dilar®</td>
<td>Sika® Dilar®</td>
<td>Sika® Dilar®</td>
</tr>
<tr>
<td>Type E/ER sealing strips</td>
<td>Type E/ER sealing strips</td>
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</tr>
<tr>
<td>Sika®-Combiflex® sealing system</td>
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</tr>
</tbody>
</table>

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

1:5

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

1:10
Flexible Waterproofing with Sikaplan® Membrane Systems

Drill-and-blast Excavation with Drainage

1. Drainage pipe with gravel package
2. Invert drainage with gravel
3. Sikaplan® FlexoDrain for preliminary waterproofing
4. Geotextile or drainage mats for draining and levelling out
5. Polymer waterproofing membranes Sikaplan®
6. Manholes for inspection and cleaning
7. Separation layer

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

TBM driving with Drainage

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

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

- Mountain water flows without head of pressure into the drainage
- No accumulation of water
- Loose-Flange construction
Flexible Waterproofing with Sikaplan® Membrane Systems

Drill-and-blast / TBM Excavation

1. Sika® FlexoDrain 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. Injection barrier/compartment
9. Drainage during construction
10. Groundwater relief socket

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

- Construction phase drainage, possibly with groundwater relief drains filled by cement grout after structural completion
- Polymer waterproofing membrane Sikaplan® with geotextile
- Waterproofing membranes Sikaplan® with knops-embossed surface (knops height: 0.3 mm, knops area: < 30% of membrane surface)
- Polymer waterproofing membrane Sikaplan®, protective membranes in invert, shuttering and reinforcement steel zones
- Segmental weld of double layer membranes
- Connection point for vacuum test and injection
- Groundwater relief drain
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
- Leveling layer/Geotextile
- Leveling 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®
- Leveling layer/Geotextile
- Sikaplan® membrane
- Sikaplan® protection sheet
- Leveling grout
- Steel sheet piling
- Partitioning with Sikaplan® waterbars, injectable
- Protective concrete layer
- Substrate
- Excavated surface
- Leveling 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.

<table>
<thead>
<tr>
<th>Drainage of water, not holding a head of water</th>
<th>Displacement of water, holding the head of water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drainage system</strong></td>
<td><strong>Waterstop system</strong></td>
</tr>
<tr>
<td>Single-layer polymer waterproofing membrane with geotextile or drainage mats or open tubbing segment joints</td>
<td>Single-layer polymer waterproofing membrane with partitioning</td>
</tr>
<tr>
<td><strong>Evacuation of leak-water system</strong></td>
<td><strong>Active control system</strong></td>
</tr>
<tr>
<td>Double-layer polymer waterproofing membrane with knobs or with an intermediate drainage layer and partitioning</td>
<td>Double-layer polymer waterproofing membrane with injection space and partitioning with compartments; ability to actively test the waterproofing seal</td>
</tr>
</tbody>
</table>

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**Rigid Waterproofing**

**Waterproof Concrete and Joint Sealing**

- Sika® ViscoCrete® SCC technology and Sika®-1 capillary pore blocking technology
- Sika® Waterbars, Sika® Injectoflex, SikaSwell®, Sikadur®-Combiflex®, 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.
  - Clean masonry lining and joints
  - Sikacrete®-Gunit® 113 for joint sealing and preliminary masonry waterproofing
  - SikaCem®-Gunit® 143 for the main thin-shell waterproofing lining

- **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.
  - Shotcrete application for immediate support upon excavation
  - Waterproofing shell with SikaCem®-Gunit® 143
Raw Material

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 thermoplastics elastomers (polyolefine elastomers/TPO) for permanent waterproofing.

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
- Self extinguishing (approx. 21 MJ/kg)
- High resistance to mechanical impact in relation to flexibility
- Thermal extension
- Ageing through plasticiser loss
- Affected by cold (depending on the plasticiser)

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

### Table: Properties of Tunnel Sealing Materials

<table>
<thead>
<tr>
<th>Material Base</th>
<th>Signal Layer</th>
<th>Roll Width (m)</th>
<th>Special Standards</th>
<th>Fire Resistance Class</th>
<th>Section Elasticity Module E1-2-Modul</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC-P</td>
<td>Yes (yellow)</td>
<td>2.00</td>
<td>EN 13967/13968</td>
<td>EN 11025</td>
<td>&lt; 20 N/mm²</td>
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### Ancillary Products

#### Sika® Waterbar, PVC and FPO based types
- Sika® Waterbar type AR (PVC)
- Sika® Waterbar type DR (PVC)
- Sika® Waterstop type MP AF (FPO)
- Sika® Waterstop type MP OF (FPO)

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

#### Sikaplan® WP/WT protection sheets
- Sikaplan® WP Protection sheet (PVC)
- Sikaplan® WP Protection sheet HE (PVC)
- Sikaplan® WT Protection sheet (TPO)
- Sikaplan® WT Protection sheet HE (TPO)

#### Sika®-Combiflex® joint sealing system
- Sika®-Combiflex tape
- Sika®-31 (EP adhesive)

For compartments and terminations with FPO membranes

#### Sika® Dilatec®, type E / ER joint sealing strips
- Sika® Dilatec E-220 for expansion joints
- Sika® Dilatec ER-350 for waterproofing terminations
- Sika®-31 (EP adhesive)

For compartments and terminations with FPO membranes

#### Sika® Control and injection flange
- Sika®-31 (EP adhesive)

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

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).

Sekaplan® approved Systems

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, Sarnafil MP 916 Neat and a PE drainage inclusive studs.

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 developed 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 achieve such a close fit to the shotcrete profile, the floss committee set strict requirements concerning the quantity and location of fixing points, the jointing procedure and the friction between waterproofing membrane and drainage material.

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

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### 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.

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

<table>
<thead>
<tr>
<th>Evenness of shotcrete</th>
<th>Section elasticity module $E_{1-2}$, according to DIN ISO 527 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq 1:5$</td>
<td>$&lt; 20 \text{ N/mm}^2$</td>
</tr>
<tr>
<td>$\geq 1:10$</td>
<td>$&lt; 70 \text{ N/mm}^2$</td>
</tr>
<tr>
<td>$\geq 1:15$</td>
<td>$&lt; 100 \text{ N/mm}^2$</td>
</tr>
</tbody>
</table>

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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>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>Depth</td>
<td>Sandfill as per ZTV-SIB measured at Ø 250 mm</td>
</tr>
<tr>
<td>Evenness</td>
<td>Small waves $R \leq 200$ mm</td>
<td>Manual measurement of substrate at negative form</td>
</tr>
<tr>
<td></td>
<td>$R_u$, Radius (mm)</td>
<td>Min. value $B_u$ at $B = 1$ = 10 : 1</td>
</tr>
<tr>
<td></td>
<td>$B_u$, $B$, Ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large Waves $R \geq 200$ mm</td>
<td>Measurement of substrate with profilometer</td>
</tr>
<tr>
<td></td>
<td>$R_u$, Radius (mm)</td>
<td>Min. value $B_u$ at $B = 1$ = 10 : 1</td>
</tr>
<tr>
<td></td>
<td>$B_u$, $B$, Ratio (GW)</td>
<td></td>
</tr>
</tbody>
</table>
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.

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
- Sikaplan seam surfaces to be welded must be clean and dry (cleaning / seam preparations).
- Adjoining sheets should overlap at least 80 mm.

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.

Leister PID
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.

Heat welding of Sika Waterbars onto the installed Sikaplan® membrane with heated blades

Butt joints between Sika Waterbars type AR/AF are made with hot copper blades whilst the waterbar’s ends are fixed into special clamps.
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.)

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.

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.

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.

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.

Testing of watertightness for the double-layer system, which is the only waterproofing system which can be tested during any of the construction phases.
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. – These are the principles we follow as we provide our customers with high-quality 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 waterproofing 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.

**Quality in terms of substantially meeting the expectations of customers**

- Professional competence in line with current knowledge and technology
- Punctual delivery of goods and services
- Effective problem-solving with verifiable actions

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  
N4.1.5 Ueltliberg tunnel - Birsmdorf/ Switzerland, 4200 m, 360 000 m

Sika solution  
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® 30 PECO
Sikaplan® Waterstop AR 60-6 inject PECO
Sikaplan® Waterstop AR 40-6 inject PECO
Sikaplan® Waterstop AR-10/1 PECO
Sikadur® Combiflex® 2502

Project  
Gotthard-Tunnel/ Switzerland, year 1910

Protection of Electricity against water

Sika solution  
Drainage System

Improvement of concrete structure with mortar sealing compound

Sika solution  
Waterproofing adhesive for mortars

Project  
NBS-Köln-Rhein Main/ Germany

60 m water pressure

Sika solution  
Active Control System with double membrane layer (3+2 mm) & vacuum control

Using of high flexible TPO 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 gouing hoses

Products  
Sikaplan® WT 2200-32 NL2
Sikaplan® WT 2220-25 HLE
Sikaplan® WT Protection sheet-30H
Sarnafil® Waterstop MP 6-STEIGIG AFI 600/35
Sikaplan® W FELT PP RL 850
Sikaplan® WT Control socket 6 mm PE
Sikaplan® W Flexible PP protection pipe
Sikaplan® W Pli-control tube
Sikaplan® WT Disc grey PE

Project  
Road tunnel Bad Ems/ Germany, 1.600 m, 36 500 m

Thermal water up to 55°C incl. lime corrosive carbonic acid, under pressure

Sika solution  
Waterstop System

Full round sealing with a 3 mm flexible polyethylene membrane – Sikaplan® WT 1200-30 G – including contraction preventing with glass fleece

Installation of flexible – membrane compatible – polyethylene waterstops including pre-fabricated cross-joints

Additional products:
Sikaplan® W FELT PP ZTV 950
Sikaplan® WT Protection sheet-30H
Sika® Waterstop MP AF 340/30 (4 anchors)
Sika® Waterstop MP AF 400/30 (6 anchors)
Sika® Waterstop MP DF 400/30 (6 anchors)
Sikaplan® WT Disc grey PE

High flexible TPO membranes allow to weld difficult sections of tunnels without cutting.
Global Case Studies
Flexible Waterproofing of Tunnels with Sikaplan® Membranes

Project
- Katzensberg Tunnel / Germany, cross section, 90 m/WS
- Main tunnel with pre-cast-concrete elements/ tubbings (TBM)

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

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

Project
- Islisberg 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 S.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
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 Sikakote®, surface waterproofing with Sika®-1

1930 Paris metro, Chalfer station (F), waterproofing with Sika® mortars

1940 Oberhauser power station (CH), preliminary waterproofing with Sika®-4a

1950 Walensee road, Kreuzer tunnel (CH), isolation of interior tunnel vault with Sika® bitumen felts

1960 Leib tunnel, Carinthia (A), tunnel waterproofing with Sika® Colmanay polyester coating

1960 Felber-Tauern tunnel (A), preliminary waterproofing with Sika®-4a and application of shotcrete layer with Sigunit® and Sikalite®

1968 Belchentunnel, highway (CH), installation of 1 mm thick PVC-P water-proofing membrane fastened spot-wise with pres-studs

1968/69 Bärenburger tunnel (A13/CH), waterproofing membrane (Sarnafil) with hot-melt technology

1968 Arstertunnel (A2/CH), PVC-P membrane made at Dübinger (CH)

1969 Viamala, Rolitunnel (CH), waterproofing with Sikaplan® bitumen membranes, fully glued to inner concrete ring with hot-seal adhesive

1971 Furka railway tunnel (CH), preliminary surface waterproofing by machine with Sikadur® hot (ready-mix concrete/ sprayable membrane)

1972 Gotthard road tunnel (CH), application of frost-resistant concrete with the admixture Plastocrete®

1976 Schönbuchtunnel (D), Herrenberg, water-pressure resistant sealing with Sikaplan® (Sarnafil) mod. TPO membranes, double welding seam with test canal

1977 Seelisbergunnel (CH), use of setting accelerator Sigunit® and waterproofing by the Bituflex-Sika Norm Hyytalan

1978 Belmont tunnel (CH), waterproofing with Sikaplan® PVC-P tunnel membranes, spot-fastened by the “suspendeur 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

1986/87 Tranchée couverte de Sévaz, A1 (CH), waterproofing with Sikaplan® PVC-P membrane fully glued

1990 Tunnel Planzetta Sierre, A9 (CH), waterproofing with Sikaplan® FPO membrane

1995 Gersbachunnel (D), first Active Control System with a PVC-P membrane

1996 Girsberg tunnel AT Krenzlingen (CH), PVC-P waterproofing against pressurized water (25 m WS) with spot-wise fixing based on Sika hook and loop technology

1997 Umbertunnel (CH), adhesive fixing technology with fully automatic installation, Sikaplan® FEDO fleece-backed, on tubbings NBS Köln-Rhein/Main (D), tunnel under water pressure (60 m WS), Active Control System with Sikaplan® (Sarnafil) FPO

1998 Lütschberg base tunnel (CH), waterproofing with Sikaplan® PVC-P

2000 Metro São Paulo (BR), waterproofing with PVC-P membrane according to SIA V 280 standard

2001 Halländska Tunnel (S), 120 m WS, cross section, Sikaplan® (Sarnafil) FPO membranes

2003 Isdubertunnel (CH), adhesive fixing technology with fully automatic installation, Sikaplan® PVC-P fleece-backed on tubbings

2007 Tunnel Gornif (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 stoppers

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

2008 Alptransit/ Tunnel San Gottardo, spot-wise fixing based on Sika® hook and loop technology, Sikaplan® PVC-P Next fleece-backed and Sikaplan® (Sarnafil) FPO Next
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
Specialties Sikagard® 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 polyacrylic 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 waterstops. 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.

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

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

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

Sika® Injection-200
Low-viscous, flexible polyurethane injection resin for permanent watertight sealing even in wet conditions

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

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

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

Sika® Injection-101
Low-viscous, flexible polyurethane injection resin for permanent waterproof sealing

Sika® InjectoCem-129
Two-component injection grout based on microfine cement for permanent waterproof sealing of cracks and non-moving cracks in the structure.

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.

Sika® Injection-205
Flexible, very low viscous and quick-setting polyacrylate injection gel for permanent waterproof 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.

Sika® Injection-305
Flexible, very low viscous and quick-setting polyacrylate injection gel for permanent waterproof 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.

Sika® Injection Pumps and Packers

Sika® Injection Pumps

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. Sika® Injection Pump EL-1, EL-2, Hand-1 and Hand-2 are suitable for Sika polyurethane, epoxy and polyacrylate injection resins.

Two-component Pumps for Polyacrylate Gels
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.

Mixing and Pumping Equipment for Microfine Cement Suspension
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.

Mechanical Packers
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.

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

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