11-18-2019

Sika Waterproofing Solutions for Tunnels (Traditional Excavation)

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Shotcrete for Underground Structures SUS XIV
17—20 November 2019, Nong Nooch Garden / Thailand

SIKA WATERPROOFING SOLUTIONS FOR TUNNELS (TRADITIONAL EXCAVATION)

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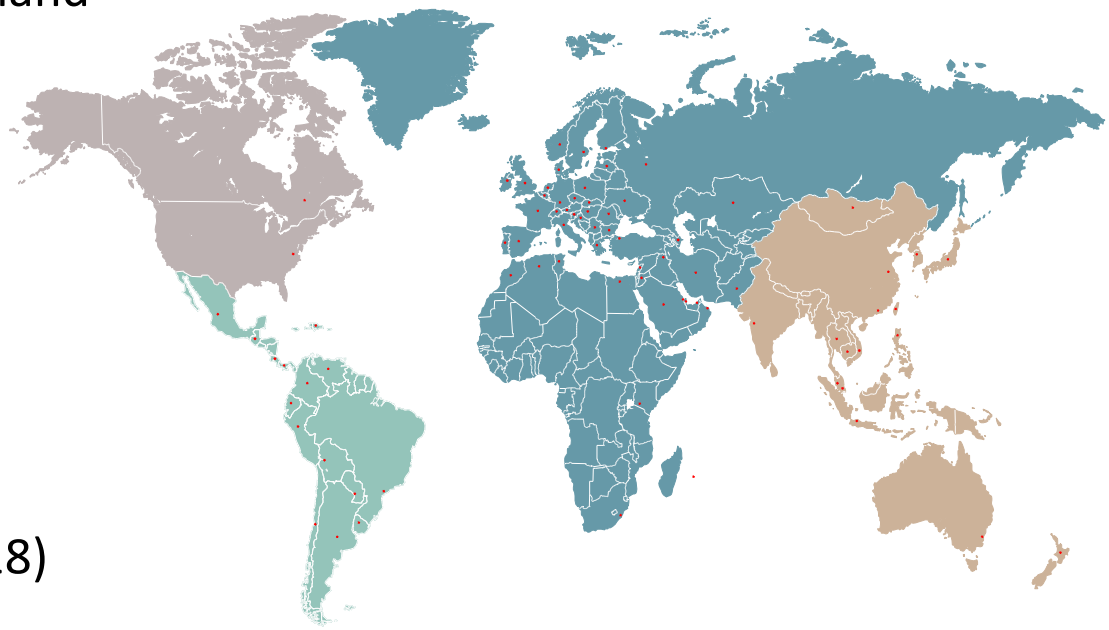
SIKA GROUP – BRIEF INTRODUCTION

SIKA GROUP, SWITZERLAND - WORLDWIDE MARKET PRESENCE

- Headquarter in Baar, Switzerland
- Founded in 1910
- 20,060 employees
- Subsidiaries in 101 countries (Honduras => 101st)
- Over 200 factories
- 20,600 employees

- Sales of CHF 7.09 billion (2018)



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SIKA GROUP – BRIEF INTRODUCTION

SIKA FOCUSES ON 7 TARGET MARKETS

OUR CORE COMPETENCIES
BONDING, SEALING, DAMPING, REINFORCING AND PROTECTING


Concrete


Waterproofing


Roofing


Flooring & Coating


Sealing & Bonding

Refurbishment


Industry

SIKA COMPETENCE IN TUNNELLING

VARIOUS APPLICATION POSSIBILITIES

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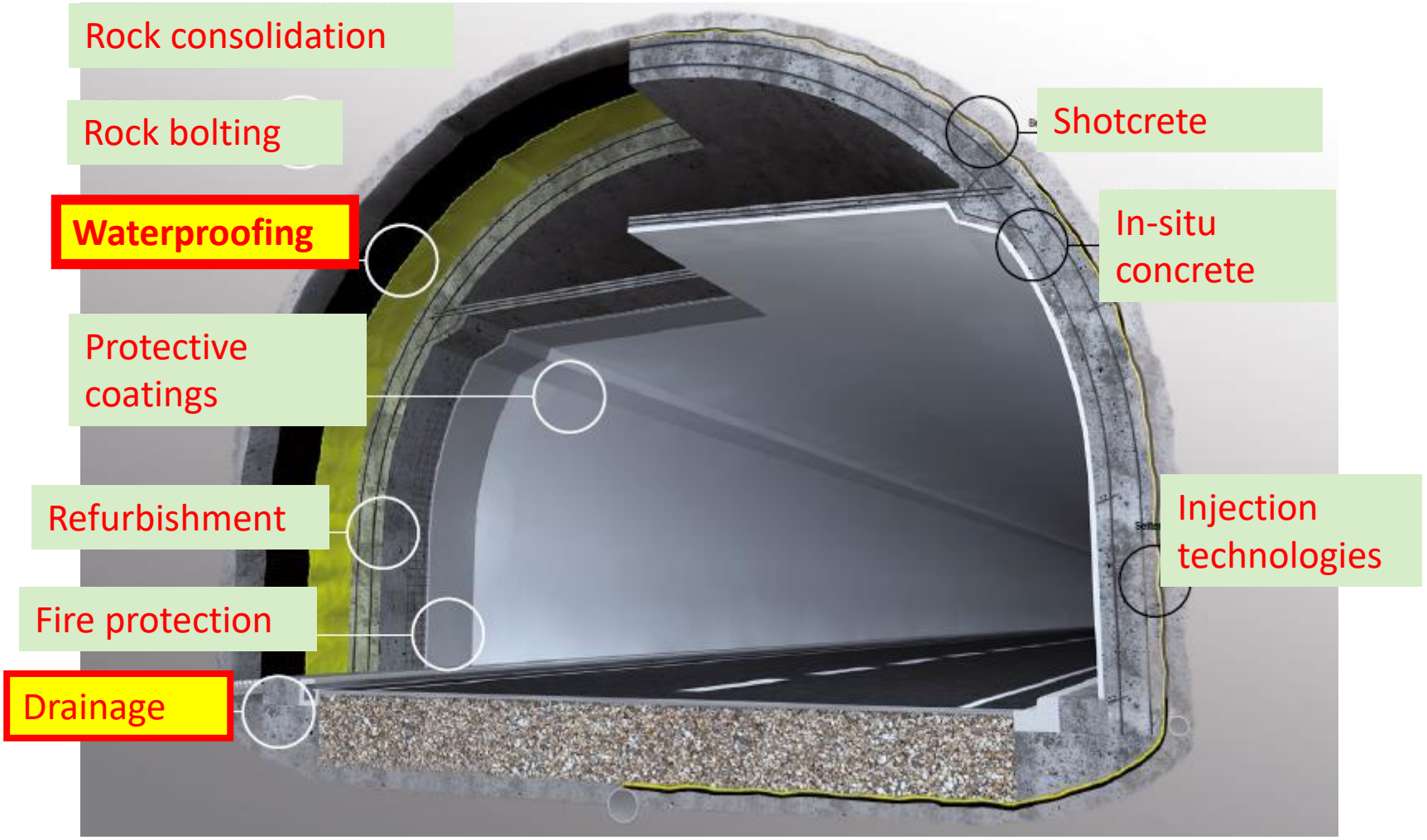
TRADITIONAL EXCAVATION
SIKA COMPETENCE IN TUNNELLING



TRADITIONAL EXCAVATION WATERPROOFING **THERMOPLASTIC SHEET**

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AUSTRIAN STANDARD

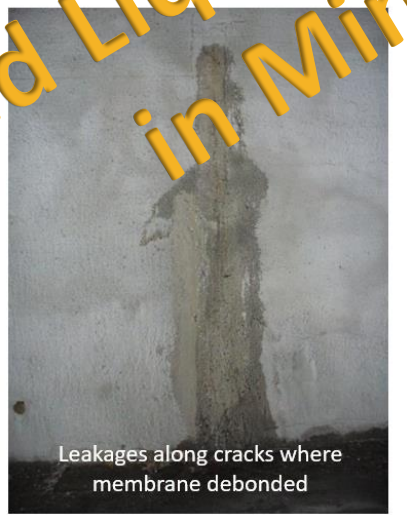
Öbv (Austrian guidline)/ 2012

- Due to the system, the sprayable membrane is not suitable for drained tunnelling based on the fully bond of the system to the substrate, which allows no adequate water migration. As a consequence, local water pressure spots are expected.
- Because of the current lack of experience, the procedural requirements and the uncertain long-term behavior, such an application of a sprayable membrane has no technical equivalence to an execution by a plastic sheet waterproofing membrane.

ACHILLES HEEL OF COMPOSITE SHELL

The real Achilles heel of composite shell linings remains the position of the waterproofing layer in the center of the lining.

TYPICAL FAILURES OF SPRAYED SYSTEMS



Project example for complete failure of sprayed system

Project: Metro Buenos Aires, Line B

- Owner: Buenos Aires Subway Authority (SBASE)
- Construction company: Roggio
- Sub-contractor/applicator: Apliancor S.A
- Application period: 2005-2010

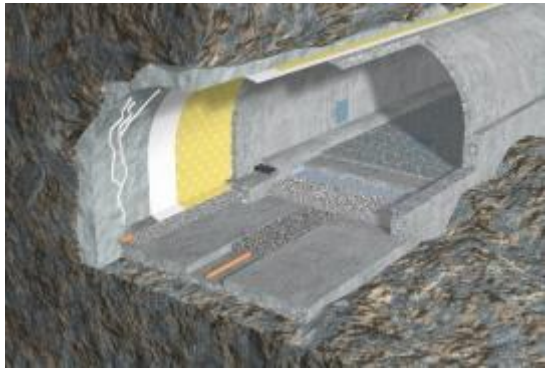
Construction:

NATM, 10-15m below the water table, undrained concept (arch & wall: spray-applied membrane, invert: waterproof concrete), double shell concept (not monolithic), supporting shotcrete (20-30cm), 8cm mortar layer for smoothening, additional use of mortar as waterstop (spot-wise), partly surface grinding, primer 1.7mm (epoxy based, solvent free), 1st coat (yellow,1.5mm), 2nd coat (white, 1.5mm), additional mortar to strengthen the bonding of final shotcrete (spot-wise), 2nd layer of shotcrete as inner liner (wall 50-60cm, roof 40-45cm) and cast-in-place concrete for invert. Special requirement of substrate condition: dry with max. 4% humidity

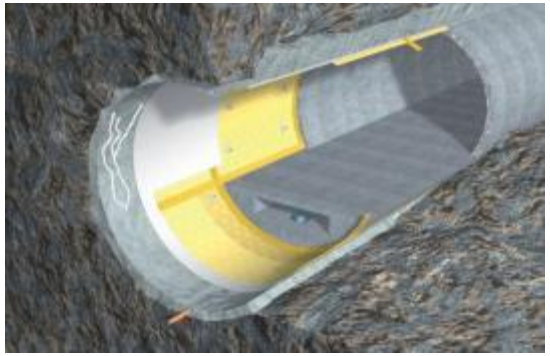
- 20.000sqm of a 3mm MMA spray-applied membrane
- 6.000sqm of an EVA-modified spray membrane, 3mm
- Electrical full-surface scanning for leak detection
- Putzmeister/Aliva shotcr equipment, Sigunit L500AR
- Problems: Substrate condition, smoothening, dust, membrane curing process, blistering (pinholes), bonding strength of final shotcrete, crack of inner liner, water ingress, difficult crack injection, etc.

CONSTRUCTION METHOD FOR TUNNELS
WATERPROOFING WITH SHEET MEMBRANES

- **Mined tunnel**
- Traditional excavation
- Partial waterproofing

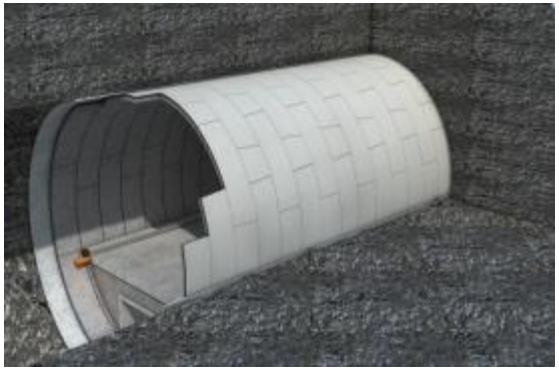


- Complete waterproofing

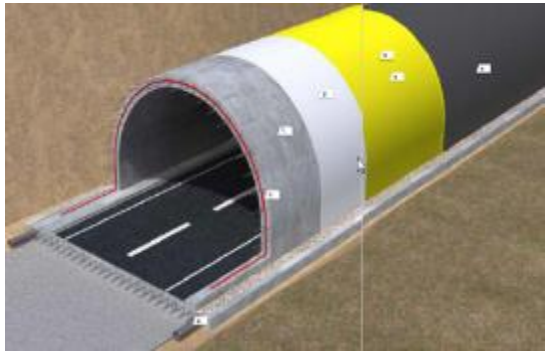


- **Mined tunnel**
- Mechanized excavation
- Partial waterproofing
- Complete waterproong

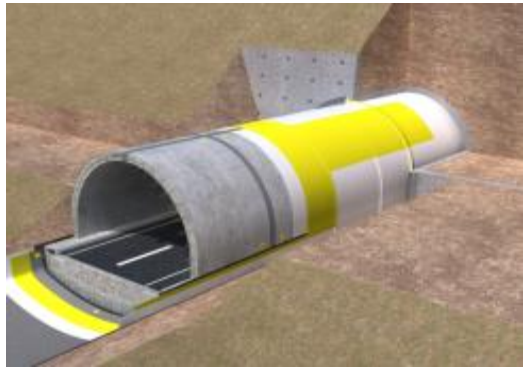
- Swelling strip



- **Artificial tunnel**
- Cut and Cover concept
- Partial waterproofing



- Complete waterproofing



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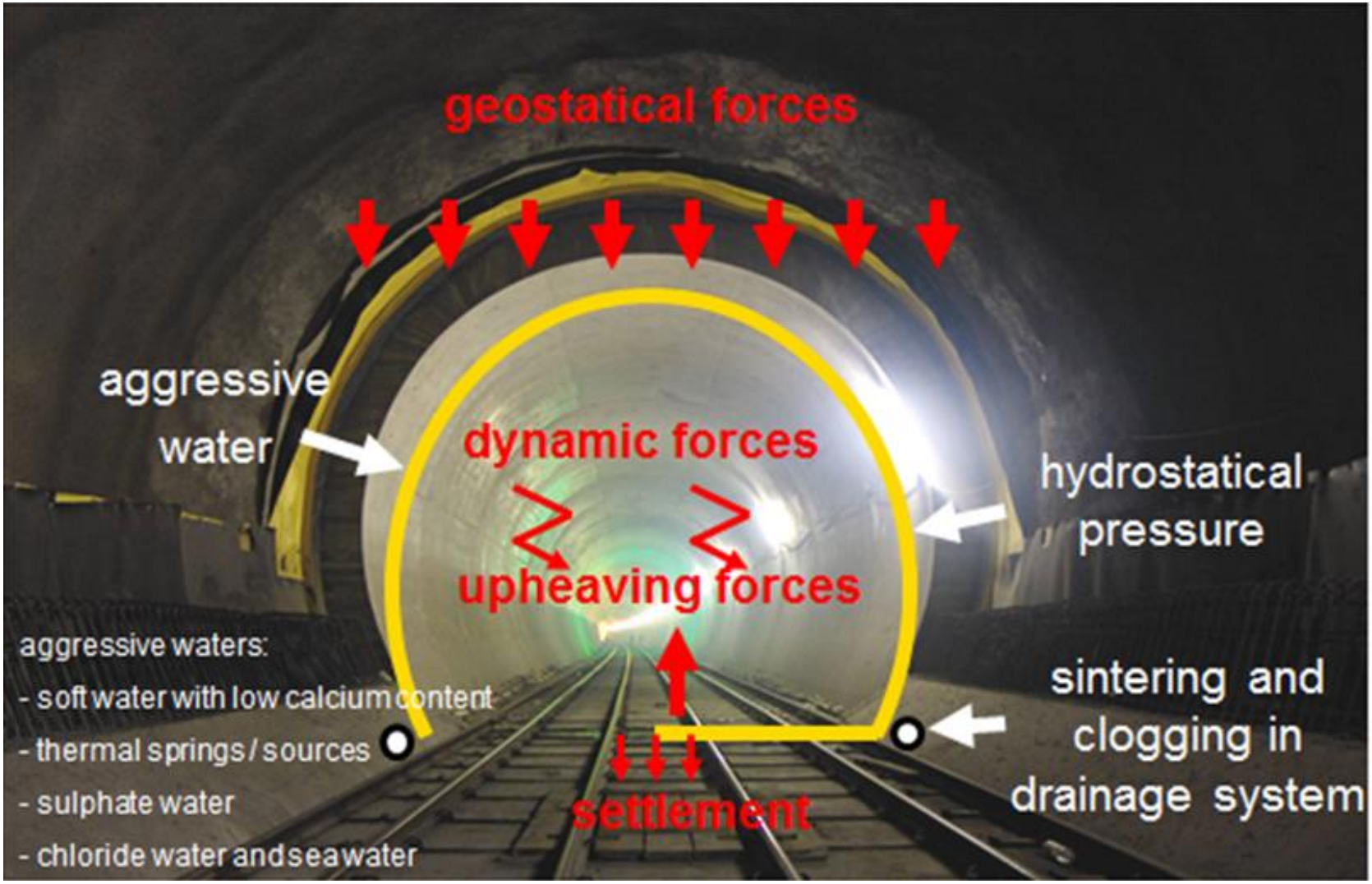
CONDITIONS
EXPOSURES AND STRESS



CONSTRUCTION METHOD FOR TUNNELS
WATERPROOFING WITH SHEET MEMBRANES

- **Partial waterproofing**

- Resists percolating water
- Lateral drainage systems required where membrane terminates

- **Full waterproofing**

- Resists full water pressure
- No drainage systems required

INTRODUCTION
OWNER'S PROJECT REQUIREMENT

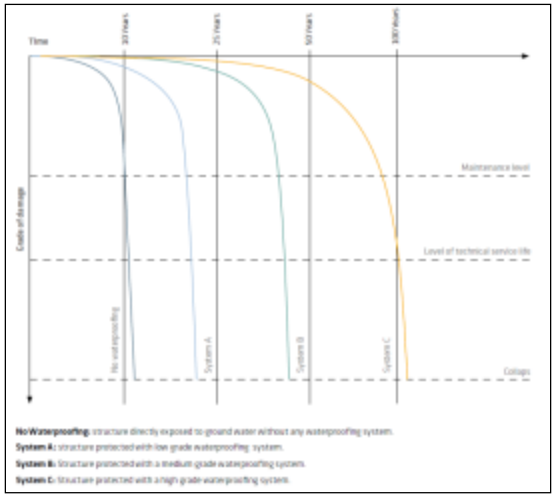
Owners requirements

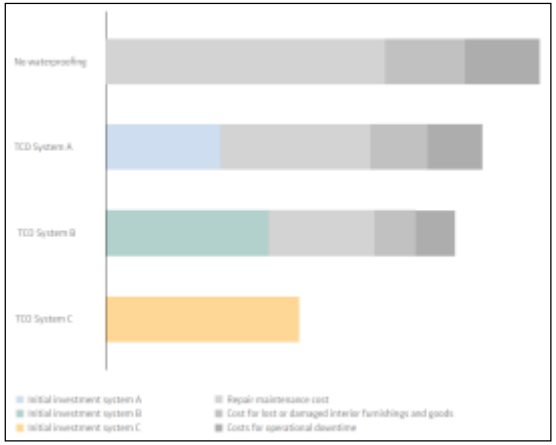
1 Functionality (Use, grade of watertightness)

2 Service Life / Durability

3 Total Cost of Ownership (incl. maintenance cost)

Class 1	Class 2	Class 3	Class 4
Completely dry	Dry to slightly moist	Moist	Moist to wet
No moist parts on the dry part of the tunnel surface permitted	Single failing parts permitted. No dropping water on the dry part of the tunnel surface permitted	Partly limited moisty parts and single dropping parts on the dry part of the tunnel surface permitted	Moisty parts and dropping parts permitted
• Clean air rooms • Dry rooms • Energy supply rooms • Metro stations (presence of people)	• Road tunnels highway • Road tunnels in frosty zones • High-speed train tunnels • Parking areas	• Regional railways • Metro lines	• sewage tunnels
Water infiltration in l/sqm within 24h acc. STUVA			
0	0-0.1	0.1-0.5	0.5-1.0





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BELOW GROUND WATERPROOFING
EUROPEAN STANDARDS / GUIDELINES

- **According to EN – 13491**

Degree of watertightness	Characteristic of damp and moisture	Use of underground space	Water infiltration in l /m^2 within 24 h
1	vapour diffusion from outside not permissible	- clean air rooms and dry rooms - prolonged presence of people - storage of moisture sensitive goods (paper, foodstuff)	0
2	dry vapour diffusion permissible	- civil defense installations and its wet rooms like toilets, showers etc. - energy supply rooms - general purpose underground space	0
3	dry	- storage and otherwise commercialized rooms - metro stations	< 0,001
4	almost dry	- road tunnels highway - road tunnels in frosty zones - high speed train tunnels	< 0,01
5	capillary soaking	- parking areas - road and pedestrian tunnels	< 0,1
6	light dripping	- regional railways - metro lines	< 0,5
7	dripping water	- sewage tunnels	< 1,0

BELOW GROUND WATERPROOFING
SWISS STANDARDS / GUIDELINES

- **Extract from SIA 272 (Swiss standard) 2009** – recommended waterproofing systems

(According to Pre Norm SIA 272)

Class 1	Class 2	Class 3	Class 4
Completely dry	Dry to slightly moist	Moist	Moist to wet
No moist parts on the dry part of the tunnel surface permitted	Single falling parts permitted. No dropping water on the dry part of the tunnel surface permitted.	Partly limited moisty parts and single dropping parts on the dry part of the tunnel surface permitted.	Moisty parts and dropping parts permitted.

BELOW GROUND WATERPROOFING
SWISS STANDARDS / GUIDELINES

- **Extract from SIA 272 (Swiss standard) 2009** – recommended waterproofing systems

Application field	•Open pits •Cut&cover •Galeries	Mined tunnel	Pit& Ponds	Water canals	Swimming-pools	Water reservoirs	Sewage plants	Upcom-ming humidity
according standard SIA 270, table 3	B1.1 B1.2	B2	B3	B4	B5	B6	B7	E
								
Watertightness class of the whole structure	1 or 2	1 or 2	2 or 3	2 or 3	1 or 2	2	2	1
rigid								
3.1 watetight concrete	x	x		x	x	x	x	
3.2 watertight mortar	x	x		x	x	x	x	
3.3 fluid asphalt	x							x
flexible								
3.4 polymer-bitumen	x	x[1]						x
3.5 plastic sheet membrane	x	x	x	x	x	x		x
3.6 bentonite layer	x		x					
3.7 liquid applied membrane	x	x[1]		x	x	x	x	
3.8 polymer- mod. bituminouse coatings	x							

[1] lower-ranked (subordinated) application fields (e.g. canal lining, emergency escape tunnel)

X recommended

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DURABILITY OF WATERPROOFING MEMBRANES
WITH + 40 YEARS SERVICE

SKZ German Plastics Center

6th International Conference GEOSYNTHETICS MIDDLE EAST 2013

Durability of PVC Membranes in Tunnel Waterproofing – Testing of Membranes With 40+ Years of Practical Service Life

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ABSTRACT
A long service life of tunnel constructions requires durability of all components. A major part in this context plays the waterproofing layer. The paper describes the investigation of two waterproofing PVC membranes. Samples removed from 41 and 44 year old road tunnels in Switzerland were subject to detailed examination. Waterthightness, mechanical and chemical properties have been determined as well as the welding ability with new membranes. The aged membranes still largely fulfill German and Swiss standard requirements for virgin tunnel membranes. A further service life of several decades can be expected with a high probability of reaching the nowadays required 100 years durability.

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DURABILITY OF WATERPROOFING MEMBRANES
WITH + 40 YEARS SERVICE

- Tunnel built in 1970
- PVC membrane installed in 1971
- 600m long twin tubes, 3 lanes each tube
- Recently upgraded for new EU safety & security regulations
- Inspection & testing of the membrane became possible

Figure 1: The European E35 highway (Koch, 2011).

Figure 2: Map of Lucerne with course of the city bypass

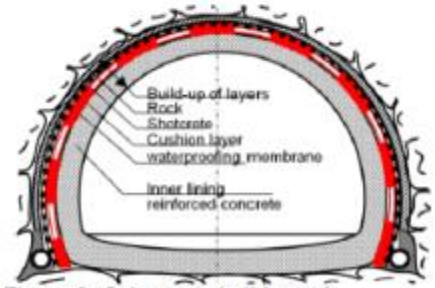


Figure 3: Schematic build-up of Reussport tunnel.

Figure 4: North portal of Reussport Tunnel.

DURABILITY OF WATERPROOFING MEMBRANES
WITH + 40 YEARS SERVICE

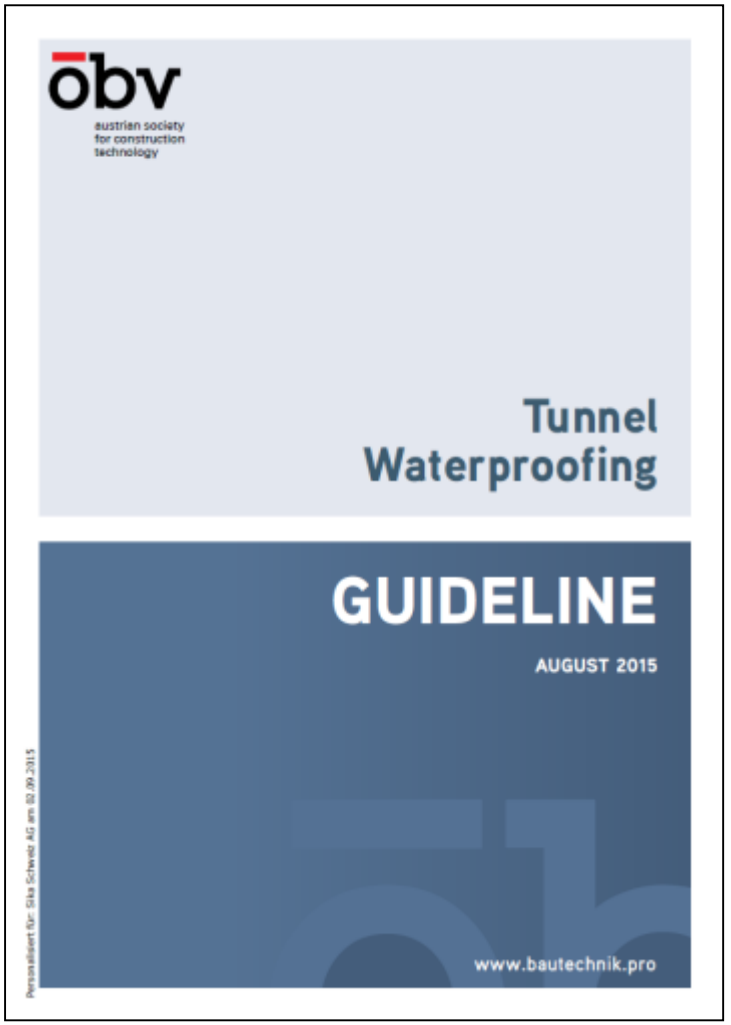
Table 1. Properties of Samples From Tunnel Reussport

Property	Test Method	Requirement[1)]	Retain Sample 1970	Sample From Reussport Tunnel
Thickness	DIN EN 1849-2	-	1.50 mm	1.25 mm
Tensile Strength	DIN EN ISO 527-3	12 MPa [1)]	17.0 MPa	15.8 MPa
Elongation at Break	DIN EN ISO 527-3	> 250 % [1)]	300 %	278 %
Impact Resistance	DIN EN 12691 Method A	750 mm [1)]	1'000 mm	750 mm (2/5 1'000 mm)
Folding at Low Temperature	DIN EN 495-5	- 20 °C [1)]	- 20 °C pass	- 20 °C pass
Water Tightness	DIN EN 1928	no leakage at 10 kPa/24h [2)]	pass	pass
Plasticiser Content	Manufacturer's Test	-	36 %	32.8 %
Seam Test (Peel) with New Membrane	DIN EN 12316-2	break outside of seam [1)]	pass	pass

[1)] Requirements by ZTV/ING 2007, [2)] Requirements by SIA V280

DURABILITY OF WATERPROOFING MEMBRANES
LEADING INT. TUNNEL STANDARDS - TUNNEL GUIDELINE ÖBV

- Guideline incorporating the **latest know-how** in tunnel waterproofing for closed (NATM and TBM) and cut-and-cover tunnels
- First standard to define test methods and limits for **durability** requirements, to achieve **>100 years** for PVC and TPO membranes (Table 4.6)
- Describes **additional durability** requirements for harsh conditions similar to the Gotthard base tunnel (NEAT) specification (Table 4.7)
- Describes environmental and health aspects (REACH) to be met
- Includes requirements for system components (e.g substrate, installation, fixing, welding, flexibility, quality control, inspection & joint design).

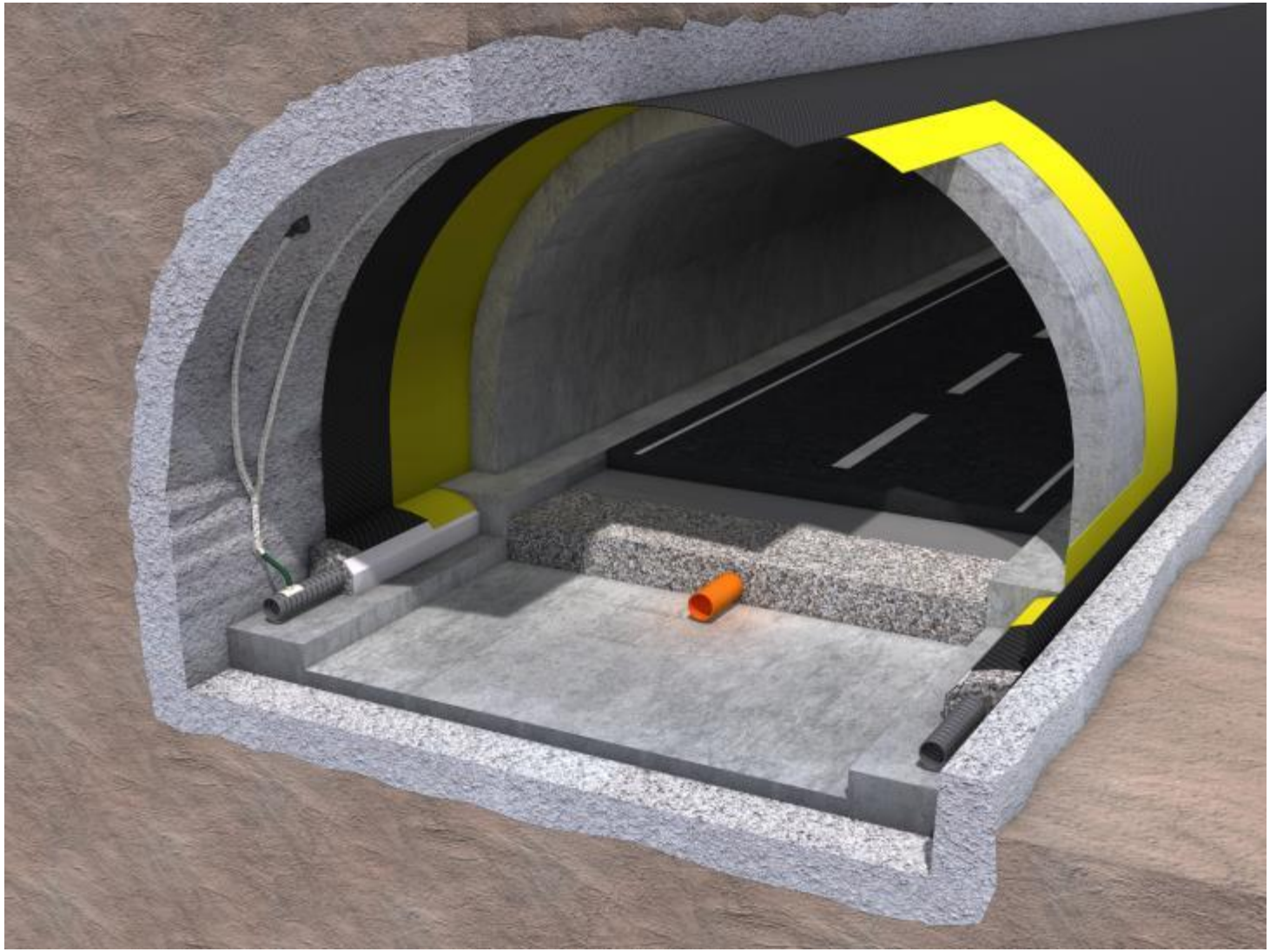


ÖBV DESCRIPTION OF THE WATERPROOFING SYSTEM
DURABILITY OF WATERPROOFING MEMBRANES

- Extract from the 2015 Austrian Tunnel Waterproofing Guideline ÖBV Table 4.7
  - States performance after **long term** accelerated ageing tests on membrane properties
  - If durability of >100 years is truly the main focus, the project specifications should include these performance tests
  - Manufacturers should provide test data to PROVE durability
    - Not just a manufacturers letter "confirming 100 years durability"!!!

Durability tests for an expected service life of 100+ years, acc. ÖBV Table 4.7		
Behavior after storage in hot water (=Leaching) **360 days at 70°C**	EN 14415	Reduction of tensile strength and elongation: ≤ 25% Change of mass: ≤ 7% Reduction of impact load (drop height): ≤ 40%
Behavior after storage in saturated limewash **360 days at 50°C**	EN 14415	Reduction of tensile strength and elongation: ≤ 25% Change of mass: ≤ 7% Reduction of impact load (drop height): ≤ 40%
Behavior after storage in 5-6% sulphurous acid **120 days at 23°C**	EN 1847	Reduction of tensile strength and elongation: ≤ 25% Change of mass: ≤ 4% Reduction of impact load (drop height): ≤ 30%
Behavior after storage in 0.5% sulphuric acid **360 days at 50°C**	EN 1847	Reduction of tensile strength and elongation: ≤ 25% Change of mass: ≤ 7% Reduction of impact load (drop height): ≤ 40%

WATERPROOFING MEMBRANE SHEET INSTALLATION
DRAINAGE WATERPROOFING (UMBRELLA)

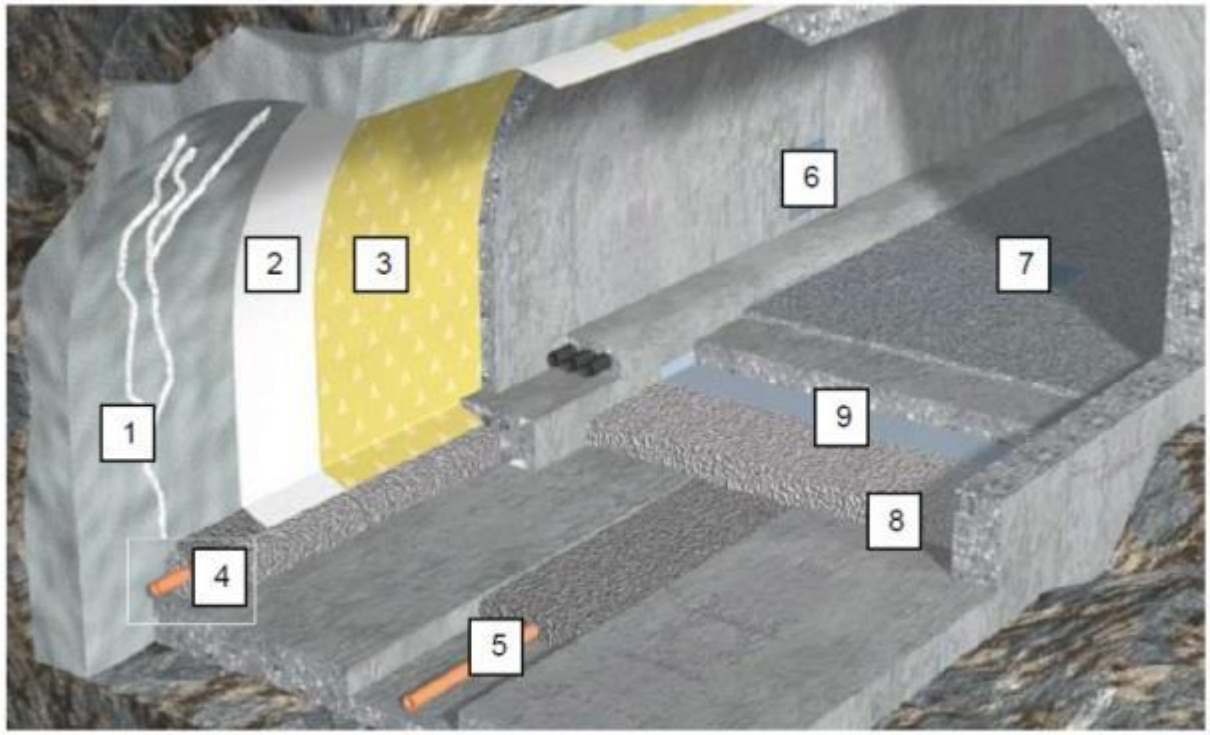


WATERPROOFING MEMBRANE SHEET INSTALLATION
SUBSTRATE PREPARATION

Requirement of membrane flexibility in connection with shotcrete eveness			
Eveness of shotcrete	≈ 1:5	≈ 1:10	≈ 1:15
Section elasticity module E_{1-2} acc. ISO 527 of membrane	≤ 20 N/mm²	≤ 70 N/mm²	≤ 100 N/mm²

Roughness of shotcrete (NEAT/ SIA 272)			
	Definition	**Requirement**	Method of measurement
Roughness	Depth	Max. value 4-16 mm	Sandfill as per ZTV-SIB measured at Ø 250 mm
Eveness	Small waves (R≤ 200 mm)		
	R_{KW} Radius (mm) B_A: B_T Ratio	Min. value B_A at B_T =1 = 10:1	Manual Measurement of substrate at negative form
	Large waves (R≥ 200 mm)		
	R_{KW} Radius (mm) B_A: B_T Ratio	Min. value B_A at B_T =1 = 10:1	Measurement of substrate with profilometer

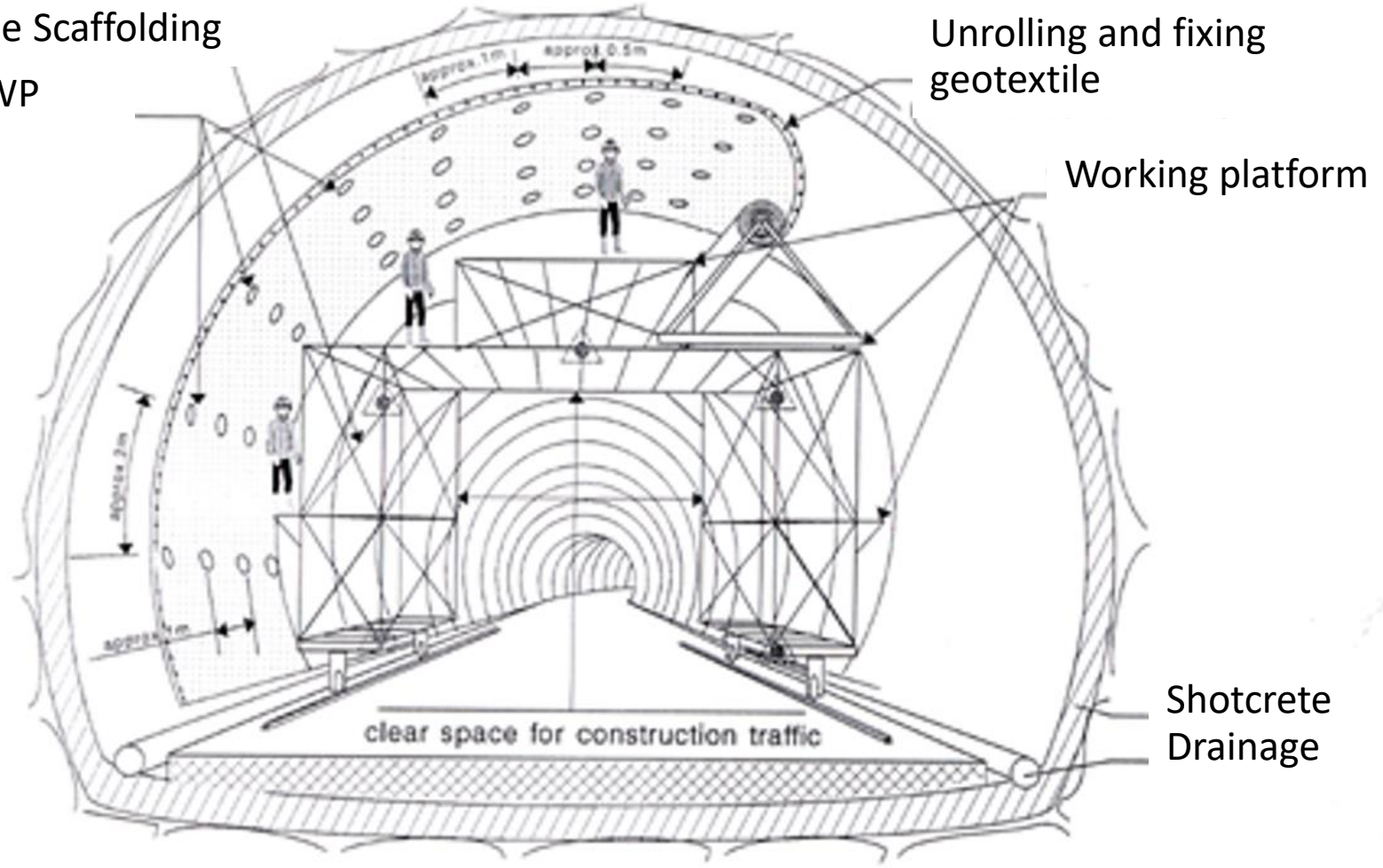
WATERPROOFING MEMBRANE SHEET INSTALLATION
COMPLETE SYSTEM



1.Preliminary waterproofing with Sika® FlexoDrain
2.Drainage , protection layer with Sika® Geotextile or Sika®Drain
3.Synthetic waterproofing membrane Sikaplan® WP
4.Lateral drainage pipe with gravel package, connection with Sikaplan® W Drainage Angle (optional)
5.Main collector pipe, connected every ~100m with lateral drainage
6.Niche for inspection and cleaning of lateral drainage pipe
7.Shaft for inspection and cleaning of main drainage
8.Invert drainage with gravel
9.Separation layer, PE-Foil 0.3mm
(Invert drainage pipe and protection sheet not shown in the picture.)

WATERPROOFING MEMBRANE SHEET INSTALLATION

INSTALLATION OF DRAINAGE LAYER



WATERPROOFING MEMBRANE SHEET INSTALLATION
DISC FIXATION

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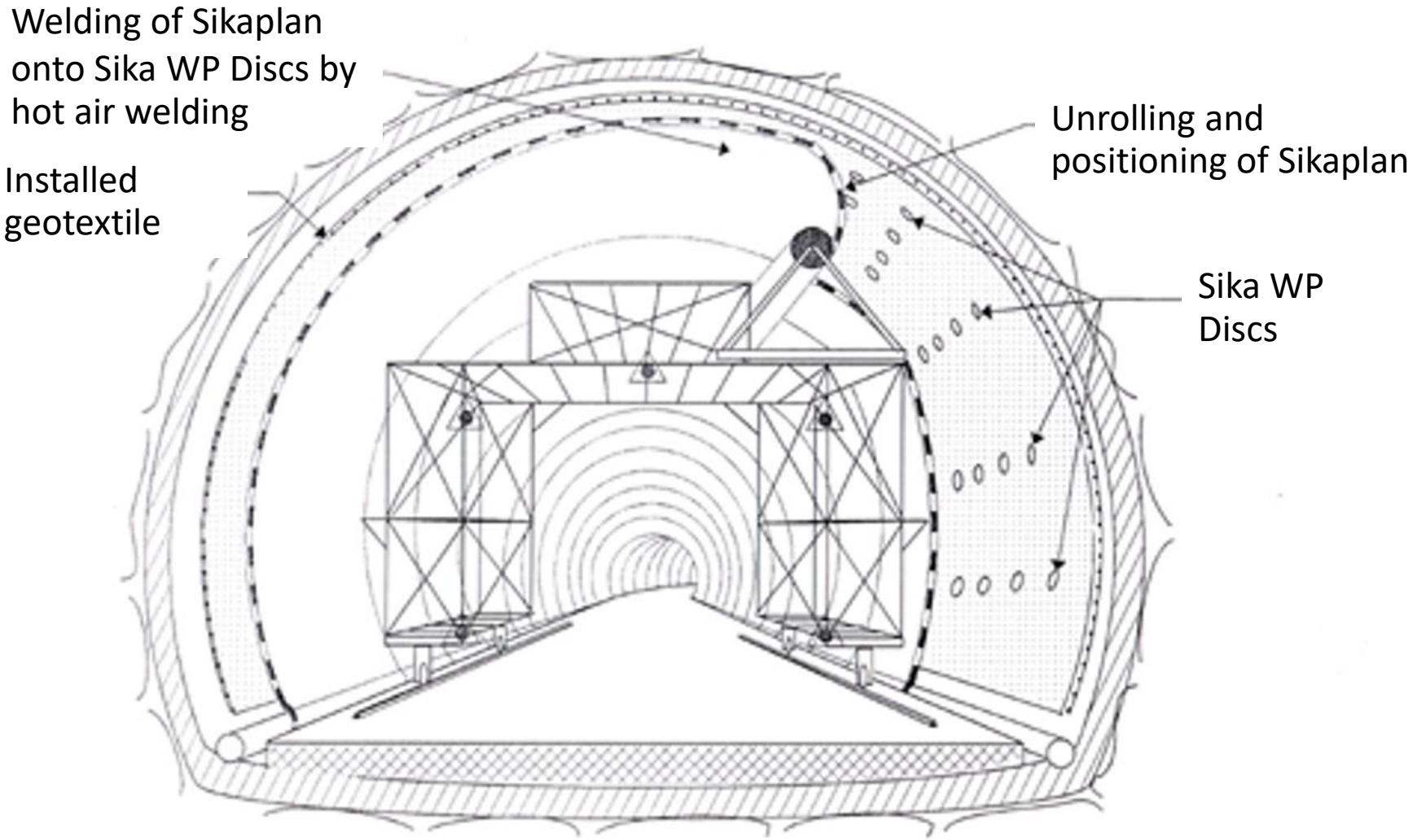
WATERPROOFING MEMBRANE SHEET INSTALLATION

INSTALLATION OF MEMBRANE WATERPROOFING

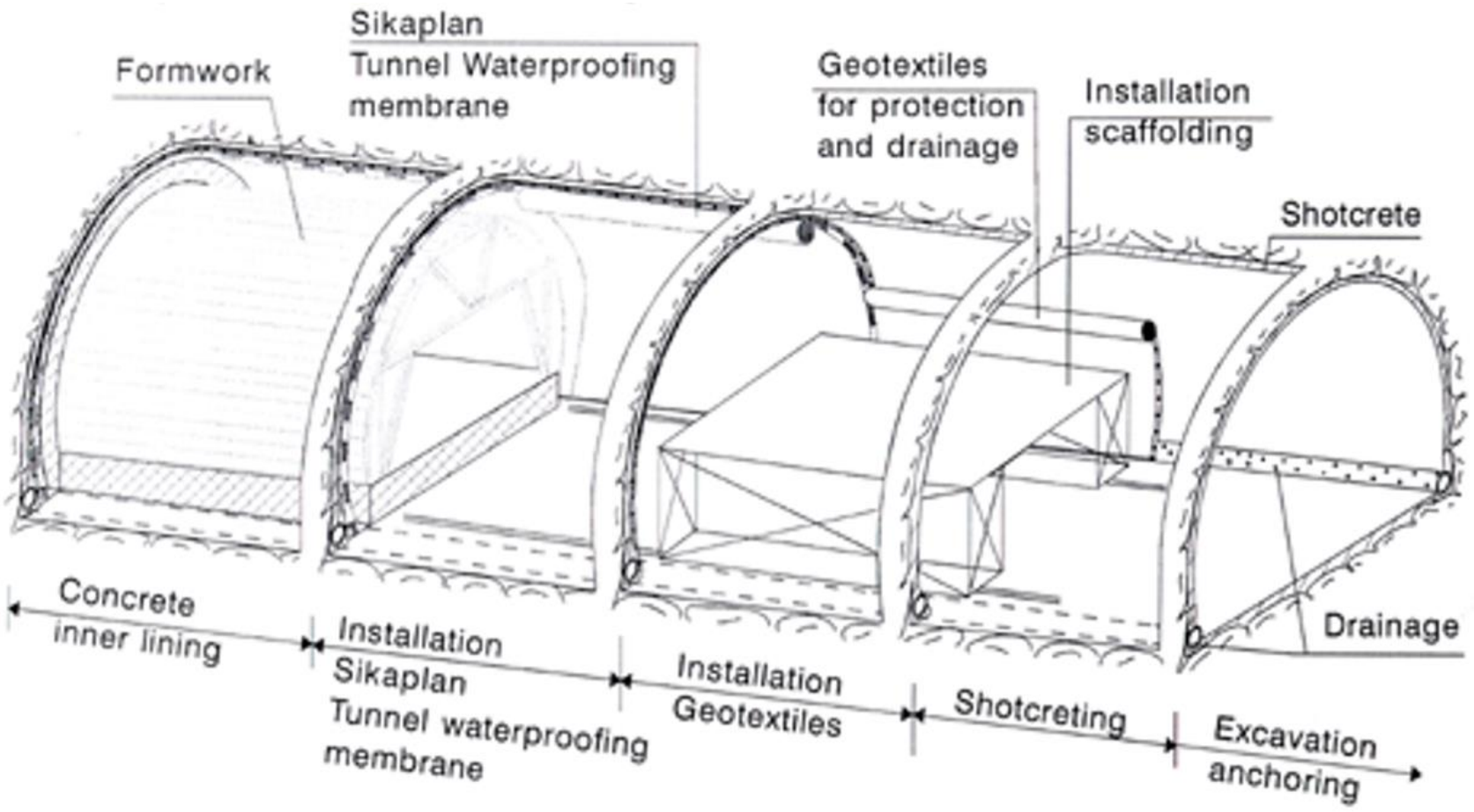


WATERPROOFING MEMBRANE SHEET INSTALLATION
MEMBRANE POSITIONING

WATERPROOFING MEMBRANE SHEET INSTALLATION
MEMBRANE POSITIONING

WATERPROOFING MEMBRANE SHEET INSTALLATION

INSTALLATION SEQUENCE SUMMARY



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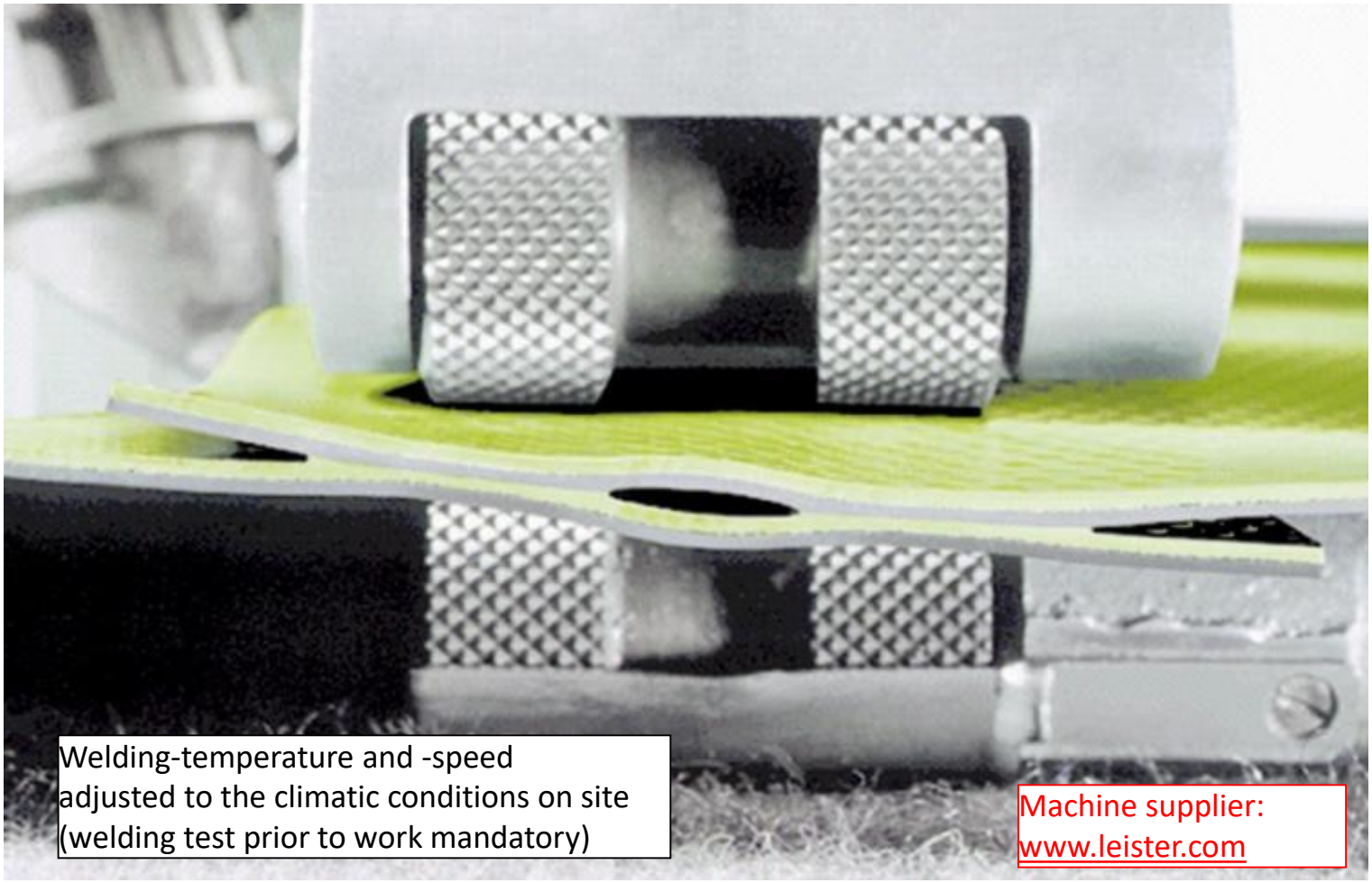
WATERPROOFING MEMBRANE SHEET INSTALLATION
FIXATION AT SIKAPLAN WP DISCS

WATERPROOFING MEMBRANE SHEET INSTALLATION
LONGITUDINAL SHEET MEMBRANE SEAM WELDING

WATERPROOFING MEMBRANE SHEET INSTALLATION
SEAM WELDING

Double seam welding with automatic heat welding machine



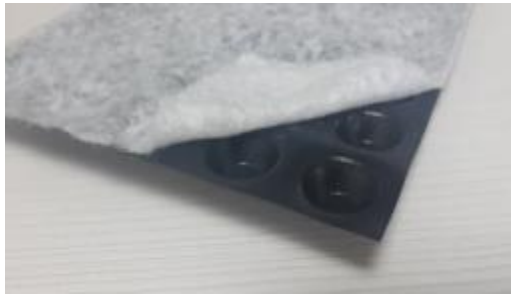
WATERPROOFING MEMBRANE SHEET INSTALLATION
DOUBLE SEAM TESTING

Seam testing with compressed air:

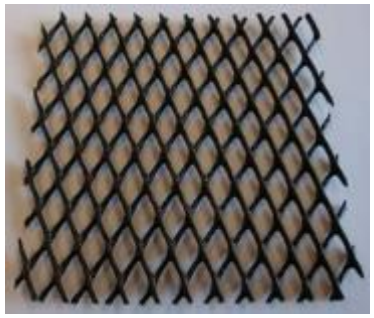
- 2 bars for 20min
- Target pressure loss <10%

WATERPROOFING MEMBRANE SHEET INSTALLATION
WATERPROOFING MEMBRANE ACCESSORIES

- Sika®Drain Dimpled Sheet

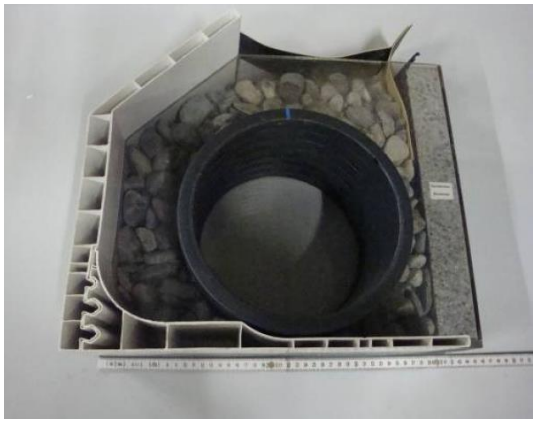


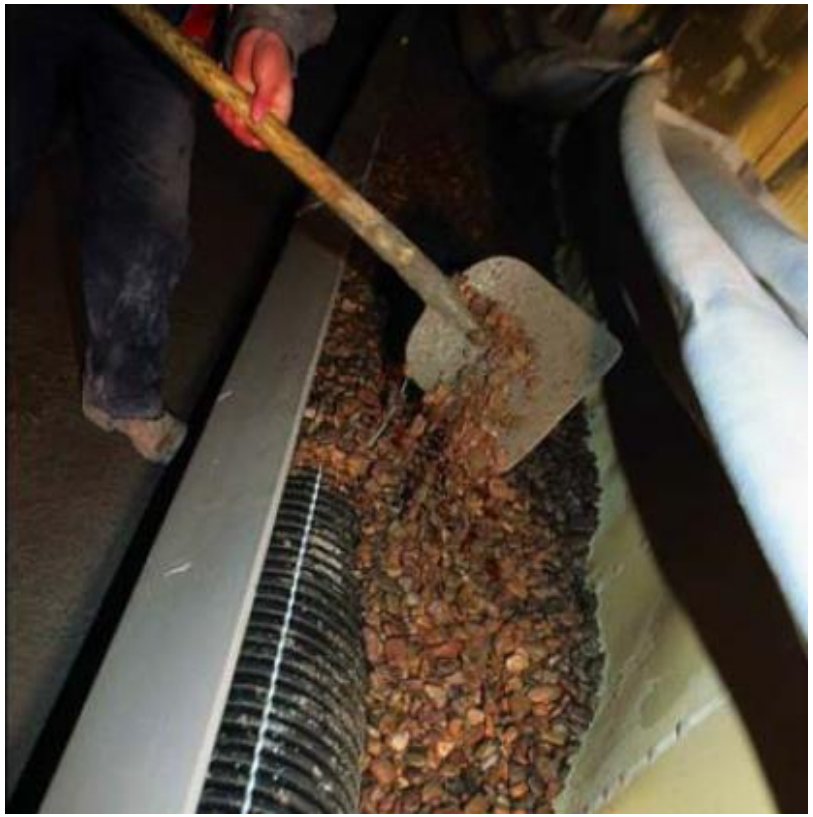
- Sikaplan® W Tundrain drainage mesh:



- Other solutions such as geocomposites or waffles can be an alternative supplied by Sika.

WATERPROOFING MEMBRANE SHEET INSTALLATION
CONNECTION TO DRAINAGE PIPE



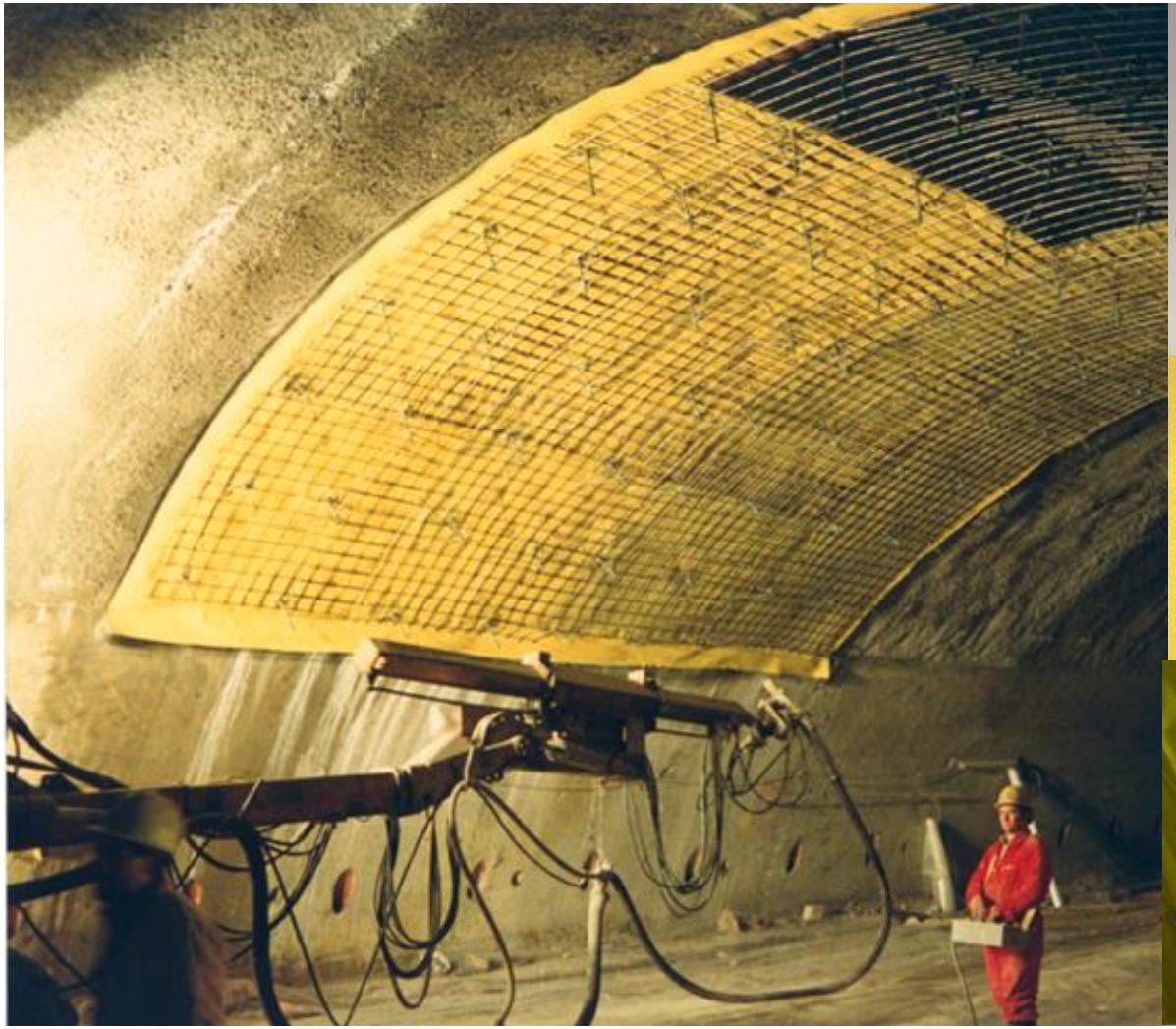


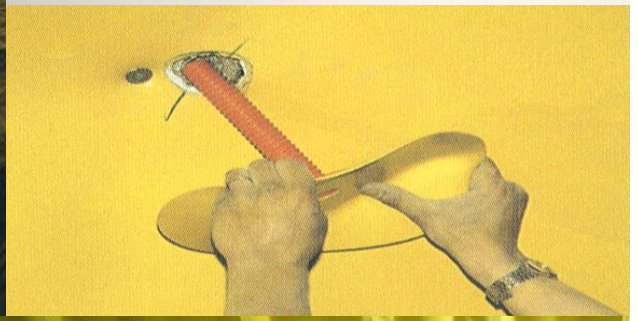
Backfilling of Sika Drainage angle with gravel
-> high drainage capacity

Connection with membrane by spot-welding

OPTIONS FOR SECOND LINING REALIZED BY SHOTCRETE

INNER SHOTCRETE ONTO SIKAPLAN



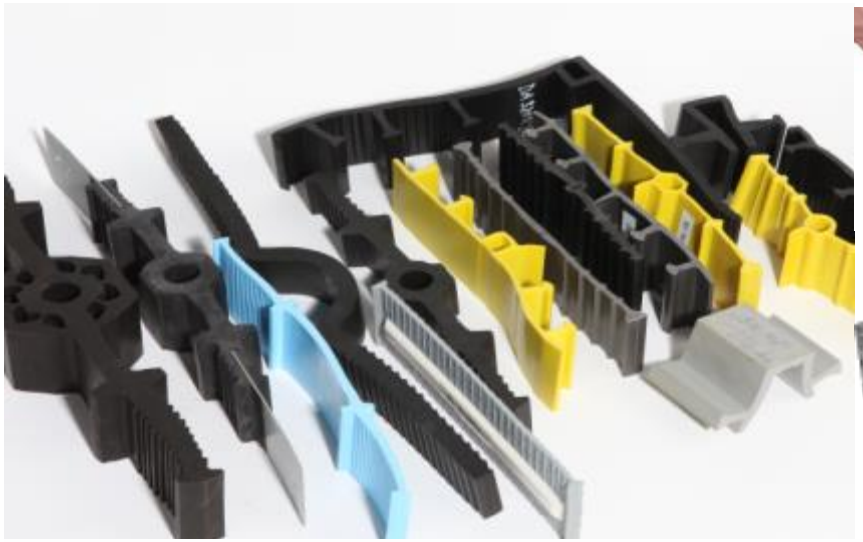


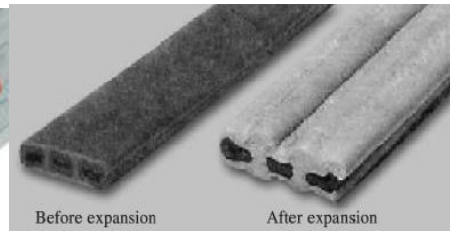
Inner Shotcrete onto Membrane

WATERPROOFING MEMBRANE SHEET INSTALLATION

JOINTS SYSTEMS SIKA® OVERVIEW

Technology	Brand	Base	Application	Location
Waterstop	Waterbars Tricosal Greenstreak	PVC Rubber, SBR PVC	Movement Non movement	Internal External
Adhered	Combiflex Dilatec	TPO PVC	Movement Non movement	External
Hydrophilic	SikaSwell Hydrotite	PU Polymer Rubber	Non movement	Internal
Injection hoses	SikaFuko	PVC	Non movement	Internal





SIKA JOINT **WATERPROOFING** SYSTEMS

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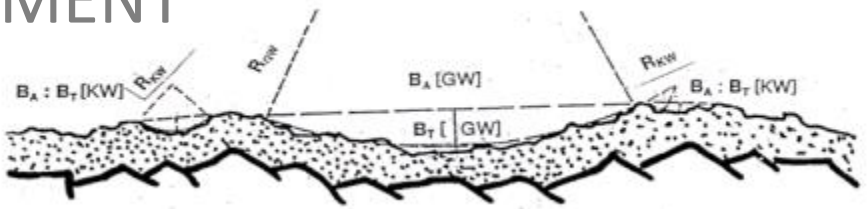
WATERPROOFING MEMBRANE SHEET INSTALLATION
SUCCESSFUL PROJECT ACHIEVEMENT

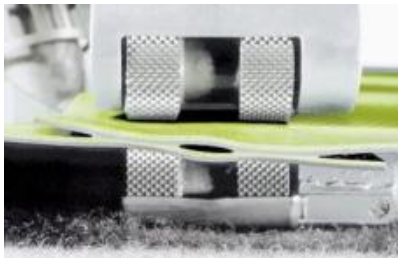
- Definition and control of substrate evenness -> contractor



- Product and system specifications according to leading European tunneling standards (ZTV-ING, OEBV, SIA)

- Specification of details like drainage, shafts, rebar fixation etc.

- Application know-how



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GOTTHARD BASE TUNNEL

PROJECT OF THE CENTURY

THANK YOU VERY MUCH FOR YOUR ATTENTION

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