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HYDROIZOLAČNÉ SYSTÉMY V PODZEMNEJ PRÁCE. BEZPEČNOSTNÝ TUNEL MITHOLZ VO ŠVAJČIARSKU

WATERPROOFING SYSTEMS IN UNDERGROUND WORKS. THE SAFETY TUNNEL MITHOLZ IN SWITZERLAND

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ABSTRAKT

V oblasti veľkých podzemných stavieb je na zabezpečenie odolnosti a funkčnosti konštrukcie v rekonštrukčných prácach dôležité zrealizovať vhodný hydroizolačný systém. Článok opisuje jedinečný prípad rekonštrukcie bezpečnostného tunela Mitholz, vo Švajčiarsku. Tunel Mitholz o dĺžke asi 1,5 km bez hydroizolačného systému, sa nachádza v severnej časti hlavného tunela Lötschberg. V nadväznosti na výskyt zvyšujúcich sa prítokov vody v rámci bezpečnostného tunela, MAPEI UTT navrhla na základe presných prieskumov a predbežných skúšok kombináciu dvoch rôznych typov hydroizolačných systémov. Pre tento problém bol vybraný najvhodnejší hydroizolačný systém pre druh sekcie tunela na základe ďalších faktorov ako sú podmienky prenikania vody, geometria tunela, atď. MAPEI UTT vyvinul techniku prekrytia v mieste styku dvoch hydroizolačných výrobkov, zhotovených s príslušnými zariadeniami a lepiacimi produktmi, za účelom získania dokonalého hydraulického utesnenia medzi týmito dvoma systémami. Voľba použitia oboch hydroizolačných riešení, ktoré môže ponúknuť iba MAPEI ako jediný partner, bola rozhodujúca pre riadenie celej výstavby, ako aj konečných nákladov.

ABSTRACT

In the field of the major underground works to ensure structures durability and functionality for reconstruction works, it is essential to realize a proper waterproofing system. The paper describes a singular case of reconstruction of the Safety Tunnel Mitholz, in Switzerland. The tunnel Mitholz of about 1.5 km length without waterproofing system, is situated at north of the Lötschberg Base Tunnel. Following the occurrence of increasing water inflows within the safety tunnel, MAPEI UTT has proposed a combination of two different types of waterproofing systems through accurate surveys and preliminary tests. For this problem it has been chosen the most suitable waterproofing system for the kind of tunnel section, on the basis of additional factors such as conditions of water infiltration and the tunnel geometry, etc. MAPEI UTT developed an overlap technique in the passage phase between the two waterproofing products, made with proper devices and adhesive products for the intersection area, in order to obtain a perfect hydraulic sealing between the two systems. The choice of using both waterproofing solutions that only MAPEI can offer as a single interlocutor, it was of fundamental importance for final cost purposes and management of entire work.

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1 Introduction to the waterproofing systems

For the underground structures a properly waterproofing system is an essential factor to guarantee the durability during the opera exercise.
In particular, it is necessary to realize a waterproofing system able to eliminate concrete degradation and to avoid phenomena leakage of waters, consequent cause of limitation of structure functionality. The goal is to ensure a long service life to the underground structures with security increase in both structural and functional.
The waterproofing system will must be able to deal with waters that flow into tunnel and to prevent or intercept entrance of fluids, bring down the hydraulic overpressure that burden on the final lining and restore the existing equilibrium of hydrologic conditions.
Nowadays, the big customers in the field of major underground structures, require a life expectancy of over 100 years, therefore the products used shall ensure durability and high performance not only in tunnels under construction but also in existing tunnels that need the restoration or introduction of waterproofing from scratch if this is not provided in original project. The techniques used in the past for the waterproofing, employed bituminous or prefabricated membranes based on bitumen-polymer. The high degree of groundwater contamination has created the need to study new materials more and more performing and obtain a waterproofing systems long-lasting and eco-compatible for the environment. The market evolution has started since the '60-'70s with the first synthetic membranes characterized by easy management and handiness of set-up application. PVC and polyethylene, have become increasingly familiar terms thanks to the diffusion of solutions dependent from various production techniques. The PVC membranes have made their entry in waterproof systems panorama initially in hydraulic works and later for roofing and underground works. These two last sectors have knew exploit technical characteristics by making the PVC membranes partners irreplaceable whereas were requests of an excellent protection benefits, impermeability associated with lightness and ease of installation. In case of underground works and sector of tunnelling, the synthetic membranes have become irreplaceable because the only ones able to create waterproof protection directly on the first layer of shotcrete. MAPEI S.p.A. with the division Underground Technology Team (UTT), has become since years a well-known reference point for products in the field of waterproofing, bringing to market several solutions to the waterproofing problem specialized in the field of underground works. Through the study of new technology materials and thanks to test carried out on field on special products and innovative techniques, there was a study phase and growth of synthetic membranes until to get to a generation of waterproofing products in different materials with excellent characteristics and performance.
Recently in R&D laboratories, MAPEI SpA has been developed an innovative technology applied by spray directly on the surface to be waterproofed. This technology consists in a one-component membrane based on polymer, that waterproof all surfaces and present an high adhesion with pre-existing surface; especially used for waterproofing works in tunnel rehabilitation. Also synthetic membrane and accessories are currently on the market for the waterproofing systems.

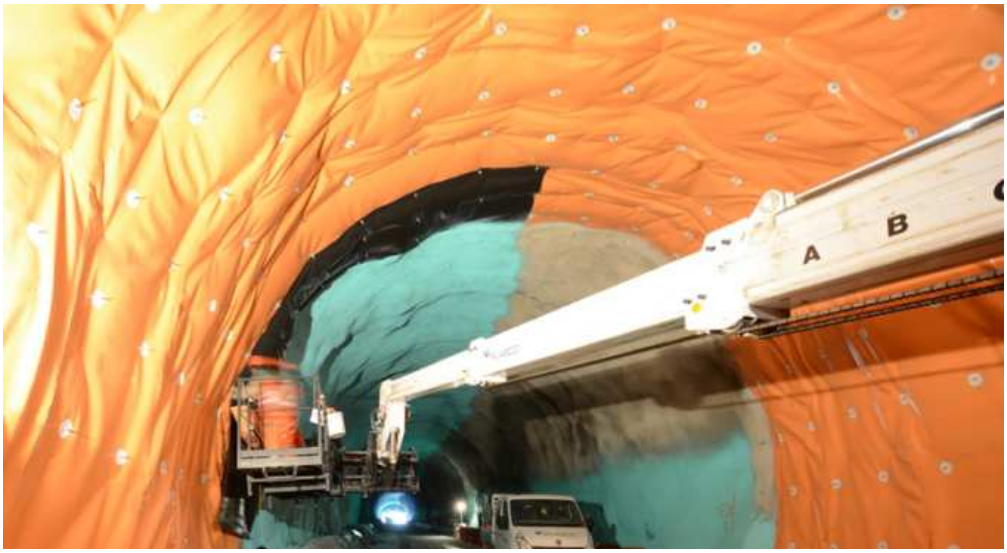
2 Application of waterproofing systems in safety Tunnel Mitholz in Switzerland

The Lötschberg Base Tunnel in Switzerland, is a railway tunnel of 34.6 km-long that connects the Swiss cities of Frutigen and Raron and it was inaugurated on the 16th June 2007. The tunnel is part of the Alp Transit railway project for the high speed railway designed to be a twin-tube tunnel. The provided commercial speed transit varied between the range of 100 km/h for freight trains up to 200 km/h for trains IC and body tilting (eg. Pendolino, with

technical possibility of up to 250 km/h). Two are the safety tunnels: the first is “Mitholz“ and the second is near the city of Ferden, that will be used in case of emergency and for access of the rescue and as escape hatch for passengers from trains. Both are designed to realize the excavation and construction of the base tunnel. The access tunnel Mitholz, of about 1.5 km-long, is located towards the north entrance, is one of the tunnel without waterproofing as foreseen in the project.

Obr. 1 The Lötschberg hlavný tunel vo Švajčiarsku s bezpečnostným tunelom Mitholz (BLS Alp Transit AG)
Fig. 1 The Lötschberg Base Tunnel in Switzerland, with the safety tunnel Mitholz (BLS Alp Transit AG)

For the case of safety tunnel Mitholz both waterproofing systems patented MAPEI SpA have been used for works that expected the introduction of the waterproofing for the construction of the final lining. Through the experience of MAPEI Team and by means of preliminary tests it was possible the installation of the waterproofing system in the entire longitudinal length of tunnel.



Obr. 2 Realizácia hydroizolácie v bezpečnostnom tuneli Mitholz oboma technikami
Fig. 2 Waterproofing realization in the safety tunnel Mitholz with both techniques

Following the occurrence of serious problems of water inflows, rapidly increasing in a short time till to reach critical levels, it was required at the specialists to participate and to carry out the waterproofing solution for the entire tunnel. In this case, with the MAPEI operative procedure selected it was possible choose locally the most appropriate waterproofing system in according with the tunnel geometry, the characteristics of the existing support and the conditions of existing water seepage. Once established the construction requirements, dictated by the tunnel characteristics, it was chosen the type of the most appropriate waterproofing system and through the firm Plasco AG Niedergesteln were performed the works in the tunnel under the assistance of the MAPEI Team. Both designer and enterprise that has carried out the work, saw the waterproofing introduction by using both waterproofing systems: synthetic membrane in plasticized polyvinylchloride PVC-P and one-component sprayable waterproofing membrane polymer based. The synthetic membrane in PVC-P was used to waterproof all those sections that showed water inflows, in presence of preexisting poor quality concrete, very degraded too, with evident concrete cracks through which water inflows occurred. Instead, in the areas that showed low presence of water and dry concrete surface, the waterproofing technique by one-component elastic membrane, spray applied, was used, directly on the existing concrete free of visible cracks.
It was realized an effective combination of the two techniques thanks to the alternation of the two systems, appropriately actualized by an accurate survey of the areas which present higher or lower water infiltration and depending on the different degradation levels of the preexisting shotcrete lining surface.

3 Synthetic waterproofing system in PVC-P

The synthetic membrane based on PVC-P was the waterproofing system used to waterproof several sections. MAPEPLAN TU WL consists of a main layer of black color and a special, orange coloured Warning Layer. The innovative concept of warning layer allows to easily detect any eventual damaged parts during installation and to make even more visible any damages, even small, that may occur during installation or subsequent works, thus safeguarding the integrity of the whole system. As a guarantee against problems during installation, such as accidental damages or for its maintenance, the system is easily repairable at low cost. Integrity, functionality and efficiency of the membrane can be restored with simple operations. Often the works in tunnels are developed into tight spaces and an easy procedure it can simplify timing and sequence of different processing stages thus reducing the implementation costs. The synthetic membrane has characteristics of: flexibility, ease of application and installation. For the welding is possible to use various welding techniques, thanks to his excellent weldability and workability. In this way is guaranteed the waterproofing system continuity, especially in those sections manufactured in successive times and at different parts, along the development of the entire tunnel. To specify, the membrane has excellent mechanical properties of resistance to permanent and localized pressures.This waterproofing system has plasticity characteristics (high elongation, tensile strength and load at break) and resistance to hydraulic and lithostatic pressures (punching and root penetration and burst strength), it can absorb deformation caused by rock/structure settlement that should occur during the construction. The Mapeplan TU WL is also in line with SIA V 280. To ensuring the CE certification, the waterproofing systems are tested and in compliance with the UNI EN 13491: 2005: "of Geosynthetic barriers - Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures ".
In table 1 are shown some of the main characteristics of the waterproofing system PVC-P.

Tabuľka 1 Tabuľka vybraná z technického listu produktu MAPEPLAN TU WL, ukazuje niektoré z jeho technických charakteristík

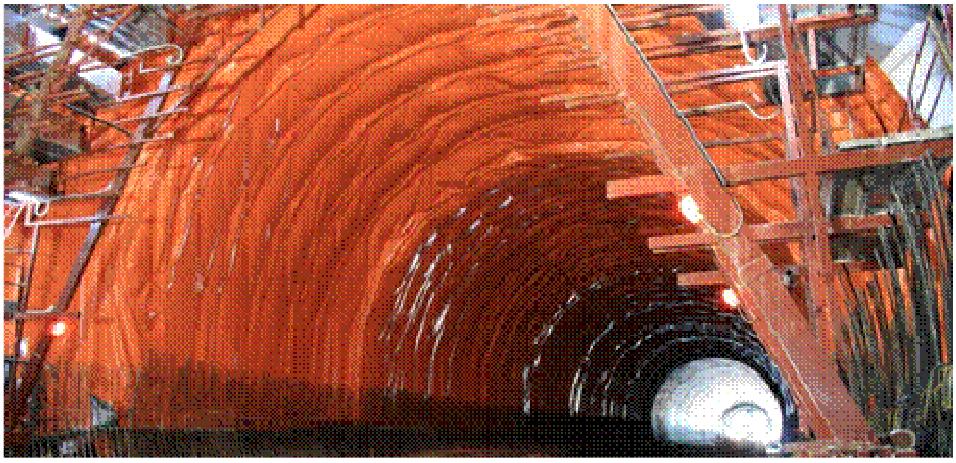
Table.1 Table extracted from MAPEPLAN TU WL Technical Datasheet showing some of the technical characteristics

MAPEPLAN TU WL				
Thickness (included warning layer) (mm)	1.5±5%	2.0±5%	2.5±5%	3.0±5%
Standard roll length (m)	20 (-0/+5%)	20 (-0/+5%)	15 (-0/+5%)	15 (-0/+5%)
Width (m)	2.00/2.10 (-0.5/+1%)			
TECHNICAL CHARACTERISTICS				
Tensile strength at break (ISO R 527) (MPa)	15(±2)	15(±2)	15(±2)	15(±2)
Elongation at break (ISO R 527) (%)	250±10%	250±10%	250±10%	250±10%
Resistance to tearing (ISO 34) (kN/m)	≥45	≥45	≥45	≥45
Puncture CBR test (UNI EN ISO 12236)(kN)	≥2	≥2	≥2.5	≥2.5
Water permeability (EN 14150) (m^3/m^2)	< 10-7			
Cold bending = - 40°C (UNI EN 495/5)(°C)	No break or crack			
Thermal expansion (ASTM D 696-91)	≤ 130 x 10^{-6} (± 50 x 10^{-6})1/K			
Fire reaction classification (EN 13501-1)	Class E			

MAPEI synthetic waterproofing membrane, thanks to the high quality standards of production, has in addition the following characteristics:

- Resistance to mold, funghi and bacteria (microbial resistance).
- Resistance and eco-compatibility with the watertable: also suitable for the contact with water basic and acidic.
- High resistance to cold and current liabilities (50 kV).
- self-extinguishing characteristics in case of fire: Class E (EN 13501-1).
- Resistance to aging and oxidation: the system guarantees the stability in time and if subject to external factors does not undergo change or decreases in technological efficiency.
- Ease of disposal: the product can be sent to an approved landfill or recycling plant for plastics or to an authorized facility incineration, in compliance with local regulations.

The Mapeplan TU WL is also in line with SIA V 280. To ensuring the CE certification, the waterproofing systems are tested and in compliance with the UNI EN 13491: 2005: "of Geosynthetic barriers - Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures ".

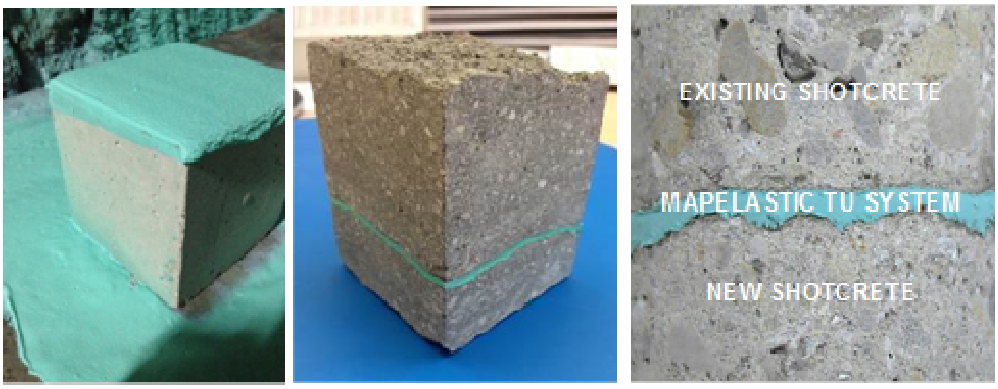


Obr. 3 Príklad realizovania hydroizolácie v tuneli pomocou syntetickou hydroizoláciou

Fig. 3 Example of waterproofing realization in tunnel with the synthetic waterproofing

4 One-component waterproofing system

For waterproofing works in Safety Tunnel Mitholz was also employed one-component membrane elastic waterproofing system based on special polymer according to a formula developed in MAPEI Research and Development Laboratory. It has an appearance of paste, green or white colored, ready to use. The novelty of this special product concerns the innovative application technique. In the case in question, the spray technique proved to be perfectly suitable to all those tunnel sections without major degradation and water seepage problems. In fact, the concrete lining surface did not show visible concrete cracks or water inflows, therefore the membrane was directly applied on the existing shotcrete lining. The Mapelastic TU System provides excellent waterproofing for every type of surface due to its high flexibility. The technology has an high grade of adaptability even in complex geometries (tunnels, by-pass, etc). The product can also be sprayed onto uneven or complex geometry surfaces and on irregular geometries and can be used for shotcrete and concrete, in-situ or precast. It is also compatible with fiber-reinforced concrete (steel, PP). Once sprayed, the Mapelastic TU System forms a flexible barrier and an elastic support, able to minimize the effects of degradation due to aging, to water, to the attack of atmospheric agents, etc. When polymerization is completed, the product ensures high impermeable characteristics and water resistance, on the existing concrete support.



Obr. 4 Detail vzhľadu jednozložkovej pružnej membrány na testovanej vzorke
Fig. 4 Details of the one-component elastic membrane appearance on a test sample and layers

Tabuľka 2 Tabuľka vybraná z MAPELASTIC TU SYSTEM technického listu, v ktorom sú zahrnuté niektoré zo základných technických charakteristík
Table 2 Table extracted from MAPELASTIC TU SYSTEM Technical Datasheet in which are summarized some of the main technical characteristics

MAPELASTIC TU SYSTEM	
Shore hardness (A) after 7 days at +23°C (DIN 53505)	50-55
Tensile Strength (DIN 53504-S2)	
after 7 days at +23°: C = 0.75 N/mm2 (elongation 340%) after 28 days at +23°: C = 1.10 N/mm2 (elongation 290%) after 7 days at +23°: C + 7 days at +70°C +1 day at +23°C = 2.05 N/mm2 (elongation 170%) after 7 days + 7 days in H2O = 0.70 N/mm2 (elongation 400%) after 7 days +7 days in saturated lime water =0.8 N/mm2 (elongation 430%)	
Pull Out test over concrete after 14 days at 23°C and 50 % U.R. (MPa)	≥ 0,75 (cohesive failure)
Resistance to water pressure (EN 14891): 3 mm of MAPELASTIC TU SYSTEM	5 bar per 7d
Reaction to fire classification (EN 13501-1)	B, s2, d0

The one-component membrane elastic waterproofing system is characterized by the ease of application because sprayable and ready to use, cement-free and finds optimal application

through the use of a simple equipment: airless pump and spraying projection equipment with small dimensions. The use of manpower is limited and is not required the continuous intervention of specialized personnel. It does not require any mixing as it is ready to use and does not produce rebound during projection. The high speed of application and the high grade of polymerization can reduce processing times, allowing the cast of the final lining, depending on the environmental conditions even in a short time. In this way, the interferences with other processes presents in the tunnel are reduced (2/3 workers are able to achieve an advancement performance of about 300 m^2/day).
The main characteristics are summarized below:

- Good tensile strength and excellent adhesion properties on every type of support (the value of adhesion between the elastic membrane and the shotcrete layers is ≥ 1 MPa at 28 days).
- High elongation: possesses a remarkable elongation and deformation capability, maintaining good adhesion to the substrate.
- Effective passive barrier to radon (possibly present in the Tunnel).
- Simple equipment use for a fast cleaning with water.

5 Description of the waterproofing works for the safety tunnel Mitholz

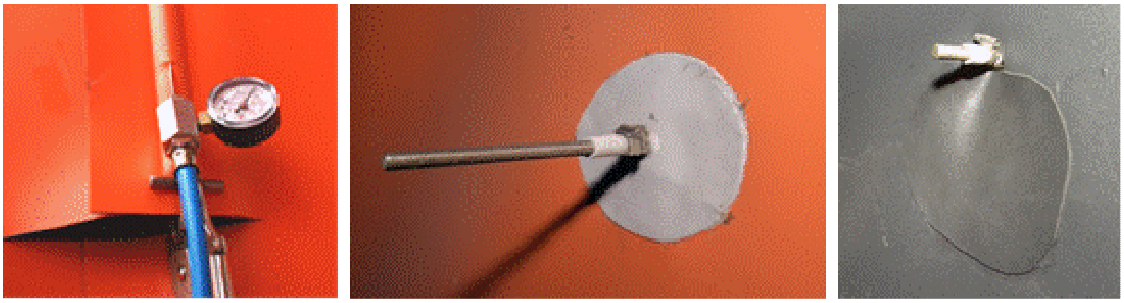
The waterproofing works in the Mitholz safety tunnel, for a total length of about 500 m, lasted about eight months. As already mentioned, they consisted in the application of both the innovative waterproofing techniques: the plastified polyvinylchloride PVC-P synthetic membrane and the one-component sprayable membrane. This was possible thanks to the development of an overlap method between the two systems specifically realized for this case and carried out through properly devices adhesive products.
Figure 1 shows both waterproofing techniques applied for the safety tunnel Mitholz.
The installation of the waterproofing system in PVC-P consisted in the following main stages:

- Installation of stainless steel dowels by means of a pre-drill and chemical fixing
- into the existing lining surface using MAPEFIX PE SF. Application of the first regularization layer: POLYDREN 500 PP in geotextile, (100 % polypropylene (PP) with a weight of 500 g/m^2). Rolls, 2.0-2.10 m in width, are unrolled starting from the crown center down to the tunnel sidewalls for the whole development of the cross-section. Sheets are fixed onto the existing lining surface through MAPEPLAN DISK using a nail gun and arranged in staggered rows. Finally these sheets are fixed in the stainless steel anchors already installed. This first regularization layer is so realized with an overlap of about 8-10 cm between two consecutive sheets.
- Application of Synthetic membrane PVC-P: MAPEPLAN TU WL 21. The membrane chosen for this work is 2.1 mm in total thickness (including signal layer) and about 2.0-2.10 m (± 0.5-1 %) in width. The initial phase of installation and application is to lift the first layer of MAPEPLAN TU WL 21at the centre of tunnel crown and begin to unroll it down to both sides until the tunnel sidewalls. Meantime a worker in the main basket of the telescopic lift provided with a manual welder, welds the layer to each MAPEPLAN DISK (already arranged in staggered rows) continuously checking that the membrane between two point disks is not in tension. The layer is then stuck to the stainless steel dowels. By using an automatic roller-welding machine, the welding of two successive sheets is made with an overlap of about 8-10 cm. Finally the last operation consists to insert MAPEPLAN COLLAR in correspondence of the stainless steel anchors welded to the membrane to seal all points as showed in Figure 6.

To ensure the success of the entire operation, some welding characteristics must be controlled in this phase: temperature, speed and pressure to never interrupting the operation.

The automatic welding equipment makes a double track welding, in order to obtain an air chamber useful for carrying out a welding verification test by pressure trial test. If an irregularity is found, the defective weld point can be detected and repaired using a piece of membrane.

- Application of the protection layer: MAPEPLAN PROTECTION 15 with a black color is made with recycled PVC-P, without internal ribs. The methods is the same as the installation used for MAPEPLAN, then is installed in each stainless steel anchors to finish the works.



Obr. 5 Skúšobné technické testovane a tesniaca technika, MAPEPLAN TU WL s MAPEPLAN COLLAR (vložená do kotvy z nerezovej ocele) a MAPEPLAN PROTECTION 15

Fig. 5 Technical trial testing and sealing technique, MAPEPLAN TU WL with MAPEPLAN COLLAR (inserted in stainless steel anchors) and MAPEPLAN PROTECTION 15

- Application of the protection layer with MAPEPLAN PROTECTION 15. That is the protection layer made with recycled PVC-P, without internal ribs, with a black color. The methods of installation used are the same as MAPEPLAN TU WL 21. Then it was installed in each dowel as shown in FIG.7.
- Application of the welded mesh properly fixed to the stainless steel anchors ready for the last operation of the shotcrete application in a thickness of about 15-20 cm.

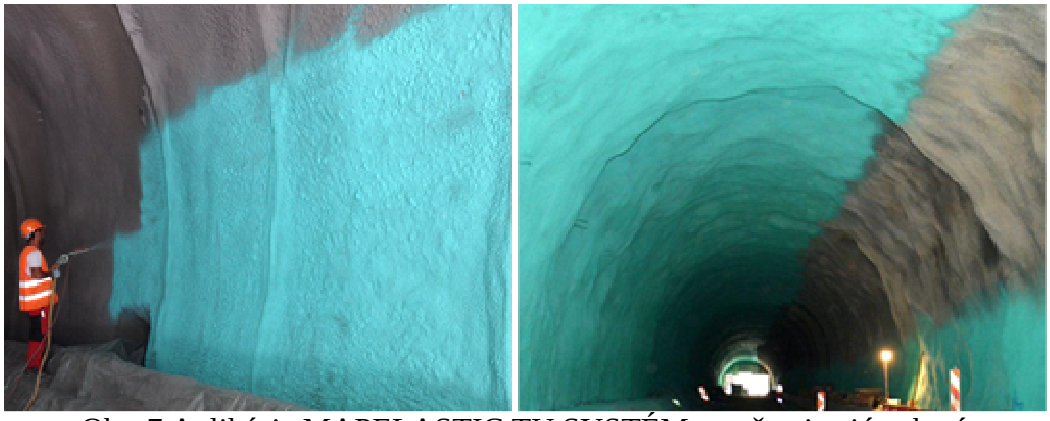
Obr. 6 Pohľad na MAPEPLAN PROTECTION finálnu aplikáciu striekaním

Fig. 6 View of MAPEPLAN PROTECTION for the final shotcrete application

For all sections established in the project, it was realized the application of the waterproofing system with the one-component sprayed membrane with the following main application stages:

- Cleaning the existing support from residual dust to increment the membrane adhesion.
- Restoring the concrete surface with a one-component premixed mortar in those point with high degradation through MAPEGROUT GUNITE 300 AF.

- Application of the sprayable waterproofing membrane MAPELASTIC TU SYSTEM in thickness of about 3 mm.
- Final shotcrete application in thickness of about 15-20 mm for the final lining of the tunnel with the use of MAPEQUICK AFK 777 an alkali free accelerator.



Obr. 7 Aplikácia MAPELASTIC TU SYSTÉM na už existujúcu betón
Fig. 7 MAPELASTIC TU SYSTEM application on preexisting concrete support

6 Conclusions on waterproofing systems

In the case of the safety tunnel Mitholz, all products and innovative technologies used were appropriate to the project requirements and the technical and construction needs. The choice of using both waterproofing solutions was also fundamental for final cost purposes and for managing the entire work.
The overlap technique developed to use both synthetic waterproofing membrane and one-component sprayed membrane has led to a waterproofing system within the tunnel that has proved to be versatile and innovative, able to be used in any situation. Good results in terms of installation timing and production obtained have been achieved, for a total of about 2500 m^2 of MAPEPLAN TU WL 21 and MAPEPLAN PROTECTION 15 and approximately 2500 m^2 for the MAPELASTIC TU SYSTEM.
The progressive affirmation of the two systems described above is based on the effectiveness of the results (as testify by the numerous references) and on the technical characteristics and application techniques, qualities more and more appreciated by the experts in the underground field.

7 References

[1] ITAtech Design Guidance for spray applied waterproofing membranes. ITAtech Activity Group Lining and Waterproofing membranes. Report N°2 – April 2013.