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Case Study: Hydrophobic Compound In Tunnelling

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Abstract

The Swiss San Bernardino Tunnel, built in 1967, undergoes an important renovation work. The state of the tunnel is currently very critical due to the harsh environment (de-icing salt, extreme climatic conditions at 1600 m above sea level etc...). New concrete segments will be placed and to protect them on the outer layer from running water coming from the mountain rock, engineer has decided to apply an hydrophobic compound. As the concrete used is very dense, selection was made on 99 % silane impregnation to insure deep penetration in the concrete. Monitoring of the performances will be carried out over a 10 years period in real life conditions.

1 Background

The San Bernadino Tunnel in Switzerland crossing the Alps was completed in 1967.

The total length of the tunnel is 6 596 m and situated in harsh climate mountain conditions at 1 600 m high.

It is a two lanes tunnel built on top of escape and service galleries. Two parapets made of precast concrete are situated at both sides of the lanes.

Concrete was casted based on the standards available in 1967 and none of the concrete were protected against aggressive elements.

Due to the increase traffic in the tunnel, the cars were bringing along them a lot of de-icing salts in the tunnel. Combination of these salts with carbonation of the concrete cover due to the escape gas from the car together with the lack of protection lead to severe deterioration of the reinforced concrete.

However, despite the damage of the various concrete elements, the structural part of the tunnel is still sound.

2 Concrete repair strategy

Global program of refurbishment initiated in 1991 and planned to be completed by 2006 is estimated to cost around 236 Million CHF (~150 Million €).

This program includes modification of the air flow, issues of fire safety (measuring as well as device and design) and concrete repair.

This paper will deal with part of the concrete repair strategy.

Concrete Ceiling: Damages did occur only at both openings of the tunnel (over a distance of ~80 meters).

Classical concrete repair using PCC mortars has been selected without additional protective coating.

Base Slab: Existing slab is completely removed, a new one is in-situ casted. The concrete grade is C30/37 and the slab is placed 50 cm lower than the previous.

A waterproofing layer is planned beneath the asphalt surfacing.

Escape galleries: Repair and protected with waterproofing system and efficient draining to evacuate the aggressive water from the mountain.

Concrete Parapet: Due to the state of decay, demolition and replacement was the selected options.

Table 1: Concrete Parapet characteristics

Cement	350 kg/m^3
Grading	0 – 16 mm
Core strength (Ø 50 mm) at 83 days	72,3 N/mm²
Concrete density	2,370 kg/m^3
Pore factors AF	0,116 mm
Frost resistance	Good

Two different protective coatings were required:

- **On the intrado:**
  Epoxy based coating, high resistance to chloride
  Layer thickness > 200 µm
  Resistant to mechanical cleaning - brush and high pressure (> 400 bars)
- **On the extrado:**
  Hydrophobic Impregnation

3 Specification document for the hydrophobic impregnation

Tender document did not give any requirement for the chemical base of the hydrophobic impregnation – requirements were based purely on performances bases.

The particularity of the specification is the time frame of the test data required – up to 10 years.

Table 2: Hydrophobic Impregnation Requirements

	After 1 year	**After 10 years**
Water Absorption (DIN 52617 Modified)	$\leq$ 0,250 kg/m² · h^{0,5}	$\leq$ 0,100 kg/m² · h^{0,5}
Water vapour diffusion	$\leq$ 2,0 m	$\leq$ 2,0 m
Water absorption after alkali immersion	$\leq$ 0,120 kg/m² · h^{0,5} (or at least 50 % of normal water test)	$\leq$ 0,120 kg/m² · h^{0,5}
Penetration	$\geq$ 1,0 mm	$\geq$ 2,0 mm

4 Proposed product and test report

The principal requirements of the product in the tender document was its durability in the time and its ability to penetrate deeply to a fairly dense concrete.

Based on these criteria, a pure silane hydrophobic impregnation was proposed for this application.

A testing program based on the Swiss standard SIA 162/5 was carried out at the LPM laboratory in Switzerland:

- Water absorption – depth profiles (DIN 52 617 Modified)
- Water vapour diffusion (DIN 52 615 Modified)
- Freeze-thaw salt behaviour (SIA 162/1, Testing No. 9 – 50 cycles)
- Alkali resistance (Determination of the water absorption test as per DIN 52 617 modified after 28 days storage in alkali solution at + 60 °C)

4.1 Water absorption tests – depth profiles

The results from the water absorption tests (tables 3 and 4) show a significant reduction of water intake not only at the surface but also up to a depth of 4 to 5 mm in the concrete.

The penetration of the hydrophobic impregnation is further confirmed by measuring the Infra-red spectrum (table 5) at different depth. Using this method, the hydrophobic impregnation has been analysed up to a depth of 5 mm (see table 3, 4 and 5).

Table 3: Water absorption test – depth profiles

Depth profiles	Water absorption coefficient w [$kg/m^2 \cdot h^{0,5}$]			
	1st measure	2nd measure	3rd measure	Average
Surface	0,05	0,03	0,03	0,04
1 mm	0,01	0,01	0,01	0,01
2 mm	0,02	0,02	0,03	0,02
3 mm	0,04	0,07	0,09	0,07
4 mm	0,08	0,09	0,10	0,09
5 mm	0,09	0,12	0,10	0,10
6 mm	0,12	0,13	0,12	0,12

Table 4: Water absorption test – reference sample

Depth profiles	Water absorption coefficient w [$kg/m^2 \cdot h^{0,5}$]			
	1st measure	2nd measure	3rd measure	Average
Surface	0,24	0,08	0,11	0,14

Table 5: Determination of depth profile using the FT IR-method

Depth profiles	Area of peak at 2956 cm^{-1}
1 – 2 mm	11,3
3 – 4 mm	10,5
4 – 5 mm	12,2

4.2 Water vapour diffusion

The average diffusion equivalent air layer thickness of the treated specimen is 2,7 meter (non treated concrete: 1,6 m)

The diffusion equivalent layer S_d brought by the hydrophobic impregnation is then: 2,7 m – 1,6 m = 1,1 m

The standard SIA 162/5 required for a surface applied system (OS 1) an equivalent air thickness S_d lower than 4 m.

Table 6: Water Vapour Diffusion

Treated specimen	Sample thickness [mm]	Water vapour diffusion resistance value μ	Diffusion equivalent air layer thickness S_d [m]
1 2 3	13,6 13,6 13,4	190 200 210	2,6 2,7 2,8
Average	13,5	200	2,7
Reference concrete	13,4	120	1,6

Table 7: Weight Loss after Freeze-thaw salt load

Weight loss after 50 freeze-thaw salt cycles	Average loss of dry mass m 50 [g/m²]
Sample	30
Reference	80

Table 8: Alkali Resistance

Depth profiles	Water absorption coefficient w ($kg/m^2 \cdot h^{0,5}$)			
	1st measure	2nd measure	3rd measure	Average
Surface	0,03	0,01	0,02	0,02

4.3 Freeze-thaw salt behaviours

The standard SIA 162/5 required for a surface applied system (OS 1) to show a reduction in the mass loss after 50 freeze-thaw cycles. That is comply with the product tested as the average mass loss of the treated specimen is lower than the non treated concrete (refer to table 7).

4.4 Alkali resistance

28 days immersion in alkali solution has not affected the treated specimen as the results of table 8 show equivalent water absorption as for the test carried out on normal storage (see table 3 also).

5 Conclusion

Data presented are indeed not from specimen exposed to the required timing. However as the results well exceed all requirements, the product was selected.

Test panels were erected at the site and application of the product was performed on June 2004. Concrete was then ~28 days old. Concrete will be analysed based on the requirement after 1 and 10 years exposures to the tunnel conditions. This project will be the perfect opportunity to monitor the evolution of performances of this product in real traffic conditions

6 References

[1] LPM report A-25'198-1E

[2] LPM report A-21'699-6E