Hydrophobe VI
6th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 15 - 22 (2011)

Water-Repellent Silanes Protect the Concrete Ceiling of the Gotthard Road Tunnel

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Abstract

Under a vast massif of gneiss and granite, the flow of traffic in the Gotthard Tunnel seldom abates. Every year, millions of trucks and cars pass through the 16.9-kilometer road tunnel – the third longest in the world. In winter, they carry some undesired freight into the structure: salt water, which gets deposited on the roof and walls of the tunnel. Over the years, the intrinsic porosity of the concrete enables the chlorides to penetrate further and further into the concrete. Despite its durability, concrete can be seriously damaged by corrosion of the steel reinforcement. Fortunately, the ingress of chloride ions into concrete can be prevented by impregnation with water-repellent silanes.

Traffic logistics mean that the Gotthard Tunnel, as a heavily used road infrastructure, can only be closed for a short period, so the repairs are a race against time. Starting from both ends of the tunnel, 7,000 m² of ceiling surface were treated with a silane-containing cream product in only a single night. This suspended ceiling is a delicate structural element inside the Gotthard Road Tunnel and must withstand all environmental influences for the next two decades. This paper gives an overview of the implemented protective measures and further information on quality control.

Keywords: concrete, water repellent, silane, durability

1 Introduction

The Alps may present a fabulous panoramic backdrop for skiers, but they are a real nuisance to traffic. In 2008, about 1.27 million trucks crossed over the four major Alpine passes in Switzerland alone. Much of the burgeoning stream of traffic also flows underground through tunnels. The Swiss Alps are permeated by several road tunnels. Of these, the St. Gotthard tunnel is by far the longest, and carries the heaviest burden of traffic. Closing off an extremely busy artery like the Gotthard tunnel is like obstructing a blood vessel – and the results can be similarly devastating: there is a serious risk of congestion.

The Gotthard tunnel lies at the heart of the most direct road link between the North Sea and Southern Italy. The flow of cars, buses, and trucks under the legendary massif of gneiss and granite rarely comes to a standstill. Vehicles have been passing through the 16.9-kilometer tunnel since 1980, carrying holiday-makers, auto parts, and electrical goods from north to south, and hauling tomatoes, machinery, and textiles back from Italy to Germany, the Netherlands, and Denmark. Every year, some 750,000 trucks alone trundle through the single-lane corridors in the depths of the Gotthard massif.

And every winter, these vehicles unintentionally transport additional freight into the tunnel – salt water. For the spray thrown up from the wet road surface by millions of tires splashes directly onto the roof and walls of the tunnel. The deposited salt attracts more water, and the constantly damp conditions favor its slow penetration into the concrete. Over the years, the porosity of the concrete enables the chlorides to eat their way further and further inside. Once salt-laden moisture makes contact with the reinforcing steel bars, an ominous corrosion process is set into motion.

Usually, the pH of concrete is high enough to protect the steel. But it is powerless against chlorides, which cause pitting corrosion of the rebar. As this corrosion quickly spreads, the metal starts to dissolve causing the pH to fall and thus accelerates the corrosion process. Because corroded steel is bulkier, pressure builds up inside the concrete and forces parts of it to eventually break off. This can have serious consequences: an accident could occur if pieces of concrete suddenly start raining down from the roof onto vehicles traveling at 80 km/h. Preventing this is the goal of the maintenance measures.

2 First protection strategy

Since 2002, therefore, a special “Suspended Ceiling" working group at the Swiss Federal Roads Authority (ASTRA) has been keeping tabs on the structural condition of the Gotthard tunnel, initiating repairs as needed. In 2006, it instigated rehabilitation work to the entrances, treating some 250

meters at each end of the tunnel with a water repellent. The concrete was impregnated with an active ingredient that lines its pores and renders them water-repellent while retaining their vapor permeability. The concrete thus continues to breathe. Concrete impregnated with a water repellent thus retains its special properties. It is still adequately protected, even if the surface is cracked, for example. This is a major advantage over protective coatings that form a surface film. Coatings of this kind are apt to delaminate or crack because water from within cannot escape from the surface and soon lose their protective effect.

Measurements and online monitoring of corrosion currents showed that these steps greatly reduced the extent of corrosion. It was therefore decided to impregnate a further 750 meters on each side of the tunnel with water repellent.

Structural and rehabilitation work of this kind requires extensive preparation and safety precautions, both of which are very costly and almost impossible to do while the tunnel remains open. This is especially true of the busy Gotthard tunnel, which can only be closed for brief periods because of the huge volume of traffic.

For this reason, the tunnel operators opted for deep impregnation and arranged for more than 7,000 square meters of ceiling to be impregnated with silane in a single night. This protects the concrete ceiling against ingress of salt water.[1] It has been shown that a cream containing alkylated silanes is the best product for such tasks.[2-3] Unlike conventional liquid products, they can be applied in the right thickness at one go. The substrate's porosity determines how quickly the active ingredient can penetrate. This was a key argument for the decision to use silane cream product in the Gotthard tunnel. After all, time was of the essence.

3 Preparation of the tunnel ceiling

Prior to applying the water repellent, the experts had to prepare the roof properly.

The first step was to clean the suspended ceiling in the entrance area at both ends of the tunnel. All dirt was hydrojetted off with water pressure between 280 to 520 bar. Gravel nests, steel reinforcement close to the surface, and other imperfections in the ceiling were marked and retreated with a special hydrojetting method that uses a water pressure of about 2500 bar.

The next step was to replace the missing concrete. After application of a protective coating to the exposed reinforcement, repair mortar was sprayed onto the open areas and then smoothed over. The quality of the finish was checked after the concrete had hardened by testing the pull-off

strength of the mortar at selected points. Since penetration of the silane cream depends on the quality of the concrete substrate, a few test areas were treated with the cream.

Figure 1: Tunnel roof after the cleaning and concrete repair work

Only then could the waterproofing begin. Everyone knew the stakes were high – just one night had been allocated for the job. There was no question of overrunning this schedule, since the traffic had to flow promptly again in the morning. Work was carried out during the night so that the tunnel traffic did not have to be permanently stopped. The Gotthard Tunnel was closed between 8 p.m. and 5 a.m for four nights over three weeks. Before each reopening, the roadway had to be completely cleared and cleaned. Everyone had to keep to the time schedule: the lane closure times had to be strictly observed by the companies doing the work.

4 Application of the impregnation

All systems stopped: at precisely 8 p.m. on September 21, 2009, the tunnel was closed for the application process. Work started simultaneously on the northern and southern entrances. The workers at both ends of the tunnel had until 4.30 a.m. to finish the job because the traffic could not be held up for any longer.

With all the precision of a Swiss watch, the repair gangs swung into action. As soon as the last truck had exited, some two dozen workers dressed in protective clothing and high-visibility jackets began “Operation Gotthard” at both entrances. First, painters and concrete repair specialists covered the entire roadway with special matting using unrolling equipment. In three hours, they covered 7,000 square meters of road at both ends. The spray mist containing the silane cannot be allowed to get onto the road surface because that would make it slippery and cause drivers serious problems. In addition, traffic signals and measuring equipment had to be protected against the spray.

Figure 2: Unrolling the matting to cover the road inside the Gotthard tunnel

After everything had been covered, the high-tech spray guns at each end of the tunnel got to work: these automatic sprayers traversed the 750 meters of tunnel in two passes. The multiple nozzles covered the roof with about 330 grams of material per square meter. Because it is a paste, it can be applied much more thickly. The cream adheres to the surface better, and that enables more of it to penetrate into the concrete. The silane cream has a long contact time and is designed to ensure maximum penetration of the concrete by the active ingredient. The depth to which the waterproofing agent penetrated the concrete was examined by materials experts during quality control measures after the treatment. The goal of deep impregnation with the silane cream ingredients is to penetrate to a depth of about six millimeters, to provide a water-repellent lining within the concrete pores and to keep out saltwater.

Figure 3: Multinozzle sprayer in action

After around five hours of loud hissing, the job was complete: the workers sprayed around four-and-a-half metric tons of material onto the ceiling. The tunnel ventilation system was running at full blast to dry the roof, not stopping until the silane cream had penetrated. Then the workers quickly

removed the sheeting from the road and cleaned up the site. At 4.04 a.m., the construction gang left the tunnel, 25 minutes ahead of schedule.

At precisely 5 a.m., it was all systems go: the column of trucks started to move through the heart of the mountain. It was a risky undertaking, and everyone had to work at full speed.

5 Quality assurance

Various quality assurance measures were carried out while work was in progress. All process materials were checked with regard to their suitability, type, and quantity every day. The participating companies also continuously monitored and logged the work. To verify the protective effect of the applied repair mortar, its adhesive tensile strength was checked by tests in selected areas. Furthermore, several drill cores were taken about 6 months after the treatment. These provided proof that the hydrophobic impregnation complied with the specified quality. The suspended ceiling is also routinely monitored. Further tests on the efficacy and durability of the hydrophobic impregnation are planned.

6 Outlook

In general conventional repairs to concrete structures, such as tunnels and bridges, can cost ten times as much as preventive measures such as hydrophobic impregnation. For this reason, we recommend preventive hydrophobic treatment of new structures as a matter of course. This innovative technology can greatly reduce the amount of necessary repair work – and so avoid high costs and consumption of energy and resources.

However, with a thirty-year-old structure like the Gotthard tunnel, the only economical way to prolong its lifetime is through a combination of repair measures at the damaged areas and protection of the ceiling by hydrophobic impregnation.

Andreas Gerdes is Professor at Karlsruhe University of Applied Sciences and head of the Department of Chemistry of Mineral Surfaces and Sensor Technology at the Institute of Functional Surfaces at Karlsruhe Institute of Technology (KIT). He is convinced of the economic benefits offered by such preventive measures. Gerdes also advocates prophylactic surface protection for concrete structures and is convinced that the long-term savings for the developer can be immense.[4] After all, actual construction work accounts for only about 20 % of the repair costs. Most of the money goes into the accompanying measures, such as traffic diversions and the setting up and cordoning off of the construction site. Selective prevention makes for longer intervals between periodic renovations – and that cuts the overall costs for developers and operators.

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