INTERNATIONAL EDITION

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# Tunnels
AND TUNNELLING

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*Excavating Europe's latest high-speed rail line*


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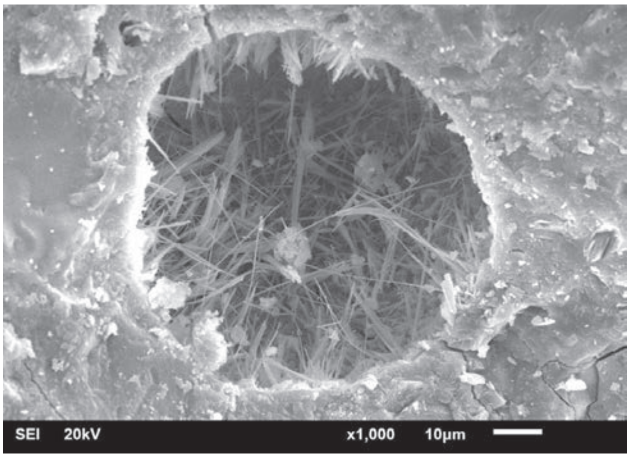
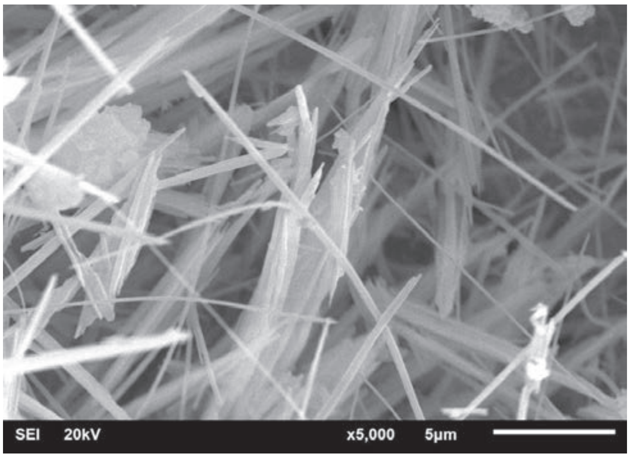
# WATERPROOFING CRYSTALLISED

**Chris Miller,** Director of International Business Development for Xypex Chemical Corporation, explains how it is possible to achieve watertight tunnels using crystalline waterproofing technology




*Above: Electron microscope images of Xypex crystallisation at 150mm below the surface of treated concrete, magnified 1000x (left) and 5000x*

MANY OPTIONS WERE CONSIDERED FOR waterproofing the 292m-long, two-lane cut-and-cover tunnel moving pedestrian traffic away from the ferry terminal at Bremerton, Washington, US. Ultimately, the design team chose to forego membranes and coatings and instead included crystalline waterproofing admixture in the concrete for the cast-in-place tunnel.

The onsite project engineer for Washington State Department of Transportation (WSDOT) had concerns about traditional waterproofing methods. The tunnel was to be built in a high water-table area and would need to be watertight along its entire length. The close working conditions and varying shoring techniques for the 9m-deep x 304m trench would have required a blind waterproofing system for the walls and slab. In addition, the extensive rebar for the base slab and the 3m of backfill raised the risk of damaging a membrane or coating and making the system difficult to repair.

By integrating crystalline waterproofing technology directly into the concrete as an admix for this road tunnel, the builders not only provided the city with the lowest possible long-term maintenance and low operating costs, but also minimised scheduling conflicts and reduced head count on the job by moving waterproofing offsite to the ready-mix provider.

## THE PROBLEM WITH WATER PENETRATION

Tunnels are inherently vulnerable to many natural and manmade threats to their structural integrity, longevity, and ongoing operation. Depending on their depth, they are especially susceptible to groundwater intrusion at varying pressures; this makes waterproofing and drainage strategies a critical part of tunnel design and construction.

Whether a tunnel is single or double wall, segmentally lined, sprayed concrete, or cast-in-place, ground water intrusion over time can lead to reduced life-span, corrosion of reinforcing steel, unsafe traffic conditions and challenges from freeze-thaw cycles.

Tunnels used for sewage storage and conveyance—such as combined sewer overflow (CSO) correction – are often built in densely populated areas where groundwater protection is of vital concern. These tunnels must be able to resist both positive and negative water pressure to prevent potential ground water contamination and inflows through the liner, both of which would compromise the CSO's function

## KEEPING WATER OUT

In almost every case, tunnels must include a waterproofing system to prevent:

- Groundwater and runoff from causing flooding;
- Structural damage;
- Contamination of contents, and
- Creation of unsafe travel conditions.

The type of waterproofing system and the way it is installed, will depend on the tunnel construction method.

## MEMBRANES

When a membrane is breached, pressurised groundwater can flow along the tunnel liner until it emerges through a concrete joint or crack some distance away from the penetration point. Even if the joint or crack is repaired, pressurised water will continue to flow along the concrete lining until it reaches the next faulty area, thus creating a potentially lengthy and continuous repair process.

Membranes can also present challenges where sprayed concrete primary linings are used, as they are generally most effective if planar surfaces are prepared, requiring an additional step in the waterproofing process. Poor installation of the membrane can result in inconsistent shotcrete consolidation and rebound pockets in the concrete. Indeed, shotcrete's high velocity can force open membrane seams, providing further leakage potential. Where membranes require anchoring, the multiple piercing brings additional leakage possibilities.

## SPRAYED MEMBRANES

Sprayed membranes or liquid coatings, such as ethylene vinyl acetate, epoxy or methyl methacrylate provide further waterproofing alternatives. Unlike preformed sheet membranes, they do not require anchoring, making them less expensive and faster to install. But they require surface preparation, curing time, high-quality workmanship and cannot withstand active water-flow during the curing process. Other drawbacks can include pinholes, de-bonding under hydrostatic pressure, and thermal changes which can cause shearing between concrete and membrane as they each have different physical properties.

Bentonite membranes and panels have self-healing capabilities and more flexibility than sprayed coatings or preformed sheet membranes. Although they do not require any special tools, they are labour intensive and difficult to install. If not under constant compression they can lift away from the concrete surface allowing water ingress. A common issue for all barrier systems can be manifested after installation and commissioning, when repairs are impossible, and replacement after failure requires excavation.

## CRYSTALLINE WATERPROOFING

Crystalline waterproofing products are made up of Portland cement, very fine treated silica sand and proprietary chemicals. They exploit the chemical nature of concrete to make it waterproof. Such products also endow concrete with self-healing abilities to remedy hair-line shrinkage cracks.

Crystalline waterproofing reacts with moisture and the by-products of cement hydration to form mineral-based dendritic crystalline structures that are insoluble in water. The formation of crystals in concrete pores, cracks and other voids is a gradual, on-going process which allows the crystals to reach maturity – a process usually taking between several days to a couple of weeks.

As the crystals grow across the diameter of the concrete pores, they form a microscopic, mesh-like barrier that blocks the flow of liquids, even under extreme hydrostatic pressure. This barrier – a characteristic of crystalline waterproofing – inherently improves the durability and performance of concrete structures, lowers maintenance costs and extends longevity by protecting against the effects of water ingress and aggressive chemicals, such as chlorides and sulphates.

Whether added to new concrete as an admixture, or surface-applied as a slurry coating for repairs or as a waterproofing treatment, crystalline waterproofing works in the same way. It becomes a permanent part of the concrete and will continue to work for the life of the structure, preventing the ingress of water from any direction and sealing static hairline cracks and pores up to 0.4mm. When applied as a coating to concrete and moist-cured for 2–3 days, the active chemicals in crystalline waterproofing diffuse into the concrete surface.

Crystalline waterproofing is increasingly used in various types of tunnel. This includes both cast-in-place concrete and sprayed-concrete liners where the shoring system can be secant/tangent, soldier or sheet piles. For cut-and-cover tunnels, crystalline waterproofing has also been included in thick-section matt slabs. In bored and mined tunnels, it has been used successfully in precast segmental linings as well as shotcrete. Various metro projects have taken advantage of this technology to waterproof station boxes and maintenance halls. A recent trial on the use of crystalline admixtures in cement grouting applications has also given positive results

Regardless of waterproofing system used, crystalline technology is used in the repair of both new-build and existing tunnels. Crystalline coating systems allow the waterproofing of tunnels from the inside. Plugging and mortar systems have also been developed permitting the economical and immediate sealing of active leaks and the repair of poorly consolidated concrete. In slurry walls and secant/tangent piles, crystalline repair systems have been used for both remediation and leakage prevention, as well as for joints and cracks in sprayed or cast-in-place concrete liners.

In some below-grade projects where building codes or traditional practices require the use of membrane or coating systems, crystalline admixtures can be included in the concrete in conjunction with these systems. Cost savings and construction schedule reductions are also possible by using crystalline technology. In one study, the technology was compared to membrane systems for the waterproofing of 3,700m$^2$ of tunnel arches and 60,000m$^2$ of wye/crossover arches. It was estimated that the use of crystalline technology would eliminate 660 shifts from the project and achieve US$10m of direct cost savings.

Today, many tunnel projects have an expected life-span of 100 years or more. The use of crystalline waterproofing and protection technology can help extend the life of concrete structures and reduce ongoing maintenance costs.

## COMPLETED PROJECTS

### *Thames Tideway, London*

London's new 'super sewer', the Thames Tideway Tunnel, aims to prevent millions of tonnes of sewage infiltrating the River Thames. Xypex was used within the west section of the tunnel and is the sole waterproofing in the Hammersmith Connection

Tunnel. During the design phase, technical discussions were held to explore how crystalline technology could assist in reducing concrete permeability – especially important across the construction joints. Trials were undertaken to establish how the technology behaved within the very specific mix design and to prove its water tightness over standard tunnel construction methods. A number of trials were set up with and without Xypex products for a clear comparison. The trial results proved that the addition of Xypex C-Series Admix to the concrete gave the greatest protection against permeability. The growth of the crystals across the joint gave a seal in excess of what was thought possible. Cores were also taken through 45° degree day joints in three-axes to test for water permeability. The results confirmed the effectiveness of the technology.

The west section was originally planned to be constructed using a sprayed concrete primary liner and a cast-in-place secondary liner with a waterproof membrane in between. The addition of Xypex C-Series Admix to the primary liner meant that following the trials, the stakeholders were sufficiently confident to remove the membrane in the Hammersmith connection tunnel and throughout the whole of the west section.

In addition to self-healing cracks up to 0.4mm, Xypex can also provide durability against aggressive chemicals and microbial induced corrosion (MIC). More than 100,000kg of Xypex C-Series Admix was incorporated into the sprayed-concrete primary liner, followed by the secondary liner cast directly against it. In the Hammersmith Collector alone, time savings of seven weeks on the tunnel and eleven weeks on the drop shaft were achieved.

### Mitchell Interchange, Wisconsin, US

The I-94 North-South Freeway is one of Wisconsin's most important transportation corridors and was in need of a major re-structuring to significantly reduce congestion and improve travel safety. A critical component of the project is the Mitchell Interchange which includes three separate cut-and-cover tunnels. The tunnel walls comprised a combination of secant piles with shotcrete facing. Xypex Crystalline technology was used for waterproofing prior to the walls being tiled.

### Blacklick Creek Sanitary Interceptor sewer tunnel, Columbus, Ohio, US

This US$108.9m project for the City of Columbus featured a 3.05m-diameter sewer tunnel around 7km long and at depths of between 12 to 42m. Mainly TBM-excavated and segmentally-lined, the tunnel also included a short section constructed by open-cut prior to its launching. In order to protect the precast concrete segments from microbial-induced corrosion and the harsh environment, the specification included Xypex to improve the acid resistance of concrete and provide protection against sulphate attack. Thanks to labour- and time-saving measures such as integrated offsite waterproofing and protection with Xypex Admix, the project was substantially completed by April 2019, 436 days ahead of schedule.

### Vuosaari Harbour Tunnels, Helsinki, Finland

Two 1.6km road and rail tunnels have been drilled and blasted through solid rock near the Vuosaari harbour, Helsinki. They were reinforced with rockbolts and coated with a base layer of 60-80mm of standard shotcrete on which a drainage tube system was installed. A second, 40-60mm layer of shotcrete mixed with Xypex Admix C-1000 NF was applied to provide a permanent seal against moisture intrusion. Finally, a 25mm inner layer of standard shotcrete was applied. Now, more than 10 years after the opening of the tunnels, the treated shotcrete continues to prove its effectiveness.

### Ankara Metro Extension, Turkey

Faulty installation of the original membrane on metro lines KIZILAY – ÇAYYOLU (M2) and BATIKENT-SINCAN (M3) which opened in 2014 resulted in significant water ingress at 12 stations. To repair active leaking joints and wider cracks, Xypex Patch 'n Plug was used, followed by the concentrate applied to the entire wet concrete surface to achieve a waterproof structure. The diffusion process enables the crystalline chemistry to enter and react with the concrete to fill cracks, voids and capillaries.

### Ho Chi Minh City Metro, Opera House Station

Xypex Concentrate was used as the primary waterproofing system for the diaphragm wall at Opera House Station on metro Line 1 in Ho Chi Minh City, Vietnam. Defects and spot leaks in the wall were first repaired with Xypex Patch 'n Plug followed by the concentrate sprayed in two coats over the full depth of the structure.

## CONCLUSION

Every tunnel project relies, to some degree,on concrete as a major component. While strong and durable, it is not inherently waterproof. Crystalline waterproofing can be added directly to concrete during batching, incorporated into precast tunnel segments, in cast-in-place linings, and sprayed-on linings. Formulated to prevent water penetration from any direction, even under extreme pressure, it can also provide additional protection from common corrosive chemicals and elements.

*Above: Thames Tideway: early technical discussions explored how crystalline technology could reduce concrete permeability*