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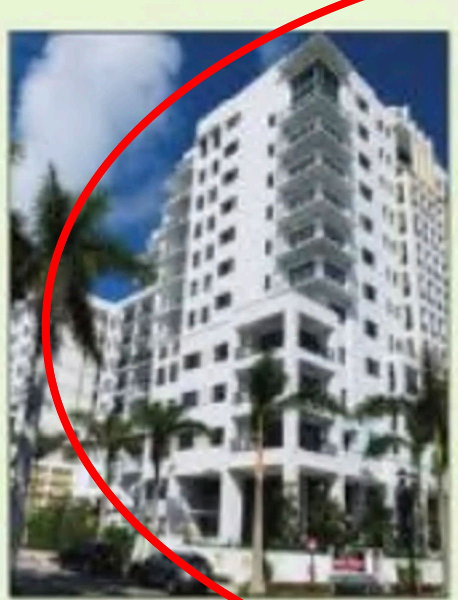
volume 73 . number 12 . december 2020



ON THE COVER

The parking garage at Tower 155, Boca Raton, Florida, is two levels below grade with the presence of extreme hydrostatic pressure. The area's water table is 1 m (3.5 ft) below the ground level, so making sure the structure is watertight was extremely important. Due to space constraints and a difficult installation process, a crystalline waterproofing system was used on this project.

Photo courtesy Xypex Chemical Corporation

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DEPARTMENTS

Crystalline Waterproofing and Protection for Concrete

by Dave Ross

All images courtesy Xypex Chemical Corp.

CONCRETE HAS BEEN USED FOR THOUSANDS OF YEARS AND IS THE MOST WIDELY EMPLOYED BUILDING MATERIAL IN THE WORLD. ACCORDING TO THE CEMENT ASSOCIATION OF CANADA (CAC), MORE THAN TWICE AS MUCH CONCRETE IS USED IN CONSTRUCTION AROUND THE WORLD THAN THE TOTAL OF ALL OTHER BUILDING MATERIALS, INCLUDING WOOD, STEEL, PLASTIC, AND ALUMINUM.

Yet, despite its apparent solidity, strength, and durability, concrete is porous. It is also and permeable to fluid and vapor infiltration and migration. Water and dissolved chemicals, such as chlorides, sulfates, and acids, can penetrate deep into concrete, sometimes resulting in premature damage, such as reinforcing steel corrosion, freeze/thaw cracking, spalling, and chemical attack.

Added to this 'natural' porosity is the fact newly poured concrete develops cracks. This can be due to excess water, rapid drying, improper strength, settlement, and shrinkage. When it comes to building foundations, elevator pits, water/wastewater treatment and water containment structures, and many other applications, waterproofing and protecting the concrete is critical.

The porous and permeable nature of concrete

Concrete is a mixture of rock, sand, cement, and water. Rock and sand form the aggregate base of the concrete. The mixture of the cement and water provides a paste, which binds the aggregates together. As the cement particles hydrate and form calcium silicate hydrates, the whole mixture hardens into a solid, rock-like mass.

To make this mixture workable, easy-to-place, and consolidate, more water than necessary is used to hydrate the cement. This extra water, known as the water of convenience, bleeds out of the concrete, leaving behind pores and capillary tracts.

Despite the use of admixtures to reduce the amount of water in the mix, pores, voids, and capillary paths still form in concrete. These pathways carry water and aggressive chemicals that can corrode steel reinforcement and deteriorate the concrete, thus jeopardizing the structure's integrity.

Porosity

Porosity is the amount of holes or voids left in concrete, expressed as a percentage of the total volume of a material. Since it is porous, concrete is also permeable.

Permeability

A broader term than porosity, permeability is an expression of how well the voids are connected, providing the ability of water to flow through a material. Together, these pathways allow the movement of water into and through the concrete. Permeability is described by a quantity that is known as the 'permeability co-efficient,' also called Darcy's Co-efficient. The water permeability of concrete is a good indicator of its quality and durability. The lower the permeability co-efficient, the more impervious the concrete and the higher its quality and performance. Nevertheless, concrete with low permeability may still need a waterproofing agent to seal micro-cracks.

It is possible to reduce the permeability of concrete with certain admixtures. These admixtures can be divided into three categories per the American Concrete Institute (ACI) 212.3 R-10, "Report on Chemical Admixtures":

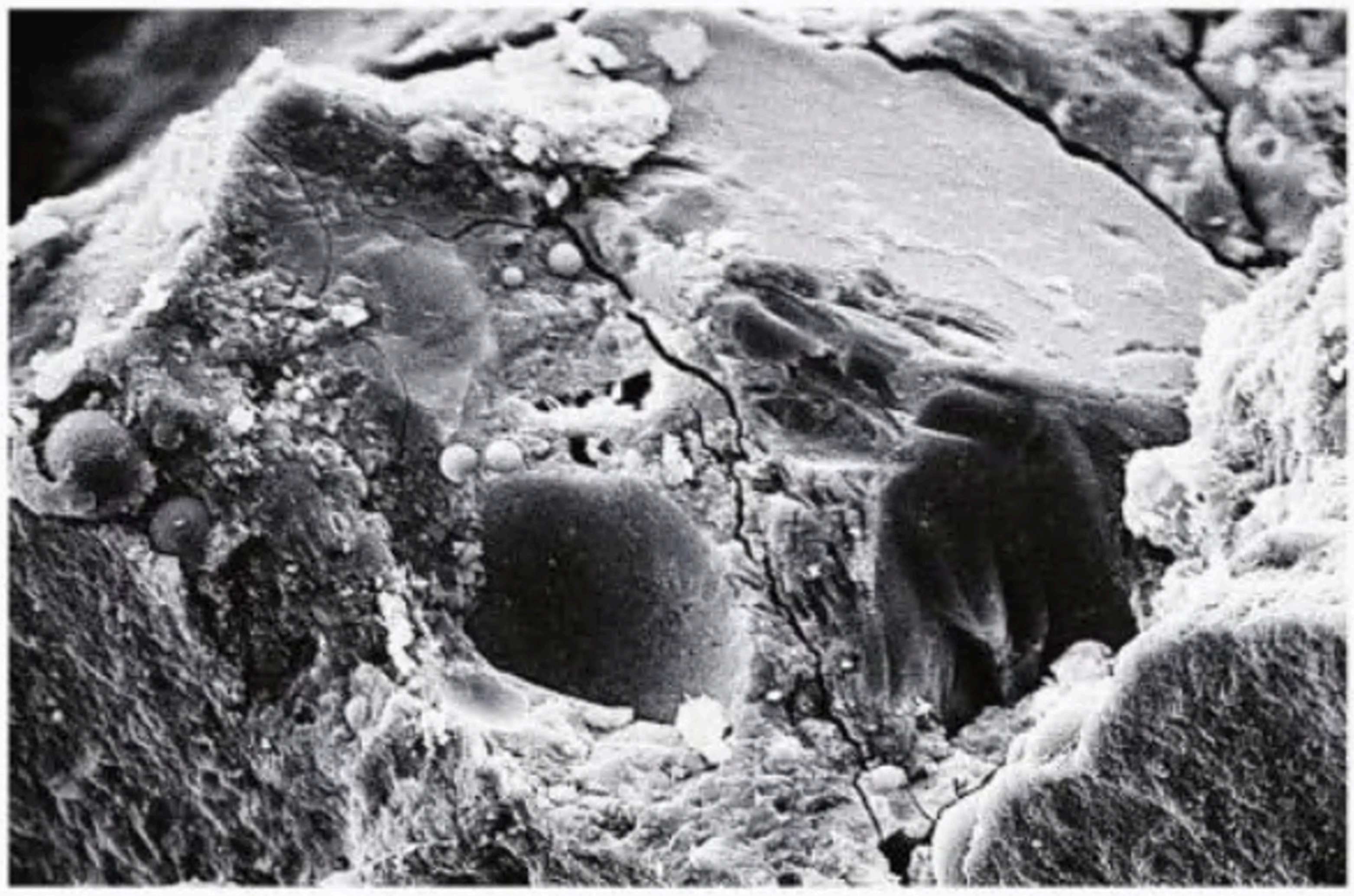
• hydrophobic or water repellent admixtures;
• mineral fillers such as talc, bentonite, and clays; and
• crystalline admixtures.

Vapor flow in concrete structures

Water can also migrate through concrete in the form of vapor. The flow travels from high vapor pressure, generally the source, to low vapor pressure by a process of diffusion and can vary based on environmental conditions.

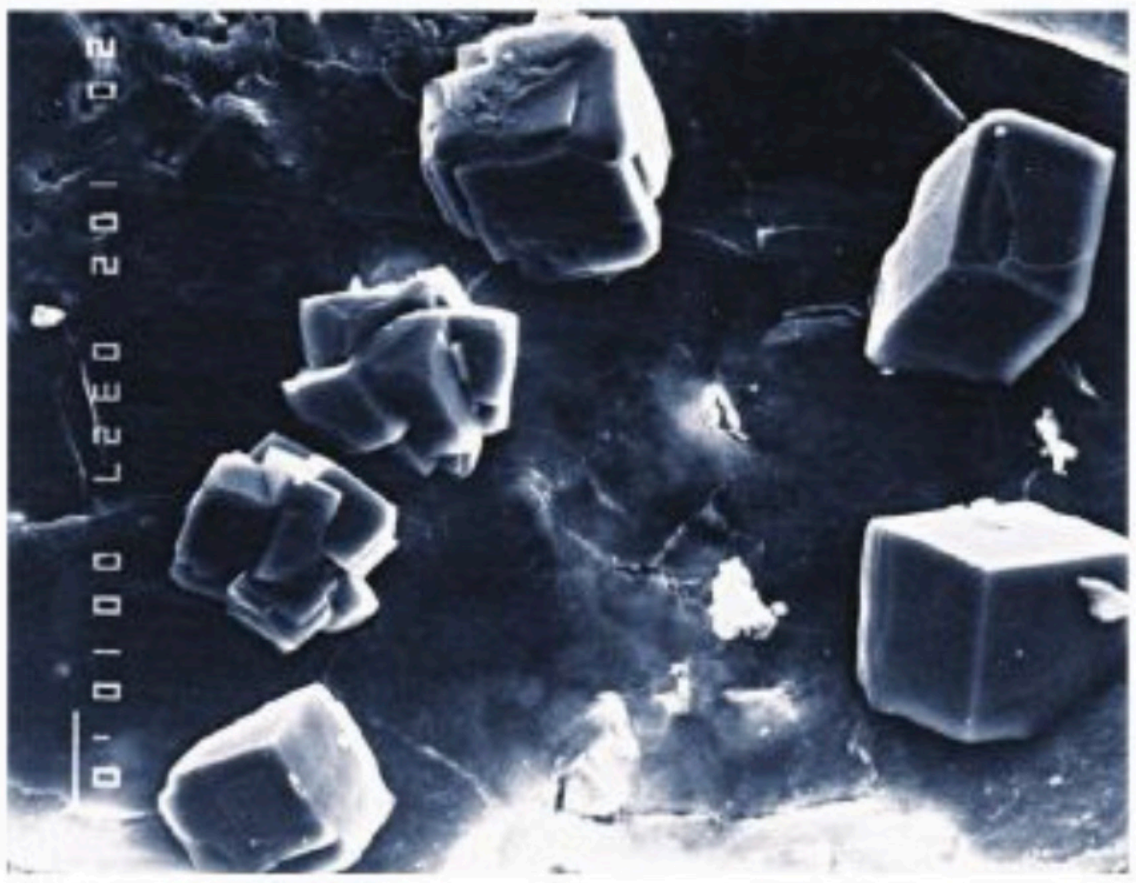
Vapor flow direction is critical when applying a waterproofing treatment in situations where an unbalanced vapor pressure gradient exists. Some typical examples of this are as follows:

• applying a low vapor permeable membrane, such as a traffic deck coating over a damp concrete surface (even if the very top surface is dry) on a warm day results in vapor pressure buildup and pin-holing or blistering;
• adding a coating or sealant to the outside of a building wall may trap moisture if the sealant is not sufficiently vapor permeable; and
• installing low vapor permeable flooring over a slab-on-grade with high subsurface moisture content may result in delamination.



Magnified view of micro-crack.

As a general rule, a coating with low vapor permeability should not be placed on the downstream face (negative or dry side). Either vapor or water pressure will 'push' the coating from the surface, causing it to blister. Some types of coatings (*e.g.* cement-based ones) and water permeability-reducing admixtures accommodate considerable vapor movement, thus allowing them to be placed successfully on the downstream side.



Scanning electron microscope (SEM) view of a concrete pore.

SEM view of a concrete pore as it fills with multiplicative crystalline formation.

How crystalline waterproofing works

Crystalline waterproofing technology improves the waterproofing and durability of concrete by filling and plugging pores, capillaries, and micro-cracks with an insoluble, highly resistant crystalline formation. The process is based on two simple properties—one chemical and the other physical.

Concrete is chemical in nature. When a cement particle hydrates there is a reaction between water and the cement, which causes it to become a hard, solid mass, but there are also chemical byproducts given off that lay dormant in the concrete.

Crystalline waterproofing introduces a second set of chemicals. When these two groups are brought together (*i.e.* the byproducts of cement hydration and the crystalline chemicals) in the presence of moisture, a reaction takes place, resulting in the formation of an insoluble crystalline structure.

This crystalline structure can only occur where water is present, and thus, will form in the pores, capillary tracts, and shrinkage cracks in concrete. Wherever water can penetrate the concrete, the crystalline formation will follow.

When crystalline waterproofing is applied to the surface as a coating, a process called chemical diffusion takes place. The theory behind diffusion is a solution of high density migrates through a solution of lower density until the two equalize.

Water in the capillary tracts provides the solution of low chemical density. When crystalline waterproofing is applied to saturated concrete a solution of high chemical density is created at the surface, triggering the process of diffusion. The crystalline waterproofing chemicals must now migrate through the water (the solution of low density) until the two equalize.

The crystalline waterproofing chemicals now spread through the concrete and become available to the byproducts of cement hydration, allowing the chemical reaction to take place and the formation of a crystalline structure. As chemicals migrate through water, this crystalline growth will form behind an advancing front of chemicals. This reaction continues until the crystalline chemicals are either depleted or run out of water.

Chemical diffusion can take these chemicals about 300 mm (12 in.) into a completely saturated concrete substrate. Where concrete is not completely saturated, the crystalline chemistry only diffuses to the depth of water saturation. However, the crystalline structures still have the potential to travel deeper into the concrete in the future if water penetrates the material from the opposite direction, thus reactivating the crystalline chemistry.

Instead of just reducing the porosity of concrete, like water reducers, plasticizers, and super plasticizers, the crystalline formation engages the material filling and plugs the voids in concrete to become an integral and permanent part of the structure.

Since the crystalline formation occurs within the concrete it cannot be punctured or otherwise damaged like membranes or surface coatings. Crystalline technology also improves the durability of concrete structures, lowering their maintenance cost and extending their lifespan by protecting them against the effect of aggressive chemicals. Crystalline waterproofing is resistant to chemicals where the pH range is between three and 11 under constant contact and two to 12 under periodic contact.

Crystalline waterproofing tolerates temperatures between –32 C (–25 F) and 130 C (265 F) in a constant state. In the author's experience, humidity, ultraviolet (UV) light, and oxygen levels also have no impact on the material's ability to perform.

Crystalline waterproofing offers enhanced protection against the following agents and phenomena.

Crystalline waterproofing in water soluble bags is added to the back of a ready mix truck.

Tower 155 in Boca Raton, Florida, is a 14-story condo complex featuring 170 luxury units. The foundation is constructed 6 m (20 ft) below grade and has a two-level, below-grade parking garage. Crystalline admixture waterproofing was added to the 5199 m^3 (6800 cy) concrete used to pour the foundation slab, walls, swimming pool, and spa fountain.

Carbonation

This is the result of the dissolution of carbon dioxide (CO_2) in the concrete pore fluid, which reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite ($CaCO_3$). This process reduces the pH of concrete and its natural protection of reinforcing steel.

Alkali aggregate reactions

By denying water to these processes, crystalline waterproofing helps prevent these types of swelling reactions.

Chloride attack

Extensive chloride-ion diffusion testing shows concrete structures protected with a crystalline waterproofing treatment slows the diffusion of chlorides, thus extending the time-to-corrosion of the reinforcing steel.

Due to their limitations, membranes and coatings may leave concrete susceptible to water and chemical damage. The addition of crystalline technology can seal the pores and micro-cracks.

Matching the right crystalline technology with the application

Crystalline waterproofing and protection technology is sold in powder form and is mixed with water. It can be used in two ways:

- as a coating applied to the surface of existing or new concrete structures, such as foundation walls, floor slabs, or the inside of underground structures; and
- an admixture added directly into the concrete batch at the plant or truck for new construction, shotcrete, and precast applications.

Crystalline waterproofing coating

As mentioned earlier, when applied to clean, bare, and previously saturated substrate as a slurry mixture, the reactive chemical ingredients in crystalline waterproofing can penetrate up to 300-mm deep inside the concrete by using water as the migrating solution. As these chemicals penetrate through the capillaries and pores, the reaction with the mineral byproducts of cement hydration creates the crystalline formation that fills the cracks and pores.

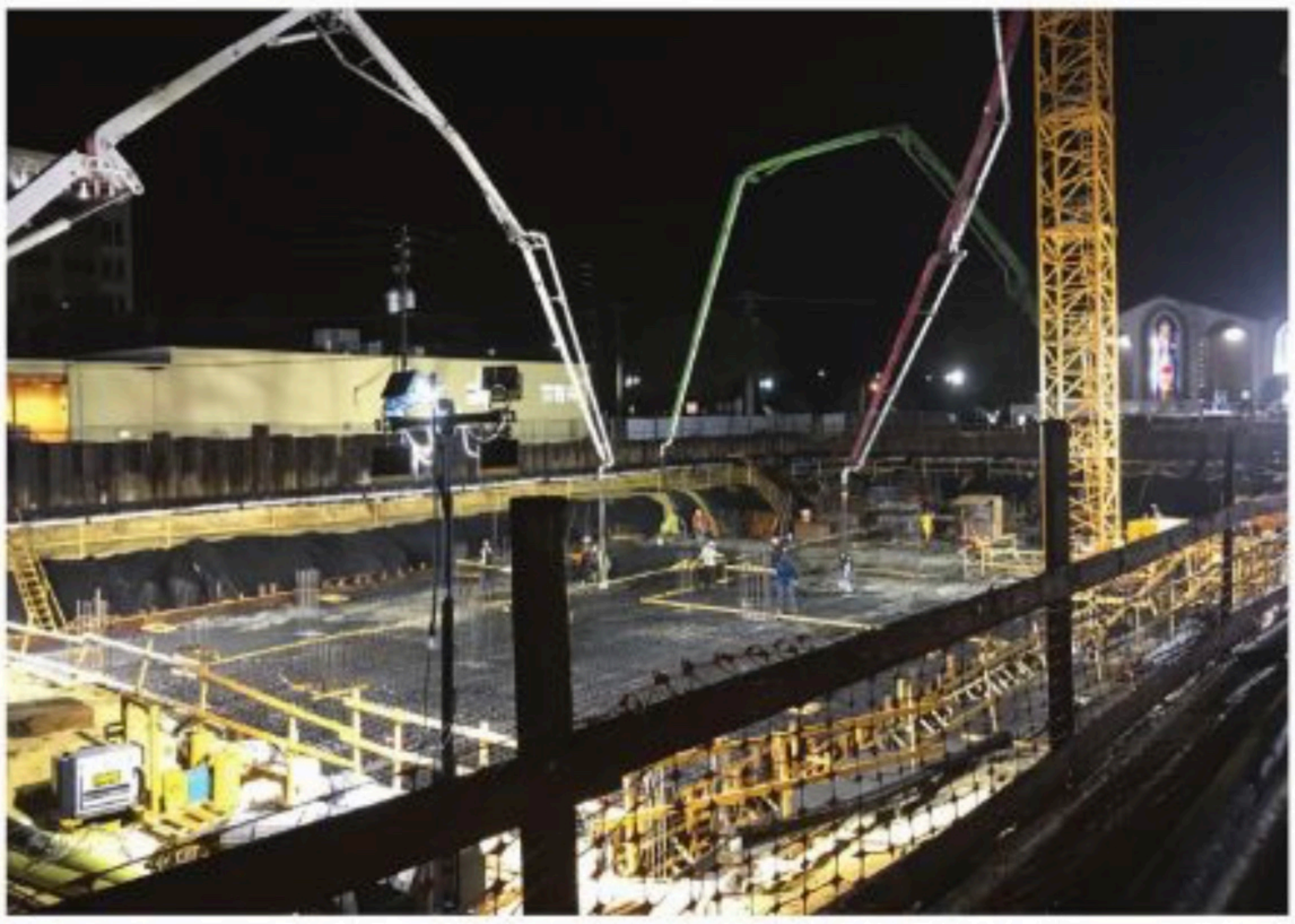
Crystalline waterproofing can be applied by a brush or with spray-on equipment. To ensure the success of the application, care must be taken to ensure correct surface preparation, substrate saturation, coverage rate, and curing time.

Since the crystalline waterproofing coating system has a unique chemical diffusing characteristic, proper surface preparation of the concrete is critical to the performance of the treatment. Concrete surfaces need to have an open pore texture to allow the transfer of the reactive crystalline chemicals from the coating into the concrete substrate. The surface also needs to be clean and free of form oil, laitance, and other foreign matter to ensure proper adhesion of the coating.

Crystalline waterproofing admixture

When used as an admixture the same chemical reactions take place, but cost is lowered by eliminating the labor associated with the application of a surface treatment. Additionally, the utilization of crystalline waterproofing as an admixture moves labor offsite, eliminating scheduling and delays.

Since the admixture is added to the concrete mix at the batch plant or a ready-mix truck, it ensures the crystalline formation occurs uniformly throughout



Tower 155 features a 40,413-m² (43,500-sf) matt foundation with concrete ranging from 1067 mm (42 in.) to 2 m (6 ft) deep. The concrete was fully treated with an admixture to provide integrated crystalline waterproofing.

the structure rather than penetrating from the surface as would be the case with a surface application. In addition to waterproofing, crystalline admixture can reduce shrinkage cracking as well as increase compressive strengths. This may be because the water is taken up into the crystalline structure, leading to a longer, internal moist cure that is beneficial for shrinkage reduction and compressive strength development. For most mix designs, the dosage rate is two to three per cent based on the Portland cement content.

While crystalline waterproofing admixture is compatible with super plasticizers, air-entraining agents, water reducers, fly ash, pozzolans, and other ingredients used to improve the performance of modern concrete mixes, it is best to check with the manufacturer to ensure there is no incompatibility with other elements of the concrete mix, particularly concrete set retarders.

Negative-side waterproofing

Where existing underground structures are experiencing water seepage because of failed exterior membrane or coating systems, the problem can be remedied by the application of crystalline waterproofing on the negative side (inside) of the structure. Under these conditions, surface coatings—depending on the adhesion—blister and peel when moisture seeping through the concrete from the exterior dissolves soluble minerals and deposits them under the coating in the form of efflorescence. Since crystalline waterproofing penetrates into the concrete and plugs the pores beneath the surface, it stops water seepage in the concrete before it reaches the inside surface. This does not depend on its adhesion to the surface and will not blister and peel off like surface barriers.

Vapor transmission through basement floors and walls is also a common problem leading to unpleasant damp, musty odors. Testing in Japan and countries in Europe has shown the application of crystalline technology can reduce vapor flows as much as 50 percent by reducing the size of the capillary tracts in the concrete as well as making some of them discontinuous, which, in most cases, provide a drier, more pleasant atmosphere.

Crystalline waterproofing materials also have the ability to self-heal micro-cracks (<30 µm [1181 µin]) in the concrete substrate as well as macro-cracks up to 0.4 mm (16 mils) in width. The rate of self-healing depends on the size and nature of the crack (static or moving) and the hydrostatic pressure the crack may be subjected to. Self-healing could be evident in only a few days or as long as a few months depending on the ambient conditions.

When cracking takes place over a longer period of time water penetration activates the crystalline chemicals and the self-healing process will take place. Testing conducted in Japan on a cracked bridge deck 10 months after being treated with reactive crystalline waterproofing demonstrated cracks self-healed very quickly compared to control samples.

Real-world examples

Several examples of how crystalline waterproofing technology products were employed in real-world construction applications situations are illustrated by the following projects.

May Bank Headquarters

The triple tower development designed as a new headquarter building for May Bank in Kuala Lumpur, Malaysia, involved diaphragm wall construction incorporating a nine-level underground parking garage. A crystalline technology admix was selected for the project to assist with controlling hydration heat, reduce shrinkage cracking, give the slab the capacity to 'self-heal,' and waterproof the concrete as well as increase its strength and durability.

The basement slab required approximately 24,000 m³ (31,391 cy) of crystalline admix-dosed mass concrete. Commencing on September 26, 1997, the initial pour of approximately 13,200 m³ (17,265 cy) was conducted over a 60-hour period; it was then and remains today the third largest continuous pour conducted in the world and the largest in Southeast Asia.

Tower 155

This 14-story mixed condominium complex in Boca Raton, Florida, features 170 luxury residential units with one, two, or three bedrooms, as well as two-story townhomes and penthouse units. Along with its rooftop spa and in-ground swimming pool, Tower 155 also features two levels of below ground parking.

Located near the water, the area's high water table meant foundation waterproofing was essential. Designers considered a membrane system, but rejected it due to space constraints and the difficult installation it would require. By choosing an integrated crystalline waterproofing admixture as its waterproofing system, the builders saved an estimated 28 days on the construction schedule.

The crystalline admix was included in the post-tensioned slabs, foundation walls, 130-m^2 (1400-sf) swimming pool and spa fountain. A total of 5199 m^3 (6800 cy) of crystalline admixture-treated concrete was used in Tower 155 structures. The complex required a matt foundation constructed 6 m (20 ft) below grade and measuring 40,413 m^2 (435,000 sf) with concrete ranging in depth from 1067 mm (42 in.) to 2 m (6 ft).

According to the lead architect Derek Vander Ploeg, of Vander Ploeg and Associates, "Despite the use of cold joints in the slab and walls due to the amount of concrete used and many separate pours, there is not a leak anywhere."

Columbia College

Columbia College is the oldest university transfer college in Vancouver, British Columbia, Canada. The main campus is housed in a five-story, 6782-m^2 (73,000-sf) building just east of Vancouver's downtown core at 438 Terminal Avenue. The building has a one-level, below-grade parking garage falling just above sea level from the nearby False Creek Inlet. Due to the local climate and high-water table, the structure was subject to ongoing groundwater and below-grade hydrostatic pressure.

To waterproof the foundation slab, walls, and elevator pit, without the uncertainty and extra labor of membranes or coatings, the project designers selected a crystalline admixture to add to the 500 m^3 (17,657 cf) of ready-mix concrete that was required for the project. The crystalline admixture was introduced at a two per cent dosage (based on the total weight of the cementitious ingredients).

Crystalline waterproofing patching material and coating products were used in combination with a polyvinyl chloride (PVC) waterstop to permanently seal the joints where exterior walls landed on the slab. Additionally, crystalline waterproofing admix was also used as a modified grout to ensure a well-consolidated wall/slab interface. Once completed, all walls and joints in the foundation structure were dry and free of leaks.

A mix of crystalline waterproofing admixture, coating, and repair products were used to ensure a watertight foundation for the new Columbia College headquarters near downtown Vancouver, British Columbia, Canada.

Other applications

Crystalline waterproofing admix is also used by precast concrete producers to add value and enhance the performance of concrete pipes, manholes, septic tanks, and architectural panels. Apart from waterproofing these products, crystalline technology enhances chemical resistance and reduces shrinkage cracking, thus prolonging service life. Since it is sold in powder form, crystalline waterproofing can also be included in the mix design for bagged cement products such as shotcrete, mortar mixes, and stuccos.

The effectiveness of crystalline waterproofing technology can be limited by the concrete mix design. As the active chemicals in crystalline waterproofing react with by-products of cement hydration, there needs to be a certain amount of Portland cement or reactive cementitious materials (*e.g.* slag cement) in a concrete mix design. Additionally, the porosity of the concrete should also be taken into consideration, and this will be directly related to the water/cement ratio of the concrete. As a general rule, crystalline waterproofing is effective in concrete mix designs where the compressive strength is 20,684 kPa (3000 psi) or greater and a maximum water/cement ratio of 0.65.

Conclusion

Although concrete may appear to be a simple product to manufacture, it requires a highly engineered approach. In today's design and construction environment, where more stringent requirements, such as longer life cycles, more durable concrete, and value-engineering concepts are expected, careful consideration must be paid to not only the basic requirements, such as the water/cement ratio and materials, but also to more sophisticated chemical admixtures. With its ability to reduce the porosity and permeability of conventional concrete, crystalline waterproofing technology is a valuable addition to building sciences. **CS**

ADDITIONAL **INFORMATION**

Author

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Key Takeaways

Concrete is the most widely used building material in the world. Despite its apparent solidity, strength, and durability, the material is porous and permeable to fluid and vapor infiltration and migration. Water and dissolved chemicals, such as chlorides, sulfates, and acids, can penetrate deep into concrete, sometimes resulting in premature damage, such as reinforcing steel corrosion, freeze/thaw cracking, spalling, and chemical attack. When it comes to building foundations, elevator pits, water/wastewater treatment and water containment structures, and many other applications, waterproofing and protecting the concrete is critical.

MasterFormat No.

07 16 16–Crystalline Waterproofing

UniFormat No.

A2010.90–Subgrade Enclosure Wall Supplementary Components
A4090–Slab-On-Grade Supplementary Components
B3040.30–Horizontal Waterproofing Membrane

Key Words

Division 07
Concrete
Crystalline admixtures
Waterproofing

XYPEX Concrete Waterproofing by Crystallization

The concrete waterproofing benefits provided by Xypex products have been used by architects in project around the world for more than 40 years. Architects who have specified Xypex have seen first-hand how its unique crystallization technology waterproofs and enhances the performance of concrete.

Xypex Chemical Corporation manufactures a line of products used to waterproof a wide range of concrete structures: foundation walls and floors, retaining walls, water tanks, water and sewage treatment plants, tunnels, manholes, and marine structures. Xypex has been tested and proven worldwide in all climates and in widely varying construction situations. Today, through an international network of distributors and licensees in over 70 countries, XYPEX is specified on thousands of major concrete structures around the world. Xypex takes advantage of the natural porous and chemical characteristics of concrete to precipitate a chemical reaction with the moisture and the natural chemical by-products of cement hydration. The result is a non-soluble crystalline structure that plugs the pores, capillary tracts and micro-cracks in the concrete. In this condition, the concrete becomes impenetrable by water and other liquids from any direction.

Because Xypex becomes an integral part of the concrete structure, the advantages are numerous: Xypex cannot puncture, tear or come apart at the seams; it does not require protection during backfilling; seals hairline cracks up to 0.4mm; does not require costly surface priming or leveling and is less costly to apply than most other methods.

Xypex Crystalline Waterproofing is available as a coating, dry-shake (for new slab construction) or as an admixture. This product mix gives the architect and contractor the flexibility to use the most appropriate method for their particular application.