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FR House, Philippines

In-situ concrete house on the South China Sea

Transportation

Concrete Repair

Low-Carbon Construction

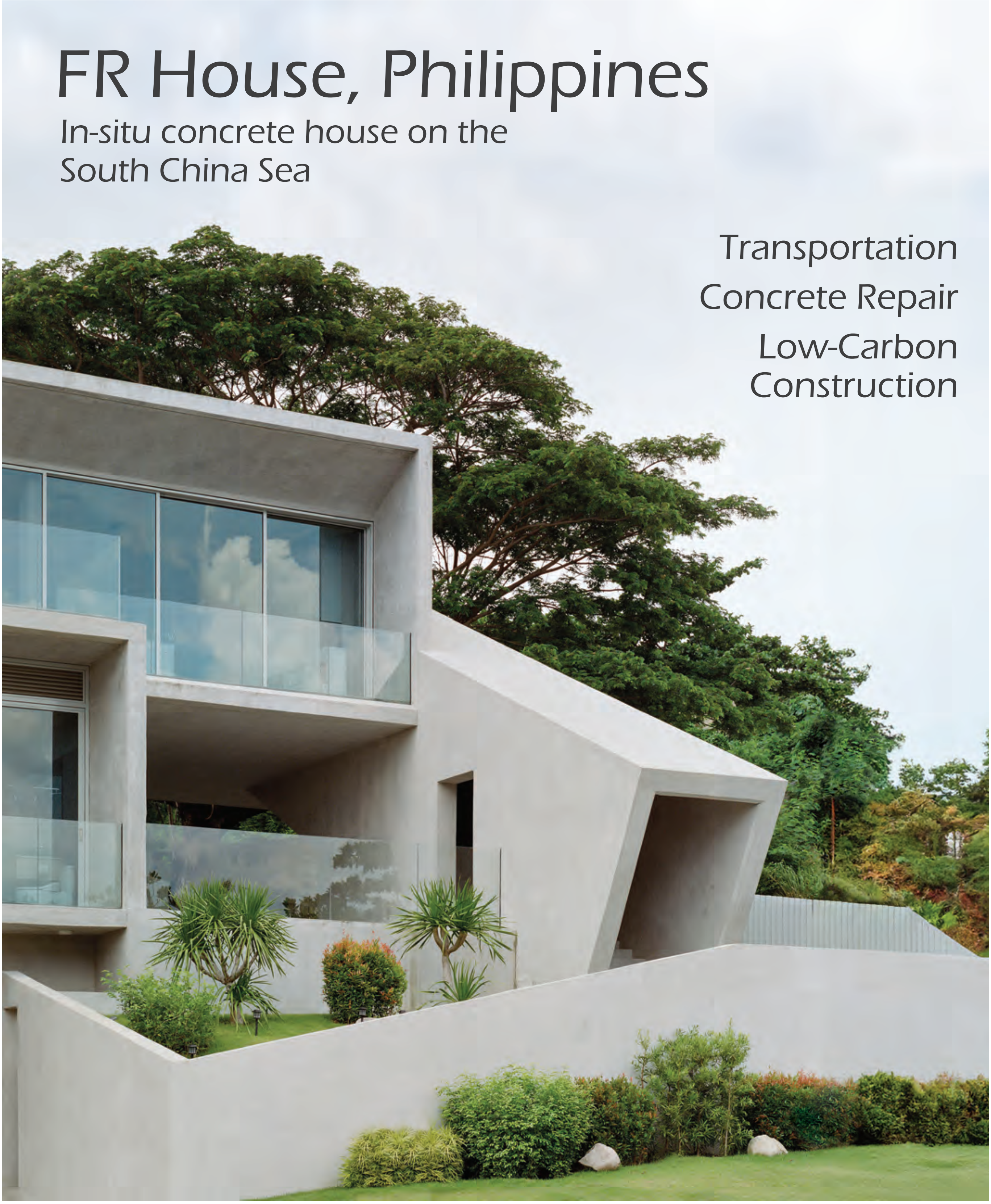


Figure 1: Krk Bridge, Croatia.

Using migrating corrosion inhibitors for restoration and repair of reinforced concrete structures

Corrosion of embedded steel is a major cause of deterioration in reinforced concrete structures. Although concrete mix designs have improved durability, cracking from shrinkage, movement, or other forces remains a concern for achieving long service life. Additionally, maintaining the integrity and extending the useful service life of existing structures is crucial. For over 30 years, migrating organic corrosion inhibitors (MCIs) have been used in construction as a cost-effective method for mitigating corrosion.

Ana Juraga, Cortec, Zagreb, Croatia

New concrete initially offers an excellent protective environment for steel. The concrete's high alkalinity or pH causes a passive oxide film to form on steel reinforcement, protecting it from corrosion. However, environmental factors such as chlorides and carbonation can lower the pH or compromise the passive oxide layer, putting reinforcing steel at greater risk of corrosion. The corrosion process involves an electrochemical reaction where certain areas of the reinforcement become active 'anodic' points. Ions from these anodic points migrate to 'cathodic' points, where they react and form rust. Once started, the rate of corrosion is affected by the concrete's electrical resistivity, moisture content and the rate at which oxygen migrates through the concrete to the steel. As rust formation continues, it can take up to four times the volume originally occupied by the embedded reinforcement, causing cracking and spalling of the concrete.

MCI properties

MCIs are based on amine technology (amine alcohols and amine carboxylates). They are classified as mixed inhibitors, meaning they affect anodic and cathodic portions of a corrosion cell. MCIs adsorb onto metals, forming a protective molecular layer on metal surfaces. This film prevents corrosive elements from further reacting with embedded reinforcement and reduces existing corrosion rates.

MCI moves as a liquid into the concrete matrix (Figure 2). It is mixed either with the batch water or directly into a mixer. With adequate mixing, the inhibitor is dispersed through the concrete.

It moves in a vapour phase throughout the concrete's pore structure (Figure 3). This movement is governed by Fick’s Law, meaning molecules move randomly throughout the matrix from areas of high concentration to areas of low concentration.

When MCI encounters steel, it has an ionic attraction and forms its protective molecular layer (Figure 4). Its affinity to the metal is stronger than water, chlorides and other corrosive contaminants.

Independent testing has confirmed that MCI can absorb metal to a depth of 75–85nm, forming a layer that is between 20 and 100 Å thick (Figure 5). In the same testing, chlorides were shown to penetrate only 60nm deep. This confirmed the ability of MCI to displace chlorides on the metal surface and provide protection even in their presence.

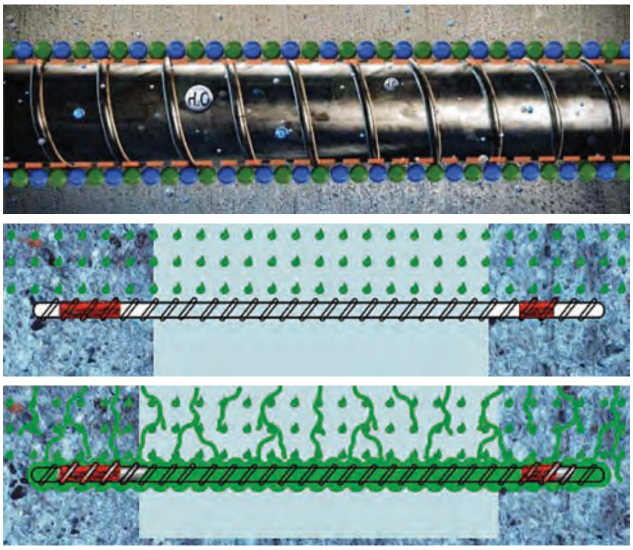
Krk Bridge Preservation Project

The Krk Bridge in Croatia, which includes one of the world’s longest reinforced concrete arches, is in a corrosive environment where strong winds blow salt spray onto the bridge’s surface. Almost four decades of chloride exposure led to corrosion problems that, due to inadequate maintenance, threatened to endanger the bridge’s stability unless proper preservation measures were taken. With 1 million vehicles travelling across the bridge every year, mitigation was critical.

The chlorides that accumulated on the bridge surface and penetrated the bridge, caused corrosion problems. This has had a negative impact on the structure, which has required constant monitoring and maintenance for the bridge to achieve its expected service life. An investigation found that the stability of the bridge could be in danger if appropriate preservation measures were not taken.

The current repair stage started at the beginning of 2018. Before the project began, the investor, designer and contractor agreed to conduct an experimental study on several materials from five different producers. The investor chose to use Cortec MCI-2020 as part of the preservation programme after the inhibitor was tested in the field and laboratory.

One of the first stages of the repair is to perform a detailed visual inspection of the condition of the concrete,



Above: Figure 2 (top), 3 (middle) and 4 (bottom) – Properties of migrating organic corrosion inhibitors.

identifying cracks and examining reinforcement (Figures 6 and 7). When problems are found, operatives remove concrete and replace reinforcement as needed. MCI-2020 is applied to concrete in areas where corrosion has already started. The surface must then be saturated with water (excess water removed) before applying repair mortar, which has been tested and found to be compatible with MCI-2020, in an independent laboratory in Italy.
The preservation project is part of a long-term plan for sustaining the Krk Bridge. Cortec MCI-2020 met all the project’s technical requirements and was economical and easy to apply. It will play an important role in mitigating corrosion on the bridge to delay its deterioration and extend its service life.

The Severn Bridge is a 988m-span suspension bridge that carries the M48 motorway over the Severn River between Bristol and south Wales. It was built in 1966 and featured a few unique innovations, such as inclined hangars and the use of streamlined box girder deck construction. Inspections completed in 2006–2007 found that the PT cables were corroded and had reduced structural strength. Following this investigation, an acoustic monitoring system and dry air injection system were installed on both main suspension cables to control the deterioration. The purpose of the dry-air injection system was to reduce the relative humidity (RH) within the cables to <40% – an accepted percentage to prevent corrosion of metals.

Below: Figure 5, Properties of migrating organic corrosion inhibitors.

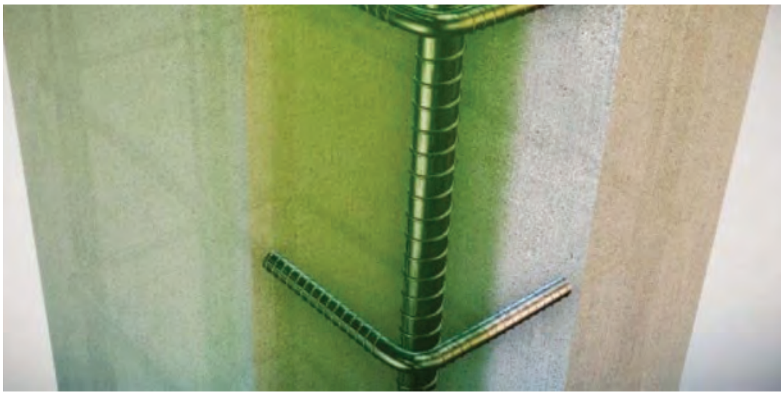


Figure 6: Repairs to Krk Bridge.

To provide additional corrosion protection to the PT cable wires during the initial period of moisture reduction – when corrosion rates could increase as oxygen became more available – and to provide a back-up if the dehumidification system went out of service (ie, for maintenance), an organic corrosion inhibitor system was developed for introduction into the dry-air stream. Concerns over fogged MCI powders blocking air voids in the cables, water-based systems being unsuitable when looking for moisture reduction to reduce the corrosion rate and solvent-based systems being incompatible with the cable wrap and RH probes, meant a different approach had to be used in the development of the MCI. For these reasons, a powder-version, contained in a vapour-permeable pouch, was developed to introduce pure inhibitor vapour into the system using the dehumidification air stream as the carrier. This ensured a sufficient level of inhibitor would be present within the air voids to protect exposed metal surfaces, while avoiding the risks of blockage by solid or liquid material. As the protective inhibitor layer is at a molecular level, it has no influence on clearances and only a minimal effect on other physical properties. Testing showed that use of the inhibitor caused a small increase in wire-to-wire friction at low contact pressure and no significant frictional effect at higher loads. Further testing was carried out to confirm the inhibitor would not adversely affect other components in the system, including cable wraps, sealants and probes. ■

Figure 7: Below: – Application of MCI to the bridge.
Figure 8: Left – Repairs to Krk Bridge.