MULTI-STORY CAR PARK REPAIR AND MAINTENANCE: A HOLISTIC APPROACH FOR CORROSION CONTROL

BY DAVID SIMPSON

Following the need for modernization and the replacement of buildings impacted during World War II, many towns and cities in the United Kingdom (UK) were heavily developed in the 1960s. This modernization was accompanied by an increased demand for shops and other commercial opportunities because of greater disposable income that became available in the UK. This change, coupled with an increase in the use of cars as a preferred mode of transport, led to a greater need for public parking and, in particular, multi-story car parks.

While there are over 4000 multi-story car parks in operation in the UK, closure of these facilities for routine repairs can result in a high demand for parking in the surrounding areas. Oftentimes, these structures are located adjacent to or attached to shopping and business centers. Superficial schemes are commonly used to increase aesthetic appeal, but these schemes may ignore the underlying issues that can negatively impact structural stability and maintenance.

STRUCTURE CHARACTERISTICS

Many of these structures were originally designed and built to standards that failed to recognize the harsh environmental conditions they would be exposed to during their life. The majority of these structures were made from reinforced concrete which, at the time, was considered to be a stable medium. This lack of understanding combined with flawed design features and poor construction practices resulted in extensive and repetitive maintenance requirements over their life.[1] Various types of deterioration on multi-story car parks in the UK today can be seen in Fig. 1 to 3.

Chloride-induced corrosion can be a contributing factor in the cause of reinforced concrete deterioration. It wasn't until 1977 that the use of chloride was restricted as an accelerating admixture for concrete in the UK.[2] Another common source of chloride coming into contact with multi-story car parks is in the form of deicing salts and airborne chlorides in and around marine environments. Design features may also increase the probability of chloride reaching the reinforcement steel; this chloride content in the vicinity of the reinforcement could contribute to the risk of corrosion.[2] In temperate climates where deicing salts are used, chlorides tend to build along trafficked areas and at wheel positions in parking bays. These areas of high contamination are often most common on the first two levels of a car park, where the entrance is located and through-traffic is more pronounced.

EVALUATION OF STRUCTURES

Over the past 10 years, testing has been used more frequently in the evaluation of concrete structures. While the need for testing is increasingly being understood, the degree and level of testing is often inadequate to fully determine the extent of deterioration due to chloride-induced corrosion.

With the recent economic downturn and tighter budget constraints felt in both the public and private sectors, structure owners are looking for the best value to address deterioration of their structures. Corrosion and destructive mechanisms need to be fully understood to implement appropriate methods for remediation. Corrosion testing can provide important information to enable the owner and/or their consultant to assess the extent and magnitude of existing corrosion and the risk of future corrosion. Once evaluated, an economical design for corrosion control and protection of the structure can be developed.

BRE Digest 444,[3] Part 2, provides a good summary for corrosion testing of concrete. Common testing reports can denote the depth of chloride penetration, carbonation depth, concrete cover over the reinforcing steel, and areas of concrete delamination. Half-cell corrosion potential mapping can provide a visual image of chloride content. These tests and their general use on structures can be implemented more frequently and in depth if needed.

Test reports may selectively identify certain locations for the use of half-cell corrosion potential mapping. Such select test areas could represent only a small percentage of the total car park square footage. While advanced corrosion is

Fig. 1: Cosmetic surface patching

Fig. 2: Cracking and delamination

easily identified and accounted for by visual signs such as concrete spalling and delamination, other potential corrosion sites remain invisible to the naked eye and sample testing may not identify the hidden vulnerabilities.

While thorough testing can be expensive and may usually be an up-front cost, its use could be an investment to economize the repair and design of corrosion control systems. If a limited testing regime indicates a high corrosion risk and the same corrosion risk is assumed for the entire structure, then a global remedial measure such as impressed current cathodic protection (ICCP) might be considered.

However, structures may not experience corrosion uniformly and an ICCP approach for the entire structure could be unnecessary to achieve the owner objectives for durability and service life. Through an enhanced testing program, the asset owner might be able to reduce the need for complete cathodic protection. Enhanced testing could also reveal hidden deficiencies so they might be corrected prior to failure. Planned interventions could result in savings to the owner by maintaining future access, minimizing closures only to areas needing treatment, and loss of revenue from complete closure of the structure.

While no single test method is proficient in determining the actual risk and rate of corrosion, full half-cell potential mapping combined with other sample tests may be more effective. The potential map shown in Fig. 4 is taken from The Institute of Structural Engineers guide to the "Design Recommendations for Multi-story and Underground Car Parks" (fourth edition)[4] and illustrates the information that can be gathered and subsequently used to identify invisible but at-risk areas of future corrosion.

A HOLISTIC CORROSION CONTROL APPROACH

The risk of corrosion throughout a parking structure can vary greatly depending on the location and exposure conditions. In many cases, a single

Fig. 3: Corroded areas prepared for patching

system may not be completely effective to control corrosion over the entire structure and multiple solutions, which work in combination with each other, could enhance the protective effect of each system.

ICCP is one corrosion control method that addresses the problems caused by chloride-induced corrosion. ICCP is a permanent electrochemical system that applies current onto the steel reinforcement of the structure, thereby lowering its potential and reducing its corrosion rate. Such systems may offer owners high levels of control and could be effective over long periods of time (25-plus years). The ICCP process is most cost-effective when large areas are protected and the costs are spread out over a long period of time. To ensure their long-term effectiveness, ICCP systems require continuous monitoring and maintenance over their active life. If the structure does not have a widespread corrosion risk or budgetary restraints are not present, then ICCP systems can be an effective approach for car park decks, especially when combined with waterproofing coatings and membranes.

The incorporation of galvanic anodes into patch repairs to inhibit the onset of "incipient anode formation" (induced new corrosion at the periphery of the patch) has been a growing technique for more than a decade. The occurrence of incipient anode formation on car parks is a common sight in the UK (Fig. 5), with failure initiating in as little as 5 years depending on the severity of the environment. With the incorporation of galvanic anodes (Fig. 6), a repair may be stabilized for up to 15 to 20 years, thereby improving durability and reducing maintenance. While this type of corrosion protection is a simple and commonly used technique, it only protects areas just outside of the repair area from incipient anode formation. Other high-risk undetected corrosion sites are not affected by this installation.

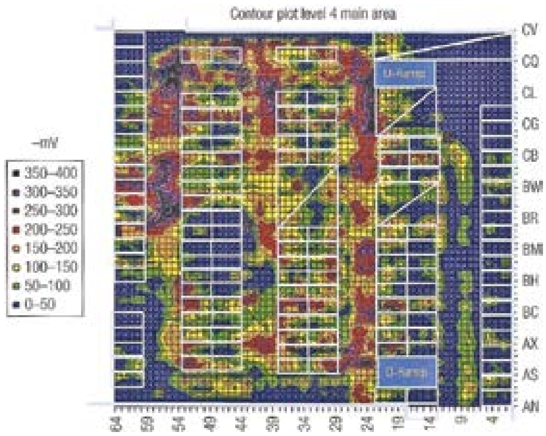

Fig. 4: Half-cell potential map illustrating variable corrosion potential[4]

Fig. 5: Premature failure on car parks due to incipient anode formation

Fig. 6: Incorporation of galvanic anodes at periphery of patch

Corrosion is a chemical reaction and is dependent on the presence of the right environmental conditions. With reinforcement corrosion, water and oxygen are two key components that must be present in sufficient quantities to allow propagation. The use of waterproofing membranes to reduce moisture and limit further chloride contamination is a practice commonly encountered in the UK. In addition to the sealing benefits, they may also provide antislip characteristics, improve the visual appearance, and potentially increase the safety of a car park. In situations where chloride contamination has already taken place, other strategies should be considered.

For carbonated concrete, corrosion risk may be minimized by controlling moisture content.[5] Moisture content in the concrete can be measured by determining the relative humidity (RH) in the slab. *BRE Digest 491*[6] discusses the impact of moisture in the concrete (Fig. 7). This publication reveals that the rate of corrosion may be controlled by reducing the internal RH of the concrete. However, this approach might not be completely effective if significant chloride concentrations are already present.[7] Corrosion of reinforcing steel affected by carbonation could also be the result of minimal concrete cover over the reinforcement. For areas with minimal cover, even low levels of chloride (0.4% by weight of cement) can increase the corrosion rate at relatively low RH values.[5]

Just reducing the RH of concrete with a waterproofing coating may not provide sufficient protection from corrosion in areas that are more likely to contain high chloride levels; corrosion could continue beneath a coating. These high-risk areas may need additional protection so that the concrete and coating remain stable. The use of embedded galvanic

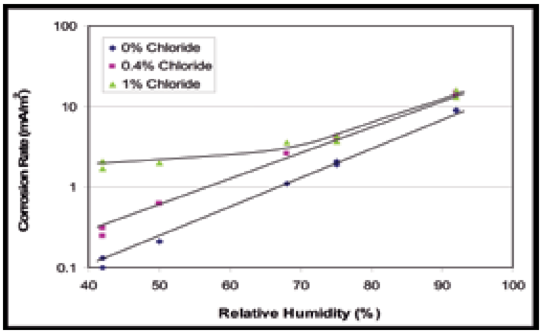

Fig. 7: Relationship between RH and corrosion rate of steel-reinforced concrete on carbonated mortars dosed with chloride. (1 mA/m^2 ~ 1 $\mu m/year$)[5]

Fig. 8: Installation of zonal embedded galvanic anodes

anodes is one method that might address this risk. Half-cell mapping can identify those high-risk areas that may be related to minimal concrete cover and/or very high chloride concentrations. Once these at-risk areas are detected, galvanic anodes (Fig. 8) could be installed in the identified areas. A completed galvanic anode installation can be seen in Fig. 9.

Another consideration for installing galvanic anodes is that waterproofing coatings may be subject to the most severe stresses from vehicular traffic and the coating could be worn off quickly by this traffic. These areas may also be the most prone to chloride exposure and once the coating is worn off, RH and corrosion activity increases significantly. With the incorporation of galvanic anodes, the impact from the loss of the coating may be minimized. This additional protection allows repairs to be made to the coating before significant corrosion activity occurs.

EXTENDING SERVICE LIFE OF STRUCTURES

Alkali-activated embedded galvanic anodes have been used to provide targeted corrosion control for multi-story car parks in the UK for more than a decade. Galvanic systems do have a finite life and in temperate climates such as the UK, they are likely to last in the region of 15 to 20 years.[8] Their holistic use with systems such as waterproofing membranes and properly placed high-quality concrete repair mortars provide a multi-faceted approach to controlling corrosion when aesthetic and safety improvements to parking structures are undertaken. Controlling corrosion may extend the service life of a parking structure and

Fig. 9: Completed galvanic anode installation

investigating the causes of the corrosion could assist in determining the most effective strategies to use in solving corrosion issues.

REFERENCES

1. "Recommendations for the Inspection, Maintenance and Management of Car Park Structures," Institute of Civil Engineers, London, UK, 2002, 116 pp.

2. "Corrosion of Steel in Concrete: Durability of Reinforced Concrete Structures," *BRE Digest 444*, Part 1, 2000, 12 pp.

3. "Corrosion of Steel in Concrete: Investigation and Assessment," *BRE Digest 444*, Part 2, 2000, 16 pp.

4. "Design Recommendations for Multi-story and Underground Car Parks," fourth edition, Institute of Structural Engineers, London, UK, 2011, 98 pp.

5. Sergi, G.; Seneviratne, A. M. G.; Maleki, M. T.; Sadegzadeh, M.; and Page, C. L., "Control of Reinforcement Corrosion by Surface Treatment of Concrete," *Proceedings of the ICE, Structures and Buildings*, V. 140, No. 1, Feb. 2000, pp. 85-100.

6. Sergi, G., and Dunster, A., "Corrosion of Steel in Concrete: A Review of the Effect of Humidity," *BRE Digest 491*, 2004, 8 pp.

7. Glass, G. K.; Page, C. L.; and Short, N. R., "Factors Affecting the Corrosion Rate of Steel in Carbonated Mortars," *Corrosion Science*, V. 32, No. 12, 1991, pp. 1283-1294.

8. Sergi, G.; Simpson, D.; and Ball, J. C., "Galvanic Anodes for Steel Reinforced Concrete Structures," technical paper presented at the International Corrosion Council Conference, Perth, Western Australia, Nov. 2011.

David Simpson *is the Business Development Manager (Europe) for Vector Corrosion Technologies Limited. Simpson holds a first class Honors Degree in chemistry and biology from Aston University and is a certified ICorr Level 1 Cathodic Protection Technician. Prior to working for Vector, he held the positions of Corrosion Product Manager for Fosroc International and Technical Manager at Fosroc Ltd, where he specialized in electrochemical repair methods. Simpson is the incumbent Chairman of the Corrosion Protection Association. Simpson currently resides in the United Kingdom and can be contacted at davids@vector-corrosion.com.*