Figure 3: An engineer tests the electrical resistance of a cathode in the ICCP system at the Stena Ro-Ro terminal, Fleetwood.

to allow control of the current and voltage of each of the 15 separate zones of the ICCP system during operation.

With the three main elements of the system installed – cathodes, anodes and monitoring system – it was possible to commence reinstatement of the beams to their original profile using sprayed concrete.

Sprayed concrete repair

Dry spray-applied concrete was used for the repair to the reinforced structural elements. The proprietary bagged material was pumped in its dry powder state over distances of up to 200m through the areas of the temporary working platform. Water was added only at the spray nozzle. This method meant that works which required continuous start-and-stop routines were accommodated without material setting in the spray lines. The compressed air-driven spray equipment enabled a very high velocity of placement, ensuring high compaction and density. Modern materials are capable of strengths in excess of 50MPa and with this process shuttering is almost entirely eliminated. An excellent steel float finish was achieved with complex profiles where required.

Conclusion

The Fleetwood ICCP system is computer controlled by technology located on site. However, this can also be monitored remotely by a modem connection from anywhere in the world. The control unit will be capable of monitoring corrosion potentials at points on each crosshead in order to automatically alter currents and voltages which are applied to various parts of the system in response to changes in potential. Typically, ICCP systems have a life expectancy of 25 years before any major maintenance or replacement of cabling or components is needed. ■

Figure 4: An operative charges the spray concrete machine for pumping to a remote application point.

New anode for cathodic protection of car parks

With increasing use of motor vehicles, many reinforced concrete car parks have been built in cities and towns all over Europe and North America. They were designed to be inexpensive and simple to construct. Although they conformed to the Standards for reinforced concrete buildings at the time, there was insufficient understanding of the severity of the environment in which they were constructed.

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Due to the aggressive conditions to which these structures were exposed, concrete repair contractors have repeatedly been required to carry out repairs to concrete damaged by reinforcement corrosion and there have even been instances where full-scale collapses have resulted where inadequate maintenance has led to structural failure[1,2] (see Figure 1). A committee was set up in the UK by the Institution of Civil Engineers to address issues of inspection, repair and maintenance of these structures following problems with crash barriers allowing cars to fall from upper floors and a punching shear induced collapse at Pipers Row car park in 1997[2,3].

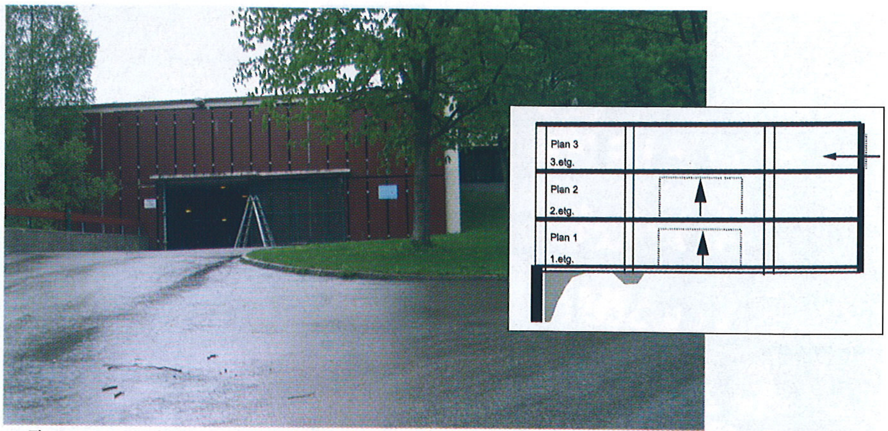
Once chlorides from de-icing salts achieve a sufficient concentration at the reinforcement to induce corrosion, simple patch repairs move the problem around the structure or may increase the rate of corrosion due to the incipient anode or ring anode effect[4]. The corrosion products have a larger volume than the steel consumed and cause cracking and spalling of concrete, leaving pot holes in the parking deck and the risk of structural weakening and ultimately of collapse. One alternative to repeated patch repairing is to apply impressed current cathodic protection (ICCP) to the reinforcing steel. This has a number of advantages over other forms of repair:

- It will control the corrosion rate in the area protected as long as sufficient impressed current is applied.
- It has a monitoring system that demonstrates its effectiveness.
- It can be constructed to US and European Standards[5,6].
- It minimises the amount of cutting out and repair of concrete, thus minimising propping requirements and minimising loss of revenue as repair is quicker and one-off.
- It will work regardless of the concentration of chlorides in the concrete.

For these reasons, ICCP is frequently used on

(Photos and illustrations: Protector A.S.)

Figure 1: The MONY car park, Syracuse NY which collapsed without personal injury due to reinforcement corrosion.



Figures 2a and 2b: Entrance to the multi-storey car park in Norway and section showing the

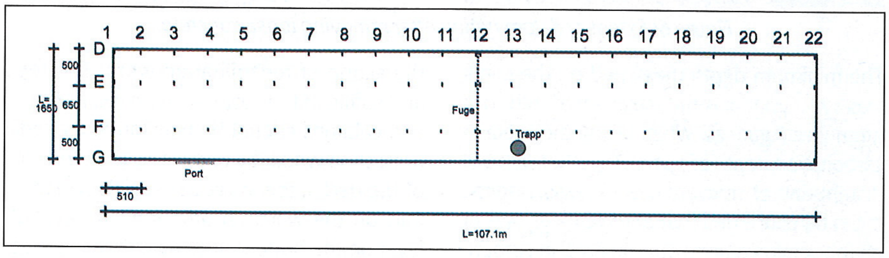


Figure 3: Plan of floors two and three showing the centrally located construction joint and column locations.

car parks in North America and northern Europe as part of the rehabilitation of deteriorating structures due to de-icing salt ingress.

New anode system

When a car park is repaired, an overall upgrade is usually required; this will involve clear marking of parking bays and pedestrian areas, improved lighting and new paint, as well as considering structural issues such as corrosion and other damage. One major issue is controlling water leakage. Through-cracking is frequently a problem in the deck slabs, allowing water leakage to damage cars on lower floors and leaving unsightly stains. Waterproofing membranes may not have been installed originally but are frequently retrofitted during rehabilitation. Given the minimal head room and limited structural capacity of the decks, the new membrane and its wearing course keep the change in thickness and dead load to a minimum.

A new anode system has been developed which combines a conductive coating anode for distributing the current with a waterproofing membrane to protect it and to protect the floors below from leakage. This combination is far more durable than many other organic-based conductive coating anode systems. It has been applied to about 30 car parks covering over 70,000m^2 since 1994.

Case study

The system was applied to a reinforced concrete multi-storey car park in Norway, built around 1976. The lowest floor had an asphalt overlay to the deck; there were two upper floors. The structure was totally enclosed to provide protection from the severe Norwegian winters. Figure 2 shows the entrance and a cross-section. Figure 3 shows a typical suspended floor plan with the columns and the construction joint.

Survey results

A survey carried out in 1998 showed chlorides exceeding the corrosion threshold of 0.4% chloride by mass of cement at the top mat of reinforcement. There was also some carbonation of the concrete. The drains were insufficient to deal with the water accumulation and there were delaminations on the top surfaces of the suspended slabs. After the consultant's initial inspection, contractors were invited to offer proposals including a more detailed investigation. The winning contractor offered the following services:

- condition evaluation (to determine the areas to be protected)
- elaboration of a concept for the cathodic protection system
- installation of cathodic protection using the ZEBRA-thin film anode on the concrete decks, the beams and walls
- covering the anode on the concrete decks with a protective wearing-resistant layer
- anti-carbonation coating on the other areas
- renewal of the façades, exchange of façade elements
- remote monitoring and adjustment of the protection system
- six-year service guarantee.

Evaluation report

A condition evaluation report was issued in early 1999. From measurements of the reference electrode potential *vs.* steel, the chloride concentration, concrete resistivity and freeze/thaw damage, a set of criteria were developed to choose where ICCP was required. Untreated areas should achieve all the following criteria:

- the chloride concentration should not exceed 0.4% by mass of cement(3)
- the potential of the steel should not be more negative than -200mV *vs.* a saturated copper/copper sulfate reference electrode(7)
- the concrete resistivity should be greater than 70 kohm.cm(8)
- there should be no evidence of freeze/thaw damage.

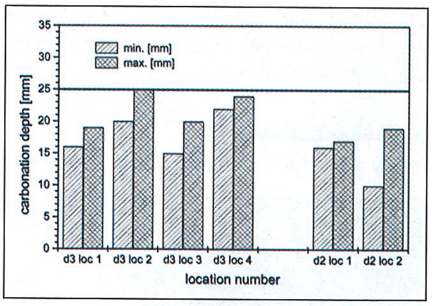


Figure 4: Measured minimum and maximum carbonation depth on cores taken from both decks.

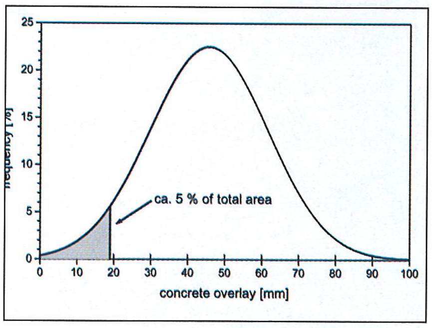


Figure 5: Combination of concrete cover and carbonation measurements: 5% of the reinforcement is lying in carbonated concrete.

Carbonation depths were determined on cores taken from the two suspended decks.

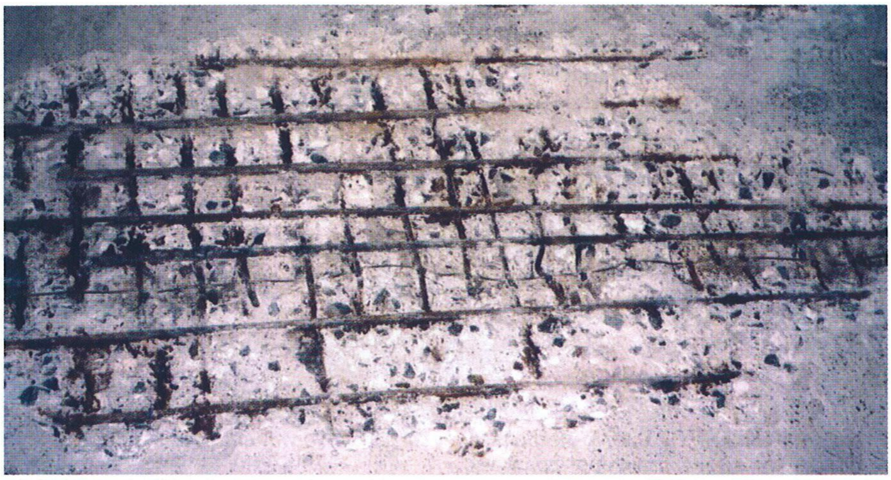


Figure 6: Extent of delamination after removing loose concrete.

The minimum depth measured on the cores was 17 × 4mm and the maximum depth 21 × 3mm (see Figure 4). When taking the average carbonation depth of 19mm, together with the distribution of concrete cover measurements, it can be concluded that approximately 5% of all top reinforcement was situated in carbonated concrete (see Figure 5). Carrying out electrical resistance checks between reinforcing bars according to EN 12696: 2002[6], showed that there was considerable discontinuity which would require bonding during installation of the ICCP system.

Rehabilitation work

In July 1999, the contractor and client agreed the scope of rehabilitation work. The tops and soffits of the suspended decks, the walls and columns should be reinstated. Cathodic protection would be applied to the top sides of the decks, the lower parts of the columns and on the walls. In addition, the asphalt layer on the bottom floor would be repaired, new façade elements would be installed and the building would be rewired. There was agreement to chisel up visual delaminations and to use a cement-based mortar for patch-repair, the anode to be applied on the structure and the necessary probes and electronics installed. A wear-resistant layer was to be applied on the top of the decks to avoid further ingress of chloride ions and to stop the carbonation process. The expansion joints also required repairs. Finally, the columns, walls, and soffit of the decks would be covered with an anti-carbonation coating.

Figures 6 and 7 show the extent of the delaminations found after removing loose concrete, and the installation of a welded steel wire to make electrical continuity between bars to carry the impressed current back to the negative terminal of the d.c. power supply. The location of the embedded reference electrodes is shown in Figure 8. These were the most anodic locations identified by the reference electrode potential survey.

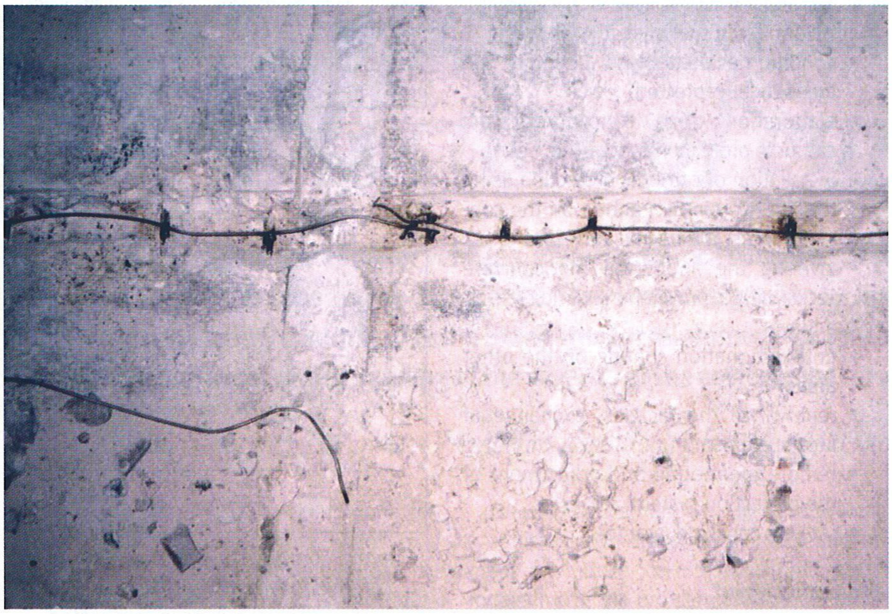


Figure 7: Establishing electrical continuity between the reinforcing bars.

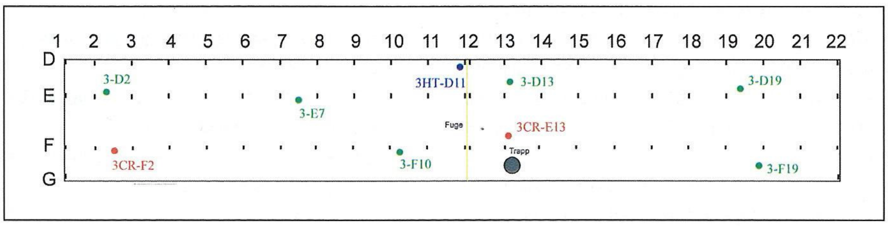


Figure 8: The location of embedded reference electrodes, concrete resistivity probes and temperature sensors on the third floor of the structure.

Application of the anode system

The application of the anode system is shown in Figure 9. Primary anode wires are fixed in recesses in the deck, conductive coating is applied over them and in strips between them. This maximised the adhesion of the waterproofing layer to give the finished product shown in Figure 10. The conductive coating is specially formulated so that the binder is conductive as well as the carbon pigmentation. This leads to a very low applied current as can be seen in Figure 11 and a good degree of polarisation with a very modest average current density. The seasonal fluctuation in temperature, current and concrete resistivity can be clearly seen in Figure 11.

The system started collecting pre-energisation data on 23 March 2000. Impressed current was applied on 12 April 2000. The data in Figure 11 show two depolarisation tests, in April and in September 2002. The results of the 24-hour depolarisations are shown in Figure 12 where it can be seen that all reference electrodes are achieving 100mV depolarisation except 3-D2.

In this work, the E-log I measurements[5] were used as a qualitative electrochemical tool to characterise the long-term effect that CP as a remedial system has on the electrochemical state of the embedded reinforcement. In order to investigate the change of the average degree of protection, it is possible to compare the results of the consecutive decay measurements with the values of the

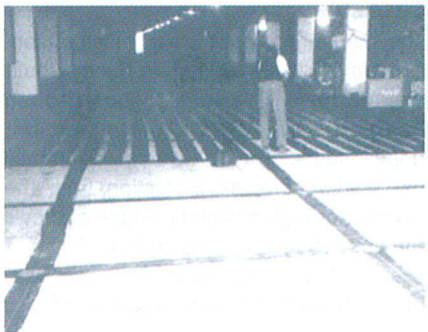


Figure 9: Laying-out of primary anode wires and conductive coating anode strips on the deck and anode to the lower parts of columns.

Figure 10: The car park after application of the water-resisting layer.

Tafel-constants determined prior to CP and generate the average value. When achieving a depolarisation value of one Tafel constant, the corrosion rate equals 10% of the unprotected steel, and at a value of two Tafel-constants the steel is nominally corroding at only 1% of its unprotected value. In Figure 13, the course of the corrosion rate over the period 2000–2004 is shown as a percentage of the initial value before energisation. At start-up, the corrosion rate was reduced to 10% of the original, and then after a few months by two orders of magnitude to approximately 1% of the original corrosion rate.

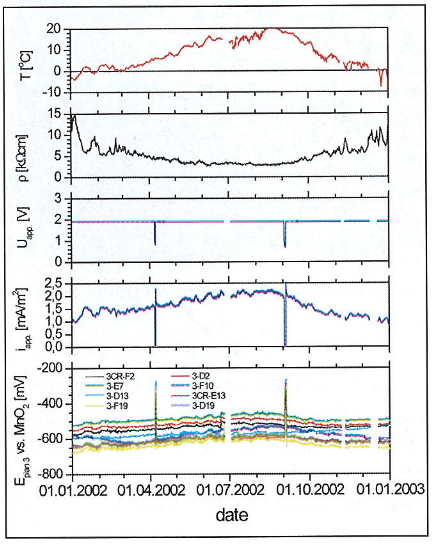


Figure 11: A continuous set of readings for the year 2002 showing temperature at reinforcement depth, concrete resistivity, applied (constant) voltage, current density and steel potential vs. a Mn/MnO_2 reference electrode.

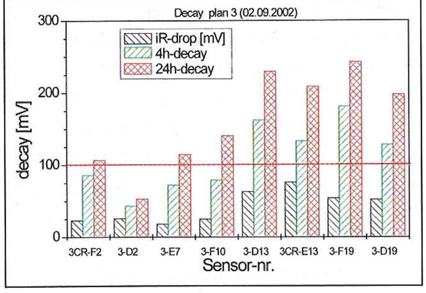


Figure 12: The results of the depolarisation tests in September 2002.

Conclusion

Approximately 30 installations on car park structures covering over 70,000m² have been carried out using this novel cathodic protection anode system. ■

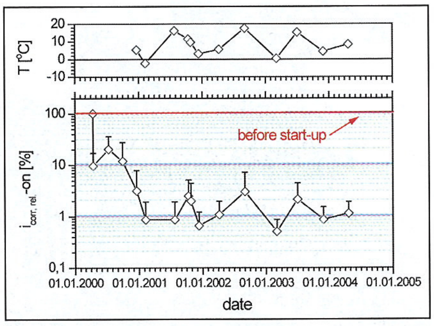


Figure 13: Course of the average relative corrosion rate of the reinforcement in level three for the current being switched on with time of CP.

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