Rebar Corrosion Control

By Bob Gummow, *P.Eng.*

The Corrosion Problem

A 1985 study prepared by Canada Mortgage and Housing Corporation stated that "the overall cost of repairs to damaged parking structures in Canada has been estimated at 1.5 to 3 billion dollars" (1). Most of the damage which has necessitated these repairs has been caused by corrosion. In fact the deterioration of reinforcing of steel in reinforced concrete structures is undoubtedly the most serious corrosion problem in Canada today. Corrosion activity on reinforcing steel is both initiated and sustained by the continual presence of chlorides, moisture, and oxygen at the reinforcing steel/concrete interface. Although the primary source of chlorides is de-icing salts, chloride salt is sometimes added to accelerate curing and in some instances, there are residual chlorides in the concrete aggregate. Moisture available from vehicles, or simply as a result of high humidity is sufficient to support the corrosion process. Oxygen is readily available in the porous concrete structure.

Repairs involving replacement of delaminated concrete and corroded steel and the subsequent application of a moisture proofing barrier typically costs about $3,000.00 per parking stall. (2) Unfortunately, these rehabilitation measures often do not reduce corrosion activity and in some cases, can actually increase the corrosion rate. One major restoration consultant has stated that "it is therefore of great importance that all owners are made aware of the fact that all repaired structures continued to deteriorate after repair and that the annual cost of such ongoing deterioration is significant". (3) Since chlorides are seldom completely removed during the repair process and are not consumed in the corrosion reaction but act simply as a corrosion catalyst, then corrosion action continues even after repair, whether or not any additional chloride intrusion occurs. Furthermore, membranes applied to prevent moisture ingress can actually serve to prevent the reinforced slab from drying out thereby perpetuating the corrosion activity. Accordingly, well intentioned and costly repairs can often make the corrosion situation worse much to the surprise of the building owner. However, many structural consultants and building owners are beginning to recognize that the standard repair and rehabilitation methods that have been used over the past decade have little, if any, beneficial effect in reducing corrosion.

Cathodic Protection

If the constant cycle of concrete repairs is going to be broken, then a method which specificially mitigates the corrosion reaction must be used. One such method is an electrochemical technique called cathodic protection (CP) which is considered to be "by far the most versatile method of corrosion control . . . and even structures exposed to the atmosphere such as bridge decks can be protected cathodically". (4) The overall effectiveness of CP in preventing corrosion to reinforcing steel was emphasized in U.S. Federal Highway Administration report which concluded that "the only rehabilitation technique that has proven to stop corrosion in salt contaminated bridge decks regardless of the chloride content of the concrete is cathodic protection" (5). In order to appreciate the power of this corrosion fighting measure, the activity of a corrosion cell must be considered.

A typical corrosion cell as illustrated in Figure 1 shows that there is a corrosion current (ic) flow,

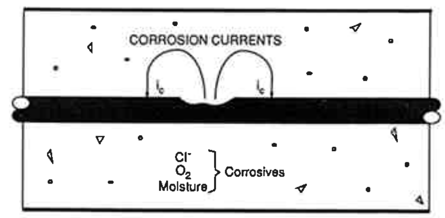

FIGURE 1
Typical Rebar Corrosion Action

between the corroding site and adjacent sites on the same rebar. The magnitude of the corrosion current depends primarily on the concentration of the necessary corrosive substances in the concrete; namely, the chloride ion, oxygen and moisture. Corrosion current can be reduced by the application of an opposing direct current as illustrated in Figure 2. If the magnitude of this CP current (icp) is large enough and uniformly distributed then the electrical potential that exists between the rebar and the corrosive concrete will be changed sufficiently to stop the corrosion. The practical application of cathodic current to an actual structure however involves a number of necessary steps and conditions.

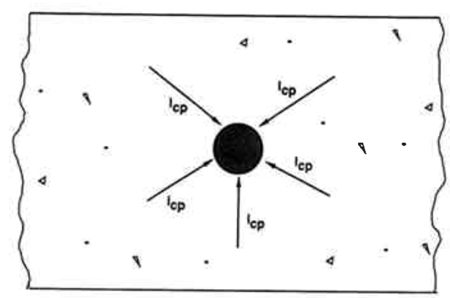

FIGURE 2
Cathodic Protection

Application of CP to Reinforced Concrete

Firstly, it is necessary to have a CP anode (an electronic conductor) to supply and evenly distribute the current over the surface of the concrete so that the current will be

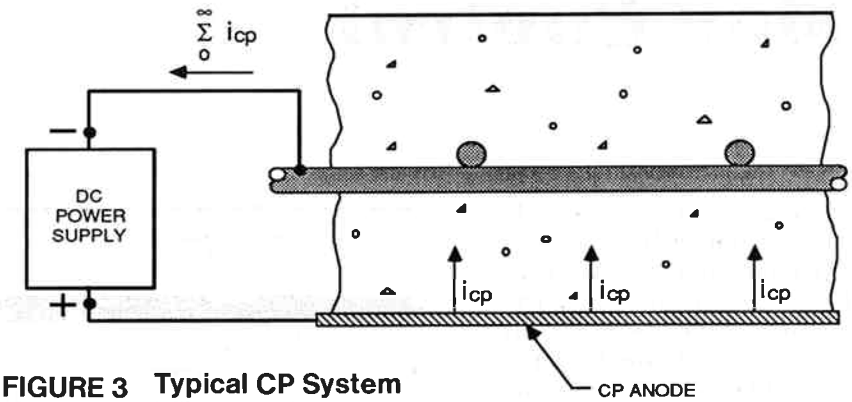

FIGURE 3 Typical CP System

introduced in a relatively even manner. Secondly, the rebar must be electrically continuous from one location to another in order for the CP current to flow uniformly from the concrete onto all of the rebars. Thirdly, there must be a source of power which provides the electrical energy for the CP system. This method is illustrated in Figure 3 showing the CP anode on the soffit surface, although the anode can also be mounted on the top surface in some instances.

Nominally, the system current capacity is designed to provide a maximum of 21 mA per m^2 (2 mA/ft^2) of steel surface. Since this current density is applied at a relatively low voltage (48 V or less), the power consumption of the CP system is quite low, typically 20 watts per 93 m^2 (1000 ft^2). At this power consumption a 4600 m^2 (50,000 ft^2) parking structure CP system would consume about as much power as the average household toaster.

CP in general is a well established corrosion prevention technique used extensively to prevent corrosion on structures such as pipelines, docks, ships, and underground storage tanks. Its application to reinforcing steel dates back to 1973 when it was applied to a reinforced bridge deck in California. It was not until the early 1980s however that cathodic protection applications to parking garage structures was attempted. Much of the development of CP components and materials has arisen from its application to bridge structures. CP systems are presently operating on over 276,000 m^2 (3 million ft^2) of reinforced concrete structures in Canada.

Types of CP Systems

The predominant system for the cathodic protection of parking garage suspended slabs incorporates a cathodic protection anode that is composed of an electronically conductive coating. The basic resin is loaded with graphite and carbon to provide the required electronic conductance. The concrete surface is wet or dry sandblasted to provide a clean and solid substrate. The coating is then spray applied using airless equipment to a minimum dry film thickness (DFT) of 0.305 mm (12 mils). The CP anode coating is black and therefore normally top-coated with a light colored latex coating in order to provide an aesthetic appearance consistent with the rest of the building structure. Various suppliers supply anode coatings which can range generically from acrylic latex based coatings through to solvent based acrylics and coal tar mastics. In the U.S., recent applications of conductive coating CP systems have been on the top surface of the reinforced concrete slab in combination with a membrane topping. The membrane/CP combination prevents both corrosion and leakage. Another anode material composed of titanium mesh having a rare metal oxide coating has seen limited use both on the top surface and the bottom surface. Usually this mesh is covered with an acrylic bonded mortar.

Control Zones

The power supplies are normally of the constant current type that maintain a selected DC output current despite seasonal fluctuations in the concrete resistance. Some power supplies can also be converted to constant potential operation should the circumstances warrant it. It is usual, as illustrated in Figure 4 to supply an independent power circuit for each 450-550 m^2 (5000-6000 ft^2) of surface.

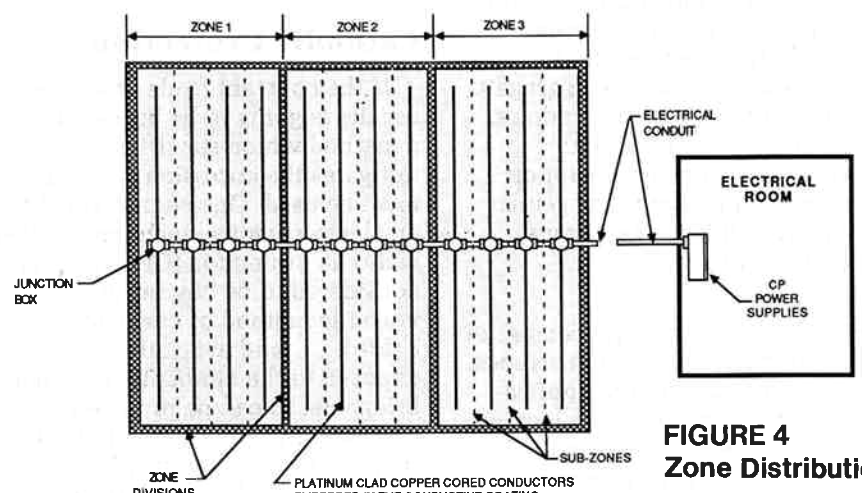

FIGURE 4 Zone Distribution Of CP Current

These zones are further subdivided into sub-zones of 45-55 m^2 (500-600 ft^2). Each sub-zone is isolated from adjacent zones and is provided with power by a primary anode made of platinum clad copper cored wires embedded in the conductive coating. The platinum wires are connected to a common header cable in a junction box attached to a conduit within which the header cables are run back to the power supplies located in an electrical or utility room. The separation of the structure into small zones facilitates the measurement and control of the CP current distribution. Zone isolation is simply achieved by leaving a 50-75 mm (2"-3") gap in the coating and the primary anode wires are usually centered in the middle of each sub-zone which is no wider than 3 m (10 ft).

Performance Standards

Although there are no published performance standards at the moment, there are two impending CP standards for reinforced concrete structures. One is being prepared by Committee T3K-2 of the National Association of Corrosion Engineers (NACE) and a similar document is in process by Task Group E4-9 of the UK, a joint venture (NACE) committee. Both standards are adopting a performance criterion which stipulates a minimum potential change of 100 mV on the reinforcing steel. To test the CP system involves measuring the electrical potential of the reinforcing steel similar to the method outlined in ASTM standard C876-77 entitled "Standard Test Method for Half Cell Potentials of Reinforcing Steel in Concrete" as illustrated in Figure 5.

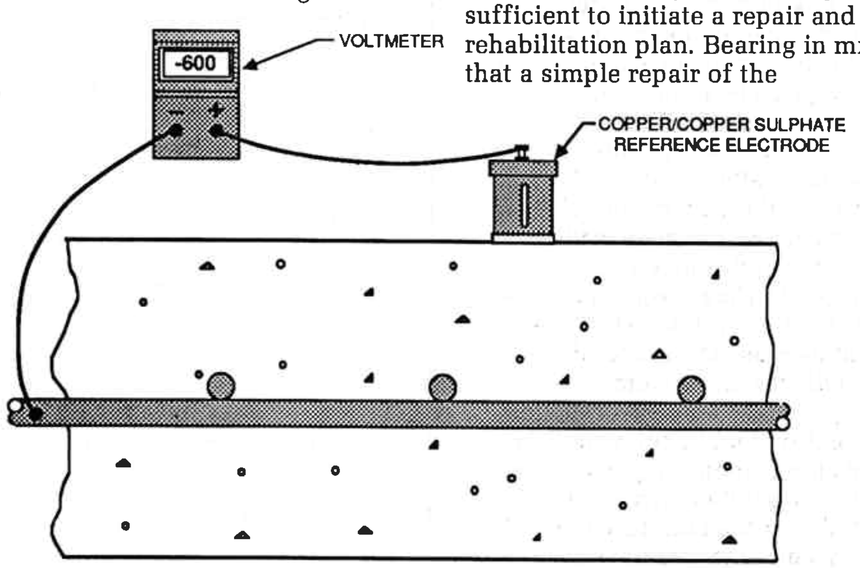

FIGURE 5 Rebar Potential Measurement

A high resistance voltmeter is connected to a reference electrode placed on the concrete surface and also connected to the rebar. The standard criterion will require that when the cathodic protection system is shut off there must be a minimum of 100 mV potential decay from the "instant-off" potential to the potential measured at the same location 4 hours later. This potential survey should be taken on a minimum 1220 mm (4 foot) square grid over the entire surface of the protected structure.

In some cases, reference electrodes can be embedded in the concrete and these reference electrodes used to provide a feed-back signal to the power supply so that the output current can be adjusted automatically to maintain a fixed potential criterion.

Steps to Implementing a CP System

Usually a condition survey of the reinforced concrete structure conducted by a structural consulting firm will reveal areas of significant delamination. This survey, augmented by a corrosion potential survey done to the ASTM C876-77 standard, can reveal areas of corrosion activity. Aligning the delamination survey results with the potential survey data will identify the significance of corrosion and its contribution to delamination. These surveys are usually sufficient to initiate a repair and rehabilitation plan. Bearing in mind that a simple repair of the delaminated concrete or even the application of a membrane on the surface is unlikely to reduce the corrosion, it then becomes apparent that the application of CP has merit in order to break what would normally be a reoccurring cycle of patch repairs. Before cathodic protection can be applied, a rebar electrical continuity check must be made on the reinforced slab. This entails exposing the rebar at various locations and measuring the electrical continuity from one point in the structure to the other points. Often then continuity testing is to be done at the same time that repairs are being made since the rebar is already exposed, thus eliminating the requirement to make special exposures.

Any delaminated concrete on the soffit side of the structure must be repaired prior to the application of a conductive coating on the soffit. Epoxy bonding agents should not be used in patch repairs since the epoxy film will inhibit CP current flow. Preparation of the concrete surface to receive the conductive coating normally entails either a sand or water blast. Dry sandblasting creates dust which necessitates the use of plastic film to curtain off areas to prevent the spread of the dust to other areas in the building. Wet blasting although cleaner than dry blasting can leave the concrete surface water laden which can inhibit proper curing of some of the conductive coatings. Following the sandblasting application, the coating and embedded platinum wires are installed. The platinum wires may be secured to the soffit prior to spraying of the conductive coating or may be taped on top of the conductive coating and overcoated with another 0.4 mm (16 mil) application. The platinum wires are then connected to the common header cable inside at junction boxes interconnected by metallic conduit and subsequently connected to the power supplies.

One problem that must be overcome on most existing reinforced concrete structures is that the conductive coating must be prevented from touching any metal appurtenances. Should the coating touch any metal structures such as protruding rebar chairs, and hangers, this will produce a short-circuit between the anode and the rebar and protection will be lost. Accordingly, various techniques such as potential gradient mapping and thermography have been used to identify accidental contacts between the conductive coating and rebar. It is essential for all such contacts to be removed in order for the CP system to achieve the performance standard. In fact when the protection criterion is not met in a zone or sub-zone, short-circuits are usually the cause.

Operating and Maintenance Requirements

A CP system is a corrosion control system that must operate continuously in order to abate any corrosion activity. Accordingly, it is important to ensure that the power supplies are adjusted properly and that they do not become inadvertently turned off. In this regard most suppliers provide remote monitoring facilities in order that the operating parameters of the CP system can be monitored remotely via telephone interconnection. The option exists for the owner or supplier to do the monitoring. Daily monitoring ensures that the CP system operates continuously and identifies quickly any operational problem that might occur. This relieves the owner from having to retain staff to measure operational parameters of the CP system. It is normally recommended that a potential survey be completed on an annual or bienniel basis to ensure that the rebar potentials meet the recommended standards and to provide an opportunity to make necessary system adjustments. Figure 6 is a photograph of power supplies and remote monitoring equipment.

Cost Benefit

CP systems of the conductive coating type are more expensive than membranes or sealers and where an entire structure is protected, the cost is usually greater than the repair costs. A CP system usually costs about \$37 – \$43 per square metre (\$3.50 – \$4.00/ft^2) of concrete surface area depending on the total area that is protected. The economics of applying CP are very favourable when it is considered that future repairs arising from corrosion will not be required. Accordingly, many CP systems that have been installed to date have been done in conjunction with minimal patching repairs.

Parking garages without question have seen the largest use of cathodic protection of reinforced steel but other reinforced concrete structures such as foundations, piers, piles, silos, and tower footings are also potential applications. As long as the cathodic protection system is adjusted and operating properly, the reinforcing steel will last indefinitely and corrosion problems will cease.It has been estimated [6] that the annual expenditure for concrete restoration in Canada by 1995 will be 500 million dollars. Much of this expenditure will be for repairs to existing structures that have been repaired periodically in the past. Cathodic protection offers a unique and effective means to brake the repair cycle. A handful of structural consultants are now recognizing the extreme value and benefit achieved by the use of CP. The bulk of consultants however, remain either unaware or skeptical of this powerful corrosion control technique. The Reinforced Concrete Cathodic Protection Association has concluded [7] "it is clear that cathodic protection, since it is the only means of controlling corrosion in chloride contaminated concrete, has an important primary role in the protection of reinforcing steel". A rapid increase in the use of cathodic protection and its recognition as a viable corrosion prevention tool by the structural consulting community, as well as by major building owners is anticipated over the next few years. An important factor for the owner when contracting for the application of a CP system is the recognition that many of the coatings being offered for this application have a very short service history. It is the responsibility of the specifier to make sure that both the materials and contractors have a proven track record and that adequate case history references are supplied for confirmation. □

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