CATHODIC PROTECTION
FOR CONCRETE STRUCTURES IN ASIA

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Abstract - Traditional concrete repairs for chloride contaminated concrete structures cannot reduce the corrosion rate of steel to insignificant levels. As a result, new concrete damage would develop again in several years from the time of repair due to the continuation of the corrosion process. The failure of traditional repair methods has been demonstrated on many reinforced concrete structures in Asia and throughout the world. Economic and life cycle costs of corrosion protection systems are also important in determining suitable repair methods. Even though the initial costs for conventional repair methods (i.e., patching, sealers, concrete overlays, coatings, etc.) are generally lower than that for a cathodic protection (CP) system, the life cycle costs of conventional systems are higher because the costs of frequent concrete repairs are far more expensive than that of the CP system installation. As a result, CP becomes a more valuable corrosion control method for chloride contaminated concrete structures. This paper discusses the use of cathodic protection on various reinforced concrete structures throughout Asia.

Keywords : chloride, carbonation, corrosion, cathodic protection, cathodic prevention, concrete structure, Asia

1. INTRODUCTION

Chloride-induced corrosion of the reinforcing steel is the most destructive cause of early deterioration of concrete structures. The majority of concrete structures that are experiencing severe corrosion are located in coastal areas and the deterioration is directly related to seawater splashing and airborne salts. The typical structures that are associated with this type of deterioration include wharves, jetties, piers, bridges, and buildings.

Concrete structures located in sub-tropical and tropical marine climates are experiencing severe corrosion of concrete structures due to the ingress of chloride ions. It is know that chlorides can diffuse into the concrete at a faster rate with increasing temperature. Furthermore, once corrosion of reinforcing steel starts, the corrosion rate of the reinforcing steel exponentially increases with increasing temperature and moisture. Therefore, the countries located in the South side of Asia have been facing severe corrosion problems as a result of chloride ingress.

Concrete structures in countries which are located in north side of Asia, such as Japan and Korea are experiencing corrosion not only from seawater but also from de-icing salt. The amount of deicing salts used is much less than that in the United States, and the history of the de-icing salt is relatively short. Therefore, the structures suffering from corrosion are still limited at present. However, the corrosion problem for such structures is expected to grow with time.
In addition Taiwan, Hong Kong and the Okinawa Island have additional corrosion related problems. Since these areas do not have sufficient clean river sand, chloride contaminated beach sand is often used in the new concrete mix. When concrete structures were built with chloride contaminated aggregates, the corrosion of the reinforcing steel can be a very serious problem in a relatively short period of time. Even though they are not exposed directly to a chloride environment, these structures have deteriorated prematurely due to the corrosion of reinforcing steel.

When a concrete structure is exposed to a chloride environment, the outer layer of the reinforcing steel that is exposed to the environment begins to corrode. However, when the structure is built with chloride-contaminated concrete, all reinforcing steel within the structure corrodes. Therefore, it is more difficult to control the corrosion activity.

Carbonation of concrete is another cause for the corrosion of reinforcing steel. Carbonation is a process which takes place when carbon dioxide in the air penetrates into the concrete and reacts with the alkaline components of the cement paste. It is known that the pH of concrete is approximately 13. This high (alkaline) pH results in passivation of the steel surface and therefore protects the steel from corrosion. However, the carbonation process leads to the reduction of the pH value to below 9. This lower pH causes depassivation of the steel and allows corrosion to initiate. In general, carbonation is a slow process.

In general, concrete structures in Asia are relatively new compared to European countries. However, when the concrete cover is insufficient and/or when the permeability of the concrete material is high, the carbonation process causes premature failure of concrete structures by corrosion. This type of problem is sometimes found in concrete structures which were built with poor quality control.

It is important to distinguish between “Repair” and “Rehabilitation” of the concrete structure which is experiencing corrosion of reinforcing steel. "Repair" is a method that restores a deteriorated concrete element to a service level equal to or almost equal to the as-built condition. A typical example is a concrete repair that uses patching or overlays. Conventional repair method consist of removing damaged concrete, cleaning the affected steel and patching with concrete mortar. This technique has proven to be ineffective since in the repair process no effort is made to prevent or significantly retard deterioration mechanisms (corrosion) because chloride-contaminated concrete is left in place. Therefore, these repairs must be repeated every five to ten years with each successive repair being of increasingly greater magnitude.

"Rehabilitation" is a method that corrects the deficiency that resulted in the assessed deteriorated condition. When cathodic protection is applied to a corroding structure with conventional concrete repair, the structure is restored not only to the as-built condition, but also the cause of the deterioration (corrosion) is eliminated. Therefore, “Rehabilitation” with cathodic protection is considered as a long-term and cost effective (minimum life-cycle cost) solution to the corroding structure.

Most countries have been repairing corrosion induced damage to concrete structures using conventional repair methods. The cost of such repairs and maintenance becomes a significant expenditure to many owners. During last 10 years, several countries in Asia realized that to reduce such expenditure and to provide cost-effective solutions to their structures, cathodic protection must be applied to significantly reduce or stop further corrosion. With estimates of service lives and construction prices, cathodic protection is typically the most cost-effective rehabilitation method when used with conventional concrete repairs for corroding concrete structures.

The first cathodic protection system was developed in California in 1973 for reinforced concrete bridge deck in June 1973. Since then, significant advancements have been made in cathodic protection system components and test procedures, and today cathodic protection is an accepted technique. After the US Federal Highway Administration (FHWA) invested in many research and development projects, they reached a conclusion that:
Cathodic protection is presently recognized as the only existing technology that is both sufficiently mature and proven in practice for controlling ongoing corrosion of embedded steel in concrete. This approach to corrosion control is being promoted and employed increasingly for various concrete structure life extension in conjunction with conventional repair of areas where corrosion induced concrete damage has already occurred.

The use of cathodic protection (prevention) for new concrete structures has also become popular in several countries. Current practice to prevent the corrosion of reinforcing steel is to use less-permeable concrete and increase rebar cover to achieve longer corrosion-free services times. This type of protection is called "Passive Protection." However, this practice is effective for only crack-free concrete that is constructed with high quality control. In reality, unexpected concrete cracking often occurs in many structures due to shrinkage, thermal expansion, stresses and so on. Once the cracks develop in the concrete, low permeability and sufficient concrete cover are not effective any more to prevent the corrosion. Furthermore, when more than 75 years design life is required, passive protection is sometimes not sufficient. The use of cathodic protection as "Active Protection" is sometimes a variable option and a cost-effective system for new concrete structures.

Over 1,000 structures are protected by CP worldwide and the concrete surface area is more than 2 millions square meter since the first CP system was installed in 1973. In Japan, cathodic protection has recently been applied to 10,000 m² to 15,000 m² of concrete surfaces of various structures in a year. Typical concrete structures protected by CP in various Asian countries are as follows:

<table>
<thead>
<tr>
<th>Country</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>bridges, wharves, piers, intake structures, rock shed, culvert boxes, tetra pots</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>piers, wharves</td>
</tr>
<tr>
<td>S. Korea</td>
<td>wharves, bridges</td>
</tr>
<tr>
<td>Taiwan</td>
<td>wharves, bridges, buildings</td>
</tr>
<tr>
<td>Thailand</td>
<td>bridges</td>
</tr>
<tr>
<td>Indonesia</td>
<td>plant structure</td>
</tr>
<tr>
<td>Singapore</td>
<td>wharf (trial)</td>
</tr>
<tr>
<td>Australia</td>
<td>wharves, jetty, bridges</td>
</tr>
</tbody>
</table>

2. VARIOUS TYPES OF CP SYSTEMS

CP system can be of the impressed current type or the galvanic type. One of the major components of both systems is called an anode, which distributes CP current to steel reinforcement. The impressed current CP (ICCP) employs a transformer-rectifier (an external power supply) and the anode to force all of the steel reinforcement into functioning as a cathode, resulting in no corrosion activity on the steel surface. On the other hand, a galvanic CP system does not require a rectifier because the source of the current is the anode. When two different metals (steel and galvanic anode) are electrically connected to each other, a galvanic cell is established. As a result, electrical current flows naturally from the galvanic anode to the steel through the concrete electrolyte.

Cathodic Protection Systems for Existing Structures

A. Concrete Overlay Titanium Mesh CP System (ICCP)

The catalyzed titanium mesh anode system consists of an expanded titanium mesh with a mixed metal oxide catalyst applied to the surface. The schematic presentation of this system is shown in Figure 1. The titanium mesh is 1.2 m wide coiled on a wood spool (Figure 2) and unrolled on a concrete surface (Figures 3 and 4). The mesh anodes are fastened to the prepared concrete surface using plastic fasteners after the damaged concrete is repaired. The titanium mesh is connected to a bare titanium current distributor bar using a spot-welder (Figure 5). The anode mesh is the overlaid with a cementitious material, such as standard Portland cement concrete mix or shotcrete.
A catalyzed titanium mesh anode system was first introduced in 1985 and has since the most commonly used CP system for bridge deck surfaces that are exposed to the de-icing salt environment. This titanium mesh system has also been installed on deck soffit of several wharf structures in Japan, Korea and Hong Kong. The titanium mesh anode system using was used on the walls of several buildings in Taiwan. After damaged concrete was repaired with shotcrete, titanium mesh was attached on the walls with formed concrete overlay.

It is known that the application of shotcrete to concrete surfaces requires extensive concrete surface preparation for bonding. In the past, poor concrete surface preparations resulted in poor bonding or delamination of the shotcrete.

B. Titanium Ribbon Mesh Slotted CP System (ICCP)

The slotted system (Figure 6) has been extensively used on deck soffit and walls of concrete structures. This system involves the use of catalyzed titanium ribbon mesh anodes (Figure 7) and non-shrink cementitious grout as the slot backfill. Typical ribbon mesh is 13 mm and 19 mm wide by 1.3 mm thick. Slot spacing is dependent on rebar steel density, but is typically 200 to 400 mm on centers. Typical concrete slot is 8 mm wide by 25 mm deep (Figure 8). The advantages of this system are:

- Can be installed on the painted concrete surface without removing the paint (Figures 9 and 10).
- Eliminates the need for a concrete overlay
- No additional dead load is applied to the structure

This system has been used on many wharf deck structures in Japan and Australia. In addition, a slotted system was recently installed on the deck soffit of a railroad bridge in Thailand and the walls of Taipei World Trade Center in Taiwan. Slotted systems have also been specified for several major harbor projects in Hong Kong.

C. Discrete Anode CP System (ICCP)

The discrete anode system is one of the most cost-effective CP systems for beams, piles and columns (Figure 11). The anodes are relatively easy to install and does not require extensive saw cutting or use of concrete overlay. The discrete anodes, are installed in drilled holes (approx. 20 to 25 mm in diameter), as shown in Figure 12 and backfilled with non-shrink cementitious grout (Figure 13). The length and spacing of the anodes are dependent on the steel density and protection current requirements for the structure to be protected. Anodes are connected to a common bare titanium current distributor bar in a saw slot to deliver protection current from a rectifier.

D. Thermally Sprayed Aluminum Alloy System (Galvanic)

This system is relatively new to concrete structures. The aluminum alloy anode (aluminum-zinc-indium) is applied onto concrete surfaces using electrical arc spray equipment to form galvanic coating. (Figure 146) This system has inherent simplicity and low maintenance requirements. In particular, the sprayed form of a galvanic system is preferred for atmospherically exposed concrete structures, which often have complicated or curved concrete surfaces. In addition, protection of prestressed concrete structures using this type of system will eliminate the risk of hydrogen embrittlement caused by overprotection of the prestressed strands. (Figure 15)
3. SUMMARY

Cathodic Protection (CP) has become a popular rehabilitation method for various concrete structures in Asia. The application of the CP system to a corroding concrete structure has proven to be a cost-effective method with significant life cycle cost benefits.

It has been recognized that conventional methods of repair (i.e., removal of defective concrete and replacement with patch repair, sprayed concrete and/or partial casting) are only short-term in nature and can only restore structural integrity to localized areas where defects are limited in scale. For structural elements where the chloride ion has penetrated to the reinforcement level, conventional concrete repair methods can only restore the structural integrity on a temporary basis, and hence the next repair would be required in shorter periods of time. It is also envisaged that repeated cycles of such repairs would inevitably impair the structural integrity of the structure in the longer term.

To stop further deterioration, a long-term solution to corrosion of the reinforcing steel is required. CP is the only technology that has proven to halt corrosion in reinforced concrete structures, regardless of the chloride ion content in the concrete. With proper design, installation and maintenance, cathodic protection can provide a long-term solution to reinforcing steel corrosion and concrete deterioration for structures located in aggressive environments.

REFERENCES


Figure 1 – ICCP System using titanium mesh with concrete overlay

Figure 2 – Titanium mesh anodes on rolls

Figure 3 – Titanium mesh anode on a deck
Figure 4 – Titanium mesh ICCP system installed on deck soffit and beams

Figure 5 – Connecting titanium current distributor bar using a spot welder

Figure 6 – ICCP slotted system using titanium ribbon mesh

Figure 7 – Titanium ribbon mesh anodes

Figure 8 – Slotted titanium ribbon mesh ICCP system installed over deck soffit

Figure 9 – Slots on deck soffit
Figure 10 – Slots on the painted beam

Figure 11 – Discrete titanium anodes

Figure 12 – Drilled holes for discrete anodes in a pier structure

Figure 13 – Discrete anodes installed in a beam

Figure 14 – Thermally sprayed aluminum alloy galvanic system applied to a bridge substructure

Figure 15 – Application to prestressed beams