GENERAL PAPER

Cathodic Protection of Steel in Concrete in Australia: History And Current Status

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INTRODUCTION

This paper will review the history of Cathodic Protection (CP) of steel in concrete in Australia, the design of CP systems, the various anode and control systems used, the maintenance and monitoring of existing CP systems and the method of project delivery of CP contracts in Australia.

The information presented in this paper is the point of view of the authors. Other organisations involved in CP in Australia may have different views and different experiences than those expressed in this paper.

HISTORY

Some of the early references to CP of reinforced concrete include a paper by Stratfull in 1957 [1].

The first reported full scale CP installation for steel in concrete was for a concrete bridge in 1973 in California to control de-icing salt induced corrosion of the deck reinforcement. Since then hundreds of systems have been installed in the USA with the bulk of these systems installed to bridge decks. Further information related to the development of the reinforced concrete CP industry within the USA and the UK is presented in a paper by Wyatt [2].

In Australia, various trials with impressed current CP systems were conducted in the mid 80s and two full scale CP installations were undertaken in the late 80s, early 90s; The Cockburn Cement building where conductive coating was used as anode material and the Port Headland Ore Pier where conductive asphalt overlay was used as anode material on the top deck and MMO Titanium anode mesh was used for the beams[3].

The first CP impressed current system installed by Savcor was in 1989 in Mosman, Sydney, for a reinforced concrete slab suffering from chloride induced corrosion due to magnesite floor topping. Today, over 100 CP systems have been installed across Australia.

The bulk of the CP systems in Australia were installed to bridges and wharves. Some of the prominent cathodic protection systems installed in Australia includes the Sydney Opera House western under broadwalk[4] [7], wharves 4 & 5 of Port of Brisbane [5], the Trident building in Manly [8], Swanson Dock wharves for the Port of Melbourne, the cathodic prevention system of the Lawrence Hargrave Drive, Seacliff Bridge[6] and the Newcastle and Port Kembla wharves.

As de-icing salt exposure is not the cause of existing deterioration to bridges in Australia, the bulk of the CP systems were installed to the sub-structure elements, generally located in the tidal and splash zones for bridges and wharves located along the coastline of Australia.

Figure 1: MMO Titanium mesh anode applied to the slab of a unit in Mosman, Sydney in 1989

CATHODIC PROTECTION DESIGN

Since 1989, the bulk of the CP projects undertaken by Savcor are design and construct projects where the CP design has been completed internally by the Savcor technology division. It has been Savcor's philosophy to undertake a comprehensive pre-design electrochemical assessment of the structure as a part of the design process. The aim of this assessment is to confirm the suitability of cathodic protection, determine the extent of the cathodic protection system, provide system design input information and where applicable, undertake a small scale CP trial to assess the likely current demand for cathodic protection and confirm the design assumptions.

The electrochemical assessment generally includes detailed inspection of the structure, chloride content analysis, depth of carbonation measurement, concrete cover measurement, alkali aggregate reaction assessment, reinforcement continuity, concrete resistivity and half-cell potential mapping.

The detailed inspection of the structure would normally include delamination testing, verification of reinforcement for the various elements of the structure using a covermeter, inspection of reinforcement at breakout locations and inspection of construction joints and cracks. This information is essential to determine the extent of the CP system, provide all the input design information and to establish any significant water penetration areas that may affect the performance of the CP system.

The chloride content and depth of carbonation measurements will assist in determining the extent and the zoning of the CP system.

The concrete cover to reinforcement is essential to determine the orientation, location and the type of the anode material. The alkali aggregate reaction testing is essential to determine if the structure contains aggregate which may be sensitive to alkali and assess the risk associated with CP installation in this case.

Reinforcement continuity testing is essential for any cathodic protection system. The failure to assess the extent of discontinuity of reinforcement may result in major variations in the cathodic protection contract. In addition to this, under certain circumstances, CP systems may not be a cost effective solution for a particular structure if there are large areas of discontinuities of embedded steel reinforcement.

Half-cell potential mapping and concrete resistivity testing are extremely important tests for the elements of the structure receiving cathodic protection. CP zoning is related to the reinforcement corrosion activity in a particular element of a structure and this can be verified by the results of these tests.

The information obtained from the various testings in addition to other considerations such as the geometry of the structure, the proposed control system and the capacity of each power supply unit, would normally provide the design engineer with the input information required to complete the CP design.

With reference to current density, normally the design current density for CP systems is 20mA/m^2 of steel based on the greatest steel density within the CP zone. In some structures it is impractical to fully adhere to the above requirement due to the existence of small areas of high steel density in a particular CP zone or the existence of many layers of reinforcement within the CP zone, mainly for heavier reinforced structures. In such cases a combination of engineering judgement, experience and in some cases trial applications is needed in order to determine the optimum current density. It is also important to bear in mind that the current density that is required to maintain a given reduction in the corrosion rate will decrease with time and it is possible to impress a higher current for a short period, if necessary, to polarise the steel. In addition to this, it is the authors' experience that under certain circumstances for highly corroding structures, the commonly used 20mA/m2 of steel is not sufficient.

It is the authors' opinion that the electrochemical assessment must be undertaken thoroughly by an experienced CP engineer. For all major CP installation undertaken by Savcor to date, trial installations and design verification were conducted as a part of the design process. In most cases the results of the trials have had a major impact on the final design. Trial installations may result in overall major reduction of the cost of the installation of the CP system and in the selection of the optimum system design that will deliver long term corrosion protection for the structure.

As a part of the design process, design verification is normally carried out during construction for the various zoning of the cathodic protection installation. Temporary power supply units are normally used to undertake progressive energising of the system for the purpose of design verification and ensuring that all the system components are fully operational and free from defects.

METHOD OF PROJECT DELIVERY

The method of project delivery of CP systems in concrete in Australia can be divided into two categories; consultants detailed specifications and tendering or design and construct by a specialist CP contractor.

The consultants detailed specification method includes full preparation of a detailed specification for repair and CP by a consultant, calling for tenders and contract award based on price or other selected criteria specified by the consultant or the client.

The design and construct method includes the preparation of a performance specification by a consultant, calling for tenders based on detailed designs prepared by a specialist CP contractor and contract award based on price or other selected criteria specified by the consultant or the client. The design and construct method may also apply for direct negotiation between the specialist CP contractor and the client without the involvement of a consultant.

There is no doubt that any method of project delivery can be successful under various circumstances. With regard to the method of project delivery applied to Savcor contracts since 1989; 67% of the total amount of the contracts were design and construct, 16% of the contracts were for systems designed by consultants and constructed by Savcor and 17% of the contracts were projects designed by Savcor and constructed by the client's workforce or other contractors.

MAINTENANCE AND MONITORING

There is no doubt that it is extremely essential that on the completion of the CP system installation, a long term maintenance contract is established for the system. Unfortunately, this has not been the case in Australia for all systems installed and large investments, which have been made at a certain point in time, have been totally wasted because of discontinuing the monitoring of the installed systems. Based on our experience, one of the main reasons for this, is the change of the client's personnel involved in the initial CP installation with the new staff responsible being unaware or ignoring the necessity for continuous monitoring. Based on our experience and up to now, 55% of our installed systems are still being monitored by Savcor since 1989, 22% of our installed systems are monitored by clients or consultants and for the remaining 23% of our installed systems, it is very likely that no monitoring is currently undertaken.

We strongly believe that a key role for any consultant or contractor involved in CP projects is to inform clients of the need to establish a maintenance programme for a structure receiving CP. Such maintenance programmes should include regular monitoring and regular system adjustments to ensure that the structure is receiving the appropriate CP current during its service life. It is the authors' opinion that the maintenance programme should include regular inspections to the CP areas, regular rectification of any defects in those areas and regular monitoring and adjustments of the CP system. Generally, the cost associated with system monitoring is approximately 2% annually of the total value of the system installation. It is essential that the client is aware, in advance, of the long term maintenance commitment prior to embarking on the use of this technology to ensure the long term protection of the structure.

In addition, it has become clear from a history of monitoring and maintaining systems that the original design should take into account considerations for ease of maintenance and accessibility of components that need to be checked and maintained. Accessibility of components will greatly reduce maintenance costs over the service life of the system.

CONTROL SYSTEMS

Two types of control systems have been used for the CP installation in Australia; manually operated control systems (with and without data loggers) and remote control systems. The systems installed by Savcor until now are 47% remote control systems and 53% manually operated systems.

The perceived advantage of the manually operated system is the less likelihood of component failure due to simplicity of design and also the lower cost of these systems. The main disadvantages of these systems are:

- In the case of any current failure or any component failure, the system will be ineffective until the next monitoring session, which in many instances could be up to twelve months or more. In this instance the structure is left unprotected.

- Physical attendance is required on site to carry out

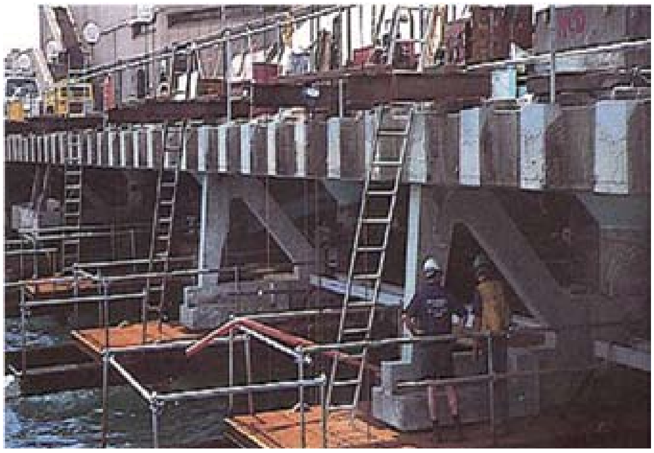

Figure 2: Cathodic Prevention applied to the Western Underbroadwalk of the Sydney Opera House in 1995-96 (First cathodic prevention system in Australia)

Figure 3: Cathodic Protection applied to the Trident building in Manly in 1997 (first application of CP to a residential building in Australia).

depolarisation testing and system adjustment. This can be costly depending on the location, and requires organisations to have sufficient well-trained manpower resources to cover many locations.

In particular, where manual systems are used without data loggers:

- In general the 'Instant Off' reading of the reference electrodes is taken either by an interrupter or by manually switching the system OFF and ON, while reading the values from a multimeter. The accuracy in both cases is questionable and can influence the accuracy of the results and consequently the level of protection.
- There is no recording of any data. The measurements for the reference electrodes are accurate only at the time of measurement. In general, these measurements can vary substantially in tidal situations or with the influence of weather conditions. This may lead to adjustment of the system based on misleading results and consequently may compromise the system performance.
- Manual recording of data and re-transcribing increases the possibility of errors.

The computer-controlled systems can be controlled off-site from a computer, and importantly they offer more functions associated with data recording whilst providing a greater degree of accuracy.

The main advantages of these systems are:

- Any full or partial failure of the system can be detected easily by simply dialling into the system from a remote location via a normal phone line or GSM modem. Some advanced systems have facilities for alarm functions that are capable of dialling out to report any faults.
- The systems that have data recording and saving facilities will allow historical analysis of the system performance, which may allow for more accurate system adjustment. Adjustment of the CP systems based on historical data will optimise the level of protection provided to the structure.
- The 'Instant Off' reading is carried out automatically and with greater accuracy than with manual recording. More accurate readings will lead to optimisation of the system performance.
- Adjustment of the system can be carried out more frequently, especially in the first year of operation of the system, which is normally the requirement.
- Some control systems offer automatic data collection, data saving and automatic depolarisation tests at selected intervals.
- Some systems have facilities for customised data and depolarisation test results in an easy to read formats. This will simplify the system monitoring and save time.

The main disadvantages of these systems are:

- Being computer-dependent, they may require more servicing depending on the system technology being used.
- The systems have a higher initial cost over a standard manual system.
- In some cases there may be a lack of local manufacturing and technical backup for these systems.
- Some systems require more extensive operator training than that required for a manual system.

Over the past 19 years, both manually operated and computer control systems have been used successfully and have provided the required protection to the structures where a maintenance programme was established for the CP installation.

The selection of the type of system for any CP installation would depend on the location of the site, the size of the project and the areas of the structure to be protected (tidal, splash etc).

It is the authors' opinion that computer control systems have a greater advantage over manually controlled systems, however it is essential that the selected computer control system can automatically revert to manual operation in the event of remote monitoring failure. Selecting such systems will offer the great advantage of continuous monitoring by remote access and the continuity of operation in case of any malfunction in electronics.

ANODE SYSTEMS

The first installations undertaken by Savcor in the early 90s included various applications of activated titanium mesh anodes; following this, various systems were installed using discrete platinised titanium rod anodes with graphite backfill. Since the mid-90s and until today, the bulk of the anode material used by Savcor has been mixed metal oxide (MMO) ribbon mesh anodes installed in the concrete cover or into drilled holes as discrete anodes.

The authors are aware of various applications in Australia of conductive ceramic anode systems supplied in a tubular shape with gas venting systems and embedded in the concrete.

With reference to the overall performance of the various types of anode systems installed in Australia; the mesh anode system has and is being used very successfully for various applications. However, the use of mesh anode with gunite concrete cover may be associated with some delamination problems under certain circumstances. As the bulk of the CP systems in Australia are for sub-structure elements such as piles, beams and headstocks, alternative anode systems, rather than mesh, have been considered more appropriate.

With regard to the use of discrete rod anodes with graphite backfill, there have been some installations in the early 90s. Recently, the bulk of the discrete anodes used in Australia are mesh based anodes with cementitious grout.

There is no doubt, that ribbon mesh anode is the major type of anode material currently used in Australia. The use of this anode in the tidal and splash zones has been associated with grout deterioration problems. The problems related to grout deterioration were not known for the early installations of ribbon mesh anode and it took some time before the industry became aware of these problems. Currently, Savcor has developed various details of anode embedment in the critical areas where there is likelihood of grout deterioration and also has promoted the use of special cathodic protection grout that will reduce significantly or eliminate the possibilities of grout deterioration.

The predominant ribbon mesh anode materials used in Australia were manufactured by DeNora Permelec in Italy or Eltech in the USA. All our systems have used the anodes from these companies due to long term track records and proven quality of performance. Currently there are other ribbon anodes offered in the market at lower prices and with unproven track records or performance history. It is essential that the selection of anode material is undertaken carefully as the quality of the anode is essential to guarantee long term performance.

CONCLUSIONS

There is no doubt that CP of steel in concrete in Australia has emerged from being an experimental method in the mid-eighties to a very well established technique today.

Various aspects of cathodic protection of steel in concrete are detailed in AS2832.5-2002, Australian Standard for Cathodic Protection of Metals, Part 5, Steel in Concrete Structures.

Today, cathodic protection of steel in concrete in Australia is a very well recognised and accepted method for the repair of reinforced concrete structures suffering from chloride induced corrosion.

Figure 4: Cathodic Protection applied to Wharves 4 and 5 at the Port of Brisbane (completed in 1997)

Figure 5: Cathodic Prevention applied to Seacliff Bridge, Lawrence Hargrave Drive, in 2005.

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