CATHODIC PROTECTION OF A MULTI-STOREY BUILDING, METHOD OF PROJECT DELIVERY AND LONG-TERM MAINTENANCE

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ABSTRACT

The Trident Building is a 15 storey apartment complex situated on a beach frontage in the Sydney suburb of Manly. As a part of a major building refurbishment during 1996-1997, cathodic protection repair was carried out to selected elements of the building.

The refurbishment work included major repair work and cathodic protection application to various elements of the building, the installation of new windows and doors, waterproofing, tiling, plumbing and the application of an external protective coating. The design and construct project was completed in 1997 and some aspects of the work related to concrete repair were subject to an extended 10 year warranty issued by the builder.

This paper will describe the cathodic protection system, the system maintenance and monitoring for the past 10 years and the method of project delivery for these types of structures.

INTRODUCTION

The Trident building in Manly NSW is one of the most distinctive apartment towers consisting of 41 prestige units. During 1996-1997, a major refurbishment work was undertaken for the building

The scope of the refurbishment work included conventional patch repair, waterproofing membranes, tiling, protective coatings and cathodic protection to various elements of the building. The refurbishment works included the enlargement of the lounge area into the existing balconies, new perimeter windows, doors tiling and painting.

The project was completed whilst the units were occupied and access to the units gained externally by using several hi-climber platforms.

CONDITION SURVEY

As a part of the refurbishment work in 1996, an initial condition survey of the building was undertaken in February 1996. 60% of the units were accessed and inspected as a part of the inspection programme. The investigation techniques used were visual inspection, reinforcement concrete cover survey, half cell potential and resistance mapping, electrical continuity testing, carbonation analysis and chloride content analysis.

Based on the detailed investigation carried out, the major cause of existing deterioration of the structure was found to be a combination of low concrete cover to reinforcement, concrete carbonation and chloride contamination of the concrete. The areas most affected were in the main triangular balconies especially in the drip groove areas. The level of chloride contamination and deterioration of concrete generally was much higher in the lower floors than the top floors. Full analysis of the results was undertaken prior to determining the repair programme. This analysis was based on the test results and the likely cost of alternative repairs. The client's initial options considered the demolition and rebuilding of the triangular balconies, or carrying out repair work to the structure. The latter option was adopted. The recommendations for the repair work of the external building areas fell into two categories (i) those elements and areas to be repaired and protected by cathodic protection in conjunction with patch repair techniques and protective coating and (ii) those elements and areas to be repaired and protected by patch repair techniques in conjunction with protective coating.

For the internal floor areas, it was found that the problem was localised mainly around the window line and in the kitchens. Moisture in these areas had contributed to existing spalling caused by the penetration of chloride from the chloride-rich magnesite floor topping (which was applied to all floors during construction for sound proofing purposes). The recommendation was to remove the magnesite from the floor slab areas adjacent to all existing window lines, treat the concrete, apply a cathodic protection system, and reinstate these areas of the floors only.

CATHODIC PROTECTION

Introduction

Electrochemical techniques for the repair of reinforced concrete structures suffering from chloride induced corrosion are being widely recognised as an effective and long-term solution to stop reinforcement corrosion.

Chloride induced corrosion is the most serious cause of deterioration of reinforced concrete structures. The presence of chlorides in concrete does not directly affect the concrete but rather allows corrosion of the steel reinforcement to occur. The chloride in the corrosion reaction on the steel surface is not consumed, thus the reaction will continue until all the raw material of the corrosion process, namely steel and oxygen are consumed.

There are several methods to stop corrosion of steel reinforcement in chloride contaminated concrete.

These methods are:-

- full or partial rebuild of the structure
- removal of all concrete where critically high levels of chloride have penetrated, and
- the use of electrochemical techniques such as chloride extraction or cathodic protection
- the selection of the most appropriate technique requires careful consideration and is related to the condition of each particular structure.

What is cathodic protection?

When reinforcement steel corrodes in concrete, the process is similar to a battery. In batteries, there is generation of electricity because two dissimilar metals are exposed to an acidic solution (paste or gel in practical batteries) that corrodes one metal and creates a harmless reaction in the other. This corrosion reaction at the 'anode' generates electrons that are consumed by the 'cathode'.

For the steel reinforcement that corrodes in concrete, one very small area is the positive pole (anode) and another much larger one is the negative pole (cathode). The corrosion current flows out of the steel at the anode, the part corroding, through the concrete and into another part of the steel where there is no corrosion occurring, i.e. the cathode. This current flow is called the corrosion circuit and the steel dissolved at the anode forms iron dioxide.

For a battery, the electrical connection between positive and negative poles can be disconnected. The circuit is then broken and the dissolution of metal stops.

In concrete, the corrosion circuit is buried in the structure and the current running through the concrete cannot be disconnected. The only method of stopping the current from running through the concrete is to provide a new current from an external source via an external anode in or on the concrete. The flow of electrons between the new anode and the reinforcing steel changes previously positive poles (anodes) into current receivers. Thus all the reinforcement becomes a negative pole or cathodic, hence the name 'Cathodic Protection'.

Anode materials selected for this project

Various anode materials were considered during the design process. The materials selected for this installation were the ribbon anode LIDA® grid for all the external elements of the building, and the LIDA® CN25 titanium mesh for the floor slab.

The ribbon anode LIDA® grid was considered the most appropriate anode for the external elements of the structure because of its flexibility of application regarding the variation of anode spacing to satisfy the variation in current requirements.

Other systems such as conductive paint were considered inappropriate because of the life requirement of the CP system.

CATHODIC PROTECTION INSTALLATION

Zones of the CP system

The cathodic protection system was divided into 3 separate sections (A, B and C). Each section was divided into 15 separate electrical zones. The following points were taken into consideration in the creation of the zoning of the CP system:

- Geometry of the structure
- The different corroding conditions of the elements to be protected
- Variation in concrete resistivity
- The extent of deterioration of the elements to be protected
- Size of power supply units

A total of 45 electrical zones (including 3 spare zones) were created (Figure I) to satisfy the above conditions. The relatively large number of zones was essential to ensure that any short-circuit problems encountered during construction were easily found and rectified. In addition to this the large number of zonings would provide proper current distribution and effective system control and adjustment.

Each section of the system was divided into 5 separate main electrical zones. Each main electrical zone was divided into sub-zones as shown in Figures I and II.

Figure I: Building view and cathodic protection zoning for sections A, B and C

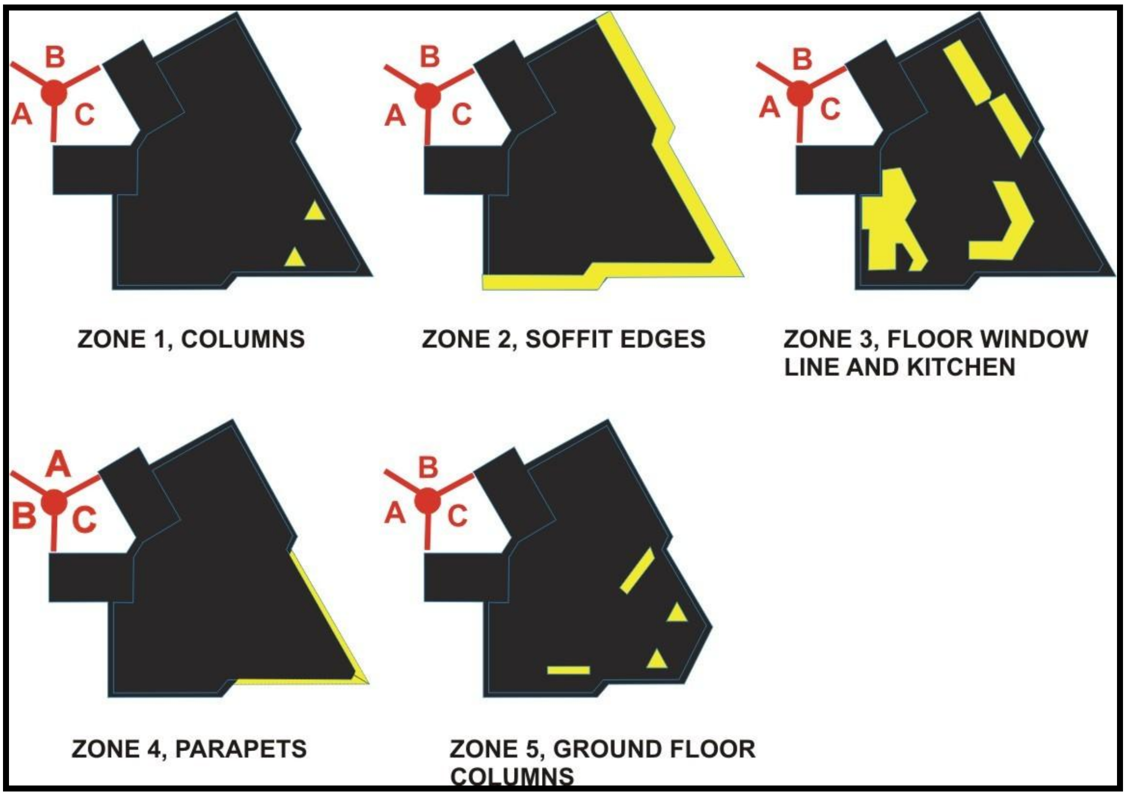

Figure II: Typical main zoning of the cathodic protection system for sections A, B and C

Anode Installation

The mesh ribbon anode LIDA® grid was used in the parapet walls, columns and the slab soffit, while the CN25 LIDA® mesh was used in the kitchen floor slab and along the window lines. Continuity of reinforcement was checked in all breakout locations and at random good concrete locations. The reinforcement was made continuous at all breakout locations and at good concrete locations if found to be discontinuous.

After carrying out the repair work, 10mmx30mm slots were cut into the concrete; the mesh ribbon anode grid was placed in the slots and backfilled with cementitious material. For the internal floor areas, the mesh was cut to size and installed onto the concrete surface after the magnesite had been removed and the floor slab repaired. For some sections of the parapet walls where full/partial replacement of the walls was carried out, the mesh ribbon anode grid was attached onto the reinforcing cage with specially designed insulating cementitious material prior to concrete placement.

Anode and steel connections were established from each electrical zone and Silver/Silver Chloride and Titanium reference electrodes were installed in selected locations for monitoring purposes. All cables from the various elements of the structure were terminated into junction boxes located on each floor behind a false wall. All cables from the junction boxes on each floor were terminated in 3 main substations located in the basement. The control and monitoring of the CP system was carried out via a control unit also located in the basement.

For aesthetic purposes, all cables were embedded in concrete and all wiring, junction boxes etc were concealed from view.

As part of the testing procedure for the system, a fixed current was applied to the steel/anode circuit for each zone during installation to ensure proper operation of the system and to detect any defects during construction. The change in steel potential with respect to embedded reference electrodes or external reference electrodes on the concrete surface was measured. For selected elements of the structure, potential mapping was undertaken during testing to check current distribution and to verify design assumptions.

Monitoring and Control System

The ‘Savcor’ computerised control and monitoring system was selected for the monitoring and control of the CP installation. Some of the features of the system are:

- On line monitoring
- Remote control facility
- Recording of power supply current and voltage
- Recording of reference electrode ON readings and instant OFF readings
- Potentiostatic mode control
- Constant current control
- Alarm functions
- Automatic depolarisation test

Performance Data

The remote control system is equipped with macros that are capable of automatic downloading of the system data into a spreadsheet that includes location of reference electrodes, base potential, instant OFF potential, 24hr OFF potential, 24hr decay, positive shift and voltage and current for each zone of the system.

Following analysis of the data, the system is adjusted remotely. A typical spreadsheet for one section of downloaded data of the system is shown in Figure III.

24h depolarisation test - Trident Building, Manly, August 2007. Section C

Zone			Ref. Name	Floor	Base potential	Inst. OFF	Last OFF	24 hr dep.	Positive shift	Current mA	Volt.
Z	11	C	11	8	-124	-361	-92	269	32	40	3.3
Z	11	C	11	11	-66	-215	-44	171	22		
Z	12	C	11	2	-145	-254	-92	162	53	60	3.8
Z	12	C	11	3	-97	-318	-107	211	-10		
Z	12	C	11	5	-168	-262	-95	167	73		
Z	21	S	21	11	-254	-197	-97	100	157	60	5.0
Z	22	S	21	8	-54	-80	-15	65	39	100	10.1
Z	23	S	21	3	-174	-68	-43	26	131	100	2.9
Z	23	S	21	5	-341	-328	-134	194	207		
Z	24	S	21	2	-290	-140	-116	23	174	100	4.6
Z	31	F	31	11	-302	-228	-81	147	221	40	1.4
Z	31	F	32	11	-315	-253	-82	171	233		
Z	32	F	31	8	-208	-282	-173	109	35	40	1.7
Z	32	F	32	8	-303	-634	-195	438	108		
Z	33	F	31	5	-227	-108	-46	62	181	80	3.1
Z	33	F	32	5	-255	-271	-21	250	234		
Z	34	F	31	2	-212	-540	-125	416	87	60	2.1
Z	34	F	32	2	-212	-128	-108	21	104		
Z	34	F	31	3	-295	-421	-331	90	-36		
Z	34	F	32	3	-282	-583	-329	255	-47		
Z	41	P	41	11	-197	-226	-86	140	111	100	4.0
Z	41	P	42	11	-191	-252	-83	169	108		
Z	41	P	43	11	-261	-194	-94	101	168		
Z	41	P	44	11	-185	-213	-42	171	143		
Z	53	W	53	1	-870	-542	-173	369	697	20	0.5
Z	53	W	53	1	-450	-198	-120	78	330		
Z	4E	P	41	2	-130	-169	-61	108	69	40	3.1
Z	4E	P	44	2	-168	-57	-41	16	127		
Z	4E	P	41	3	-206	-634	-137	497	69		
Z	4E	P	44	3	-228	-194	-90	104	138		
Z	4E	P	41	5	-157	-98	-12	86	145		
Z	4E	P	44	5	-154	-306	-106	200	48		
Z	4E	P	41	8	-126	-549	-106	443	20		
Z	4E	P	44	8	-195	-350	-130	220	65		
Z	4N	P	42	2	-224	-83	-60	23	164	80	1.8
Z	4N	P	43	2	-269	-379	-249	130	20		
Z	4N	P	42	3	-241	-262	-79	183	162		
Z	4N	P	43	3	-225	-167	-136	31	89		
Z	4N	P	42	5	-147	-119	-22	97	126		
Z	4N	P	43	5	-239	-40	-16	24	223		
Z	4N	P	42	8	-181	-639	-146	493	35		
Z	4N	P	43	8	-213	-345	-100	245	113		

Figure III: Downloaded performance data before system adjustment – August 2007

Maintenance Contract and Warranty Repair

In 1996, the design and construct project was awarded to the builder (Savcor) based on a tendering process. The builder provided a 10 year warranty for concrete repair as a part of a 10 year maintenance programme for the building.

The maintenance programme included a six monthly remote monitoring of the cathodic protection system operation and one year detailed inspection of the CP system components including system adjustment and provision of a detailed monitoring report.

Concrete defects occurring during the maintenance period have been identified and repaired. The procedure was for the unit owners to submit a written defect form on a yearly basis to the builder; with the repair be completed within 6 months of notification. This process which is reliant on feedback from the owners (many units have tenants) has proven to be inefficient. This process would have been managed in a more effective way if a full maintenance programme was established for the building with all communication restricted to a maintenance manager.

The maintenance contract for the building included the monitoring of the cathodic protection system for 10 years from the date of commissioning and provision of warranty to the building façade for concrete spalling defects. This includes the areas repaired and protected by cathodic protection; the areas repaired using conventional repair methods and the areas which were not repaired as a part of the refurbishment work

Over the 10 year maintenance period, various concrete defects were identified and rectified by the builder as a part of the maintenance contract.

These defects can be categorised into 2 categories:

1. Concrete defects outside the cathodic protection areas and the areas of conventional repair undertaken as a part of the refurbishment work. Such areas were identified as low risk areas during the condition survey carried out for the building in 1996.
2. Concrete defects in the cathodic protection areas: it appears that most of these defects were in areas which had been repaired prior to the refurbishment work carried out in 1996. This was established on the basis of observed differences in the concrete found at repair locations: generally it was different to the mortars used for the refurbishment. Additionally, coated reinforcement was also found at such locations.

The overall repair process during the 10 year maintenance programme included 5 repair sessions with approximately one repair session carried out every 18 months.

Methods of Project Delivery

The two common methods of project delivery for electrochemical protection systems are detailed specification tendering or design and construct.

The detailed specification tendering method includes full preparation of a detailed specification for repair and cathodic protection 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 a detailed design prepared by a contractor or his consultant and contract award based on price or other selected criteria specified by the consultant or the client.

For electrochemical projects, it is the authors' opinion that the design and construct method may have an advantage in comparison to the detailed specification tendering method for the following reasons:

- This method will offer single point accountability, especially if the project is associated with an extended warranty period. Using this method, in case of any future warranty issues, the client can request any defects be rectified from one single party without going into the exercise of identifying if the defect has been caused by a design fault or if associated with workmanship.
- This method will offer an independent design verification by a third party consultant which is normally a part of the requirement of a design and construct tender. Normally, any cost associated

with modification of design as a part of the design verification is met by the contractor without any additional cost to the client.

- This method will offer flexibility for the main consultant to request, as a part of the performance specification, for trials and pilot installations to verify the design prior to starting the construction work. If the results of these trials suggests that a design change is required to meet the performance specification, this change is normally carried out by the contractor at no additional cost to the client.
- Normally, when the contractor is fully responsible for the system performance, it is very unlikely for reputable contractors to use any substandard product or workmanship as the final product is their full responsibility.
- This method is generally free from significant contract variations due to the nature of the contract.

There is no doubt that both methods of project delivery can be successful under various circumstances. The quality of documentation of the consultant and the workmanship of the contractor in most cases dictate the final outcome of the project. With regard to the Trident building, there is no doubt that the selected method of project delivery was the optimum choice which has delivered to the owners a satisfactory project.

DISCUSSION

In carrying out any cathodic protection repair, it is essential that all previous repair areas are identified and tested for compatibility with the cathodic protection system.

Although, previous repairs were found to be generally localised, there is a risk that such locations would not receive an adequate cathodic protection current and a current consistent with other parts of the structure: i.e. the original concrete and repairs using compatible cathodic protection materials. The reason for this difference is the large variation in concrete resistivity between the different types of repair products.

During the refurbishment, any detected areas of old incompatible repairs were removed; however, some localised spots were concealed beneath the coating and remained undetected.

Over the ten year warranty period the extent and nature of any subsequent repairs have been localised and relatively minor – particularly in comparison to the extensive damage found at the building prior to the refurbishment.

The remote cathodic protection control system operated highly satisfactorily for the initial 10 year period and is expected to operate for an additional 10 years without replacement.

After 10 years of system operation, all cathodic protection system components are fully operational.

CONCLUSIONS

The philosophy adopted for the repair of the Trident building has proved extremely successful in delivering an excellent result for the building owners. This philosophy was based on carrying out repair work based on corrosion risk assessment instead of partial demolition of the building.

The alternative to the repair philosophy was to undertake partial demolition and reconstruction to various sections of the building – this would have cost substantially more. And in addition, the owners would have had to vacate the building adding further cost and disruption.

The approach to undertake repair work with a 10 year maintenance contract with a reputable builder has provided the building owners with a 10 year maintenance free building. In addition to this, the builder's warranty has contributed to a major increase in the value of the units over the last 10 years.

The method of project delivery adopted for this work was based on single point accountability philosophy. The builder was involved in all the aspects of the work including condition survey, cathodic protection design, provision of concrete repair specification and carrying out the actual work.

This project was the first major cathodic protection application for a building structure in Australia. The design and construct approach adopted for this structure has proved to be an ideal method of project delivery for this type of complex electrochemical repair projects.

Cathodic protection techniques can be used for the rectification of buildings located in marine environments.

A maintenance programme which will include routine inspections of the building and monitoring and adjustment of the cathodic protection system for an initial 10 years (2017) is being finalised. This maintenance programme will ensure that the building remains fully maintained to the highest standard.

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