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CORROSION 99

CATHODIC PROTECTION TO THE PORT OF BRISBANE STRUCTURE, AUSTRALIA

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ABSTRACT

Electrochemical treatment of reinforced concrete structures has been used extensively in Australia. This paper will describe one of the largest cathodic protection systems for reinforced concrete structures in Australia. The area of the cathodic protection (CP) system for the Port of Brisbane is over 8000m². Over 30km of ribbon anode was used in this installation. The system is monitored by a fully computerized remote control system.

Keywords: Cathodic protection (CP), corrosion, monitoring, potential, protection, chloride, concrete, steel.

INTRODUCTION

The wharf structures in Australia are subject to aggressive chloride attack. An increasing number of structures are now reaching their serviceability limit and major repair work is necessary for reasons of economy, preservation and safety. Practical, cost-effective methods of repair to provide long-term life extension with minimal maintenance are in demand.

This paper presents details of the CP installation to wharves 4 and 5 of the Port of Brisbane in Queensland, Australia.

The 'design and construct' contract for the rehabilitation of wharves 4 and 5, which totals 600 meters in length, was designed to meet the complex needs of the Port of Brisbane Corporation. The Port's primary requirement was to address the severe concrete deterioration to the wharves' substructure and to adopt a solution which would allow the structure to continue to remain fully operational while the rehabilitation works were being carried out.

DIAGNOSIS

Various repair techniques involving full-depth conventional repair trials and a cathodic protection trial installation were commissioned by the Client in order to select the most effective long-term repair solution. These trials indicated that conventional repairs were impractical because of the major disruption that would occur to Port operations during repair work and the structural implication of the removal of all the chloride-contaminated concrete from the structure. Based on the results of the CP trial, the Port of Brisbane Corporation decided to proceed with this method of repair. As a part of the design and construct contract for the CP repair of the structure, a detailed electrochemical analysis was undertaken. This analysis included resistance and potential mapping, electrical continuity testing, determination of chloride concentration, delamination testing, resistivity measurements, and dynamic load testing of some segments of the wharf in order to confirm that the wharf could still support the crane loading. The results of the investigation showed large areas of concrete delamination, being up to 90% of some of the elements of the structure, and very high chloride concentration and corrosion activity of reinforcement for nearly all the elements of the structure.

SYSTEM DESIGN

As a part of the design process, pilot repair and CP installations were carried out to various elements of the structure. The aim of these pilots was to test design assumptions and to verify that the proposed anode type would provide optimum protection to the reinforcement. Various types of anodes were considered for this installation. Activated titanium anode mesh was considered inappropriate due to possible problems associated with the application of a concrete overlay on the mesh. Sprayed zinc was considered inappropriate due to the harsh environment of the structure and the life requirements of the CP system. Mesh ribbon anode[1] was considered the most appropriate anode material due to its flexibility of application i.e. installation with flexibility of spacing to satisfy the variation in current requirements.

The CP system was divided into thirteen sections. Each of these sections (approximately 48 meters long) was divided into fourteen separate electrical zones. The following issues were taken into consideration in the zoning of the CP system.

- Variation in concrete resistivity.
- The different corroding conditions of the elements to be protected.
- Tidal variations.
- Geometry of the structure.

INSTALLATION

Anode Installation

Two methods of installation were used for the anode material (activated titanium mesh ribbon). In the first method, 10mm x 30mm deep slots were cut into the concrete, the mesh ribbon anode was placed in the slot and back-filled with cementitious material. The second method involved placing the ribbon anode between two layers of gunite, which was specially chosen to ensure compatibility with the existing concrete. Anode and steel connections were established from each electrical zone and 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 the front crane beam and the abutment wall. All cables from the junction boxes were terminated in thirteen main sub-stations fixed to the abutment wall. The thirteen sub-stations were connected via a telephone line and power supply cable to the Main Control Unit, which was located in the main control room near wharf number 4.

Reference Cell Installation

The system contained a total of 365 embedded reference electrodes. The types of electrodes used were silver/silver chloride and titanium electrodes. The locations of the reference electrodes were determined from the results of a detailed potential and resistance mapping survey, which was carried out during construction, for every element of the structure. The reference electrodes were installed away from repaired areas where practical, in highly corrosive areas, and away from the main anode connections. For each reference electrode, a dedicated steel connection cable was installed in order to obtain accurate potential readings.

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[1] LIDA® Grid is a trade name of Oronzio De Nora S.p.A – Lugano - Switzerland

Testing During Installation

As a 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 detect any defects during construction. The change in steel potential with respect to the embedded reference electrodes was measured. For selected elements of the structure, potential mapping was undertaken during testing to check current distribution and verify design assumption.

Operational Aspects

A major requirement for the repair of wharves 4 and 5 was for minimal impact on the operations of the Port of Brisbane's tenant, the Stevedoring Company. With this in mind, construction activities were designed to accommodate all activities being carried out below the wharves.

Access for men and materials to the underside of the entire 600 meters of structure was established via a single penetration cut in the deck at one end. Special purpose systems for materials handling were devised, and barges were designed and built for guniting operations and for removal of concrete rubble. These were required to accommodate the extremely confined space limitations at high tide and their constantly changing loading conditions.

Purpose built platforms provided access to 50 meters of the structure at a time and were easily floated into position as the work progressed. Due to the relatively low level of the structure in relation to the tide, much of the work was completed in the water, with waders and wetsuits a common accessory during the colder months.

The scale of this project placed considerable emphasis on the installation and constant movement of temporary services such as air, water, power and lighting, with temporary lines in excess of 300 meters long. Concrete repairs to the crane beams, relieving slab and abutment total around 5,000m^2, with approximately 2,000 tonnes of dry gunite being placed.

To further minimize disruption to both the owner and operator of the wharves, the construction was accelerated with a double shift, around the clock operation.

MONITORING AND CONTROL SYSTEM

The computerized 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 (Real-time data in display. The data can be updated continuously).
- Remote control facility (The system is accessible from a remote location. All parameters can be set from a remote PC).
- Recording of power supply current and voltage.
- Recording of reference electrodes Instant Off readings.
- Potentiostatic mode control (Allows for current adjustment of circuits based on a selected optimum potential value of reference electrodes. The selection of this value is based on the depolarisation data and is related to the adopted criteria for the system). This function is very important in tidal situations to ensure that overprotection/underprotection is avoided during tidal variations. In addition, this function is essential for ensuring optimum operation of the system with the required current only, in order to maximize equipment and anode life.
- Constant current control.
- Alarm functions (The ability to dial out and leave messages for any faults in the system performance).
- Automatic depolarisation test.
- Graphical user interface which allows for plotting the trend for any circuit (current, voltage and reference electrodes) for a selected period.
- Automatic data collection and saving.
- Automatic stray current testing (The ability to switch ON and switch OFF the whole system at the same time for selected periods).

QUALITY ASSURANCE AND SAFETY

All construction activities were controlled by a comprehensive Project Quality Plan. Checklists were completed on a daily basis by site technicians for concrete breakout, rebar continuity, guniting and the various aspects of the anode and electrical installation.

The specially commissioned gunite materials were tested at the start of the project and during construction for resistivity, shrinkage, compressive and bond strength. During installation, tests were carried out at every $3m^3$ of materials consumed. Compressive and bond strengths typically at 28 days resulted in measurements of 60-70MPa and 1 to 3MPa respectively. Dynamic testing of the crane beams was undertaken in order to confirm the structure's ability to continue to perform under loading while the cover concrete was removed.

A detailed Project Safety Plan was developed with strict safety procedures put in place to take into account the site's continuing operation and extensive cargo movement. A comprehensive network of communications was established to ensure the smooth and safe conduct of contract works and Port operations. A Project Safety Committee was established to manage and execute the Project Safety Plan, and shipping movements and handling of hazardous goods were closely monitored to avoid possible conflict with works below the wharf.

PROTECTION CRITERIA

The CP system is considered to be providing satisfactory corrosion protection to the reinforcing steel when the system meets or approaches at least one of the following criteria subject to a most negative instantaneous off potential of –1100 mV referenced to Ag/AgCl/KCl reference electrode.

a) A minimum 150mV negative shift from the "Base" potential to the "Instant Off" potential ("*Potential Shift Criterion*") or

b) A potential at "Instant Off" that is –800mV or more negative to Ag/Ag/Cl/KCl reference electrode ("*Absolute Potential Criterion*"). This criterion is adopted where the structure is immersed or frequently wetted or

c) A minimum 100mV potential decay over a minimum period of depolarisation of 4 hours ("*Potential Decay Criterion*").

An additional criterion for the assessment of the system was to determine whether potential after decay/depolarisation is more positive that the "Base" potential taken before the system was energised ("*Positive Base Potential Shift Criterion*"). This criterion will provide an indication of the long-term reduction of corrosion activity of reinforcement, especially after an extended period of CP application.

PERFORMANCE

Based on the adopted criteria for the assessment of the CP system and the initial performance data presented in Tables 1, 2 and 3, it was concluded that the system was operating very satisfactorily.

CONCLUSIONS

Cathodic protection is becoming a widely recognized technique in Australia for the repair of marine structures suffering from chloride-induced corrosion. The experience gained from this project suggests that for large-scale CP installations it is essential to ensure that the design is verified by pilot installations, that a comprehensive program of site testing including energizing during construction is implemented as part of a Quality Assurance Plan, and that a fully computerized control system is used to ensure proper monitoring and control of the system for optimum protection and long term performance. The system was completed in late 1998. Monitoring will be carried out jointly by the Contractor and the Client, and adjustments made according to the adopted criteria for the assessment of the system in order to maintain optimum protection to the reinforcement with minimal maintenance to the structure.

ACKNOWLEDGEMENTS

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TABLE 1
INITIAL PERFORMANCE DATA OF THE SYSTEM DURING CONSTRUCTION

Section No.:1												
Zone	Ref. title	Natural potential (mV)	On (mV)	Instant off (mV)	24 hr off (mV)	24 hr depolarisation (mV)	Positive shift (mV)	Potential shift (mV)	Criteria 1 (decay >100 mV)	Criteria 2 (Positive shift > +0 mV)	Criteria 3 (Potential shift >-150mV)	Criteria 4 Instant off potential >-800mV
1	1A	-281	-511	-485	-301	184	-20	-204	■	-	■	-
	1C	-315	-570	-542	-377	165	-62	-227	■	-	■	-
2	2A	-620	-915	-869	-780	89	-160	-249	-	-	■	-
	2C	-746	-936	-889	-779	110	-33	-143	■	-	-	■
31	31A	-208	-262	-249	-30	219	178	-41	■	■	-	-
	31C	-157	-298	-283	90	373	247	-126	■	■	-	-
32	32A	-57	-141	-134	-24	110	33	-77	■	■	-	-
	32C	-135	-117	-111	-74	37	61	24	-	■	-	-
33	33A	-144	-157	-149	-68	81	76	-5	-	■	-	-
	33C	-148	-440	-418	-41	377	107	-270	■	■	■	-
34	34A	-44	-319	-303	-29	274	15	-259	■	■	■	-
	34C	-55	-216	-205	-63	142	-8	-150	■	-	■	-
4	4LA	-164	-617	-586	-230	356	-66	-422	■	-	■	-
	4SC	-85	-130	-124	-66	58	19	-39	-	■	-	-
51	51A	-85	-258	-245	-76	169	9	-160	■	■	■	-
	51C	-110	-254	-241	-90	151	20	-131	■	■	-	-
52	52A	-235	-352	-334	-130	204	105	-99	■	■	-	-
	52C	-236	-521	-495	-193	302	43	-259	■	■	■	-
6	6A	-95	-263	-250	-108	142	-13	-155	■	-	■	-
	6C	-160	-257	-244	-149	95	11	-84	■	■		-
71	71A	-155	-358	-340	-133	207	22	-185	■	■	■	-
	71C	-245	-306	-291	-150	141	95	-46	■	■	-	-
72	72A	-91	-252	-239	-94	145	-3	-148	■	-	■	-
	72C	-213	-895	-850	-688	162	-475	-637	■	-	■	-
73	73A	-54	-444	-422	-271	151	-217	-368	■	-	■	-
	73C	-77	-433	-411	-82	329	-5	-334	■	-	■	-
74	74A	-190	-767	-729	-591	138	-401	-539	■	-	■	-
	74C	-121	-307	-292	-120	172	1	-171	■	■	■	-

A : Titanium reference electrode
C : Silver/silver reference electrode
Criteria 4 is for silver/silver reference electrodes only

TABLE 2
INITIAL PERFORMANCE DATA OF THE SYSTEM DURING CONSTRUCTION

Section No.:2												
Zone	Ref. title	Natural potential (mV)	On (mV)	Instant off (mV)	24 hr off (mV)	24 hr depolarisation (mV)	Positive shift (mV)	Potential shift (mV)	Criteria 1 (decay >100 mV)	Criteria 2 (Positive shift > +0 mV)	Criteria 3 (Potential shift >150mV)	Criteria 4 Instant off potential >-800mV
1	1A	-352	-551	-523	-321	202	31	-171				-
	1C	-337	-467	-444	-333	111	4	-107			-	-
2	2A	-709	-988	-939	-868	71	-159	-230	-	-		-
	2C	-806	-1054	-1001	-905	96	-99	-195		-		
31	31A	-283	-675	-641	-182	459	101	-358				-
	31C	-173	-227	-216	-154	62	19	-43	-		-	-
32	32A	-188	-290	-276	-99	177	89	-88			-	-
	32C	-200	-536	-509	-149	360	51	-309				-
33	33A	-156	-330	-314	-77	237	79	-158				-
	33C	-408	-427	-406	-331	75	77	2	-		-	-
34	34A	-112	-255	-242	-99	143	13	-130			-	-
	34C	-100	-386	-367	-8	359	92	-267				-
4	4LA	-185	-437	-415	-124	291	61	-230				-
	4SC	-107	-164	-156	-85	71	22	-49	-		-	-
51	51A	-157	-607	-577	-82	495	75	-420				-
	51C	-127	-327	-311	-140	171	-13	-184		-		-
52	52A	-105	-365	-347	-98	249	7	-242				-
	52C	-135	-347	-330	-121	209	14	-195				-
6	6A	-142	-165	-157	-93	64	49	-15	-		-	-
	6C	-99	-177	-168	-71	97	28	-69			-	-
71	71A	-192	-313	-297	-132	165	60	-105			-	-
	71C	-211	-329	-313	-138	175	73	-102			-	-
72	72A	-185	-392	-372	-107	265	78	-187				-
	72C	-139	-335	-318	-101	217	38	-179				-
73	73A	-130	-366	-348	-136	212	-6	-218		-		-
	73C	-154	-385	-366	-139	227	15	-212				-
74	74A	-68	-411	-390	-150	240	-82	-322		-		-
	74C	-113	-273	-259	-97	162	16	-146				-

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C : Silver/silver reference electrode
Criteria 4 is for silver/silver reference electrodes only

TABLE 3
INITIAL PERFORMANCE DATA OF THE SYSTEM DURING CONSTRUCTION

Section No.:3												
Zone	Ref. title	Natural potential (mV)	On (mV)	Instant off (mV)	24 hr off (mV)	24 hr depolarisation (mV)	Positive shift (mV)	Potential shift (mV)	Criteria 1 (decay >100 mV)	Criteria 2 (Positive shift > +0 mV)	Criteria 3 (Potential shift >-150mV)	Criteria 4 Instant off potential >-800mV
1	1A	-377	-560	-532	-383	149	-6	-155	■	-	■	-
	1C	-188	-343	-326	-194	132	-6	-138	■	-	-	-
2	2A	-596	-892	-847	-606	241	-10	-251	■	-	■	-
	2C	-665	-931	-884	-669	215	-4	-219	■	-	■	■
31	31A	-390	-649	-617	-391	226	-1	-227	■	-	■	-
	31C	-188	-724	-688	-195	493	-7	-500	■	-	■	-
32	32A	-409	-768	-730	-413	317	-4	-321	■	-	■	-
	32C	-114	-615	-584	-118	466	-4	-470	■	-	■	-
33	33A	-184	-409	-389	-191	198	-7	-205	■	-	■	-
	33C	-346	-614	-583	-353	230	-7	-237	■	-	■	-
34	34A	-198	-368	-350	-203	147	-5	-152	■	-	■	-
	34C	-64	-486	-462	-74	388	-10	-398	■	-	■	-
4	4LA	-162	-601	-571	-163	408	-1	-409	■	-	■	-
	4SC	-62	-367	-349	-60	289	2	-287	■	■	■	-
51	51A	-143	-403	-383	-144	239	-1	-240	■	-	■	-
	51C	-113	-351	-333	-124	209	-11	-220	■	-	■	-
52	52A	-120	-441	-419	-110	309	10	-299	■	■	■	-
	52C	-189	-395	-375	-68	307	121	-186	■	■	■	-
6	6A	-117	-388	-369	-123	246	-6	-252	■	-	■	-
	6C	-64	-379	-360	-193	167	-129	-296	■	-	■	-
71	71A	-114	-337	-320	-116	204	-2	-206	■	-	■	-
	71C	-118	-415	-394	-124	270	-6	-276	■	-	■	-
72	72A	-93	-407	-387	-99	288	-6	-294	■	-	■	-
	72C	-129	-376	-357	-138	219	-9	-228	■	-	■	-
73	73A	-149	-421	-400	-148	252	1	-251	■	■	■	-
	73C	-168	-390	-371	-174	197	-6	-203	■	-	■	-
74	74A	-166	-290	-276	-166	110	0	-110	■	■	-	-
	74C	-239	-384	-365	-240	125	-1	-126	■	-	-	-

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C : Silver/silver reference electrode
Criteria 4 is for silver/silver reference electrodes only