Paper No.
RCC25

CORCON 17-20 September 2017 Mumbai, India

CORROSION CONTROL OF REINFORCED CONCRETE IN CORROSIVE ENVIRONMENT

Haixue Liao

P.Eng., P.E., CP Specialist
Vector Corrosion Technologies Ltd., Milton, Canada
liaoh@vector-corrosion.com

Dhruvesh Shah

Vector Corrosion Technologies Ltd., Gujarat, India
dhruveshs@vectorgroup.com

ABSTRACT

Corrosive environments have caused tremendous damages, structural deterioration and failure of reinforced concrete structure. Corrosive environments include tidal zone and splash zone of marine piles, heavily chloride-contaminated concrete due to di-icing salts or cast-in chloride (such as sea-sands used as fine aggregates in concrete), and concrete repairs in which complete removal of chloride contaminated concrete is not desired such as prestressed concrete.

Current density of 1-7mA/m2 by galvanic anodes embedded in concrete has been found to effectively control the corrosion in many projects and studies (Gulis, Lai & Tharmabala, 1997). As a result of corrosion control, many existing structures have been conserved and their service lives have been extended, future repairs of many existing and new structures have been delayed.

This paper will discuss the corrosive environments, introduce the concept of corrosion control. Finally case studies of service life extension are presented.

CORROSIVE ENVIRONMENTS

Corrosion of reinforcing steel is recognized as the major cause of the deterioration of reinforced concrete structures. Corrosive environments play significant role in reinforcing concrete corrosion. The corrosive environments include:

- Tidal zone and splash zone of marine structures
- Abutments, beam ends and cross beams at leaking expansion joints
- Concrete structures built with seasands as fine aggregate
- Concrete structures with calcium chloride as set-accelerator
- Exposed concrete structures that are heavily contaminated with di-icing salts

Figure 1. Marine pile corrosion

Figure 2. Concrete column corrosion under a leaking expansion joint

CORROSION CONTROL

Corrosion mitigation systems generally fall into three performance categories: corrosion prevention, corrosion control, and cathodic protection. In all categories, the anodes provide a level of protective current to the reinforcing steel to mitigate corrosion activity. However, they differ in terms of the intended application and the intensity of the protective current required for achieving the mitigation objective.

Corrosion control is characterized by a significant reduction in the corrosion rate of actively corroding steel in concrete. Corrosion control may or may not completely stop on-going corrosion, but the reduction in corrosion activity will significantly extend the service life of existing corroding structures. In corrosion control applications the conditions for corrosion (such as chlorides) already exist and corrosion may have already initiated in some areas, but has not progressed to the point of concrete damage. The applied current necessary to address corrosion activity (after corrosion initiation) is in the range of 1 to 7 mA/m^2 (0.1 to

0.7 mA/ft^2), while study shows that 1mA/m2 current density is effective in mitigating corrosion damage and reducing the rate of the delamination per year to 0.04% from the average 1% per year for unprotected structures (lai). Polarization of the reinforcing steel will typically occur at these current densities although the level of polarization may be less than the NACE 100mV depolarization criteria for cathodic protection (Liao, 2013).

GALVANIC CORROSION PROTECTION

Galvanic corrosion protection is a technique to reduce rebar corrosion by making the rebar surface the cathode of an electrochemical cell. The cathode in an electrochemical cell is the electrode where reduction (no corrosion) occurs. In a galvanic anode system, the current is generated by the potential difference between the zinc anode (-1100mV) and the steel reinforcement (typically at 350 to 500mV for corroding steel). There is no monitoring required to keep the sacrificial anodes working.

Partial Galvanic Series	
Metal	Voltage
Zinc	-1100 mV
Steel in concrete	-200 mV to -500 mV
*Typical potentials measured with respect to copper-copper sulfate electrode	

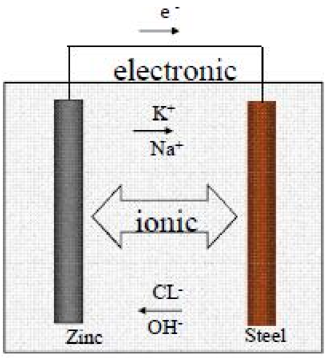

Fig. 3 How galvanic anode works.

CASE STUDY 1 TORONTO UNION STATION AT BAY STREET STRUCTURE

There was intensive corrosion in the bars due to the leaking expansion joints. A passive corrosion protection system was designed to provide corrosion protection to the main structural bars - the 27mm diameter crank bars on top of the archway.

The selected corrosion protection system consisting of three embedded distributed anodes was designed to provide corrosion control or cathodic protection to the reinforced concrete so as to extend the service life of the structure. Three line anodes (distributed anodes) were installed under the bearings. Each anode is 25mm diameter 450mm (1.5') long and contains 0.34kg (0.75lb) of zinc. 32mm diameter 500mm holes were drilled at downward angle and grouted half-full, then the line anode was inserted into the grouted hole to force the grout out. Finally the line anodes were connected to the rebars. The selected anodes have been monitored and the average current output is about 3mA/m2. The estimated life of the anodes is expected more than 20 years.

Figure 4. Concrete archway corrosion damages due to joint leaks with de-icing salts.

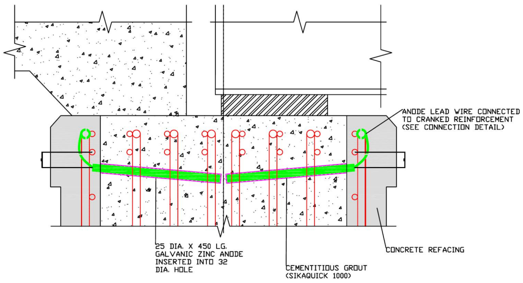

Figure 5. Galvanic anodes were designed to control the on-going corrosion of the top main rebars due to leaking joints.

CASE STUDY 2 WHITE BEACH SEAWALL RECONSTRUCTION, OKINAWA, JAPAN – AMERICAN NAVAL BASE

Galvanic anodes can be used to prevent corrosion from initiating. However, in corrosion environment such as splash zone and tidal zone, corrosion control current density of average 3mA/m2 is used as design current density.

The protection mechanism is as follows due to the direct current from the galvanic anodes:

Shifts the potential of the steel to a more passive state where corrosion is less likely to initiate

Cathodic reaction produces hydroxyl ion (OH-) which increases pH at the steel surface

Cathodic reaction draws positively charged ions to the steel (Na+, K+, Ca2+, Fe2+) and repels negatively charged ions (OH-, Cl-, SO4-)
The passive oxide film is improved

Residual benefit remains after galvanic anode consumption

Reduced chloride levels at the steel. Chloride is naturally repelled away from the steel while current is applied

Increased chloride threshold Alkalinity is increased at the steel surface
Reduces the chloride/hydroxyl ratio

The anode will delay the initiation of the corrosion and the service life of the seawall is extended.

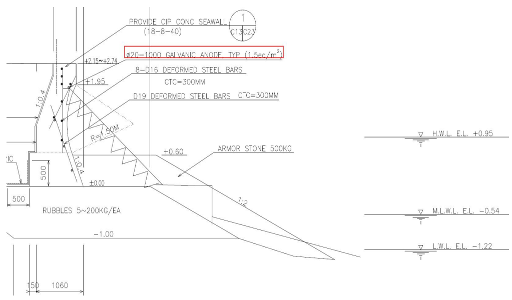

Figure 6. Seawall Sketch.

Figure 7. Seawall under construction.

CASE STUDY 3 HIGHWAY 417 ISLAND PARK DRIVE OVERPASS, OTTAWA, CANADA

The Island Park Drive Overpass, constructed in 1961, is comprised of a 178 mm thick reinforced concrete deck with asphalt wearing surface on welded wide flange steel girders at 2.36 m centres. The bridge is a single span of length 25.2 m and is constructed at a 50^0 skew to Highway 417. Overall width of the structure is approximately 36.3 m as measured perpendicular to the centreline of Highway 417. The abutments are reinforced concrete on spread footings, with reinforced concrete wingwalls constructed on individual spread footings and piles on the east and west sides respectively. The bridge underwent a major rehabilitation in 1983.

The superstructure was replaced with rapid structure replacement in an over-night traffic closure. The substructure had to be maintained. The substructures was heavily contaminated from di-icing salts from the highway 417 leaking expansion joints and traffic splash of Island Park Drive. Its corrosion conditions were as follows:

Abutments:
Spalls and delaminations covers approximately 14.5% (36.5m2) and 10.5% (28m2) of the exposed faces of the east and west abutments respectively

Chloride contents at the steel level of west and east abutments are 0.111% and 0.297% respectively, which are well above the threshold of 0.025% by mass of concrete inducing corrosion

Over 95% (238.5m2) and 74.5% (204m2) of the east and west abutments respectively exhibit corrosion potentials more negative than the threshold valur of –0.35V required to induce corrosion in the reinforcing steel.

Wingwalls

North wingwalls are in good condition, however 100% (36.1m2) and 97% (63.6m2) of the northeast and northwest wingwalls respectively, exhibit corrosion potentials more negative than the threshold value of –0.35V required to induce corrosion in the reinforcing steel

South wingwalls exhibit severe delamination with 55% and 20% concrete delamination and spalling for southeast and southwest wingwalls respectively.

Since the superstructure is new, the corrosion of the abutments and wingwalls have to be arrested such that the substructures would have the same service life as the superstructures. Corrosion control with galvanic DAS anodes was designed. The anodes were spaced typically at 500mm on centers, the exception was at top of the abutments where heavy reinforcing was present and anodes are spaced at 250mm on centers. The galvanic anodes were embedded in 225mm refacing. The galvanic corrosion control system was installed in May 2007, and the superstructure was replaced in 2007 during Civic Holiday traffic closure at that Saturday night.

Figure 8. Highway 417 Island Park Drive Overpass , Ottawa, Canada

Figure 9. Abutment corrosion control and re-facing before rapid structural replacement

CASE STUDY 4 ROBERT MOSES CAUSESWAY, LONG ISLAND, NEW YORK, UNITED STATES

The Robert Moses Causeway is part of the north-south corridor from Sunken Meadow State Park in Kings Park to Robert Moses State Park at the western tip of Fire Island. The causeway was built over a 10 year period from 1954 to 1964. In 2005, the New York State DOT (NYSDOT) embarked on a major project to rehabilitate the superstructure and repair and protect the 24 inch square precast concrete piles exposed to saltwater environment.

The scope of work for the pile protection included the removal of existing steel jackets and the installation of a galvanic pile protection system. NYSDOT specified activated distributed anode strips in conjunction with stay-in-place fiberglass reinforced polymer (FRP) jackets filled with a standard flowable concrete mix.

The galvanic jacket consisted of a 6 ft. high FRP shell, FRP bottom form and 8 Galvanode DAS anode strips (two per face). Each Galvanode DAS had nominal dimensions of 1 3/8 in. x 3 in. x 5 ½ ft in length.

During 2006, the system was installed to protect 1008 precast concrete piles. The initial design of the pile protection system was to achieve a 35 year service life. A representative sample of the piles is being monitored using by a battery powered data logger and periodic site visits by a technician. Based on the most recent data collected, the system is performing very well with 24-hour depolarization averaging 297 mV. The anode service life is estimated at 50+ years, well in excess of the initial design criteria.

Figure 10. Galvanic anodes installation for Robert Moses Causesway, Long Island, New York.	**Figure 11. Marine pile jackets with DAS galvanic anodes inside for corrosion control at tidal zone and splash zone.**

CONCLUSIONS

Corrosive environments have led to severe corrosion in many concrete structures. Corrosion control with galvanic anodes has been proved to provide long term corrosion protection in existing and new reinforced concrete structures in corrosive environments.

REFERENCES

Gulis, E., Lai, D. and Tharmabala, B., (1997). “Performance of Cathodic Protection on the Burlington Bay Skyway Substructure”, The 1997 XIIIth IRF world Meeting, Toronto, Ontario

Liao, H., (2013). ‘Concrete Corrosion Protection with Various Galvnaic Systems’, NACE East Asia Pacific Conference, Kyoto, Japan