Extending the Service Life of Existing Long-Span Bridges Beyond 100 Years

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ABSTRACT

New bridges are being built using the design concepts presented in FIB Bulletin 34 (Model Code for Service Life Design) and SHRP2 R19A (Bridges for Service Life Beyond 100 Years: Innovative Systems, Subsystems, and Components) and to achieve 100^{+} year service life.
Existing bridges may not have been built with a specific design service life in mind but the principles of SHRP2 R19A can be used to maintain and extend the service life of existing bridges. Application of these principles and methods can extend service life by mitigating corrosion of embedded reinforcing steel by over 80%.
Extending the service life of existing bridges provides many benefits to owners and the traveling public. Direct benefits include cost savings for owners, and delays to the traveling public. Extending service life also provides many indirect benefits including; reduction in the use of materials, reduction in the generation of demolition waste, reduction of environmental emissions, and the protection of sensitive habitat and existing ecosystems.
This paper presents bridge case studies which illustrate how the SHRP2 R19A protocol was used to design durable repairs to extend service life of the structures and the direct and indirect benefits which were achieved. Service life extension of existing bridges is a sustainable practice and should be encouraged.
*Keywords**:** bridge, service life, extending, protection, sustainable*

1. INTRODUCTION

New bridges are being built using the design concepts presented in FIB Bulletin 34 (Model Code for Service Life Design) and the SHRP2 R19A (Bridges for service life beyond 100 years: innovative systems, subsystems, and components) to achieve 100+ year service life.

The principles of SHRP2 R19A can be used to maintain and extend the service life of existing bridges. Application of these principles and methods can extend service life by mitigating corrosion of embedded reinforcing steel and structural cables.

The SHRP2 R19A guide outlines the design of new structures for 100+ year service life with two principles in mind; immunity and avoidance. The guide also discusses the design of repairs to extend the service life of existing structures beyond 100 years.

With the ongoing pressure on owners to stretch their limited infrastructure dollars over an ever-increasing infrastructure deficit, and the pressure to minimize delays and disruptions to the traveling public, extending the service life of existing bridges is an effective option. Extending service life also provides many indirect benefits including; reduction in the use of materials, reduction in the generation of demolition waste, reduction of environmental emissions, and the protection of sensitive habitat and existing ecosystems.

The case studies presented will show how the use of electrochemical treatments can extend the service life of structural components and extend the service life of entire structures.

2. DESIGN PROCESS

When designing new structures many strategies can be used to improve the corrosion resistance and durability of new structures. These include:

- The use of low-permeability concrete;
- The use of increased concrete cover;
- The use of improved construction methods such as curing to minimize cracking;
- The use of corrosion-resistant reinforcement;
- The use of corrosion inhibitors to increase the corrosion initiation threshold;
- The use of membranes, coatings, and sealers; and
- The use of improved design details to keep elements dry and to prevent exposure to chlorides.

SHRP2 R19A outlines two concepts which can be used for service life design. These concepts are immunity and avoidance.

Immunity concept refers to the selection of materials or components that are immune or are not susceptible to deterioration or service life issues. An example of immunity is the use of corrosion resistant reinforcing to protect against corrosion in reinforced concrete. Avoidance eliminates or bypasses a particular service life issue. When avoidance is not practical, mitigation techniques should be implemented to improve service life. When considering the strategies to improve corrosion resistance and durability of new structures by using better quality concrete or construction details, we are using avoidance techniques. These strategies provide corrosion resistance by managing the environment around the reinforcing not through the corrosion resistance properties of the reinforcing itself.

The concept of Avoidance or Mitigation is paramount in the design of maintenance or repair strategies for existing structures to achieve 100^+ year service lives. The reality when you are doing a repair is that the structure is already in its existing condition. Service life extension starts from the existing condition of the structure. Service life extension focus is generally on “Avoidance” since it is generally too late to implement most immunity options. The designer uses the avoidance concept by either delaying the onset of damage or limiting future damage.

For existing structures, the first part of the design process is to determine the current condition of the structure and the condition of specific components of the structure that will reduce the overall service life. One of the main factors limiting service life in concrete structures is corrosion of embedded reinforcing steel. This applies to all types of bridge structures.

A detailed corrosion survey can provide invaluable information to delineate the areas currently showing signs of corrosion and those exhibiting potential for future corrosion. It is important to determine the areas that show a high potential for future corrosion so that one does not repair a limited area only to have the area directly adjacent to the repair fail after the repair. It is also important to understand the potential for future corrosion if one is trying to determine the viability of extending the service life of the overall structure.

There are typical areas which deteriorate on bridge structures, whether short span or long span. These common areas include, but are not limited to, bridge substructures and decks, areas adjacent to expansion joints, areas directly below expansion joints on abutments and pier caps, and piers and piling in marine environments, particularly in the tidal and splash zones.

The most common causes of corrosion of steel in concrete are;

1. Chloride (salt) contamination of the concrete,
2. Carbonation of the concrete, and
3. The presence of dissimilar metals within the structure.

The rate of corrosion is related to the level of contamination of the concrete, the amount of moisture present and the temperature.

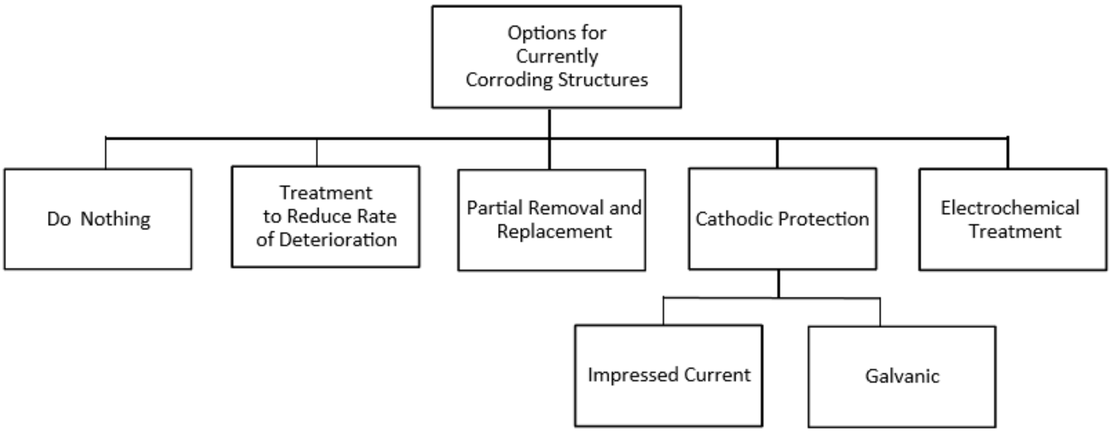

Figure 1 Options for Corroding Structures as per SHRP2 R-19A

The selection of the appropriate level of corrosion protection is based on many factors, such as the level of chloride contamination and carbonation, the amount of concrete damage, location of corrosion activity (localized or widespread), cost and design life of the corrosion protection system, and the expected service life of the structure.

The SHRP2 R-19A design guide delineates four levels of corrosion protection for electrochemical corrosion mitigation systems.

Level of Protection	Description
Cathodic protection	Stops active corrosion by applying ongoing electrical current
Corrosion prevention	Prevents new corrosion activity from initiating
Corrosion control	Significantly reduces active corrosion
Corrosion passivation–electrochemical treatment	Stops active corrosion by changing the chemistry of the concrete around the steel

Table 1 Summary of Levels Corrosion Protection for Electrochemical Corrosion Mitigation Systems as per SHRP2 R-19A

The three levels of continuous, active corrosion protection available are cathodic protection, corrosion control, and cathodic prevention. All are similar in that a protective current is applied to prevent or reduce corrosion activity of the reinforcing steel. Each level is suitable for a given range of applications. They differ in terms of the intensity of the protective current provided to the steel.

Electrical current can be supplied in two ways. Impressed Current Cathodic Protection (ICCP) Systems utilize a DC power supply to power the system with permanent anodes embedded in the concrete to be protected. ICCP systems need to be maintained and monitored over their life. Galvanic systems utilize sacrificial anodes connected directly to the reinforcing steel to be protected and corrode preferentially to the reinforcing thus providing the protective current. The current provided by a galvanic system is self-regulating. Limited maintenance or attention is required with a galvanic system.

New two-stage systems have been introduced that provide a higher initial impressed current applied to reestablish alkalinity around the reinforcing steel followed by a lower galvanic current which is applied to maintain corrosion protection over the long term.

Corrosion passivation - electrochemical treatment is a process where a current is applied for a period of time to change the chemical environment around the reinforcing steel to passivate the steel and providing long term protection without ongoing intervention.

3. CASE STUDY – OHIO DOT

This Ohio DOT bridge substructure repair project was completed in July 2005 with a galvanic encasement. The ODOT bridge substructure repair included the removal of delaminated concrete and refacing the abutments of multiple bridges with self-consolidating concrete (SCC) and distributed embedded galvanic anodes as shown in Figure 2, Figure 3, and Figure 4. The embedded galvanic anodes were designed to provide cathodic protection. The bridge was monitored as part of ODOT technology evaluation program from May 2005 to 2010. This repair strategy is now commonly used to extend the service life of bridge abutments and columns across Ohio.

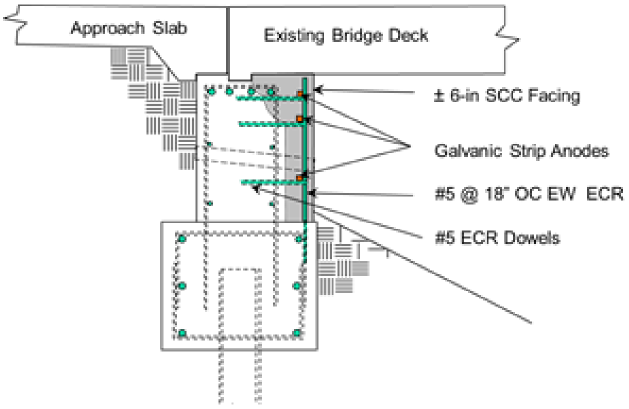

Figure 2 Galvanic Encasement of Abutment

Figure 3 Galvanic Anodes Installed Across the Face of Abutment

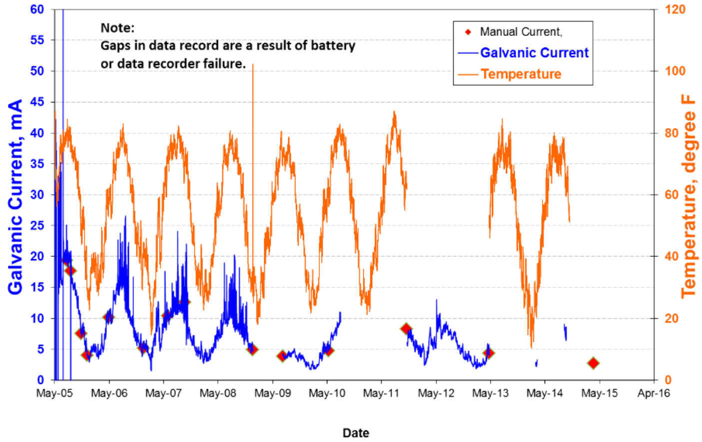

Figure 4 Ohio DOT Galvanic Current Temperature History

Galvanic current data collected at regular intervals can be integrated to calculate the consumption of the galvanic anodes. The service life of the installed anode system is over 40 years.

Date	Temperature (C)	Instant Off Potential (mV)	Current Density (mA/m^2)	Polarization, (mV)
2005-05-06	(*Native*)	*-654*	37.7	
2005-07-20		-990	14.0	**346**
2005-08-16	30.6	-998	12.7	**344**
2005-10-26	12.2	-1023	5.4	**369**
2005-12-07	10.6	-964	2.9	**310**
2006-05-01	13.9	-967	7.3	**313**
2006-12-20	4.6	-1113	3.7	**459**
2007-05-30	26.3	-1104	7.5	**450**
2007-09-20	23.9	-1136	9.1	**482**
2008-12-19	4.4	-1105	3.5	**451**
2009-07-09	23.3	-1125	2.8	**471**
2010-05-11	12.2	-1139	3.4	**485**
2011-10-16	22.2	-1142	5.9	**488**
2013-04-22	21.1	-1079	3.1	**425**
2015-03-24	1.7	-1035	2.0	**381**
2018-09-17	25.6	-1007	5.3	**353**
2020-09-09	26.7	-1005	3.6	**351**
2022-08-23	26.7	-986	2.0	**332**

Table 2 Ohio DOT I-75 Galvanic Cathodic Protection Performance

Note: Polarization greater than 100 mV, Meets Cathodic Protection Standard, Steel Fully Protected

The performance data indicates that the installed galvanic cathodic protection system is performing well. The following NACE SP0216 cathodic protection criteria are satisfied:

- Cathodic polarization exceeds 100 mV,
- The polarized instant-off potential is more negative than -850 mV vs CSE

The abutment is in very good condition 15 years after the galvanic encasement was completed, as indicated in the photos below. Prior to completing this galvanic encasement, this type of abutment was being repaired every 5 to 7 years.

Figure 5 Photos of completed abutment in 2005 and 2020

The performance of this galvanic encasement installation verifies the system has been providing galvanic cathodic protection for over 15 years, and that there is sufficient zinc supplied to provide corrosion protection for over 40 years.

4. CASE STUDY – NEW YORK STATE DOT PILE PROTECTION

The Robert Moses Causeway near New York City, 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.



Figures 6, 7, 8 Anode installation, Temporary support of jackets during concrete placement, Completed galvanic pile jackets.

The scope of work for the pile protection included the removal of existing steel jackets and the installation of a galvanic pile jacket system. NYSDOT specified activated distributed anode strips in conjunction with stay-in-place jackets filled with a flowable concrete.

The galvanic jackets consisted of a 6 ft. high shell, bottom form and 8 Galvanic anode strips (two per face). During 2006, the system was installed to protect 764 precast concrete piles. Embedded galvanic anodes were used to extend the service life of localized concrete repairs above the jackets.

The pile protection system was designed to achieve the specified 35-year service life extension. A representative sample of the piles are being monitored. Based on the most recent data collected, the system is performing very well with 24-hour depolarization exceeding the NACE 100 mV cathodic protection criterion (average polarization 297 mV). The anode service life is estimated to be over 50 years, well in excess of the design requirement.

5. CASE STUDY – FLORIDA DEPARTMENT OF TRANSPORTATION (FDOT) MARINE BRIDGE COLUMS

Two Florida DOT marine bridges one located in south Florida and the other located in the Florida Keys were suffering from corrosion due to chloride contamination from storm surges and atmospheric exposure (Figure 9).

Florida DOT has utilized other corrosion protection options such as arc-sprayed zinc and zinc mesh jackets on this type of structure in the past with varying degrees of success. These projects utilized alkali-activated distributed galvanic anodes installed inside stay-in-place forms as shown in Figure 10,

Figure 11,

Figure 12 to protect concrete sections which are always out of the water. The stay-in-place form can be either fiberglass or modular PVC.

The advantages of using the modular PVC interlocking panels and spacers include: improved bond between the stay-in-place form and the cementitious grout fill, improved durability, and the modular form is easily adjusted in the field to fit each the site conditions for each column.

Figure 9 Deteriorated Columns (left) and Damaged Concrete Removed (right)

Figure 10 Installation of Alkali-Activated Galvanic Anodes (left) and Stay-in-Place Form Installed (right)

Figure 11 Installed PVC Galvanic Cathodic Protection Jacket with Monitoring Station

As with all FDOT projects, monitoring provisions were provided when the column jackets were installed such that the galvanic cathodic protection systems can be monitored over time.

Figure 11 shows a typical monitoring station located above the jacket, and
Figure 2 shows wires protruding from the boxes prior to energizing.

Figure 12 Above-Water Alkali-Activated Galvanic Cathodic Protection Jackets

These alkali-activated galvanic cathodic protection jackets are installed above high tide such that even the bottom of each jacket is out of the water except during storms. The jackets are monitored by Florida DOT. Monitoring parameters include potentials, current, polarization, and anode service life. Due to the number of monitored columns, the data is too voluminous to present herein. Data from one column installed in 2012 in the Florida Keys is shown in **Error! Reference source not found.**. Polarization data for the jacketed columns of one of the bridges in South Florida is shown in Figure 14. This data shows that the alkali-activated jacket systems have met or exceeded the NACE SP0216 cathodic protection criteria by polarizing the reinforcing steel more than 100mV.

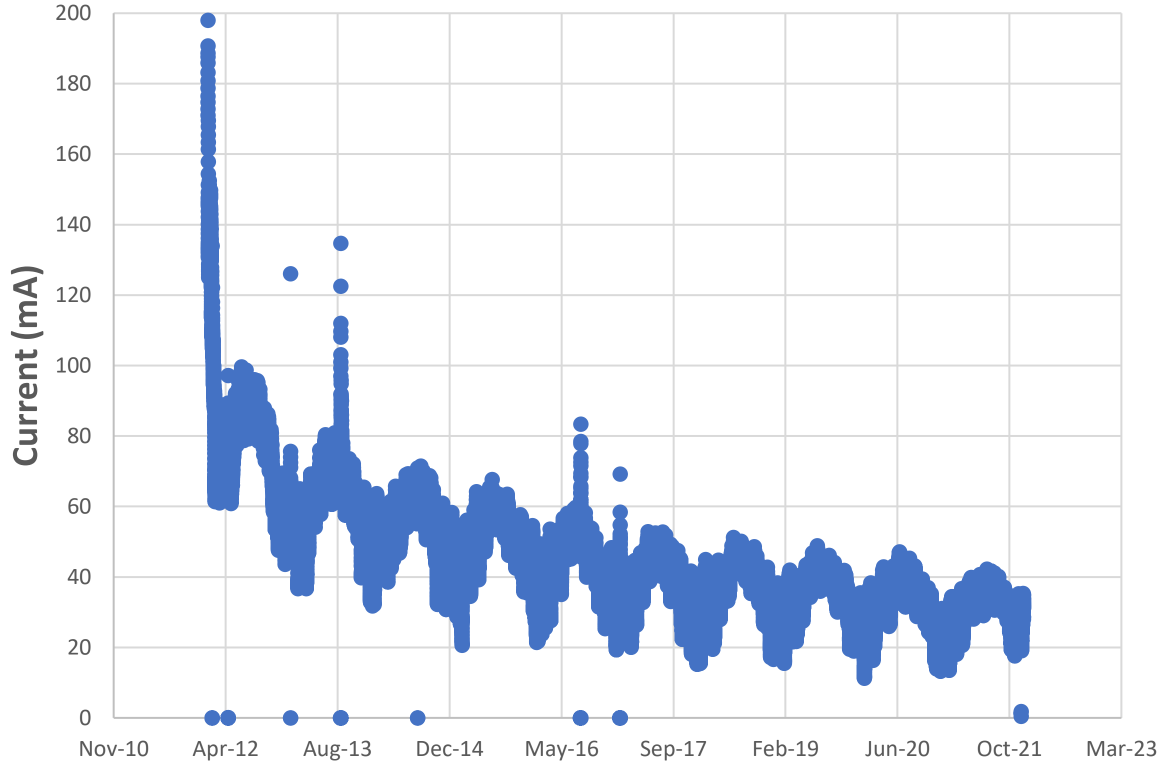

Figure 13 Current Output from Above-Water Alkali-Activated Galvanic Cathodic Protection Jackets in Florida Keys

Time	Current	Native Potential	Instant Off Potential	Polarization / Depolarization	NACE SP0216 CP Standard
	(mA)	(mV)	(mV)	(mV)	
Native Potential		-458			
12-Jan-12					
Instant On	725		-825	**367**	Meets CP Criteria
1 day	228		-652	**194**	Meets CP Criteria
1 month	98		-657	**199**	Meets CP Criteria
3 months	72		-667	**209**	Meets CP Criteria
9 months	54		-664	**206**	Meets CP Criteria
1.7 Years	67		-679	**221**	Meets CP Criteria
4.5 Years	49		-751	**293**	Meets CP Criteria
10.3 Years	35		-814	**356**	Meets CP Criteria

Table 1 Alkali-Activated Galvanic Cathodic Protection Performance in Florida Keys

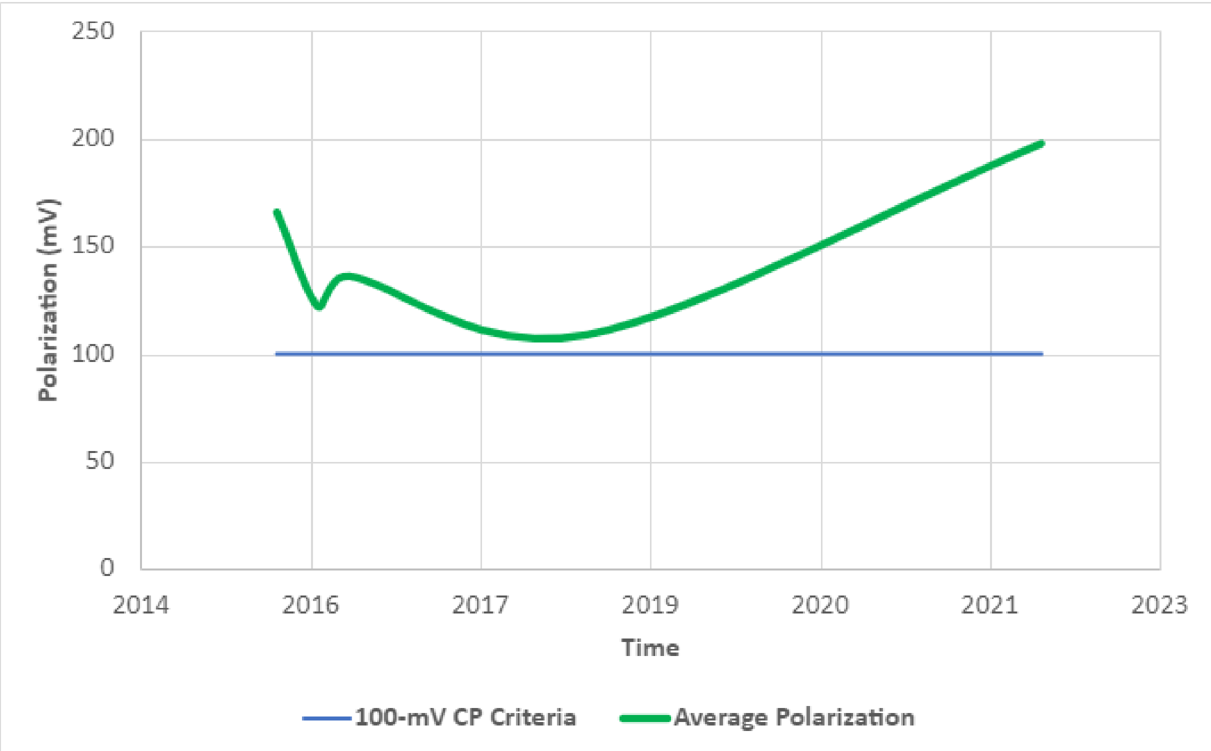

Figure 14 Polarization of Reinforcing Steel in Above-Water Alkali-Activated Galvanic Cathodic Protection Jackets in South Florida (2015 to 2022)

6. CASE STUDY – THE GARDINER EXPRESSWAY, TORONTO, ONTARIO

The Gardiner Expressway in Toronto, Ontario Canada is 11.2 miles (18 km) long and is an elevated expressway for 4.2 miles (6.8 km). This municipal Expressway is 8 to 10 lanes wide. It was built in segments between 1955 and 1964. It now serves as one of the busiest pathways to the center of the city. The Expressway, in particular the elevated structure, is a critical link in the city's transportation infrastructure. The effects of age, heavy traffic, weather and salt have taken their toll on the structure. The city considered numerous options for the replacement of the structure including tunneling. It was determined that the most viable option was rehabilitation. To that end a rehabilitation plan which will be completed over 10 years is being implemented.

The scope of that rehabilitation plan includes the replacement of the superstructure utilizing Accelerated Bridge Construction Techniques and rehabilitation of the substructure. A number of options were considered for rehabilitation of the substructure. The extensive damage and need for repairs to the piers and pier caps precluded the use of Electrochemical Treatment as a cost-effective option. The repair option selected is to jacket or overbuild the existing piers and pier caps. This option allows for the installation of additional reinforcing to the structure. The existing concrete is heavily contaminated with chlorides, generally well above threshold levels. Impressed current cathodic protection was considered but was not pursued due to the maintenance requirements over the life of the system. The option incorporated into the design is to use of a Galvanic Cathodic Protection/Corrosion Prevention system embedded in a concrete overbuild. The requirement of the system is to provide active corrosion protection to the reinforcing steel for a minimum of 35 years. This rehabilitation will extend the service life of the 60^{+} year-old structure to be over 100 years old.


Figure 15, 16 Condition of Structural Elements Prior to Rehabilitation

The first phase of the repair was removal of all delaminated and unsound concrete. Sound concrete was not removed around all the reinforcing bars or stirrups as per ICRI guidelines but is being left in place so shoring of the structure is not required. Galvanic anodes are installed in the concrete overbuild and are connected to the existing reinforcing steel to provide corrosion protection. The size and spacing of the galvanic anodes is designed to provide the level of current required to provide the desired corrosion protection for the 35 year design service life.

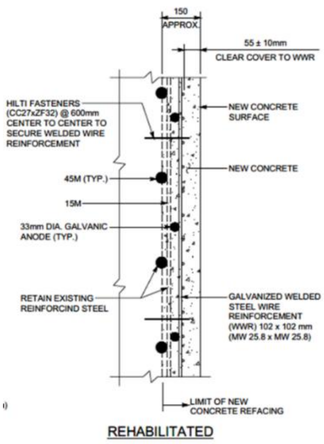

Figure 17 Repair Design

Figure 18 Partial Repair

Once continuity of the reinforcing steel is confirmed and the galvanic anodes have been installed galvanized welded wire mesh is installed to provide reinforcement and crack control. Forming is completed and the Self – Consolidating Concrete (SCC) is placed to jacket the desired portion of the substructure. The SCC fills all concrete repair areas and encapsulates the galvanic anodes so they can provide corrosion protection and extend the service life of the structure to 100^+ years.

The Gardiner Expressway case study also allows us to discuss sustainability. In addition to keeping existing structures in service, shortening construction time and keeping the traveling public happier, we reduce demand for concrete and other construction materials when we extend the service life of existing structures. While this is a challenge, it is possible if we make it a priority. Concrete is the most widely used man-made building product in the world with over 33,000,000,000 tons produced per year (14 Billion m^3). Concrete is a huge consumer of materials and energy. Despite the environmental impact, concrete is one of the most environmentally friendly materials available if it is used properly. Concrete is extremely durable and has ability to last for many years. Keeping existing concrete in service is very beneficial. The Gardiner Expressway Accelerated Bridge Repair project will extend the service life of the structure by 35^+ years. In doing so 70,450 yd.^{3} (53,865 m^3) of concrete will be maintained in service. Keeping this quality of concrete in service will reduce CO_2 emissions by 35,225 tons (equivalent to the annual emissions of 7,045 people.)

7. CONCLUSIONS

The case studies demonstrate how corrosion protection utilizing design protocols presented in NFIB Bulletin 34 (Model Code for Service Life Design) and SHRP2 R19A (Bridges for Service beyond 100 Years: Innovative Systems, Subsystems, and Components) can contribute to extending the service life of existing structures to over 100 years. These systems are capable of providing effective, long-term corrosion protection to substructure elements which are common areas of deterioration and often limit the service life of marine and other concrete bridges.

Case studies on galvanic protection using distributed galvanic anodes for the repair and protection of reinforced concrete bridge elements exposed to both marine and non-marine environments were presented. Long term monitoring of galvanic anode systems indicates a high level of corrosion protection performance for over 20 years.

The service life extension of critical bridge components, particularly substructures in marine environments can provide significant benefits to owners, the traveling public and the environment. These benefits include reduced maintenance and lifecycle costs as well as environmental benefits.

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