11th International Conference on Short and Medium Span Bridges
Toronto, Ontario, Canada,
July 19 – 22, 2022

GALVANIC CATHODIC PROTECTION FOR ACCELERATED BRIDGE CONSTRUCTION

Liao, Haixue[1,5], Wang, Jerry[2], DiRienzo, Adriano[3], and Whitmore, David[4]
[1] Vector Corrosion Technologies, Canada
[2] Ministry of Transportation Ontario, Canada
[3] WSP, Canada
[4] Vector Corrosion Technologies, Canada
[5] liaoh@vector-corrosion.com

Abstract: Accelerated bridge construction (ABC) that uses innovative planning, design, materials, and construction methods safely and cost-effectively can reduce the onsite construction time that occurs when building new bridges or replacing and rehabilitating existing bridges. ABC can improve site constructability, total project delivery time, reduce traffic impact and on-site construction time. In Canada and around the world, many bridge decks have been replaced with ABC while supported by existing substructures of 50 years or older, which may have high corrosion potentials and heavy chloride contamination. The durability and the service life of the existing substructures were a concern initially, which requires cathodic protection to address the corrosion issues. This paper will present long-term monitoring results of the galvanic cathodic protection, its applications in accelerated bridge construction projects.

1 INTRODUCTION

With the ever-increasing demand on transportation infrastructure, and the number of bridges that are approaching the end of their service lives, the need for ABC becomes more apparent. ABC can reduce the project schedule, on-site construction time, and public impact. Three main benefits of using ABC methods include minimized impact to traffic, increased safety during construction, and minimized impacts in environmentally sensitive areas.

Where conventional bridge construction takes months or years, a bridge utilizing ABC may be placed in a matter of weeks, days, or even a few hours depending on the methods used. ABC methods are generally safer than conventional construction methods because much of the construction can be done off-site, away from traffic. Quality can also be improved because the construction is often completed in a more controlled environment compared to on-site conditions. On the other hand, as with the implementation of all new technologies, the use of ABC comes with challenges that need to be overcome on a project-specific basis. One of the common challenges is how to maintain and extend the service life of the substructure to match the new superstructure.

Many bridge engineers have opted for galvanic cathodic protection to prolong the service life of the substructures. A cathodic protection system is effective in mitigating corrosion damage and reducing the rate of delamination per year to 0.04% from the average 1% per year for unprotected structures (Gulis et al. 1997).

2 DEVELOPMENT AND MONITORING OF DISTRIBUTED ANODE

Since 1974, impressed current cathodic protection has been used in North America as part of the corrosion protection strategy to rehabilitate corrosion damaged bridges containing black steel (Stratfull 1974). It has been well documented that for cathodic protection to function properly and arrest corrosion the systems must be monitored on an ongoing basis. Many transportation agencies, port authorities, and facility owners, either because of lack of understanding of cathodic protection technology or inability to provide dedicated staff to conduct the required ongoing monitoring and maintenance, simply do not specify cathodic protection rehabilitation of their bridges. The need for ongoing monitoring and maintenance of current supply is a major drawback for impressed current systems. What is needed is a sacrificial anode system that can supply sufficient current to provide effective cathodic protection, does not require specialized knowledge for installation, and can significantly minimize the need for future monitoring and maintenance.

With experience gained through the applications of pointed galvanic anodes in patch repairs for corrosion prevention and drilled-in anodes for corrosion control of sound concrete with high corrosion potentials and chloride concentrations, the Ontario Ministry of Transportation (MTO), Ontario, Canada, and Vector Corrosion Technologies conducted a trial using distributed galvanic anodes in bridge deck overlay to address the global corrosion issues in the structure on 20 September 2003.

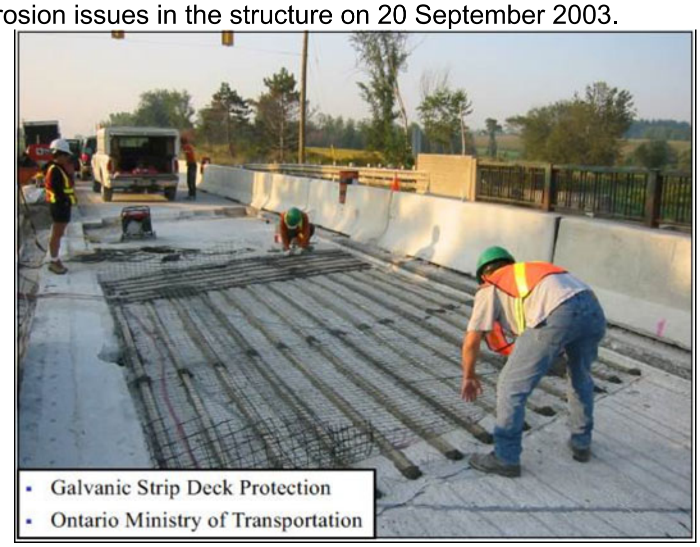


Figure 1: First Trial of DAS Anodes in Bridge Deck Overlay, Ontario, Canada, in 2003

The North Otter Creek Bridge is a rigid frame structure with a span length of 20m and a roadway width of 8.5m. The bridge was built in 1960 and was first rehabilitated in 1984 with the MTO's "first-generation" cathodic protection system. The cathodic protection system included an impressed current system consisting of high silicon cast iron anodes in a conductive – asphalt overlay.

A condition survey conducted in 2000 found that the concrete deck (assessed using cores and sawn samples) was in good condition. The core samples extracted from the bridge deck confirmed that the reinforcing steel was also generally in good condition. The compressive strength of the concrete was 36.2MPa and the concrete cover to the top reinforcement ranged from 60 to 135mm and averaged 100mm. The chloride ion content at the level of the mean cover depth (100 mm) was approximately four times the chloride level generally accepted as the threshold to initiate corrosion (0.025% chloride by weight of concrete). The corrosion potential survey was conducted according to ASTM (C-876) using a copper-copper sulphate reference cell indicated that approximately 88% of the concrete deck area had corrosion potential readings more negative than - 0.35v. The remainder of the readings were in the uncertain range (- 0.20 to - 0.35v). The findings of the condition survey confirmed that the cathodic protection system successfully extended the service life of the deck as evidenced by the good condition of the structure (i.e. no delaminations or other corrosion damage in the presence of high corrosion potentials and high chloride levels). However, the system had reached the end of its service life.

In September 2003, DAS anodes were installed at the south end of the bridge to monitor a deck area of about 26 square metres. This consisted of precast strips placed on approximately 300 mm (1ft) centers. Each DAS anode consisted of two zinc rods encased in a proprietary cementitious backfill containing lithium hydroxide. The DAS anodes measured 12mm by 50mm and were 2440mm in length. A carbon fibre mesh was used to prevent or reduce shrinkage cracks in the concrete overlay and to provide a better bonding surface. Plastic anchors were used to fasten the carbon fibre mesh in place until the concrete overlay was placed. Prior to the installation of the anodes, the bridge was scarified.

Four multiple-element probes (MEP) were installed at two locations. At each location, a MEP was placed next to the top and bottom mat of reinforcement. The MEP consisted of a manganese dioxide reference cell, a stainless steel and a mild steel probe, and a connection to the reinforcement. This arrangement allows for the long-term evaluation of reinforced concrete structures and can be used to evaluate the effectiveness of a cathodic protection system. The distributed anode system along with the respective instrumentation was terminated in a junction box. Each junction box contained a system on/off switch and a 0.001 ohm precision resistor. This arrangement allowed the anode current to be measured and the current density generated by the anodes to be evaluated (with respect to concrete surface area). The MEP may be used to confirm the current density value. The manganese dioxide reference cell from each probe was used to determine the polarization received by the reinforcement. The four values were then averaged to determine a polarization value for each system. It should be noted that all the embedded instrumentation was backfilled with concrete containing the typical amount of chloride found in the deck (at the reinforcement level).Except for winter months when the bridge deck froze and current and corrosion potential readings were not reliable, more than sufficient current was being supplied by each of the anodes to meet the 100 mV criteria generally accepted as indicative of effective cathodic protection (Table 1).

Table 1. Monitoring Data of DAS Anodes.

Months	Temperature	Current Density mA/m^2	Polarization mV
Installed on Sept 3, 2003	(°C)		
0.5 month	7	6.5	273
1 month	10	6.1	238
2 month	11	3.5	57 *
5 month	-1	1.9	24
6	4	3.5	54*
7	20	3.8	271
8	23	2.6	220
9	21	2.5	260
11	23	1.7	211
14	8	1.4	230
16	-20	0.55	142
19	3	1.4	293
22	20	1.7	350
23	20	1.8	313
25	8	1.3	284
26	0	1.1	276
29	-7	0.8	167
31	10	1.4	330

Table 1. Monitoring Data of DAS Anodes (continued)

Months		Current Density mA/m2	Polarization
	Temperature		mV
Installed on Sept 3, 2003	(oC)		
35	25	1.6	353
39	7	1.24	281
43	-3	1	201
48	22	1.5	501
52	0	7.6	322
55	3	1.1	314
59	20	1.6	421
67	-5	0.65	273
106	22	1.8	278
120	23	1.13	388
141	25	1.08	432
171	23	0.6	202
179	20	0.57	181
192	23	0.66	212
205	23	0.23	185
218 (August 31, 2021)	22	0.59	174

*4-hour depolarization in a waterproofed deck is not long enough

The subject anodes in this trial project have been performing well. Many transportation agencies including the MTO have used this type of anodes in many different components, including abutment refacing, concrete deck overlay, concrete jackets for columns, piers, and marine piles.

Since 2007, the MTO has specified the DAS anode in the abutment refacing for many ABC projects on Highway 417 to extend the service life of the abutments supporting new superstructures. The existing concrete in the front face of the abutments was heavily contaminated with chloride due to years of leaking expansion joints in the deck and the use of de-icing salts on the roadway above.

3 CASE STUDY: HIGHWAY 417 RAPID BRIDGE REPLACEMENT – KIRKWOOD AVENUE OVERPASS

Highway 417 is a major urban freeway that serves as the only east-west highway corridor through the City of Ottawa. The segment of Highway extending Island Park Drive to Maitland Avenue in Ottawa's west end was constructed between 1959 and 1967 and carries more than 150,000 vehicles each day (150,000 AADT). Six twin structures (twelve bridges in total) carrying Highway 417 eastbound (EB) and westbound (WB) traffic were nearing the end of their design life and required rehabilitation or replacement. Ten bridges (five sites) were selected for rapid replacement including overpasses at Clyde Avenue, Carling Avenue EB, Kirkwood Avenue, Carling Avenue WB, and Island Park Drive. The sixth site, the Merivale Road Overpass bridges were rehabilitated by conventional methods that required construction staging when Highway 417 was widened along the corridor. All 6 sites but Island Park Drive were to be widened to 4 lanes in each direction. Rapid replacement of the two superstructures located at Island Park Drive was the first project which occurred in 2007. Unlike the other five sites, widening was not necessary at Island Park Drive as these structures already comprised 4 lanes in each direction.

At the initial planning stage, the MTO investigated the option of rehabilitating or replacing these bridges using a conventional approach of staged construction. Staged construction would have involved closing traffic lanes to work on the bridges one section at a time over two construction seasons (April to November each year). The MTO realized that rehabilitation or replacement of these bridges using a conventional approach would impose considerable traffic congestion, traffic delays, significant environmental impacts associated with traffic congestion, and the potential of increased accidents. The challenge faced by the MTO was to undertake this work with minimal disruption to the daily life of road users and to keep the environmental impacts to a minimum.

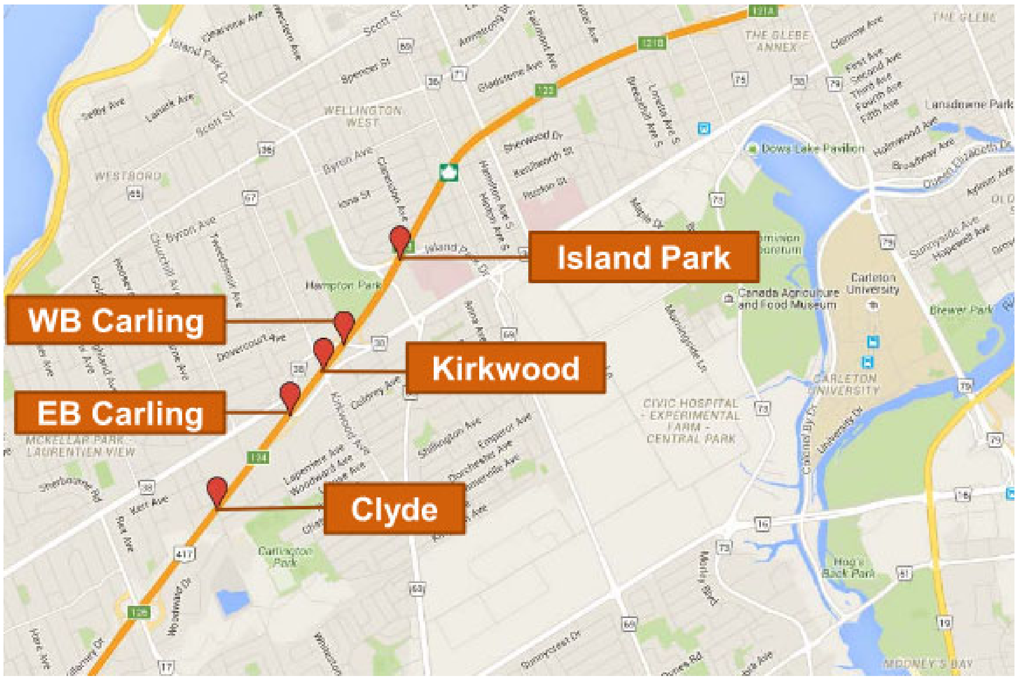


Figure 2: Rapid Replacement Bridges on Highway 417 2007-2012

The MTO investigated various alternatives and decided to adopt a rapid replacement rehabilitation approach along with the installation of DAS anodes on the existing abutments with concrete refacing. The approach used for Highway 417 was to build the new bridge superstructures in a staging area located close to the bridge site, lift out the old bridges using self-propelled modular transporters (SPMTs) and move them to a staging area for future demolition, and transport the new bridge superstructures from the staging area and placing them in position.

The Kirkwood Avenue Overpass consists of twin structures that were built in 1961 and span over Kirkwood Avenue below. The bridges are single-span, slab-on-steel girder superstructures and skewed 24.4 degrees to Kirkwood Avenue. The span length is 24.1 m and the width of each of the structures is approximately 16 m. The abutments are conventional concrete walls supported on HP 360 x 108 piles driven to bedrock. The scope of the rehabilitation was to replace the existing superstructure with a new slab-on-steel girder superstructure, abutment widening, and re-facing the existing abutment faces with galvanic cathodic protection to extend the service life of the existing abutments.

The main bridge replacement operation involved the following:

1. Widen existing abutments (i.e. drive new piles and construct pile caps, abutment walls, and new wingwalls)
2. Construction of new superstructures in the designated construction staging area.
3. Rehabilitation of abutment walls with the installation of new sacrificial cathodic protection to extend the service life and concrete re-facing

4. Pre-rapid lift operations. This includes closing selected traffic lanes on the weekends, removing the existing approach slabs, removing granular fill behind the ballast wall, attaching the ballast wall to the existing superstructure, saw-cutting the ballast wall for removal with the superstructure as a total entity and backfilling with granular and temporary pavement placement for the highway to be fully operational

(a) West abutment south side (b) East abutment south side

Figure 3 Rehabilitation of abutments with DAS galvanic cathodic protection

5. Rapid lift operation completed on July 6, 2013, in 17 hours. This involved completely closing a 3 kilometres portion of the Highway, removing the asphalt and granular back fill behind the ballast wall, raising and moving the existing superstructures to the staging area, transporting/placing/levelling the new superstructure in position, backfilling/paving/placing of temporary traffic barriers and opening the bridge to regular traffic.

(a) Removing existing bridge decks (b) Installing new bridge decks

Figure 4 Transporting existing and new prefabricated t bridge deck

6. post-rapid lift operations
This includes closing selected traffic lanes on the weekends after rapid bridge replacement to construct new approach slabs in stages. Temporary pavement and granular are excavated, new approach slabs are constructed and paved, and the final lift of asphalt is applied to the bridge deck and approaches.

3.1 Abutment Rehabilitation

3.1.1 Existing Conditions

A condition survey performed on the abutments revealed chloride penetration had attained depths of 150 mm due to the penetration of roadway salts resulting from leaking expansion joints. A summary of the condition of existing abutments stem walls is as follows:

- Spalls and delaminated concrete covered approximately 15% (26.4m^2) and 10% (16.4m^2) of the exposed faces of the east and west abutments respectively
- Chloride content at the steel level of the west and east abutments was 0.111% and 0.297% respectively, which are well above the threshold of 0.025% by mass of concrete inducing corrosion
- Over 93% (159.7m^2) and 97% (164.5m^2) of the east and west abutments respectively exhibited corrosion potentials more negative than the threshold value of –0.35V required to induce corrosion in the reinforcing steel.
- Shotcrete repairs from a 1983 bridge rehabilitation extend over 25.8% and 20.6% of the east and west abutment respectively exhibit delaminations, map cracking (Figure 5).

Figure 5 Elevation of the East Abutment, looking northeast

3.1.2 Design Approach

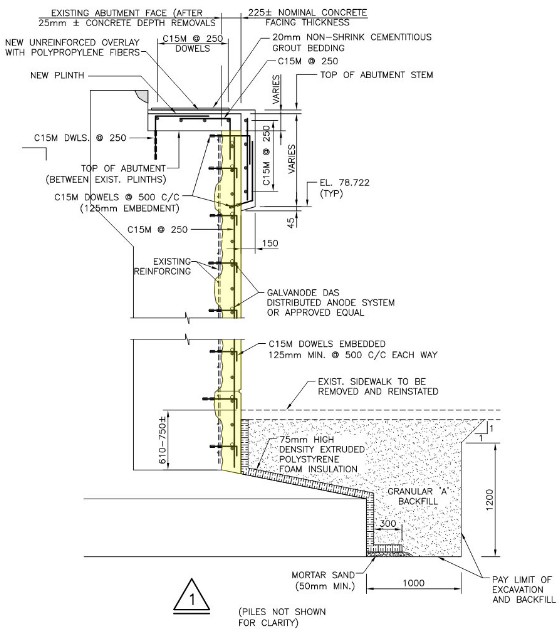
To preserve and extend the service life of the existing abutments, it was decided to remove 25 mm of concrete from the abutment face and all delaminated concrete. A sacrificial distribution anode system was designed and installed on the concrete abutment stem wall. The continuous anode strip system was spaced at 500 mm vertically throughout the abutment and wingwall surfaces. The system was designed to provide a minimum of 20 years of service life assuming a maximum annualized average anode current density of 10.0 mA/m^2; an anode efficiency factor of 0.9 and an anode utilization factor of 0.8.

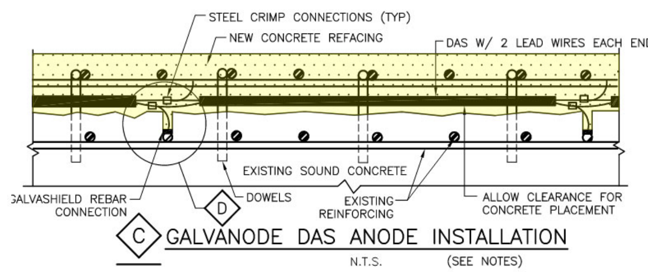
A 225 mm thick reinforced concrete resurfacing dowelled into the existing substructure was placed on all exposed concrete surfaces. Following the rapid lift replacement, a fibre reinforced concrete overlay was placed at the bearing seats to completely embed the steel shims at the bearing location and to complete the abutment resurfacing. A grout bed was also placed between the underside of the steel bearing plate and the concrete overlay. The abutment rehabilitation strategy was developed in conjunction with the widening of the existing abutments to accommodate the Highway 417 future widening.

3.1.3 Monitoring

A monitoring device was installed on the west abutment of the Kirkwood Avenue Overpass to measure the voltage drop across the resistor at one-hour intervals for a surface are area of 9 square metres of rehabilitated abutment face. Voltage drop readings across the resistor have been recorded at one hour intervals. A total of 55,872 readings from the year 2013 to 2019 were recorded with an average voltage drop of 2.37mV corresponding to an average current output is 23.7mA, and the average current in the last 12 months is 17.27mA (refer to Figure 8).

Based on 15M at 300mm both ways for existing and new reinforcing respectively, the steel surface area is 0.67m^2 /m2 concrete surface or total 6.03m^2 for 9m2 concrete surface. The average current density in 2019 is 17.27/6.03=2.86mA/m^2. The average content is 0.2% by weight of concrete or about 1.2% by weight of cement, the required current density at the end of the protection life is 0.8mA/m^2. Galvashield Alkali-activated anodes have a half life of 12.5years. The current density will take another 23 years to decrease from 2.86 to 0.8mA/m^2. Therefore the anodes can provide 29 years of protect until the current density goes below 0.8mA/m^2.





(a) Abutment section (b) Detail of DAS anode

Figure 6 Design Details of DAS Anodes and Abutment Re-facing

Figure 7 DAS galvanic cathodic protection installation

The anode had 0.89kg/m and were spaced at 500mm on centers, the zinc mass/m^2 is 1.78kg. Using Faraday's law and the average current density of 2.86mA/m^2 and basing the zinc mass alone, the zinc can last 60 years.

Due to the anode slow aging, the current density of 0.8mA/m^2 likely governs the protection level rather than the zinc mass. The anodes can provide sufficient corrosion protection to the steel for 29 years and can provide some protection after 29 years.

The corrosion potentials were measured manually, depolarizations of reference electrodes 1 and 2 have achieved 100mV, the NACE full cathodic protection criteria, see table 2.

Table 2. Monitoring Data of DAS Anodes.

ReferenceElectrode	ON	Instant Off 20-Aug-19	Off 23-Oct-19	Instant ON	Depolarization
R1	-570	-549	-420	-480	129
R2	-584	-480	-332	-650	148

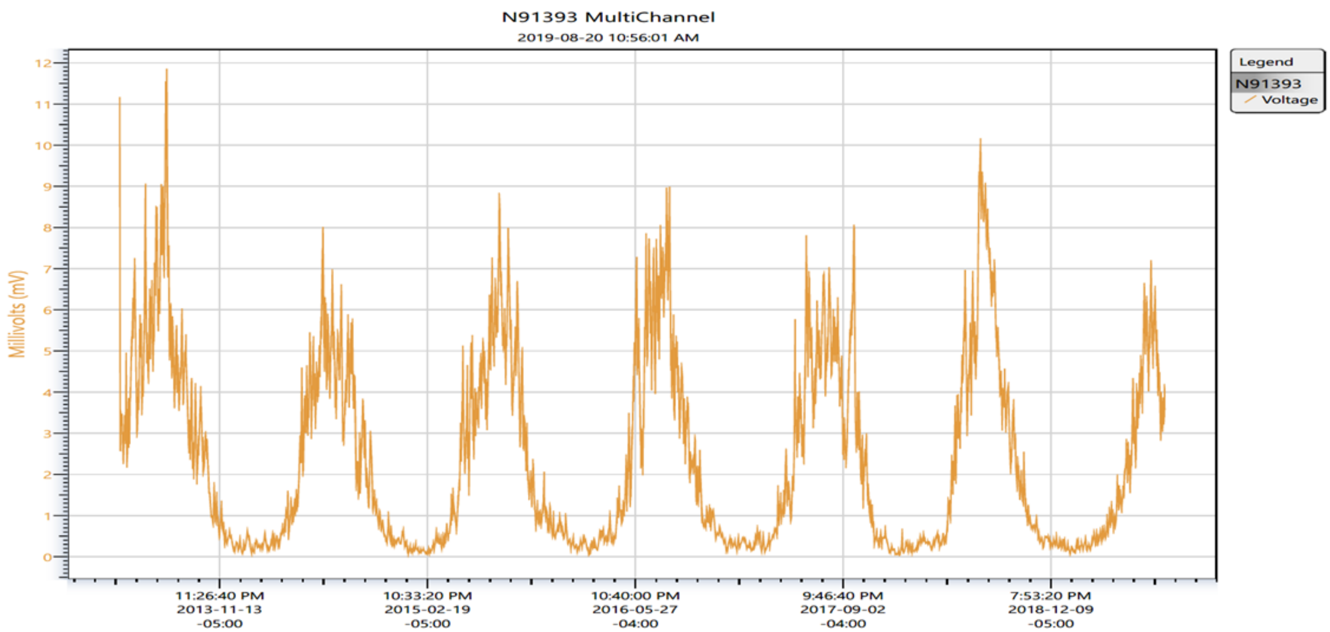


Figure 8 Monitoring galvanic current

CONCLUSIONS

With many bridges that are approaching the end of their service lives, ABC has become more practical to replace bridge superstructures. ABC can reduce the project schedule, on-site construction time, impacts to the public and environment. From a traffic operations perspective, congestion and delay related impacts were reduced from years to days. It has been demonstrated that this technology can reduce the environmental impacts of highway construction activities by reducing hydrocarbon, carbon monoxide, and nitrogen monoxide emissions by as much as 97% compared to a traditional bridge replacement method.

Concrete re-facing with galvanic cathodic protection has been tested and proven to resolve one of the major ABC challenges – extend the service life of the existing substructure to match that of the new superstructure. Where substructures have become contaminated with chlorides due to leaking expansion joints and the use of de-icing salts, this approach is a cost-effective way to extend the service of existing substructures and avoid the increased cost of reconstructing new substructures. The result is a sustainable new crossing that is not only designed for a 75-year lifespan achieved through careful material selection (e.g. stainless reinforcing steel, GFRP, sacrificial cathodic protection system) but will have greatly reduced maintenance costs with the elimination of expansion joints.

The Ministry has successfully implemented this design approach of rapid superstructure replacement supplemented with galvanic cathodic corrosion protection of existing substructures at several sites including the following:

- 2007 Highway 417 Island Park Driver Overpass
- 2008 Highway 417 Clyde Avenue Overpass
- 2011 Highway 417 Carling Avenue Eastbound Overpass
- 2013 Highway 417 Kirkwood Avenue Overpass
- 2013 Highway 417 Carling Avenue Westbound Overpass
- 2014 Highway 417 Riverside Drive Underpass
- 2015 Highway 417 Kent St Overpass
- more bridges to come……

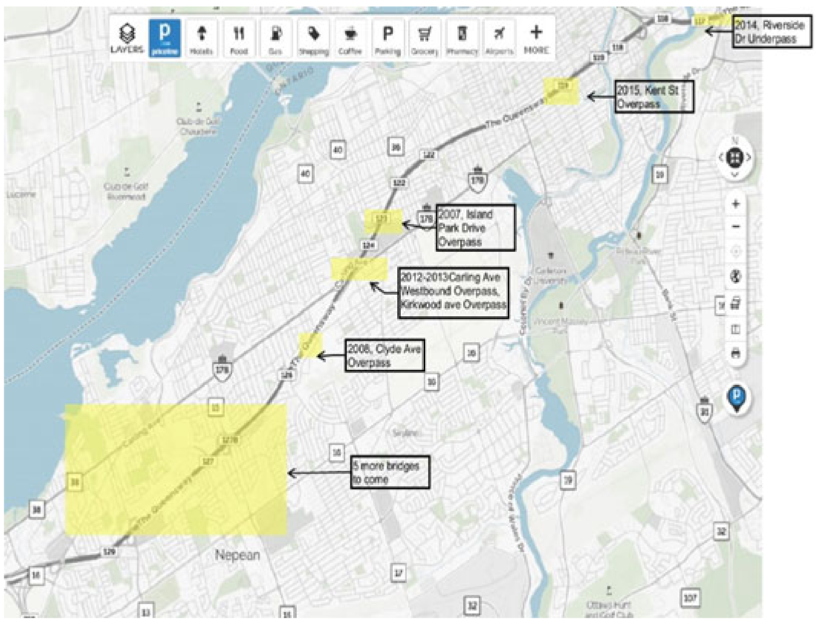


Figure 9 Bridge location map

References

ASTM C876-15, Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete, ASTM International, West Conshohocken, PA, 2015, www.astm.org

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

Stratfull, R.E. 1974. Materials Performance 13, H4, 24 (1974). Houston: NACE International.