Disraeli Bridges Project

Concrete Repair and Corrosion Mitigation of Concrete Piers

Disraeli Bridges Project

In 2009, the City of Winnipeg utilized an innovative design-build-finance-maintain (DBFM) contract to address corrosion damaged bridges on the Disraeli Freeway. The selected DBFM contractor would be responsible for the design, construction and subsequent maintenance for a 30 year period. The final design concept was to replace the two 50-year old bridges with new parallel structures to minimize the significant lane closures expected if the structures were to be rehabilitated. This was the City's preferred solution as the Freeway is an important link to downtown Winnipeg from northeast sections of the city.

The original bridge over the railway was demolished after the new bridge was opened to traffic. The second bridge, spanning the Red River, would be repurposed as an attractive pedestrian bridge. A new bridge superstructure was constructed on top of the existing Red River bridge piers to stay within the budget and project schedule.

The 4 existing Red River bridge piers were significantly chloride contaminated and actively corroding. To meet the needs of the DBFM entity and the City, a long-term repair and corrosion mitigation solution was necessary. Spalled and delaminated concrete were replaced using form and pour concrete repairs and cracks repaired using epoxy injection. The two land-based piers underwent an electrochemical chloride extraction treatment and the two river-based piers would have an activated arc sprayed zinc galvanic anode system installed. The systems were selected based on their expected long-term performance without on-going system maintenance and the ability of the system installation to fit into the tight construction schedule.

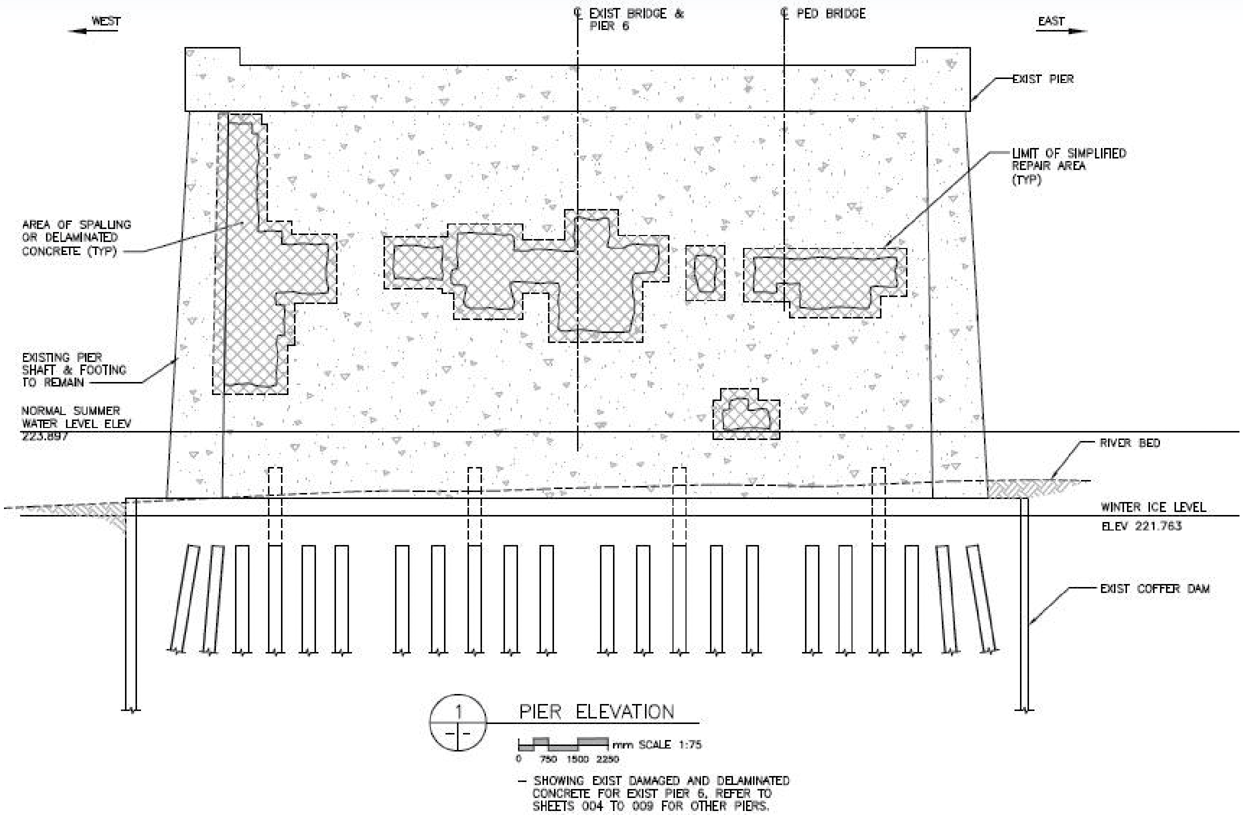
All rehabilitation work was successfully completed during the winter of 2013 within heated enclosures and the bridges opened in the summer of 2013.

Example of Corrosion Damage on Red River Bridge Piers

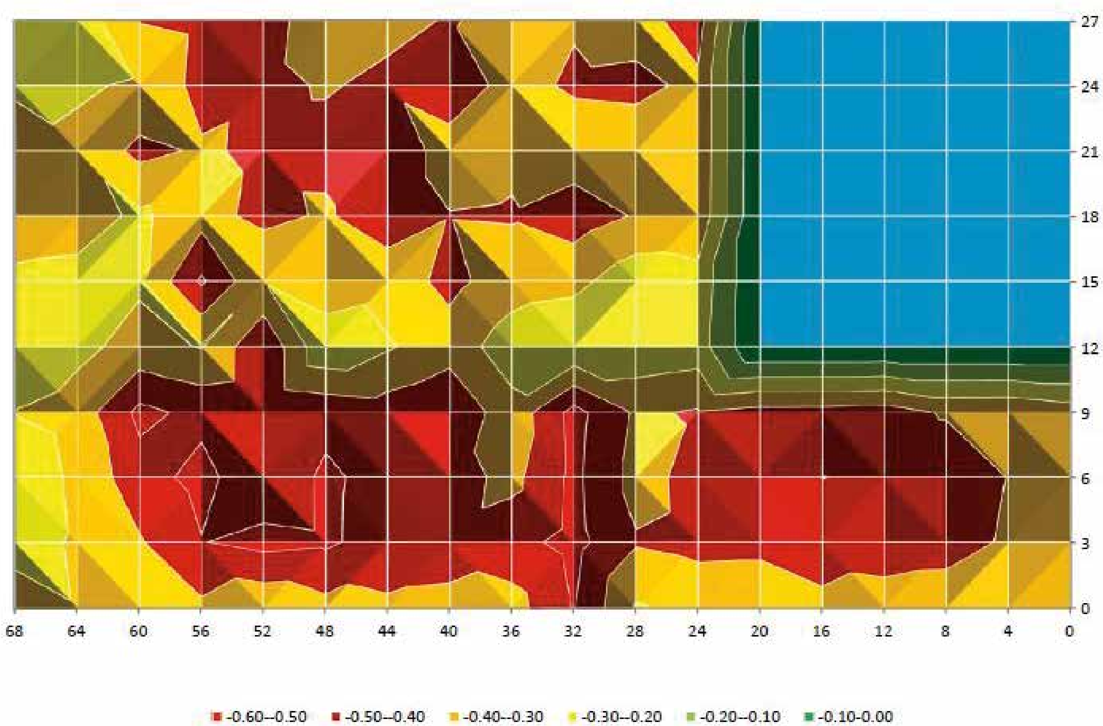
Disraeli Bridges

The Disraeli Freeway connects the Henderson Highway with Main Street in downtown Winnipeg, the provincial capital of Manitoba. The Freeway, part of Route 42, provides a major link between the northeast Winnipeg and the busy downtown district. The Freeway consists of two bridges spanning the Red River and a CP Railway line, built in 1959 and 1960 respectively. Since the construction of the original Disraeli Freeway Bridges, Winnipeg's population has increased by approximately 50% so these structures are well-traveled.

The original bridges were built as open-grate structures which was a popular method of inexpensive, lightweight construction at the time. The open-grating, combined with increasing use of winter de-icing salts, lead to significant corrosion and a high level of maintenance. In 2006, the City hired a consulting engineer to develop a plan to rehabilitate these structures. The City's initial expectation was that a comprehensive rehabilitation project would be the lowest cost approach but would have the downside of significant bridge closures and disruption.



Locations of Damage Determined by the Engineer of Record



Half Cell Corrosion Potential Map of Bridge Pier Indicating Locations with a High Probability of Active Corrosion

Project Delivery Model

Due to the size of the project and the importance of the Disraeli Freeway to the community, both traditional and non-traditional project delivery mechanisms were considered. Ultimately, the project was carried out using a Design-Build-Finance-Maintain (DBFM) structure, one of the first municipal infrastructure DBFM projects in Canada. After a comprehensive procurement process, a private entity that consisted of major financing, design, construction and maintenance partners was selected to execute the project. The DBFM entity was responsible for all engineering, construction and on-going maintenance over the following 30 years at which time the structure will be returned to the City. Because the DBFM entity is contractually accountable for structure maintenance over this period of time, there is a substantial financial incentive to implement innovative, cost-effective practices that achieve long-term durability.

After the project reached substantial completion, a one-time commissioning payment of $75,000,000 was provided to the DBFM entity followed by annual service payments of $12,000,000 to cover capital and maintenance costs. An independent review of the project confirmed that the DBFM contract resulted in a $47,000,000 savings to the City compared to a traditional project delivery approach. The consultant also stated that the DBFM model provided advantages in terms of innovation, risk, project delivery, quality and cost certainty.

Conceptual Drawing of the Red River Bridges – the Existing Bridge Piers were Rehabilitated and used to Support the Pedestrian Bridge

Project Approach

The DBFM entity provided a design solution that would keep all four lanes of the Disraeli Freeway open during the 4 year construction process. A new bridge would be constructed over the railway adjacent to the existing bridge, with the existing bridge demolished after the new bridge is completed. A similar approach would be taken with the Red River Bridge. However, the existing bridge would remain and be redesigned for use as a separate pedestrian and bicycle crossing to increase public safety.

Arial View of the Disraeli Bridges Project over the Red River with Traffic Diverted onto the New Bridge

The Red River bridge superstructure was demolished and rebuilt to suit its new function. However, a key component to meeting the cost and schedule restraints was to utilize the existing reinforced concrete piers and foundations. With the DBFM entity responsible for maintaining the structure for 30-years, a long-term cost effective repair solution was necessary to extend the life of the piers so that they have minimal maintenance and are in good condition when the structure is handed back to the City. With significant chloride contamination, any repair strategy would require the overall corrosion problem to be addressed.

Repair and Corrosion Mitigation of Piers Proceeded inside Heated Enclosures

Red River Bridge – Concrete Repair

The Red River Bridge has an approximate length of 319m (1,050 ft.) and spans over four concrete piers, two on land and two in the river. To complicate matters, the repairs would need to be completed during difficult winter conditions. Access to the middle two piers would be off the frozen river and all structures would be hoarded and heated to allow work to proceed.

The Heated Enclosure Allowed Work to Proceed Despite Exterior Temperatures as Low as -30ºC

After the damaged concrete was removed, the repairs were sandblasted to remove any loose material and create a rough but sound surface for mechanical bond of the repair material. The repair areas were formed using plywood to match the existing pier profile. Prior to placing the flowable concrete, the substrate was maintained in a saturated surface-dry condition, then concrete was placed using a concrete pump. The forms remained in place for 7 days and then a curing compound was applied after form removal. A total of 197m2 (2,120 ft2) of structural concrete repairs were completed from January to March of 2012. Structural cracks in the piers, potential areas of vulnerability for future chloride-ingress, were epoxy injected using low viscosity resin and a plural component pump.

Plywood Formwork in Place

Ports in Place for Epoxy Injection Crack Repair

Pump Truck Delivering Concrete for the Repairs

Completed Concrete Repair of Red River Bridge Pier

Red River Bridge – Corrosion Mitigation

One of the most common causes of deterioration of concrete structures is corrosion of the reinforcing steel. Corrosion is caused by the elimination of the passive oxide layer on the reinforcing steel, typically due to exposure to chlorides in de-icing salts. Without addressing a chronic corrosion problem, structures are destined for a cycle of on-going maintenance repairs which accelerate over time.

Due to the level of chloride contamination and corrosion, a globally-applied corrosion mitigation solution was required to meet the needs of the DBFM entity – long-term protection with low maintenance requirements. Two technologies were identified and implemented; the two land-based piers would undergo an electrochemical corrosion treatment procedure and the two water-based piers would utilize surface applied galvanic corrosion protection.

Electrochemical treatments such as electrochemical chloride extraction (ECE) are non-destructive technologies that directly address the root cause of corrosion problems by changing the environment around the steel and mitigating active corrosion. The ECE treatment generates increased alkalinity while significantly reducing the amount of chloride around the reinforcing steel. This dual action positively alters the chloride-hydroxide ratio to ensure continued rebar protection. The first structure in North America to be treated with the ECE in was the Burlington Skyway in Ontario in 1989 and the treated area remains in a non-corroding state.

A temporary DC electric field is created by transformer-rectifier connected between the reinforcing steel and an external electrode mesh embedded in a mixture of potable water and cellulose fiber. During the treatment, the anode mesh is continuously wetted by an irrigation system and water runoff is collected. The applied electric field causes the negatively charged chloride ions to move from the reinforcing toward the positively charged external electrode mesh. Once the chloride content has been

Temporary Anode Mesh and Wiring in Place for Electrochemical Chloride Extraction Treatment for the Two Land-Based Piers

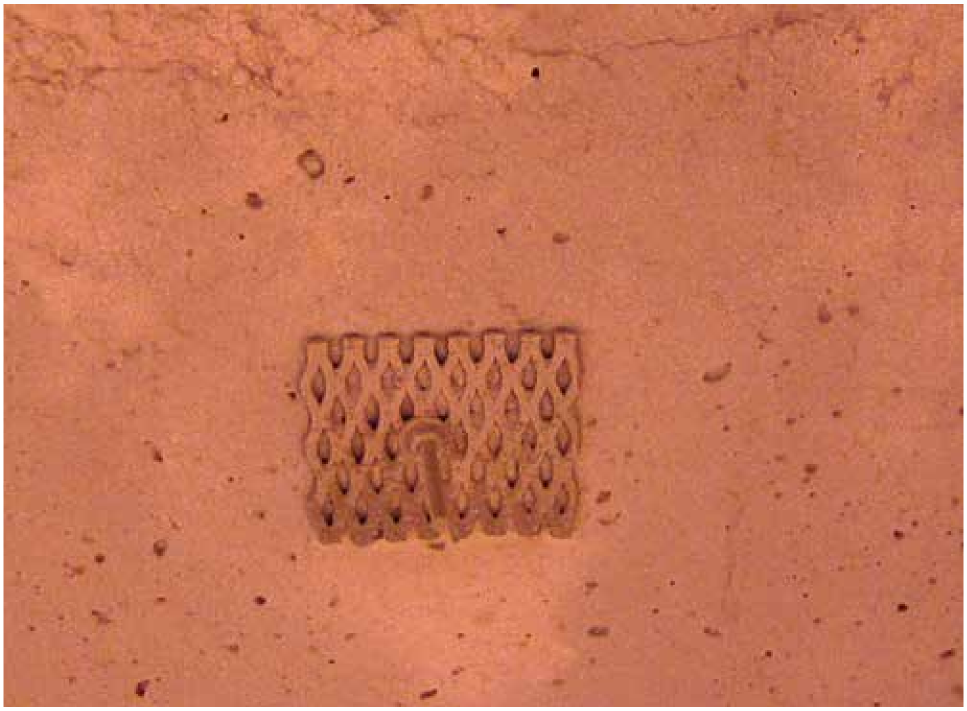
reduced to acceptable levels, and the pH of the concrete surrounding the reinforcing steel has been raised, the temporary anode and electrolyte media is removed.

A total area of 637m2 (6,860 ft2) was treated by the ECE process between November, 2012 and March, 2013. Because of the project schedule constraints, the ECE treatment duration lasted as long as possible with all equipment and materials removed prior to the spring thaw. Each zone was energized for 41 days, achieved an average current of 1508 A-hrs/m2, and chlorides at the level of the steel were reduced by 68 to 88%.

For the two piers over water, it was determined that the duration of the ECE process was too lengthy to meet the project schedule. As an alternate, impressed current cathodic protection and galvanic protection systems were considered. However, the DBFM entity decided that despite the long-term protection provided by impressed current systems, the requirement for monitoring and maintenance of the electrical components over the 30-year contract period was undesirable.

With a galvanic system, the protective current is generated by the potential difference between the zinc anode and the steel reinforcement. There is no electrical equipment or monitoring necessary for the sacrificial anodes to operate. Metalized zinc anodes have been used to protect reinforced concrete structures for more than 25 years. The zinc anode is applied to the surface of the concrete and serves as a sacrificial anode that corrodes in preference to the reinforcing steel. The zinc anode can be applied to complex concrete surfaces and the finished surface has a similar appearance to concrete.

Published studies have shown that in certain environments such as non-marine bridge piers, “unactivated” arc spray zinc may not provide an adequate level of protection unless the anode is subject to periodic direct saltwater wetting. In some cases, the current generated by arc spray zinc without periodic wetting can decrease to nearly zero. Humectants were developed to improve the performance of arc spray zinc systems. The humectant solution promotes the retention of moisture which lowers the system resistance thus allowing the anode to function more efficiently.



Reinforcing Steel Connection

From January to February of 2012, a humectant activated arc spray zinc system was installed under the supervision of a Cathodic Protection Technician certified by the National Association of Corrosion Engineers to protect a total area of 873m2 (9,392 ft2). High purity zinc was applied onto the prepared concrete surface at a thickness of 500µm (20 mils). Connection to the reinforcing steel was made using flattened expanded zinc mesh plates bolted to the surface over threaded rebar connections with galvanized nuts and washers. After zinc application, the humectant activator solution was sprayed on the surface of the zinc anode at rate of 100mL/m^2 (0.0026 gal/ft^2).

Quality control procedures included verification testing of anode thickness and bond strength. The thickness was confirmed by coupon testing every 6m2 (64 ft2) of anode surface. The bond of the anode to the concrete was tested using the direct tension method every 92m2 (1,000 ft2) to verify that the bond strength exceeded 1 MPa (145 psi).

Humectant Activated Arc Sprayed Zinc was used to Protect the Two Interior Piers

Summary

An innovative design-build-finance-maintain project delivery model was used by the City of Winnipeg to address the deteriorating Disraeli Freeway Bridges. As part of the project, 4 existing concrete piers under the Red River Bridge were to be maintained and repaired. The repair scope included form and pour concrete repairs, epoxy injection, electro-chemical chloride extraction and activated arc sprayed zinc. The concrete repair and protection work was performed over a 5 month period from November 2012 to March 2013 in heated and hoarded enclosures which lead to difficult working conditions. However, all work was performed to meet and exceed the project requirements and the structure was open to the public in the autumn of 2013.