St. Andrews Lock and Dam Corrosion Protection System

5 Year Case Study

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Abstract

The St. Andrews Lock and Dam (SALD) Corrosion Protection System exemplifies engineering foresight, innovation and the practice of investing in the future to protect this historic, vital structure. The 1900 vintage main truss spans, comprised of detailed, built-up, riveted latticed steel members, were successfully metallized using zinc aluminium (85/15) wire material during the harsh 1998/1999 Manitoba winter. Over 380,000 ft^2 of structural steel was coated in the seven, 40-m-long spans. This was the largest metallizing project in North America at that time.

One of three camere-style removable dam structures in the world, the St. Andrews Lock and Dam contributes to the quality of life in the Greater City of Winnipeg area and provides a vital road link between the communities of Lockport and St. Andrews, Manitoba.

A five-year case study of this project, evaluates the key elements to this project's success, which include the coating selection process and the life cycle cost analysis, construction inspection arrangement and innovative five-year warranty arrangement with a $300,000 returnable incentive. The life cycle cost analysis explores the need to critically evaluate real long-term costs required to maintain a structure over a selected 50-year service life. The unique 5 year warranty arrangement examines methods to add incentive, to motivate contractors to "take ownership" to provide superb workmanship and to protect the owner's interest.

This case study provides an evaluation of a successful solution for the treatment of problematic maintenance areas such as packed rust joints with the use of stripe coating and caulking. It also discusses the 100% environmental containment system used to contain the blast media during removal of the old lead-based paint and how it allows metallizing to be applied at below 0^oC temperatures.

Minimal warranty work has been required during the five-year warranty period, which ends this summer; and it has been a significant measure of the success of the coating system. Owned and Operated by Public Works and Government Services Canada, this $8 million dollar investment will ensure the structures vitality throughout the century.

St. Andrews Lock and Dam Corrosion Protection System – 5 Year Case Study

1.0 Introduction

Maintaining bridge structures has become an increasing financial burden in Canada and the United States. Many structures built between 1950-1990 have coating systems, often containing lead-based paints, approaching the end of their viable life. Over the last 20 years the bridge coating industry has undergone immense changes, largely driven by the tightening of environmental regulations which has increased recoating costs. Costs have increased primarily due to the legislation that requires the hazardous lead based paints to be contained and properly disposed of upon removal.

Coating suppliers are continually developing more durable coating systems to meet the strict environmental standards and to offer superior protection and long life. Today, costs and longevity of different engineered coating systems vary significantly. With this in mind, bridge owners have a continual challenge of protecting their investment by finding a superior coating system that does not compromise the biophysical environment or human health.

In 1996, PWGSC retained Wardrop Engineering Inc. to provide engineering services for the selection and application of a coating system at the St. Andrews Lock and Dam (SALD) as the final stage of a $25 million reconstruction project for this structure. Areas to be coated were the six 38.6-m river spans and the dam frames above the water line along with the single 38.6-m overland span, which is adjacent to the east approach. These seven spans cover a length of 283 m and the structural steel surface area that was metallized is in excess of 35,300 m^2 (380,000 ft^2).

A total of four contractors submitted bids and the base bids ranged from a low of $7, 421,808 to $9,730,325. Clara Industrial Services Ltd. from Thunder Bay, Ontario was the low bidder and was awarded the project on August 26, 1998. The base bid included zinc metallizing the majority of the structure and applying Termarust (Bridgecote) to the steel members at the soffit. An alternate to metallize the complete structure was included as part of the bid package. Prior to the start of construction, this alternate was accepted and the contract was increased by $300,000 to $7,737,053.

Construction work involved the removal of the existing lead paint and coating of the St. Andrews Lock and Dam using 10 mils of zinc metallizing, an 85% zinc and 15% aluminium metallizing coating system was completed in the spring of 1999. The end of the five-year warranty period will be completed this year (2004). A five year case study of this project evaluates the key elements to this project's success which include the coating selection process and life cycle cost analysis, construction inspection arrangement and innovative five year warranty arrangement with a $300,000 returnable incentive. In addition, the case study reports on the performance of the coating during the five-year warranty period and the repairs required during this period.

The Structure

The St. Andrews Lock and Dam (SALD) commonly known as the "Lockport Bridge" is a multi-use facility owned and operated by Public Works and Government Services

Canada (PWGSC) located on the Red River, 25 km north of the City of Winnipeg, at the town of Lockport, Manitoba (Figure 1). The Lock and Dam was originally constructed in 1910 and a road deck was installed in 1913 linking west and east Lockport. It facilitates navigation along the Red River from Lake Winnipeg to the City of Winnipeg by regulating the water levels on the Red River.

The structure consists of six identical 38.6 m long river spans that house a 6-bay spillway with a camere-type moveable dam, a lock, a seventh 38.6 m overland span adjacent to the east approach, three east approach spans totalling 73.0 m and an 89.9 m west approach comprised of two spans (Figure 2). The six river spans are made up of three main trusses, upper framing members supporting the road above, a working floor providing access to the moveable dam, a main floor, sway bracing and the moveable dam frames (Photo 1 and Figure 3). The main trusses are comprised of built-up lattice box beams riveted together. Channels, I-beams and latticed built-up sections were employed to make up the other components of the structure. Below the working floor are the moveable, tapered/built-up, dam frame girders. These are supported by an elaborate system consisting of steel hangars, thrust wedges, and steel castings. The seventh span is made up of two main trusses identical to those supporting the road deck in Spans 1-6. It also includes a crane storage facility.

Historical Background

The Lister Rapids, located on the Red River between Winnipeg and Lake Winnipeg, have provided an obstacle to boats since the start of the Fur Trade. In 1896, after attempts to dredge the rapids failed, a plan was devised to construct a lock and dam system to regulate water levels, facilitating travel over the rapids.

The design of the present lock and dam structure took a great deal of thought and ingenuity. A permanent dam structure could not be constructed because it had the potential to cause an ice jam during the spring freshet, which would cause serious flooding upstream. In the end, the present camere-style moveable dam was chosen which could be placed in the water during the navigation season and removed during the winter months. Only two other similar camere type structures have been constructed in the world and both are located on the Seine River in France; SALD is the largest of the three.

In October 1900, construction began and after many set-backs including outbreaks of typhoid and the loss of many workers, the St. Andrews Lock and Dam was scheduled for completion for the start of the 1910 navigation season. On July 14, 1910, Sir Wilfred Laurier officially declared the Locks open.

In 1913, a bridge deck complete with a bascule lift over the lock structure (that has since been removed) was added to allow the movement of vehicles and pedestrians.

Over the years, commercial shipping between Lake Winnipeg and the City of Winnipeg has declined. However, recreational and passenger vessels still depend on the structure for navigation. The City of Winnipeg depends on the structure to help increase the quality of life by providing an artificial summer water level, the benchmark elevation to which many structures are built.

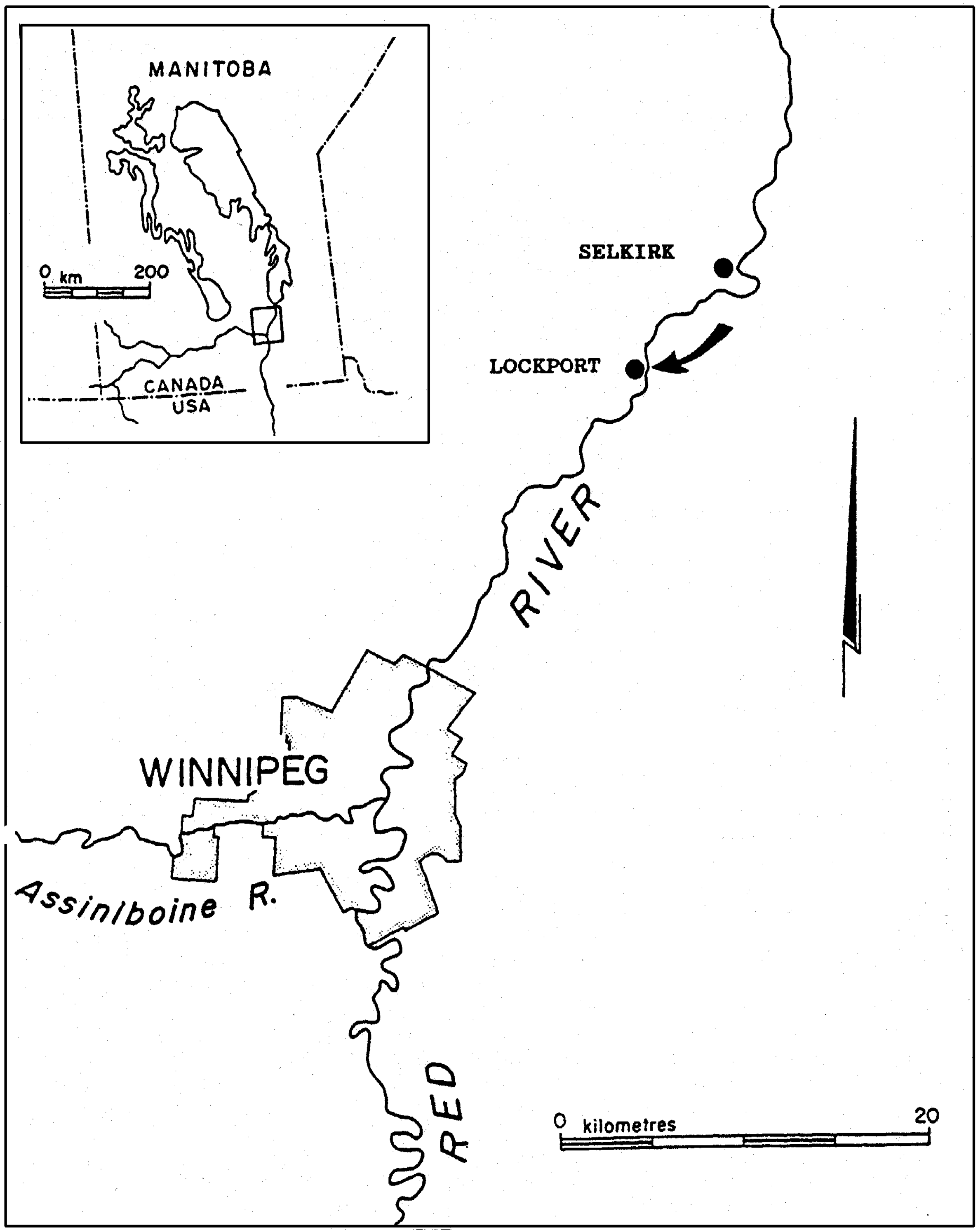

Figure 1. Location of Lockport

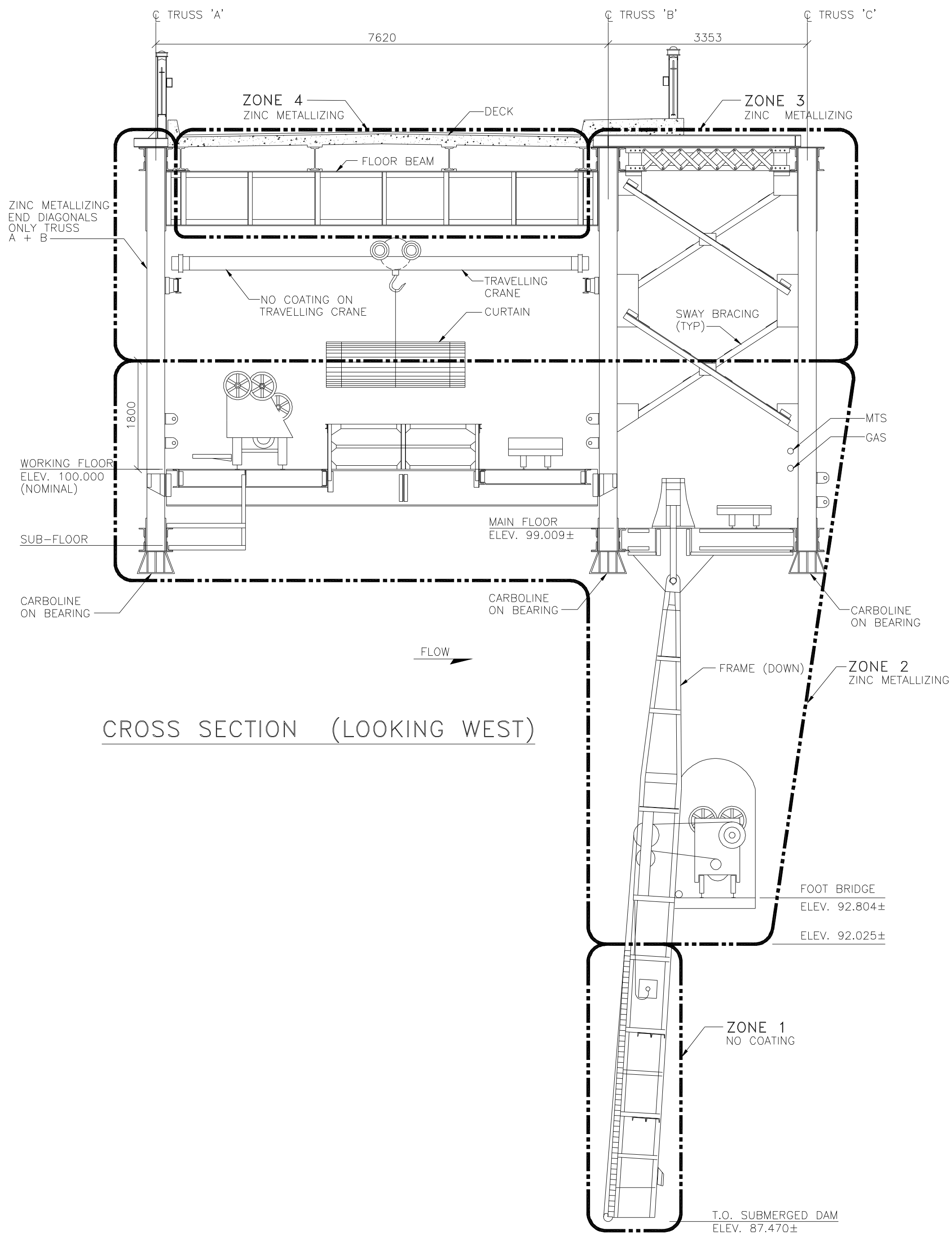

Figure 2. Cross Section of Bridge Showing Coating Zones

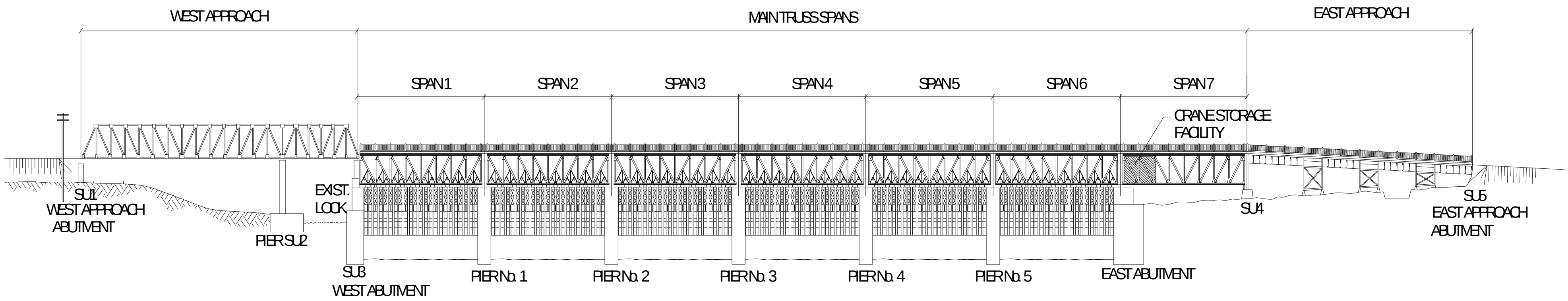

Figure 3 – South Elevation of the Entire Bridge Structure

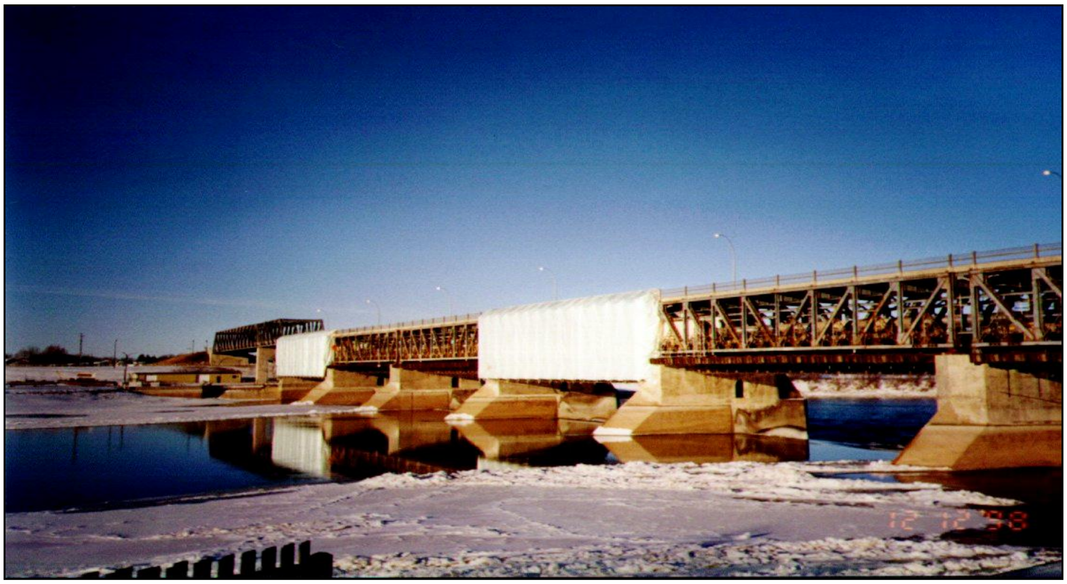

Photo 1. Photo of SALD During Construction

PWGSC initially employed a large crew of workers to maintain the structure. All work was performed "in house" which included a yearly painting of the dam frames. However, continued cutbacks to staff has only left a "skeleton crew" which operates the Lock and Dam and now all major work to the structure is performed by consultants and contractors.

Painting this structure over the years has proven to be a difficult task due to the immense detail of this built-up riveted/lattice structural steel, typical of 1900 vintage steel bridges. The bridge has seen many contractors underbid the work to coat the structure and end up not completing the work and/or facing bankruptcy. The last major coating of the bridge occurred in 1974. Since then, only touch ups have occurred on a limited basis and the coating had deteriorated significantly.

SALD Operations

The SALD operates during the navigation season, which runs from the end of the spring freshet to the fall drawdown. In a "normal year" the freshet ends in late May, at which time PWGSC operational personnel organise a sizeable crew to lower the 89 frames and curtains at the six river spans. Once the moveable frames are placed in the water, Douglas Fir curtains are lowered into the water to act as a dam. PWGSC is continually challenged by the weather and resulting flows from the Red and Assiniboine river basins to keep water levels upstream as consistent as possible. As a result, curtains are continually moved up and down to regulate the water levels.

During the operational season, PWGSC requires continual access to the steel working deck for proper control of the river water level. After heavy rains in the Red River watershed, PWGSC may require adjustment of the curtains or removal of the frames at any time. Drawdown usually begins around October 15 and is usually complete by November 1. PWGSC lowers river water levels by approximately 300 mm (1") per day to mitigate any riverbank destabilisation and all frames and curtains are removed prior to freeze-up.

It should also be noted that during all months of the year water is open on the downstream side of the dam causing high humidity conditions.

2.0 Coating Selection Process and Life Cycle Analysis

General speaking, a coating is applied to structural steel to provide corrosion protection. The costs considered when selecting a new coating system includes both the application initial (capital) costs and future (maintenance) costs. Presently, bridge owners are faced with the challenge of escalating bridge maintenance costs and at the same time shrinking or stagnant maintenance budgets. This and the fact that more and more bridges require maintenance has led to a changed philosophy in the bridge coating industry as the focus of expenditures has shifted from incremental maintenance budgets to life-cycle cost budgets. Presently, most bridge owners are using paint systems which will hopefully provide a service life of 30 years and fewer maintenance requirements. With this in mind, a net present value analysis on various high performance coating systems was performed to determine which coating system would be the most cost-effective when considering a 50+ year period coating life. The coating selection process consisted of the following steps:

- Define Corrosion Environments
- Identify Coatings Suitable for Corrosion Environments
- Define Initial Construction Costs and Expected Maintenance Costs
- Undertake Comparison of Coatings using a Life Cycle Cost Analysis

Our first step in the analysis was to define the different types of corrosion environments present at the SALD. The structure was divided into four distinct corrosion zones (Figure 3) according to the National Association of Corrosion Engineers (NACE) and SSPC guidelines. These zones were treated separately when analysing and selecting coating systems.

Zone 1, the "Fresh Water Immersion Zone," consisted of the lower portion of the dam frames that are immersed in the water when the dam is in operation. This area has the harshest corrosion environment as the frame sections are partially submerged in water during the summer months; and they are exposed to ice fog in the winter. Prior to construction this portion of the original frames were deteriorated to such a degree that it would be impossible to sandblast them. Therefore, they were not coated and were replaced in 2001-2002.

Zone 2, the "Moderate (Industrial) Zone," consisted of the remaining portion of the dam frames and lower half of the main truss section. This zone was determined to be in a high humidity environment typical of moderate industrial exposure. Zone 3 was defined as " Seacoast Marine," and is the upper half of the trusses excluding the main floor beam protected by the bridge soffit. This zone is also exposed to humidity as well as very corrosive deicing salts, which come from the roadway above. Finally, Zone 4, the "mild (rural)" Zone contains the main floor beams and cross bracing located immediately under the roadway. Bridgecote was specified as the base bid for this zone and was changed to metallizing during construction for a small incremental cost. This area is well protected from almost all environmental elements and exposed to a very passive corrosion environment.

Once the bridge had been divided into various zones, a number of coating alternatives were identified to protect the steel in each zone. Over fifty possible systems were examined. Once this was done, several factors were considered to form the basis of a coating system selection. These included: material and labour costs, suitability of coating systems to particular zones, total number of coatings, life span selected for life cycle cost analysis, and the interest rate used.

Construction cost data was obtained from a number of sources including PWGSCs past experience at SALD, other bridge owners in Manitoba, NACE, contractors, and suppliers. Material cost is the actual cost of the paint or coating and surface preparation is the cost to achieve the required degree of blast cleanliness; both of which are well defined. Application costs are somewhat more subjective and are dependant on factors such as the curing times, number of coats required, time of year when construction occurs, and the equipment required to perform the work were included in this calculation. Consideration was also given to the number of different coating systems that would be applied in different corrosion environments. Minor adjustments were made; depending on the number of zones a particular coating system would coat to reflect quantity discount of a product. Net interest rates are variable depending on inflation and interest rates. For this project, both 3% and 5% interest rates and a 50-year life span were used for the cost calculations.

In addition to the above, adjustments were made to the costs based on the following factors:

- containment and hoarding requirements;
- soft costs including overhead and inspection costs including differences between one coat and multicoat applications; and
- winter work premiums.

Some of the high performance coating options examined included:

- part Zinc Rich Moisture Cure Urethane (MCU) with two coats of MCU;
- zinc rich primer with two coats of MCU;
- Inorganic Zinc (IOZ) with an HB Epoxy intercoat and Polyester Urethane top coat;
- Zinc Metallizing with an HB Epoxy intercoat;
- Zinc Metallizing;
- two coats of coal tar epoxy; and
- Termarust (Bridgecote).

Various coating systems had advantages and disadvantages specific to the SALD. Our cost analysis revealed that although zinc metallizing had the highest initial cost, its' Net Present Value over a 50+ year period proved it was the most economical option at the SALD. In addition to cost, the following distinct advantages which helped to put metallizing on top:

- mechanical durability in a destructive environment (many chains, cables and workers are constantly moving over the steel structure;
- coating requires relatively minor maintenance over a 50-year period; and

- affords galvanic protection to the structural steel (protecting the structural steel from corroding if a small portion of the steel is exposed to the elements).

Costs that were not included in the original analysis that should be examined include project costs and user costs. Project costs include the cost to the owner to prepare, tender and manage maintenance work of a project. These costs were ignored since the size of the structure is very large which makes these costs less influential. However, on smaller projects, these costs could have a larger influence.

User costs are defined as the estimated value of time lost as a result of maintenance activities which require lane closures or detours. Typically these costs are ignored since they are not direct costs to the bridge owners and they are often much larger than the cost of the construction work. The soul purpose of any traffic bridge is to provide safe and efficient movement of people and goods and user costs are real costs to the users of a bridge and the surrounding economy. All construction activities at the SALD minimally impacted vehicular traffic since the trusses are located beneath the bridge and only a few nighttime lane closures were required. However, user costs should be carefully considered when examining these costs.

Zinc metallizing has the highest initial cost compared with cadillac three coat paint systems. Generally speaking the breakeven point for metallizing is at 40 to 60 years when comparing using a NPV. In cases where lead abatement necessitates elaborate contaminant systems, the incremental costs to switch to metallizing over a paint system is lowered as a percentage of the overall cost. However, metallizing is the only system available that can last 50 years or more. The service life of this system is directly proportional to the thickness of the coating. Therefore, in order to achieve a longer service life additional coating thickness can be applied at a very low square area cost.

Presently, the cost to zinc metallize in the shop is between 10 to 12 $\$/ft^2$ and the cost of a 3 coat paint system is approximately 8 to 9 $\$/ft^2$.

3.0 Zinc/Aluminum Thermal Spray Process

Thermal spray coatings have the ability to revolutionize the coating industry, since they are an extremely durable, single coat system which can offer life spans in excess of 50 years with little or no maintenance. Thermal spray coatings or metallizing have been around since the early 1900s and have seen widespread use in Europe; however, until about a decade ago equipment used to metallize was very arduous and expensive to use in the field. Recent improvements to the “arc spray” technology have increased production rates and has helped to make metallizing a more viable alternative.

Thermal spray coatings can spray many types of metallics or even ceramics. Metallizing involves the spraying of molten metal onto a prepared steel surface by means of atomized air (usually compressed air). Typical applications of metallizing include the application of pure zinc or aluminum; or a combination of zinc and aluminum via a flame spray gun or an arc spray gun. Flame spray is an older technology that uses a gas flame to heat either zinc powder or zinc wire. When powder is used it is “dusted” onto a prepared steel surface. The flame spray metallizer then heats the powder and melts it, causing it to mechanically fasten to the steel surface. When zinc wire is used, the wire is continuously fed thru a flame which turns it to molten zinc. Compressed air then thrusts it onto a prepared steel surface. This technology covers approximately 1/4 of the total area that can be covered by an arc spray metallizing machine.

The arc spray metallizer has been around for over 30 years; however, recent modifications to this machine has helped to make metallizing an economically viable option. An arc spray metallizer functions by continually feeding two oppositely charged wires through a metallizing machine. At the point of contact, the wires "arc," instantly turning into molten metal. The molten metal is then thrust onto the prepared steel surface by three 90-psi directional compressed air nozzles, instantly cooling and mechanically bonding to the steel. Until the 1990s, the arc spray metallizer had very low deposition rates and were very cumbersome to use in the field. Older machines used a 3.2-mm (1/8") wire, as opposed to new machines that have been capable of using 4.8 mm (3/16") since about 1990. This change in wire diameter and modifications to the field portable machines has provided contractors the ability to increase production by up to 6-fold; again significantly lowering costs.

Why 85% Zinc and 15% Aluminum

In the 1960s, extensive research was performed to determine the effects of combining varying amounts of aluminum and zinc and how well it protects the steel. It was determined the combination of 85% zinc and 15% aluminum wire (by weight) offered superior protection in chloride environments. In this combination, small zinc particles affords the steel galvanic protection, and elongated particles of aluminum form an inert barrier protecting the steel from any airborne contaminants. A combination of 85/15 wire was applied to the SALD. It should be noted that the 85/15 wire is recommended on steel structures that are exposed to harsh salt environments. The 85/15 wire cannot be used on concrete, as the aluminum will cause the concrete to disbond from the reinforcing steel. Steps must be taken when metallizing steel adjacent concrete surfaces to ensure only minimal amounts of overspray hit the concrete surface.

Advantages

Metallizing offers many distinct advantages over a conventional coating system. These include:

- Mechanical durability;
- Cathodic protection;
- 50 year plus life span with little or no maintenance (directly proportional to coating thickness);
- Single coat systems; and
- No curing time.

Unlike many conventional paint systems, metallizing mechanically bonds to a prepared surface and has had typical adhesion values for this job ranging from 700 to 1100 psi. Because of this strong bond, the metallized coating may only "nick" off if it is struck on a corner with a heavy object. If there is a small area of exposed steel, the zinc coating is able to cathodically protect this area by sacrificing itself. Depending on the corrosion environment and with the right amount of dry film thickness (DFT) metallizing can protect a steel surface for 50 years or more.

Application

There are many keys to successfully applying 85/15 wire, the two most important are having a properly prepared surface and an adequate profile on the steel surface. Steel surfaces must be prepared to a SSPC-SP10, Near White Metal Blast, as a minimum requirement. This ensures that the surface is free from all paint, mill scale, pact rust, dirt and any other corrosion producing contaminants. Often a SSPC-SP5, White Metal Blast, is recommended; however, this is almost impossible to achieve in the field especially when the steel is 90 years old. Metallizing does not have the ability to "bridge" over any contaminants as it bonds mechanically to a prepared steel surface. Our experience at the SALD has shown that if tightly adhered pact rust covering a surface the size of a thumb tack was not removed and was metallized, a coating failure would occur in which the metallizing would simply fall off. For this reason, strict quality control and quality assurance was enforced to ensure that a SP10 blast was achieved.

The profile on the steel surface is defined as the size of the indentation made by the blast media. Looking under a microscope, the steel should appear to have a "toothed" surface. It is essential that angular blast grit be employed, as it will cause the steel to have a "barbed" surface. A surface profile of 2-3 mils was specified and on average the surface profile ranged between 3-4 mils throughout the project. It is recommended that a 3-4 mil profile be specified for future work since it improves bond and increases the amount of zinc on the steel surface.

A 3-4 mil profile occurred because the contractors' blast hoses had pressures between 110 to 120 psi and heavy blast media to remove tightly adhering pack rust. The dry film thickness (the actual thickness of the coating) of various coating systems is measured from the top of the blasted profile to the top of the coating; therefore, with a deeper profile or deeper "pits" more zinc is required to fill these areas. The longevity of a zinc metallizing coating is directly proportional to the coating thickness. Other important factors to note include SP 1 Solvent Washing for the removal of chlorides and oils from the steel surface prior to the commencement of abrasive blasting. Surface steel temperature at application was also closely monitored, as it is believed to affect the adhesion values.

4.0 Construction at SALD

The coating system for this project included the following:

- Surface preparation – SP10 Near White Metal Blast with a 3 to 4 mil profile
- Coating - 10 mils of 85/15 zinc/aluminum metallizing
- Stripe Coat – Stripe coat all joints in Zone 2 using Carboline 242
- Pact Rust Joints – Seal all pact rust joints whose widths exceed 3/32" with caulking (Mulco Supra Expert Caulk)
- Inaccessible Areas – Coat with stripe coat material

As new technology in the metallizing industry, namely the application of 3/16" wire has emerged; the SALD provided the largest testing ground in North America for the 85/15 wire at the time of construction. The painting project was awarded to Clara Industrial Services Ltd. of Thunder Bay, Ontario in November 1998 and construction began immediately. Since the existing paint contained lead, the contractor was required to contain all materials used to remove the paint and the paint itself and provide net negative air pressure. The contractor elected to construct an elaborate containment system which completely encapsulated one of the seven 38.4m bridge span at a time.

Up to three different spans were completely enclosed at any one time enabling the contractor to sequence their work in the most efficient manner. It is extremely important to understand the actual operations, the level of effort, and cooperation between all parties that took place to ensure the success of this project. At SALD, Clara Industrial Services Ltd. was awarded the contract to metallize the structure. They are a very experienced contractor who have the necessary financial and human resources to complete a project of this magnitude. The key to the success of meeting a tight schedule within the SALD operations, complying to strict environmental constraints and guidelines, and meeting all specified requirements can only be understood by describing the sequence of their operations and adjustments made to increase production and improve quality.

Operations continued 7 days a week and 24 hours a day beginning in November 1998 and ending in May 1999. During the work in all spans of this project the operations performed followed the same sequence; however, changes occurred in the time during which these operations were performed. Operations in the first span were notably different than in the subsequent spans as the contractor had little flexibility in how operations could proceed. Metallizers and sandblasters worked hand in hand and the steel that was abrasive blasted during the night shift was metallized during the day. This sequence caused the sandblasters and metallizers to constantly trip over one another and it also left little time for the required inspections to take place. Because there were typically many sandblast misses each night, the day shift spent the better part of the morning spot blasting and blowing down the surfaces to be metallized.

Normally, metallizing could only take place for half of the 10-hour day shift. In the next spans, the contractor wisely adjusted their sequence of operations and attempted to get the sandblasters ahead of the metallizers. They were able to do this by constructing multiple containment systems. By the third span the sandblasters were approximately 10 days ahead of the metallizers and would actually be abrasive blasting in a different containment system which allowed the contractor to abrasive blast during the day time as well.

A typical day was broken down as follows:

Table 1 – Typical Daily Operations of the Contractor at St. Andrews Lock and Dam

OPERATIONS PERFORMED	Operation Time
Abrasive blasting	9:30 p.m. to 6:00 a.m.
Blowdown of steel to be metallized for inspection	6:00 a.m. to 7:30 a.m.
Inspection of steel by QC/QA	7:30 a.m. to 8:15 p.m.
Spot blasting and blowdown	8:15 a.m. to 9:00 p.m.
Reinspection of steel by QC/QA	9:00 a.m. to 9:30 p.m.
Metallizing	9:30 a.m. to 6:00 p.m.
QC/QA Inspection of steel	6:00 p.m. to 9:30 p.m.

During the night shift abrasive blasting took place. Prior to starting their work the blasters would speak to the quality control inspector to find what areas had been missed the night before, and would often be given a drawing outlining the general locations. The blaster would then enter the containment system and walk through their work area identifying “misses” and their area to sandblast that night. Sandblast operations continued until approximately 6:00 a.m., at which time the sandblasters would stay and blow down (clean off) the sandblasted areas for inspection. Once this was done, usually around 7:30 a.m., the quality control and quality assurance inspectors would reexamine the specific area that would be metallized that day and identify any blast misses. Quality assurance would follow quality control to help expedite this work in a timely fashion.

The day shift would arrive at 8:00 a.m. and would begin by speaking with the inspectors and surveying the area that they wished to metallize that day. Because there were always misses from the night before, the metallizers would begin by spot blasting or sweep blasting the steel areas. Once the sandblasters were well ahead of the metallizers the steel was always swept blasted (given a quick, light sandblast) to remove any potential flashrust that may have occurred. This ensured that the surface always met an SSPC-SP10, Near White Metal Blast, and was free from any corrosion producing contaminants.

After this occurred, a brief inspection occurred to ensure that all “misses” were blasted off and the areas were ready to be metallized. Final checks of ambient conditions, steel temperature, and humidity were performed. At this point the metallizers were told what areas could be metallized. Metallizing occurred for roughly 7 hours a day. Areas covered ranged between 232.25 m^2 to 325.15 m^2 a day (with a 10-mil thickness), depending on the number of metallizers. Typically, six metallizers ran daily and towards the end of the project as many as eight were running to increase production.

Once the day shift was complete, the night inspection shift started. During this shift, quality control would inspect first round blast quality, identify misses and sometimes perform dry film thickness checks. Dry film thicknesses were usually checked during metallizing operations in the daytime. Quality control would use this time to inspect blasted areas and quality assurance normally was able to complete this work in half the time. As this project progressed, typically quality control had to look at the blasted steel twice identifying any blast misses. Once quality control was satisfied with the blast quality, the quality assurance inspector would look at the blasted surface and identify any misses. Touch-up blasts were then performed as required. The role of quality control and quality assurance is further described in the next section of this paper.

5.0 Quality Investment – Five-Year Warranty

Bridge owners have always had the dilemma of finding better means to increase the quality of coating application and maintaining a coating system after a contractor had completed the work. PWGSC’s goal was to protect the investment that the Government of Canada was making in the SALD and to adequately manage their risks. With this in mind, Wardrop took the following measures to ensure that the best coating application for this project was achieved. Some of these measures were:

- Prequalification requirements for the construction contractor including requirement for NACE certification, conformance to SSPC-QP 1 and QP2.
- Specifying that the contractor was required to provide an independent full time NACE inspector for quality control inspections.
- Providing a full-time quality assurance NACE inspector to provide PWGSC with quality assurance review and inspection on the coating operation. This system guarantees contractor conformance with the plans and specifications of the project.
- Obtaining a 5-year, single-source warranty from the contractor to keep the contractor responsible for any deficient work over a reasonable period of time.

Prequalification

The coating industry has been infamous for "fly by night" contractors, and therefore all efforts had to be taken to ensure the contractor had previous experience and could complete a job of this size. Contractors had to prequalify to bid on this project by showing evidence of NACE, SSPC-QP1 and QP2 certification. During the tender period, it was found at that time that only one company in Canada had SSPC-QP1 and QP2 certification. As a result, contractors were asked to provide evidence of application for SSPC-QP1 certification. SSPC-QP1 is defined as the, "Standard Procedure for Evaluating Qualifications of Painting Contractors (Field Application of Complex Structures). SSPC defines the objective of this program is to determine if a painting contractor has the personnel, organization, qualifications, procedures, knowledge, and capability to produce surface preparation and coating application of the required quality for complex structures. Management procedures, technical capabilities, quality control and safety formed the outline of the general qualification requirements. This requirement ensured that the contractor had knowledge, experience, the necessary equipment, human resources, and financial backing to complete a job of this magnitude.

Quality Control/Quality Assurance

The contract documents also specified that the contractor was to provide an independent NACE certified inspector to perform all quality control. The quality control inspector was to ensure that all operations related to abrasive blasting, metallizing and coating of the structure were done in accordance with the contract specifications. Some of the key responsibilities were to ensure:

- prepared steel surface was sandblasted to an SSPC SP-10, Near White Metal Blast, and free from any corrosion producing contaminants;
- all pack rust in pack rust joints was removed to a depth greater than or equal to the width of the joint and sealed;
- the steel temperature was 3^{o}C greater than the dew point and rising prior to any coating operations;
- all chlorides were removed by hand solvent wash to a level of less than 30 ppm prior to abrasive blasting;
- all oils and grease were removed by hand solvent washing prior to abrasive blasting;
- adhesion values of the metallizing were a minimum 700 psi during cold weather application of the metallizing (cold temperature application was defined as when the steel or air temperature was less than 4^{o}C);
- zinc metallizing was applied to a minimum dry film thickness of 10 mils; and
- all joint member connections were striped in Zone 2.

Wardrop's subconsultant To-Spec Ltd., provide NACE-certified quality assurance inspections to ensure that the Contractor's work met or exceeded the requirements of all items listed above and all coating items outlined in the contract specification. One could compare the requirement for full-time NACE-certified quality control and quality assurance as a reinforced web. Quality Control's role was to ensure all surface preparation and coating operations met or exceeded the contract specifications and quality assurance would provide a second check on all this work preventing anything from "slipping through the cracks." This system of QC/QA helped to ensure that the contractor would continually be "pushed" on two sides to achieve high quality results required.

5-Year, Single-Source Warranty

Selection of a warranty and warranty period was paramount to achieve the best quality and a long lasting coating. Either a single-source warranty with the general contractor or a joint warranty with the general contractor, paint suppliers, and painting subcontractors could have been selected. A single-source warranty with the general contractor was selected. Responsibilities can become diluted when joint warranties are specified and painting failures occur. General Contractors blame suppliers and suppliers claim that their product was not applied according to the manufacturers' guidelines. Battles between the General Contractor and coating supplier can become the problem of the owner; in the end the warranty work may still be performed, but not without a lot of negotiations with different parties and wasted time and resources.

By having a single-source warranty, PWGSC had no contractual obligations with anyone but the general contractor; the general contractor was held solely responsible to PWGSC for the total work. Therefore, for example, if the coating material fails and the supplier does not honour the warranty, the contractor is still fully responsible to the owner for all repairs and the owner does not have to waste time dealing with suppliers.

Warranty Period

Owners' investments in coating systems have not always been adequately protected with standard one- or two-year warranty periods for projects of this type. Since, after five years most, if not all, defects in coating material or application will have been identified, Wardrop agreed with PWGSC that a five-year warranty was desirable for this project. This project, along with projects like the abrasive blasting and painting of Edmonton's downtown "High-Level Bridge," are setting a precedence for extended warranties on bridge painting contracts.

Why was a Warranty Period of this Length Chosen?

As with any project of this nature a certain level of warranty work was expected. Three categories of warranty work were anticipated, which can be identified by the required level of repair. They are:

- **Minor failure** – e.g., A painting crew required on-site for a few days (approximately <$50,000).

- **Localized failure** – e.g., All truss A connections fail. Here a painting crew will be required on site for a few weeks (approximately $50,000 to $300,000).
- **General failure** – e.g., Complete spans require repainting. Here a painting contractor will be required on-site for months (approximately $300,000+).

Generally speaking, the more costly the required warranty repair, the more difficult it is to get the contractor back on-site to perform the required warranty repair work. It would be relatively easy to get a contractor back on-site to perform touch-up repairs since the contractor can repair the work at relatively little cost. On the other hand, general failure of the coating system will probably lead to legal action before the contractor will return to the site to perform the required repair. In both cases, repair will be performed and the owner is reasonably protected. However, based on previous experience, the most likely scenario is "localized failure" of the coating system which will require repair in the order of $50,000 to $300,000. It is very difficult to get the contractor back on-site to perform this required repair and the value of repair probably does not warrant costly legal action on behalf of the owner. Many times in the past the owner has been left with the cost of repair and the contractor has simply "walked away."

To protect PWGSC from a contractor who may be delinquent in performing required warranty repair for "localized failure," and to ensure added quality and care during construction, it was decided that the contractor would warranty the coating and its appearance against all defects in material and workmanship for a period of five years. The warranty included a $300,000 returnable incentive that was retained by PWGSC. The contractor was required to engage an independent inspection agency to provide annual inspections, complete with annual reporting showing required repair at Years 3, 4, and 5. All identified painting failures had to be repaired prior to payment. Table 2 describes the warranty and schedule of holdback release.

Failures of the coating system included but were not limited to:

- Any debonding or failure of adhesion of the coating either to the structural steel or inter-coat adhesion.
- The appearance of any rust stains on the structure due to loss of coating or due to leaking from joints between structural members.
- Failure of the coating to resist chipping due to traffic-thrown sand or road chips

Warranty Works

Wardrop Engineering inspected the structure in 2000 and 2001 (Years 1 and 2 of the warranty period) to monitor the condition of the coating. Inspections during these two years revealed that there was approximately one failure for every 65 ft^2 of structural steel and that the typical failure size was smaller than a quarter. It confirmed that overall the condition of the coating was in excellent shape and was performing very well. Coating failures were isolated to the backs of rivets and edges of flanges (Photo 2). In addition, the caulking of the pact rust joints was also performing extremely well (Photo 3).

Formal warranty repair works occurred in 2002 and 2003 and will be completed in the early summer of 2004. Each year the contractor mobilised a small crew of painters and a NACE certified inspector to perform the repair work and inspection. The repair areas were identified by the NACE inspector and by Wardrop to the painters. The painters then worked ahead of the inspectors making repairs to all failures. Once the painter was satisfied that all areas had been completed they were inspected by the contractor's NACE quality control inspector. Any areas requiring touch-up were identified and repaired. Finally, a quality assurance inspection was performed as the final litmus test for the work. Again, any areas requiring repair were identified and repairs were made. In addition, the contractor's inspector monitored all aspects associated with the work including the ambient conditions, mixing of the paint and application.

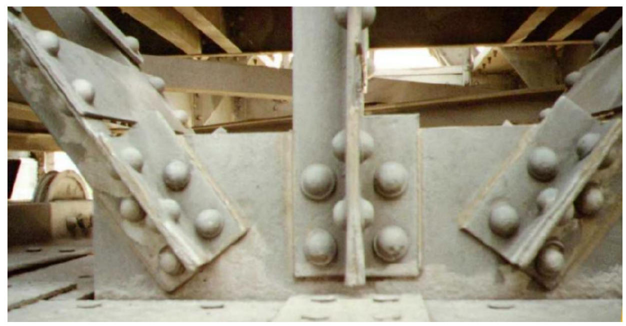

Photo 3. Typical Condition of Caulking of Pact Rust Joints

Photo 2. Typical Condition of Coating

All failures that required repair were minor in nature and would be defined as localised failures. They typically included the backs of rivets, and the edges of flanges. Overall, less than 0.1% of the structural steel required repair. These areas were difficult to coat areas and locations where the dry film thickness of the coating could not be measured. Areas of galvanizing that were partially damaged during the abrasive blasting were also repaired. Although the size of failures was minimal, it still took the contractor a signifigant amount of time to inspect the structure and walk/climb over the 380,000 ft^2 plus of structural steel.

Table 2 below, summarises the work during the warranty period:

Warranty Year	Calendar Year	Work	Payment	Person Days Spent on Repairs
1	1999-2000	Warranty Inspection	N/A	N/A
2	2000-2001	Warranty Inspection	N/A	N/A
3	2001-2002	Warranty Repairs and Inspection	$100,000	44

4	2002-2003	Warranty Repairs and Inspection	$100,000	15
5	2003-2004	Warranty Repairs and Inspection	$100,000 plus interest	20 (Estimated)

6.0 Coating Performance and Corrosion Study

The overall performance of the coating system has been excellent as evident by the minimal amount of repair works required during the warranty period. During this period 32 test locations measuring 50mm x 50mm were set up to monitor the rate of corrosion of the metallizing coating. In addition, five locations were set up to photographically monitor the condition of the caulking.

Results from four years of monitoring the rate of corrosion indicate that there is no measurable corrosion loss. The measured corrosion loss falls within the accuracy of the dry film thickness gauge and the large amount of variability which is inherent of the metallizing. Dry film thickness were measured using a Delfasko Positech 6000 F1 gauge.

At each measurement location, three measurements were taken across the top, middle and bottom. The average of these nine measurements was recorded. The minimum applied dry film thickness was 10 mils, however, much greater thicknesses were found in most locations. Typical variability of the coating dry film thickness was 1 to 3 mils when taking measurements within only one mm of the last measurement. The reason for this is that the gauge measures the coating thickness from the steel surface to the top of the metallizing. Since both the steel and metallizing surfaces are "toothed", there is a high degree of variability. Remember that the blast profile was 3-4 mils.

The performance of the caulking has been exceptional. The areas monitored photographically show no signs that the caulking is drying out and losing adhesion to the metallized surface. This is also the case for the remaining caulked joints throughout the structure.

Reasons for the success of the caulking are likely attributable to the excellent adhesion to the metallizing surface, the extremely dry ambient conditions during the construction, and the extensive removal of the pact rust during construction. At all locations, Mulco SupraExpert caulk was applied to the joints.

7.0 Conclusion

The zinc metallizing coating system applied to the St. Andrews Lock and Dam will ensure that the structural steel is protected from corrosion for over 50 years with minimal maintenance requirements. Although the initial cost of this coating system was greater than the best 3 coat paint systems, the long-term cost of the coating system is more economical in the long run. This coating system challenges bridge owners to evaluate the coating system they are applying to a bridge over the same service life of the bridge itself.