A Practical Field Method for Chloride Remediation

Here’s a method for reducing chloride contamination when water cleaning methods are not feasible

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Editor’s Note: This article is based on a paper given at SSPC 98, November 1998, Orlando, FL, and published in the conference proceedings, Increasing the Value of Coatings, SSPC 98-11.

The New York State Thruway Authority (Thruway) is an independent public benefit corporation established in 1950 by the state legislature for the purpose of building, operating, and maintaining the highway system. The Thruway comprises approximately 40% of New York State’s interstate highway system. Revenues to support the infrastructure are drawn from tolls, bonds, and a small portion of federal aid. The Thruway’s 496-mile (800-kilometer) mainline, including over 700 steel bridges, connects New York City and Buffalo, the state’s two largest cities. The Niagara section of the Thruway provides access off the mainline to Buffalo, NY, and further north to Niagara Falls, NY.

The 4,025-foot (1,227-meter), 16-span, twin North Grand Island Bridges are located along the Niagara section of the highway. The spans over land are built-up plate girders and comprise less than 10% of the structures. The spans over water are arch-deck truss designs with five suspended spans and six anchor spans per bridge. Each suspended span has four pin and

The Project

The Governor Thomas E. Dewey Thruway, running through the heart of New York, is one of the world’s longest toll highways.

thorough planning, the adaptation of new technology to old practices, and the skillful use of a partnering approach to construction management were brought together on a challenging long-span bridge coating project. This article presents distinctly new findings obtained from laboratory tests conducted on steel sections removed from the bridge, field tests, and actual application for the effective removal/reduction of chlorides before applying a protective coating system.
hanger connections. These truss structures use box chords, lacing boxes, extensive back-to-back angles for cross bracing, and other engineering design details that present challenges for cleaning and painting operations. The bridges have approximately 1.5 million sq ft (140,000 sq m) of steel to be cleaned and painted.

A coating evaluation determined that the existing paint system was in such bad condition that it was not viable for effective overcoating, especially with the bridge’s complex design geometry. It was estimated that nearly 40% of the coating system had completely failed; the exposed bridge steel was heavily corroded and contained extensive pitting corrosion. The exposed steel had significant levels of chloride contamination, and the remaining paint was lead-based.

Removal of the lead-based paint requires full containment meeting standards set by the Occupational Safety and Health Administration (OSHA), New York State Department of Environmental Conservation (NYSDEC), and other agencies. The full Class A Containment and associated work practices (as mandated by law) represent a large added cost but help ensure that the Thruway’s health and safety concerns as well as its liability are controlled. The regulations and mandates associated with lead hazards have been in place for a number of years. Additional containment issues include a 40-foot (12-meter) minimal vertical clearance and 270-foot (82-meter) normal channel width required by the United States Coast Guard.

The northbound structure was originally constructed in the mid-1930s and the southbound during the early 1960s. Both structures are similar in form and construction except that the newer structure has some shop-riveted connections and field-bolted connections. Other differences include various on- and off-ramp configurations to connecting roadways. Combined traffic on the two North Grand Island Bridges totals more than 48,000 vehicles per day. These structures are located at the northern terminus of the Niagara section, and they span the Niagara River approximately 4 miles (6 km) south of Niagara Falls. Water passing under the bridges reaches Niagara Falls in just 40 minutes and the Fall’s mist can be seen from the bridges. Thus, high humidity and wide-ranging humidity changes are unavoidable on the project.

Problem Statement

It is well known and documented that chlorides or hydrophilic contaminants on substrates reduce the expected service life...
of coatings. Mechanical methods for reduction or removal of these contaminants improve the situation but fall short of complete mitigation of the reduced service life of protective coating systems. Typical premature coating failures are underfilm corrosion and osmotic blistering. In many cases, the corrosion cell or corrosion activity initiates immediately after abrasive blast cleaning operations are completed. Many of the contaminants found on rusted bridge steel originate from extensive snow and ice removal operations, industrial pollution, acid rain, and salt water mist. Contaminant concentrations increase during the evaporation process and may decrease with rain or bridge washing and cleaning. Additionally, substrates may be contaminated before fabrication and erection through the same mechanisms previously mentioned. Surface preparation with contaminated abrasives can also contaminate clean steel.

Protective coating systems for steel bridge structures subjected to the above-described environment need to provide good protection against chloride corrosion. The coating needs to be forgiving of residual chloride that is difficult to remove while affording sufficient long-term protection.

A system consisting of a zinc-rich primer, epoxy mid-coat, and urethane topcoat can perform well and is considered safe when applied on a substrate containing less than 50 micrograms of chloride contamination per sq cm. "Perform well" refers to the ability of the protective coating system to provide a reasonable service life. The goal of this study is to discuss a practical field method to reduce chloride levels below 50 micrograms per sq cm.

Commonly used and relatively inexpensive methods for chloride measurement used in this study include SSPC’s Swabbing Method (found in SSPC-TU 4, Field Methods for Retrieval and Analysis of Soluble Salts on Substrates, SSPC Publication No. 98-06) and the laboratory boiling method. A major shortcoming is that quantitative results developed using these procedures measure the chloride and other contaminants over a specific surface area but not at a specific point of corrosion. For example, the swab test method is generally performed on a test area of 100 sq cm (16 sq in.). Collection of and reliance on these mean values may camouflage higher spot results. These spots or areas may provide locations for accelerated coating failure. Rust-back evaluation, a qualitative method, can determine more precise locations where chlorides may be found on substrates or in corrosion pits.

**Measurement Methods**

This study uses SSPC’s swab test method. This method can extract approximately 25% of the hydrophilic contaminants and chlorides. On a known surface area and with a known amount of de-ionized water, the technician swabs the steel surface with water to solubilize the chloride contaminants. The technician will then place the solution of water and contaminant into a beaker. The chloride level is determined in
parts per million using an ion-specific titration strip and then converted to micrograms per sq cm. For reporting and analysis purposes, one must assume that the chloride contaminants are evenly distributed across the entire surface area tested.

To confirm the swab test results, a laboratory method known as the boiling method involves taking a contaminated surface of a known area and boiling it in deionized water. This water solution is diluted to a known volume, and the chloride content is measured using an ion-specific electrode. Ninety to ninety-five percent of chlorides can be extracted using this method. Again, the results of this test procedure are reported and analyzed with the assumption that chloride contaminants are evenly distributed. When applicable, this laboratory test is used in this study to verify swab test findings.

Abrasive can cause contamination of substrates during the abrasive blast cleaning operation. It is commonly believed that high enough contaminant levels in or on the abrasive can be transferred to the steel surface. There are various reasons for abrasives to be contaminated, from rinsing abrasive with salt water to a buildup of contaminants in recyclable abrasives when blast cleaning contaminated substrates. A practical evaluation technique is ASTM D4949, Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives. Acceptable levels for contaminants have been developed. The recommended maximum is 1,000 microsiemens.

Chloride Corrosion

Severe pitting on steel substrates often results from chloride corrosion. Typically, these corrosion areas form as a result of a protective coating system failure, with holidays and gaps in existing coating systems, or beneath mill scale. Pitting corrosion continues with destructive corrosion forces targeting the bottom of the pit. In this phase, anions (chlorides) migrate from the surface toward the bottom of the pit. Typically, the pit grows larger beneath the surface and tends to form a pocket beneath a small opening, which is associated with measurement and mitigation of chloride contamination.

Rust-back, or turning, associated with chlorides is generally described as the formation of dark gray blotches of iron oxides ($\text{Fe}_3\text{O}_4$ and $\text{Fe}_2\text{O}_3$) on the surface of the blast-cleaned steel. The formation of these blotches is attributed to chloride anion migration to the surface of the blast-cleaned steel. Higher humidity greatly facilitates this process. Typically, nocturnal humidity and the passage of time allow for the steel to turn, although steel has been known to turn within hours.

In the past, paint would be applied quickly to prevent the steel from turning. Additionally, humidity reduction equipment could be employed to prevent steel from turning. The end result of these field practices is to camouflage the existing chlorides, which are discovered again later when premature coating failure occurs.

Laboratory Study

The Thruway contracted with a coatings consulting firm to investigate and provide a field-suitable and cost-effective method to reduce chlorides to acceptable levels so that a three-coat zinc-rich epoxy urethane coating system could be used for these bridges. Several gusset plates that were being replaced during a 1995 repair were used for investigation. These gusset plates were severely corroded and exhibited a large degree of section loss. Chloride levels reached 2,120 parts per million (0.212%) in the loosely adherent corrosion product lo-
cated on the gusset plate surface. This material was easily removed by hand or power tool cleaning. Initial chloride measurements ranged from 105 to 219 micrograms per sq cm on these panels prior to abrasive blast cleaning.

Ideally, some sort of waterjetting method would be used for the most effective removal of chloride contamination, but the use of water methods on this project was cost-prohibitive for the owner. Thus, in an effort to control costs, it was decided that a dry blast method of removal would be a first choice. The laboratory study was to determine if any dry abrasive blast cleaning methods could meet the established requirements. Abrasive blast cleaning was the preferred solution because the bridge contained lead-based paint applied over mill scale. The lead-based paint and mill scale needed to be removed and a profile provided for the new coating system. The owner chose recyclable steel grit rather than disposable abrasives.

The removal of lead-based paint and mill scale generally requires larger abrasive particle sizes that can provide a great deal of mass and energy when blast cleaning. Typical abrasive sizes that are used for such operations are G-25, G-40, and even G-25. Table 1 presents particle size distributions for steel grit abrasives discussed in this study.8

Since these larger particles are coarse, it was thought that they would not provide a mechanical scouring action that may be necessary to provide the desired chloride reduction. G-80 abrasive is finer and provides a greater number of impacts with smaller particles. It may, therefore, be able to provide the desired scouring action.

The laboratory study indicated that the chloride levels could be reduced to less than 50 micrograms per sq cm (actual

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### Table 1

**Particle Size Distribution of Typical Abrasive Grades**

<table>
<thead>
<tr>
<th>NIST Screen No.</th>
<th>Standard mm²</th>
<th>Screen Size (in.²)</th>
<th>G-25</th>
<th>G-40</th>
<th>G-50</th>
<th>G-80</th>
</tr>
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<tbody>
<tr>
<td>16</td>
<td>1.18</td>
<td>(0.0469)</td>
<td>All Pass</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>1.00</td>
<td>(0.0394)</td>
<td>—</td>
<td>All Pass</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>20</td>
<td>0.850</td>
<td>(0.0331)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>25</td>
<td>0.710</td>
<td>(0.0278)</td>
<td>70%</td>
<td>—</td>
<td>All Pass</td>
<td>—</td>
</tr>
<tr>
<td>30</td>
<td>0.600</td>
<td>(0.0234)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>35</td>
<td>0.500</td>
<td>(0.0197)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>40</td>
<td>0.425</td>
<td>(0.0165)</td>
<td>80%</td>
<td>70%</td>
<td>—</td>
<td>All Pass</td>
</tr>
<tr>
<td>45</td>
<td>0.355</td>
<td>(0.0139)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>50</td>
<td>0.300</td>
<td>(0.0117)</td>
<td>—</td>
<td>80%</td>
<td>65%</td>
<td>—</td>
</tr>
<tr>
<td>80</td>
<td>0.180</td>
<td>(0.007)</td>
<td>—</td>
<td>—</td>
<td>75%</td>
<td>65%</td>
</tr>
<tr>
<td>120</td>
<td>0.125</td>
<td>(0.0049)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>75%</td>
</tr>
<tr>
<td>200</td>
<td>0.075</td>
<td>(0.0029)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>325</td>
<td>0.045</td>
<td>(0.0017)</td>
<td>—</td>
<td>—</td>
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</tr>
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</table>

**Suggested Removal Sizes for Cleaning Structural Steel (in.²)**

<table>
<thead>
<tr>
<th></th>
<th>0.0062</th>
<th>0.0059</th>
<th>0.0049</th>
<th>0.0029</th>
</tr>
</thead>
</table>

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rather than measured amount) using various sizes of abrasives and abrasive combinations when cleaned to an SSPC-SP 5, White Metal. Also, the results indicated slightly lower levels could be attained using the G-80 abrasive. A G-25/G-80 abrasive blended at a ratio of 1:1 also provided similar lower chloride levels. Of interest was the fact that the G-25/G-80 blend had particles coarse enough to provide the brute force needed for abrasive blast cleaning the coating and corrosion products on the bridges. Abrasive blast cleaning nozzle pressure for the laboratory study was approximately 100 psi (700 kPa).

The G-25 blast-cleaned samples exhibited quicker and greater rust-back. Chloride blotches were more prevalent, darker, and larger on the panels cleaned with G-25 than those cleaned with the G-25/G-80 blend. Chloride measurements from the swab test of about 5 micrograms per sq cm were attained on the sample panels cleaned in accordance with SSPC-SP 5. Given that the swab test extracts approximately 25% of water-soluble contaminants, the measurements obtained indicate that the actual contaminant level was approximately 20 micrograms per sq cm. These results were at or near the lower limit of detection. To verify actual chloride content, the boiling extraction method was used on several samples.

Results indicated that the chloride concentrations were 10.2 micrograms per sq cm for sample 1A, the panel cleaned with G-25; and 2.1 micrograms per sq cm for sample 1E, the panel cleaned with the G-25/G-80 mix (Figs. 1 and 2).

Field Test
In early August 1995, a field verification study was performed with Thruway personnel and equipment. Initial chloride measurements before abrasive blast cleaning ranged from 75 to 200 micrograms per sq cm. Only two steel grit abrasive sizes were used, G-25 and a G-25/G-80 blend. Two sample areas were chosen.

The area cleaned with the G-25 grit reduced chlorides to 14, 5.8, and 10 micrograms per sq cm (in three tests). The G-25/G-80 mix had resultant chloride levels of 6, 7, and 2.6 micrograms per sq cm in each test performed. Slightly better chloride reduction was achieved with the addition of the smaller abrasive particles. Maximum air pressure achieved during blasting was about 80 psi (500 kPa) at the nozzle, a pressure lower than normally found on production jobs, where nozzle pressure can range from 100 to 140 psi (700 kPa to 900 kPa).

The following morning, the visible chloride blotches were more prevalent, darker, and larger on the G-25 sample area than on the G-25/G-80 sample area. The area blast cleaned with the G-25/G-80 showed little, if any, rust-back.

It was determined that abrasive blast cleaning to SSPC-SP 5 should be required in all severely corroded and pitted areas. Additionally, the abrasive should be monitored to insure that water-soluble contaminants would not build up to a level that might contaminate clean steel substrates. Figure 3 shows a blast-cleaned area, and Fig. 4 shows swab testing.

Specification Enhancements
The specification, which resulted from the laboratory and field tests, required, among other things, that chloride reading with swab tests would be conducted each day after abrasive blast cleaning. The maximum level allowed when using the swab test method would be 15 micrograms per sq cm. Because the swab test only extracts about 25% of the chlorides, this threshold level would ensure that actual chloride
contamination would be below approximately 60 micrograms per sq cm. Additionally, SSPC-SP 5, White Metal, would be required in all heavily corroded and pitted areas as directed by the engineer; other areas would require an SSPC-SP 10, Near White Metal. Reference to the study and success of using a blended G-25/G-80 abrasive mix was provided, but the blend was not specified. Other methods such as water blasting and pressure washing were allowed. ASTM D 4940, Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives, would be performed regularly on the abrasive mix to prevent re-contamination of the steel.

**Practical Use of Technology**

On the current project, dry abrasive blast cleaning with a mixed abrasive is being used successfully to meet the requirement of chloride levels below 15 micrograms per sq cm. The working mix is created by allowing smaller particles to remain in the abrasive blend and then regularly adding only small amounts of new abrasive. Typically, the working mix has small amounts of G-25 abrasive added to improve cutting characteristics. A G-40/G-50 mix is added to increase the volume of abrasive. Smaller particles that provide the scouring effect to remove or reduce chloride contamination are created through the breakdown of the working mix. Through the use of a working mix with a broader range of particle sizes than is commonly used, the objective of reducing chloride contaminants while maintaining productivity can be accomplished.

However, methods of selecting and controlling particle size distribution for the working mix are not readily available and need to be learned on the job. Contractor personnel have worked diligently to achieve the results attained so far on the project. Typical chloride measurements average 2 to 8 micrograms per sq cm, below the threshold limits. Actual abrasive particle distributions, as measured per ASTM C 136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, can vary significantly. By adding only small amounts of new abrasive, the practitioner can keep the mix from varying in size distribution too quickly.

The chart in Fig. 5 shows a random abrasive sieve test result from the project. The vertical axis represents the percentage of weight retained on each screen, with each screen representing a particle size. The horizontal axis represents screen sizes set by the National Institute of Standards and Technology. Average particle size by weight is calculated to be 0.8350 millimeters for this sample. The chart in Fig. 6 shows a more typical abrasive sieve test result. Average particle size by weight for this sample is 0.4732 millimeters. Table 1 gives the screen opening sizes.

Qualitative rust-back analysis may provide a better solution to identifying specific chloride contamination areas. Figure 7 shows rust-back that developed immediately after abrasive blast cleaning. The condition of the steel was nearly the same the following morning. Figure 8 shows blast area 19, and Fig. 9 shows blast area 19 the following morning. In both cases, the blast area is very clean and shows little or no sign of rust-back.

**Recommendations**

Further experimentation needs to be conducted to explore more practical chloride remediation and measurement techniques. In the planning stages, owners should know which structures need chloride remediation and then expect to have the chloride levels reduced to appropriate levels.
Verification is an important step, and practical methods such as the swab test should be used for quantitative analysis; otherwise, premature coating failure and shortened coating life may result. In conjunction with the swab test, small rust-back areas should
be inspected daily during blast cleaning activities. Daily inspection will verify qualitatively the effectiveness of the blast cleaning operation and the overall reduction and elimination of rust-back. In pitted or highly corroded areas, blast cleaning in accordance with an SSPC-SP 5 is needed to minimize the chance of confusing staining with rust-back.

Further study in blast cleaning and abrasive replenishing practices may improve the operating mix. Better control over abrasive sizing equipment and attention to abrasive particle sizes will be beneficial and may well prove to be cost effective for the contractor—and ultimately the owner. More automated equipment for maintaining the abrasive blend may also be appropriate. Most important, owners and contractors need to study and determine the best abrasive working mix for a particular project. Abrasive operating mixes should be optimized for productivity and chloride pit scouring as required.

Disclaimer
The views and opinions stated in this paper do not necessarily reflect the opinion of the New York State Thruway Authority.

References