

**NCHRP Project 10-97
Final Report**

**Detection and Remediation of Soluble Salt Contamination
Prior to Coating Steel Highway Structures**

Volume 2 – Technical Report



Submitted by:

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October 31, 2018**

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Executive Summary

NCHRP Project 10-97, *Detection and Remediation of Soluble Salt Contamination Prior to Coating Steel Highway Structures*, studied detection and remediation methods to guard against the tendency of retained soluble salts to reduce the life of protective coatings. The project included extensive testing on laboratory prepared test panels and field work on five structures.

There is substantial data demonstrating that soluble salts can affect coating performance, though there is disagreement over what level of soluble salt contamination is acceptable. Soluble salts are not visible to the naked eye at the levels of concern unless they cause steel to rust. Fortunately, the industry has developed several methods to detect soluble salts. These methods extract the soluble salts from a test area into water. The conductivity or specific ion content of the water is measured to determine the extent of soluble salt contamination. Unfortunately, the methods have several limitations. For example, they cannot extract salts from crevices formed between two pieces of steel, they have varying degrees of effectiveness on pitted steel, and they can be challenging to use in a bridge construction setting. Furthermore, required soluble salt levels are near the detection limits of these methods. Since soluble salts vary in composition and distribution on a structure, these factors make it difficult to obtain accurate, repeatable measurements when characterizing surface soluble salt contamination.

To evaluate various issues surrounding soluble salt detection, nearly 2,500 soluble salt measurements were recorded in field and laboratory evaluations with eight detection methods. The most important result of the testing is that there is considerable variability in the soluble salt detected on representative bridge surfaces. Furthermore, salts seem to be less extractable from a steel surface over time. While there is no clear consensus regarding the parameter of interest, the testing demonstrates relationships among the three primary indicators of soluble salt contamination (chloride ion concentration, conductivity, and “total salt” derived from a conductivity measurement). Each of the detection methods evaluated has strengths and weaknesses. The data in this report will help users understand when and why different methods might provide different results.

For the purposes of this study, soluble salts include chlorides, sulfates, and nitrates or other soluble ionic species. Soluble salts are deposited onto coated and bare steel surfaces. Soluble salts are relatively easy to wash off smooth surfaces. Soluble salts may find their way into a porous coating or corrosion scale. It is difficult to remove soluble salts from these materials using water methods at any reasonable production rate. Mechanical methods are required to remove salt contaminated coatings or rust scale. Washing may be required after the mechanical removal to further reduce the soluble salt level. In the bridge industry, abrasive blasting is generally adequate to remove soluble salts below required limits. Power tool cleaning methods used during maintenance painting are less likely to remove soluble salts to the limits achieved by abrasive blasting.

To evaluate various issues surrounding salt remediation, over 20 combinations of commercially used soluble salt remediation techniques were evaluated in a laboratory setting. The reduction in soluble salts was measured for each technique. In addition, over 250 rusted-then-remediated test panels were coated and exposed in natural and accelerated tests. The data shows that a combination of mechanical and water methods is the most effective way to reduce salts to the requirements that are commonly used in bridge coating specifications. The most robust strategy for remediating soluble salts from heavily rusted steel is to wash the surface, use mechanical methods to clean the surface to bare metal and then wash the surface again prior to painting. On the other hand, washing alone is sufficient to remove salts

from painted surfaces. Panel testing confirmed that industry standard levels for soluble salt contamination provide a sufficient margin of error to account for measurement and sampling variability which was observed in this project.

The first volume of this report contains a guide and suitable training materials to inform steel structure owners of processes to minimize the impacts of soluble salts on bridge coating life, and thus bridge structural deterioration. The report also contains an interactive Excel spreadsheet with all the soluble salt detection data collected during this study.

Background

Soluble Salt Effects on Coating Performance

Literature in the late 1980's and early 1990's all began to point to underfilm, soluble salts as a major contributor to coating deterioration. Salts just above the Lower Detection Limit (LDL) of commercially available detection technologies were shown to accelerate the deterioration and rust-through of coatings over time. In many studies, it was shown that corrosion also occurred under coatings applied over salts in non-immersion environments. Work by Morcillo¹ identified corrosion rates over 4 mils per year (mpy) when as little as 2 $\mu\text{g}/\text{cm}^2$ of chloride ion was present under the coating on steel in a high humidity atmosphere. Soltz² observed "considerable underfilm corrosion" when surface chlorides under an epoxy coating were above 1 $\mu\text{g}/\text{cm}^2$.

Since the deleterious effects of salts have been recognized and practical field measurement techniques have been developed, coating specifiers have recognized the benefits of requiring cleaned surfaces meeting certain soluble salt levels, especially in marine and immersion service. A recent report identified requirements ranging from 1 to 40 $\mu\text{g Cl}^-/\text{cm}^2$ depending on the coating type and service environment.³ Lower limits were applicable to immersion service while higher allowable limits were applicable to non-marine atmospheric exposure.

Chlorides are among the most common soluble ionic species that contribute to coating deterioration. It is often not practical, or necessary, to measure all forms of soluble salts on a surface. Industry has developed conductivity-based techniques to detect total soluble ionic species present on the surface. These methods do not allow identification of individual species.

Several studies have investigated the impact of soluble salt contamination on coating performance in accelerated and natural exposure testing for highway, industrial, and marine structures. A review of these studies suggests that while soluble salts certainly can affect coating performance, the relationship between soluble salts and coating performance is somewhat complicated and depends on the coating type, service environment, and critical failure mode.

The complexity of this relationship is illustrated in a Federal Highway Administration report.⁴ Coating performance data suggested that the level of tolerable soluble salt contamination is a function of coating type and service environment. As part of the study, five coating systems were applied to steel contaminated at six different levels (ranging from 1.6 to 63.3 $\mu\text{g Cl}^-/\text{cm}^2$) and evaluated in four accelerated and exposure tests. All coatings over the various contamination levels were rated very good or excellent after 12 months of conventional and accelerated outdoor exposure. In a pressurized immersion test, only the solvent based inorganic zinc system showed good tolerance for all levels of contamination. In the cyclic exposure test, performance varied with soluble salt levels and coating type.

¹ M. Morcillo, Soluble Salts: their effect on premature degradation of anticorrosive paints, *Progress in Organic Coatings* 36 (1999)

² Soltz, Gerald, The Effect of Substrate Contaminants on the Life of Epoxy Coatings Submerged in Sea Water, MARAD contract number MA-81-SAC10011, March, 1991.

³ Frenzel, Study to Determine the Level of Salt Mitigation as related to the Accuracy of the Measurement and Cost Benefits, National Shipbuilding Research Program, February 2011.

⁴ B. Appleman, S. Boocock, R. Weaver, and G. Soltz, Effect of Surface Contaminants on Coating Life, FHWA Publication No. FHWA-RD-91-011, 242 pp., November 1991

The extent to which locations on a bridge experience “immersion” conditions and the coating material selected are important factors when specifying a maximum allowable soluble salt level. In the FHWA testing, coating systems with zinc rich primers in atmospheric exposure tolerated the highest level of soluble salt contamination.

The FHWA report observations that zinc based coatings tolerate chloride contamination better than non-zinc systems is corroborated by accelerated testing performed by the Kentucky Transportation Center.⁵ The laboratory testing included six coatings sets applied over six levels of chloride contamination ranging from zero to 98 $\mu\text{g Cl-/cm}^2$. The coated test panels were tested for 5000 hours in accordance with ASTM D5894-05, *Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal*. Other than the difference between the three zinc-based and three non-zinc coatings, the report did not show any consistent relationship between rust-through and chloride concentration in the range of 0 to 98 $\mu\text{g Cl-/cm}^2$.

Studies performed for the Naval Sea Systems Command⁶ show the propensity for blistering in a condensing humidity environment is increased drastically by chloride contamination values at or above 5 $\mu\text{g Cl-/cm}^2$. The study included test panels of a military epoxy coating system exposed in an ISO 6270 condensing humidity test (Figure 1). Failing was defined as blistering exceeding ASTM D714 “8M” or rusting exceeding ASTM D610 “8.” Under this exposure environment, a successively shorter time-to-failure was observed for each increasing level of salt contamination.

In this test environment, coating applied over surfaces with chlorides below the detection limit experiences a failure rate nearly 7 times less than that applied over the surfaces with 5 $\mu\text{g/cm}^2$ salt: increasing the salt level to 10 or 25 $\mu\text{g/cm}^2$ increases failure rate about 40% over the lower salt level.

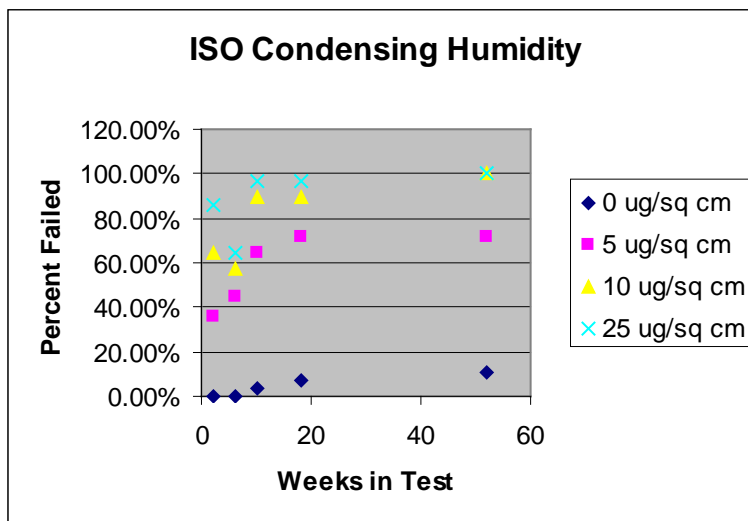


Figure 1. Military Epoxy over Salt in Condensing Humidity

⁵ B. Meade, S. Palle, T. Hopwood, R. Younce, “Effects of Chloride Contamination on Coatings Performance,” Kentucky Transportation Center, Report No. KTC-10-10/SPR 366-08-1F, July 2010

⁶ Novel Coating Analysis Practices, Final report for Naval Sea Systems Command, December, 1995.

Salting Methods

Application of salts to the surface of a roadway during winter weather is common highway agency practice. Salt serves as a freezing-point depressant that reduces freezing of snow to the roadway, allowing for more effective snow removal and safer traffic. Application of freezing-point depressants can happen in several different variations.

Anti-icing

Anti-icing is the process of preventing the formation of bonded snow and ice to pavement surfaces through the strategic application of freezing-point depressant prior to initial precipitation fall⁷. Anti-icing is a weather and time sensitive process, therefore careful monitoring of environmental conditions is required for successful use. If done correctly, anti-icing can substantially decrease the quantity of material used than its deicing counterpart. Anti-icing solutions can be formulated in the form of sodium chloride, calcium chloride or magnesium chloride, depending on the requirements of the agency. Anti-icing procedures use liquid solutions, referred to as brine, that are applied to roadways using trucks outfitted with tanks and spraying equipment.

Deicing

Deicing is the process of breaking the bond between snow and ice and the pavement surface through the application of a freezing-point depressant. This is often done in the form of deicing rock salt, sometimes with addition of a pre-wetting agent. The rock salt is typically formulated in the form of sodium chloride, calcium chloride or magnesium chloride, depending on the requirements of the agency.

Pre-wetting

Pre-wetting is the process by which a liquid solution is applied to a solid material of salt or sand prior to being applied to the roadway. This process is completed by the throwing truck in the form of spray nozzles over the solid media. Typically, pre-wetting is used during deicing and sanding procedures. The pre-wetting agent can include brine (salt) solution of various chemical compositions or various other freezing-point depressants including agricultural additives like beet and corn extracts and acetates. Pre-wetting of solid material helps to decrease the bounce and scatter. The decreased scatter allows for a more controlled application and the use of less total material per lane-mile.

Salting Materials

Anti-icing and deicing materials are selected based on the local weather, cost, environmental impacts, and other variables. There are three common forms of deicing salt – sodium chloride (NaCl), calcium chloride (CaCl₂), and magnesium chloride (MgCl₂). Each type will be most effective in different range of conditions. For example, Figure 2 shows the phase diagram of sodium chloride and calcium chloride as a function of the solution concentration. Calcium chloride allows for functional use to temperatures as low as -60°F as opposed to sodium chloride whose functional limit is approximately -5°F.⁸ Magnesium chloride, like calcium chloride, can substantially lower the freezing point of water when mixed in the right concentration. The use of these alternative chlorides is particularly important in regions of the

⁷ Fay, Shi, and Huang; NCHRP Synthesis 449, “Strategies to Mitigate the Impacts of Chloride Roadway Deicers on the Natural Environment,” February 2013, 16.

⁸ AASHTO M143-14, “Standard Specification for Sodium Chloride.”

country where winter weather temperature frequently approach, or drop below, 0°F. All three salts can be used in the form of rock salt or brine solutions for anti-icing.

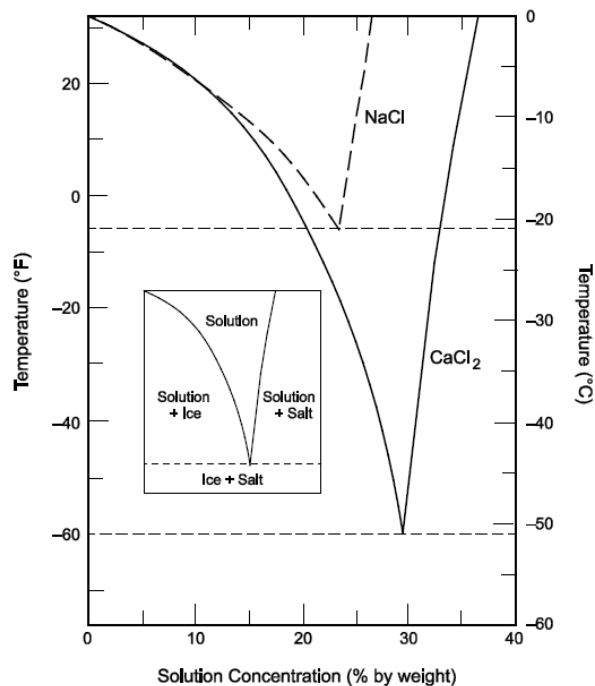


Figure 2. Phase Diagram of Typical Salts

Impacts of Deicers on Steel Corrosion Rate

In a DOT study of the impacts of different deicers on equipment, laboratory evaluation of different salts applied to carbon steel in a humid environment showed that magnesium chloride tended to create more significant corrosion than sodium chloride deicers.⁹ This is attributed to the lower deliquescence RH for magnesium chloride vs. NaCl (35% vs. 76%). Maximum corrosion appeared during the onset of humidity exposure and could exceed 60 mpy for the MgCl₂ material.

An NCHRP study of a variety of testing protocols concerning material corrosion exposed to deicing salts summarized that all chloride-based snow and ice control materials (NaCl, CaCl₂, and MgCl₂) all showed the potential for similar, high corrosion rates on bare steel.¹⁰ The specific rankings and corrosion rates were highly dependent on the test method. In some test methods, materials that tend to stay wet longer such as magnesium chloride exhibit a higher corrosion rate. In a completely aqueous phase, sodium chloride may have a slightly higher corrosion rate. Acetate-based materials showed substantially lower corrosion rates for carbon steel. Acetate-based materials may be more corrosive to aluminum alloys than the chloride-based materials. Both are equally corrosive to galvanized steel.

⁹ "Assessment of Best Practices to Protect DOT Equipment from the Corrosive Effects of Chemical Deicers," X. Shi et. al., WA-RD-796.1, Washington State DoT, March 2013

¹⁰ "Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Problems," NCHRP 577, Transportation Research Board, Washington DC, 2007

Although corrosion of exposed carbon steels may be similar for all chloride-based deicers, the same may not be true for reinforcing steel in concrete.¹¹ In concrete, the cation affects the diffusion rate of the salt to the rebar. The diffusion rate of MgCl_2 is 2 to 3 times greater than NaCl and can lead to more rapid depassivation of rebar.

Based on periodic immersion of metallic coupons in alternative deicing solutions that were otherwise maintained in an enclosed 120°F, drying environment, studies found:¹²

- Sodium Chloride (NaCl) was 4 to 15 times as corrosive as calcium magnesium acetate (CMA).
- A36 steel exhibits corrosion rates of ~ 35 mils in one year of testing exposed to NaCl and ~ 10 mils exposed to CMA. For A588 steels, corrosion rates were about 65 mils in one year with NaCl and 10 mils for CMA solutions. Maximum depths of penetration could exceed 60 mils for A36 steel and 100 mils for A588 steel exposed to NaCl solutions.

Salt Detection Methods

The state of the art in soluble salt detection involves two basic steps: 1) extraction of salts from the surface into a solution and 2) analysis of the solution. Currently available technologies incorporate different approaches for each step. It can be challenging to compare results from different techniques and ensure compliance with specifications. This section of the report generically discusses the two process steps.

Soluble Salt Extraction Methods

The current state of the art for extracting soluble salts from a surface involves exposure and confinement of a salt extraction solution to specifically sized test area. Variables among methods include the solution chemistry, methodology for confining the solution to a given area on the surface, and physical processes intended to improve the extraction efficiency.

Some detection methods specify reagent water with a low conductivity (e.g., $< 5 \mu\text{S}/\text{cm}$). Other methods provide a proprietary extraction solution. The proprietary extraction solutions may have a unique chemistry (e.g., some are slightly acidic to improve extraction efficiency) or be packaged specifically to work with the device (particularly for automated methods). Whether proprietary or not, it is critical to use the extraction fluid specified for the detection method being used.

The extraction fluid must be contained in contact with a specified area to be tested. There are various ways to accomplish this objective including rigid test chambers, bonded latex patches and sleeves, manually delineated areas for swabbing methods, and adsorbent sampling materials. At least four factors are important when considering the containment mechanism – the surface area tested, the volume of fluid, the details of the extraction process (e.g., contact time and physical agitation methods employed), and susceptibility of the test solution to contamination. Following are some of the more common approaches.

¹¹ “Corrosion of Deicers to Metals in Transportation Infrastructure; Introduction and Recent Developments,” Shi et. al., Western Transportation Institute, 4W1095 (web report accessed 1-28-2016)

¹² “Corrosion Evaluation of Calcium Magnesium Acetate (CMA), Salt (NaCl), and CMA/Salt Solutions,” R. McCrum, Research Report R-1295, Michigan Transportation Commission, 1988

Adhesively bonded patch methods were the first technique to see widespread use. These methods utilize watertight, specifically engineered patches that adhere to surfaces and form test cells. Reagent water is injected into the test cells with a hypodermic needle and can be agitated by massaging the patch or cycling the liquid in and out of the syringe. ISO 8502-6 describes some patch designs and sampling procedures. After a pre-determined time, the extraction fluid is removed from the patch using the hypodermic needle and can be analyzed using several conductivity or ion-specific methods. Issues to be aware of when using patches include leakage when the adhesive does not properly seal, maintaining proper geometry when affixing the patch to the surface (i.e., not stretching the cell), and the potential for the patch material to increase the conductivity of the extraction fluid.

Latex sleeves are similar to latex patches except they are designed to be filled with a specified amount of solution and then adhered to the test surface. Once adhered, the user can physically massage the extraction fluid against the surface through the sleeve to help extract salts from the surface. After a pre-determined time, the sleeve is removed from the surface and the extract analyzed. Latex sleeves are commonly associated with a proprietary extraction solution and ion-specific detection method. Issues to be aware of when using sleeves include leakage when the adhesive does not properly seal, maintaining proper geometry when affixing the sleeve to the surface (i.e., not stretching the cell), and the potential leakage when removing the sleeve from the surface (especially on a horizontal surface). Ionic contamination of the extraction solution by a sleeve has not been reported as a concern.

Rigid cell methods are fully automatic methods that involve attaching an instrument to the surface. The user injects reagent water into the chamber and automatically agitates the fluid to help extract salts from the surface. Embedded sensors then measure the solution conductivity in the chamber. Issues to be aware of when using the rigid cell devices include ensuring that they are clean prior to testing and that they fully seal to the surface without leakage.

Some methods employ sampling pads or filter paper to extract salt from the surface. The material is wetted with a specified amount of reagent water and then held against the test surface. After a given time, the pad is removed from the surface for conductivity analysis. If the sampling pads are not evenly wetted and fully saturated, they can give erroneous results. If the paper does not fully conform to the surface being tested it may not pick up as many salts. Also, air bubbles between the saturated paper and the meter can impact the measured conductivity value.

For swabbing methods, an operator delineates a surface area and uses a wetted cotton ball to transfer the salts from the surface to the reagent water. Typically, four swabbing and rinsing procedures are specified followed by removing the water from the surface with a dry cotton ball. The extraction fluid can be analyzed using conductivity or ion-specific methods. Issues to be aware of when using a swabbing extraction technique include contamination of the water and minimizing water loss during the process.

Analysis Methods

Once removed from the surface, the extraction fluid must be analyzed to determine the level of surface contamination. The analysis step includes two components – measurement of the parameter of interest (e.g., conductivity or ion-specific determination) and the mathematical calculation required to convert the measurement into a meaningful surface concentration (e.g., $\mu\text{S}/\text{cm}$, $\mu\text{g Cl}^-/\text{cm}^2$, or $\mu\text{g salt}/\text{cm}^2$). While many procedures and manufacturer's instructions provide a formula to calculate the result, it is

not always straightforward to correlate the result given by the formula with a specification requirement. An understanding of the mathematical calculation and underlying assumptions may be necessary to ensure that the desired result is obtained.

One method to analyze extraction solution is using ion-specific (e.g., Cl^-) tests. Ion-specific techniques include titrations, test strips, turbidmetric techniques, and detection tubes. Ion-sensitive test strip and detection tube wick up solution and provide a visual color change at a level consistent with the ionic concentration of the solution. Titration methods involve dropwise addition of a titrant until visual color changes occur. These techniques typically result in a volumetric concentration (parts per million) of the ion being evaluated. The volumetric concentration is converted to a surface area concentration. Because of the gradations involved, these techniques may be sensitive to very low ion concentrations. The sensitivity of the detection can be increased by decreasing the volume of extraction fluid or increasing the surface area being evaluated.

An alternative method to determine soluble salt content of the extraction fluid is by measuring the solution conductivity. Dissolved ions increase the conductivity of the water. Several relatively inexpensive instruments are available which can measure low levels of conductivity with small volumes of liquid. The operator simply needs to immerse the sensor area with the extraction fluid and read the conductivity. Fully automatic devices contain embedded conductivity sensors. Instruments are also available which measure the conductivity of saturated filter paper or absorbent pads. Most instruments have built-in temperature correction. At the low levels of conductivity required, background conductivity of the extraction solution may be significant and should be accounted for in the measurement. Conductivity gages should be cleaned and calibrated before each set of measurements.

Formulae exist to convert conductivity readings to ion-specific readings. The conversion is a function of the surface area tested and volume of extraction solution. The conversion formula will also contain a factor that is a function of the type of salt assumed to exist (and may incorporate unit conversions). Each cation and anion in a solution contributes to the solution conductivity. To convert from conductivity to ionic content, an assumption regarding the ionic composition of the solution is required (i.e., what species are present and in what proportion). Based on this assumption, the conductivity contributions of the various ionic species can be calculated and the quantity of any one species determined. The type of salt present can have a significant effect on the conversion between conductivity and ion concentration. Figure 3 shows the theoretical relationship for a typical patch cell assuming one of three situations:

- Surface salt composition as specified in ANSI/NACE SP0508 (24.3% Na_2SO_4 , 22.1% NaNO_3 , and 53.6% NaCl) versus the surface *anion* concentration of that salt composition.
- Pure sodium chloride (NaCl) versus the surface chloride concentration.
- Surface salt composition as specified in ANSI/NACE SP0508 (24.3% Na_2SO_4 , 22.1% NaNO_3 , and 53.6% NaCl) versus the surface *chloride* concentration from that salt composition.

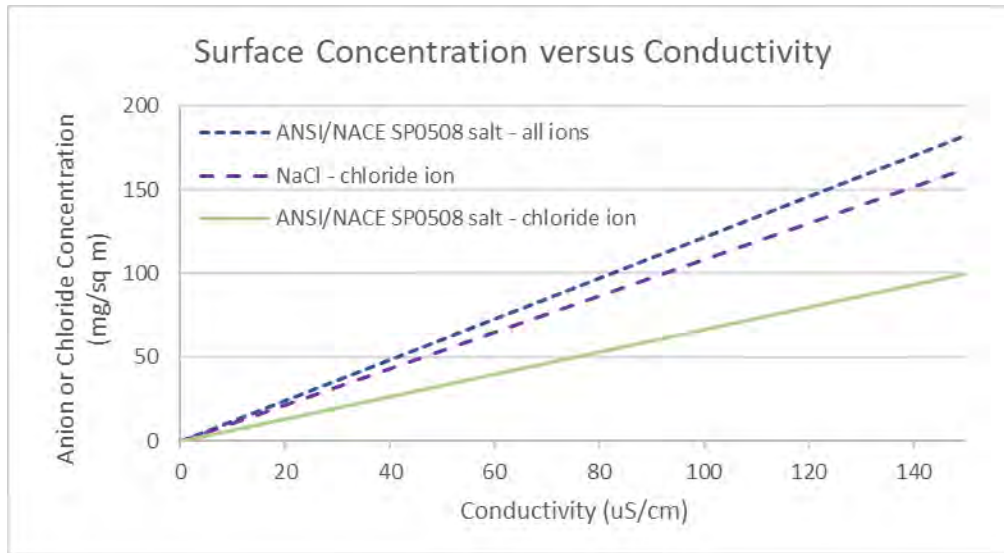


Figure 3. Relationship Between Surface Ion Concentration and Conductivity

There are many other potential combinations of interest, but the figure illustrates that the same conductivity measurement could be converted into a wide range of surface salt concentrations depending on how one defines the salts or species of interest – the problem is one of semantics, not of chemistry. Unfortunately, the calculations provided in specifications or equipment manuals are vague regarding the specific requirements and users are not sufficiently aware of these issues.

Conversion of ion-specific data to surface contamination is much more straightforward. Given a volume concentration, the volume of extraction solution, and the surface area, the surface ion concentration can be calculated:

$$\text{Surface Concentration } (\mu\text{g}/\text{cm}^2) = \text{Solution Concentration } (\mu\text{g}/\text{cm}^3) \times \text{Surface Area } (\text{cm}^2) / \text{Extract Solution volume } (\text{cm}^3)$$

Soluble Salt Remediation

Salt remediation efforts can be grouped into two categories – those associated with bridge cleaning (with or without additives) and those associated with surface preparation prior to coating application. Each of these categories is discussed in this section.

Bridge Cleaning with Water

Bridge cleaning is becoming more common as highway agencies focus on asset management and preservation practices. In addition to removing soluble salts, bridge cleaning helps keep drainage paths clear and removes poulitice. Bridge cleaning typically involves pressure washing accessible portions of the bridge with water. Northern states often perform bridge cleaning in the spring after the end of the road-salting season.

The University of Pittsburgh investigated the effectiveness of cleaning practices on three Pennsylvania bridges that experience anti-icing and deicing practices typical for the Northeast.¹³ After the winter salting season, the structures were washed using pressure washers and potable water. The study included the testing of the surface before and after washing using a Soluble Salt Meter (SSM) due to its ease of use on easily accessible, flat steel surfaces. Figure 4 shows a typical set of measurements using the SSM. Figure 5 shows a summary of the data collected at fifteen locations. The data show a salt reduction between 20% and 95%, depending on the location.

Palle, et al of the Kentucky Transportation Center (KTC) evaluated bridge cleaning, bridge cleaning with additives, and surface preparation.¹⁴ In their study, the sleeve style test was used for all salt measurements. The KTC study showed three examples of washing a structure with water at a pressure of 3,500 psi.

Table 1 shows the results of their study pre- and post-washing. Most test areas show nearly a complete remediation of chloride, even in low quantities.

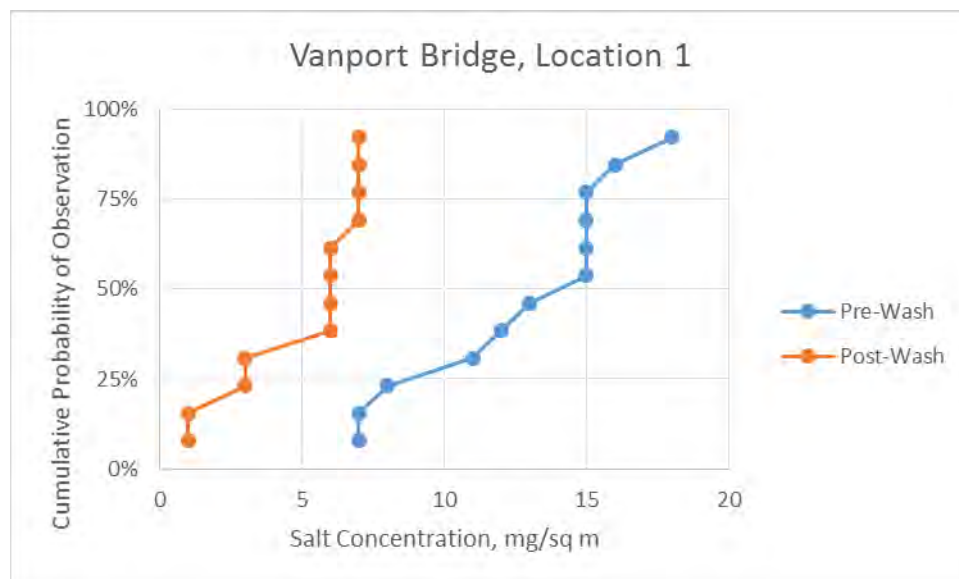


Figure 4. Typical Data Set for Salt Concentration Before and After Washing

¹³ Evaluation of Bridge Cleaning Methods on Steel Structures, FINAL REPORT, Kevin Alland, Julie M. Vandenbossche (PI), P.E., Ph.D., Radisav Vidic, P.E., Ph.D., and Xiao Ma. University of Pittsburgh, FHWA-PA-2013-007-PIT WO 2.

¹⁴ Palle, Younce, and Hopwood II, "Investigation of Soluble Salts on Kentucky Bridges," January 2003.

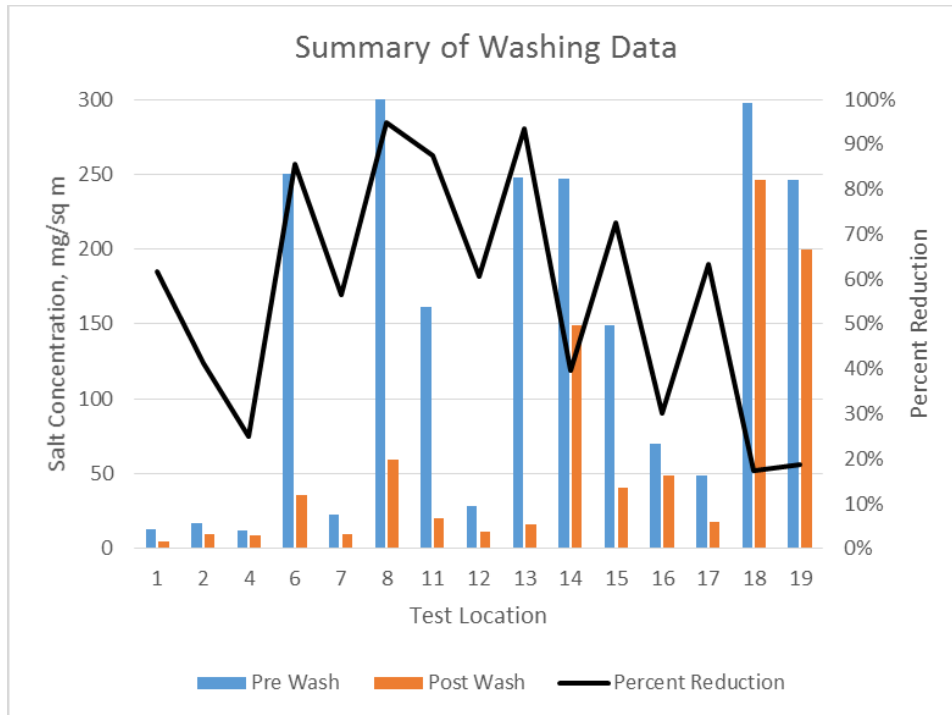


Figure 5. Summary of Data on Washing Effectiveness for Salt Removal

Table 1 – Pre- and Post-Wash Chloride Measurements by KTC¹⁴

Test Area A – I-71 crossing over I-75 (µg Cl ⁻ /mL)				
Location	1A	2A	3A	4A
Pre-Wash	23	7	7	25
Post-wash	1	7	0	0
Test Area C – I-71 crossing over I-75 (µg Cl ⁻ /mL)				
Location	1C	2C	3C	4C
Pre-Wash	7	5	11	15
Post-wash	0	0	0	3
Test Area A – KY-355 (µg Cl ⁻ /mL)				
Location	4A			
Pre-Wash	8			
Post-wash	0			

Bridge Cleaning with Additives

Independent testing completed by KTA-Tator showed that the use of CHLOR*RID® can cause a 50% reduction in surface chlorides versus water washing after abrasive blasting steel panels in a laboratory

scenario.¹⁵ Another study (written by the manufacturer) documented the value of washing with CHLOR*RID® additive during cleaning of bridges in Illinois.¹⁶ The reported data suggest that a 1% CHLOR*RID® solution, can reduce the total salts by up to 83% whereas water alone reduced the total salt levels by 56% or less. Interestingly, no matter the initial chloride concentration, the final chloride concentration was between 8.3 and 9.4 µg/cm². In the report, the data for the salt remover wash is identical for the urban and suburban structures, a possible reporting error.

The previously mentioned KTC study included the use of CHLOR*RID® in a 1% solution while pressure washing. Unfortunately, the test area in which it was used did not have salts prior to cleaning making the post-wash measurement of 0 µg/ cm² of little significance.

Surface Preparation for Painting

Surface preparation methods for remediating salts prior to painting bridges have included pressurized water cleaning, ultra-high-pressure water jetting, wet abrasive blasting, dry abrasive blasting, power and hand tool cleaning, and solvent cleaning. Sometimes detergents or salt removal products are added to the water used during pressure washing. Table 2 summarizes some of the methods used. The final surface salt concentrations will depend on the initial surface condition, the tools used, the effort (e.g., time) spent cleaning the surface, and any supplemental washing.

¹⁵ KTA-Tator, "Investigation of the Effect of Chlor*Rid on Removing Chloride and Sulfate Contamination." November 1995.

¹⁶ Johnson, "Is Plain Water Washing Effective Enough?" JPCL, September 2003.

Table 2 – Summary of Techniques for Salt Remediation during Coating Surface Preparation

Method	Comments
Low Pressure Water Cleaning (Pressure Washing), <5,000 psi	Pressure washing at a pressure less than 5000 psi can be accomplished with equipment that is readily available at many home improvement stores. Pressure washing is an approved method in SSPC-SP 1, Solvent Cleaning. Pressure washing is commonly used for bridge cleaning and as an initial cleaning step prior to surface preparation for coating. Ranges of soluble salt removers are commercially available to enhance soluble salt removal. Salt removers can loosely be grouped into acidic and alkaline categories, each with different reported behaviors.
Waterjet Cleaning, >10,000 psi	Waterjet cleaning includes the use of pressurized water over 10,000 psi to remove loose coatings and corrosion products from the substrate. SSPC has a series of standards that describe four degrees of surface cleanliness achieved by waterjet cleaning. Each of the standards has an appendix discussing water-soluble salts in relation to the specified degree of cleaning. Waterjet cleaning is not commonly used on bridges.
Abrasive Blast Cleaning	Abrasive blast cleaning is the most common form of surface preparation in the bridge maintenance and repainting industry. Abrasive blasting can be completed to varying degrees of cleanliness, which is defined by the amount of existing material allowed to remain on the surface after completion. Abrasive blasting is most often completed to SSPC-SP 10, near-white metal blasting, which only allows for small area of staining to remain. Other grades of cleanliness are described in SSPC-SP 5, SP 6, SP 7, and SP 14.
Wet Abrasive Blasting	Wet abrasive blasting encompasses a variety of techniques that incorporate water and dry abrasive material in the same stream to clean a surface. The addition of water to the system allows for the reduction of visible, fine particulates (dust) and helps rinse contaminants (including salts) from the surface. The use of water has the inherent risk to form flash rust on the surface during cleaning. The flash rust can be combated using a corrosion inhibitor in the water. Wet abrasive blasting is not commonly used on bridges.
Hand and Power Tool Cleaning	Hand and power tool cleaning are common practices for maintenance painting operations on bridges. A variety of tools are used during these operations including needle scalers, grinders, wire brushes, embedded grit wheels, and hand tools such as chipping hammers and scrapers. The process is slow and leaves a lower quality finish than that of abrasive blasting, hence it is typically only used during maintenance practices. Four standards describe different degrees of surface cleanliness with hand and power tools – SSPC SP-2, SP-3, SP-11, and SP-15.
Organic Solvent Cleaning	SSPC-SP 1, Solvent Cleaning encompasses cleaning with a wide variety of solvents including water. Localized solvent cleaning prior to painting is most commonly completed with organic solvents.

The efficiency of salt removal techniques has been the subject of previous testing.¹⁷ Table 3 summarizes key aspects of some of the reported data. Based on the reported remaining salt and the reported percent extracted, the probable initial, maximum salt contamination was calculated. Several issues become immediately apparent:

- The wet industrial techniques appear to provide the greatest efficiency in salt removal and final surface cleanliness.
- The dry industrial blasting techniques are not as effective as the wet techniques and the removal efficiency decreases with cleanliness level (i.e., SP-6 < SP-10 < SP-5).
- For the hand-tools that might be used in spot repair, none was as effective as the more industrial processes.

Critically, the total removal efficiency is also a partial function of the initial contamination. This appears to be the case especially for hand-tools. Regarding the data for SP-3 surface cleaning, with an initial salt concentration as high as 458 $\mu\text{g}/\text{cm}^2$, a 35% cleaning effectiveness was obtained. With an initial salt concentration of 12 $\mu\text{g}/\text{cm}^2$, a 3% cleaning effectiveness was obtained. Similar results are obtained with the SP-2 cleaning method. The last 10 to 20 $\mu\text{g}/\text{cm}^2$ appear to be the hardest to remove.

The KTC study¹⁴ indicates that surface preparation using power tools does not remove chlorides and may, in fact increase the chloride levels. Table 4 shows their results when power tool was completed. Two of the three test areas showed an apparent increase in chlorides after power tool cleaning. The third indicated a decrease of 50% from 10 to 5 $\mu\text{g Cl}^-/\text{mL}$. The apparent increase may be due to a physical phenomenon of exposing chlorides beneath the rust that was removed or could simply related to the statistical variations associated with selecting test areas and the measurement process itself.

¹⁷ K. Tator, "Soluble Salts and Coating—An Overview," JPCL, February 2010.

Table 3 – Summary of the Salt Removal Effectiveness of Different Remediation Methods¹⁷

Method	Remaining Salt ($\mu\text{g}/\text{cm}^2$)	% Extracted	Initial Salt ($\mu\text{g}/\text{cm}^2$)
Wet blasting	0-3.2	96.20%	84
Water jetting (35 ksi)	0-2.4	95.90%	59
UHP water jet	1.6-1.8	93.50%	28
Blast (SP 5)	<3.2-3.4	90.20%	35
Blast (SP 10)	3.3	84.00%	21
Blast (SP 6)	44-68	83.00%	400
SP 11 + steam	3.9-7.7	84.50%	50
Power tool (SP 11)	7.0-13.9	72.10%	50
Power tool (SP 11)	41-124	17.20%	150
SP 3 + steam	8.6-12.9	69.90%	43
Power tool (SP 3)	22-97	45.40%	178
Power tool (SP 3)	16.2-24.1	43.50%	43
Power tool (SP 3)	212-296	35.40%	458
Needle gun (SP 3)	11.4	3.00%	12
Hand tool (SP 2)	160-288	43.80%	512
Wire brush (SP 2)	15.2	9.00%	17

Table 4 – Pre- and Post-Surface Prep Chloride Measurements by KTC¹⁴

Test Area A – I-471 ($\mu\text{g Cl}^-/\text{mL}$)			
Location	1A	2A	3A
Initial	30	0	10
Post-Surface Prep	45	7	5

Industry Surveys

This section presents data from three surveys of individuals interested in salt detection and remediation issues. This project conducted two surveys – one which focused on the user experience with various detection and remediation methods and a second which focused on the impact of soluble salts and industry needs. Additionally, a recent highway agency survey on painting practices includes questions related to soluble salt contamination.

DOT Survey of Bridge Painting Practices

Minnesota DOT conducted a survey of transportation agency practices for maintenance painting.¹⁸ The survey included three questions regarding salt contamination during painting. Forty-two agencies responded to the survey.

Figure 6, Figure 7, and Table 5 show the responses to three questions related to salt contamination. Figure 6 shows that nearly 30% of the agencies do not have a specific salt remediation program, nearly 25% use washing with water only, and nearly 20% use pressure washing with a soluble salt remover. Figure 7 shows that nearly 70% of the agencies who perform post-remediation testing check for chloride ion content while less than 10 percent check for conductivity after remediation. Table 5 provides more details regarding the specific requirements of the agencies surveyed. The most common requirement is for chloride ion concentrations to be less than 6 to 10 $\mu\text{g}/\text{cm}^2$.

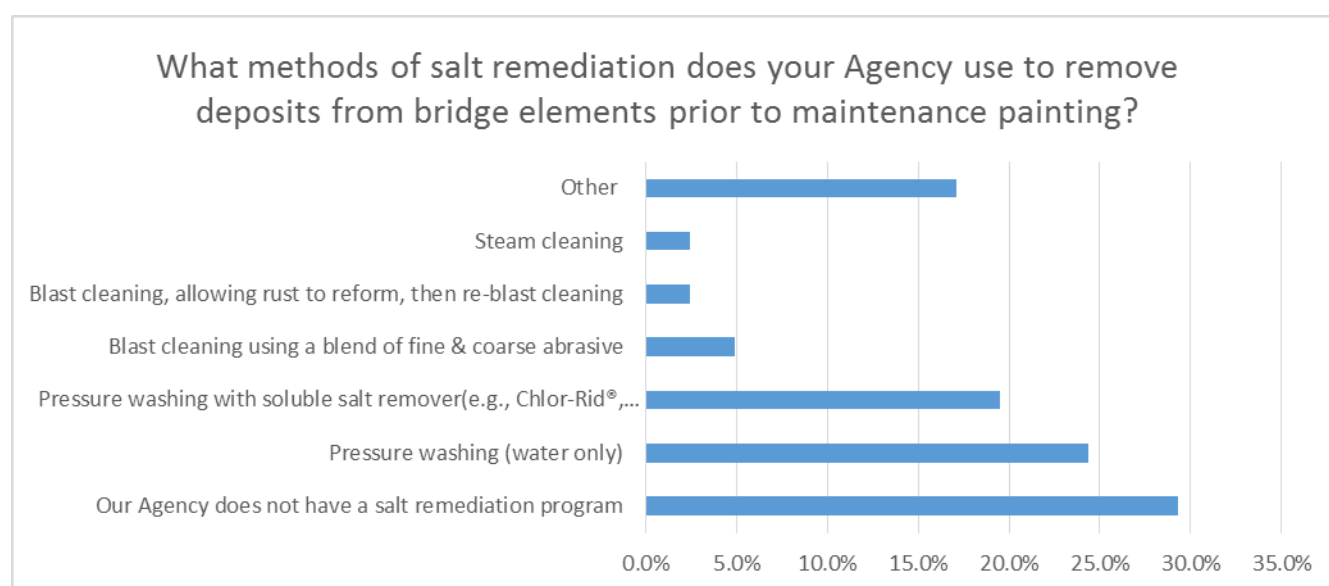


Figure 6. Minnesota DOT Survey Results regarding Remediation Methods

¹⁸ Transportation Agency Practices Currently Employed for Bridge Maintenance Painting Operations: Findings from a National Survey, Minnesota DOT Transportation Research Synthesis TRS 1404 Published March 2014.

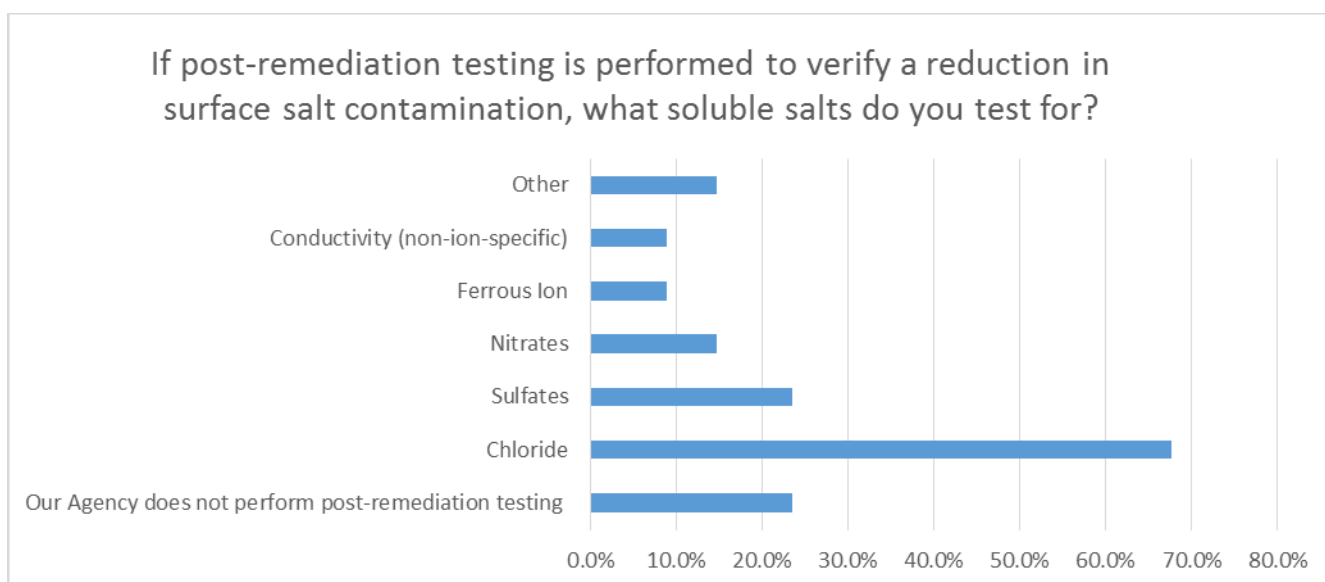


Figure 7. Minnesota DOT Survey Results regarding Detection Methods

Table 5 – Minnesota DOT Survey Results Regarding Soluble Salt Remediation Requirements

Ion Level	Chloride		Sulfate		Nitrate		Ferrous Ion		Conductivity		
Non-detectable	1	2.3%	1	0.0%	0	0.0%	1	2.3%	Non-detectable	1	2.3%
< 5 µg/cm ²	6	14.0%	1	0.0%	0	0.0%	0	0.0%	< 5 µS/cm	0	0.0%
6-10 µg/cm ²	13	30.2%	1	7.0%	3	7.0%	3	7.0%	6-10 µS/cm	1	2.3%
11-15 µg/cm ²	1	2.3%	0	2.3%	1	2.3%	0	0.0%	11-15 µS/cm	0	0.0%
16-25 µg/cm ²	0	0.0%	5	0.0%	0	0.0%	0	0.0%	16-25 µS/cm	0	0.0%
26-50 µg/cm ²	0	0.0%	0	0.0%	0	0.0%	0	0.0%	26-50 µS/cm	1	2.3%
Total Performing Salt Testing	21	48.8%	8	18.6%	4	9.3%	4	9.3%	Total Measuring Conductivity	3 ^a	7.0%
^a A fourth respondent reported a limit of < 70µS/cm											

Survey of User Experience with Detection and Remediation Methods

A survey of bridge industry user experience with detection and remediation methods was performed. The survey was accessible from December 14, 2015 through February 26, 2016. Members of AASHTO SCOBs, SCOM, and SOM committees were directly invited. In addition, a web link to the survey was provided in a group e-mail to the National Bridge Preservation Partnership Coatings Working Group. In total, 97 responses to the survey were received. A complete report of the results is presented in Appendix A.

The survey began by asking respondents whether they represent a highway agency, other industry, or a supplier of detection or remediation methods. The respondent was then directed to one of three subsets of questions based on their response to question #1. Respondents from highway agencies are asked about their experiences with salt detection and remediation technologies and are also asked a few questions about how they are used on bridges. Respondents from other industries are only asked about their experiences with salt detection and remediation technologies. Suppliers are only asked a few general questions about the state of the art in salt detection and remediation technologies.

For those from the transportation industry, only 18% of the agencies surveyed felt that the effects of salts were effectively managed or not a problem at their agency. Nearly 61% of the respondents felt that efforts to mitigate or reduce the impact of chloride deicers were reducing bridge corrosion for their agency. Bridge cleaning programs varied considerably from non-existent to annual cleaning. Regarding weathering steel bridges, 19% of the respondents indicated that they did remove salts from weathering steel bridges as part of routine maintenance. At least one state commented that they did not know how effective the practice was.

Across all industries represented by the respondents, there seems to be a need for various types of training and guidance. Roughly 80% of the respondents either felt that training materials were needed, or existing materials required improvement.

Table 6 shows the respondents feedback on the various soluble salt detection methods. The table shows the percentage of respondents indicating that the method was “Extremely Easy,” “Highly Effective,” and whether it was the respondents preferred method. The data suggest that people do not agree on a single easy, effective method for detecting soluble salts.

Table 7 shows the percentage of respondents who selected the highest effectiveness choice (i.e., removes 80% of the salt) for any given remediation method. The respondents clearly believe that wet methods at the highest pressures, water jetting methods, or washing with a soluble salt remover are the most effective methods to remove soluble salts. Not surprisingly, power and hand tools are deemed ineffective for removing soluble salts. It is interesting that low pressure water cleaning methods are deemed less effective at removing soluble salts than dry abrasive blast cleaning.

Table 6 – Consolidated Survey Responses Regarding Soluble Salt Detection

Salt Detection Method	Extremely Easy	Highly Effective	Preferred
Chlor*Test	31%	18%	31%
Soluble Salt Meter (SSM)	17%	42%	10%
Bresle w/ Conductivity	18%	23%	9%
Chlor*Test CSN	38%	38%	9%
KTA Swab SCAT	17%	6%	5%
Elcometer E130	33%	17%	5%
Bresle w Chloride Ion Measurement	9%	5%	3%
Potassium Ferricyanide Test	50%	50%	2%
X-Ray Fluorescence (XFR)	0%	75%	2%
eChlor*Test	50%	25%	0%
SaltSmart	17%	17%	0%
Electrochemical Techniques	0%	33%	0%
X-Ray Photoelectron (XPS)	0%	33%	0%

Table 7 – Consolidated Survey Responses Regarding Soluble Salt Remediation

Salt Remediation Method	80% Effective
Pressure washing (< 5,000 psi) with soluble salt remover (e.g., Chlor-Rid®, HoldTight®, Salt-X, Salt-a-Way, etc)	66%
Waterjet cleaning (>10,000 psi, with or without additives)	59%
Wet abrasive blasting	41%
Solvent cleaning using a solvent other than water	23%
Dry abrasive blast cleaning modified to address salts (e.g, through the use of a specific abrasive blend)	21%
Dry abrasive blast cleaning without any particular modifications	20%
Potable water rinsing (<100 psi)	18%
Pressure washing (<5,000 psi, water only)	17%
Power-tools for spot preparation per SSPC SP-15	8%
Power-tools for spot preparation per SSPC SP-3	6%
Hand-tools for spot preparation per SSPC SP-2	0%
Power-tools for spot preparation per SSPC SP-11	0%

Survey of Soluble Salt Impact and Industry Needs

A follow-on survey was developed for personnel in the coating inspection community. The survey was accessible from July 19, 2017 through September 26, 2017. It was promoted through social media and received sixty-five responses.

Appendix B contains a complete report of the survey results. The respondents were categorized based on the self-described industry with which they associated. Figure 8 shows the results; note that only 12% were from the bridge industry.

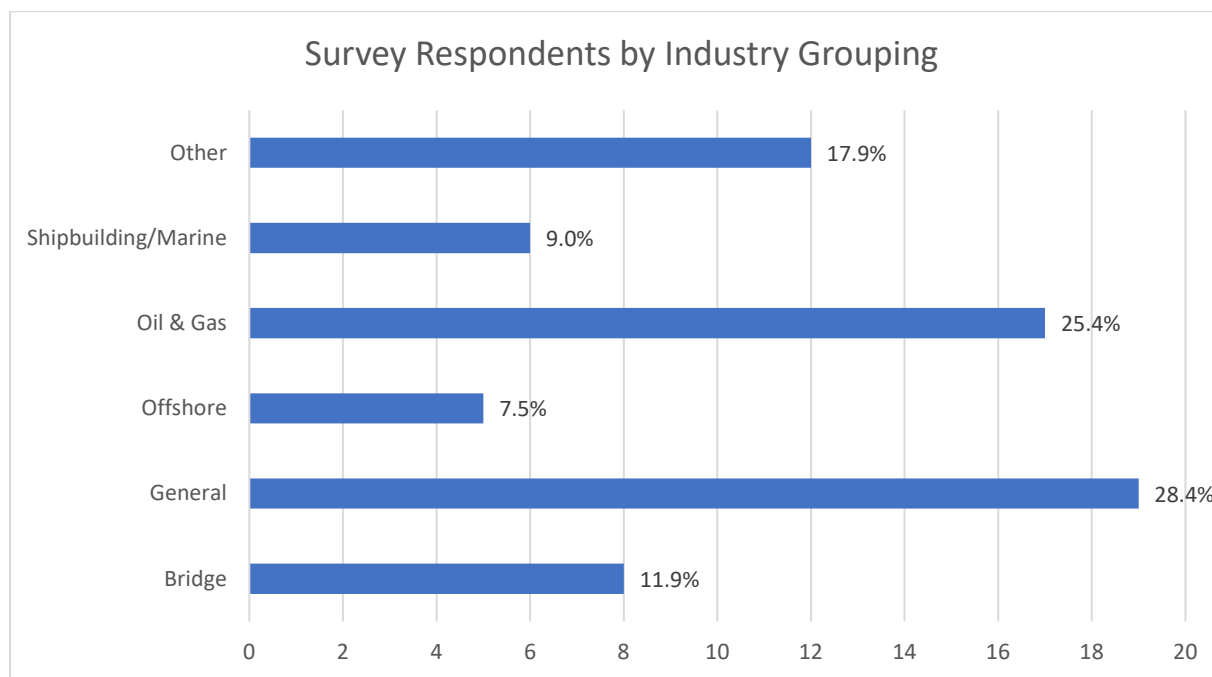


Figure 8. Survey Respondents by Industry Grouping.

The respondents are nearly unanimous in their opinion that salts can impact coating performance but evenly divided over their impact. For example, question 2 shows that about a third of the respondents believe that they can be effectively managed with the status quo, 40% believe that additional funding or training is required, and slightly over a quarter of respondents believe that they are a major problem that cannot be effectively addressed. Question 10 suggests that re-work due to salts is required about 20-25% of the time. Question 12 shows that when re-work is required, about half of the respondents consider the effort to be “modest” while 38% consider the re-work to be “significant.” It is apparently a somewhat common occurrence (10%) to obtain approval not to re-work the surface. When excessive soluble salts are observed, they are typically removed using water (with or without a salt remover).

Detection of soluble salts is most commonly achieved with a chloride ion (61%) or conductivity (65%) technique. Sulfate and nitrate ion measurements are also used; 22% and 16% of the respondents respectively indicate that they make these measurements. In contrast, the previously referenced Minnesota DOT survey indicated a clear preference for chloride ion measurement in the bridge industry and very little (<10%) use of the conductivity measurement. This survey indicates a preference for the Bresle method with conductivity measurement (29%) versus Chlor*Test (21%) whereas the dominant preferred method in the bridge industry survey performed at the beginning on this project was Chlor*Test (31%) followed by three methods in the 9-10% range.

The respondents to this survey indicate that there is a need for additional guidelines and training methods around soluble salt detection and remediation, with a slightly larger need in detection rather

than remediation. The comments in response to open ended questions regarding gaps in general understanding of soluble salt issues. Some specific issues include:

Equivalence/conversions – Specific ion tests will not find all salts; conductivity is the only method that will identify all soluble salts. Unfortunately, it is not easy or economical to differentiate among salts contributing to the conductivity in any given spot. ISO 8502-09 provides a conversion from conductivity to total surface salt concentration; however, this conversion is only accurate for a very small set of conditions. Few specifications or training highlight this issue.

Identify and understand the soluble salt problem – While many agree that soluble salt contamination is a significant problem facing the protective coating industry, the extent of the problem is very situation dependent. Inspectors, engineers, and contractors need to understand what soluble salts are on the surface, where they may be coming from, and how much can remain prior to developing a work plan. The work plan may include some combination of pre-cleaning, secondary preparation or supplemental techniques to minimize soluble salt contamination on the surface.

Determine what soluble salt species and levels are tolerable – It is generally not possible to remove all soluble salts, though it is possible to reduce *chloride* contamination below *detection limits*. Unfortunately, industry acceptable levels vary greatly for *how much* contamination and *what type* of contamination is considered acceptable. There are conflicting opinions on what salts are most detrimental to performance and whether certain salts may be acceptable at any (or at least most reasonable) concentrations. One survey respondent suggested that acceptable soluble salt levels should be on coating product data sheets rather than within owners' specifications.

Alternative/preferred methods for detecting soluble salts – There are several detection techniques available, some of which are comparable and some of which are not. Each technique has its own advantages/disadvantages. Users and specifiers of detection methods should be informed about the various methods.

Testing issues universal to all methods – Identifying testing frequency, locations to test, and threshold requirements is critical for quality control. There are visual cues to look for prior to selecting the test location – pitted steel, discolored areas, etc. It is not possible to test certain geometries (crevices, heavily pitted areas, etc.). Corrosion product seems to make “salts” less soluble; apparently some people “disturb” the surface with a wire brush to make the salts detectable. It is important to follow the instructions of the detection method (including calibration) and to avoid contamination of the test surface. Temperature can affect conductivity readings as well as the solubility of some salts. There can be significant variability in salt contamination across a surface – multiple measurements should be made.

When to clean – The importance of “pre-cleaning” (generally by pressure washing) was mentioned by several respondents. Some respondents suggested that the decision to pre-clean may be based on salt measurements made at the beginning of the job. However, pre-cleaning also removes dirt and debris before abrasive blasting which can improve the overall effectiveness of abrasive blasting (especially with recycled abrasives). Some in the industry recognize a benefit of supplemental washing activities such as mechanically removing rust before cleaning or adding “salt removers” to the wash water. One respondent indicated that “The best way to remove remaining salts is re-wash and leave it at least 12

hours before re-blasting. The chloride ions will chemically bond to the rust and will be easier to remove it with blasting."

Training – Recognized inspector training courses (SSPC, NACE, Frosio, etc.) generally cover soluble salt detection to some extent. In addition, inspectors should thoroughly understand the standards, equipment instructions, and chemistry behind what is occurring. One respondent commented "People without a chemistry background probably shouldn't be testing for contamination because often they lack understanding of the chemistry of things (seeing lots of inspectors out there that do not stop to think about many of the factors that could affect measurement accuracy, sampling efficiency, etc...)." Based on the project work to date, a basic understanding of chemistry is one item that is not included in current soluble salt training.

One responded commented "It is a massive grey area where there is very little or absolutely confusing information available for soluble salt acceptable levels, acceptable detection methods, its effects on long or short term, to identify the corrosion caused due to a particular soluble salt level, cost and time required to be dedicated for its removal, etc."

Detection & Consequence – It is imperative to perform sufficient tests in locations that are representative of the structure. In addition to testing the surface, check conductivity of water and abrasive materials prior to or during surface preparation. One respondent commented that "The Contractor's equipment more times than not is contaminated with salt." Note that porosity in metals (especially welds or cast materials) can retain ionic species which can be difficult or impossible to remove regardless of the method. Salts left on the surface are most likely to cause blistering in the short term. Over the longer term, as coatings break down the salts can contribute to accelerated undercutting.

Remediation products/methods – Several products exist for combating soluble salts including various cleaners and coatings that are designed to be tolerant of soluble salts. Some skepticism of these products exists in the industry. Each project is somewhat unique; inspectors should follow the specification requirements and contractors/specifiers should explore options to determine the methods that work best for the situation. It is possible for contaminated abrasive to contaminate the surface during abrasive blasting, hence the common recommendation to address soluble salts and areas of concern before abrasive blasting.

Experimental Approach

Laboratory Evaluation of Detection Techniques

The laboratory phase of the detection instrument evaluation includes over 1,300 measurements performed using seven detection methods in nine test conditions. Table 8 summarizes the detection methods. Details on each method are provided later in this section.

Table 8 – Summary of Detection Methods Being Evaluated

Multi-Step Conductivity Measurement Techniques
Method A - Bresle Method per US Navy procedure
Method D - Elcometer 130 Soluble Salt Profiler
Method E2 - ISO 8502-6 Bresle Extraction with Conductivity Analysis per ISO 8502-9
Method F - DeFelsko PosiTector SST Soluble Salt Tester
Fully Automated Conductivity Measurement Technique
Method B - ARP Soluble Salt Meter
Multi-Step Ion-Specific Methods
Method C - CHLOR*TEST
Method E1 - ISO 8502-6 Bresle Extraction with Chloride Analysis per ISO 8502-5

The laboratory testing was performed under various conditions intended to provide insight to the factors that result in greater variability and/or bias when performing the salt detection measurements. For the purposes of this report, “variability” is defined as the Relative Standard Deviation (RSD)¹⁹ of the measurement set and “bias” is defined as the difference between the average measured value and the “true value” expressed as a percentage of the “true value.” Depending on the set of data, the “true value” may be theoretically calculated, reported by a third party (e.g., for reference standards), or an average of the data set (e.g., for field measurements where the “true” value is unknown).

It is important to understand that while soluble salts are conceptually simple, the various ways the industry defines surface salts is inconsistent and can be confusing. Ion specific methods exist which measure chloride, sulfate, or nitrate ions. The ion concentration is **not** equivalent to the concentration of the salt compound (e.g., NaCl, NaSO₄, NaNO₃). For example, 5 µg/cm² of chloride ion is found in 8.24 µg/cm² of sodium chloride. Furthermore, conductivity measurements can be variously converted to “salt concentration” depending on the assumed relative concentration of ionic species. Chemically, the conversion requires determining the molecular concentration of each ionic species (ion and cation) and multiplying each by their respective specific conductance. Appendix C provides a detailed discussion on the technical issues regarding conversion and the preparation of standard solutions using examples from this testing.

Table 9 summarizes the laboratory test conditions. Conditions 1, 2, 7, and 9 are intended to validate the **measurement process** of each method in simplified scenarios – where a known amount of a standard solution is directly measured or where a known clean surface is measured. Conditions 3 through 6 and 8 are intended to validate the **measurement and extraction processes** by simulating field measurement

¹⁹ Relative Standard Deviation is a standardized measure of dispersion where the standard deviation of a data set is expressed as a percentage of its mean.

scenarios. The conditions involve either detecting sodium chloride in a simulated pit (conditions 3 and 5) or measuring a dried salt mixture on the surface (conditions 4 and 6). Furthermore, two of the conditions (5 and 6) evaluated salts that had “aged” on the steel surface for three days. Finally, condition 8 consisted of a pre-rusted panel that was abrasive blasted to SSPC-SP 6 / NACE No. 3 Commercial Blast Cleaning. Details on each of the test conditions are provided later in this section.

Table 9 – Summary of the Test Conditions

Summary of Test Conditions	
1	Add sodium chloride solutions directly to the detection chamber in a range of concentrations to validate the measurement technique.
2	Perform measurement on freshly abrasive blasted, steel surface rinsed with deionized water and ethyl alcohol to ensure they are as clean as practical.
3	Perform measurement on artificial “pits” with sufficient NaCl added to represent $5 \mu\text{g Cl}^-/\text{cm}^2$.
4	Perform measurement on abrasively blasted steel doped with the salt solution specified in NACE SP0508 to a target of $5 \mu\text{g Cl}^-/\text{cm}^2$.
5	Perform measurement on artificial “pits” with sufficient NaCl added to represent $5 \mu\text{g Cl}^-/\text{cm}^2$ that have been conditioned for 72 hours at 70°F and 90% RH.
6	Perform measurement on abrasively blasted steel doped with the salt solution specified in NACE SP0508 to a target of $5 \mu\text{g Cl}^-/\text{cm}^2$, which have been conditioned for 72 hours at 70°F and 90% RH.
7	Perform measurement on freshly abrasive blasted, steel surface rinsed with deionized water and ethyl alcohol to ensure they are as clean as practical.
8	Perform measurements on steel surfaces that were contaminated with salts in 10 cycles of GMW14872 cyclical corrosion testing followed by abrasive blasting to SSPC-SP 6 / NACE No. 3 Commercial Blast Cleaning.
9	Direct injection of conductivity standards into the conductivity measuring devices. Four solutions were used (23, 84, 447, and 1000 $\mu\text{S}/\text{cm}$ solutions of potassium chloride).

Multi-Step Conductivity Measurement Techniques

Detection Method A

Detection method A follows ISO 8502-9 Bresle Method as further defined in a US Navy procedure. The procedure involves injecting distilled water into an adhesively bonded latex patch secured to the test area. The area of the patch is 12.5 cm^2 and contains an adhesive foam barrier that adheres to the surface being tested. Three milliliters of distilled water are injected and withdrawn from the patch to extract the soluble salts from the surface. While in the patch, the water is rubbed against the test surface for 90 seconds to extract soluble salts from the surface. The solution is removed from the patch and its conductivity is measured using a Horiba LAQUAtwin conductivity meter. The measured conductivity is offset by the conductivity prior to extraction. The conductivity meter is checked against a standard solution before each use and adjusted as required.

Detection Method D

Detection method D is the Elcometer 130 Soluble Salt Profiler (SSP). This is an electronic device that measures the electrical conductivity of a circular pad of wetted paper among an 8 by 8 matrix of electrodes. Up to 1000 different measurements can be stored in multiple batches.

The user can access four options from the 1.5 x 2-inch display – Timer, Batch, Display, and Menu. The timer option starts a two-minute count (the amount of time a test paper should remain on the surface being tested). The batch option opens a menu allowing the creation, naming, editing, and copying of batches saved to the device. The display option opens a menu allowing the top and bottom of the screen to be set in two different sections. These sections can show selected statistics (such as a running mean of the readings being taken within a batch), the current reading being taken, a statistical graph of the readings which have been taken, and a heat map of the salt concentration on the test paper. The menu option brings up the main menu, allowing settings like the measurement mode, limits, and Bluetooth connectivity to be set. The instrument has four modes – “Bresle-Smooth,” Bresle-Rough,” “Conductivity,” and “Elcometer 130” modes. For much of the testing in this report, the device was set up in the “Elcometer 130” mode, which reports readings in both conductivity and concentration of surface salts. The remaining modes only report conductivity results.

The device calibration should be periodically verified with a calibration verification tile. The tile has rubber feet on the bottom of it which line up with the detection grid on the machines surface. After wiping both the machine and the tile off with distilled water and a piece of tissue paper, enter the menu of the device and select calibration, followed by calibration verification. The machine will prompt you to press the block firmly on the face of the device while it checks for a reading in each of 4 ranges (0.4-0.6, 1.9-2.1, 4.8-5.2, 10.5-10.9) $\mu\text{g}/\text{cm}^2$. After each check it will stop and display a number. When the user acknowledges the value is within the acceptable range, the process repeats with the next range.

Before the start of daily testing the offset must be set on the meter. This accounts for the background conductivity present in the distilled water and the high purity test papers. When setting up the offset, the device will prompt you to drop by drop wet a new piece of test paper on a magnet backing with 1.6mL of distilled water. Place this clean sheet on the meter and close the lid, waiting for the reading to be taken and stored as the offset. The offset should only require resetting if the type of water for testing is changed, or a new package of test papers is opened.

To perform a measurement, select a batch to store the reading and open the lid of the device. Unless previously done, spray approximately 1 mL of distilled water on the surface of the device and wipe clean with tissue paper. Using the supplied tongs, grab one piece of filter paper and place it on a clean magnet backing. If this is the first test of the day, flush the supplied syringe with distilled water three times. Next, draw 1.6mL of the distilled water into the syringe and wet the test paper dropwise. Once the paper is wet, the magnet and paper can be placed on the test area, paper side down. Click the timer button on the device, beginning the two-minute wait period required for this test.

After the timer indicates that the two minutes are up, use the tongs to remove the test paper and magnet from the test surface. Place both down on the testing surface, making sure to cover the electrodes with wetted paper. Close the lid and wait for the machine to take the reading. When the reading is finished, the screen will display the test results.

Detection Method E2

Detection method E2 used ISO 8502-6 Bresle extraction procedure followed by a conductivity measurement in accordance with ISO 8502-9. Note that the extraction details are different than for Method A but identical to Method E1.

This method employs an adhesively bonded latex patch and distilled water for soluble salt extraction. The watertight patch is applied to the test surface to isolate a 12.5 cm² area for the measurement. A 10mL container of distilled water is prepared for testing. To dissolve salts on the surface, a three mL sample of the water is injected into the cell using a hypodermic needle. The water is removed and re-injected once a minute for ten minutes during the testing per ISO standard. After the test injections, the water sample is extracted and re-mixed with the remaining 7mL of water in the sample container for testing. The extraction fluid is evaluated by injecting a portion of it into a Horiba LAQUATwin conductivity meter.

Detection Method F

Detection method F is the Defelsko Soluble Salt Tester (SST). The instrument consists of a rigid cell magnetically attached to the surface. A safety syringe (flexible tube in lieu of a needle) is used to inject 3mL of distilled water into the cell. The extraction fluid is manually agitated in the cell by cycling the fluid via injection and removal using the syringe. The syringe is used to remove the water and inject it into an instrument which measures the conductivity and calculates the surface salt concentration based on the conductivity value. The instrument reports both conductivity and a calculated soluble salt surface concentration.

Fully Automated Conductivity Measurement Technique

Detection Method B

Detection method B is the ARP Soluble Salt Meter (SSM). The user injects 3mL of extraction fluid (distilled water) into a chamber that is magnetically attached to the test surface. Solution can be injected into this chamber via the supplied tubing and either a syringe or a specifically supplied, 3mL dispenser. The machine has a batching feature which can hold up to 1000 measurements, 100 in each of its 10 batches. These batch names can be edited with the provided software on a PC.

Before the first reading is performed, the machine will prompt for a cleaning to be completed. Cleaning the machine is a two-step process. The first step is to flush the cell with distilled water. The operator turns the device over, so the testing area is facing up and flushes the device with 3mL of distilled water, or enough to fully cover the plunger. The second step is to confirm that the device is clean. The operator pushes the plunger out and attaches the device to a clean magnetic surface such as a coated steel plate. Then the operator injects 3mL of distilled water into the chamber and the machine agitates the fluid against the surface before generating a reading. If the test comes back less than 5µS/cm, the meter is considered clean and prompts you to continue. If the test comes back greater than 5µS/cm the meter prompts you to repeat the cleaning (flush and confirm).

Once cleaning is complete, testing can begin. Readings are taken in a similar way to cleaning process. First the plunger is extended, and the device is attached to the surface being tested. When “take reading” is selected, the user will be prompted to attach and inject. Once the device is attached, inject 3mL of solution into the test chamber, and click ok for the test to begin. The plunger will agitate up and

down for a few seconds before returning the resulting reading. The reading will display in $\mu\text{S}/\text{cm}$ at temperature, $\mu\text{S}/\text{cm}$ adjusted to 25°C , mg/m^2 total soluble salt, and mg/m^2 total soluble salt (Bresle compensated). The user is prompted to flush the meter before the next measurement. All measurement modes can be downloaded from the device with the provided software if a batch is being used.

Multi-Step Ion-Specific Methods

Detection Method C

Detection Method C is the CHLOR*TEST kit for determining surface concentration of chloride ions. To perform the test method, the user applies a fixed volume of proprietary extraction fluid to a test surface via a latex sleeve. Ten milliliters (10mL) of extraction fluid is placed in the latex sleeve. The self-adhesive sleeve is then attached to the test surface. The extraction fluid is manually worked across a circular area of 10 cm^2 within the tube to dissolve the salts on the surface. The extraction fluid is then collected in the sleeve before it is removed from the surface. The extraction fluid is tested for chlorides using a chloride ion detection tube with a range from 1 to 60 ppm. The tip of the tube is broken off and inserted into the fluid. The absorbent material in the tube draws the liquid into the tube and chemical reagent produces a color change along the tube in the presence of chloride ion. The length of color change relates to the chloride ion concentration.

Detection Method E1

Detection method E1 used ISO 8502-6 Bresle Extraction with Chloride Analysis per ISO 8502-5. This is an industry recognized test method with ion-specific analysis using chloride ion paper test strips or chloride ion detection tubes (depending on the concentration). Note that the extraction details are different than for Method A but identical to Method E2.

This method employs an adhesively bonded latex patch and distilled water for soluble salt extraction. The watertight patch is applied to the test surface to isolate a 12.5 cm^2 area for the measurement. A 10mL container of distilled water is prepared for testing. Three milliliters (3mL) of this water is injected into the cell using a hypodermic needle to dissolve any salts present. The water is removed and re-injected once a minute for ten minutes during the testing per ISO standard. After the test injections, the water sample is extracted and mixed with the remaining 7mL of water in the sample container for testing. The extraction fluid is evaluated by using ion-specific methods such as paper test strips or glass tube ion detection.

Laboratory Test Conditions for Detection Methods

Test Condition 1

Test condition 1 was intended to determine the variability and bias of each detection device without consideration of the extraction process. The methodology evaluated the results of directly injecting a known salt solution into the measurement device. This eliminated any contribution of extraction efficiency or questions about proper “doping” of test panels from the measurement. The testing evaluated a range of solution concentrations with each instrument to determine the variability and bias of each technique.

A series of twelve test solutions were prepared for this testing. Stock solutions were prepared by adding reagent grade sodium chloride (99.9%+) to ASTM D1193, Type IV reagent water with a conductivity of $2.33\mu\text{S}/\text{cm}$. The sodium chloride was weighed on an analytical balance with 0.0001g readability and the

deionized water was measured in graduated cylinders with either $\pm 2\text{mL}$ or $\pm 1\text{mL}$ readability. These stock solutions were further diluted to the desired concentration using a syringe ($\pm 0.1\text{mL}$ readability) and graduated cylinder. After preparing each solution, the conductivity and chloride of the solutions were measured with a Horiba LAQUA twin (conductivity) and chloride ion paper or ion detection tubes (average of triplicate measurements). Table 10 presents the data for all the test solutions. Detection methods A, B, C, D, E1, E2 and F were used for this test.

Table 10 – Summary of Test Solutions Used for Instrument Validation

ID	Sodium Chloride, g/L	Calculated Conductivity, $\mu\text{S/cm}$	Calculated Chloride Concentration, ppm	Measured Conductivity, $\mu\text{S/cm}$	Measured Chloride Concentration, ppm
0	0	0	0	2.33	0
1	0.03518	76.70	21.2	71	22.17
2	0.1005	219.15	60.7	194.67	60.67
3	0.2513	547.88	151.6	473.33	148.00
4	0.01005	21.92	6.1	23	6.67
5	0.03015	65.75	18.2	61.67	18.00
6	0.07539	164.36	45.5	133.33	48.67
S1	3.728	8127	2249	6000	2335
S2	2.485	5418	1500	3900	1644
S3	1.243	2709	749.8	2300	713
S4	0.7456	1625	449.9	1130	362
S5	0.2585	563.6	156.0	410	148
S6	0.03175	69.22	19.2	68	20

Test Condition 2

Test condition 2 evaluated each detection method on an abrasive-blasted panel to determine the variability (RSD) and bias associated with measuring a “clean” surface. The test panels were cut from new, hot-rolled steel and prepared by abrasive blasting to a 2-mil profile using a 36 grit aluminum oxide media. After abrasive blasting, the panels were individually wrapped in corrosion inhibitive paper. The panels were unwrapped and cleaned with acetone-soaked rag immediately prior to making the salt measurements. The panels are representative of well-cleaned structural steel. Detection methods A, B, C, D, E1 and E2 were used for this test.

Test Condition 3

Test condition 3 validated the measurement and extraction processes by simulating a field measurement scenario where sodium chloride was contained within a pit. The test panels were cut from new, hot-rolled steel and prepared by abrasive blasting to a 2-mil profile using a 36 grit aluminum oxide media. Artificial “pits” 0.0625-inch diameter by 0.125-inch deep were machined into the test panels. Immediately prior to making the salt measurements, the panels were cleaned with acetone and a micropipette was used to add sodium chloride solution to each pit in an otherwise clean panel to yield approximately $5\text{ }\mu\text{g Cl/cm}^2$ over the tested area. Because of the different surface areas of each test technique, varying volume and concentration of solution were used to obtain the target contamination level. The theoretical result was calculated for each condition using the procedure described in

Appendix C. Table 11 provides details of the doping solution quantities and the theoretical value that should be measured.

Detection method D was re-evaluated in test condition 3 using an alternate device setting. The measurements originally were taken in “Conductivity” mode, which only records a conductivity reading. For the second set of tests, the measurements were taken in “Cleanliness” mode, which returns both a conductivity and a surface salt concentration result.

Table 11 – Doping Solutions and Theoretical Values for Condition 3

Method	NaCl Concentration	Volume	Theoretical Value
A (Multi-Step Conductivity)	25.78 g/L	4 μ L	74.85 μ S/cm
B (Fully Automated Conductivity)	25.78 g/L	4 μ L	74.85 μ S/cm
C (Multi-Step Ion-specific)	25.78 g/L	3.2 μ L	4.97 μ g Cl^- /cm ²
D (Multi-Step Conductivity), “Conductivity Mode”	33 g/L	6 μ L (in each of four pits)	591.43 μ S/cm
D (Multi-Step Conductivity) “Cleanliness mode”	6.525 g/L	3 μ L (in each of four pits)	0.5 μ g “salt”/cm ² 107.3 μ S/cm
E1 (Multi-Step Ion-specific)	25.78 g/L	4 μ L	4.97 μ g Cl^- /cm ²
E2 (Multi-Step Conductivity)	25.78 g/L	4 μ L	22.46 μ S/cm

Detection methods A, B, C, D, E1 and E2 were used for this test. For most test methods, a total of 7 data points were made by each of three operators (i.e., 21 replicate measurements). Only 14 measurements were made using detection method D in cleanliness mode. Note that four of the test methods provide results as conductivity of the extraction fluid and two present results as calculated surface salt concentration. For the electronic devices that report both conductivity and salt concentration, both were recorded for analysis.

Test Condition 4

Test condition 4 validated the measurement and extraction processes by simulating a field measurement scenario where a blend of salts was somewhat evenly distributed across an abrasively blasted surface. The test panels were cut from new, hot-rolled steel and prepared by abrasive blasting to a 2-mil profile using a 36 grit aluminum oxide media. Immediately prior to making the salt measurements, the panels were cleaned with acetone and contaminated using a complex salt solution of 24.3% Na_2SO_4 , 22.1% NaNO_3 , and 53.6% NaCl as described in ANSI/NACE SP0508-2010. Specifically, a solution composed of 2.38g NaCl , 1.079g Na_2SO_4 and 0.981g NaNO_3 in 1L of distilled water solution was used. The surface was contaminated by spreading 1.5mL of the solution across the surface of each panel using a 5mm diameter glass rod to achieve a target value of 5 μ g NaCl /cm². The theoretical result was

calculated for each condition using the procedure described in Appendix C. Table 12 provides the theoretical value that should be measured.

Detection method D was re-evaluated in test condition 4 using an alternate device setting. The measurements originally were taken in “Conductivity” mode, which only records a conductivity reading. For the second set of tests, the measurements were taken in “Cleanliness” mode, which returns both a conductivity and a surface salt concentration result.

Table 12 – Theoretical Values for Condition 4

Method	Theoretical Value
A (Multi-Step Conductivity)	115.24 $\mu\text{S}/\text{cm}$
B (Fully Automated Conductivity)	115.24 $\mu\text{S}/\text{cm}$
C (Multi-Step Ion-specific)	4.64 $\mu\text{g Cl}^-/\text{cm}^2$
D (Multi-Step Conductivity), “Conductivity Mode”	552.16 $\mu\text{S}/\text{cm}$
D (Multi-Step Conductivity) “Cleanliness Mode”	5.0 $\mu\text{g “Salt”}/\text{cm}^2$ 920 $\mu\text{S}/\text{cm}$
E1 (Multi-Step Ion-specific)	4.64 $\mu\text{g Cl}^-/\text{cm}^2$
E2 (Multi-Step Conductivity)	34.57 $\mu\text{S}/\text{cm}$

Detection methods A, B, C, D, E1 and E2 were used for this test. For most test methods, a total of 7 data points were made by each of three operators (i.e., 21 replicate measurements). Only 14 measurements were made using detection method D in cleanliness mode. Note that four of the test methods provide results as conductivity of the extraction fluid and two present results as calculated surface salt concentration. For the electronic devices that report both conductivity and salt concentration, both were recorded for analysis.

Test Condition 5

Test condition 5 investigated the effect (if any) of aging contaminated surfaces on the measured value. The panels were prepared with the same procedure as test condition 3 followed by exposure to a high humidity environment for 3 days prior to soluble salt testing. The panels were stored in a sealed container which was maintained at a relative humidity of 90-95% and temperature between 73°F and 78°F. A tray containing a glycerol-water solution was used to maintain the equilibrium humidity. Detection methods A, B, C, D, E1 and E2 were used for this test.

Test Condition 6

Test condition 6 investigated the effect (if any) of aging contaminated surfaces on the measured value. The panels were prepared with the same procedure as test condition 4 followed by exposure to a high humidity environment for 3 days prior to soluble salt testing. The panels were stored in a sealed container which was maintained at a relative humidity of 90-95% and temperature between 73°F and 78°F. A tray containing a glycerol-water solution was used to maintain the equilibrium humidity. Detection methods A, B, C, D, E1 and E2 were used for this test.

Test Condition 7

Test condition 7 was performed to establish repeatability of the results of test condition 2 when (a) a different solvent is used and (b) rinsing rather than a solvent soaked rag is used to clean the surface. As

with test condition 2, the test panels were cut from new, hot-rolled steel and prepared by abrasive blasting to a 2-mil profile using a 36 grit aluminum oxide media. After abrasive blasting, the panels were individually wrapped in corrosion inhibitive paper. The panels were unwrapped and cleaned with different combinations of the methods immediately prior to making the salt measurements. Detection methods A and B were used for this test.

Test Condition 8

Test condition 8 was performed to examine the detection of soluble salts on rusted steel that was blast cleaned to an SSPC SP-6 level of cleanliness. The objective is to simulate a surface that may be presented to an inspector for acceptance but does not meet typical industry accepted soluble salt levels. For this testing, ten 6-inch by 12-inch by 1/8-inch panels and five 3-inch by 4-inch by 1/8-inch panels were subjected to 10 cycles of GMW 14872 exposure. This covered the surfaces of the panels in corrosive product, as shown in Figure 9.



Figure 9. Six-inch by 12-inch Panels after Undergoing 10 cycles of GMW14872 Exposure

These panels were remediated through a media blast with #16 mesh aluminum oxide grit until an SSPC SP-6 surface was achieved. Detection methods A, B, C, D, E1, E2 and F as well as a boiling water extraction were used for this test. The boiling water method was used on the 3x4 panels, where each was boiled for a half hour in 500mL of distilled water. After the boiling was complete, the water level was returned to 500mL with distilled water. The boiling water results were used as a comparison point for the other test methods, as it enables a high extraction percentage of salts from the surface.

Test Condition 9

Test condition 9 was performed to determine the ability of the conductivity methods to accurately measure a series of four standard conductivity reference solutions. The four solutions tested were 23 $\mu\text{S}/\text{cm}$, 84 $\mu\text{S}/\text{cm}$, 447 $\mu\text{S}/\text{cm}$, and 1000 $\mu\text{S}/\text{cm}$ of potassium chloride (KCl). Detection methods A, B, D, E2 and F were used for this test. Note that since methods A and E2 use the same conductivity gage, one set of data represents both techniques.

Remediation

Phase I Evaluation of Nine Remediation Methods on Complex Test Panels

Complex test panels were created by bolting one (1) 3-inch by 7-inch by 1/4-inch steel plate to one (1) 6-inch by 12-inch by 1/4-inch steel plate with four (4) steel threaded 1/2-inch fasteners. The plates were fabricated from A-36 hot rolled steel. The steel fasteners had a black oxide coating. A 1/4-inch diameter hole was machined at the top of the larger plate to facilitate handling.

After machining, the flat steel plates were cleaned using International 950 degreaser and power washed at 3100 psi with a 25° fan tip. The mill scale was not removed from the test panels. After washing the plates, the unassembled (flat) plates were exposed to GMW 14872 chamber for 10 cycles before being removed and assembled. This allowed rust scale to build up in the crevice between the panels. After assembly, the complex test panels were exposed to GMW 14872 chamber for an additional 5 cycles. Due to space constraints, the panels were pre-rusted in two batches.

Triplicate, 1-inch by 2-inch cold-rolled steel witness coupons were exposed with each batch of panels. These witness coupons were evaluated for salt contamination and average corrosion penetration at the end of the pre-rusting period. Salt contamination was determined using the boiling water extraction and both chloride ion test strips and conductivity measurements. Average corrosion penetration was determined from mass loss measurements. Table 13 presents the results. The corrosion rates had a relative standard deviation (RSD) of 1.1% to 2.7% and were consistent with the test method expectations. The chloride measurements had an RSD of 2.4% for batch 1 but 40.8% for batch 2. Furthermore, batch 2 had an average of twice as much chloride on the surface. There is no obvious explanation for the difference.

Table 13 – Pre-Rusting Witness Coupon Data

	Average Corrosion Penetration, mils			Chloride Concentration, $\mu\text{g Cl}^-/\text{cm}^2$		
	Avg	Std Dev	RSD	Avg	Std Dev	RSD
Batch 1	5.21	0.14	2.7%	323	7.9	2.4%
Batch 2	5.96	0.07	1.1%	608	248	40.8%

Figure 10 shows representative rusted complex panels. The panels had a uniform corrosion appearance but upon closer inspection, varying degrees of mill scale was evident on the panel surfaces. To characterize the extent of salt contamination on the test panels, four complex panels were disassembled and evaluated using a boiling water extraction as described in SSPC Guide 15. A fifth panel was reserved for later analysis.



Figure 10. Rusty, Salt Contaminated Complex Test Panels.

The boiling water method was completed by first unscrewing and disassembling the two plates comprising each complex panel. Each plate was placed on two, 4mm diameter glass rods in a separate Pyrex container with sufficient distilled water (extraction water) to cover the plate (roughly 500mL for the 3x7 plate, and 1000mL for the 6x12 plate). The panels were boiled on top of a laboratory hot plate for a half hour with distilled water added as necessary to keep the water level above the panel.

After 30 minutes, the Pyrex containers were allowed to cool. The panels were removed from the extraction water and rinsed off with distilled water. The volume of extraction solution was measured with a graduated cylinder and the solutions were tested for chloride with a 30-600ppm low-range chloride test strip. If the solution contained less than 30 ppm (noted by no color change occurring on the test strip) a 0-60ppm chloride ion detection tube was used to measure chloride concentration. The total chlorides removed from the panel was mathematically determined from the solution concentration and solution volume. The solutions were tested for conductivity with a Horiba LAQUAtwin meter.

The difference in chloride concentration on the boldly exposed and crevice surfaces was determined by assuming the two types of surface were uniformly contaminated (i.e., all bold surfaces have one average level of contamination and all crevice surfaces have another average level of contamination) and applying the following logic:

The 3-inch by 7-inch panel has roughly 135 square centimeters of boldly exposed surface and 135 square centimeters of surface in the crevice

The 6-inch by 12-inch panel has roughly 794 square centimeters of boldly exposed surface and 135 square centimeters of surface in the crevice

$$Cl_{3 \times 7 \text{ panel}} = 135 Cl_{\text{Bold Surface}} + 135 Cl_{\text{Crevice}}$$

$$Cl_{6 \times 12 \text{ panel}} = 794 Cl_{\text{Bold Surface}} + 135 Cl_{\text{Crevice}}$$

Rearranging provides:

$$Cl_{\text{Bold Surface}} = (Cl_{6 \times 12 \text{ panel}} - Cl_{3 \times 7 \text{ panel}})/(794-135)$$

$$Cl_{\text{Crevice}} = (Cl_{3 \times 7 \text{ panel}} - 135 Cl_{\text{Bold Surface}})/135$$

Where:

$Cl_{3 \times 7 \text{ panel}}$ is the total measured chloride on the 3x7 inch panel in μg

$Cl_{6 \times 12 \text{ panel}}$ is the total measured chloride on the 6x12 inch panel in μg

$Cl_{\text{Bold Surface}}$ is the unknown chloride concentration on the bold surfaces in $\mu\text{g}/\text{cm}^2$

Cl_{Crevice} is the unknown chloride concentration on the crevice surfaces in $\mu\text{g}/\text{cm}^2$

After determining the chloride concentration on the test panels, the corrosion penetration on four control panels was determined by measuring the eight deepest pits on the bold surface and crevice surface of the 3 by 7 panel. The panels were cleaned using glass bead media and eight pits that were visually estimated to be the deepest were measured using a pit depth gage. Table 14 presents the results. Interestingly, the data do not confirm the difference in chloride contamination observed on the witness panels. The data suggest more chloride contamination and deeper pitting in the crevice than on the bold surface. The data also demonstrate the variability in test panel condition.

Table 14 – Characterization Data from Control Test Panels

Panel (Batch)	Crevice Surface			Bold Surface		
	Deepest measured pit	Average measured pit	Average Chlorides $\mu\text{g Cl}^-/\text{cm}^2$	Deepest measured pit	Average measured pit	Average Chlorides $\mu\text{g Cl}^-/\text{cm}^2$
4 (1)	10 mils	8.1 mils	146	5 mils	3.7 mils	89
5 (2)	9 mils	5 mils	71	7 mils	6 mils	56
6 (2)	12 mils	6.8 mils	105	3 mils	2.2 mils	64
105 (1)	16 mils	10.7 mils	274	5 mils	3 mils	12
Average	11.8 mils	7.7 mils	149.0	5.0 mils	3.7 mils	55.3
Std Dev	3.1 mils	2.4 mils	88.8	1.6 mils	1.6 mils	32.1
RSD	26%	31%	60%	33%	44%	58%

Table 15 summarizes the various remediation techniques performed on the remaining panels. Each of the techniques is described in more detail below. Panels were prepared with nine surface preparation methods. After surface preparation, the residual salt levels were measured on a sample of the prepared test panels using the technique described above. The remaining remediated panels were used for coating performance testing as described in the next section.

Table 15 – Remediation Methods Evaluated on Complex Test Panels

Surface Preparation (Remediation Method)	Number of Panels
SP-10, Abrasive Blast Cleaning	28 panels
Pressure Washing, 3,100 psi followed by SP-10, Abrasive Blast Cleaning	24 panels
SP-11, Near White Metal Power Tool Cleaning	24 panels
SP-3, Power Tool Cleaning	32 panels
Pressure Washing, 3,100 psi followed by SP-3, Power Tool Cleaning	40 panels
Pressure Washing, 3,100 psi with the addition of an alkaline soluble salt remover followed by SP-3, Power Tool Cleaning	28 panels
Pressure Washing, 3,100 psi with the addition of an acidic soluble salt remover followed by SP-3, Power Tool Cleaning	24 panels
Ultrahigh Pressure Waterjetting (40,000 psi)	28 panels
Wet abrasive blasting	24 panels

Surface Preparation (Remediation) Techniques

Nine surface preparation methods were used to prepare panels for exposure testing. Following is a brief description of each surface preparation method used.

SSPC SP-10, Near-White Metal Blast (28 panels)

Near-white metal blasting was included in the test matrix because it is a very common surface preparation technique for maintenance and repainting of bridges. Twenty-eight (28) complex test panels were prepared to an SSPC SP-10, *Near-White Metal Blast* by abrasive blasting in a blast cabinet with 36 grit aluminum oxide abrasive. After abrasive blasting, the panels had a clean, near-white metal surface without rust or mill scale and less than 5% staining. The average surface profile after abrasive blasting was 3.3 mils.

SSPC SP-10, Near White Metal Blast after 3,100 psi pressure wash (24 panels)

This condition was added to the test matrix in lieu of one of the wet abrasive blasting techniques to evaluate the benefit of pressure washing before near white metal blasting during maintenance and repainting of bridges. Twenty-four (24) complex test panels were pressure washed at 3,100 psi and then prepared to an SSPC SP-10, *Near-White Metal Blast*. Pressure washing was accomplished using a gas-powered pressure washer capable of 3,100 psi at 2.5 gallons per minute. A 25-degree fan tip was used and manipulated across the panel such that the crevices were addressed but an unreasonable amount of time was not spent on each panel (i.e., something representative of production work). The pressure washer was connected to a city water source for this condition.²⁰ After pressure washing, abrasive blasting was performed in a blast cabinet with 36 grit aluminum oxide abrasive. After abrasive blasting,

²⁰ The city water source had a conductivity of 125-140 $\mu\text{S}/\text{cm}$ and a chloride ion concentration of 15 ppm. Because of the thin remaining water film evaporating from the surface, this will have a small but not significant impact on the surface contamination. At that concentration, a 0.05-inch thick water “film” would have to evaporate on a surface to deposit 2 $\mu\text{g Cl}^-/\text{cm}^2$. The water used is relatively high purity when compared to other city water sources. For reference, a California water board report indicates that typical conductivity of potable water is 30-1500 $\mu\text{S}/\text{cm}$ and the EPA recommended upper limit is 250 ppm Chloride ion to regulate aesthetic of drinking water like appearance, taste and odor.

the panels had a clean, near white metal surface without rust or mill scale and less than 5% staining. The average surface profile measured after abrasive blasting was 3.3 mils.

[SSPC SP-11, Power Tool Cleaning to Bare Metal using a Bristle Blaster \(24 panels\)](#)

Power tool cleaning is commonly used for surface preparation during maintenance painting of bridges (e.g., spot surface preparation during maintenance painting and touch-up). Twenty-four (24) complex test panels were power tool cleaned to SSPC SP-11, *Power Tool Cleaning to Bare Metal* using a Bristle Blaster. This level of surface preparation requires removal of all rust, scale, and paint by power tools resulting in a minimal 1.0 mil surface profile. After cleaning, most of the surface appeared shiny-metallic and clean, with little to no visible rust. Due to nature of the tool, there was difficulty remediating around the bolts and into the crevices. The average surface profile after power tool cleaning with the Bristle Blaster was 3.2 mils. Note that this measurement in part reflects the texture of the rusted surface (see pitting data in Table 14).

[SSPC SP-3, Power Tool Cleaning using a Needle Gun \(32 panels\)](#)

Thirty-two (32) complex test panels were power tool cleaned to SSPC SP-3, *Power Tool Cleaning*. This level of surface preparation requires removal of loose rust, loose mill scale, and loose paint by power tool chipping, descaling, sanding, wire brushing, and grinding. Power tool cleaning was performed using a needle scaler. After cleaning, the panels had an orange brown color due to the rust that was not removed with the scaler. This technique works fairly well around bolts and crevices. The average surface profile measured after power tool cleaning was 3.3 mils. Note that this measurement in part reflects the texture of the rusted surface (see pitting data in Table 14).

[3,100 psi pressure wash followed by SSPC SP-3, Power Tool Cleaning using a Needle Gun \(40 panels\)](#)

It is common practice to pressure wash bridges before power tool cleaning during maintenance painting of bridges. This condition will help to determine the incremental benefit of the pressure washing and power tool cleaning versus just power tool cleaning. Forty (40) complex test panels were pressure washed then power tool cleaned to SSPC SP-3, *Power Tool Cleaning*. The test panels were lightly scraped with a putty knife to take off heavy rust and scale before pressure washing. Pressure washing was accomplished using a gas-powered pressure washer capable of 3,100 psi at 2.5 gallons per minute. A 25-degree fan tip was used and manipulated across the panel such that the crevices were addressed but an unreasonable amount of time was not spent on each panel (representative of production work). The pressure washer was connected to a city water source for this condition.²⁰ After pressure washing, power tool cleaning was performed using a needle gun. After cleaning, the panels had an orange brown color due to the rust that was not removed with the needle gun. This technique works fairly well around bolts and crevices. The average surface profile measured after power tool cleaning was 2.7 mils. Note that this measurement in part reflects the texture of the rusted surface (see pitting data in Table 14).

[3,100 psi pressure wash with Alkaline salt remover followed by SSPC SP-3, Power Tool Cleaning using a Needle Gun \(28 panels\)](#)

Some owners have allowed or specified the addition of salt removers to the water used during pressure washing. This is one of two additives included in the test plan. This condition will help to determine the incremental benefit of the salt removers versus using tap water alone. Twenty-eight (28) complex test panels were pressure washed at 3,100 psi using water with Hold-Tight 102 salt remover and then power tool cleaned to SSPC SP-3, *Power Tool Cleaning*. The test panels were lightly scraped with a putty knife to take off heavy rust and scale before pressure washing. Pressure washing was accomplished using a

gas-powered pressure washer capable of 3,100 psi at 2.5 gallons per minute. A 25-degree fan tip was used and manipulated across the panel such that the crevices were addressed but an unreasonable amount of time was not spent on each panel (i.e., something representative of production work). The pressure washer was connected to a tank containing 2% by volume of Hold Tight 102. After pressure washing, power tool cleaning was performed using a needle gun. After cleaning, the panels had an orange brown color due to the rust that was not removed with the scaler. This technique works fairly well around bolts and crevices. The average surface profile measured after power tool cleaning was not measured but is expected to be similar to the panels that were prepared with the same needle scaler.

[3,100 psi pressure wash with Acidic salt remover followed by SSPC SP-3, Power Tool Cleaning using a Needle Gun \(24 panels\)](#)

Some owners have allowed or specified the addition of salt removers to the water used during pressure washing. This is the second of two additives included in the test plan. This condition will help to determine the incremental benefit of the salt removers versus using tap water alone. Twenty-four (24) complex test panels were pressure washed at 3,100 psi using water with CHLOR*RID salt remover and then power tool cleaned to SSPC SP-3, *Power Tool Cleaning*. The test panels were lightly scraped with a putty knife to take off heavy rust and scale before pressure washing. Pressure washing was accomplished using a gas-powered pressure washer capable of 3,100 psi at 2.5 gallons per minute. A 25-degree fan tip was used and manipulated across the panel such that the crevices were addressed but an unreasonable amount of time was not spent on each panel (i.e., something representative of production work). The pressure washer was connected to a tank containing 2% by volume CHLOR*RID solution. After pressure washing, power tool cleaning was performed using a Needle Scaler. After cleaning, the panels had an orange brown color due to the rust that was not removed with the scaler. This technique works fairly well around bolts and crevices. The average surface profile measured after power tool cleaning was not measured but is expected to be similar to the panels that were prepared with the same needle scaler.

[40,000 psi Ultra High-Pressure Waterjet to WJ-2 M, Very Thorough Cleaning \(28 panels\)](#)

Ultra-high pressure waterjetting is uncommon in the bridge coating industry, however it was included in this program because it may be an effective way to remove soluble contaminants during coating surface preparation. Twenty-eight (28) complex test panels were prepared to SSPC-SP WJ-2/NACE WJ-2 – Very Thorough Cleaning. This was achieved with NLB Corporation industrial waterjetting equipment operated at 40,000 Psi at 2.6GPM (0.52 GPM per jet). After being waterjetted, the panels were dried with compressed air to minimize flash rusting and get as much water out of the crevice as possible.²¹ Immediately after waterjetting, the panels had light flash rust on surface.²² Moderate flash rust had formed on the panels prior to coating application. The average surface profile measured after UHPWJ was 3.67 mils. Because UHPWJ does not impart a profile, this measurement reflects the texture of the rusted surface.

In addition to the test panels prepared at 40,000 psi, five (5) test panels were waterjetted at 10,000 psi at 1.20 GPM (0.37 GPM per jet) and five (5) test panels were waterjetted at 20,000 psi at 1.85 GPM (0.24

²¹ An air blowdown of crevices is a common way to minimize flash rusting when preparing surfaces with wet abrasive blasting or waterjetting methods.

²² Degrees of flash rusting are described in SSPC-VIS 4/NACE VIS 7 - Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting.

GPM per jet). With decreasing pressure, more residual rust was left on the surface as shown in Figure 11. These panels prepared at lower pressures will be evaluated for residual soluble salt to determine the effect of cleaning pressure on salt removal effectiveness.



Figure 11. Ultra-high Pressure Waterjetted panels (From l to r: 40ksi, 20ksi, 10ksi)

Wet Abrasive Blasting (24 panels)

SSPC and NACE standards describe a wet abrasive blast-cleaned (WAB) surface as “one prepared by combining water and abrasive in a blast cleaning operation by one of several methods, including 1) injection of water into the abrasive stream either internally or externally as the abrasive stream exits the blast nozzle; 2) injection of abrasive into pressurized water; or 3) use of an abrasive slurry under pressure to achieve the specified WAB degree of cleanliness.” Wet abrasive blasting is uncommon in the bridge coating industry, however it was included in this program because it may be an effective way to remove soluble contaminants during coating surface preparation. Twenty-four (24) complex test panels were prepared using wet abrasive blasting by an equipment vendor (Graco). The selected equipment operates by injection of abrasive into pressurized water.²⁰ Ecoquip EQ400t equipment was operated under the following conditions:

- Blast Pressure: 90psi @ blast pot
- Water/min: between 1pt and 1qt
- Abrasive/hr: about 150lbs
- Abrasive: Barton Garnet GTX 40/60/80
- Nozzle Used: #8 High Performance (w/ and w/o extension)

After being wet abrasive blasted, the panels were rinsed with water and dried with compressed air to keep flash rusting down and get as much water out of the crevice as possible. Figure 12 shows the wet abrasive blasting in process.



Figure 12. Wet Abrasive Blasting in Process

The panels were blasted to a near white metal condition. No flash rust had formed on the panels prior to coating application but some panels had minor staining emanating from the crevice. The average surface profile measured after abrasive blasting was 2.4 mils.

Phase II Evaluation of Combinations of Pressure Washing and Abrasive Blasting on Flat Panels

A series of tests was performed to explore the efficacy of salt remediation through multi-step processes involving pressure washing and abrasive blasting. These processes are commonly used on bridge coating projects, but there is some debate whether the sequence of events impacts the soluble salt removal effectiveness. The testing was designed such that the removal efficiency of each individual remediation step could be evaluated. The data provides insight on the influence of both the processes selected and the order in which they are performed on remediation efficiency.

The individual processes evaluated are shown in Table 16. The processes include combinations of the following remediation steps:

1. SSPC-SP 10/NACE No. 2 (SP-10) Media Blast – with 36 grit aluminum oxide blast media in a tabletop blast cabinet.
2. Pressure wash (PW) using potable water²⁰ and a 3,100 psi pressure washer. The wash included four double-passes over each side of the panel, taking no longer than 10 seconds per panel side (180 ft²/hr production rate). A 25-degree spay tip was used, and the pressure washer was kept at an angle between 30 and 60 degrees from the horizontal at a stand-off distance of 3-inches.
3. Pressure wash with the addition of CHLOR*RID (PW-CL) – followed the same procedure as the pressure wash but with addition of CHLOR*RID to the wash water at a ratio of 1:100.
4. Pressure wash with the addition of Hold Tight 102 (PW-HT) – followed the same procedure as the pressure wash but with addition of Hold Tight 102 to the wash water at a ratio of 1:100.

Table 16 – Multi-step Soluble Salt Remediation Processes

Step	Remediation of Pre-Rusted Panels						
1	SP-10	SP-10	PW	SP-10	PW-CL	SP-10	PW-HT
2	TEST	PW	SP-10	PW-CL	Sp-10	PW-HT	SP-10
3	SP-10	TEST	TEST	TEST	TEST	TEST	TEST
4	TEST	SP-10		SP-10		SP-10	
5		TEST		TEST		TEST	

Each remediation method was completed on two, 6-inch by 12-inch by 1/4-inch panels and one 3-inch by 4-inch by 1/4-inch panels. The larger panels were used to perform up to six soluble salt measurements on each side using detection method F (a multi-step conductivity technique). The smaller panels were chosen to utilize the boiling water salt extraction method. Boiling water salt extractions were completed by:

1. Placing panels in 1L of boiling distilled water
2. Allowing the panels to sit in the boiling water for a half hour
3. Cooling the water and panel down to room temperature
4. Removing the panel from the solution and rinsing it off with distilled water
5. Bringing the entire volume of the resulting solution up to 1L by adding distilled water
6. Measuring the solution for conductivity (Horiba Meter) and Chloride (Kitagawa Tubes)

At each “TEST” step indicated in Table 16, twelve measurements were performed using detection method F. In each case, measurement locations were randomly assigned, with the exception that if two panels were used for a test condition, one half of the measurements were performed on each panel (in randomly assigned locations). Where multiple remediation steps were performed on a given panel, the incremental salts removed with subsequent steps can be observed.

Phase III Evaluation of Combinations of Pressure Washing and Power Tool Cleaning on Flat Panels

A series of tests was performed to explore the efficacy of salt remediation through multi-step processes involving pressure washing and power tool cleaning. These processes are commonly used on bridge coating projects; this testing explored whether the sequence of events impacts the soluble salt removal effectiveness. The testing was designed such that the removal efficiency of each individual remediation step could be evaluated. The data provides insight on the influence of both the processes selected and the order in which they are performed on remediation efficiency.

Test panels were pre-rusted for 10 days in GMW 14872 exposure. Two panel sizes were chosen for the testing: 6-inch by 12-inch flat steel panels were examined with field level soluble salt detection methods A, B, C, and F and 4-inch by 3-inch panels were examined using boiling water extraction. Boiling water extraction was performed for 30 minutes in 500mL of distilled water. After extraction, the panels were removed, the water cooled to room temperature, and sufficient deionized water was added to bring the volume back to 500mL. The water was tested for conductivity with an LAQUATwin conductivity probe and chloride concentration using chloride ion detection tubes.

Power tool cleaning was performed using a needle gun to create a uniform surface free of loosely adherent pack rust. The pressure wash was completed at 3,100psi with a 25-degree fan tip at a standoff distance of 3 inches and an angle between 30 and 60 degrees from the horizontal. The wash included four double-passes over each side of the panel, taking no longer than 10 seconds per panel side (180 ft²/hr production rate).

Table 17 lists the different iterations of surface preparation completed. Each “test” step includes three measurements of each field detection method, and boiling water extraction of one test panel.

Table 17 – Testing Sequence

Steps	Scenario 1	Scenario 2	Scenario 3 ^a
1	Needle Gun	Pressure Wash	Scrape w/Putty Knife
2	Pressure Wash	Needle Gun	Needle Gun
3	Test	Test	Pressure Wash
4	Needle Gun	Pressure Wash	Test
5	Test	Test	Needle Gun
6			Test

^a Detection method b was not used for scenario 3

Coating Performance Over Remediated Surfaces

Panels prepared with nine surface preparation methods were coated with four generically different coating systems. Table 18 shows the final test matrix for the complex panel testing. Coating performance over the various remediated surfaces was evaluated in both natural and accelerated exposure tests.

Table 18 – Test Matrix for Complex Panel Evaluation

Surface Preparation (Remediation Method)		Organic Zinc/ Epoxy/ Urethane	High-Ratio Calcium Silicate	Waterborne Acrylic	Moisture Cure Urethane System
SP-10, Abrasive Blast Cleaning		(10) Natural & Accelerated	(6) Natural	(6) Natural	(6) Natural
Pressure Washing, 3,100 psi	SP-10, Abrasive Blast Cleaning	(6) Natural	(6) Natural	(6) Natural	(6) Natural
SP-11, Near White Metal Power Tool Cleaning		(6) Natural	(6) Natural	(6) Natural	(6) Natural
SP-3, Power Tool Cleaning		(6) Natural	(6) Natural	(10) Natural & Accelerated	(10) Natural & Accelerated
Pressure Washing, 3,100 psi	SP-3, Power Tool Cleaning	(10) Natural & Accelerated	(10) Natural & Accelerated	(10) Natural & Accelerated	(10) Natural & Accelerated
Pressure Washing, 3,100 psi with the addition of an alkaline soluble salt remover	SP-3, Power Tool Cleaning	(6) Natural	(10) Natural & Accelerated	(6) Natural	(6) Natural
Pressure Washing, 3,100 psi with the addition of an acidic soluble salt remover	SP-3, Power Tool Cleaning	(6) Natural	(6) Natural	(6) Natural	(6) Natural
Ultrahigh Pressure Waterjetting (40,000 psi)		(6) Natural	(6) Natural	(6) Natural	(10) Natural & Accelerated
Wet abrasive blasting		(6) Natural	(6) Natural	(6) Natural	(6) Natural

Coating Application

Four coating systems were applied to prepared panels for exposure testing. Following is a brief description of each coating system used.

Coating A, Organic Zinc/Epoxy/Urethane System from NEPCOAT List B (62 panels)

This coating system is intended to represent a standard, state-of-the-art field-applied bridge coating system. As noted in our literature review, FHWA research has shown that systems with zinc rich primers are more tolerant of soluble salt contamination than other coatings. The coating system is a Sherwin Williams NEPCOAT-approved system consisting of Zinc Clad III primer, Macropoxy intermediate coat, Acrolon topcoat. The coating system was applied to the complex test panels using brushes in

accordance with the coating manufacturers published technical literature. The total dry film thickness for this system is a minimum of 10 mils as follows:

- Prime Zinc Clad III HS 3.0 - 5.0
- Inter Macropoxy 646 3.0 - 6.0
- Finish Acrolon 218 HS 3.0 - 5.0

The final applied thickness was measured between 20 and 25 mils.

Coating B, High Ratio Calcium Silicate System (62 panels)

This coating was selected to evaluate a proprietary system for maintenance painting. The coating system is a TERMARUST high ratio calcium silicate maintenance system consisting of TR2200HS penetrant sealer and two coats of TR2100. The TR2200HS HRCSA Penetrant Sealer was applied to the crevice corroded joints and fasteners. Subsequently, three coats of TR2100 were brush-applied. The final applied thickness was measured between 10 and 20 mils.

Coating C, Waterborne Acrylic maintenance system (62 panels)

This coating system was selected to evaluate a common acrylic maintenance painting system. The selected coating was a Carboline system consisting of Carbocrylic 3358 MC primer at 2-3 mils DFT and two coats of Carbocrylic 3359 at 2-3 mils per coat. The single component materials were brush-applied. The final applied thickness was measured between 6 and 10 mils.

Coating D, Moisture-Cure Urethane System – penetrating sealer/ zinc rich (SP-10 only)/mastic/finish (66 panels)

This coating system was selected to evaluate a moisture-cure urethane maintenance painting system. The selected coating was a Wasser moisture cure urethane coating system consisting of MC-Miozinc 100 primer, MC-Miomastic 100 intermediate coat and MC-Luster 100 finish coat. A spot primer of MC-Miozinc 100 thinned 20% was brush-applied to all crevice areas for penetration into existing corrosion. A coat of MC-Miozinc was then brush-applied at 3-5 mils dft. An intermediate coat of MC-Miomastic 100 was brush-applied at 3-5 mils dft. Finally, a coat of MC-Luster 100 (semi-gloss) was brush-applied at 3-5 mils dft. The final applied thickness was measured between 16 and 25 mils.

Corrosion Testing

Coated test panels were exposed to natural and accelerated tests to ascertain the impact of soluble salt contamination and surface preparation technique on coating performance. In addition, cleaning (pressure washing) steps were incorporated into the testing to quantify the benefit of cleaning on coating performance. Each of the two tests is described in detail below.

Accelerated Corrosion Tests

Complex panel testing in modified GMW 14872 exposure began on May 25th, 2017. Four replicate panels of nine remediation and coating combinations were created, as shown in Table 19.

Table 19 – Remediation and Coating of Modified GMW Exposure Panels

Remediation Method	Coating
SP-10 Abrasive Blast Cleaning (SP-10)	A – Organic Zinc/ Epoxy/Urethane System from NEPCOAT List B
Pressure Washing, <5000 psi (PW 1)	
Pressure Washing, <5000 psi (PW 1)	B – High Ratio Calcium Silicate System
Pressure Washing, <5000psi with acidic soluble salt remover (PW 3)	
SP-3, Power Tool Cleaning, Needle Gun (SP-3)	C – Waterborne Acrylic System
Pressure Washing, <5000 psi (PW 1)	
SP-3, Power Tool Cleaning, Needle Gun (SP-3)	D – Moisture Cure Urethane System
Pressure Washing, <5000 psi (PW 1)	
Ultra-High Pressure Waterjetting, WJ-2M at 40,000 psi (UHPWJ)	

Two modifications were made to the GMW 14872 testing procedure – a modification to the spray cycle and the addition of a rinsing procedure. On the first five days of testing, the panels were sprayed in accordance with GMW 14872. On the following five days, the panels were not sprayed as required in GMW 14872. This procedure of 5 days of spraying followed by 5 days without spraying continued throughout the testing.

A rinsing procedure was added to simulate bridge washing. The panels to be washed were removed from the GMW 14872 test chamber and pressure washed (front and back) with a 3100 psi pressure wash using city water.²⁰ A 40° spray tip was used at a standoff distance of approximately 3 feet and an angle of attack between 30 and 60 degrees relative to the panel surface. The panels were laid out flat and a double pass across each panel was made before flipping them over and making a double pass on the back of each panel. The schedule for washing is visually shown in Table 20.

Table 20 – Spray Schedule

Test Cycles (white indicates no rinsing, dark blue indicates a pressure wash occurred)												
Set	7	17	27	37	47	57	67	77	87	97	107	117
1												
2												
3												
4												

Inspections of the panels has been completed at cycles 10, 20, 40, 80 and 120. The following data was collected at each inspection:

- Removal, media blasting, and weighing of four 2-inch by 1-inch mass loss coupons, one from each set.
- Through film corrosion in accordance with ASTM D610
- Blistering in accordance with ASTM D714

- Underfilm corrosion (creepage) from the scribe in accordance with D1654
- Photographs of the panels in test

After the final inspection, the edge of a utility knife was used to pick away at the coating around the scribe, removing any loosely adherent coating caused by corrosion penetrating from the scribe. Following this a set of 12 measurements were made around the scribe to determine the final destructive scribe cutback. Photographs were then taken of the panels.

The panels were then disassembled with the assistance of a pneumatic impact gun, removing the 3 x 7 coupon from the larger 6 x 12 panel. The mating surfaces of both were photographed before the crevice area of the 6 x 12 panel was media blasted with 90-120 grit glass bead. After the rust was removed from the area, the eight visually deepest pits were measured and recorded across the surface. Care was taken to inspect the entire cleaned surface by breaking the surface down into smaller 1-inch by 3-inch areas, although more than one pit could be measured in each area.

Natural Exposure Test

A rural test site in southern New Jersey was used for the natural exposure testing. One set of panels did **not** receive a deicing salt spray. The remaining two sets received periodic salt spray during the winter months in a fashion similar to the NEPOVERCOAT test protocol.²³ Specifically, they were sprayed with a 1% sodium chloride (NaCl) solution weekly from December through March. The solution was comprised of tap water and commercial rock salt. One of the salted panel sets was pressure washed (using tap water at 3100 psi) each spring to represent an annual cleaning cycle.

Field Observations

As part of the project, soluble salt data was collected on bridges in a variety of circumstances. In total, over 1,000 individual measurements were recorded by multiple operators on five structures. The intent of the field data collection is to (a) evaluate multiple salt detection methods in a field setting, (b) determine the impact of the event on the structure salt contamination levels, (c) better understand salt collection patterns and (d) determine the effectiveness of various remediation methods.

Close access to the structure was necessary to make the necessary measurements. On structures where active work was being performed (bridge washing or surface preparation), measurements were made at times and locations that did not interfere with the on-going work. Table 21 summarizes the structures where measurements were performed.

The general approach was to identify areas of interest which were 1-2 square feet of surface in a nominally identical condition based on visual assessment. In each designated test area, a measurement was made with each of the available methods. The data was logged along with any other notable observations (e.g, visible staining). Feedback was solicited from inspection personnel on the jobsite. Sometimes these discussions produced meaningful observations or experiences which are included in the discussion of the salt detection instruments.

²³ G. Tinklenberg, "Alternate Paint Systems for Over Coating," The State of New Hampshire Department of Transportation, Report No. SPR-PL-PR-1(31) Project 12323 D, October 2000

Table 21 – Summary of Field Test Measurement Locations

Structure	Condition	Measurement Locations	Detection Methods
Natural accumulation of salt on a painted overpass			
NJDOT Rt 55 Overpass	As found on four dates	6	B, C, F
Marine Parkway Bridge	As found	9	A, B, C, D, F
Throgs Neck Bridge	As found	2	A, B, C, D, F
Bridge Washing			
Verrazano-Narrows Bridge	Before & After Washing	16	B, C, D
During Bridge Painting Projects			
RFK Bridge (NYC)	Blasted Steel	7	A, B, C, D, F
Throgs Neck Bridge	Blasted Steel	1	A, B, C, D, F
RFK Bridge (NYC)	Primed Steel	12	A, B, C, D, F
Marine Parkway Bridge	Primed Steel	5	A, B, C, D, F
Throgs Neck Bridge	Primed Steel	1	A, B, C, D, F

Results and Discussion

Detection

Laboratory testing of detection methods was performed in nine conditions intended to provide insight to the factors that impact variability and/or bias of the measured value. Details on each of the detection methods and test conditions are provided in the experimental approach section. Rather than discuss each test condition individually, the test conditions with similar intentions are presented together.

The first section presents test conditions 1 and 9. These conditions involved direct injection of solutions into the test instruments, thus eliminating the variation associated with extraction of soluble salts from the surface.

The second section presents test conditions 2 and 7. These conditions involved measurement of “clean” surfaces. The data demonstrate the precision with which “zero” can be measured.

The third section presents test conditions 3 through 6. These conditions are intended to validate the measurement and extraction processes by controlling different contamination scenarios. The conditions involve either detecting sodium chloride in a simulated pit (conditions 3 and 5) or measuring a dried salt mixture on the surface (conditions 4 and 6). Furthermore, two of the conditions (5 and 6) evaluated salts that had “aged” on the steel surface for three days.

The final section presents test condition 8. This condition consisted of pre-rusted panels that were abrasive blasted to SSPC-SP 6 / NACE No. 3 Commercial Blast Cleaning, representing a realistic field measurement scenario on a protective coatings project.

Test Conditions 1 and 9 – Direct Injection of Known Solutions

Multi-step Conductivity Detection Method A

Detection method A involves the use of an adhesively bonded latex patch in accordance with the US Navy standard procedure. This technique involves adding three (3) milliliters of distilled water to the patch to extract salts from the surface and measuring the conductivity of the extraction fluid. Ion specific results are not reported using this method. To evaluate the method, patches were folded in half, 3mL of the stock was injected into the patch, the patches were massaged for 90 seconds, the solution was extracted and the conductivity was measured. Two operators each made three measurements with each solution. Table 22 provides the actual solution chemistries.

Table 22 – Solution Chemistries for Validation of Detection Method A

ID	Calculated Chloride Concentration, ppm	Calculated Conductivity, $\mu\text{S}/\text{cm}$	Stock added to patch, mL	Patch Surface Area, cm^2	Calculated surface Chloride, $\mu\text{g Cl}^-/\text{cm}^2$
0	0	2.33	3	12.5	0
1	21.2	76.7	3	12.5	5.1
2	60.7	219.15	3	12.5	14.6
3	151.6	547.88	3	12.5	36.4

Figure 13 shows the relationship between the calculated conductivity and the indicated conductivity after the simulated measurement procedure. The measurements have a variability (RSD) between 4.5% and 8%. The average measured conductivity is between 3% and -5% of the calculated value.

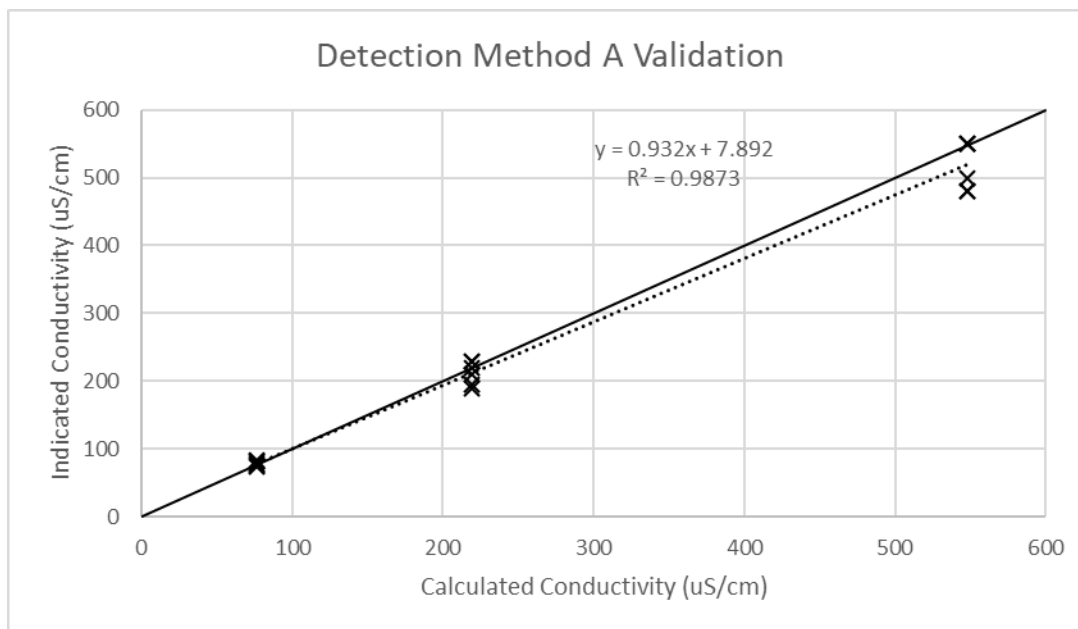


Figure 13. Conductivity Validation for Detection Method A

Fully Automated Conductivity Detection Method B

Detection method B involves an instrument consisting of a rigid cell magnetically attached to a surface. Three milliliters (3 mL) of distilled water is injected into the instrument, the water is agitated, and the conductivity of the water is measured. The instrument reports both conductivity and a calculated salt level. To evaluate the instrument, three sodium chloride solutions were directly injected into the meter. Table 23 provides the actual solution chemistry.

Table 23 – Solution Chemistries for Validation of Detection Method B

ID	Calculated Chloride Concentration, ppm	Calculated Conductivity, $\mu\text{S}/\text{cm}$	Stock added to meter, mL	Cell Surface Area, cm^2	Calculated surface Chloride, $\mu\text{g Cl}^-/\text{cm}^2$
0	0	2.33	3	12.5	0
1	21.2	76.7	3	12.5	5.1
2	60.7	219.15	3	12.5	14.6
3	151.6	547.88	3	12.5	36.4

The instrument was attached to a piece of steel with an ethylene acrylic acid film coating. Three milliliters (3 mL) of stock solution was injected into the meter and the measurement performed. Two operators each made three measurements with each solution. The result of a measurement using distilled water at the end of the series of measurements confirmed that the meter and coated surface

did not have any residual contamination that could have affected the data. Both salt concentration and conductivity indications were recorded from the instrument. Figure 14 shows the relationship between the indicated conductivity and the indicated salt concentration.

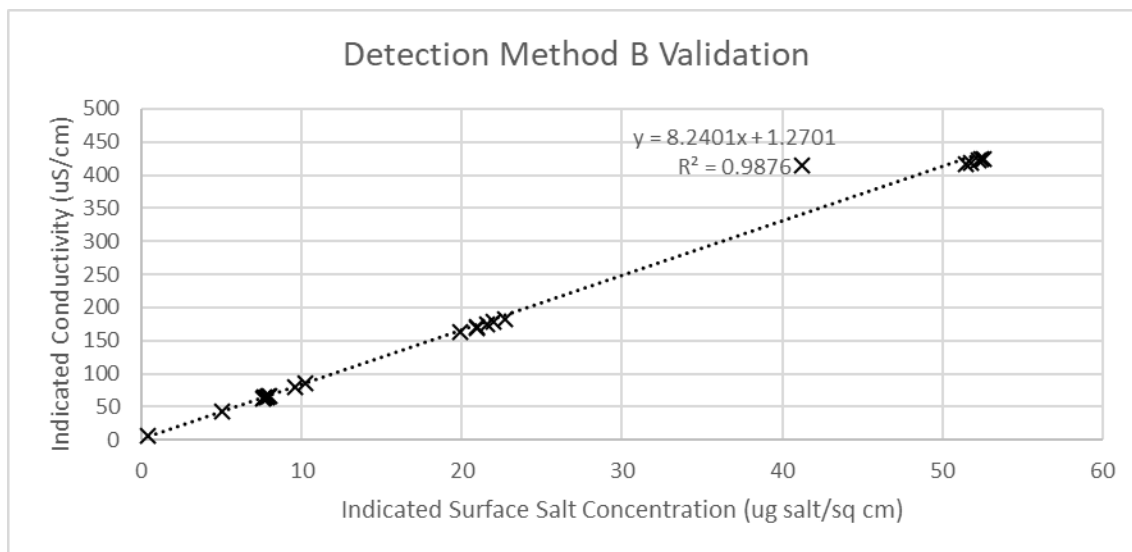


Figure 14. Conductivity-Surface Salt Concentration Relationship Generated by Detection Method B.

A least squares analysis suggests a strong correlation as expected since the instrument physically measures conductivity and calculates surface salt concentration based on the conductivity measurement. The manufacturer's literature states that they use the ISO 8502-9 equation to convert from conductivity to "surface salts." The ISO 8502-9 equation results in conductivity equaling 8.3 times the soluble salt concentration – within 4% of the experimentally determined correlation in Figure 14.

Figure 15 shows the relationship between the bulk solution conductivity and the indicated conductivity after the simulated measurement procedure. The data have a relative standard deviation (RSD) between 1.0% and 17.8%, with the higher RSD at the lowest conductivities. The average measured conductivity is between -14% and -23% of the calculated conductivity with the least bias at the lowest concentrations.

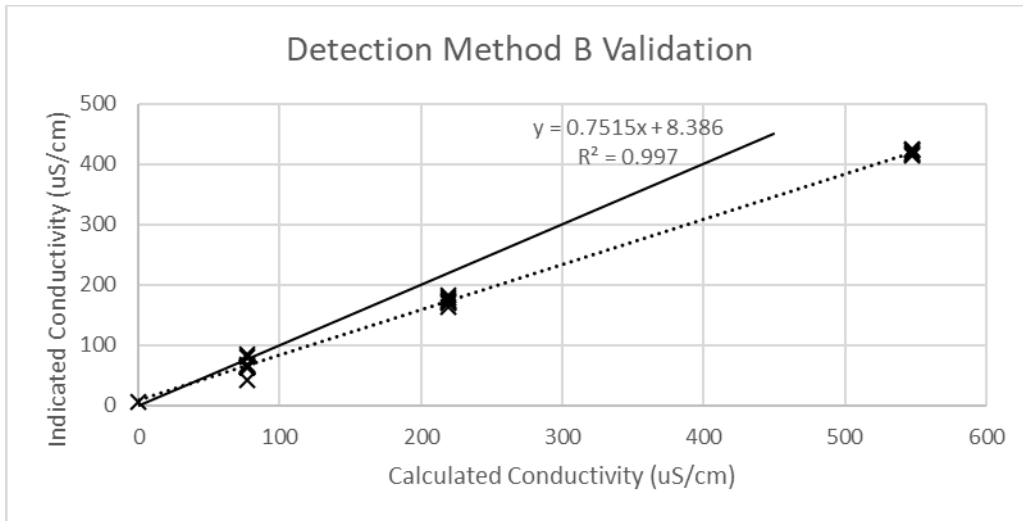


Figure 15. Conductivity Validation for Detection Method B

Figure 16 shows the relationship between the calculated surface chloride concentration and the measured total soluble salt concentration. The measurements have a relative standard deviation between 1.1% and 18.2%. The total soluble salt concentrations are 43% to 56% higher than the calculated chloride concentration. This is largely a result of the method of calculating total soluble salts.

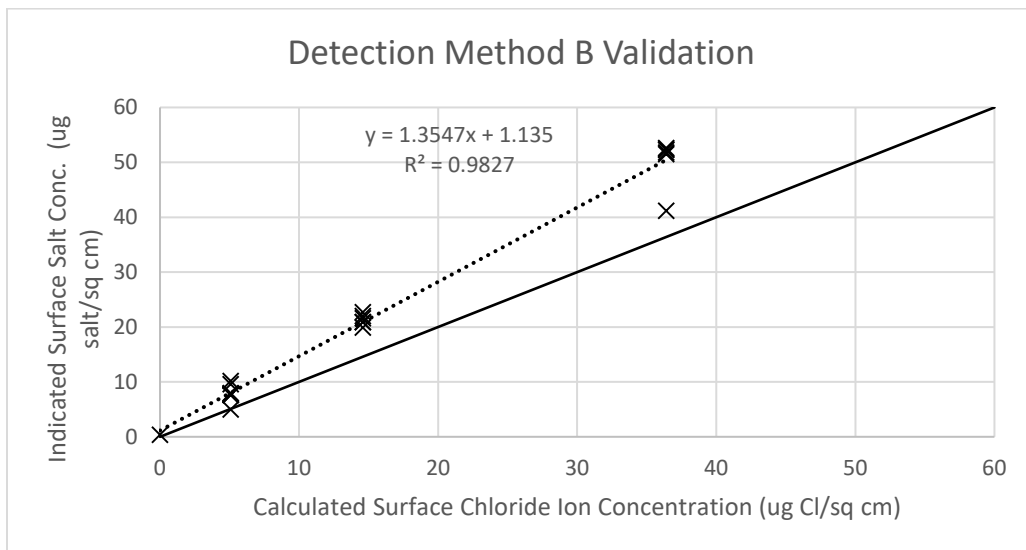


Figure 16. Surface Salt Concentration Validation for Detection Method B

Multi-Step Ion-specific Detection Method C

Detection method C allows users to apply a fixed volume of proprietary extraction fluid to a test surface via a latex sleeve. The extraction fluid dissolves salts and is collected by removing the sleeve from the surface. The extraction fluid is tested for chlorides using a chloride ion detection tube. To evaluate the procedure, five solutions were made using distilled water and sodium chloride (NaCl). Table 24 presents the characteristics of the five solutions. Three operators each made triplicate measurements of each solution for a total of nine data points per solution.

Table 24 – Solution Chemistries for Validation of Chloride Ion Detection Tubes

ID	Sodium Chloride, g/L	Calculated Conductivity, $\mu\text{S}/\text{cm}$	Calculated Chloride Concentration, ppm	Measured Conductivity, $\mu\text{S}/\text{cm}$	Chloride Concentration calculated from measured conductivity, ppm
C1	0	0	0	1.3	0.37
C2	0.0050	10.9	3	12.0	3.32
C3	0.0160	34.88	9.7	34.0	9.41
C4	0.0494	107.7	29.8	99.0	27.40
C5	0.0990	215.8	59.9	220.3	60.98

Figure 17 demonstrates the relationship between the calculated chloride concentrations the indicated chloride concentrations. The data exhibit a relative standard deviation between 0% and 10%. Except for solution C2 (3 ppm), the measured values are within 0.2% to -14.8% of the calculated value. Solution 2 has a theoretical chloride concentration of 3.32 ppm but the chloride ion detection tubes consistently read 1 ppm. This value is at the low end of the resolution for the tubes.

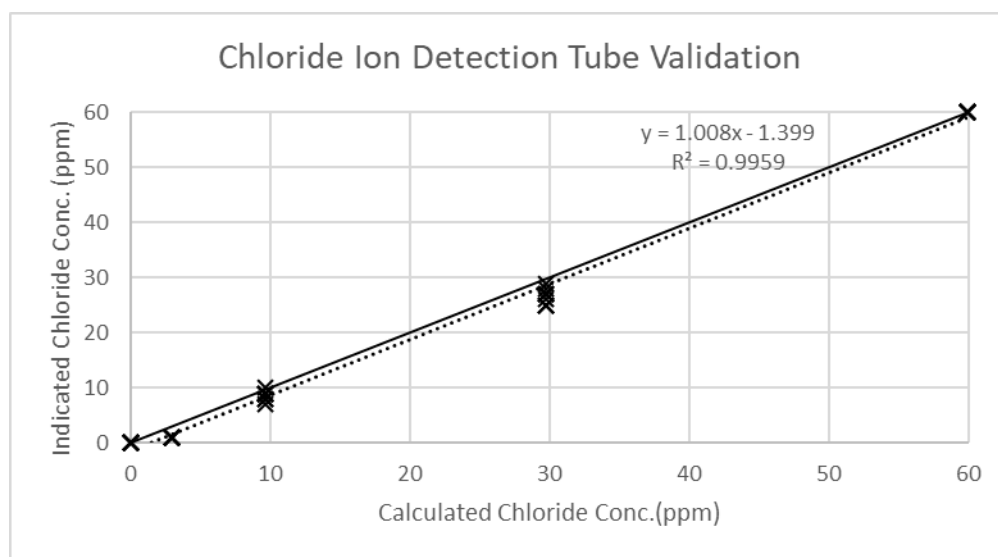


Figure 17. Chloride Concentration Validation for Chloride Ion Detection Tubes

Multi-Step Conductivity Detection Method D

Detection method D involves an electronic device that measures the electrical conductivity of a circular pad of wetted paper among an 8 by 8 matrix of contact points. The circular pad is pre-wet with 1.6 ml of distilled water and placed on the surface to be tested. Salts are expected to dissolve in the wet paper. For the current testing, aliquots of a solution with a known chloride concentration were used to pre-wet the paper that was then directly placed on the instrument. This avoided the extraction phase. A series of solutions were made using sodium chloride and distilled water. These solutions were selected such that when 1.6 mL was applied to the pad, it would result in an actual chloride concentration in the pad that spans the range of the meter (0 to 60 $\mu\text{g Cl}^-/\text{cm}^2$). Table 25 shows the solution concentrations used.

Table 25 – Solution Chemistries for Validation of Detection Method D

ID	Calculated Chloride Concentration, ppm	Calculated Conductivity, $\mu\text{S}/\text{cm}$	Stock added to meter, mL	Pad Surface Area, cm^2	Calculated surface Chloride, $\mu\text{g Cl}^-/\text{cm}^2$
S1	2249	8127	1.6	95	37.9
S2	1500	5418	1.6	95	25.3
S3	749.8	2709	1.6	95	12.6
S4	449.9	1625	1.6	95	7.6
S5	156.0	563.6	1.6	95	2.6
S6	19.2	69.22	1.6	95	0.3

Figure 18 shows the relationship between indicated salt concentration and indicated conductivity based on all measurements. A least squares analysis of the data shows that the instrument calculates salt concentration as 0.0084 times the conductivity. This is consistent with the conversion equation provided in ISO 8502-9.

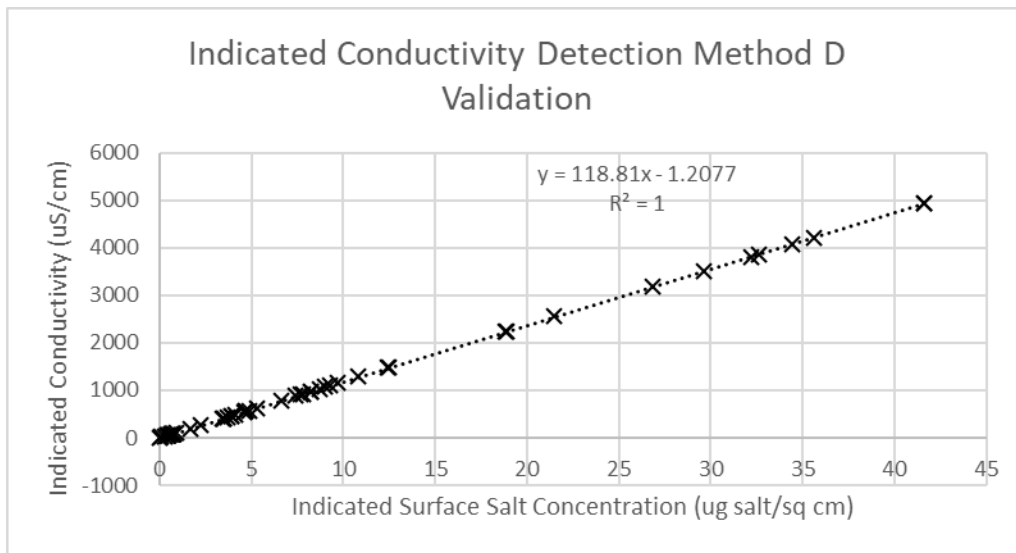


Figure 18. Conductivity-Surface Salt Concentration Relationship Generated by Detection Method D

Figure 19 shows the relationship between the calculated conductivity and the instrument indicated conductivity. The data have a relative standard deviation between 7% and 58%. The average measured conductivity is between -14% and -49% of the calculated conductivity. A least squares fit of the data suggests that the indicated conductivity is 0.55 times the calculated conductivity.

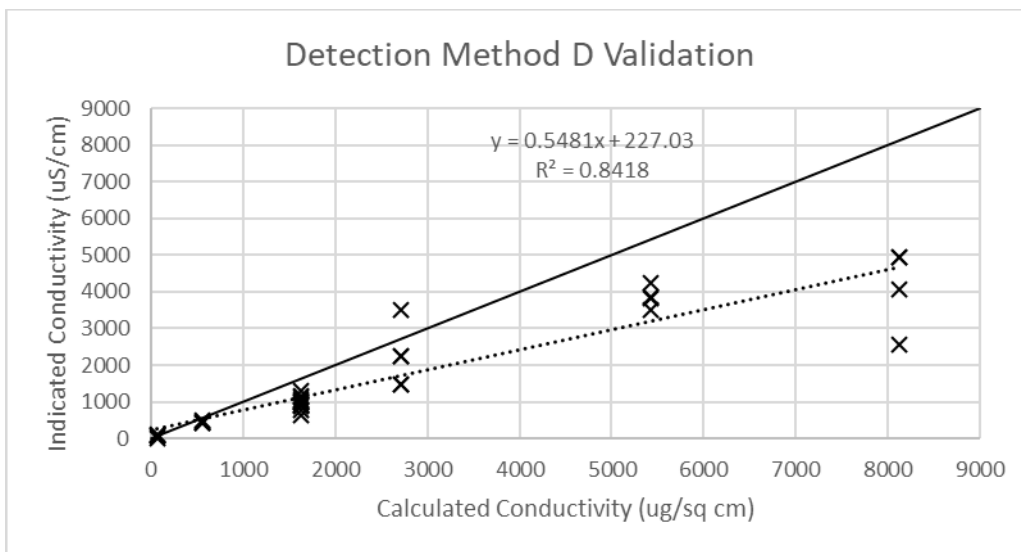


Figure 19. Conductivity Validation for Detection Method D

Figure 20 shows the relationship between the calculated surface chloride concentration and the indicated total salt concentration. The measurements have a relative standard deviation between 7% and 59%. The indicated salt concentrations are between -8% and 45% of the calculated chloride concentrations. A least squares fit suggests a close correlation between the indicated total salt concentration and the calculated chloride concentration.

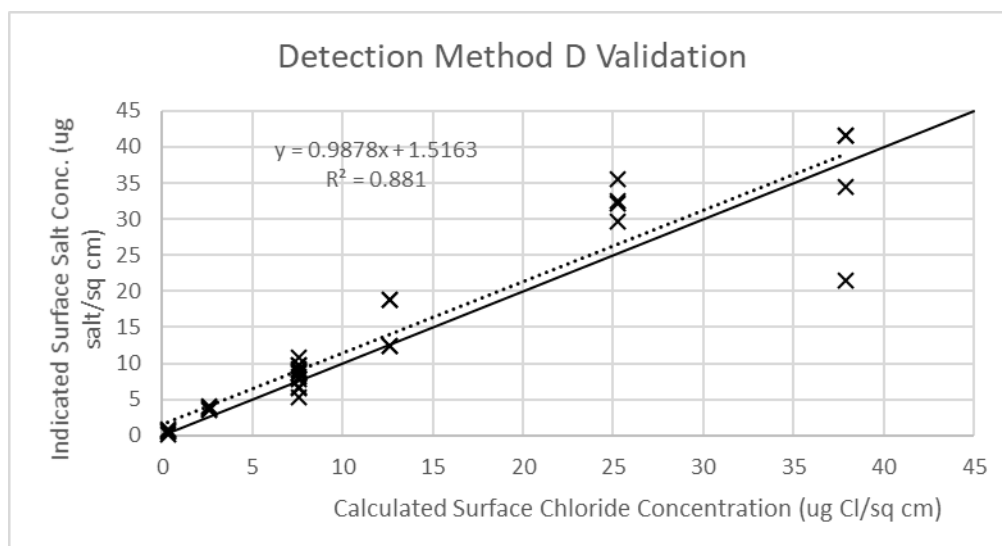


Figure 20. Surface Salt Concentration Validation for Detection Method D

Multi-step Ion-specific Detection Method E1 and Multi-step Conductivity Detection Method E2

Detection method E involves the use of an adhesively bonded latex patch in accordance with the ISO standards. This technique involves adding 3mL distilled water aliquots from a 10mL test quantity to the patch to extract salts from the surface. Conductivity and chloride ion concentration are measured using

a conductivity meter and a chloride ion detection tube or chloride ion paper strip test (depending on the concentration). To evaluate the procedure, three sodium chloride solutions were created and evaluated in triplicate by two operators. Table 26 provides the actual solution chemistries.

Table 26 – Solution Chemistries for Validation of the Detection Method E1

ID	Calculated Chloride Concentration, ppm	Calculated Conductivity, $\mu\text{S}/\text{cm}$	Stock added to patch, mL	Patch Surface Area, cm^2	Calculated surface Chloride, $\mu\text{g Cl}^-/\text{cm}^2$
0	0	2.33	10	12.5	0
1	6.1	21.92	10	12.5	4.9
2	18.2	65.75	10	12.5	14.6
3	45.5	164.36	10	12.5	36.4

Adhesively bonded latex patches were folded in half, 3mL of the stock was injected into the patch, the solution was withdrawn back into the syringe and re-injected once every minute for 10 minutes, the solution was extracted and added to 7mL of deionized water, and the chloride ion concentration and conductivity determined.

Figure 21 shows the relationship between the indicated conductivity and the indicated chloride concentration.

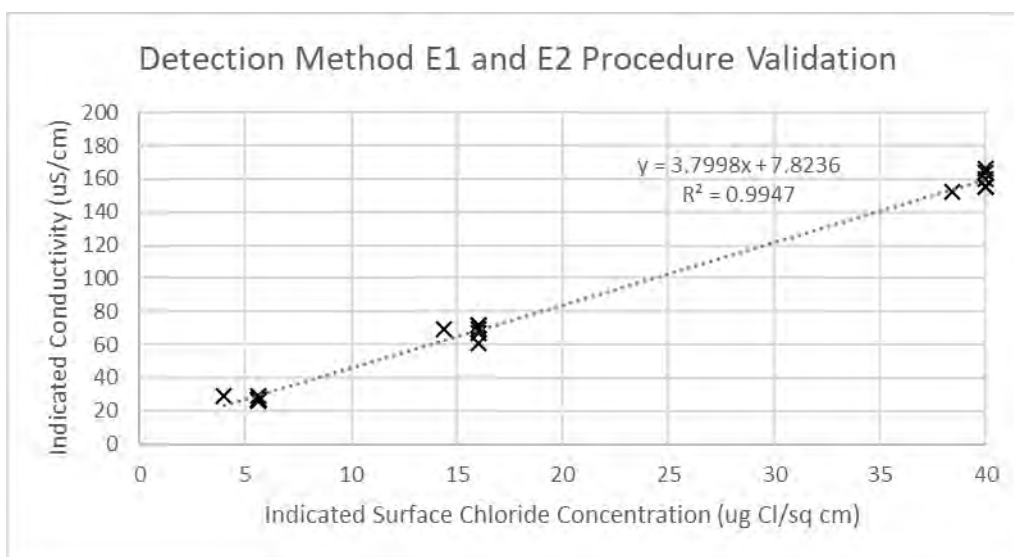


Figure 21. Conductivity-Surface Salt Concentration Relationship Generated by Detection Methods E1 and E2

A least squares analysis suggests a strong correlation between the two parameters. The equation in the figure suggests that conductivity is approximately 3.8 times the surface chloride concentration. This is within 5% of the theoretical correlation of 3.6 that would be expected in a pure sodium chloride solution.

Figure 22 shows the relationship between the theoretical surface chlorides based on the measured chloride concentration versus the indicated surface chloride concentration. The measurements have a relative standard deviation between 1.6% and 12.2%. The indicated chloride concentrations are -5% to 9% different from the calculated chloride concentration.

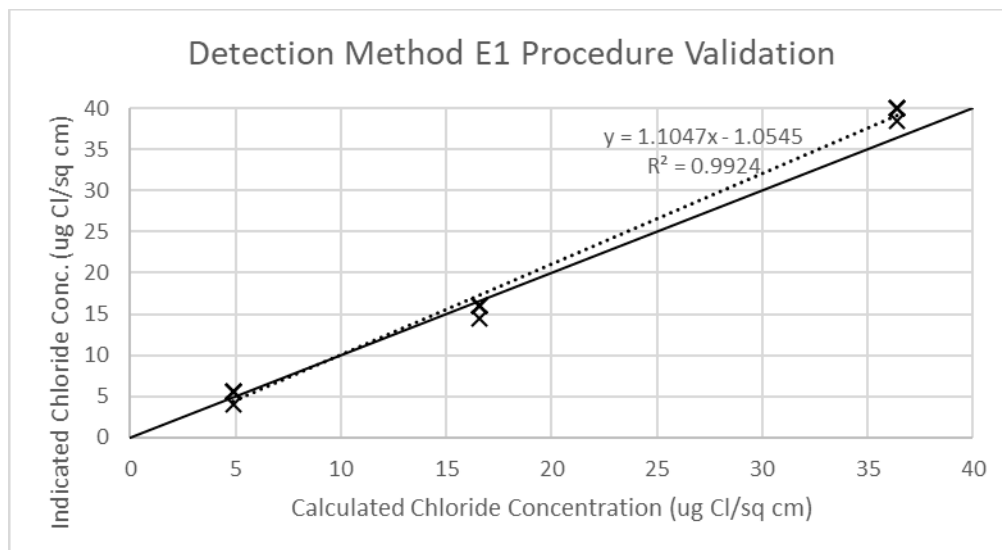


Figure 22. Surface Salt Concentration Validation for Detection Method E1

Figure 23 shows the relationship between the bulk solution conductivity and the indicated conductivity after the simulated measurement procedure. The measurements have a relative standard deviation between 3.5% and 6.0%. The average measured conductivity is between -3% and 25% of the calculated conductivity with the greatest bias at the lowest concentration.

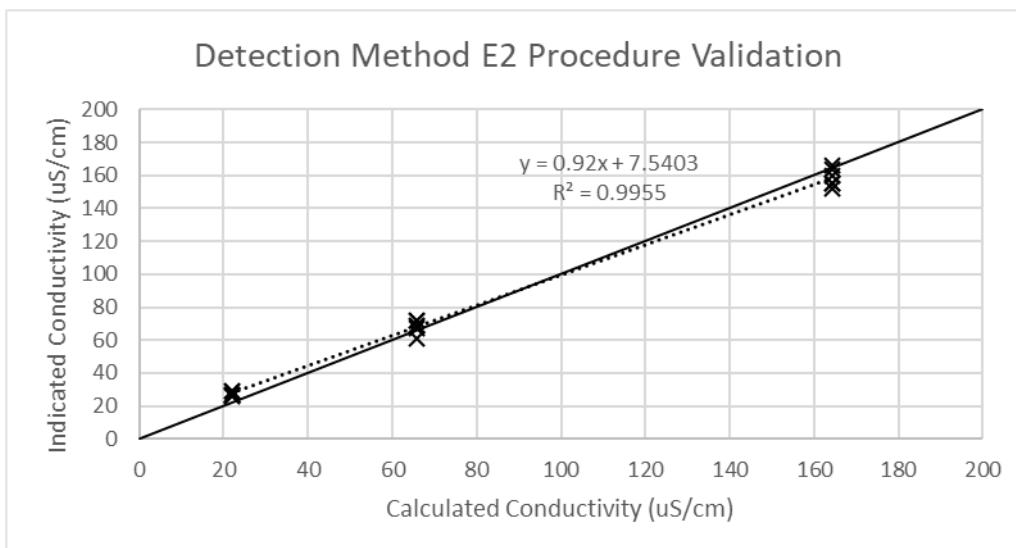


Figure 23. Conductivity Validation for Detection Method E2

Multi-Step Conductivity Detection Method F

Detection method F involves magnetically attaching a rigid cell to the surface. A safety syringe (flexible tube in lieu of a needle) is used to inject 3mL of distilled water into the cell. The extraction fluid is manually agitated in the cell by a combination of massaging the cell membrane and cycling the fluid via injection and removal. The syringe is used to remove the water and inject it into an instrument that measures the conductivity and calculates the total salt concentration based on the conductivity value. The instrument reports both conductivity and a calculated total salt level. To evaluate the instrument, two operators measured three solutions in triplicate. Table 27 provides the actual solution chemistries.

Table 27 – Solution Chemistries for Validation of Detection Method F

ID	Calculated Chloride Concentration, ppm	Calculated Conductivity, $\mu\text{S}/\text{cm}$	Stock added to meter, mL	Cell Surface Area, cm^2	Calculated surface Chloride, $\mu\text{g Cl}^-/\text{cm}^2$
0	0	2.33	3	12.5	0
1	21.2	76.7	3	12.5	5.1
2	60.7	219.15	3	12.5	14.6
3	151.6	547.88	3	12.5	36.4

The instrument was attached to a piece of steel with an ethylene acrylic acid film coating. Measurements of distilled water at the beginning and end of the series of measurements were made to confirm that the coating did not adversely affect the measurements.

Total salt and conductivity indications were recorded from the instrument. Figure 24 shows the relationship between the indicated conductivity and the indicated salt concentration.

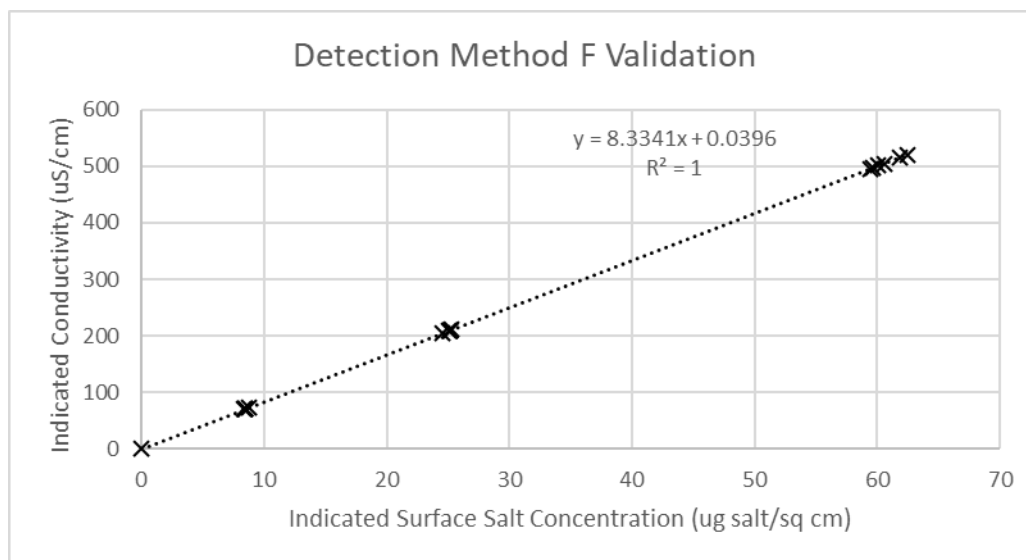


Figure 24. Conductivity-Surface Salt Concentration Relationship Generated by Detection Method F

A least squares analysis suggests a strong correlation as would be expected since the instrument physically measures conductivity and calculates surface salt concentration based on the conductivity measurement. The equation in the figure suggests that conductivity is approximately 8.33 times the surface salt concentration. The manufacturer's literature states that they use the ISO 8502-9 equation to convert from conductivity to "surface salts." The ISO 8502-9 equation results in conductivity equaling 8.3 times the soluble salt concentration – within 0.4% of the experimentally determined correlation in Figure 24.

Figure 25 shows the relationship between the bulk solution conductivity and the indicated conductivity after the simulated measurement procedure. The measurements have a relative standard deviation between 1.2% and 2.0%. The average measured conductivity is between -8% and -5% of the calculated conductivity.

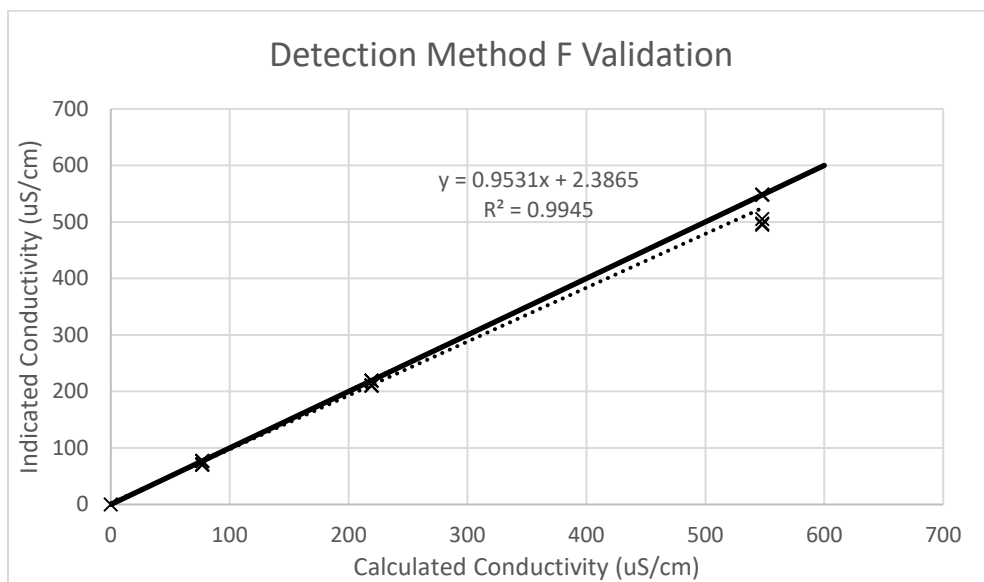


Figure 25. Conductivity Validation for Detection Method F

Figure 26 shows the relationship between the theoretical surface chlorides based on the measured chloride concentration versus the indicated surface salt concentration. The measurements have a relative standard deviation between 1.2% and 2.1%. The total soluble salt concentrations are 66% to 72% higher than the calculated chloride concentration. This is largely a result of the method of calculating total soluble salts.

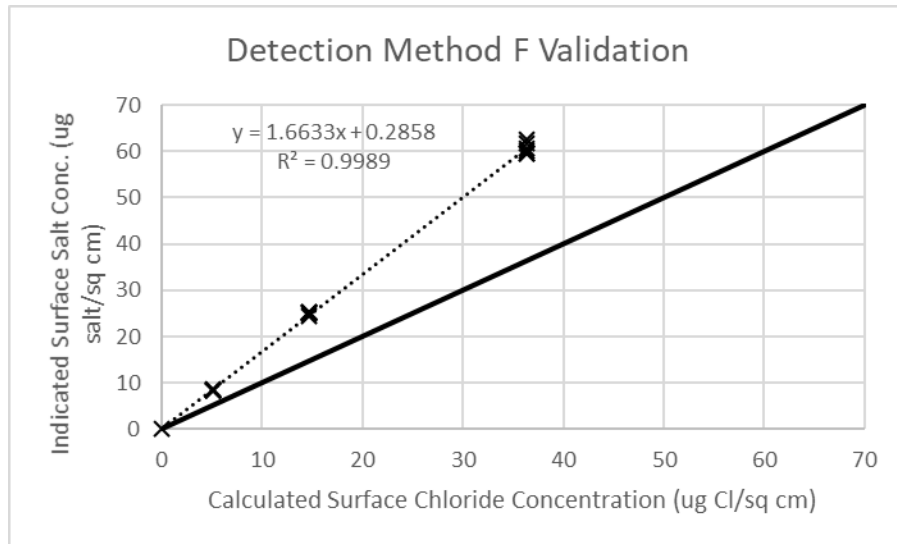


Figure 26. Surface Salt Concentration Validation for Detection Method F

Evaluation of Conductivity Detection Methods Using Standard Calibration Test Solutions

The precision and bias of the conductivity measuring devices associated with detection methods A, B, D, E2, and F were evaluated in condition 9. A series of four potassium chloride (KCl) conductivity standard solutions were directly introduced into each measuring device. The four solutions tested were 23 $\mu\text{S}/\text{cm}$, 84 $\mu\text{S}/\text{cm}$, 447 $\mu\text{S}/\text{cm}$, and 1000 $\mu\text{S}/\text{cm}$ conductivity standards manufactured by Oakton and traceable to NIST material standards. Six measurements were made with each solution on each device. Table 28 and Figure 27 summarize the test results.

Across all devices, the data suggest a practical relative standard deviation of between 2 and 14 percent and a bias of 3 to 15 percent for the three higher conductivity solutions. At the lowest standard conductivity use, the RSD and bias increases. The range significantly for the 23 $\mu\text{S}/\text{cm}$ solution to as high as 26% RSD and 21% bias. The data also suggest that the instrument used in test method F is the most accurate and repeatable, followed by methods A/E2, method B and finally method D.

The observations are consistent with manufacturers reported accuracy data. For example, the meters have a reported accuracy between $\pm 2 \mu\text{S}/\text{cm}$ and $\pm 5 \mu\text{S}/\text{cm}$ for the lowest standard solutions; an accuracy between 9% and 22% for a 23 $\mu\text{S}/\text{cm}$ measurement and an accuracy between 2% and 6% for an 84 $\mu\text{S}/\text{cm}$ measurement. This demonstrates the challenges with generating repeatable measurements in the range of concern for soluble salt measurements.

Table 28 – Results from the Testing of Standard KCl Solutions

Standard Solution Concentration / Detection Device	Average $\mu\text{S}/\text{cm}$	Standard Deviation	RSD	Bias
<i>23 $\mu\text{S}/\text{cm}$ Potassium Chloride Standard Solution</i>				
Detection Methods A and E2	22.7	1.5	7%	1%
Detection Method B	22.0	2.7	12%	4%
Detection Method D	22.5	5.9	26%	2%
Detection Method F	24.7	1.5	6%	7%
<i>84 $\mu\text{S}/\text{cm}$ Potassium Chloride Standard Solution</i>				
Detection Methods A and E2	77.0	2.1	3%	8%
Detection Method B	84.2	8.7	10%	0%
Detection Method D	89.3	12.9	14%	6%
Detection Method F	81.8	1.9	2%	3%
<i>447 $\mu\text{S}/\text{cm}$ Potassium Chloride Standard Solution</i>				
Detection Methods A and E2	388.3	36.0	9%	13%
Detection Method B	391.0	24.9	6%	13%
Detection Method D	384.3	55.7	14%	14%
Detection Method F	427.8	15.7	4%	4%
<i>1000 $\mu\text{S}/\text{cm}$ Potassium Chloride Standard Solution</i>				
Detection Methods A and E2	886.7	63.1	7%	11%
Detection Method B	889.8	51.2	6%	11%
Detection Method D	929.8	51.1	5%	7%
Detection Method F	956.0	34.9	4%	4%

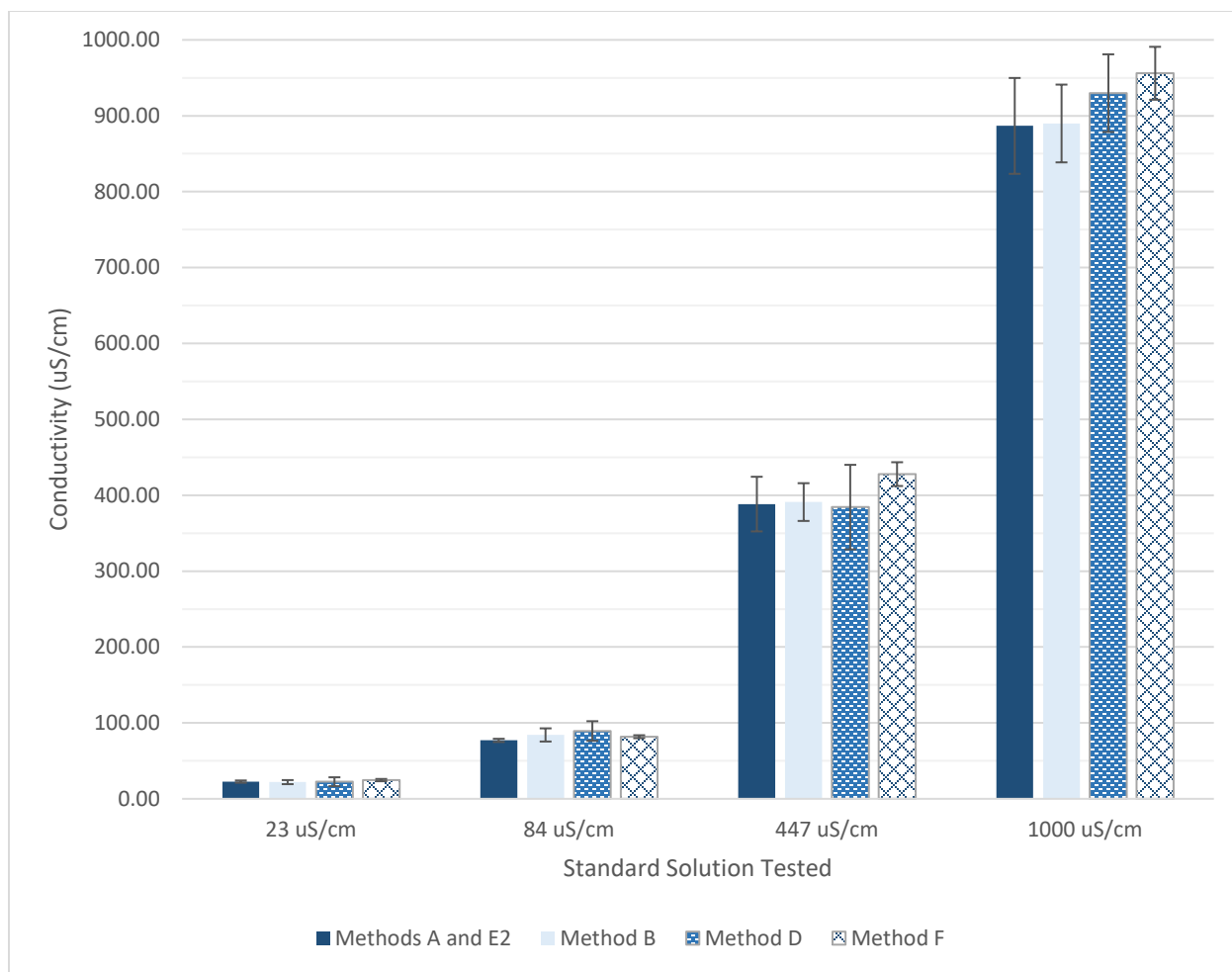


Figure 27. Results of Multiple Measurements of Standard Conductivity Solutions (Error Bars Represent 1 Standard Deviation from the Mean)

Test Conditions 2 and 7 – Measurement of Clean Test Panels

Table 29 provides the average, standard deviation, and coefficient of variation for each set of twenty-one (21) measured values on nominally identical “clean” steel panels (multiple measurements were made on each test panel such that they did not overlap).

Table 29 – Summary of Detected Soluble Salts on a “Clean” Steel Surface

Detection Method	Conductivity (uS/cm)			Chloride or total salt (ug Cl ⁻ or salt/cm ²)		
	Average	St. Dev	RSD	Average	St. Dev	RSD
A (multi-step conductivity)	8.29	1.90	23%	Not Applicable		
B (fully automated conductivity)	5.10	1.09	21%	Not Recorded		
C (multi-step ion-specific)	Not Applicable			0	0	0%
D (multi-step conductivity)	1.05	1.09	104%	0	0	0%
E1 (multi-step ion-specific) and E2 (multi-step conductivity)	11.67	4.90	42%	0	0	0%

Figure 28 shows the average, high, and low values for each measurement set. All ion-specific techniques indicated an undetectable chloride ion concentration (i.e., 0 µg Cl⁻/cm²). The methods that measure extraction fluid conductivity and relate this value to surface salts, indicated low but measurable contamination. All techniques indicated conductivities below the strictest specification limits (30µS/cm). The coefficients of variation for the conductivity measurements range between 21% and 104%.

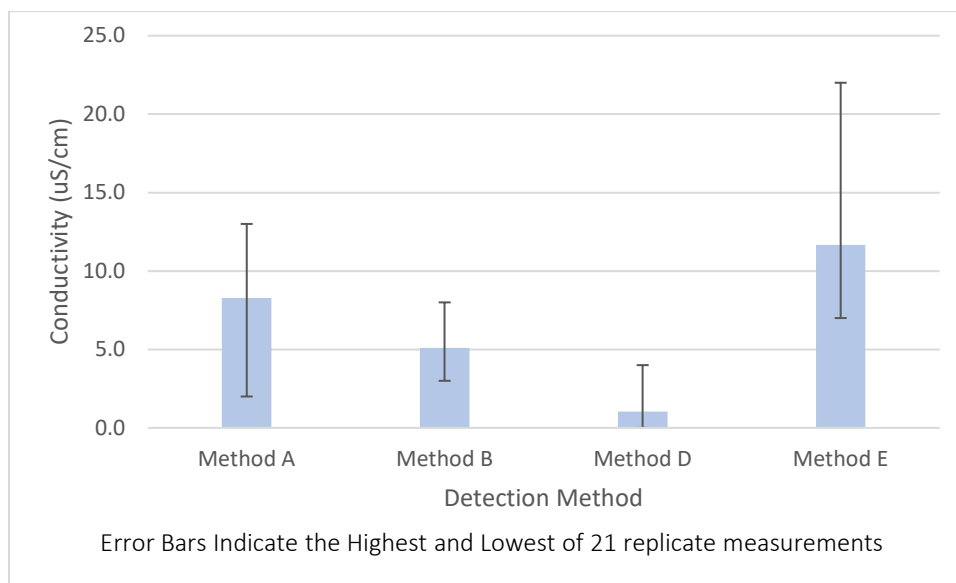


Figure 28. Surface Conductivity Measurements on “Clean” Steel Surface

The testing reported above involved measuring a surface that was abrasive blasted, stored in corrosion inhibiting paper, and wiped with an acetone-soaked rag. To ensure that the cleaning procedure did not somehow impact the results, a second series of panels was prepared by either wiping with a new, clean, cloth rag saturated with isopropyl alcohol or rinsing the panels using a squirt bottle of isopropyl alcohol. Four panels were cleaned with each method, and a total of 28 surface conductivity readings were taken, 14 using detection method A and 14 using detection method B. Figure 29 presents the average measured values for this test and the results reported in Table 29. All results were very low, indicative

of negligible contamination by current industry standards. The average conductivity readings among the conditions using detection method B were 5 or 6 $\mu\text{S}/\text{cm}^2$. The average conductivity readings among the conditions using detection method A were 8 to 11 $\mu\text{S}/\text{cm}^2$. The data sets for each method are statistically identical.

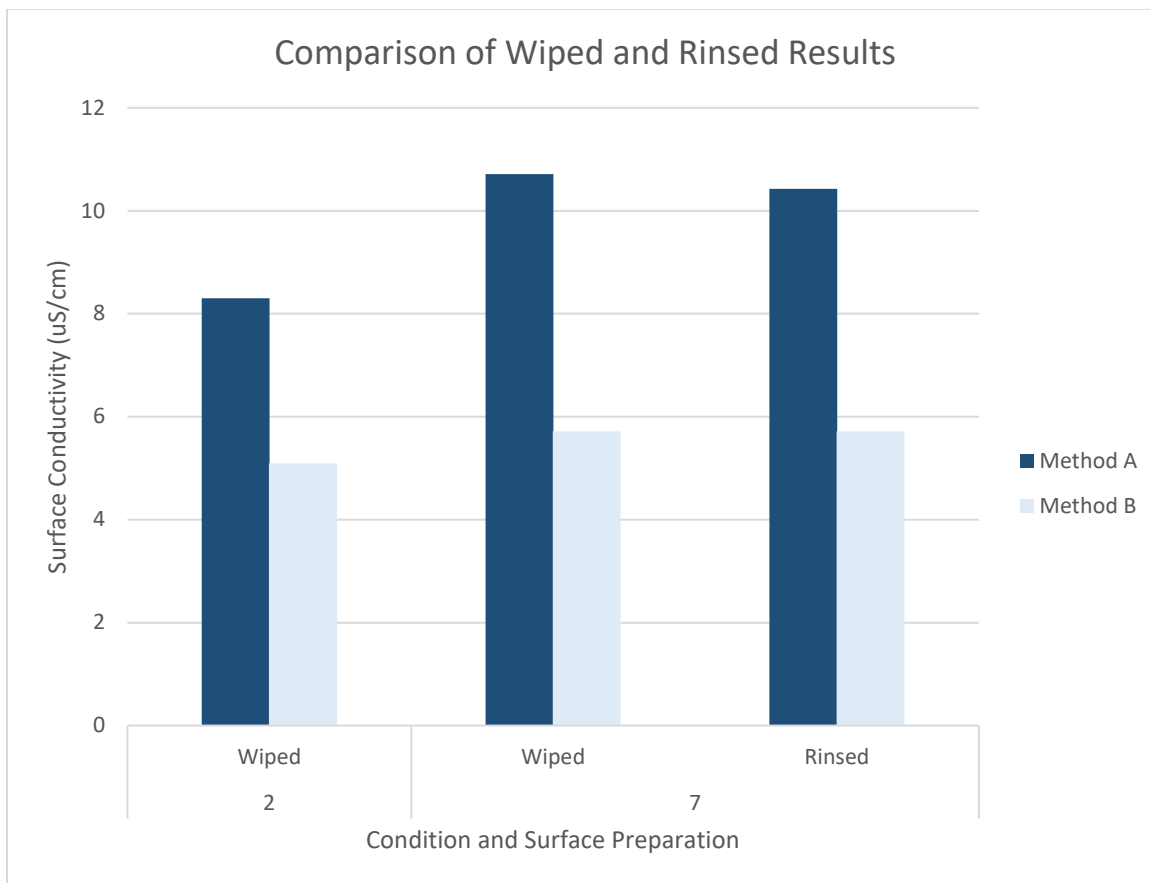


Figure 29. Reproducibility of "Clean" Panel Results Using Different Preparation Methods

Test Conditions 3 through 6 – Controlled Contamination Scenarios

Test conditions 3 through 6 are intended to validate the measurement and extraction processes by simulating field measurement scenarios. Table 30 contains details for the four panel conditions. The conditions involve either detecting sodium chloride in a simulated pit (conditions 3 and 5) or measuring a dried salt mixture on the surface (conditions 4 and 6). Furthermore, two of the conditions (5 and 6) evaluated salts that had "aged" on the steel surface for three days.

Table 30 – Salt Contamination for Conditions 3 through 6

#	Salt	Geometry	Aging
3	A micropipette was used to add 4 μL or 3.2 μL of 25.75 g/L NaCl solution to an artificial pit in an otherwise clean panel, yielding approximately 5 $\mu\text{g Cl}^-/\text{cm}^2$ over the test area.	Artificial “pit” 0.0625” diameter by 0.125” deep	None
4	1.5mL of a solution comprised of 2.38 g/l NaCl, 0.981 g/l NaNO_3 and 1.079 g/l Na_2SO_4 , yielding approximately 5 $\mu\text{g Cl}^-/\text{cm}^2$ on the test panel.	Flat panel	None
5	Same as 3	Same as 3	3 days at 70°F and 90% RH
6	Same as 4	Same as 4	3 days at 70°F and 90% RH

For each of the conditions, the theoretical result can be calculated. The calculation is straightforward for chloride ion concentration but considerably more complex for conductivity measurements, especially for the electronic instruments (see Condition 1 results). Appendix C presents sample calculations and spreadsheets showing the complete analysis. The sixth column of Table 31 contains the theoretical result and the final column contains the actual result as a percent of the theoretically correct value.

For each of these conditions, a total of 7 data points were generated by each of three operators (i.e., 21 replicate measurements). Note that four of the test methods provide results as conductivity of the extraction fluid and two present results as calculated surface chloride concentration. For the electronic devices that report both conductivity and salt concentration, both values are reported. Note that detection method D was originally used in “Conductivity” mode, which only records a conductivity reading. A second set of tests, denoted with a “b” were made using “Cleanliness” mode, which returns both a conductivity and a surface chloride concentration result. All the individual readings are contained in a spreadsheet provided as Appendix D. Table 31 presents a statistical summary of the results.

Table 31 – Statistical Data for Directly Measured Parameters

Condition	Method	Average	St. Dev	RSD	Theoretical	Bias
Results of measured conductivity ($\mu\text{S}/\text{cm}$)						
3	A	82.00	35.1	42.8%	74.85	9.6%
3	B	76.5	33.6	44.0%	74.85	2.2%
3	D	197.8	136.3	68.9%	591.43	66.6%
3b	D	36.4	24.5	67.3%	107.23	66.1%
3	E2	55.2	38.6	69.9%	22.46	145.8%
4	A	122.9	39.3	32.0%	115.24	6.6%
4	B	108.4	47.6	43.9%	115.24	5.9%
4	D	627.8	272.2	43.4%	552.16	13.7%
4b	D	619.2	317.6	51.3%	920	32.7%
4	E2	118.3	42.5	36.0%	34.57	242.2%

Condition	Method	Average	St. Dev	RSD	Theoretical	Bias
5	A	48.2	20.0	41.5%	74.85	35.6%
5	B	52.8	31.5	59.7%	74.85	29.5%
5	D	169.2	133.0	78.6%	591.43	71.4%
5b	D	150.1	95.8	63.8%	107.23	40.0%
5	E2	57.4	24.2	42.2%	22.46	155.6%
6	A	69.6	16.3	23.4%	115.24	39.6%
6	B	65.3	16.7	25.6%	115.24	43.3%
6	D	103.4	86.8	83.9%	552.16	81.3%
6b	D	280.7	245.6	87.5%	639.28	56.1%
6	E2	56.4	31.6	56.0%	34.57	63.1%
Results of measured surface Chloride ion concentration ($\mu\text{g Cl}/\text{cm}^2$)						
3	C	4.6	2.3	50.5%	4.97	7.4%
3	E1	4.6	1.5	32.2%	4.97	7.4%
4	C	4.7	0.6	13.7%	4.64	1.3%
4	E1	5	2.5	49.3%	4.64	7.8%
5	C	1.1	1.5	135.1%	4.97	78.0%
5	E1	1.7	1.3	79.7%	4.97	65.8%
6	C	0.6	0.5	88.7%	4.64	87.7%
6	E1	0.9	0.2	27.5%	4.64	80.6%
Results of measured surface "salt" concentration ($\mu\text{g salt}/\text{cm}^2$)						
3b	D	0.3	0.2	72.3%	0.5	40.0%
4b	D	5.2	2.7	51.4%	5	4.0%
5b	D	1.3	0.8	62.9%	0.5	160.0%
6b	D	2.4	2.1	87.6%	5	52.0%

Figure 30 represents the sets of conductivity data for two detection methods and four test conditions. Each bar indicates the average of 21 measured values. Each error bar represents the range of plus/minus one standard deviation for the data set.

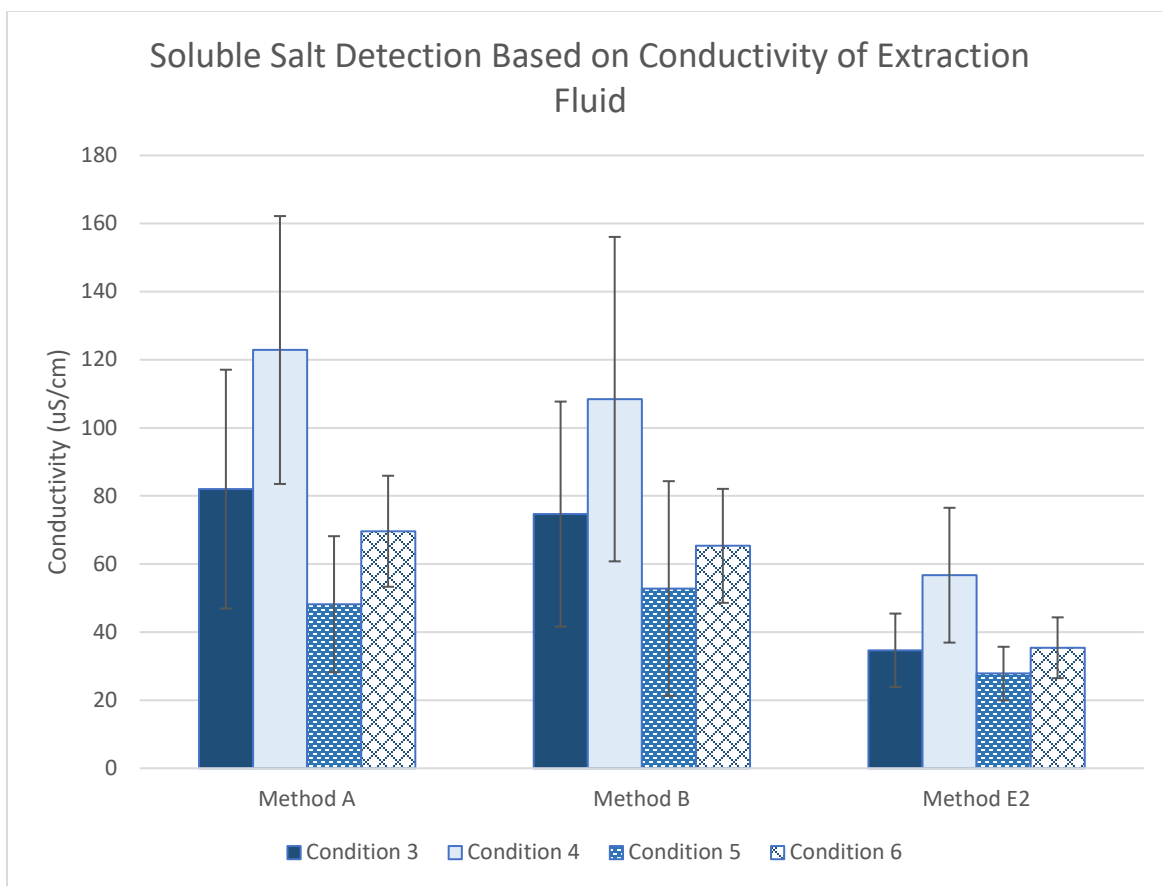


Figure 30. Statistics for Conductivity Data Sets

Figure 31 represents the sets of chloride concentration data for two detection methods and four test conditions.

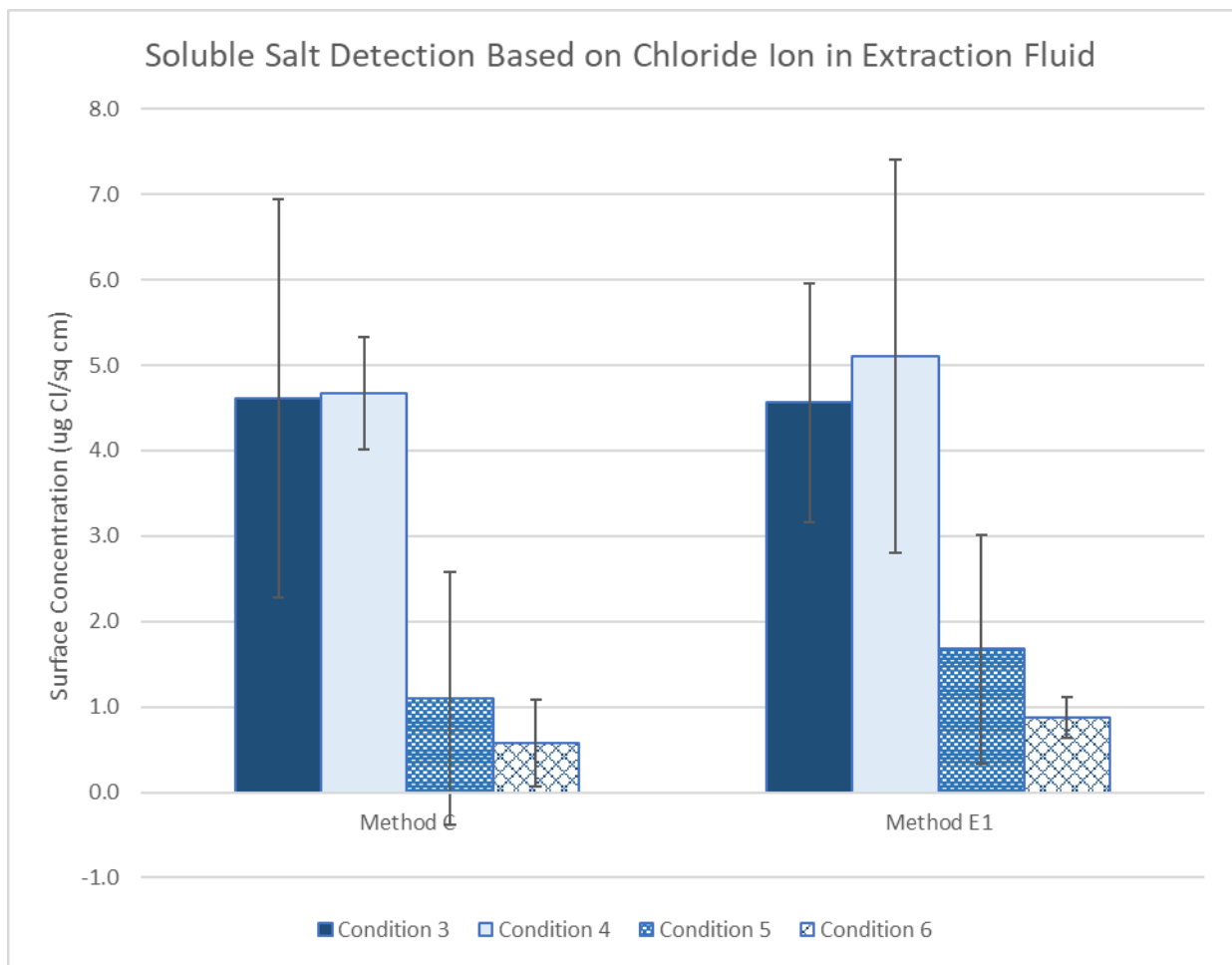


Figure 31. Statistics for Chloride Ion Data Sets

Figure 32 graphically presents the average measurement as a percentage of the theoretically correct measurement. The data shows that the average of 21 measurements is within 13% of the calculated value for nearly all techniques when the salts are measured within a few hours of being deposited on the surface. However, the ability to recover the salts appears to drop considerably after the salted surface ages for 5 days in a high humidity environment. This is consistent with results reported by others.²⁴ Figure 33 presents data showing that extraction efficiency can be reduced to 40% after 4 hours of "aging" of salt contaminated surfaces and that the effect is a function of humidity. Exposure time presumably would also have an effect.

²⁴ S-L. Chong. "Intra-Laboratory Commercial Test Chloride on Steel," JCPL, p. 42-60, August 2003

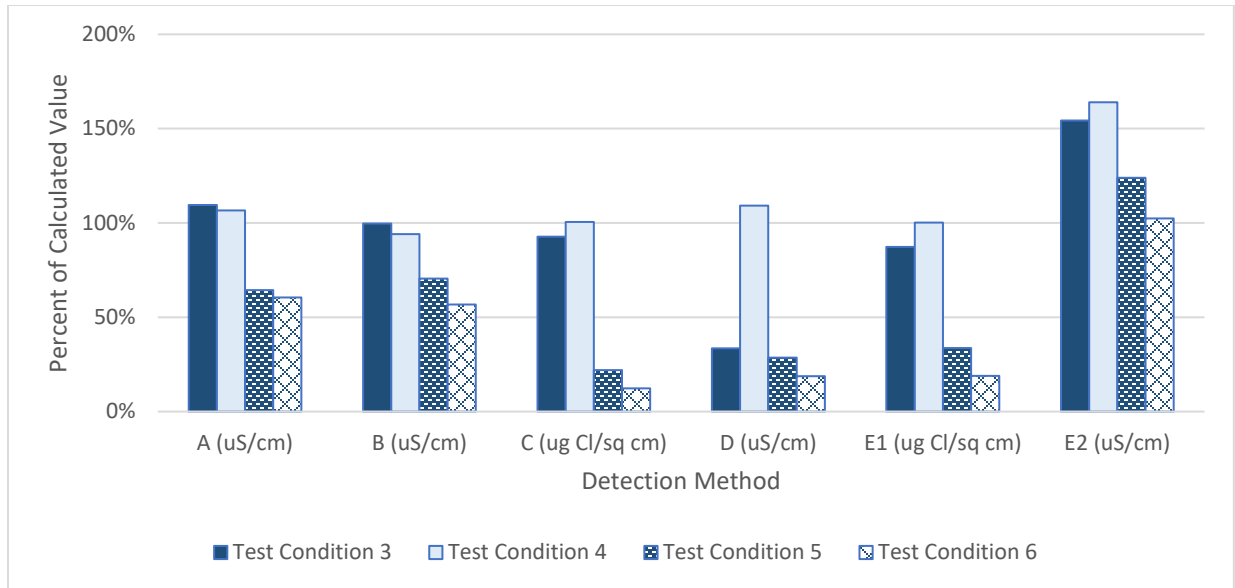


Figure 32. Average of 21 Measurements Expressed as a Percent of the Calculated Value

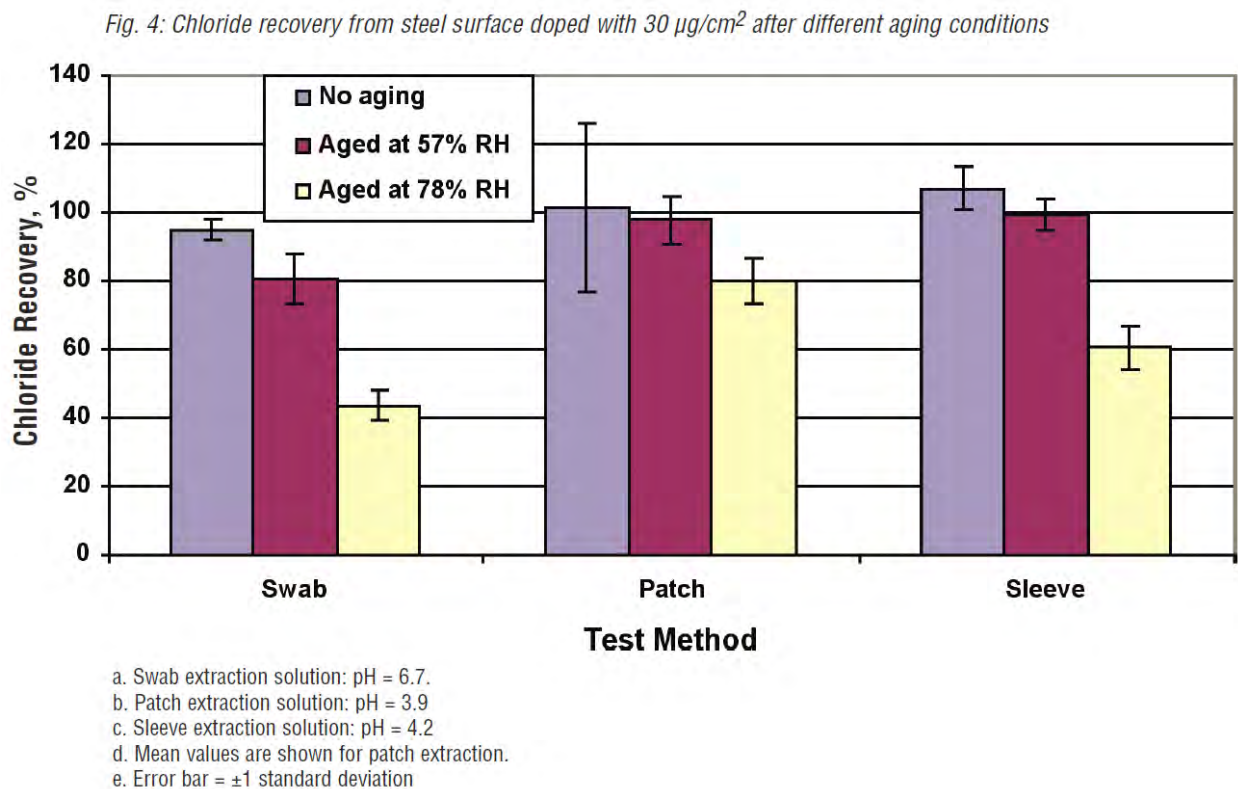


Figure 33. Figure Reproduced from Chong.²³

Figure 34 shows the relative standard deviation for each combination of detection method and test condition. For all techniques and conditions, the coefficient of variation is significant – generally 20-50%

of the actual value. The ion specific methods exhibit higher RSD on the aged panels. For all methods, the RSD is higher than observed in the “condition 1” instrument validation. As in the “condition 1” tests, method D exhibits consistently higher RSD than the other methods. It is reasonable to assume that the contamination process²⁵ and the extraction step of the detection methods contribute to the observed variation. The variability suggests that multiple measurements may help ensure that a surface is properly characterized.

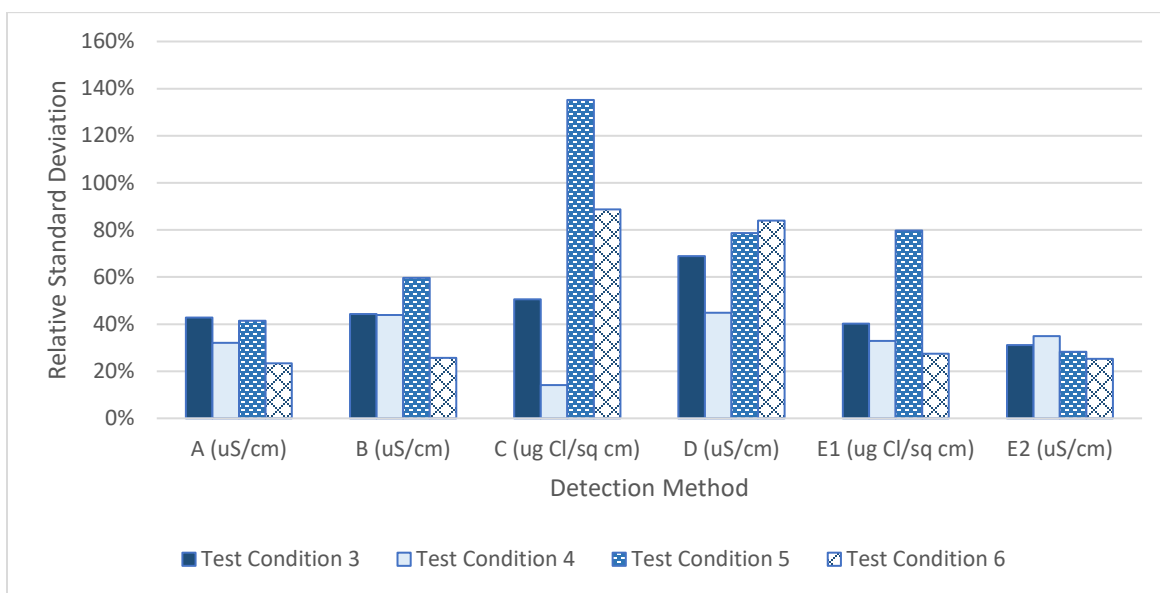


Figure 34. Relative Standard Deviation for Each Data Set

Conditions 4 and 6 were performed at two separate times using method D in conductivity mode for the first set of measurements and in cleanliness mode the second time. Both modes report the results as conductivity. Comparison of the results from the two tests lends insight to the repeatability of the experimental technique. Figure 35 presents the average (bar) and standard deviation for all four data sets. There is no reason to believe that the two measurement modes would provide different conductivity readings, thus any variation would most likely be related to preparation of the test surface. The standard deviation for the second set of data is slightly higher in both test conditions. The average result for condition 4 is similar for both data sets. However, there is considerable difference in the average for condition 6. Condition 6 contained a conditioning time which seems to impact the extractability of the soluble salts. Differences in extractability between “fresh” and “aged” surface salts would explain the different averages.

²⁵ The contamination process would include the test panel preparation in the laboratory or the natural salt deposition process in the field.

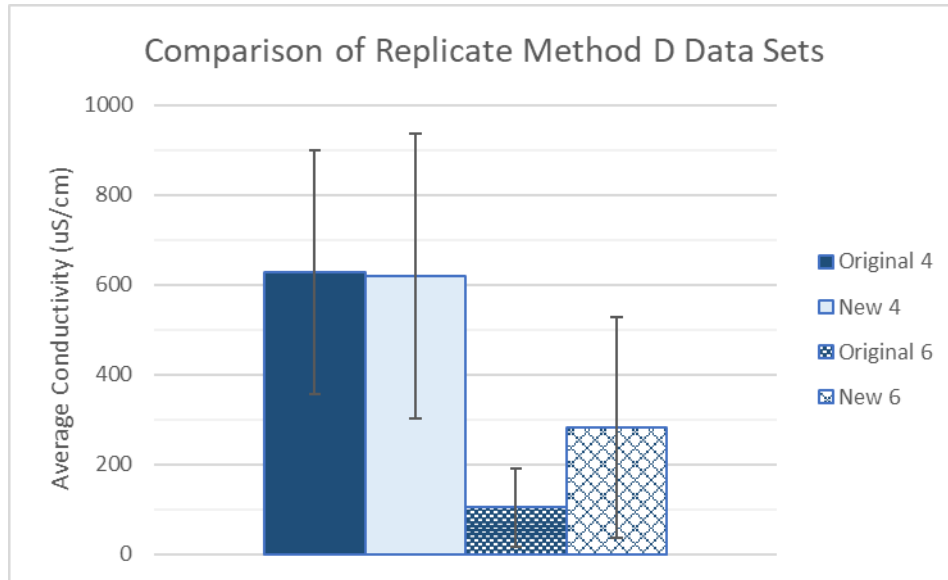


Figure 35. Comparison of Replicate Data Sets for Conditions 4 and 6 Using Method D

Test Condition 8 – Simulated Field Contaminated Surface

For test condition 8, panels were contaminated by exposure to an accelerated corrosion test environment as explained in the experimental approach. Since the level of salt contamination was not precisely controlled, five test panels were evaluated using boiling water extraction to serve as the baseline value for this test condition. Panels were placed in 500mL of boiling distilled water for 15 minutes. After the panels were removed and the water cooled, distilled water was added to make up for any evaporation. Conductivity and chloride ion concentration of the extraction fluid was measured. The results of the boiling water tests are shown in Table 32.

Table 32 – Results from Boiling of 4-inch by 3-inch panels

Panel	Chloride Ion Detection Tube		Conductivity	
	ppm	ppm	uS/cm	uS/cm
1	15	15	59	59
2	15	15	52	51
3	15	15	60	59
4	10	10	42	41
5	14	14	48	47
Average	13.8		51	
Standard Deviation	2.04		7.25	

The chloride ion concentration was converted from ppm chloride ion to $\mu\text{g}/\text{cm}^2$ chloride ion by multiplying the results by the 500mL of distilled water used in testing and dividing by the area of the panels boiled (177.4 cm^2) resulting in an average chloride ion concentration of $38.89 \mu\text{g}/\text{cm}^2$. These

results are higher than commonly specified, but consistent across the panels. The test condition represents an abrasive blasted surface that would “fail” a typical bridge requirement.

Detection methods A, B, C, D, E, and F were used to evaluate the 6-inch by 12-inch panels. One measurement was made on each panel with each method. Figure 36 shows a 6-inch by 12-inch panel after being tested with methods A through F.



Figure 36. Six inch by 12-inch Panel After Testing with Methods A-F

Figure 37 shows a comparison of the average chloride ion values detected by the methods using an ion specific test in the extraction fluid (C and E1) and the methods calculating the amount of soluble salt from the conductivity (B, D, & F). In the middle of the two sets are the results from the boiling water extractions. Each set of data is shown with one standard deviation of error.

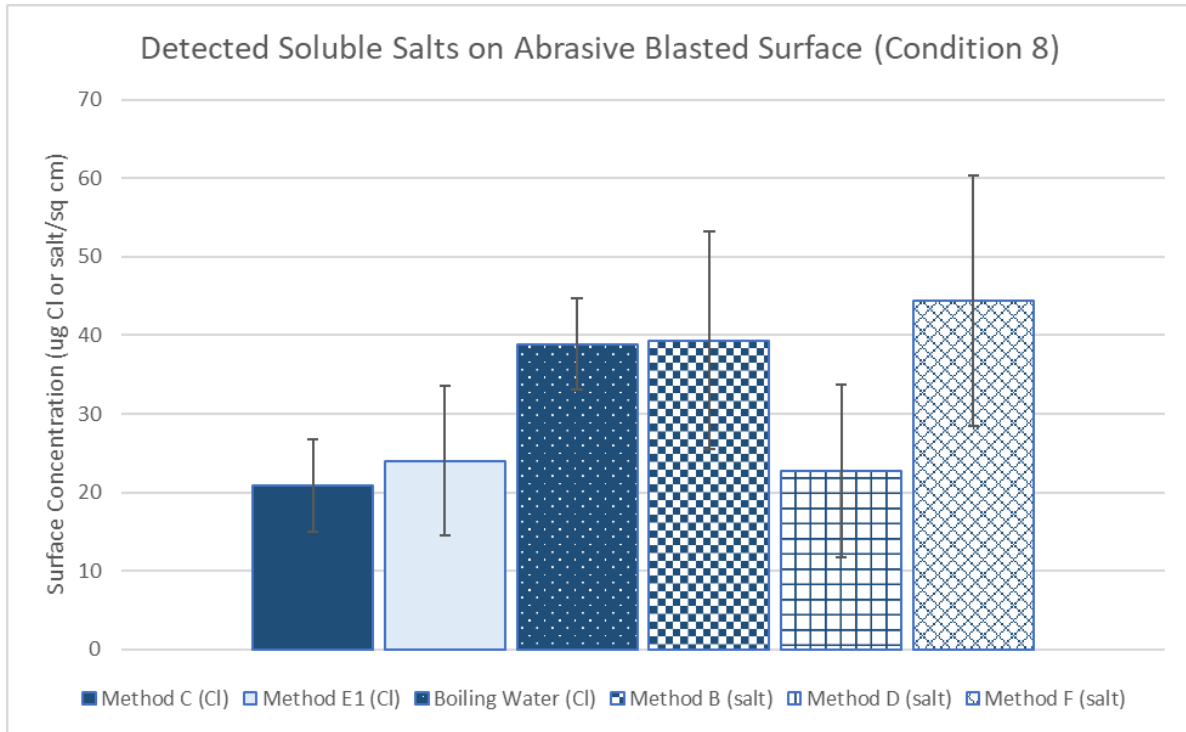


Figure 37. Average Soluble Salt Detected from 10 Tests for Condition 8

Figure 38 shows the results of the conductivity measurements. The conductivity data from boiling water extraction have a relative standard deviation of 12.4%, considerably lower than the field test methods. Detection methods F and B have a relative standard deviation around 35% while the remaining conductivity methods have a relative standard deviation around 50%.

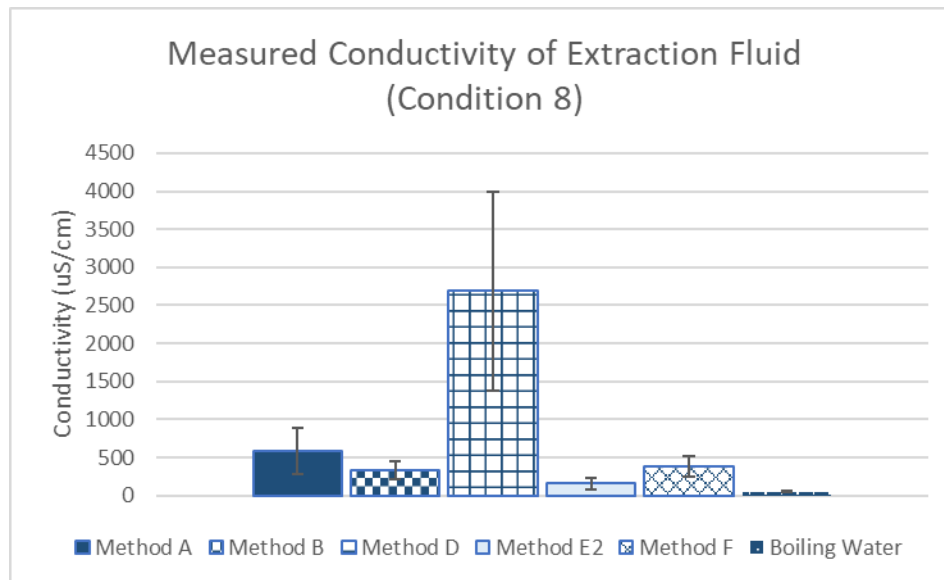


Figure 38. Average Conductivity of the 10 Readings for Condition 8

The conductivity data for methods A, B and F are directly comparable because they involve the same surface area and same volume of water. However, methods D, E and the boiling water extraction use a different water volume to test a different surface area. The boiling water methods and method E result in a more diluted water sample which is expected to have a lower conductivity. Method D uses less water over a larger surface and is thus expected to have a higher conductivity. These differences highlight the difficulty comparing conductivity measurements – the solution conductivity is dependent on the surface area tested and water volume used in addition to the amount of salts on the surface. The existing standards only address comparison of alternative conductivity techniques by converting conductivity to a total soluble salt concentration.

To compare conductivity values, each measurement was “normalized” by a factor equal to the volume of extraction fluid divided by the surface area tested for each method. Figure 39 shows the average “normalized” conductivities of the 10 readings. In this test, methods A and E were most similar to the boiling water extraction. Methods B and F provide a value roughly two-thirds of the boiling water value and method D provides a value roughly one-third of the boiling water value.

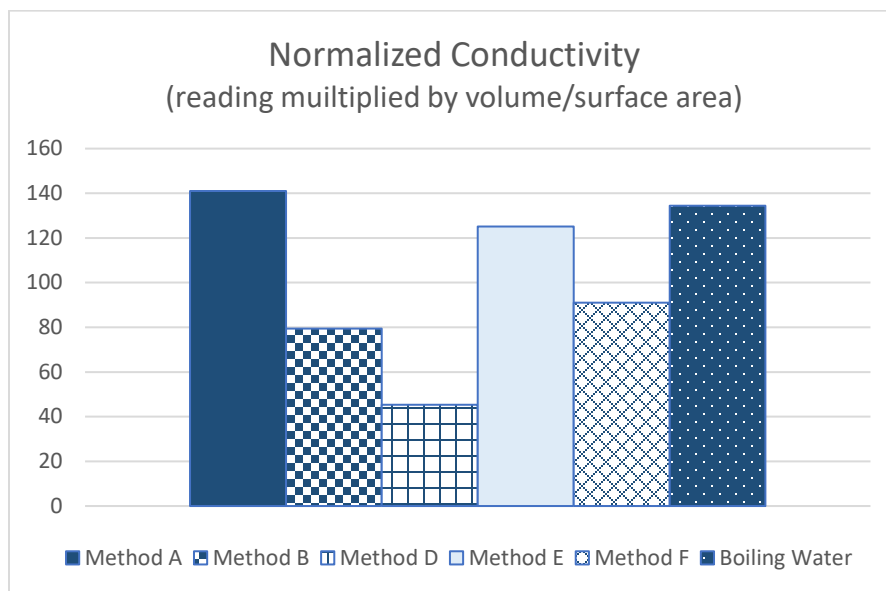


Figure 39. Normalized Conductivity Based on Volume of Extraction Fluid and Surface Area Evaluated

Remediation Effectiveness

Remediation effectiveness was evaluated in three phases. Phase I involved pre-rusting and remediating a series of test panels which included a crevice geometry. The remediation methods for Phase I included several alternative processes which may be used on a bridge. Phases II and III looked at the interaction between pressure washing with two of the most common surface preparation methods – abrasive blasting and power tool cleaning using a needle scaler. The results of each phase are presented separately in this section.

Phase I Evaluation of Nine Remediation Methods on Complex Test Panels

After remediation, a set of five complex test panels from each method were disassembled and the salt contamination was determined on each panel in the same manner as the control (non-remediated) complex panels described in the Experimental Approach section (i.e., boiling water extraction, chloride ion measurement, and algebraic calculation). Figure 40 shows the range of chloride ion concentration calculated for the crevice and bold surface on replicate panels after each remediation method (Figure 41 through Figure 43 present the same data in smaller groupings for clarity). The plot was developed using a MiniTab algorithm that eliminates “unusual observations” exhibiting inordinately large residuals compared to the applied linear model predictions.²⁶ The box represents the middle 50% of data while the horizontal line represents the median value. The whiskers represent the extreme values (neglecting the unusual observations). Based on a visual examination of the data, note that the chloride concentration on the crevice surfaces is generally higher than the bold surface. The crevices also tend to have a higher range than the bold surfaces. The “control” is the data set labeled “None” (i.e., no remediation). Several of the remediation methods appear to have more salt than the control set.

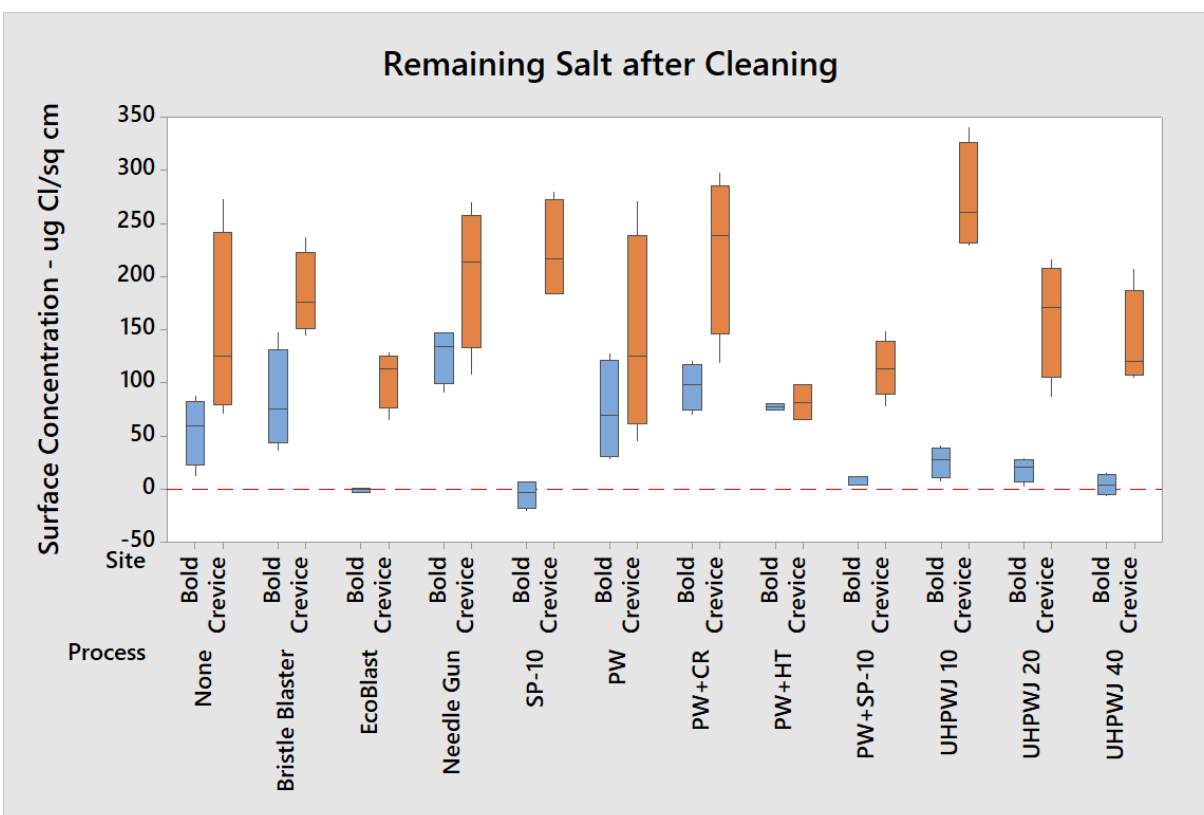


Figure 40. Average Chloride Concentration Calculated for Bold and Crevice Surfaces of Complex Panels Based on the Boiling Water Extraction Data

²⁶ Four unusual observations were identified on the bold surfaces – two panels from the Bristle Blaster set (148.1 and 35.9 $\mu\text{g Cl}^-/\text{cm}^2$) and two panels from the PW set (128.6 and 28.0 $\mu\text{g Cl}^-/\text{cm}^2$). Three unusual observations were identified on the crevice surfaces – one from the None set (274.0 $\mu\text{g Cl}^-/\text{cm}^2$), one from the PW set (272.0 $\mu\text{g Cl}^-/\text{cm}^2$), and one from the PW+CR set (118.7 $\mu\text{g Cl}^-/\text{cm}^2$).

Figure 41 shows the average remaining chloride concentration for bold and crevice surfaces remediated using mechanical means. The data suggests that the power tool methods do little to remediate crevices and that only abrasive blasting and vapor blasting effectively remediated bold surfaces. Note that both methods employ abrasive blast media.

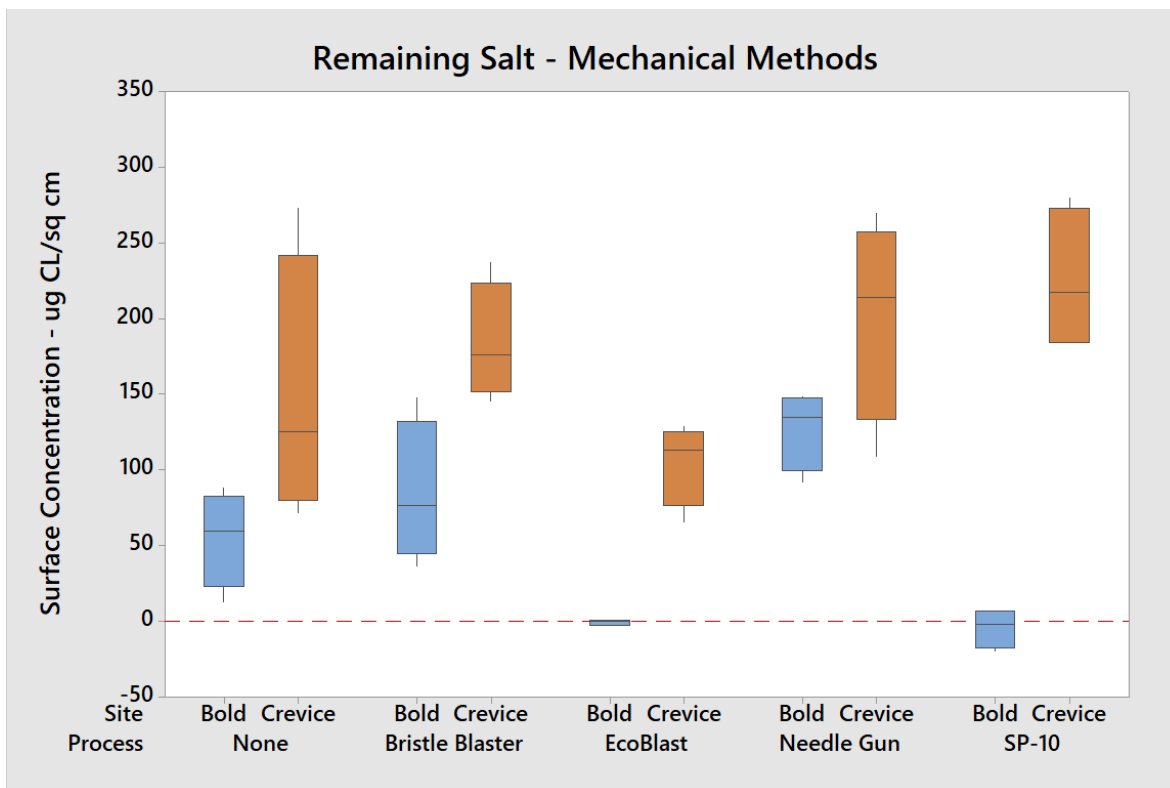


Figure 41. Average Chloride Concentration Calculated for Bold and Crevice Surfaces of Complex Panels After Mechanical Surface Preparation (Evaluated Using Boiling Water Extraction)

Figure 42 shows the average chloride concentration for bold and crevice surfaces prepared using Ultra High Pressure Waterjetting at various pressures. The data suggests that increasing water pressure improved the degree of chloride remediation on bold and crevice surfaces. However, only bold surfaces ever get to a chloride level considered acceptable by most standards. A statistical analysis of the data to address the significance of these observations is presented later in this section.

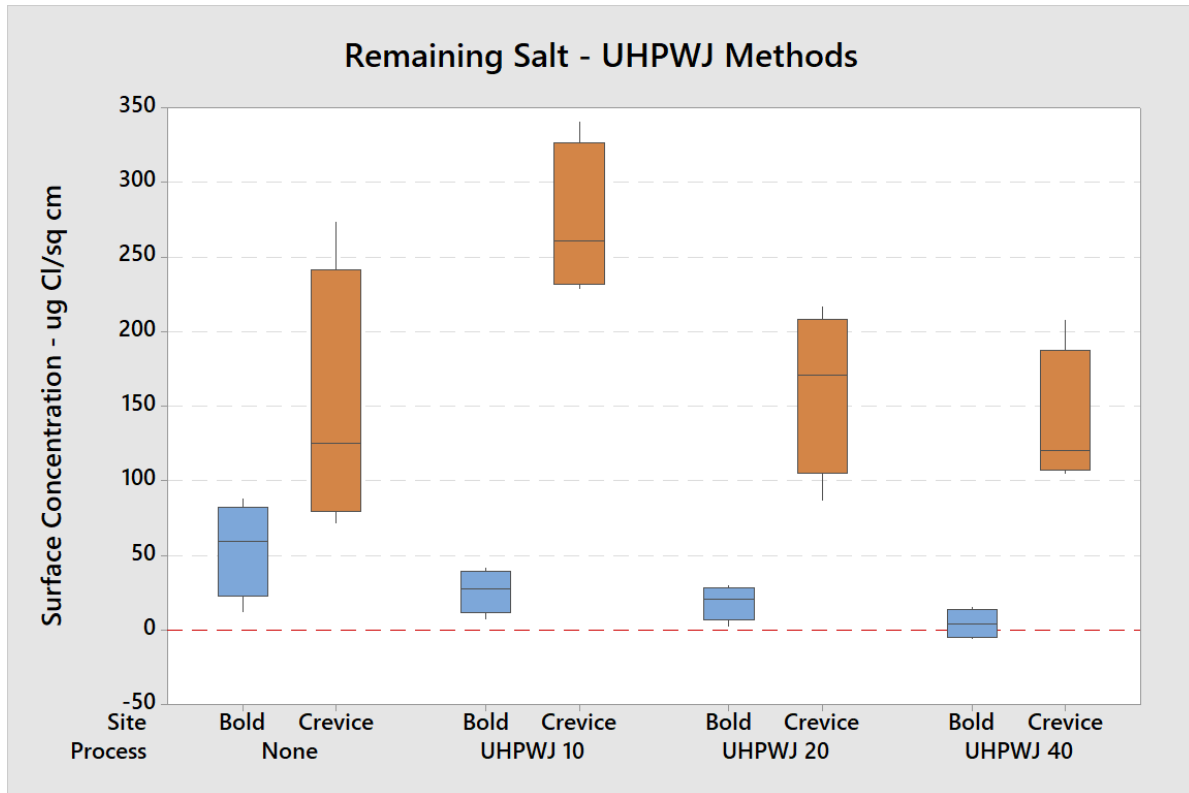


Figure 42. Average Chloride Concentration Calculated for Bold and Crevice Surfaces of Complex Panels After Varying Degrees of Ultra-High Pressure Waterjetting (Evaluated Using Boiling Water Extraction)

Figure 43 shows the average chloride concentration for bold and crevice surfaces prepared using various preparation methods involving pressure washing at 3,100 psi with a 25-degree fan tip. The data suggest that pressure washing contributes little to the remediation of chlorides in the degree of rust evaluated. Only washing in conjunction with abrasive blasting reduced the chloride concentration on the bold surface. However, recall the heavily rusted condition of these panels. It would seem logical that some salt depositions would be easier to remove with pressure washing (e.g., crystalline salt deposits on a painted surface) than the panels in this testing (e.g., salt encrusted rust film).

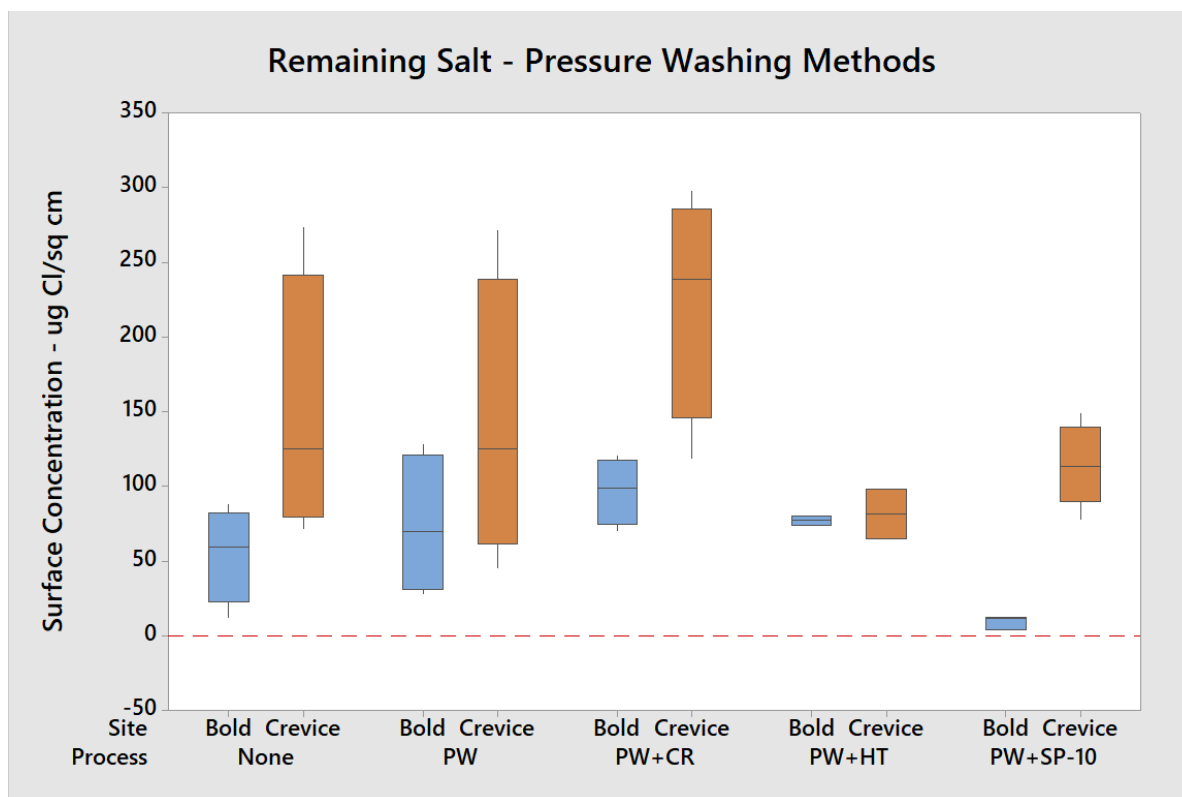


Figure 43. Average Chloride Concentration Calculated for Bold and Crevice Surfaces of Complex Panels After Various Pressure Washing Processes (Evaluated Using Boiling Water Extraction)

A statistical analysis was performed to delineate variability of the initial test panel condition from the effect of the various remediation methods. The following data analyses were performed using Minitab 17 statistical software. Prior to the evaluation of significant factors, all bold and crevice panel data were fit to an ANOVA general linear regression model and all “unusual observations” were removed as previously mentioned.²⁷ Dunnett’s method was used in ANOVA to create confidence intervals for differences between the mean of each factor level and the mean of a control group (e.g., “None” for this data set). If an interval contains zero, then there is no significant difference between the two means under comparison.

Figure 44 presents the results of the Dunnett’s analysis comparing the chloride on the bold surfaces that have been remediated to the un-remediated control (“none”). Data sets that are completely to the right of the vertical dashed line have significantly higher chloride levels than the controls while data sets to the left have significantly less chloride than the control. The remediation methods involving abrasive media (EcoBlast, PW+SP-10, and SP-10) as well as the UHPWJ methods appear to have a significant effect for removing chlorides from the bold surface. This is consistent with industry experience. For the bold surfaces, Tukey analyses (not presented) shows that only EcoBlast and SP-10 methods performed better in terms of chloride remediation than the control at a 95% confidence interval. The Needle Gun and Pressure wash with Chlor-Rid appear to add significant chlorides to the bold surface. Tukey

²⁷ Note that adding these observations back into the data set did not dramatically alter the results.

analyses revealed that only Needle Gun method appeared to add chlorides at a 95% confidence interval. The mechanism by which chlorides might be added is not clear; perhaps disturbing the corrosion product with a needle gun simply makes the soluble salts more “extractable” from the surface as some salt detection procedures suggest.

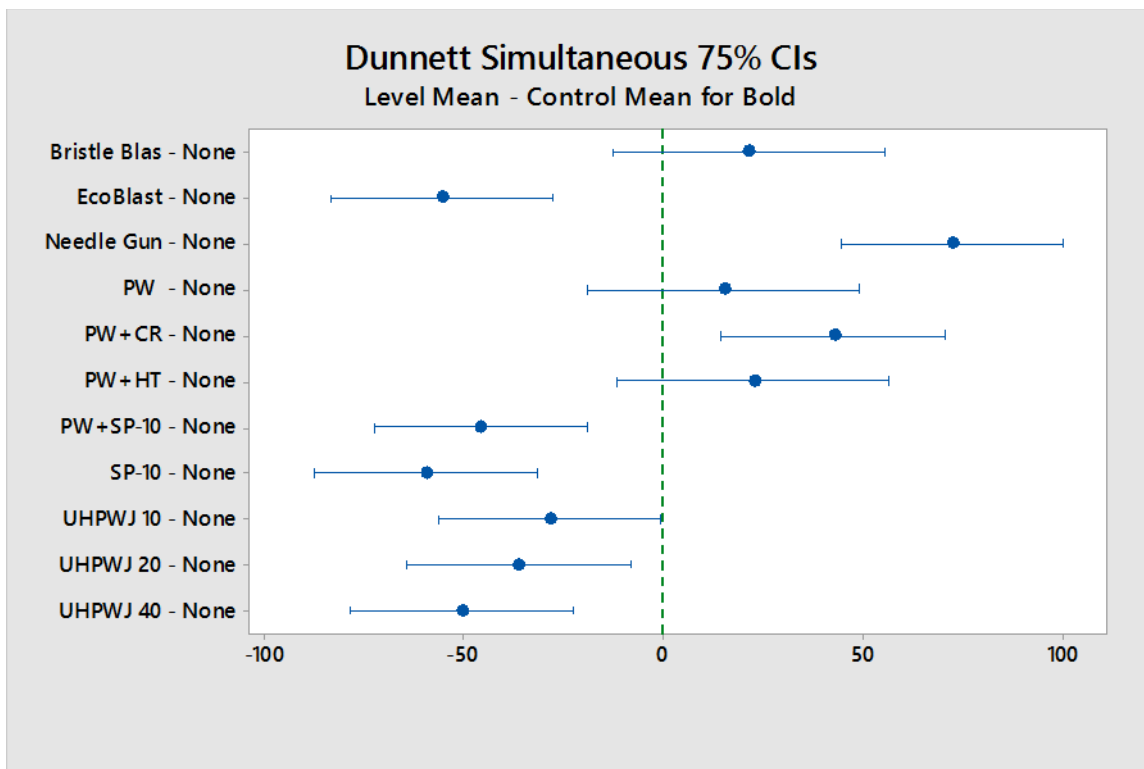


Figure 44. Dunnett Analysis of the Chloride Concentration on the Bold Surfaces

Figure 45 presents the results of the Dunnett’s analysis comparing the chloride on the crevice surfaces that have been remediated to the un-remediated control (“none”). Data sets that are completely to the right of the vertical dashed line have significantly higher chloride levels than the controls while data sets to the left have significantly less chloride than the control. Five remediation methods appear to add significant chlorides to the crevice surface. Tukey analyses (not presented) revealed that none of the remediation methods are different than the control at a 95% confidence interval. The data confirms that chlorides are extremely difficult to remove from tight crevices. Different results may be observed for alternative crevice geometries.

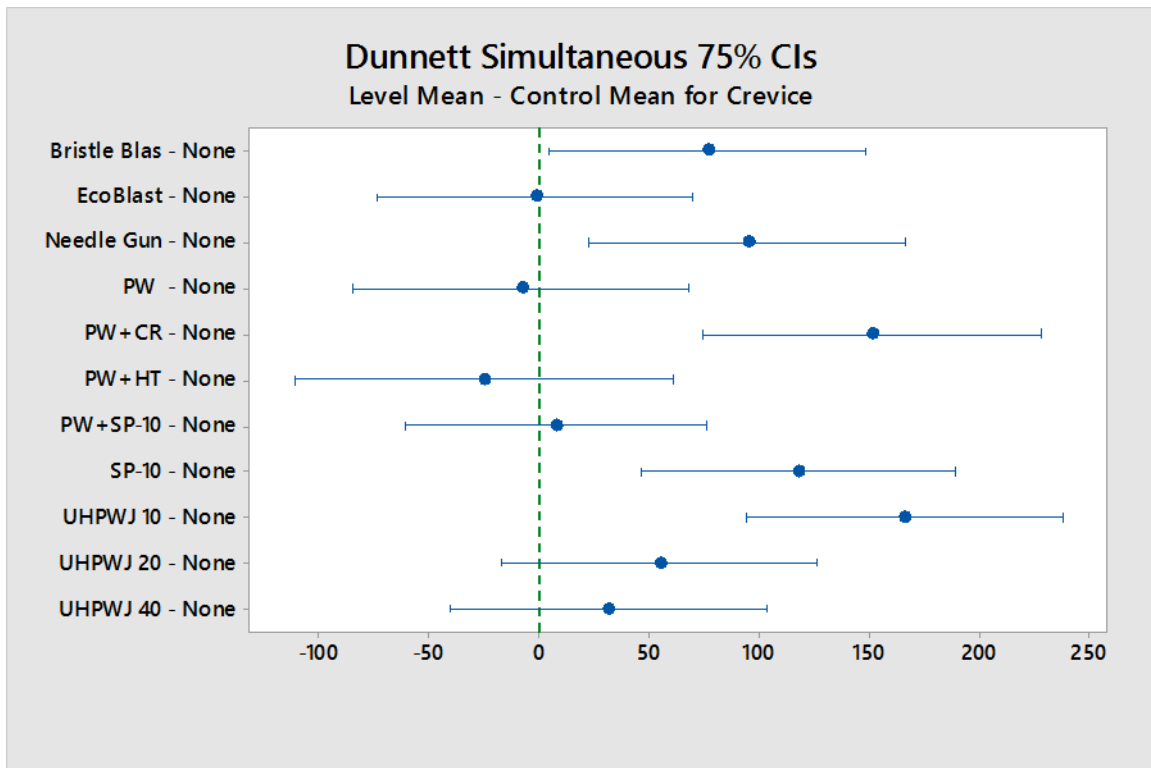


Figure 45. Dunnett Analysis of the Chloride Concentration on the Crevice Surfaces

Phase II Evaluation of Combinations of Pressure Washing and Abrasive Blasting on Flat Panels

This phase was performed to explore whether the sequence of abrasive blasting and pressure washing steps impact the soluble salt removal effectiveness. Table 33 and Figure 46 present a statistical summary of the measurements. The twelve readings taken per remediation step are represented by the boxplots in Figure 46. The “o” markers indicate the individual data points. The first and fifth quartiles are represented by the whiskers, the second and fourth quartiles are represented by the box, and the center line represents the median value of the 12 readings. The x inside the box represents the mathematical average of the 12 readings.

The surface salt concentrations measured after all combinations of abrasive blasting and pressure washing would meet most bridge cleanliness requirements. The soluble salt levels measured after only abrasive blasting may not meet some bridge cleanliness requirements.

Multiple blast operations are effective at reducing surface salt concentrations, though less effective than combining abrasive blasting with pressure washing. The data clearly show the benefit of performing a pressure wash after abrasive blasting. Unfortunately, it is somewhat impractical to introduce and manage water after abrasive blasting has been performed. A pressure wash before blasting is less effective than after blasting, but more effective than not washing at all. As a practical matter, contractors typically pressure wash prior to abrasive blasting and blast areas which rust back multiple times. The rustback should be identified during QA/QC inspections and are likely locations for excessive salt contamination.

Table 33 – Measured Soluble Salt Levels

Step	Remediation Method	Total Salt Contamination based on Bresle Method ($\mu\text{g salt/cm}^2$ – Statistics based on 12 readings)				Boiling Water Extraction ($\mu\text{g Cl}^-/\text{cm}^2$)
		Average	Std Dev	High	Low	
1	SP-10	24.7	6.2	34.6	17.5	16.9
3	SP-10	15.9	6.7	30.4	9.4	11.3
1	SP-10					
2	PW	4.3	1.2	6.5	2.8	11.3
4	SP-10	3.7	0.9	4.8	2.2	11.3
1	SP-10					
2	PW-CL	4.5	2.3	9.6	2.6	5.6
4	SP-10	4.3	1.2	7.8	3.4	5.6
1	SP-10					
2	PW-HT	4.2	1.0	6.5	2.8	11.3
4	SP-10	4.5	0.8	5.8	3.4	2.8
1	PW					
2	SP-10	9.7	2.5	15.1	6.1	5.6
1	PW-CL					
2	SP-10	7.3	2.6	14.2	3.7	11.3
1	PW-HT					
2	SP-10	7.0	9.6	40.0	4.1	8.5

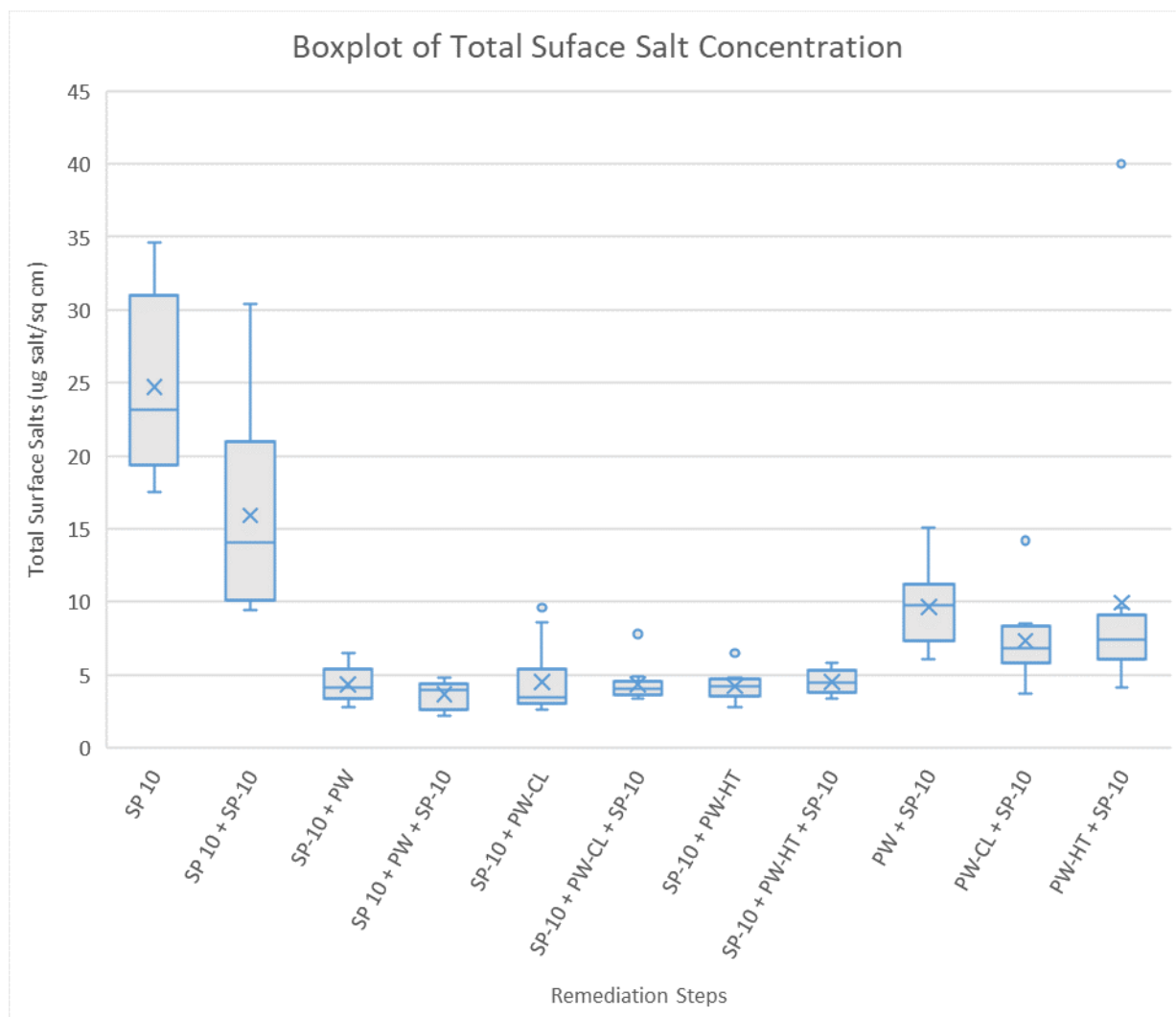


Figure 46. Comparison of Data Ranges for Each Remediation Method

Phase III Evaluation of Combinations of Pressure Washing and Power Tool Cleaning on Flat Panels

This phase was performed to explore whether the sequence of power tool cleaning and pressure washing steps impact the soluble salt removal effectiveness. Figure 47 and Figure 48 present the results of this testing. The average combined results of each field detection method for each scenario are displayed in Table 34.

The data show that the typical approach of pressure washing followed by power tool cleaning is reasonably effective but could be improved with the addition of a second pressure wash after the power tool cleaning. Consistent with the laboratory studies, the data also show that significant salts are not removed using the field methods while boiling water extraction removes soluble species from the cleaned surface.

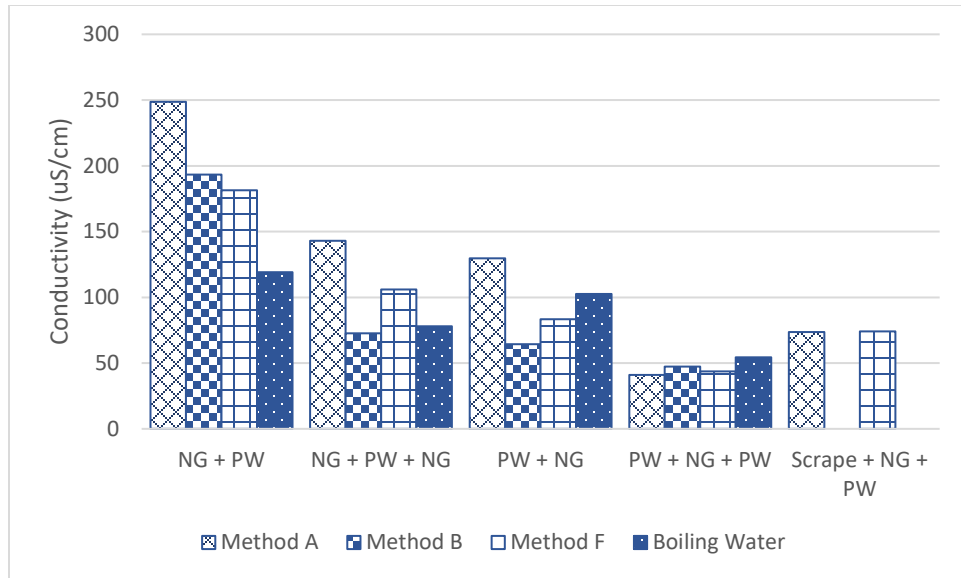


Figure 47. Conductivity After Remediation Scenarios

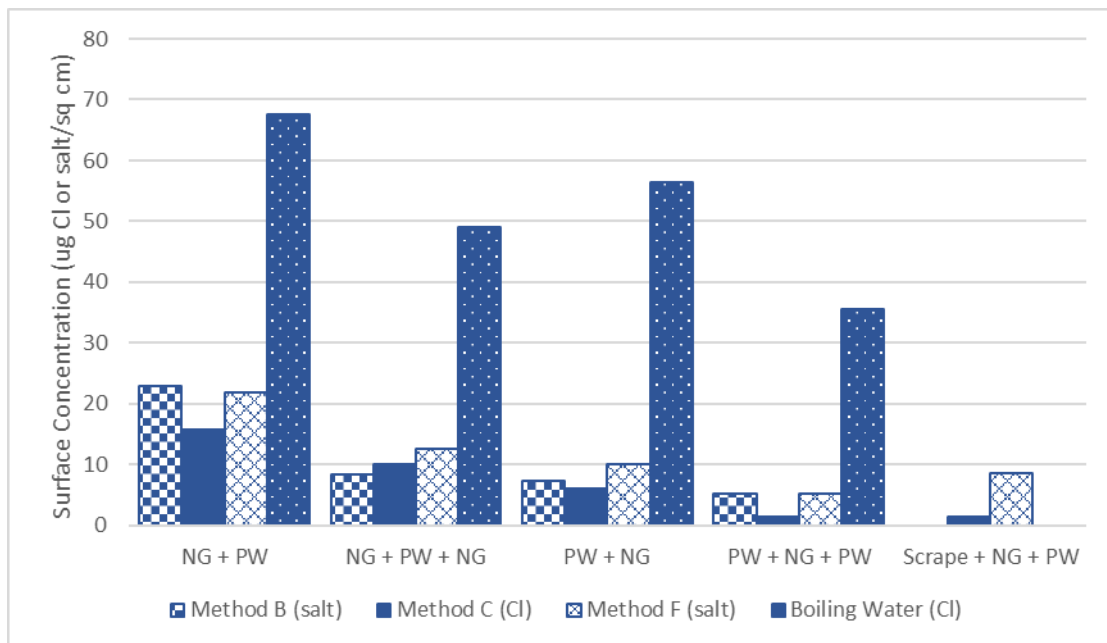


Figure 48. Average Surface Concentration After Remediation Scenarios

Table 34 – Average Salt Levels After Remediation Detected Using Field Detection Methods

Average Readings	Scenario 1		Scenario 2		Scenario 3
	NG + PW	NG + PW + NG	PW + NG	PW + NG + PW	Scrape + NG + PW
Chloride (ug/cm ²)	15.7	10.0	6.0	1.3	1.3
Salt (ug/cm ²)	22.3	10.5	8.7	5.3	8.6
uS/cm	207.8	107.2	92.4	44.0	73.8

The boiling water methods were used to determine remediation efficiency as a percent of the total original contamination level. Table 35 presents the remediation effectiveness of the four sequences in scenario 1 and scenario 2. Note that boiling water extraction was not performed on scenario 3 panels.

Table 35 – Remediation Efficiencies of Power-Tool Cleaned and Pressure Wash Combinations (Boiling Water Extraction)

Remediation Method	Chlorides (µg/cm ²)	µs/cm
NG + PW	80%	73%
NG + PW + NG	86%	82%
PW + NG	83%	76%
PW + NG + PW	89%	87%

These findings are consistent with the findings for combination of pressure washing and abrasive blasting. The surface salt concentrations measured after all combinations of power tool cleaning and pressure washing may not meet some bridge cleanliness requirements. Soluble salt removal effectiveness can be improved by using multiple methods and pressure washing after the mechanical surface preparation. Unfortunately, it is somewhat impractical to introduce and manage water immediately prior to painting. As a practical matter, contractors typically pressure wash prior to power tool cleaning.

Coating Performance Over Remediated Surfaces

Accelerated Corrosion Testing

As described in the Experimental Approach, a series of coated test panels were subjected to 120 cycles of accelerated corrosion testing. Table 36 shows the ASTM D610 through-film rust ratings for each panel, organized by the system and number of times it was pressure washed through the testing. A rating of a 10 indicates no through-film corrosion present on the panel while a rating of a 0 indicates more than 50 percent of the panel showed through-film corrosion. There are significant differences between panels which were remediated with more thorough methods (such as an SP-10 media blast and 40,000 psi water jetting) compared to less thorough methods (such as a 3100-psi pressure wash).

The differences among surface preparation and coating type are more significant than the differences in the number of wash cycles.

Table 36 – ASTM D610 Ratings After 120 Cycles in Accelerated Corrosion Exposure

System		Times Washed Over Testing				Average by System
Coating	Remediation	12	6	3	0	
A	SP-10	10	10	9	10	9.75
A	PW 1	4	6	4	5	4.75
B	PW 1	2	0	2	5	2.25
B	PW 3	1	0	0	1	0.5
C	SP-3	1	1	2	2	1.5
C	PW 1	2	2	2	2	2
D	SP-3	8	9	8	7	8
D	PW 1	7	6	5	5	5.75
D	UHPWJ	8	7	7	8	7.5
Average by Times Washed		4.78	4.56	4.33	5.00	4.67

Table 37 shows blistering ratings for each panel based for the size and density of blisters. The conversion scale shown in Table 38 was used to convert the ASTM D714 ratings to a numerical rating between 0 and 10. A rating of a 10 indicates that there are no blisters present on the panel, while a rating of a 0 indicates that there is at least one blister on the panel greater than 2cm in diameter. As with the rust ratings, coating type and remediation had a significant effect on performance while washing did not.

Table 37 – ASTM D714 Ratings After 120 Cycles (hybrid numerical rating)

System		Times Washed Over Testing				Average by System
Coating	Remediation	12	6	3	0	
A	SP-10	10	10	10	10	10
A	PW 1	0	0	0	0	0
B	PW 1	0.75	1.1	3.78	0.75	1.595
B	PW 3	3.7	1.1	3.7	0.75	2.3125
C	SP-3	0.75	1.1	1.1	0.75	0.925
C	PW 1	0.75	1.1	1.1	0.75	0.925
D	SP-3	10	10	10	10	10
D	PW 1	0	0	0	2.6	0.65
D	UHPWJ	10	10	10	10	10
Average by Times Washed		3.99	3.82	4.41	3.96	4.05

Table 38 – ASTM D714 Rating Conversion Table

Rating/Density	D	MD	M	F
1	0	1	2	3
2	0.35	1.65	2.6	3.78
3	0.55	2.1	3.2	4.56
4	0.75	2.5	3.8	5.33
5	0.9	3	4.4	6.11
6	1.1	3.7	5	6.89
7	1.6	4.6	6.25	7.67
8	2.5	6	7.5	8.44
9	4.8	8	8.75	9.22
10	10	10	10	10

Table 39 shows the average of 12 cutback measurements made from the scribe on each panel. These are destructive cutback readings, taken at 12 points along the scribe. “Undercutting” is the distance from the center of the scribe to the edge of in-tact coating as identified by probing with a utility knife. The maximum rating given at any one location is 25mm. A higher average rating dictates a lower resistance to undercutting corrosion. Again, coating type and remediation had a significant effect on performance while rinsing did not.

Table 39 – Average Cutback Measured from 12 Locations along the Scribe in mm

System		Times Washed Over Testing				Average by System
Coating	Remediation	12	6	3	0	
A	SP-10	0.0	0.0	0.0	0.0	0.0
A	PW 1	7.9	2.9	10.5	3.7	6.2
B	PW 1	20.3	25.0	24.6	6.8	19.2
B	PW 3	15.5	18.5	22.9	18.5	18.9
C	SP-3	4.5	4.0	9.6	8.1	6.5
C	PW 1	4.8	11.1	19.8	4.6	10.0
D	SP-3	0.0	0.2	1.0	0.0	0.3
D	PW 1	0.5	1.3	9.3	9.0	5.0
D	UHPWJ	0.0	0.8	2.4	0.0	0.8
Average by Times Washed		5.9	7.1	11.1	5.6	7.4

Figure 49 shows the average metal loss of bare steel coupons over 120 cycles of modified GMW 14872 testing. The witness coupons were also subjected to the four different wash frequencies. Each point is the average metal loss of two coupons which were removed at each inspection. As testing has progressed from 40 through 120 cycles, this data shows a reduction in corrosion for panels which are washed. Coupons which were not washed have approximately 25% more corrosion loss than those that were washed. The frequency of washing did not seem to affect the degree of metal loss. This may

reflect a tradeoff between removing the detrimental salts and removing some of the corrosion product which may provide some degree of protection.

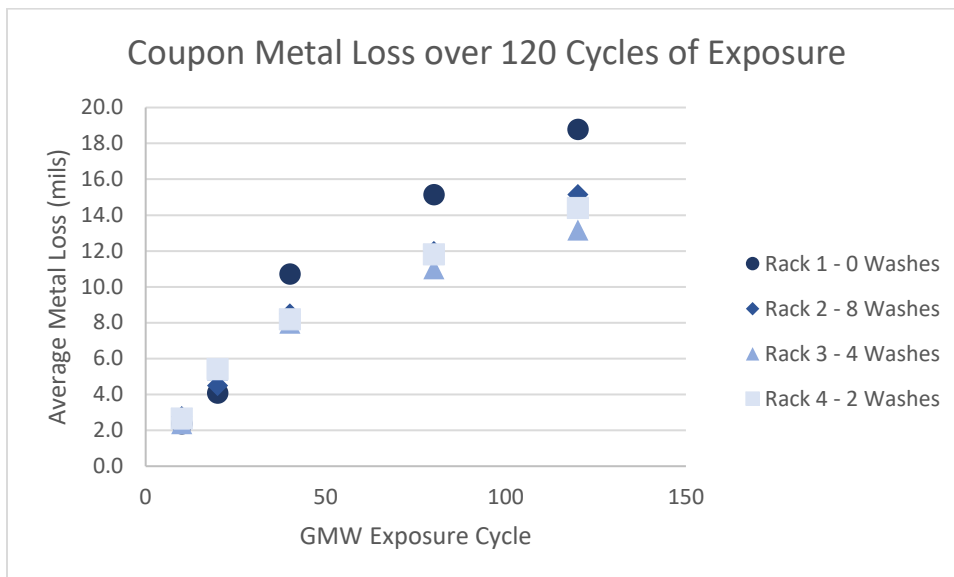


Figure 49. Coupon Mass Loss over 120 Cycles in Modified GMW Exposure

After visual inspection, the complex panels were disassembled, cleaned, and inspected for pitting. Table 40 shows the average and maximum of the deepest pit measurements made for all panels in each pressure wash condition. At the top is comparable pitting data taken from test panels after the initial pre-rusting. This data suggests negligible pitting activity occurred in the crevice of the coated test panels for all but the most frequently pressure washed panels. This may be an indication that a higher number of washes increased the likelihood that coating sealing the gaps between the two panels would be broken allowing air and water into the crevice area.

Table 40 – Pitting Data Sorted by Wash Frequency

Pressure washes over Test Period	Deepest Measured Pit	Average measured pit
Unexposed control (pre-rusted condition)	16 mils	7.6 mils
0 (never pressure washed)	15 mils	7 mils
3	17 mils	6.4 mils
6	14 mils	5.8 mils
12 (most frequent)	18 mils	8.9 mils

Table 41 shows the average of the eight deepest pits measured in the crevice of each test panel. As with the composite data, the panels which were pressure washed most frequently were most likely to have the largest average pit depths compared to those panels which were washed less. Interestingly, this trend was not true for the panels coated with system D, the moisture cure urethane coating system.

Table 41 – Average of Eight Pit Depth Measurements in the Crevice of Each Panel

System		Average Pit Depth (Mils)				Average by System
Coating	Remediation	12	6	3	0	
A	SP-10	9.0	6.5	5.1	7.0	6.9
A	PW 1	11.3	5.4	6.6	7.9	7.8
B	PW 1	9.8	3.3	4.4	9.3	6.7
B	PW 3	12.8	5.3	4.8	6.1	7.2
C	SP-3	11.1	8.8	7.4	8.8	9.0
C	PW 1	10.5	8.5	2.8	5.4	6.8
D	SP-3	3.6	2.6	8.4	8.9	5.9
D	PW 1	6.9	7.9	11.6	5.8	8.0
D	UHPWJ	5.1	4.4	6.6	4.3	5.1
Average by Times Washed		8.9	5.8	6.4	5.6	6.7

Figure 50 shows the interior crevice surface of the panel which measured the lowest average pitting after testing was completed. The pitting is smoother and more uniform across the surface. Figure 51 shows the interior surface of the panel which measured the highest average pitting.



Figure 50. Coating D - SP-3 Remediation - Washed 6 Times Over Testing



Figure 51. Coating B - PW Remediation - Washed 12 Times Over Testing

Natural Exposure Testing

Three sets of test panels were exposed to different conditions intended to represent various winter salting and washing frequencies. One set was sprayed with a saltwater solution (1% NaCl) weekly from December through March (abbreviated below as Salt Spray), one set received the same salt spray and was pressure washed once in the spring (abbreviated below as Salt Spray + PW), and the third set is neither salt sprayed nor pressure washed during the exposure (No Salt Spray).

Test panels were inspected at four intervals. The first took place within the week prior to the salt spray starting in December 2016 (winter inspection), the second within the week after the salt spray had been stopped in March 2017 (spring inspection), the third within the week prior to the salt spray starting in December 2017 (winter inspection), and the fourth within a week after the salt spray had been stopped in March 2018 (spring inspection). Figure 52 through Figure 54 include four photographs of each set of panels, one from each inspection.

During these inspections, ratings were recorded for ASTM D610, *Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces* and ASTM D714, *Standard Test Method for Evaluating Degree of Blistering of Paints*. Additionally, 12 visual measurements of corrosion undercutting from the scribe (scribe cutback) were made per panel.



Figure 52. No Salt Spray Panels from September 2016 (top), April 2017 (second), December 2017 (third), and March 2018 (bottom)

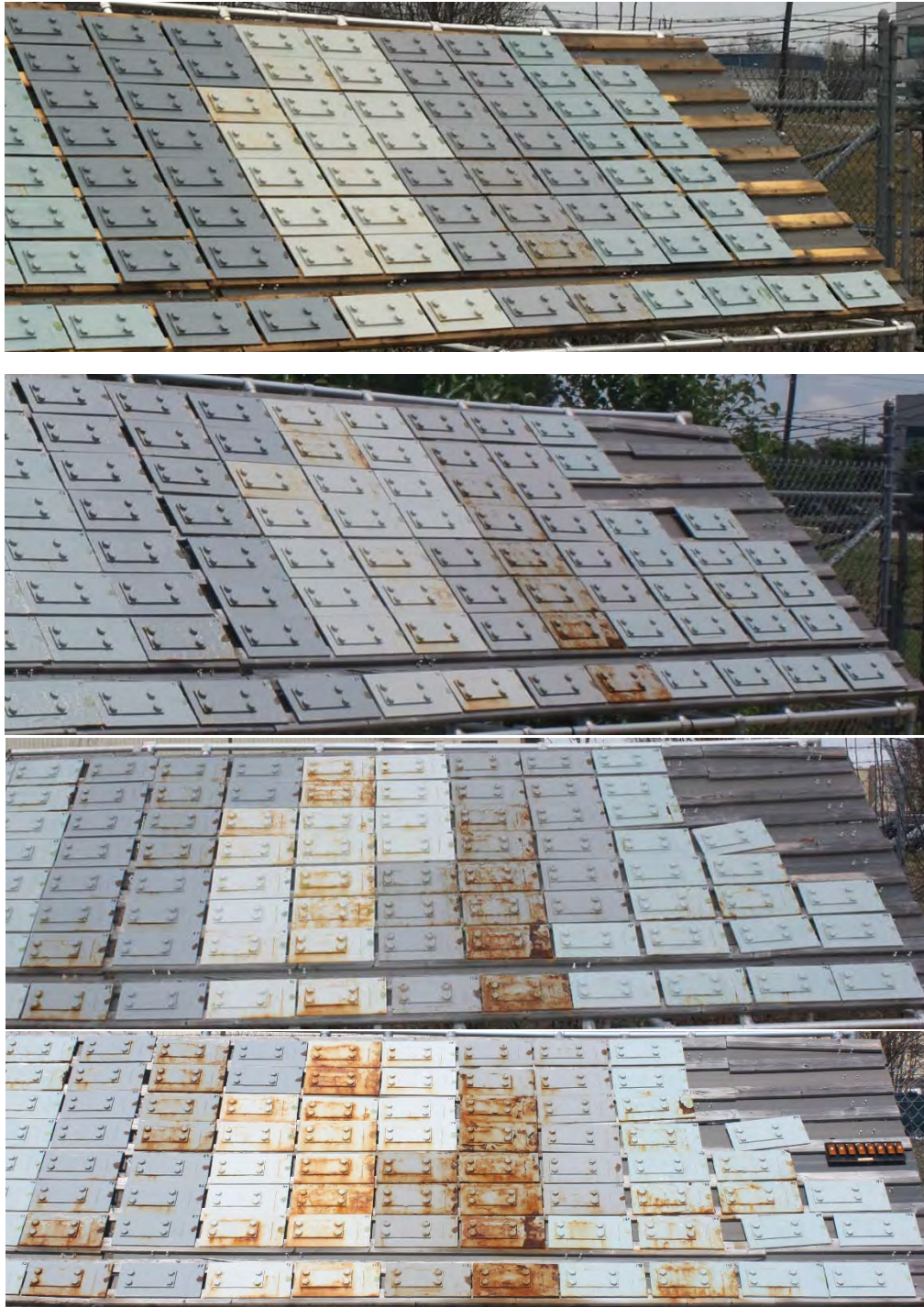


Figure 53. Salt Spray and Pressure Wash Panels from September 2016 (top), April 2017 (second), December 2017 (third), and March 2018 (bottom)



Figure 54. Salt Spray Panels from September 2016 (top), April 2017 (second), December 2017 (third), and March 2018 (bottom)

Figure 55 shows the average ASTM D610 rust ratings for each combination of coating and remediation method. ASTM D610 ratings represent the percentage of surface area exhibiting rusting on a non-linear scale from 10 (best) to 0 (worst). A bridge owner will typically consider repainting a structure once it reaches condition 4 or 5. The following ratings are provided for perspective:

10 – Less than 0.01% rusted surface	5 – 1 to 3% rusted surface
9 – 0.01 to 0.03% rusted surface	4 – 3 to 10% rusted surface
8 – 0.03 to 0.1% rusted surface	3 – 10 to 16% rusted surface
7 – 0.1 to 0.3% rusted surface	2 – 16 to 33% rusted surface
6 – 0.3 to 1% rusted surface	1 – 33 to 50% rusted surface

The data has been sorted by the remediation's final ASTM rating across all coatings, shown in the table as 'Grand Average' under the winter and spring inspections. The average initial salt contamination per square centimeter is included next to the remediation name in the table. The data shows improved performance over remediation methods that removed most of the rust scale and soluble salts (ranked 1 to 4). Pressure washing with or without additives (ranked 7 to 9) was the least effective surface preparation and the power tool cleaning methods were in the middle. Coating systems also impacted performance. The zinc/epoxy/urethane coating system is as effective as or more effective than the remaining coating systems even over less than ideal surface preparation.

Rank	Remediation (Initial Salt level in $\mu\text{g Cl}^-/\text{cm}^2$)	Winter 2016 Inspection					Spring 2018 Inspection				
		Coating				Grand Avg	Coating				Grand Avg
		A	B	C	D		A	B	C	D	
1	Vapor Blast (15.0)	9.5	9.5	10	9.7	9.7	8.3	7.3	7.7	8.5	8.0
2	SP-10 (30.4)	10	9.2	9.7	9.3	9.5	6.2	7.0	6.7	7.2	6.8
3	PW + SP-10 (21.3)	9.8	9.2	9.8	9.3	9.5	8.8	7.3	7.0	8.3	7.9
4	UHPWJ (22.4)	10	9	9.5	8.7	9.3	5.7	7.2	5.8	7.5	6.5
5	SP-11 (68.8)	10	9.7	8.7	7.7	9	7.5	5.3	6.0	8.5	6.8
6	SP-3 (92.9)	10	9.2	8.2	6.2	8.4	7.2	2.7	4.5	6.3	5.2
7	PW 3 (81.2)	9.2	9.3	6.7	7	8	5.0	1.0	3.8	5.5	3.8
8	PW 1 (74.9)	9	9	6.7	6.5	7.8	6.0	0.8	3.2	5.0	3.8
9	PW 2 (50.7)	9.2	9	6.3	6.5	7.8	5.7	1.2	3.0	5.0	3.7
Grand Average		9.6	9.2	8.4	7.9	8.8	6.7	4.4	5.3	6.9	5.8

Figure 55. ASTM D610 Ratings of Winter 2016 and Spring 2018 Inspections

Figure 56 shows the average ratings for all test panels in each exposure set. As would be expected, the panels being salt sprayed have shown more through film corrosion than those not receiving the salt spray. Throughout the exposure test, the panels receiving no salt spray have more consistent performance while those receiving salt spray have more performance variation. This is likely

compounded by variability in workmanship, as the salt breaks down the weakest points in the coating system. The pressure wash does not seem to decrease the visual extent of rusting in this timeframe.

Figure 57 shows the average ratings for all test panels of each coating type. Throughout the testing, the zinc/epoxy/urethane and moisture cure urethane (including a zinc rich primer) systems (Coating A and D) were performing notably better than the waterborne acrylic and high ratio calcium sulfonate alkyd coating systems (Coating B and C).

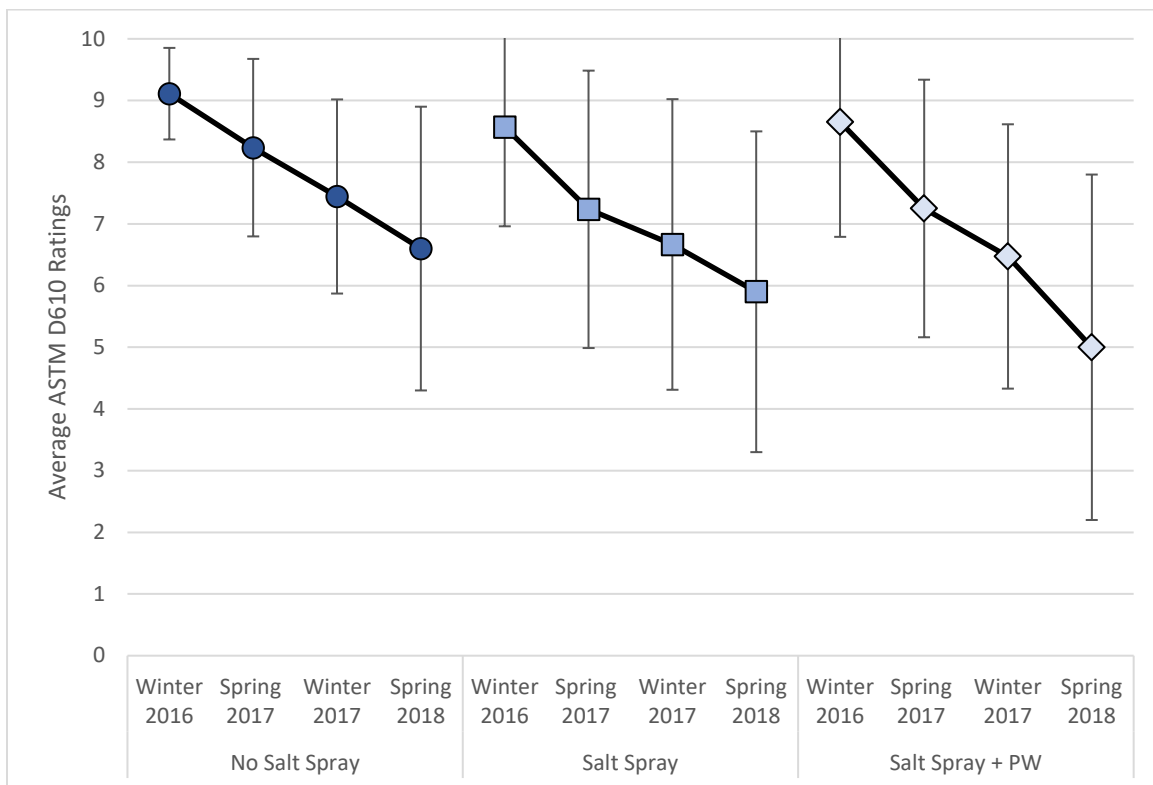


Figure 56. Average ASTM D610 Ratings by Exposure Type (Error bars indicate ± 1 standard deviation)

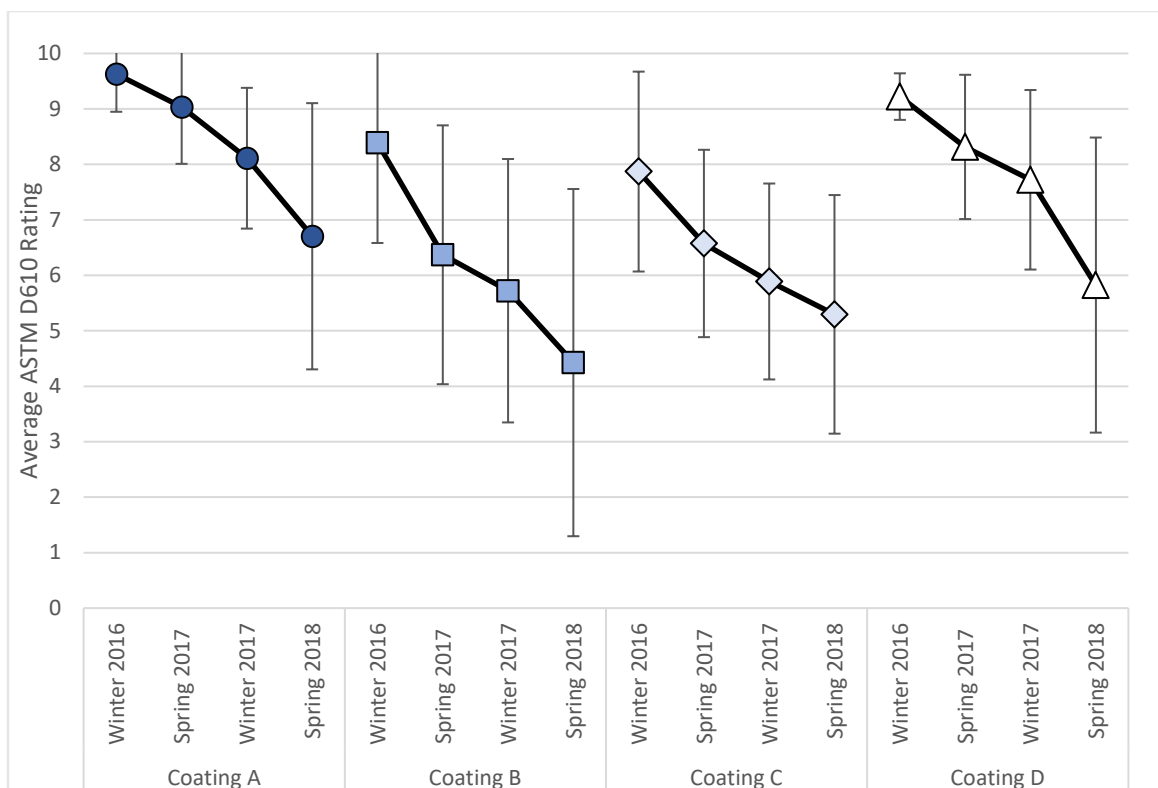


Figure 57. Average ASTM D610 Ratings by Coating Type (Error bars indicate ± 1 standard deviation)

During the winter 2016 inspection, 38% of the panels showed some form of blistering; during the spring 2017 inspection, 73% of panels showed some form of blistering; and during the winter 2017 inspection, 84% of the panels showed some form of blistering. Although the severity of the blistering increased between the winter 2017 and spring 2018 inspections, roughly the same percentage of panels showed blistering. This blistering occurs in the form of 1mm sized blisters densely formed across the B and C coated panels and greater than 5mm blisters on the pressure washed panels with coating A, where the coating is delaminating around the mating surface.

After the Spring 2018 inspection most of the panels (78%) are still showing no corrosion undercutting from the scribe; 84% show average cutback less than 1mm. Locations where large scribe cutback is present (>10 mm average) are due to lesser degrees of surface preparation, or through film corrosion so severe there is full coating loss around the scribe.

Table 42 is a list sorted from lowest to highest average surface chloride concentration following remediation. This data is based on boiling water extraction of salts from the surface of representative panels from each test condition. It is worth noting that there was significant scatter in the contamination levels. The complete data and statistical analysis of the differences was presented in the Remediation section of this reports. Figure 58, Figure 59, and Figure 60 compare three dimensions of the coated panel performance (rust through, blistering, and undercutting) as a function of salt concentration and exposure type. The data suggest that salt concentration has a correlation to blistering and undercutting but does not seem to have a strong correlation to rust through. The data suggest that a critical concentration might be in the range of 30 to 50 $\mu\text{g Cl}^-/\text{cm}^2$. This number is considerably higher than most specifications but consistent with previous research on atmospherically exposed bridge

coating performance over soluble salts.²⁸ It is worth noting that the surfaces in the present study varied by more than soluble salt levels; they had different degrees of residual scale, surface roughness, and other features.

Table 42 – Average Salt Level Following Each Remediation Technique

Remediation Prior to Coating	Average Salt Level After Remediation ($\mu\text{g Cl}^-/\text{cm}^2$)
ECO BLAST	15.0
PW/SP-10	21.3
UHPWJ	22.4
SP-10	30.4
PW+HT/SP-3	50.7
SP-11	68.8
PW/SP-3	74.9
PW+CL/SP-3	81.2
SP-3	92.9

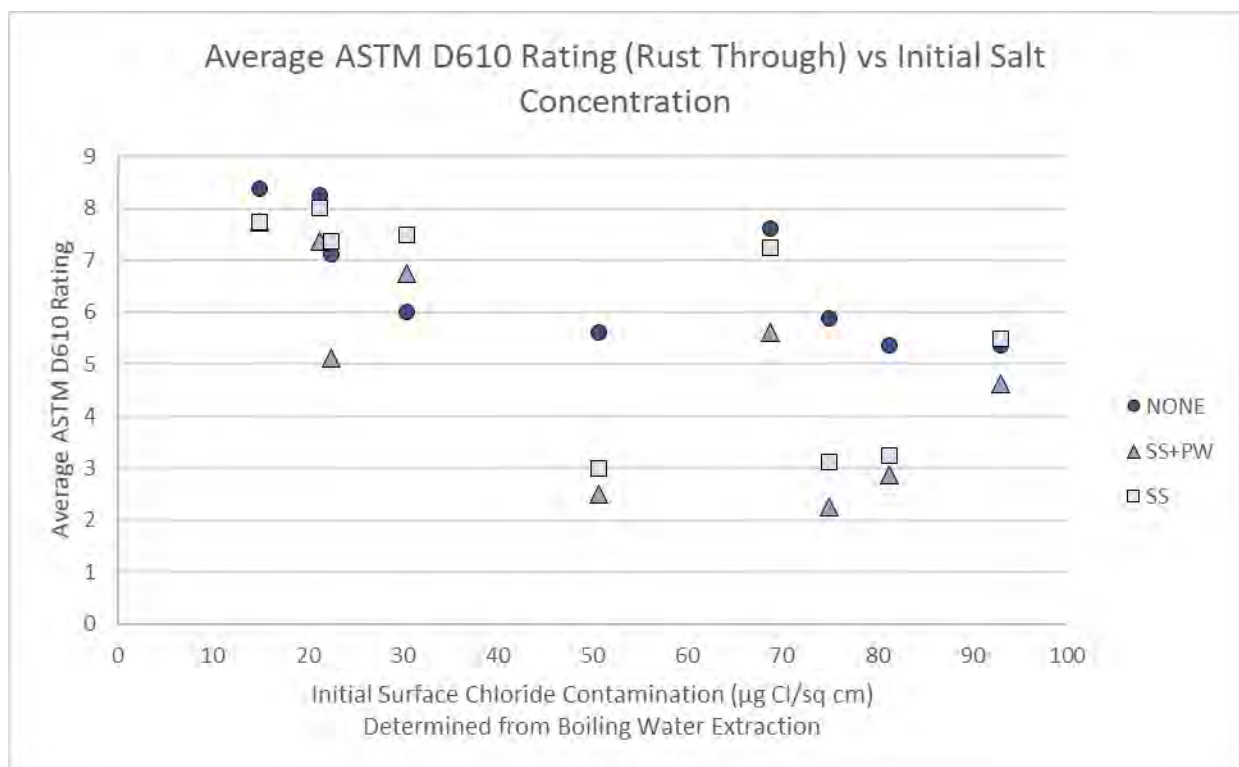


Figure 58. Average ASTM D610 Rating by Exposure Type and Initial Chloride Contamination

²⁸ See Table 18 of FHWA-RD-91-011, Effect of Surface Contaminants on Coating Life

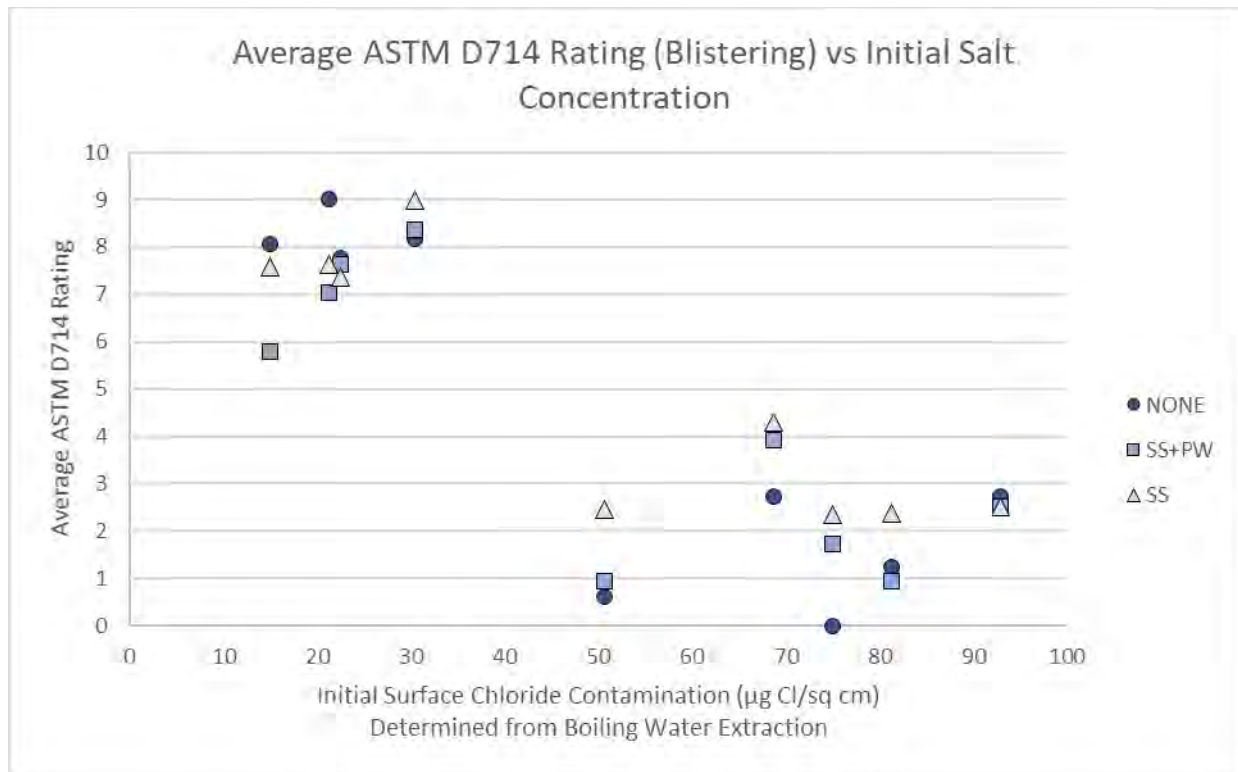


Figure 59. Average ASTM D714 Rating by Exposure Type and Initial Chloride Contamination

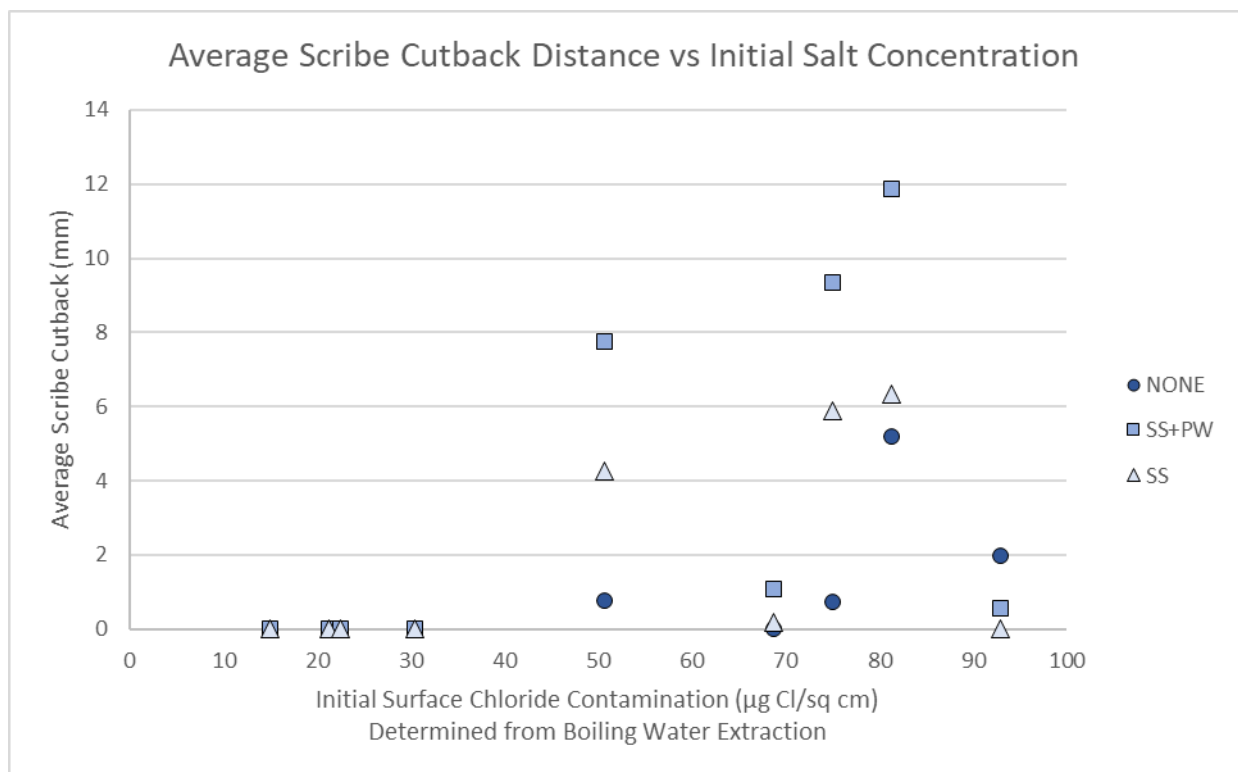


Figure 60. Average Scribe Cutback Distance by Exposure Type and Initial Chloride Contamination

Field Observations

During the project soluble salt measurements were performed at over 40 locations at various times on five structures. Data was collected on an overpass around the time of salting events, at different locations on a complex bridge over a marine estuary, during one bridge washing project, and during three active protective coating projects.

Winter Salt buildup on New Jersey Highway Overpass

Soluble salt measurements were performed near the abutment of NJDOT structure number 0610-150. The structure is an 8-girder, double span bridge with expansion joints at either abutment that carries Route 552 (a two-lane road) over Route 55 (a four-lane divided highway). The intent of monitoring this structure is to better understand the distribution and migration of soluble salts as related to weather conditions and salting events.

Six inspection areas were identified on the bridge as listed in Table 43 and as shown in Figure 61 through Figure 66. Three inspection methods were used for testing: multi-step ion-specific method C, fully automated conductivity detection method B, and multi-step conductivity detection method F. At each visit to the bridge, two measurements were made with each inspection method in each inspection area, resulting in 36 total tests. Data were obtained at four different times:

- Baseline measurements were performed on January 4, 2017, following a few days of rain with no known road salting in the week prior.
- The second inspection was completed on a warm (60°F) clear afternoon of January 12, 2017. A snow event occurred on January 5 and 6, but the snow from this event had melted by the time of the inspection.
- The third inspection was completed on a cold (29°F) clear afternoon of March 13, 2017 in anticipation of a snow event. Conditions were dry and clear when the inspection was completed.
- The fourth inspection was completed on a cold (29°F) clear afternoon of March 15, 2017 following a snow event occurring on March 14. Light snow was falling when the inspection was performed.

Table 43 – Inspection Locations on Rt 55 Overpass Structure 0610-150

Spot	Location	Approximate Area
1	Northbound Exterior Fascia, 2" from stiffener, 6" from lower flange, 2'x1' area (Figure 61)	2'x1'
2	Northbound Exterior Flange, on top (facing up), 2' from stiffener, 2'x9" long (Figure 62)	2'x9"
3	Northbound Exterior Flange, on bottom (facing down), 2' from stiffener, 2'long x 20" wide (Figure 63)	2'x20"
4	Northbound Exterior Girder, inside stiffener, facing abutment, between bracing (Figure 64)	20"x9"
5	Second Girder, southbound facing fascia, 6" from stiffener, 6" above lower flange (Figure 65)	1'x2'
6	Second Girder in from Northbound, lower flange bottom, facing down (Figure 66)	2'x20"

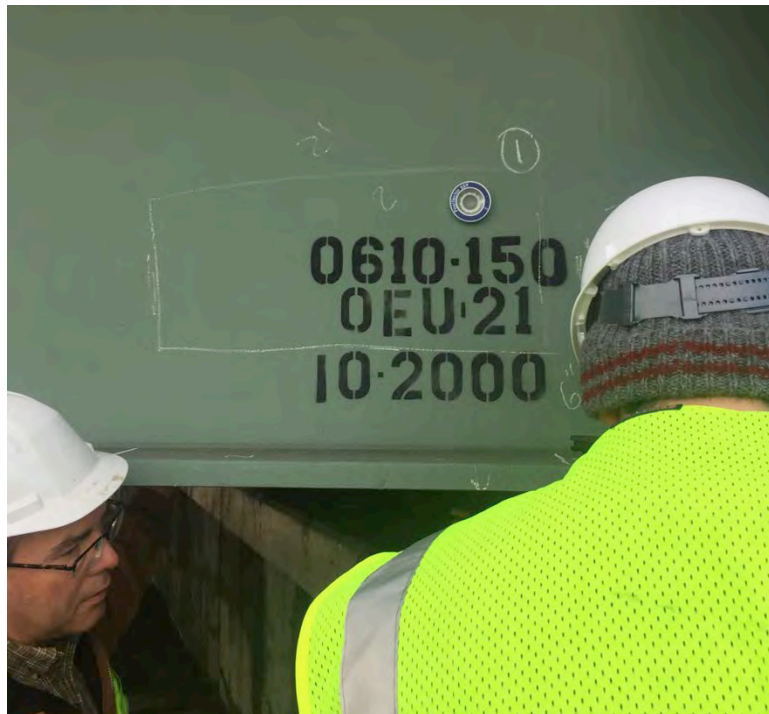


Figure 61. Location 1 - Exterior Fascia - Method F Test Cell Attached



Figure 62. Location 2 - Top of the Lower Flange



Figure 63. Location 3 - Underneath the Lower Flange



Figure 64. Location 4 - Behind the "02" on the Stiffener



Figure 65. Location 5 - Interior Fascia Facing Southbound



Figure 66. Location 6 - Underneath the Lower Flange of an Interior Beam

Figure 67 shows the average salt contamination at each date/area based on four measurements within a given area (duplicate measurements for method B and for method F). An increase in salt concentration due to the January salting event is evident from the differences in the values obtained on January 4th and 12th. The difference is most apparent on the lower flange of the exterior fascia. It is worth noting that the high averages for area 2 and 3 on January 12 is heavily influenced by one reading in each location, suggesting that the salt isn't evenly distributed. During the March salting event, areas 1, 3, and 5 appear to show salt increases while areas 2, 4, and 6 appear to show salt decreases, though none of the changes are particularly large. Perhaps most significantly, the salt levels are elevated for at least two months following the baseline measurements performed on January 4, 2017.

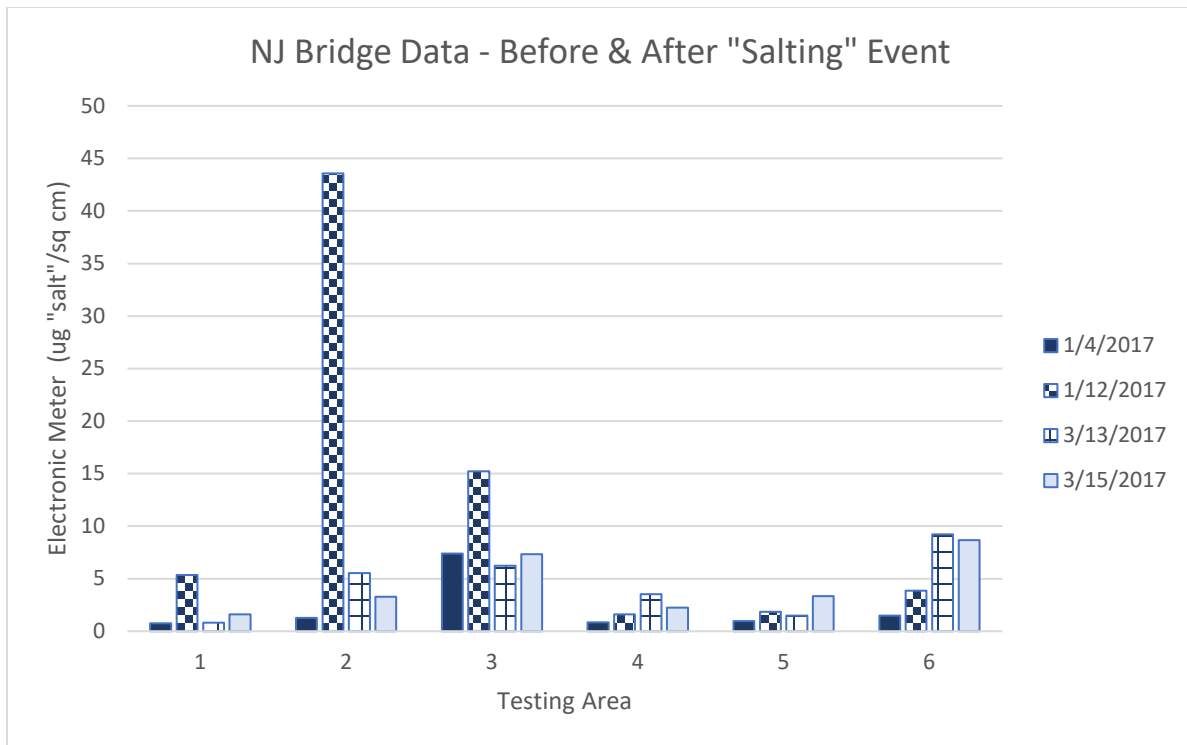


Figure 67. Average Electronic Meter Readings Before and After Two Road Salting Events

Figure 68 shows a relationship between 48 pairs of individual readings made using detection method B and detection method F. The data show a very good correlation between the two methods apart from four “outliers” which do not fit the expected relationship. Since no two measurements are in the exact same spot, it is possible that in these instances one measurement was made at a location with a locally different salt concentration.

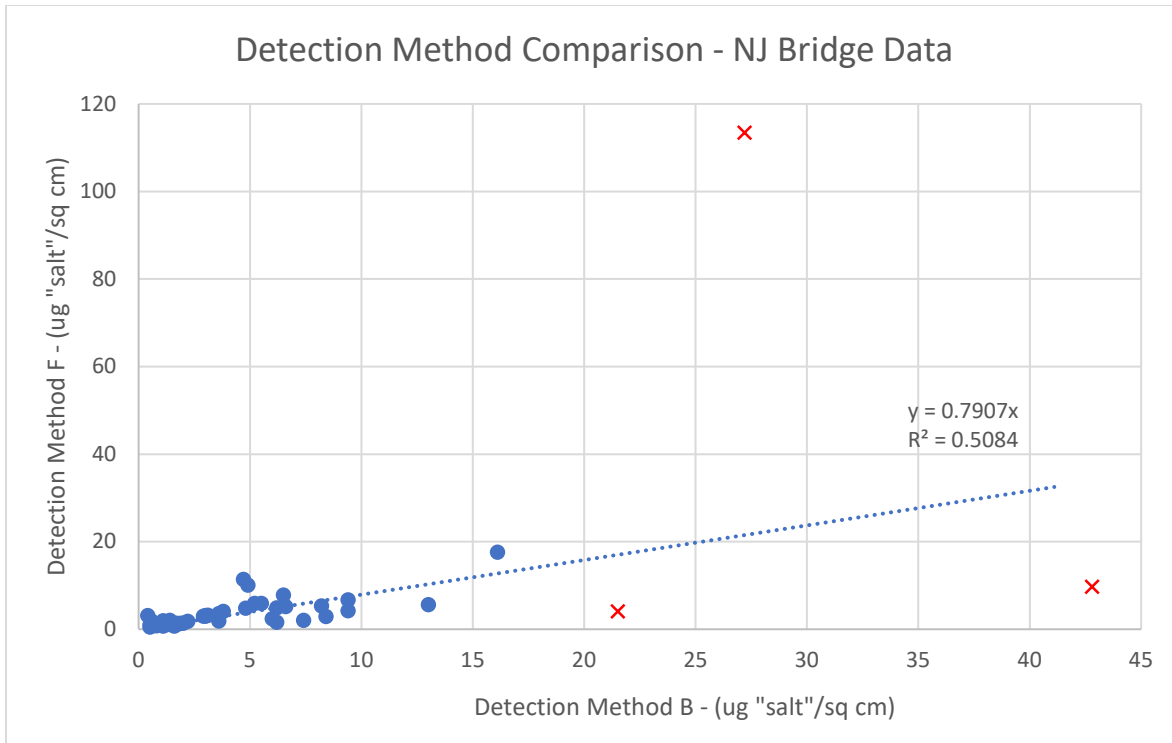


Figure 68. Relationship Between Electronic Meter Readings

Figure 69 shows the average salt contamination at each date/area based on duplicate measurements within a given area using detection method C. During the January salting event, areas 1 and 4 appear to show salt increases while areas 3, 5, and 6 appear to show salt decreases. During the March salting event, area 6 showed a significant salt increase while the remaining areas appear to show salt decreases. Unlike the conductivity methods, there is not a consistent increase from the baseline methods during the subsequent three data sets. This suggests soluble salt contamination other than chlorides.

Figure 70 compares 24 pairs of average readings for ion-specific and conductivity techniques (e.g., the average reading for each method at each of the 6 locations for each measurement period). Note that for this set of data, the conductivity methods indicate twice as much “soluble salt” as the ion specific method indicates for “chloride ion.”

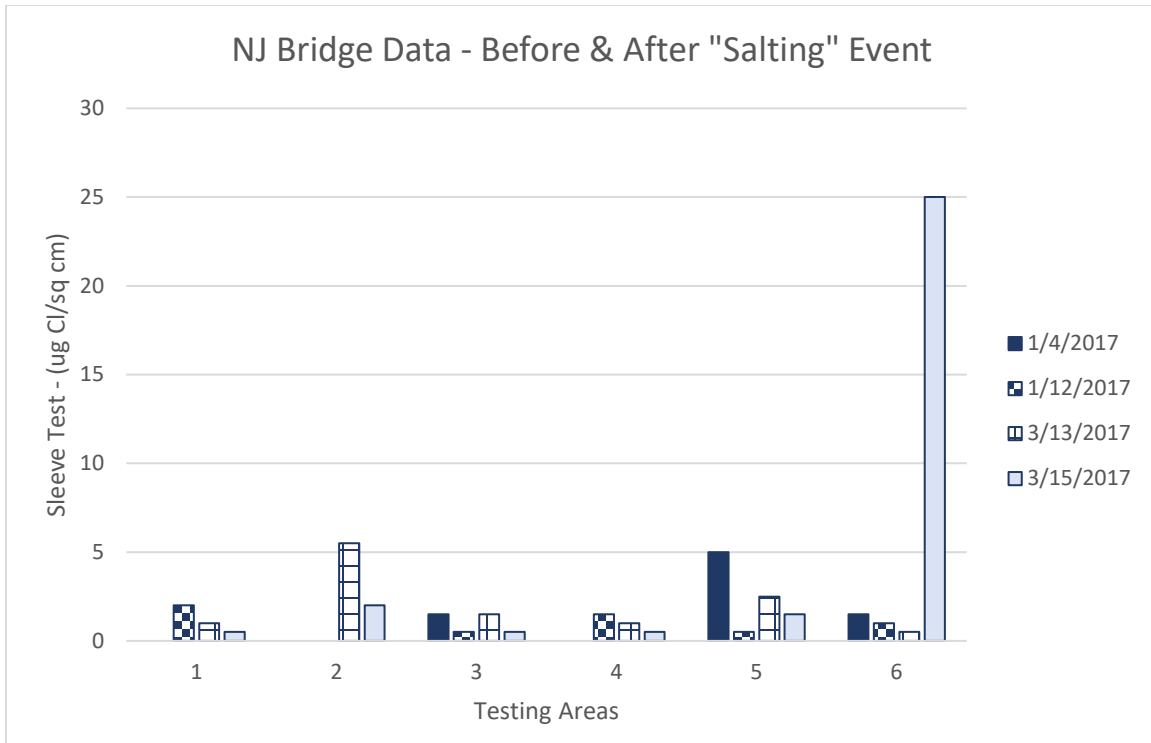


Figure 69. Average Sleeve Test Readings Before and After Two Road Salting Events

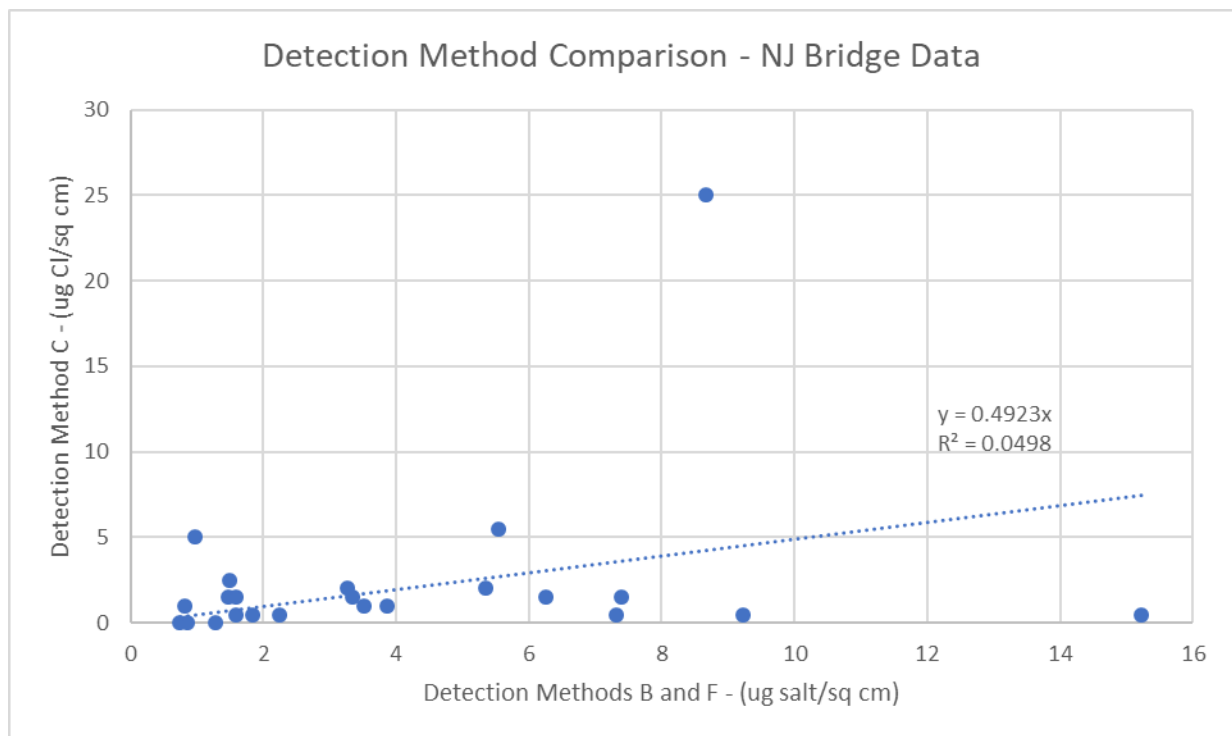


Figure 70. Relationship Between Average Electronic Meter Reading and Average Chloride Sleeve Reading

Washing of the Verrazano Narrows Bridge

The Verrazano-Narrows Bridge is a double-decked suspension bridge that spans the entrance to New York harbor and connects the New York City boroughs of Staten Island and Brooklyn. MTA Bridges and Tunnels is responsible for the operation and maintenance of the bridge. As part of their bridge maintenance program, they have an annual bridge-washing program to remove salts and other contaminants from their structures each spring. The scope is generally limited to cleaning portions of the structure that can be reached from the bridge deck. For the Verrazano Narrows Bridge, the bridge washing program includes the truss posts and parapets which are accessible from the lower level roadway.

Soluble salt measurements and observations were made during one night of bridge washing activities on the lower level westbound. During that time the crew pressure washed exterior surfaces of the north end posts and center posts of 11 floor trusses on Span 12 (Brooklyn side span) beginning at the Brooklyn Anchorage. Three of the four post faces were cleaned. The exterior face of the end post is out of scope (due to access constraints) and the fourth face of the center post will presumably be cleaned from the eastbound lane. The post interiors were not cleaned. Both parapets on the westbound roadway were also cleaned. Three 4,000 psi pressure washers drew water from a 1,500-gallon source for cleaning. One operator on each side of the roadway cleaned the parapets and posts from the roadway. A third operator pressure washed the extremities of the end posts from a bucket truck. Roughly a third of the water was consumed in 4 hours, suggesting a water usage rate of slightly over 40 gallons per nozzle-hour.

The washing visibly removed significant dirt, though some staining remained. Figure 71 and Figure 72 show the difference between a cleaned and dirty surface. In most cases, it was not possible to wipe the staining off surfaces that were just cleaned. However, the runoff did leave some dirt on previously cleaned surfaces (especially the parapet curb). While not pristine, all surfaces were clearly cleaner than before the work.

A series of soluble salt measurements were made at sixteen random locations on the bridge using the fully automated conductivity method (method B) and eight locations using the multi-step ion-specific method for chloride, nitrate, and sulfate (method C). At each location, measurements were made before and after washing. Table 44 and Figure 73 summarize the data. Note that no nitrates were detected using the ion-specific method and that sulfate was detected once before washing and three times after washing. The average sulfate concentration was $0.1 \mu\text{g SO}_4/\text{cm}^2$ before washing and $0.4 \mu\text{g SO}_4/\text{cm}^2$ after washing. Since all measurements were at the lowest detection limit, the contamination is negligible. The data show significant levels of soluble salts on the surface prior to washing and suggest that roughly 85% of the soluble salts were removed by the washing program.

Table 44 – Summary of Soluble Salts Detected Before and After Washing

	Detection method B ($\mu\text{g salt/cm}^2$)			Detection method C ($\mu\text{g Cl}^-/\text{cm}^2$)		
	Before	After	Change	Before	After	Change
Average	17.5	2.2	-15.3	8.0	1.3	-6.7
Std. Dev.	10.7	4.0		5.6	0.7	
RSD	61%	181%		70%	57%	

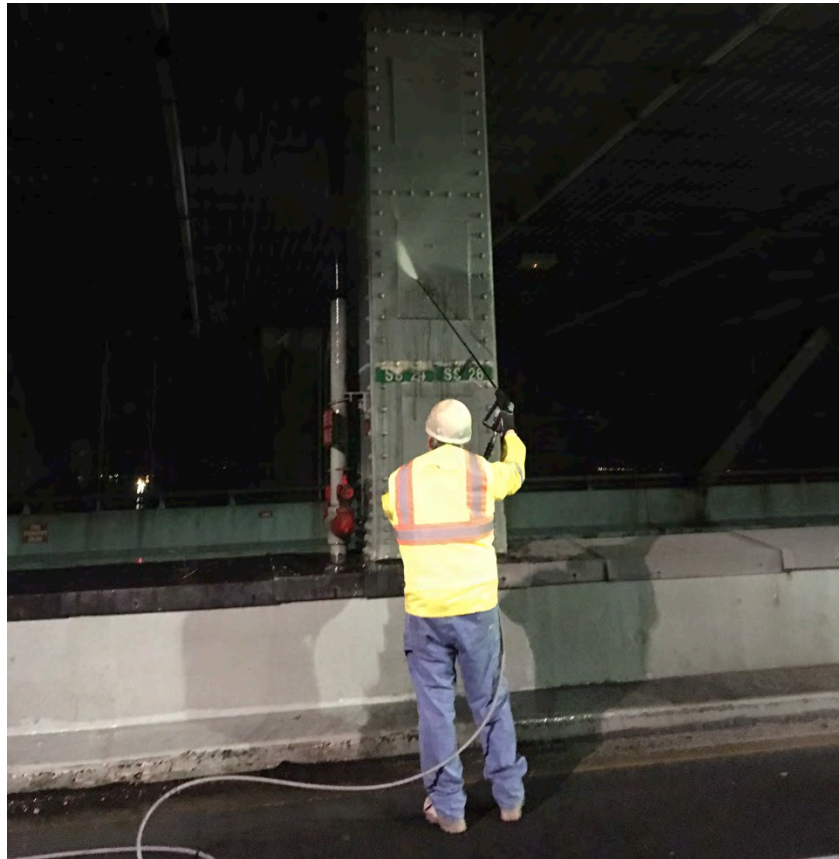


Figure 71. Dirt Removal on Pressure Washed Truss Post



Figure 72. Dirt Removal on Pressure Washed Parapet

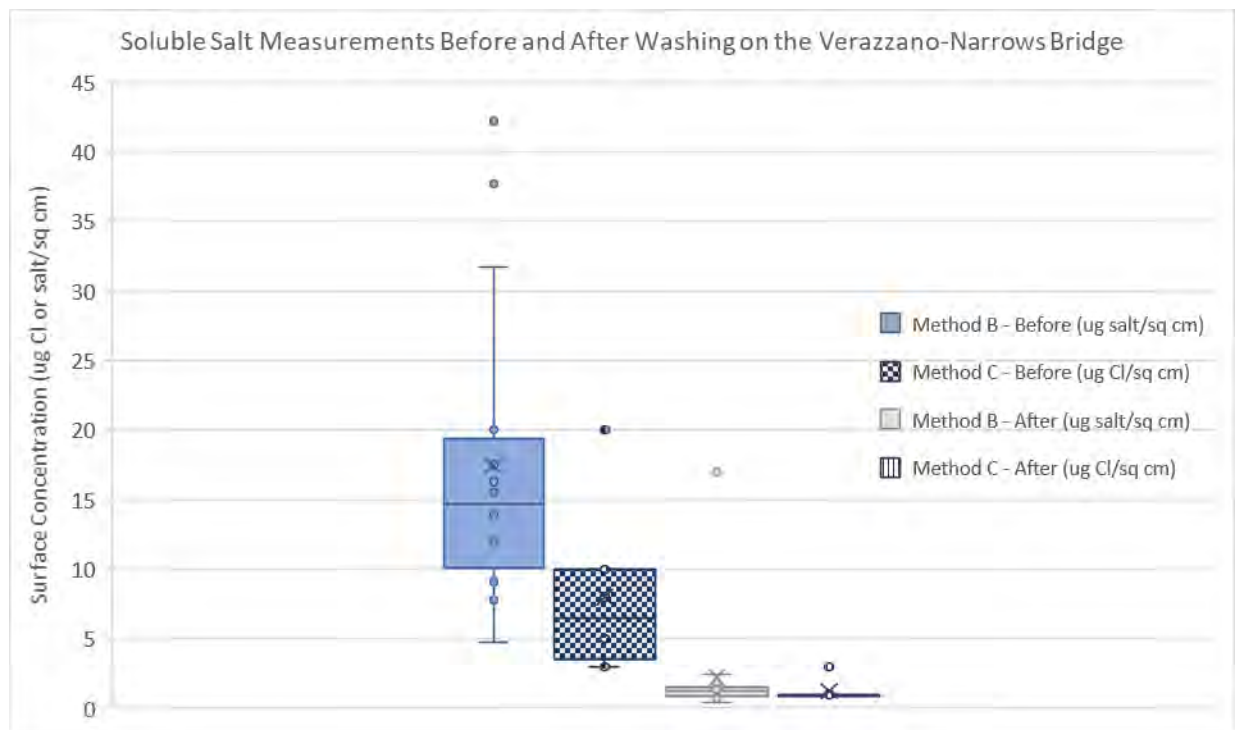


Figure 73. Soluble Salts Measured Before and After Bridge Washing

Robert F. Kennedy Bridge (New York City)

The Robert F. Kennedy Bridge (formerly the Triborough Bridge) is actually three bridges, a viaduct, and 14 miles of approach roads connecting Manhattan, Queens, and the Bronx. The bridge was constructed in the 1930's and has undergone several modifications. The RFK bridge is currently being re-coated as part of a multi-year structural rehabilitation and widening project. Soluble salt detection instruments were used during two visits to this project. Data were collected on zinc primed surfaces and abrasive blast cleaned steel.

Soluble Salt Detection on Weathered Zinc Primer

As part of the construction strategy during the widening project, the contractor chose to abrasive blast and zinc prime portions of the structure to remove lead paint hazard before proceeding with structural work. The primed surface is being subjected to weathering and contamination from construction debris prior to applying the remainder of the coating system. Soluble salt measurements were performed on the primed surface after approximately one year of exposure. Detection methods A, B, C, D, and F were used.

On the first visit, triplicate readings per detection device were taken at each of four areas of wintered zinc primer at the RFK Bridge between spans 99 and 100. Each area was roughly 3-foot by 3-foot of surface area. Two of these areas appeared to be clean to the naked eye, and two contained a white runoff that had stained the coating. This runoff appears to be residue from concrete deck cutting above the structural steel. Figure 74 shows the various instruments on the surface of area 1.



Figure 74. Salt Detection Instruments on Weathered Zinc Primer in Area 1

Figure 75 and Figure 76 show the measurements made on the weathered zinc primer. The visually contaminated areas had measurable higher levels of soluble salts as would be expected. On the visually contaminated areas, comparison of chloride ion and conductivity readings suggest that soluble materials other than chlorides are present. Again, given the probable source of contamination (concrete demolition) this is not surprising. Finally, note that two of the three reading sets in area 4 indicated contamination was present even though it was not visually apparent.

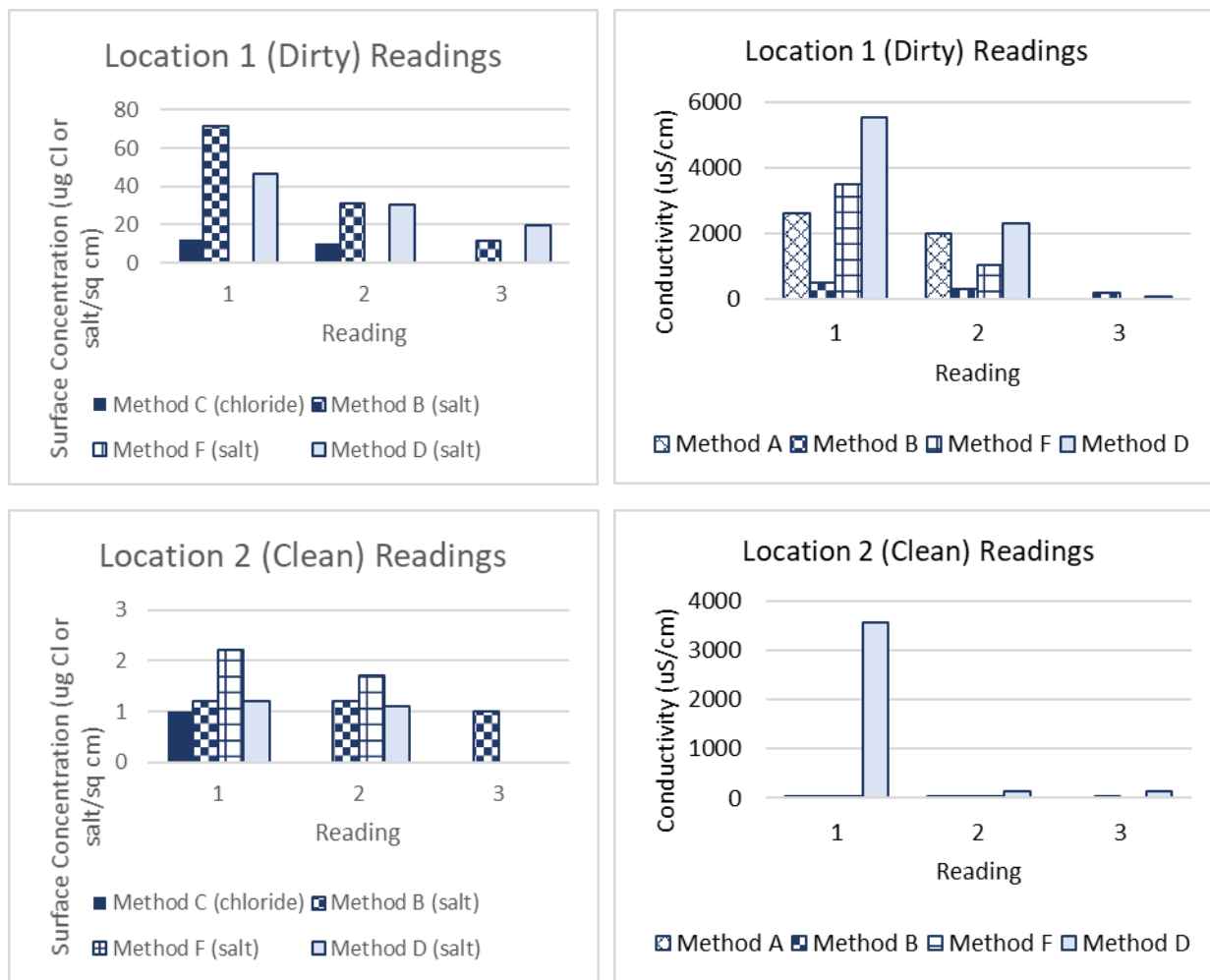


Figure 75. Soluble Salt Measurements at Weathered Primer Areas 1 and 2



Figure 76. Soluble Salt Measurements at Weathered Primer Areas 3 and 4

During the second visit to the bridge, data was collected on weathered zinc primer in five test areas. Test Area 1 included 7 different locations (numbered 1 through 6 and 18) within Spans 96-98 on the west face of Girder 2. Heavy white staining was visible throughout and did not appear to have any signs of recent cleaning. The staining could be likely caused from a combination of runoff from the deck cutting above and runoff from the expansion joint. Figure 77 shows a close-up of two test locations. Figure 78 shows the soluble salt test data expressed as both “salt concentration” and “conductivity.” Measured salt concentration ranged between 0 and 26 $\mu\text{g}/\text{cm}^2$. Conductivity measurements ranged between 43 and 217 $\mu\text{S}/\text{cm}$.



Figure 77. Overview of Test Area 1

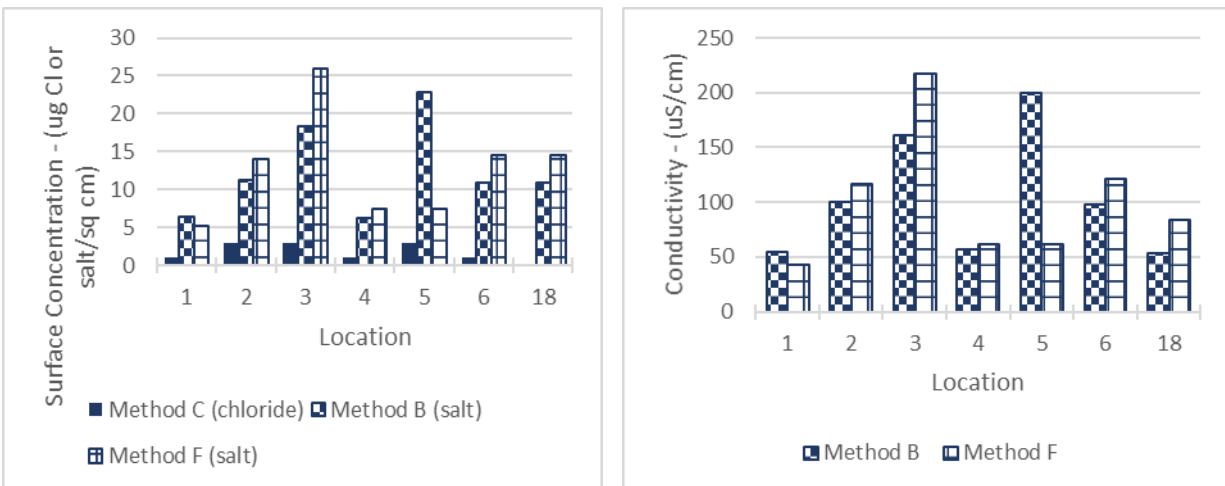


Figure 78. Soluble Salt Data Obtained at Test Area 1

Test Area 2 included 6 different locations (numbered 7 through 12) taken in Span 94-98 on the west face of Girder 1. This area was also recently washed. There were light white splatters present in many locations within this area. There were no signs of recent cleaning from a visual overview. Figure 79 shows a close-up of two locations in this area with instruments attached. Figure 80 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 1 and 83.3 $\mu\text{g salt/cm}^2$. Conductivity measurements ranged between 29 and 694 $\mu\text{S/cm}$.



Figure 79. Test Locations Within Area 2

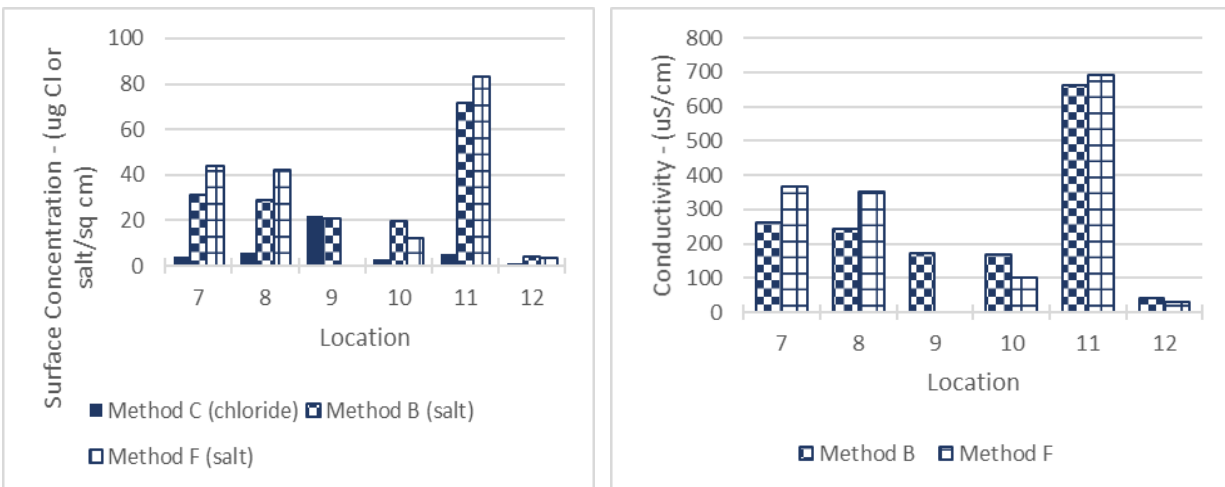


Figure 80. Soluble Salt Data Obtained at Test Area 2

Test Area 3 is comprised of three different locations (numbered 13 through 15) on girder 3 exterior facing east between spans 100-102. This area was not cleaned since the primer was applied. Light white staining was present in the area, which can be from a combination of runoff from the deck demolition. Figure 81 shows a close-up of one of the locations in this area. Figure 82 shows the test data in both "salt concentration" and "conductivity." Measured salt concentration ranged between 0 and 5.5 $\mu\text{g salt}/\text{cm}^2$. Conductivity measurements ranged between 12 and 46 $\mu\text{S}/\text{cm}$.

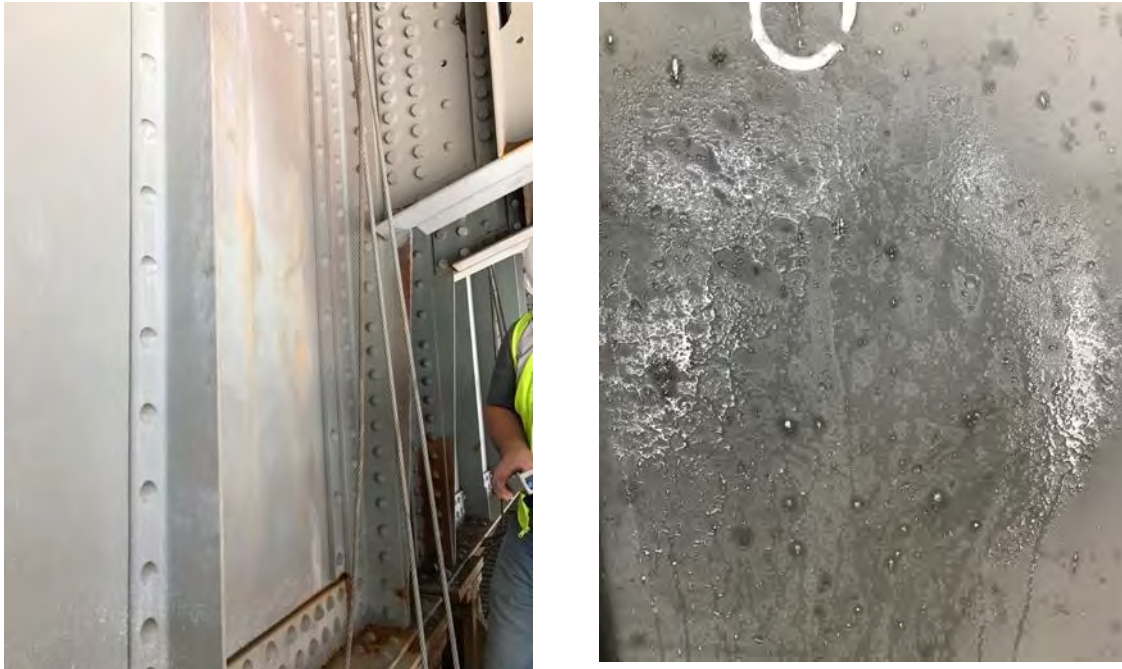


Figure 81. Overview of Area 3 and Water Break Test Performed

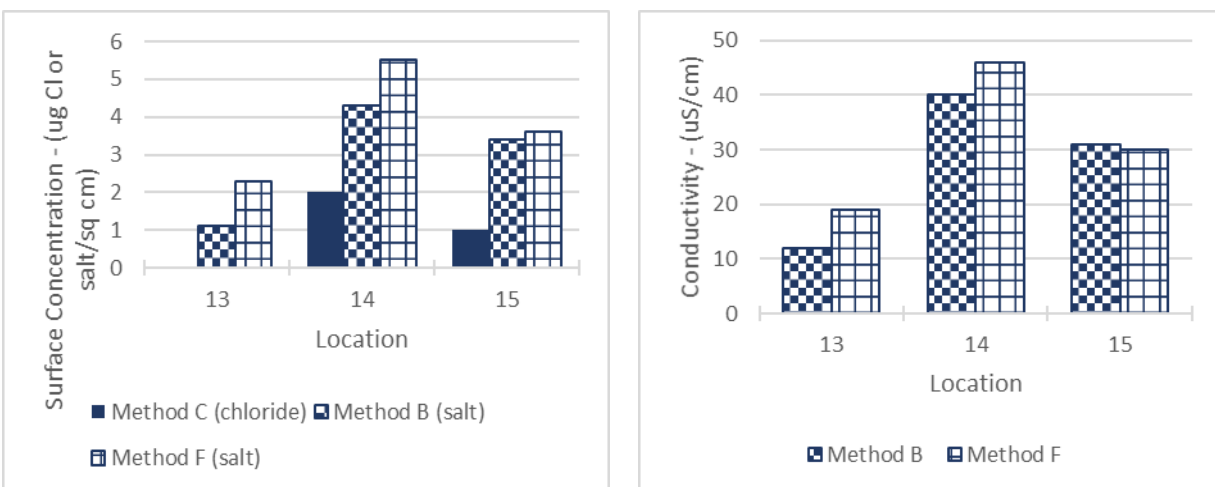


Figure 82. Soluble Salt Data Obtained at Test Area 3

Test Area 4, location 16 was performed on newly applied zinc Span 108. Figure 83 shows a close-up of the newly applied zinc primer. Figure 84 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 4.2 and 50.5 $\mu\text{g salt/cm}^2$. Conductivity measurements ranged between 38 and 421 $\mu\text{S/cm}$.



Figure 83. Containment Location for Area 4, Location 16 (newly applied zinc location)

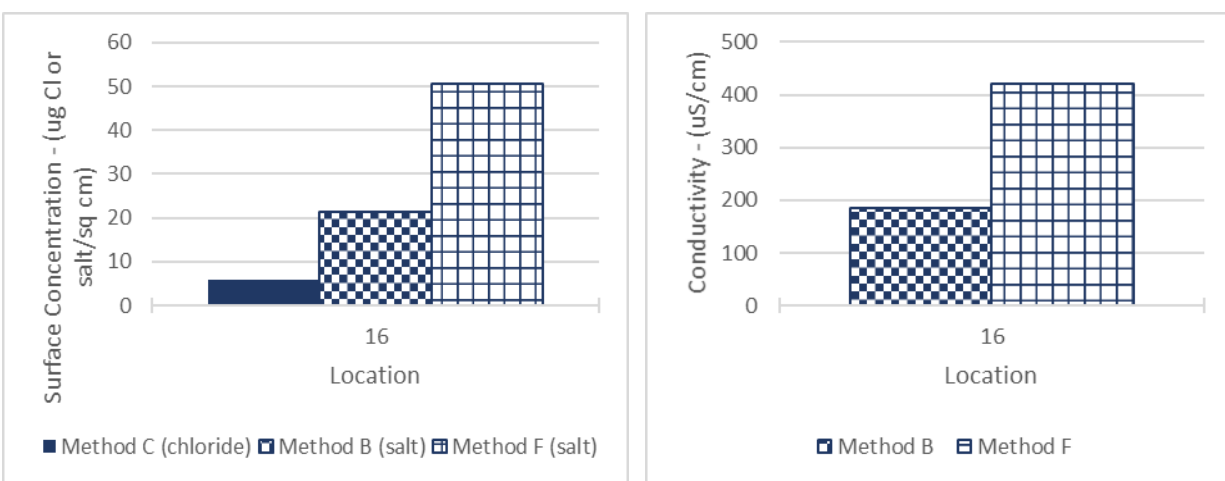


Figure 84. Soluble Salt Data Obtained at Test Area 4, Location 16

Test Area 5A and 5B were located on girder 2 facing east between spans 96-98. Area 5A was washed earlier that day using a 3,000 psi pressure washer after two different Zep Commercial cleaning products were used prior to washing. The cleaner was scrubbed to the surface with a brush prior to removal with washing. Figure 85 shows pressure washing of Test Area 5A. Three measurement locations were identified in this test area, locations 19, 20, and 21. Area 5B consisted of one location (location 22) that had not been washed just within span 97-98. Figure 86 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 0 and $11.2 \mu\text{g salt/cm}^2$. Conductivity

measurements ranged between 8 and 94 $\mu\text{S}/\text{cm}$. Note location 22 was the location not washed and was found to have higher values in salt concentration and conductivity.

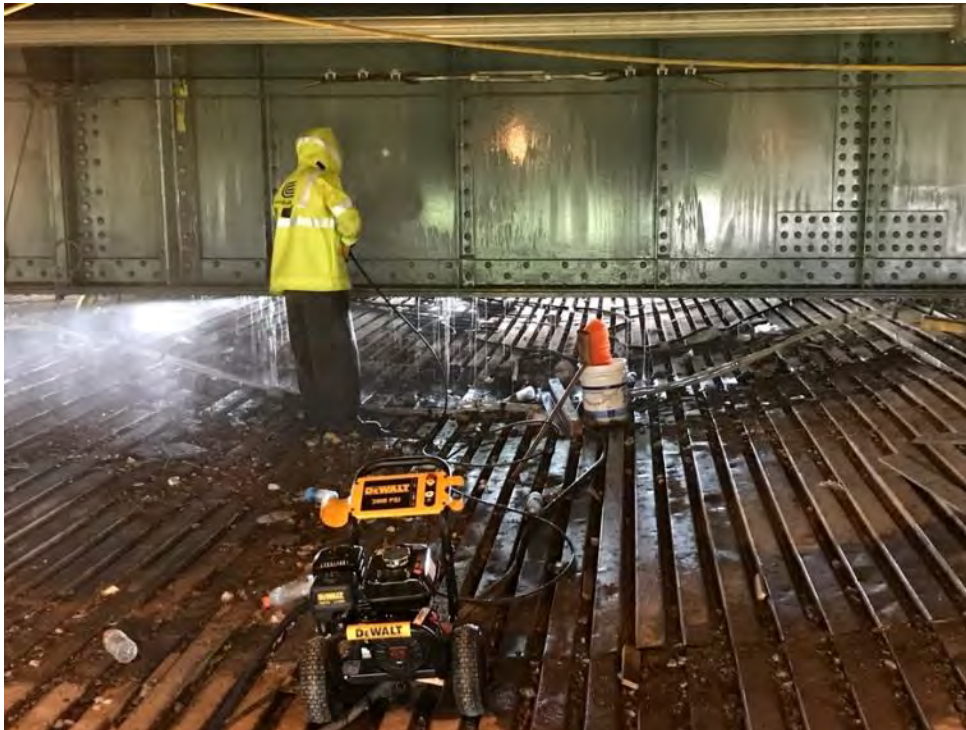


Figure 85. Area 5 During Pressure Washing

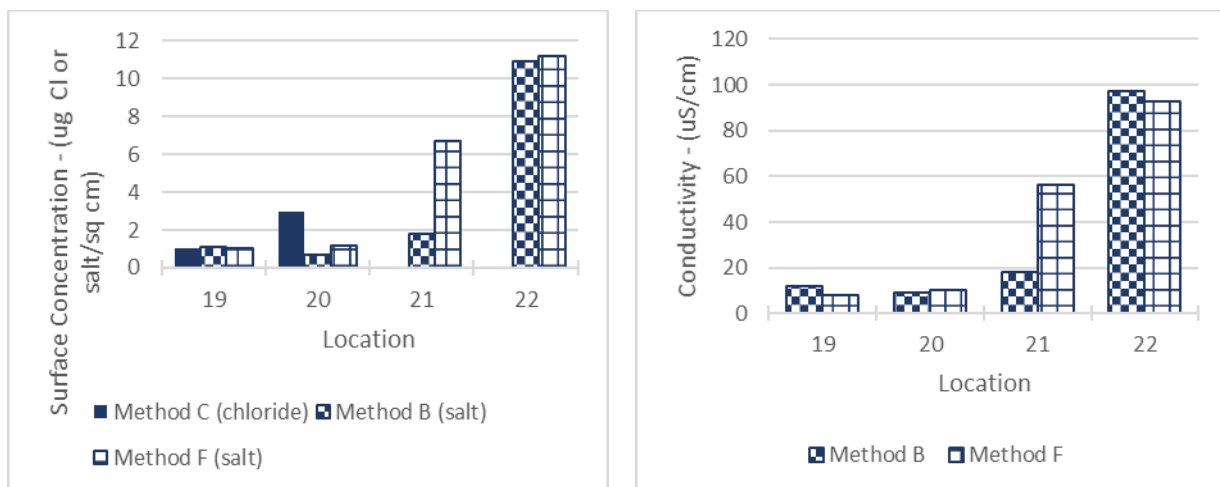


Figure 86. Soluble Salt Data Obtained at Test Area 5

Abrasive Blast Cleaned Steel

Soluble salt measurements were performed on an abrasive blasted surface of the RFK bridge in New York City. The abrasive blasting work was on-going at the time of our testing, allowing us to make measurements on surfaces that had some residual contamination in pits. Detection methods A, B, C, D, and F were used. One measurement was made with each instrument in each of 5 areas that were blasted the previous day. Each area was nominally 1 square foot.

Figure 87 shows the salt contamination indicated by each meter. Note that the electronic meters using traditional cell extraction (methods B and F) indicate a higher salt concentration than either the chloride ion specific test (method C) or the pad technique (method D). Also note that in three of the 5 locations, the method D provided a substantially higher conductivity reading and method B returned a notably lower reading in four out of 5 areas.

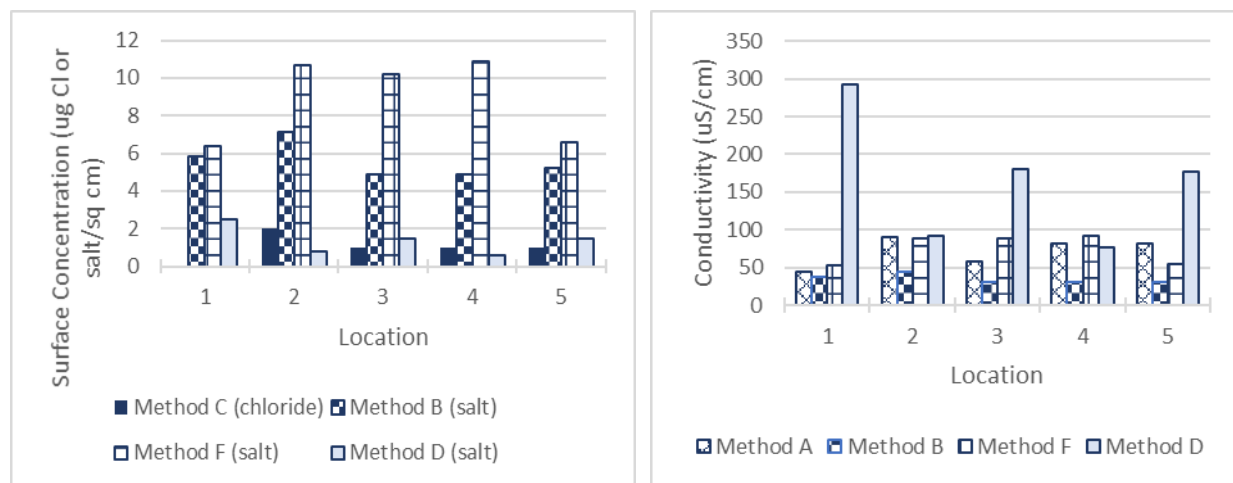


Figure 87. Surface Salt Concentration Readings on a Blasted Surface at the RFK Bridge

A sixth area containing heavy pits was measured with detection methods B, C, D, and F. The following observations were made in this area:

- Method C sleeves were able to adhere to the surface, and returned a reading of $35 \mu\text{g Cl}/\text{cm}^2$
- Method B appeared to form a good seal to the surface, but when it was removed, an area within the center of the pit appeared dry and was not washed with water during the testing (Figure 88). The readings returned from this meter were $40.2 \mu\text{g salt}/\text{cm}^2$ and $1089 \mu\text{S}/\text{cm}$.
- Method D meter returned a reading of $0.1 \mu\text{g salt}/\text{cm}^2$, indicating it detected close to no salt from the pit it was pressed into.
- Method F returned readings of $34.2 \mu\text{g salt}/\text{cm}^2$ and $410 \mu\text{S}/\text{cm}$.



Figure 88. Pitted Area After Performing Measurement with Method B

During the second visit to the bridge, data was collected on abrasive blasted steel in one test area. Test Area 4, location 17 was located at Span 108. Figure 89 shows a close-up of the blasted steel. Figure 90 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 4.2 and 50.5 $\mu\text{g salt/cm}^2$. Conductivity measurements ranged between 38 and 421 $\mu\text{S/cm}$. Comparing location 17 to the zinc primed location 16 (discussed above) it is noteworthy that the zinc primed area had higher salt calculated based on conductivity relative to chloride ion measurement. This suggests that there is a different salt composition on the primed surface than on the blasted surface and that the salt composition on the primed surface has more non-chloride soluble salts than the abrasive blasted surface.

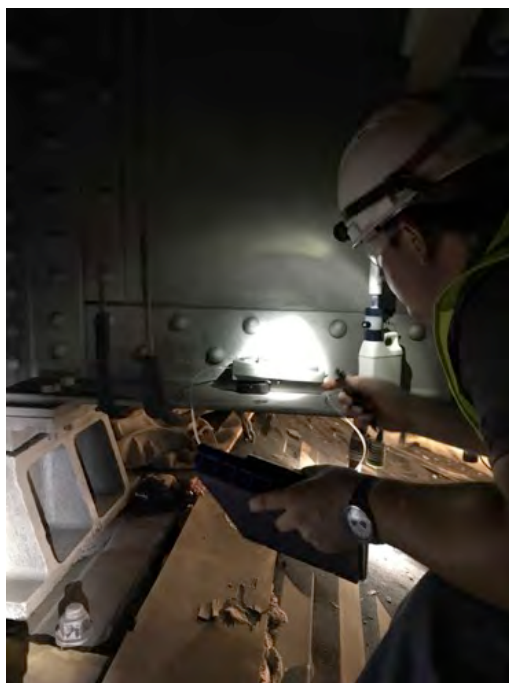


Figure 89. Containment Location for Area 4, Location 17 (abrasively blasted steel)

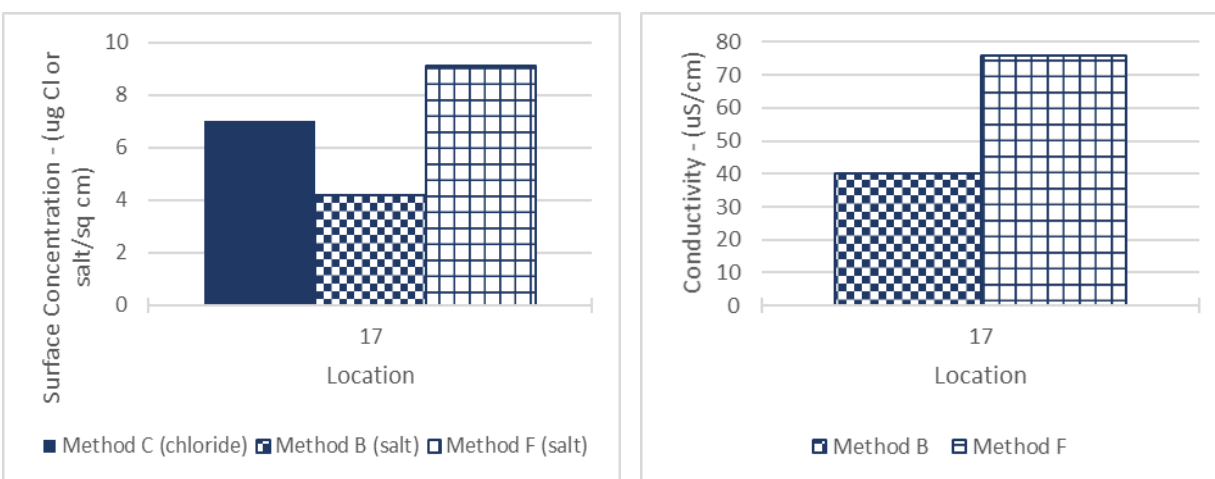


Figure 90. Soluble Salt data obtained at Test Area 4, Location 17

Marine Parkway-Gil Hodges Memorial Bridge

The Marine Parkway–Gil Hodges Memorial Bridge is a vertical-lift bridge in New York City, New York, that connects Flatbush Avenue in Queens with Brooklyn’s Rockaway peninsula by crossing the Rockaway Inlet (saltwater). The bridge was near the end of a major sandblasting and painting project. Weather and logistics precluded the ability to perform soluble salt measurements on abrasive blasted steel, but

measurements were performed on recently applied zinc-rich primer and on finish coated steel in two locations to quantify the impact of seawater on surface soluble salts.

Salt Concentration in Different Exposure Zones

Measurements were made in two spans of the Marine Parkway Bridge in New York City to quantify differences in salt buildup on coated steel. The zones included steel on the north-side deck truss in span 22 (adjacent to the north abutment) roughly 15 feet above the shoreline and steel on the south-side deck truss in span 6 (adjacent to the south abutment) roughly 15 feet above the water. Five, one square foot areas were selected on the north span (above shoreline) and four, one square foot areas were selected on the south span (above water). Table 45 provides descriptions of the nine test locations. A single measurement was made in each area detection methods A, B, C, D, and F.



Figure 91. Marine Parkway-Gil Hodges Memorial Bridge

Table 45 – Inspection Locations on Marine Parkway Bridge

Side	ID	Description
North (Over Shore)	1	Span 22.4-22.3, Exterior fascia plate facing west
	2	Span 22.4-22.3, Interior fascia plate facing east
	3	Span 22.4-22.3, West side bottom flange facing down
	4	Span 22.4-22.3, Interior fascia plate facing west
	5	Span 22.4-22.3, Exterior fascia plate facing east
South (Over Water)	1	Span 6.1-6.0, Lower chord middle gusset plate facing north
	2	Span 6.1-6.0, Interior fascia plate facing west
	3	Span 6.1-6.0, East side truss vertical beam facing south
	4	Span 6.1-6.0, Exterior fascia plate facing east

Figure 92 shows the data collected on the steel above the shoreline. The measurements were made during a light rain. Locations 1, 3, and 5 were most exposed as they faced outside and down. The interior, east-facing fascia plate (location 2) indicated the highest concentration of salts. Location 5 was also facing east, but on the outside of the structure leaving it more exposed to the rainfall, which may be a reason for the lower indicated salt concentration. The downward-facing horizontal surface of location 3 showed the next highest salt readings. This salt contamination may result from condensing salt air.

Figure 93 shows the data collected over water. This testing was performed after the light rain had cleared. Location 4 was wet at the time of testing indicating it may be subjected to salt spray or rain. Locations 1-3 were dry at the time of testing. The highest salt concentration was observed at location 1 which was in the center of the truss. Locations 2 through 4 (all of which were along the east (ocean) side) had the lowest salt concentration.

Overall, the measurements above the shoreline were higher than those taken above the water.

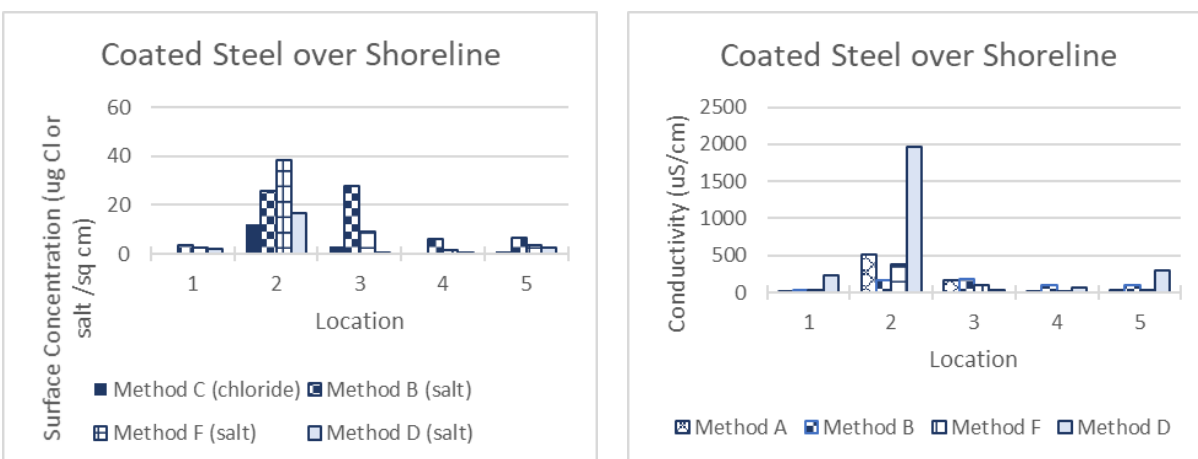


Figure 92. Soluble Salt Measurements on Steel over Shore

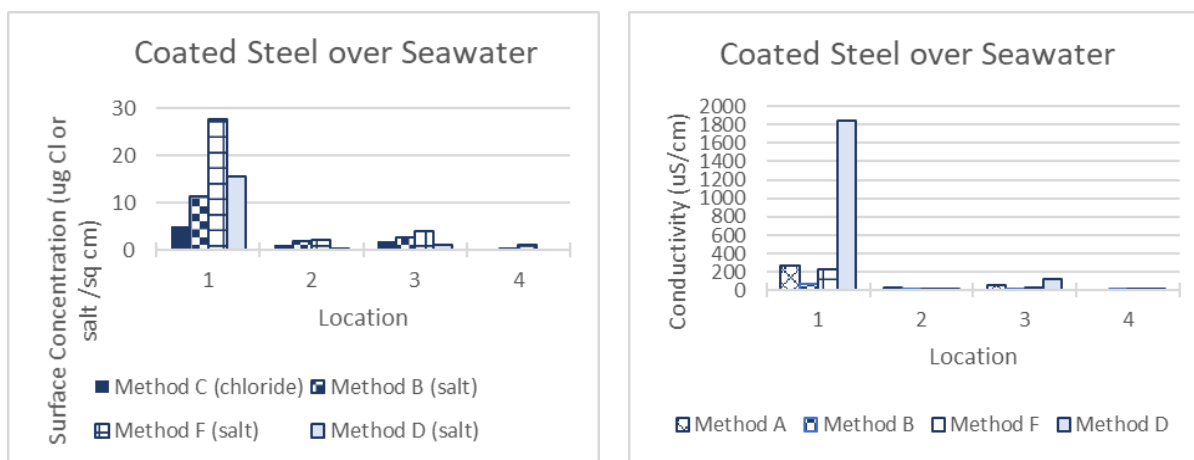


Figure 93. Soluble Salt Measurements on Steel over Water

Salt contamination on Zinc-Rich Primer

Soluble salt measurements were performed on the zinc-rich primer coating at five locations within span 14 using each of five detection methods (A, B, C, D, and F). The location of each nominally one square foot test area is identified in Table 46. Figure 94 shows a method A patch adhered to location 5. Figure 95 presents the data (note that some values are near-zero or zero). Most of the data suggest the surface is clean, however two of the 25 readings suggest significant soluble salts may be present at areas 1 and 4. High concentrations are indicated by method B at location 4 and method F at location 1. Note that the high conductivity readings for detection method D at locations 1 and 3 are consistent with the low (surface salt concentration values at the same locations. This is due to the different test geometry of Method D; since it used less water to extract salts from a larger test area, the resulting conductivity is higher for any given salt surface concentration.

Table 46 - Inspection Locations Inside Containment on Marine Parkway Bridge

Spot	Location
1	Span 14.5-14.4, Middle stringer facing east
2	Span 14.5-14.4, Floor Beam facing north
3	Span 14.5-14.4, Middle stringer facing east
4	Span 14.6-14.5, Floor Beam facing south
5	Span 14.6-14.5, underneath the lower flange of an interior stringer



Figure 94. Method A Patch and Method F Patch Adhered to Zinc-Rich Primer Coating

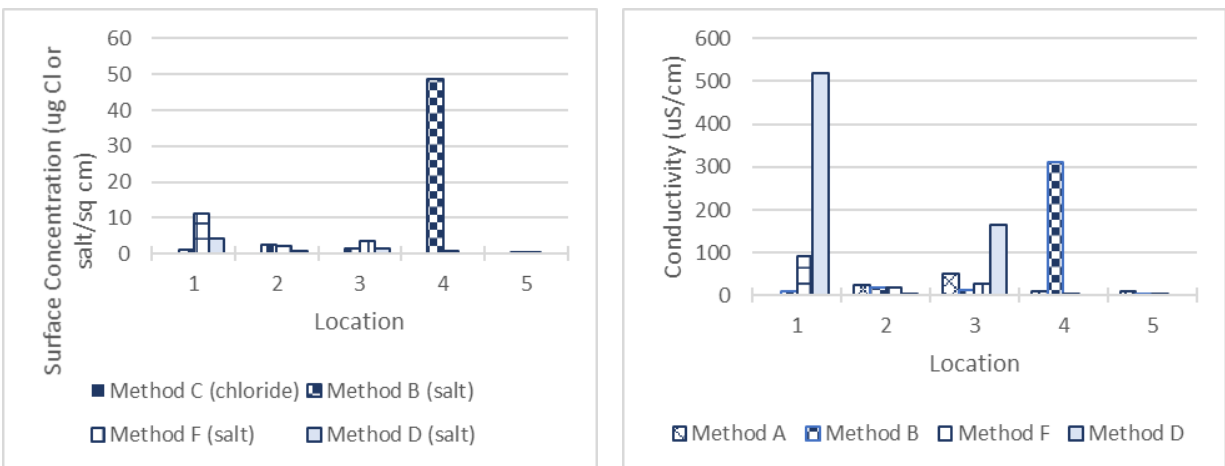


Figure 95. Soluble Salt Measurements on Zinc-Rich Primer

Throgs Neck Bridge (New York City)

The Throgs Neck Bridge carries traffic between the Bronx and Queens near the meeting place of the East River and Long Island Sound. Soluble salt contamination data was collected on various surfaces during a project to repaint steel in the suspension span anchorage. Four different areas were inspected during this visit – one recently primed, one with an aged coating system, one recently abrasive blasted, and one galvanized surface. Each location contained one measurement with each of five detection methods (A, B, C, D, and F).

Table 47 summarizes the data from all four areas. The data show that all surfaces met the chloride requirement in the project specifications, but the conductivity results suggest that salts other than chlorides may be present on the surfaces (especially test areas 3 and 4).

Table 47 – Summary of Weathered Zinc Primer Condition

Test Area	Measurement Location	Salt Concentration Range ($\mu\text{g}/\text{cm}^2$)	Surface Conductivity Range ($\mu\text{S}/\text{cm}$)	CHLOR*TEST ($\mu\text{g}/\text{cm}^2$)
1	Recently Applied Zinc	0 to 0.4	3 to 29	0
2	Blasted Steel	0.7 to 4	12 to 88	3
3	Aged coating	4 to 23.3	27 to 1544	4
4	Galvanized surface	0 to 16.8	48 to 276	0

Test Area 1 was an organic zinc coated girder face below the temporary entryway to the work being completed on the bridge. This area was painted during the previous week. Figure 96 shows a view of all of the devices at the location they were tested on the girder. Figure 97 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 0 and 0.4 $\mu\text{g}/\text{cm}^2$. Conductivity measurements ranged between 0.4 and 29 $\mu\text{S}/\text{cm}$.



Figure 96. All Devices Placed at Area 1

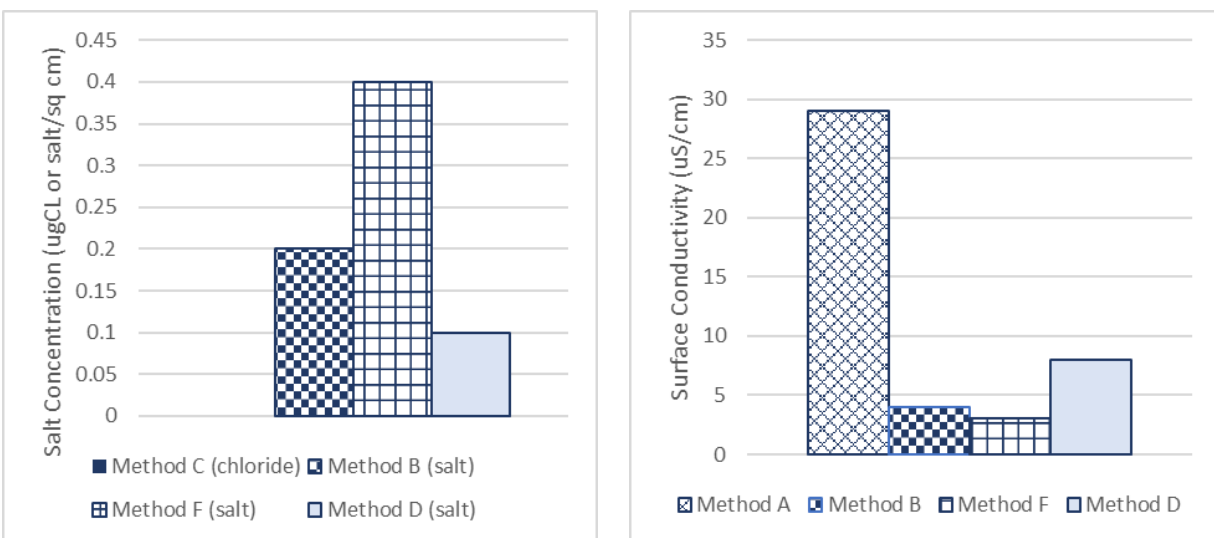


Figure 97. Soluble Salt Data Obtained at Test Area 1

Test Area 2 was on freshly blasted steel girder in a blast containment area. Readings were taken within the half hour of break time provided on the work site. Figure 98 shows a view of the area tested with a method C sleeve attached to the surface and the method B apparatus. The magnets used to attach the method B meter to the steel surface attracted a large amount of steel abrasive which needed to be carefully wiped off before the device was used. Method C was also used to measure sulfate and nitrate concentrations in this location. The nitrate and sulfate content was found to be 0 $\mu\text{g}/\text{cm}^2$ and 1 $\mu\text{g}/\text{cm}^2$ respectively. Figure 99 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 0.7 and 3 $\mu\text{g}/\text{cm}^2$. Conductivity measurements ranged between 20 and 88 $\mu\text{S}/\text{cm}$.



Figure 98. Test Area 2 Showing an Attached Latex Sleeve and the Method B Apparatus

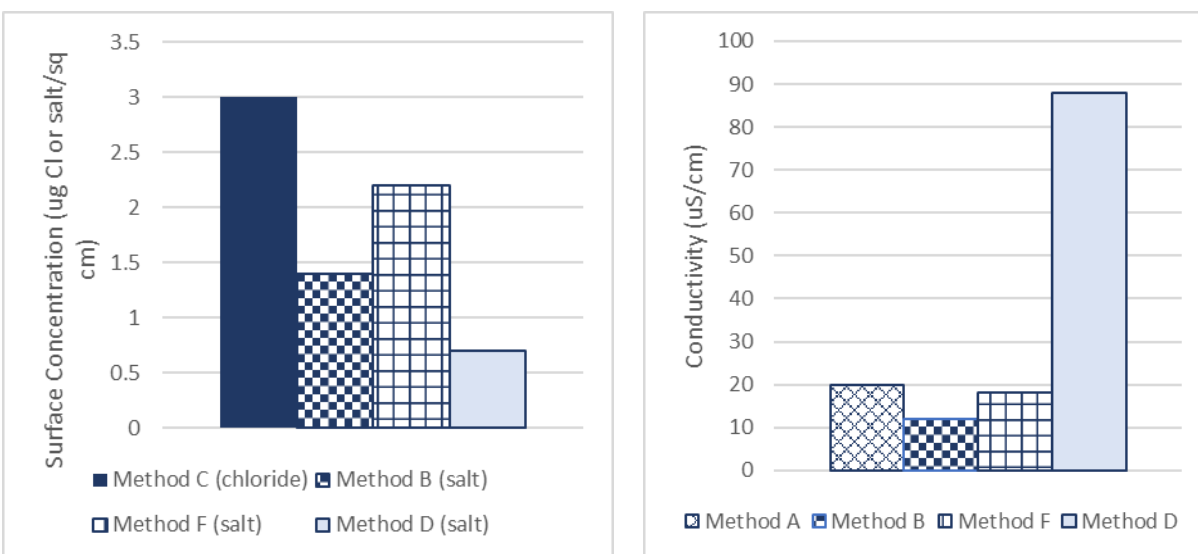


Figure 99. Soluble Salt Data Obtained at Test Area 2

Test area 3 was a finish-coated brace just outside the abutment underneath a roadway joint. This area was known to see a lot of runoff from the roadway, and therefore was expected to be dirtier than the previous two locations. Figure 100 shows a view of the detection devices adhered to the test area. Method C was also used to measure sulfate and nitrate concentrations in this location. The nitrate and sulfate content was found to be 0 $\mu\text{g}/\text{cm}^2$ and 2 $\mu\text{g}/\text{cm}^2$ respectively. Figure 101 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 4 and 23.3 $\mu\text{g}/\text{cm}^2$. Conductivity measurements ranged between 27 and 1544 $\mu\text{S}/\text{cm}$.



Figure 100. Test Locations Within Area 3

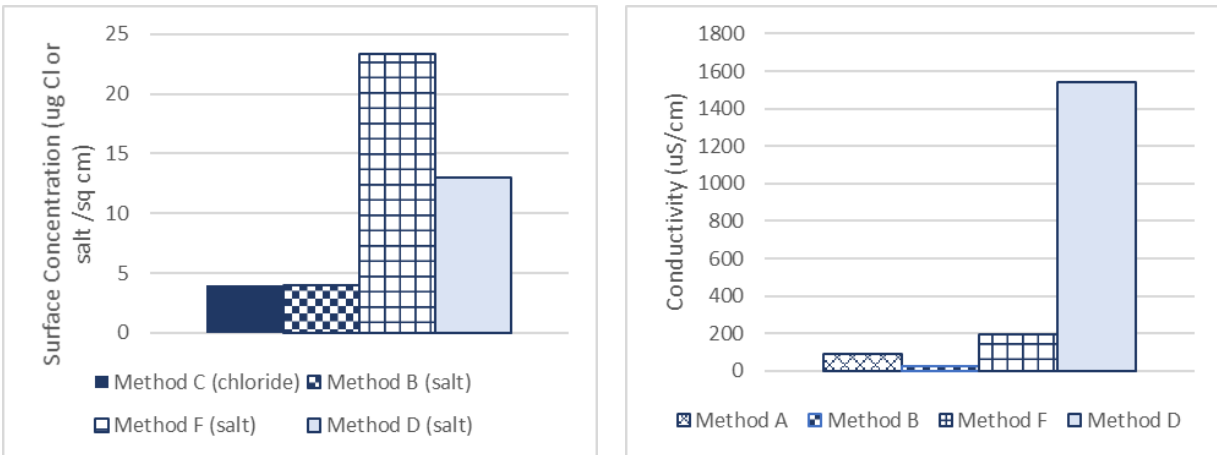


Figure 101. Soluble Salt data obtained at Test Area 3

Test Area 4 was an uncoated, galvanized beam at the bottom of the abutment. This area would not be painted but was evaluated as a finish coated surface. Figure 102 shows a view of the side of the beam with remaining adhesive from the method C sleeve. Method C was also used to measure sulfate and nitrate concentrations in this location. The nitrate and sulfate content were found to be $0 \mu\text{g}/\text{cm}^2$ and $0 \mu\text{g}/\text{cm}^2$ respectively. Figure 103 shows the test data in both “salt concentration” and “conductivity.” Measured salt concentration ranged between 0 and $16.8 \mu\text{g}/\text{cm}^2$. Conductivity measurements ranged between 48 and $276 \mu\text{S}/\text{cm}$.

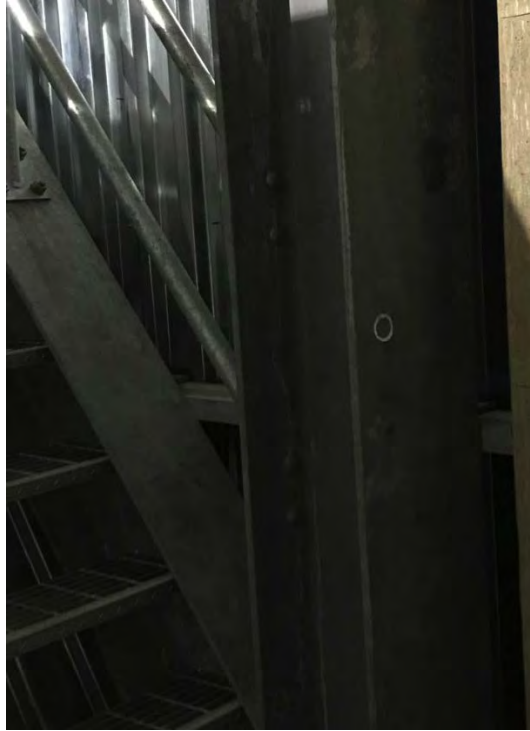


Figure 102. Girder Test Location with Latex Sleeve Attached at Area 4

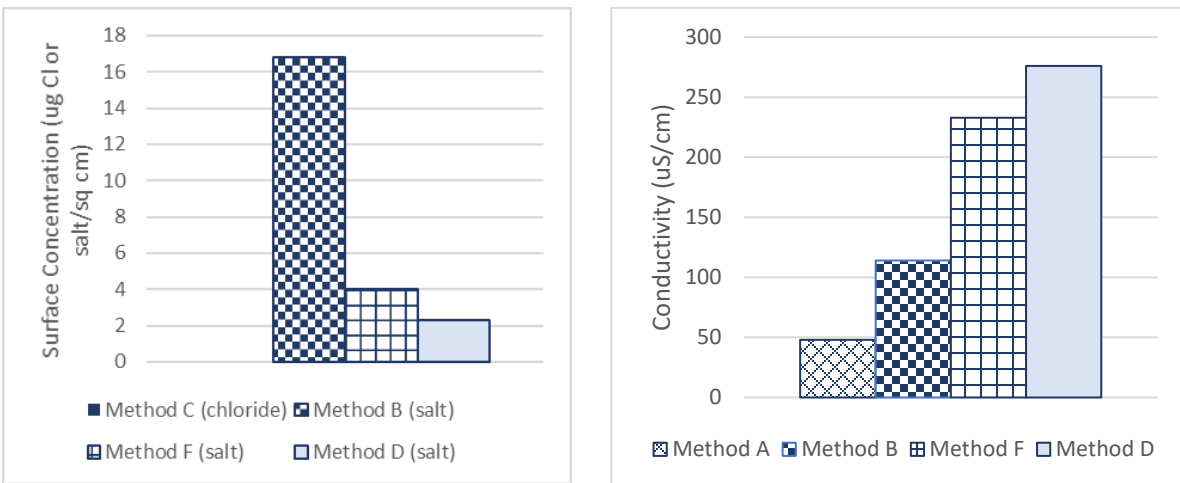


Figure 103. Soluble Salt data obtained at Test Area 4

Discussion of Field Paint Project Data

The data collected during the field painting projects was consolidated and analyzed to understand differences among the various detection methods. For this analysis, measurements were grouped into three sets – data collected on abrasive blasted steel, data collected on zinc primer, and data collected on finish coat. Table 48 summarizes the source of the data used. Figure 104, Figure 105, and Figure 106 are boxplots of the data collected on the three surface types as recorded in either conductivity or salt

surface concentration (chloride or total salt, depending on method). The “o” markers indicate the individual data points. The first and fifth quartiles are represented by the whiskers, the second and fourth quartiles are represented by the box, and the center line represents the median value of the 12 readings. The x inside the box represents the mathematical average of the 12 readings.

Table 48 – Summary of Data from Active Bridge Coating Projects

Measured Surface	RFK Bridge	Marine Parkway Bridge	Throgs Neck Bridge	Total Data Points
Abrasive Blasted Steel	6 locations	None	1 location	7 locations
Zinc Primer	33 locations	5 locations	1 location	39 locations
Finish Coat	None	9 locations	2 locations	11 locations

The boxplots in Figure 104 represent data collected on abrasive blasted steel. Note that the statistics are skewed by the high salt value at one of the seven locations (the pitted area discussed on page 124). The conductivity data show reasonable agreement among the methods using the same water volume and surface area (A, B, and F). Method D provides a higher conductivity because of the larger surface area and smaller water volume used for testing. When reported as salt concentration, methods D and C provide a lower reading than the remaining methods. For method C, this is expected as it is reporting chloride ion concentration while the other techniques are reporting total surface salt concentration. Logically the sum of all salts would be higher than the chloride ion. For method D, the difference may relate to the inability to extract soluble salts from the field surfaces.

The boxplots in Figure 105 represent data collected on zinc primed steel. The conductivity data show reasonable agreement among the methods using the same water volume and surface area (A, B, and F). Method D provides a higher conductivity because of the larger surface area and smaller water volume used for testing. When reported as salt concentration, method C provides a lower reading than the remaining methods as expected; logically the sum of all salts would be higher than the chloride ion. The methods converting a conductivity value to total salt concentration using the formula in ISO 9203-9 provide consistent results.

The boxplots in Figure 106 represent data collected on finish coat. The conductivity data show reasonable agreement among the methods using the same water volume and surface area (A, B, and F). Method D provides a higher conductivity because of the larger surface area and smaller water volume used for testing. When reported as salt concentration, method C provides a lower reading than the remaining methods as expected. Logically the sum of all salts would be higher than the chloride ion. The methods converting a conductivity value to total salt concentration using the formula in ISO 9203-9 provide consistent results.

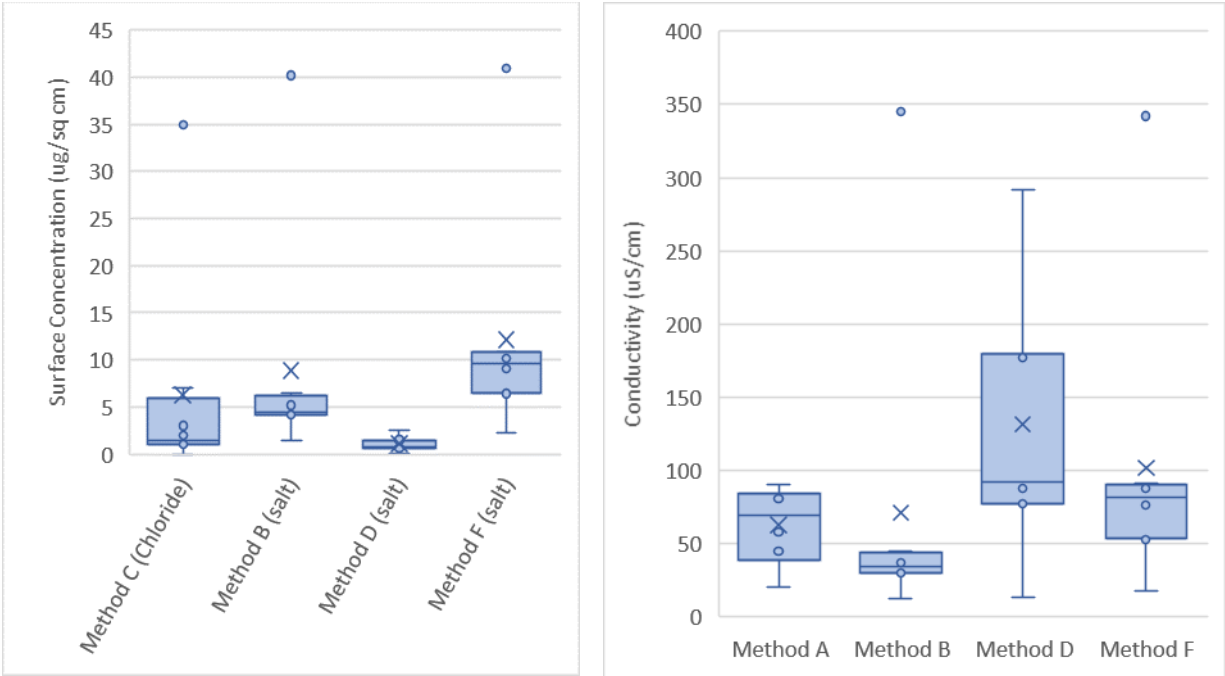


Figure 104. Boxplot of Soluble Salt Data Collected on Abrasive Blasted Steel During Active Re-Coating Projects

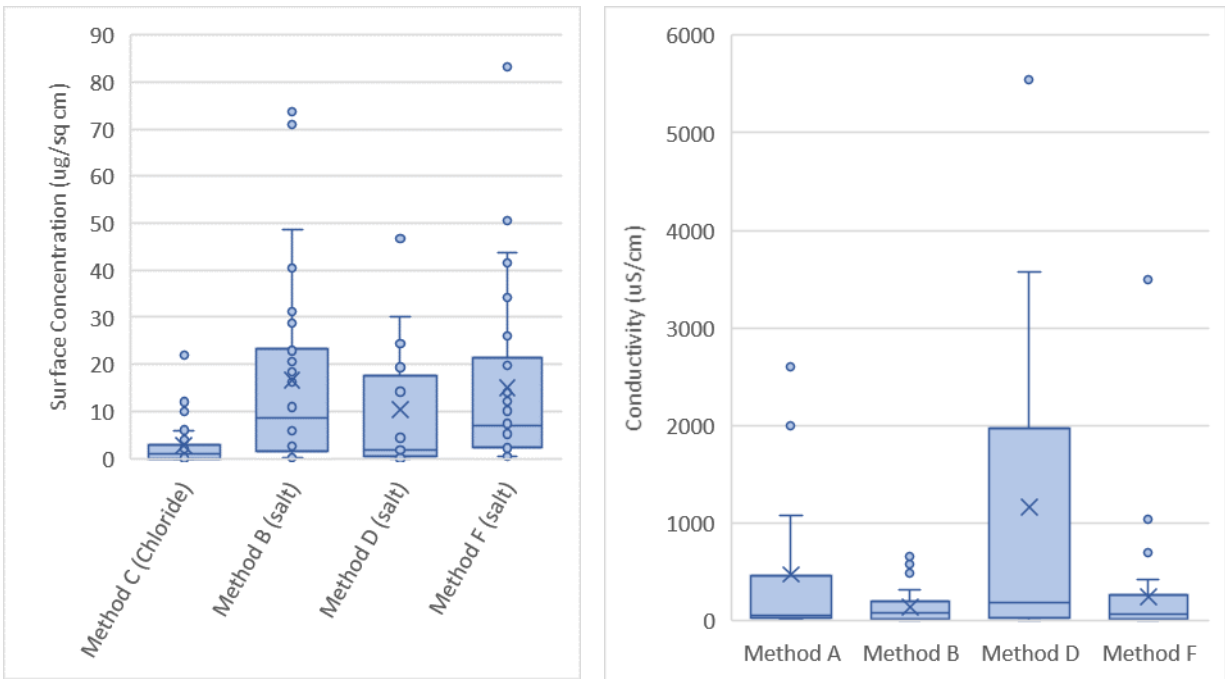


Figure 105. Boxplot of Soluble Salt Data Collected on Primed Steel During Active Re-Coating Projects

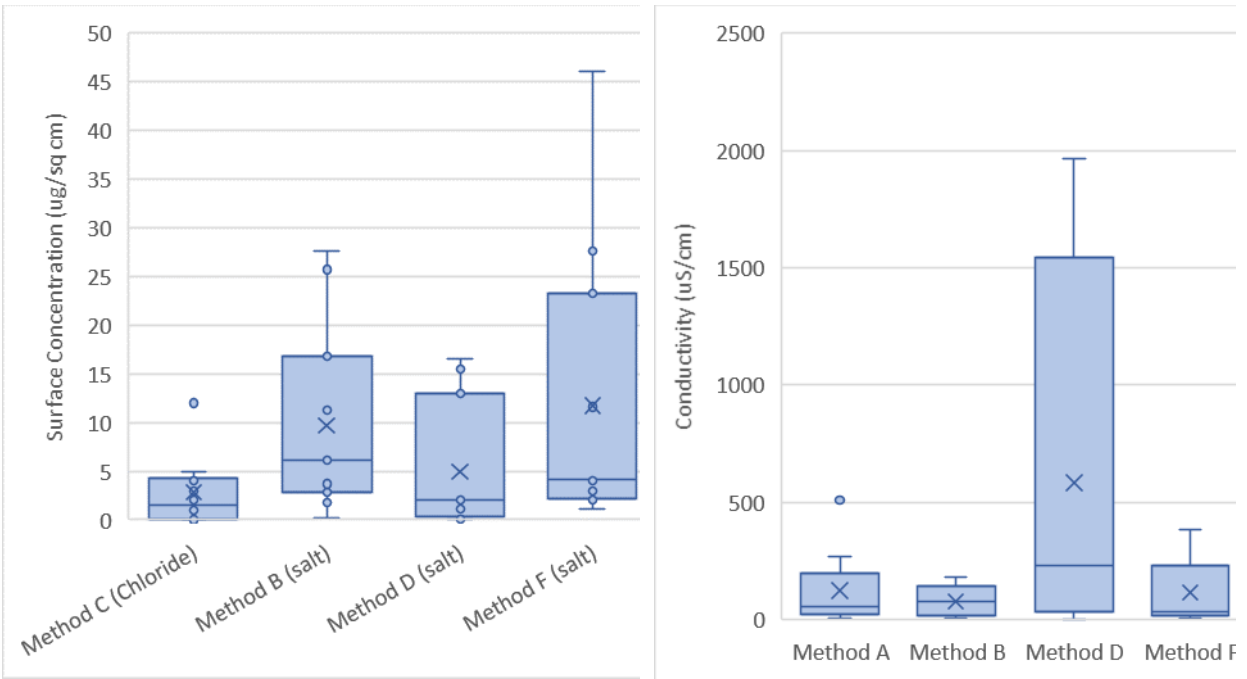


Figure 106. Boxplot of Soluble Salt Data Collected on Finish Coated Steel During Active Re-Coating Projects

Conclusions

The project has highlighted several key issues related to the detection and remediation of soluble salts.

Soluble Salt Detection

1. There is considerable variability in the terminology used to describe soluble salts. “Soluble Salts,” “Chlorides,” “Salt,” and other terms are used somewhat interchangeably without distinguishing or defining the terms. It can be challenging to discern what the methods themselves are reporting. Complications specifying and enforcing specifications may arise from these issues.
2. Conductivity measurements will detect all soluble salt species whereas ion-specific techniques will only detect the ion being targeted. The conductivity measurement is therefore a more conservative measure of soluble salt contamination than any given ion specific test. However, since some salts are reportedly more critical to coating performance, conductivity measurements may be unnecessarily conservative in some instances.
3. The conversion of conductivity to “total soluble salts” requires an assumption of the salt composition. Electronic instruments rely on the relationship established in ISO 8502-9 to perform this conversion.
 - a. While the total soluble salt density on a surface is a purely mathematical construct, it is a useful way to report the results of a conductivity test. The standard relationship established in ISO 8502-9 has been used successfully in industry.
 - b. Logically, the total soluble salt density should always be higher than the concentration of any individual ion at the exact same spot. However, due to the high variability and low levels typically measured in the field this may not always be observed.
4. The nature of the detection methods is such that a significant relative standard deviation of otherwise equivalent measurements is observed. There are a variety of sources of this error, including operator proficiency, interaction of salts with the steel surface, distribution of salts on the surface, and instrument repeatability.
 - a. Relative standard deviations of measurements on rusted, abrasive blasted surfaces was as high as 50%. This is representative of what one would expect in the field. Industry standard levels for soluble salt contamination provide a sufficient margin of error to account for measurement and sampling variability which was observed in this project (e.g., acceptance criteria of 10 $\mu\text{g salt/cm}^2$ may mean that there is a high probability all surfaces are less than 30 $\mu\text{g salt/cm}^2$, a suitable level for a typical zinc-based coating system).
5. As salt contamination “ages” the quantity of extracted salt decreases between 30% and 80% versus detection immediately after doping.
6. Soluble salts tend to cause steel to rustback; that this rust will have to be removed prior to high-performance coating application. Rustback may be a sufficient visual indicator of soluble salt presence in some instances.

Soluble Salt Remediation

1. None of the remediation methods have a significant effect on the tight crevices created for this testing.
2. Common surface preparation methods have varied effectiveness at removing soluble salt contamination. The following observations were made on the heavily rusted surfaces used during testing in this project:
 - a. Of the mechanical surface preparation methods evaluated (power tools, abrasive blasting) only near-white metal blast effectively remediated the bold, rusted surfaces to a chloride level considered acceptable by most standards. This is consistent with previous research.
 - b. Ultra-High Pressure Waterjetting (UHPWJ) at 40,000 psi effectively remediated bold, rusted surfaces to a chloride level considered acceptable by most standards.
 - c. Pressure washing alone at 3,100 psi with a 25-degree fan tip with or without additives contributes little to the remediation of chlorides in the degree of rust evaluated.
3. When properly used in conjunction with mechanical surface preparation methods pressure washing does help reduce soluble salts from heavily rusted surfaces.
 - a. Ideally, pressure wash surfaces both before and after mechanical surface preparation. Pressure washing prior to mechanical surface preparation helps to keep tools and abrasive media clean. Pressure washing is more effective at reducing final salt concentrations after surface scale and coatings are removed.
4. The total removal efficiency is also a partial function of the initial contamination. Other things being equal, remediation methods are less efficient removing soluble salts from heavily rusted surfaces than from the surface of in-tact coatings.

General Issues

1. There appears to be some phenomena that makes salts difficult to extract or remediate on real, weathered steel surfaces. This has been observed in this work and reported by others.
2. Pressure washing helps to remove soluble salts from coated surfaces. However, once coatings have begun to breakdown and significant steel corrosion is occurring, pressure washing does not appear to reduce the corrosion rate or coating degradation.
3. The research suggests that a critical soluble salt concentration for a three-coats system with a zinc rich primer might be in the range of 30 to 50 $\mu\text{g Cl-}/\text{cm}^2$. This number is considerably higher than most specifications but consistent with previous research on atmospherically exposed bridge coating performance over soluble salts. As mentioned above, industry standard levels for soluble salt contamination provide a sufficient margin of error to account for measurement and sampling variability which was observed in this project.

Recommendations

The bridge coating industry should consider the following improvements to soluble salt detection and remediation practices.

Soluble Salt Detection

1. When requiring or reporting soluble salt surface concentrations, it should be clearly stated what is being measured. For example, it is common to measure Chloride ion, Sulfate Ion, Nitrate ion, Sodium Chloride, and “total salt” (as determined according to ISO 8502-9). Reporting the values as $\mu\text{g Cl/cm}^2$, $\mu\text{g SO}_4/\text{cm}^2$, $\mu\text{g NO}_3/\text{cm}^2$, $\mu\text{g NaCl/cm}^2$, or $\mu\text{g salt/cm}^2$ will eliminate confusion when interpreting specifications, reviewing data, or performing a test method.
2. When requiring or reporting soluble salt concentration as a conductivity value, the volume of water and surface area evaluated should be clearly stated (e.g., $\mu\text{S/cm}$ measured using 3mL of deionized water on 12.5 cm^2 of surface). Other things being equal, methods which use more water or extract from a smaller surface area will detect a lower conductivity. Similarly, methods which use less water or extract from a larger surface area will detect a higher conductivity.
3. The nature of the detection methods are such that a significant relative standard deviation of otherwise equivalent measurements is observed.
 - a. It is common practice to determine if a surface is acceptable for coating application with relatively few measurements. In this case, measurements should be concentrated in areas where the highest salt concentration is expected (e.g., surfaces which were heavily rusted prior to surface preparation) to the extent practicable.
 - b. When necessary to fully characterize a surface, a significant number of measurements should be made and a significant scatter in the results should be expected. The data should be looked at statistically to describe the surface and compare sets of data (e.g., before and after cleaning).

Soluble Salt Remediation

1. Use abrasive blasting, ultra-high pressure waterjetting (UHPWJ), or wet abrasive blasting to reduce soluble salt levels to the low limits required by high performance bridge coatings.
2. Do not expect to remediate chlorides from tight crevices. Other protective strategies such as caulking may be necessary to mitigate crevice corrosion in these instances.
3. When cleaning surface with power tools, consider pressure washing **both before and after** power tool cleaning to remove soluble salts. It is generally considered a good idea to pressure wash **prior to** power tool cleaning to remove contaminants and loose material from the surface. Removing such material eliminated the possibility of embedding contaminants into the power tool cleaned surface and generally makes the tool cleaning process more effective. Pressure washing **after power tool cleaning** removes additional loose and soluble materials that may have been exposed during power tool cleaning. However, the washed surface must be allowed to fully dry prior to painting.

Summary of Practical Guidance from Volume 1

Following are the key points contained in Volume 1 of this report, organized by topic:

Soluble Salt Detection

1. Both chloride ion and total salt density calculated from conductivity are preferred indicators of soluble salts for the purposes of evaluating cleanliness of a prepared surface. Conductivity, sulfate ion, and nitrate ion are also useful methods under certain circumstances.
2. Since equivalence between chloride ion and total salt density calculated from conductivity cannot be universally determined, specifications should either (a) only allow one method or (b) specify a limit associated with each criterion. If limits associated with each criterion are specified, they should be specified as acceptable alternatives (e.g., “X $\mu\text{g salt/cm}^2$ or Y $\mu\text{g Cl}^-/\text{cm}^2$.” Since they are not equal metrics, potential conflicts may arise in the field as one criteria may be acceptable while the other is not acceptable.
3. There are several suitable field methods for detecting soluble salts on flat surfaces using ion-specific or conductometric methods.
4. The methods are sensitive to low levels of soluble salt contamination. Since typical industry requirements are near the detection limits for the technique, significant measurement variability may be observed in the field.
5. None of the field methods can effectively detect salts in crevices and most are limited in their ability to extract salts from heavily pitted surfaces or other rough geometries.
6. NACE SP0716-2016 is a good reference standard for soluble salt testing frequency and location.
7. The inspector should concentrate their measurements in areas where soluble salts are most likely to be found (e.g., corrosion, metal loss, coating failure, near joints, at drainage collection points).
8. Rusting interferes with soluble salt measurements. Since high-performance coatings will require that this rust be removed, detection of salts on visibly rusted surfaces is often of no practical use.
9. Typically, soluble salt contamination is only a concern on the prepared substrate. However, if there is a sufficient risk of soluble salt contamination (e.g., marine environment), soluble salt measurements may be made on primed steel and/or on intermediate coats of paint.

Soluble Salt Remediation

1. When abrasive blasting and re-painting a bridge structure, maximum chloride ion level of 10 $\mu\text{g Cl}^-/\text{cm}^2$ is suitable for most environments. Where soluble salt is of greater concern (e.g., one or more of the “high risk” factors identified Table 2, it is reasonable to lower the limit to 5 $\mu\text{g Cl}^-/\text{cm}^2$. Comparable values of total salt calculated from conductivity are 15 $\mu\text{g salt/cm}^2$ and 7.5 $\mu\text{g salt/cm}^2$, respectively.
2. When power tool cleaning corroded areas during maintenance painting, soluble salt testing may not be cost effective. In cases where corrosion is light, a high degree of cleanliness is specified

(e.g., SSPC SP-11, Power Tool Cleaning to Bare Metal), or supplemental washing/cleaning methods are specified a maximum chloride ion level of $10 \mu\text{g Cl}^-/\text{cm}^2$ is achievable.

3. Washing of surfaces (with or without additives) is industry best practice that helps reduce soluble salt contamination prior to surface preparation.
4. Dry abrasive blasting, wet abrasive blasting and ultrahigh pressure water jetting to a high degree of cleanliness (e.g., SSPC-SP 10/NACE No. 2 Near-White Metal Blast Cleaning, SSPC-SP 10 (WAB)/NACE WAB-2 Near-White Metal Wet Abrasive Blast Cleaning, and Waterjet Cleaning of Metals SSPC-SP WJ-2/NACE WJ-2 – Very Thorough Cleaning) are industry best practices for removing soluble salts during surface preparation.
5. Cleaning to bare metal using power tools (SSPC SP-11, Power Tool Cleaning to Bare Metal) is the best practice to remediate soluble salt contamination using power tools.
6. In instances where mechanical methods do not sufficiently remediate soluble salt contamination, water washing is effective at remediating the remaining soluble salt. However, supplemental mechanical preparation may be required to remove rusting which may occur because of the washing. Alternatively, repeated mechanical preparation may also reduce soluble salt contamination below the required levels.
7. Experienced contractors can remediate soluble salts to low levels (e.g., less than $5 \mu\text{g Cl}^-/\text{cm}^2$) with available technologies when preparing a surface to SSPC SP-10/NACE No. 2 Near-White Metal Blast Cleaning. Extra work may be required to remediate high risk areas such as expansion joints and heavily pitted steel; the cost premium of remediating salt contamination in these areas appears acceptable to most of the bridge industry.
8. When power tool cleaning corroded areas during maintenance painting, SSPC SP-11, Power Tool Cleaning to Bare Metal and/or supplemental washing/cleaning methods are specified. Pressure washing/cleaning between power tool cleaning steps will effectively achieve low soluble salt levels.

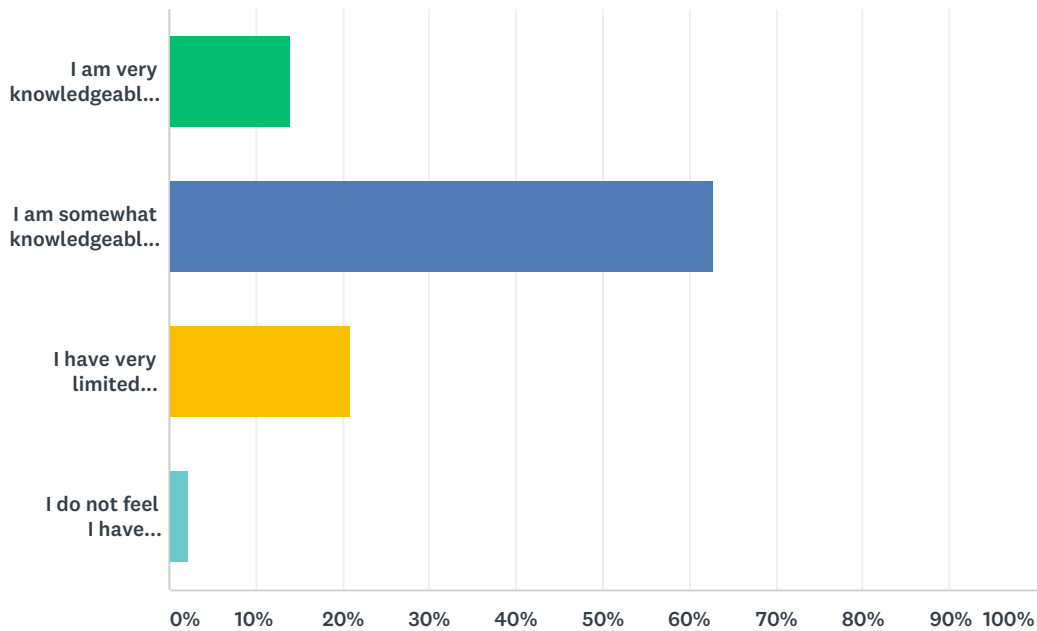
General Issues

1. Soluble salt contamination is most likely to be a significant concern in actively corroding (i.e., rusted) areas of bridges which are exposed to sources of soluble salt contamination (e.g., road salts, marine environments, industrial pollution).
2. Soluble salt contamination is most likely to have an adverse impact when it is present on the structure to be coated, thorough cleaning is not performed, a less tolerant coating system is used and/or the service environment is severe (e.g., high time of wetness, corrosive).
3. Specification language should specify the acceptable soluble salt levels as well as detection methods and sampling frequency for verifying compliance.
4. There are several available industry standards and guidelines which address various soluble salt detection and remediation issues.

Appendix A – Survey of Highway Agency User Experience with Detection and Remediation Methods

Q1 Select a statement which best describes your experience with soluble salts.

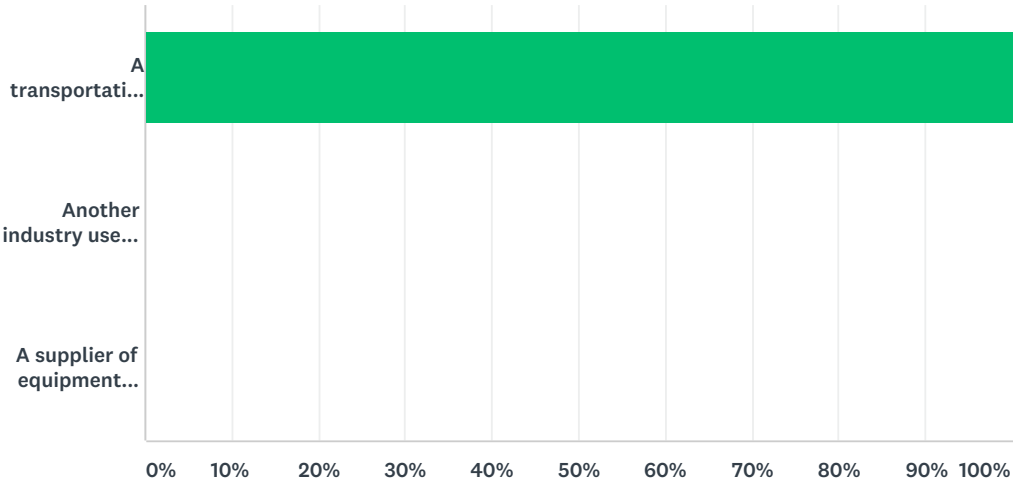
Answered: 43 Skipped: 0



ANSWER CHOICES	RESPONSES	
I am very knowledgeable about soluble salt issues related to structural steel and would like to complete the survey.	13.95%	6
I am somewhat knowledgeable about soluble salt issues related to structural steel and would like to complete the survey.	62.79%	27
I have very limited knowledge about soluble salt issues related to structural steel and would like to complete the survey.	20.93%	9
I do not feel I have sufficient knowledge about this topic to complete the survey. (This choice will EXIT the survey)	2.33%	1
TOTAL		43

Q2 To help us direct you to relevant questions, please identify your perspective for the purposes of this survey.

Answered: 43 Skipped: 0



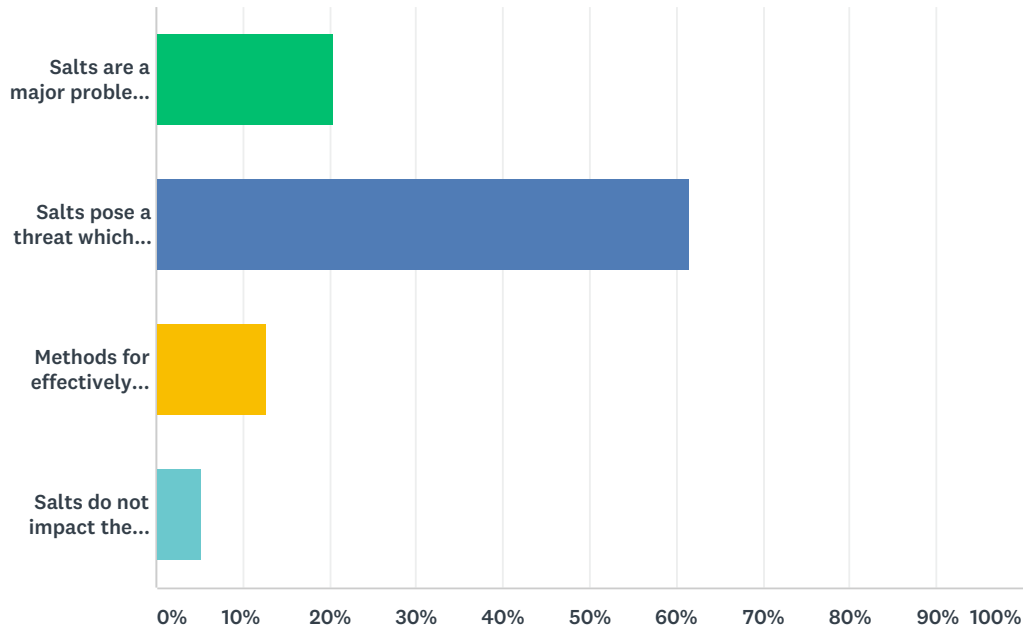
ANSWER CHOICES	RESPONSES	
A transportation industry user or specifier of equipment and/or services related to salt detection and/or remediation technologies	100.00%	43
Another industry user or specifier of salt detection and/or remediation products	0.00%	0
A supplier of equipment and/or services related to salt detection and/or remediation technologies	0.00%	0
TOTAL		43

Q3 In what state (or geographic area) do you normally work?

Answered: 39 Skipped: 4

Q4 In your opinion, how significantly do soluble salts impact steel bridges?

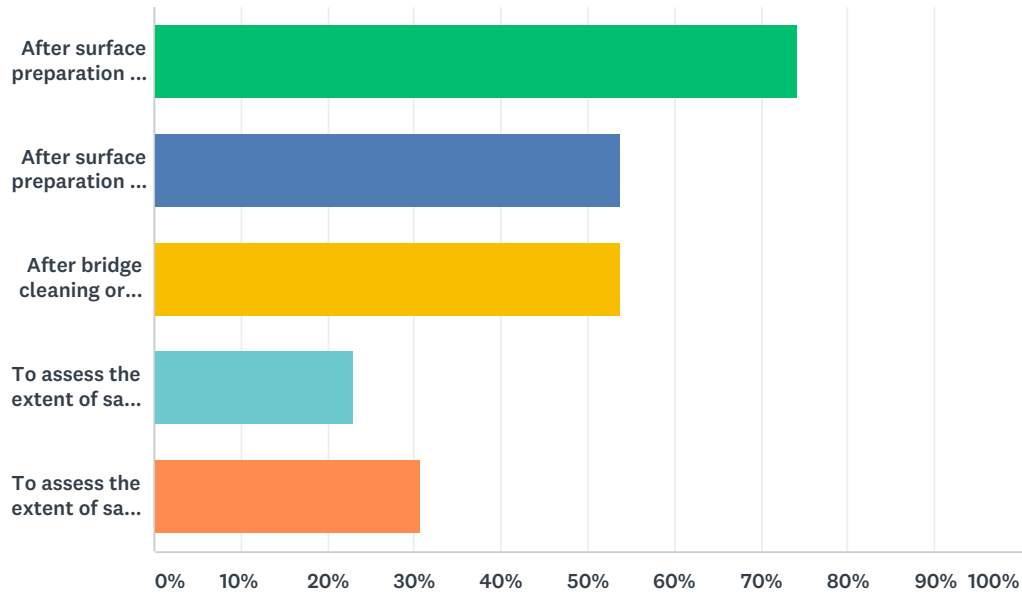
Answered: 39 Skipped: 4



ANSWER CHOICES	RESPONSES	
Salts are a major problem which is neither understood or managed well	20.51%	8
Salts pose a threat which can be managed with additional funding and training	61.54%	24
Methods for effectively managing the effects of salts are in place and adequately funded	12.82%	5
Salts do not impact the performance of steel bridges at the agency I work with	5.13%	2
TOTAL		39

Q5 During what activities do you believe salt detection methods are appropriate to use?

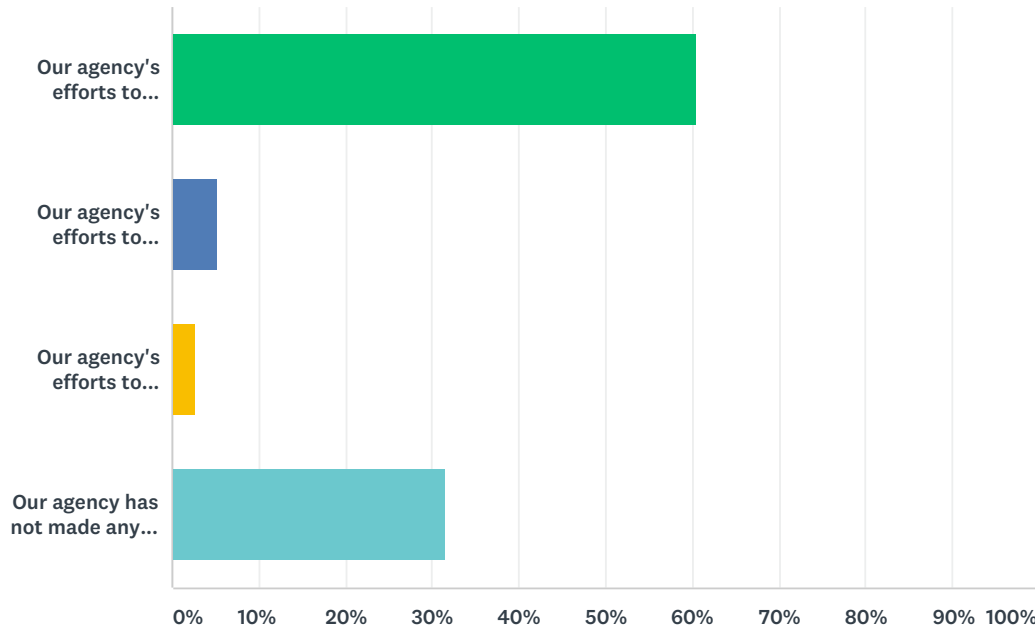
Answered: 39 Skipped: 4



ANSWER CHOICES	RESPONSES	
After surface preparation for re-painting (e.g., complete removal and re-coat) projects	74.36%	29
After surface preparation for maintenance painting projects (e.g., spot painting)	53.85%	21
After bridge cleaning or washing activities	53.85%	21
To assess the extent of salt contamination as part of a routine condition survey	23.08%	9
To assess the extent of salt contamination as part of a special study	30.77%	12
Total Respondents: 39		

Q6 Which statement most closely reflects your experience regarding the effects of salt on corrosion of bridges?

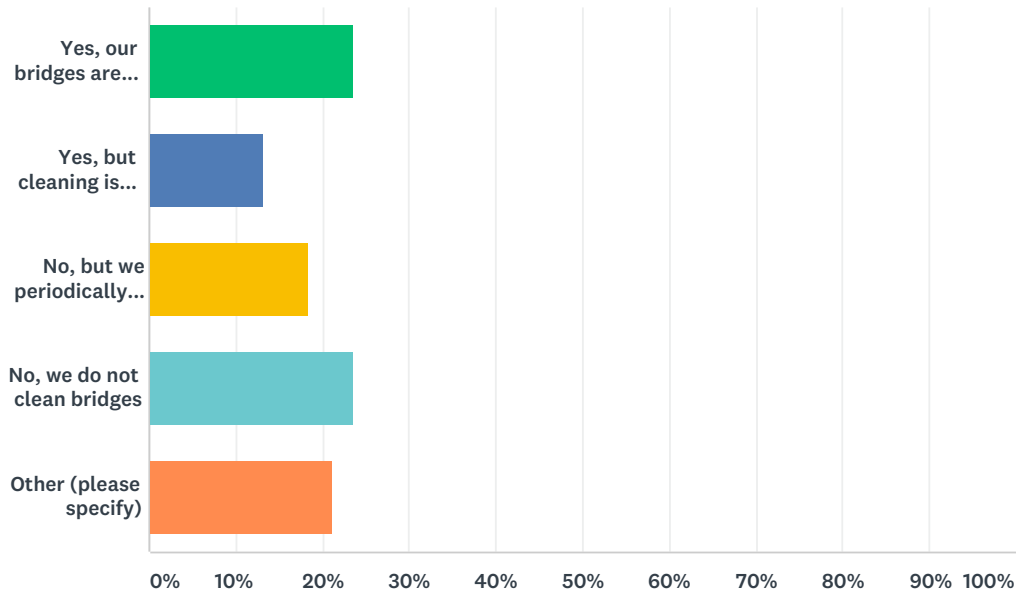
Answered: 38 Skipped: 5



ANSWER CHOICES	RESPONSES	
Our agency's efforts to mitigate or reduce the impacts of chloride deicers have reduced bridge corrosion.	60.53%	23
Our agency's efforts to mitigate or reduce the impacts of chloride deicers have had no effect on bridge corrosion.	5.26%	2
Our agency's efforts to mitigate or reduce the impacts of chloride deicers have increased bridge corrosion.	2.63%	1
Our agency has not made any effort to mitigate or reduce the impacts of chloride deicers.	31.58%	12
TOTAL		38

Q7 Does you agency have a bridge cleaning program?

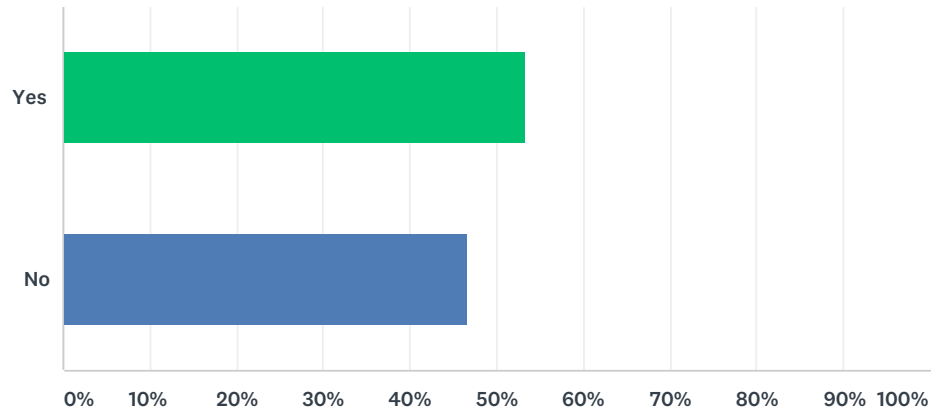
Answered: 38 Skipped: 5



ANSWER CHOICES	RESPONSES	
Yes, our bridges are cleaned on a scheduled basis	23.68%	9
Yes, but cleaning is sporadic	13.16%	5
No, but we periodically clean our bridges	18.42%	7
No, we do not clean bridges	23.68%	9
Other (please specify)	21.05%	8
TOTAL		38

Q8 Does your cleaning program include provision for removing soluble salts?

Answered: 15 Skipped: 28



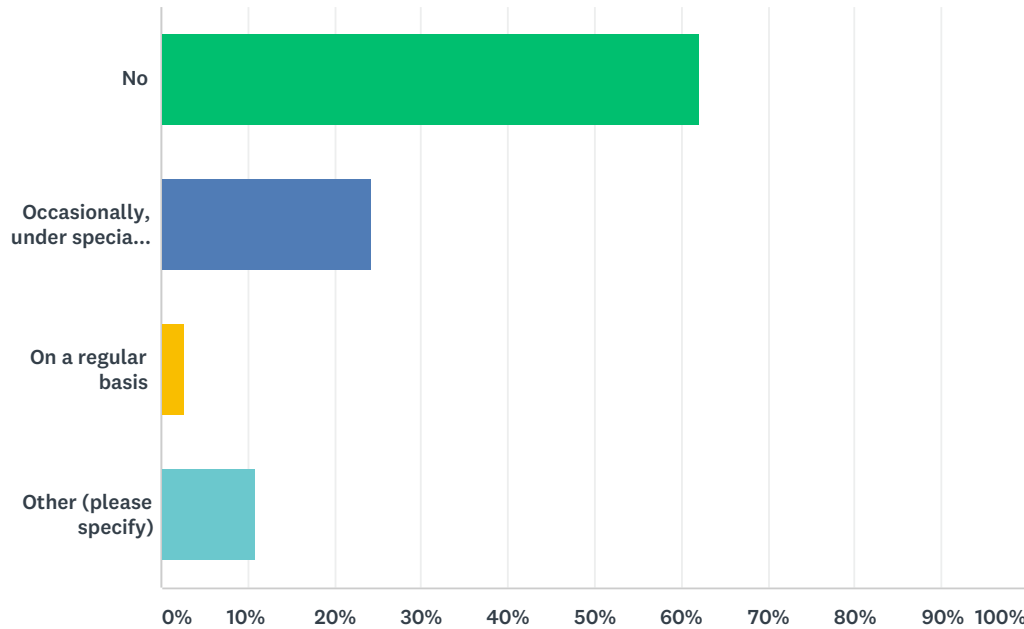
ANSWER CHOICES	RESPONSES	
Yes	53.33%	8
No	46.67%	7
TOTAL		15

Q9 How frequently does your agency clean its bridges?

Answered: 13 Skipped: 30

Q10 Do you measure salt contamination on uncoated weathering steel structures?

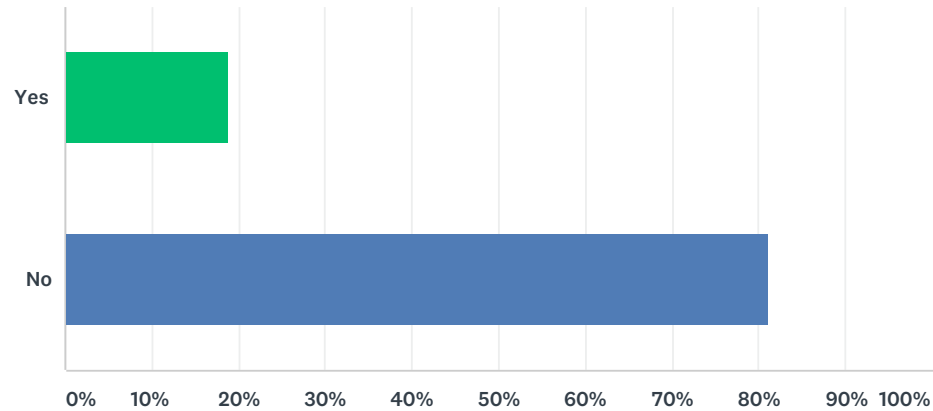
Answered: 37 Skipped: 6



ANSWER CHOICES	RESPONSES	
No	62.16%	23
Occasionally, under special circumstances	24.32%	9
On a regular basis	2.70%	1
Other (please specify)	10.81%	4
TOTAL		37

Q11 Do you remove soluble salts from weathering steel bridges as part of routine maintenance?

Answered: 37 Skipped: 6



ANSWER CHOICES	RESPONSES	
Yes	18.92%	7
No	81.08%	30
TOTAL		37

Q12 If you do remove salts from weathering steel bridges, how frequently do you remove them?

Answered: 15 Skipped: 28

Q13 What industry are you primarily associated with?

Answered: 0 Skipped: 43

Q14 In your opinion, how significantly do soluble salts impact steel structures in your industry?

Answered: 0 Skipped: 43

 No matching responses.

ANSWER CHOICES	RESPONSES	
Salts are a major problem which is neither understood or managed well	0.00%	0
Salts pose a threat which can be managed with additional funding and training	0.00%	0
Methods for effectively managing the effects of salts are in place and adequately funded	0.00%	0
Salts do not impact the performance of steel structures that I work with	0.00%	0
TOTAL		0

Q15 Under which scenarios do you believe salt detection methods are used in your industry?

Answered: 0 Skipped: 43

 No matching responses.

ANSWER CHOICES	RESPONSES	
After surface preparation for re-painting (e.g., complete removal and re-coat) projects	0.00%	0
After surface preparation for maintenance painting projects (e.g., spot painting)	0.00%	0
After structure cleaning or washing activities	0.00%	0
To assess the extent of salt contamination as part of a routine condition survey	0.00%	0
To assess the extent of salt contamination as part of a special study	0.00%	0
Total Respondents: 0		

Q16 What equipment, products, and/or services do you provide?

Answered: 0 Skipped: 43

 No matching responses.

ANSWER CHOICES	RESPONSES	
Salt detection	0.00%	0
Salt remediation	0.00%	0
Both	0.00%	0
TOTAL		0

Q17 How do you believe interest in detecting soluble salts on steel structures is changing?

Answered: 0 Skipped: 43

 No matching responses.

ANSWER CHOICES	RESPONSES	
Interest in detecting salts is rapidly increasing	0.00%	0
Interest in detecting salts is increasing somewhat	0.00%	0
Interest in detecting salts is not changing	0.00%	0
Interest in detecting salts is decreasing somewhat	0.00%	0
Interest in detecting salts is rapidly decreasing	0.00%	0
TOTAL		0

Q18 How do you believe interest in remediating soluble salts on steel structures is changing?

Answered: 0 Skipped: 43

 No matching responses.

ANSWER CHOICES	RESPONSES	
Interest in remediating salts is rapidly increasing	0.00%	0
Interest in remediating salts is increasing somewhat	0.00%	0
Interest in remediating salts is not changing	0.00%	0
Interest in remediating salts is decreasing somewhat	0.00%	0
Interest in remediating salts is rapidly decreasing	0.00%	0
TOTAL		0

Q19 What improvements in state-of-the-art do you envision for salt detection technologies?

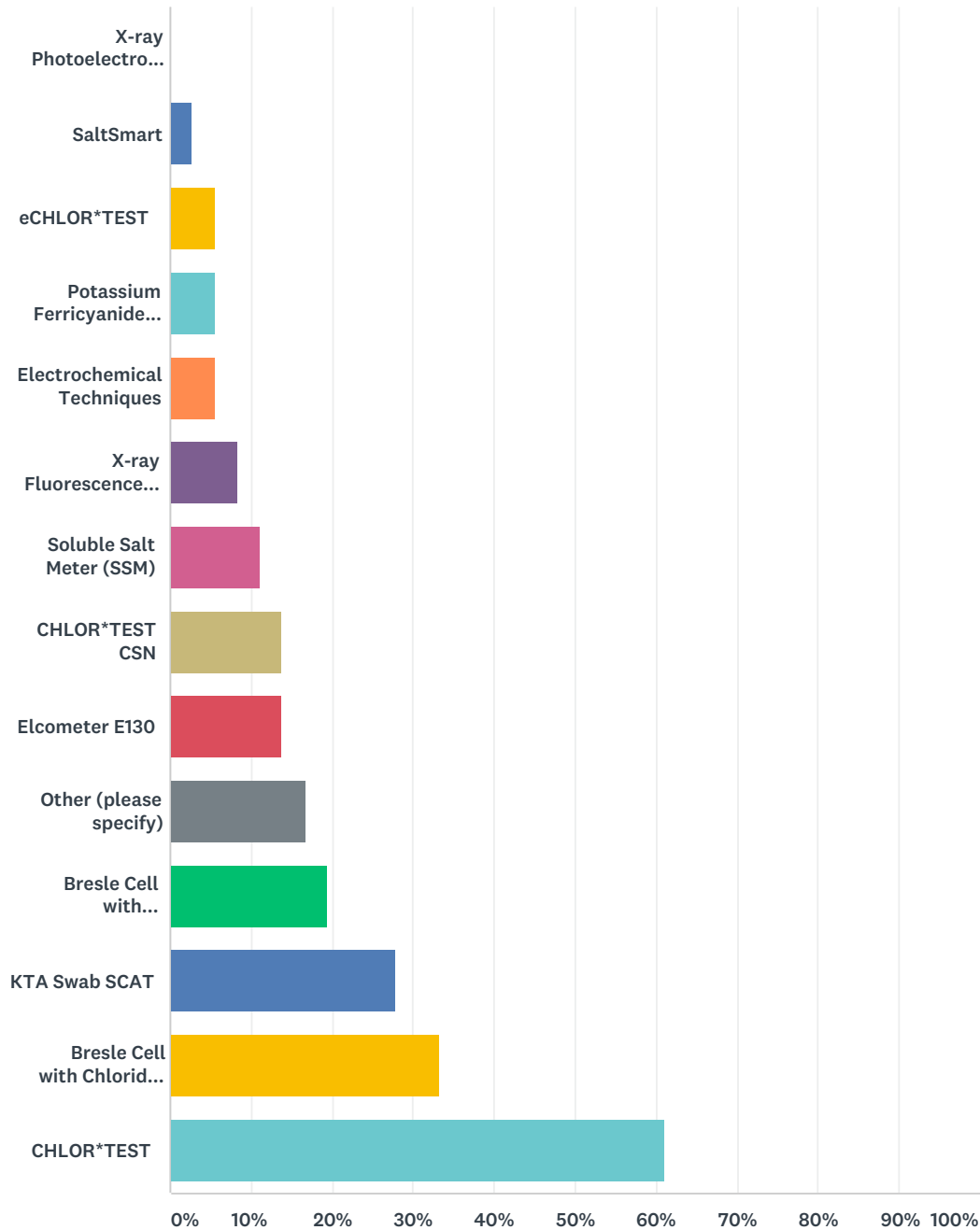
Answered: 0 Skipped: 43

Q20 What improvements in state-of-the-art do you envision for salt remediation technologies?

Answered: 0 Skipped: 43

Q21 With which of the following salt detection methods are you familiar?

Answered: 36 Skipped: 7



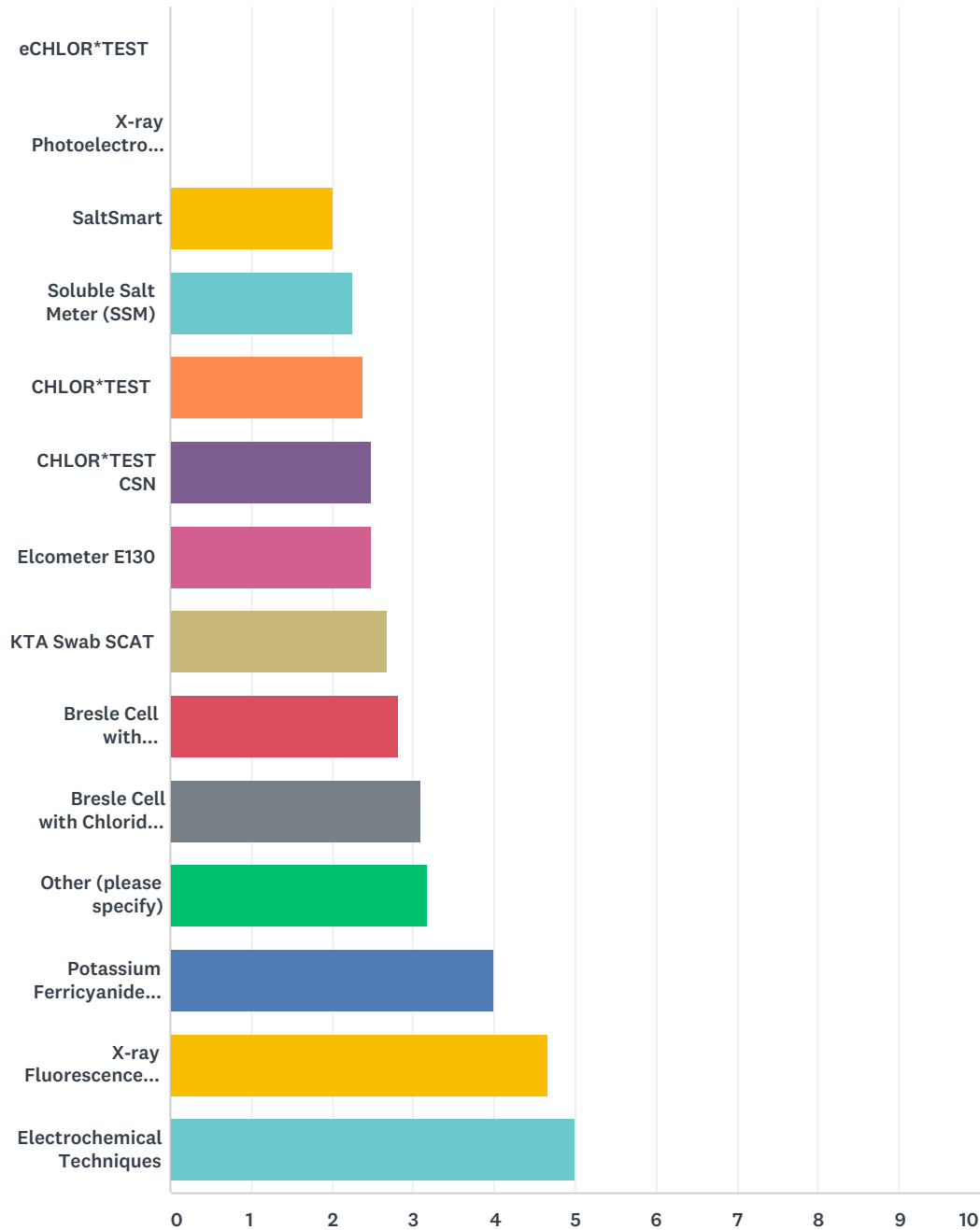
ANSWER CHOICES	RESPONSES	
X-ray Photoelectron Spectroscopy (XPS)	0.00%	0
SaltSmart	2.78%	1
eCHLOR*TEST	5.56%	2
Potassium Ferricyanide Test	5.56%	2
Electrochemical Techniques	5.56%	2

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

X-ray Fluorescence (XRF)	8.33%	3
Soluble Salt Meter (SSM)	11.11%	4
CHLOR*TEST CSN	13.89%	5
Elcometer E130	13.89%	5
Other (please specify)	16.67%	6
Bresle Cell with conductivity measurement	19.44%	7
KTA Swab SCAT	27.78%	10
Bresle Cell with Chloride ion measurement	33.33%	12
CHLOR*TEST	61.11%	22
Total Respondents: 36		

Q22 In your opinion, how easy are each of the following salt detection methods to use?

Answered: 36 Skipped: 7



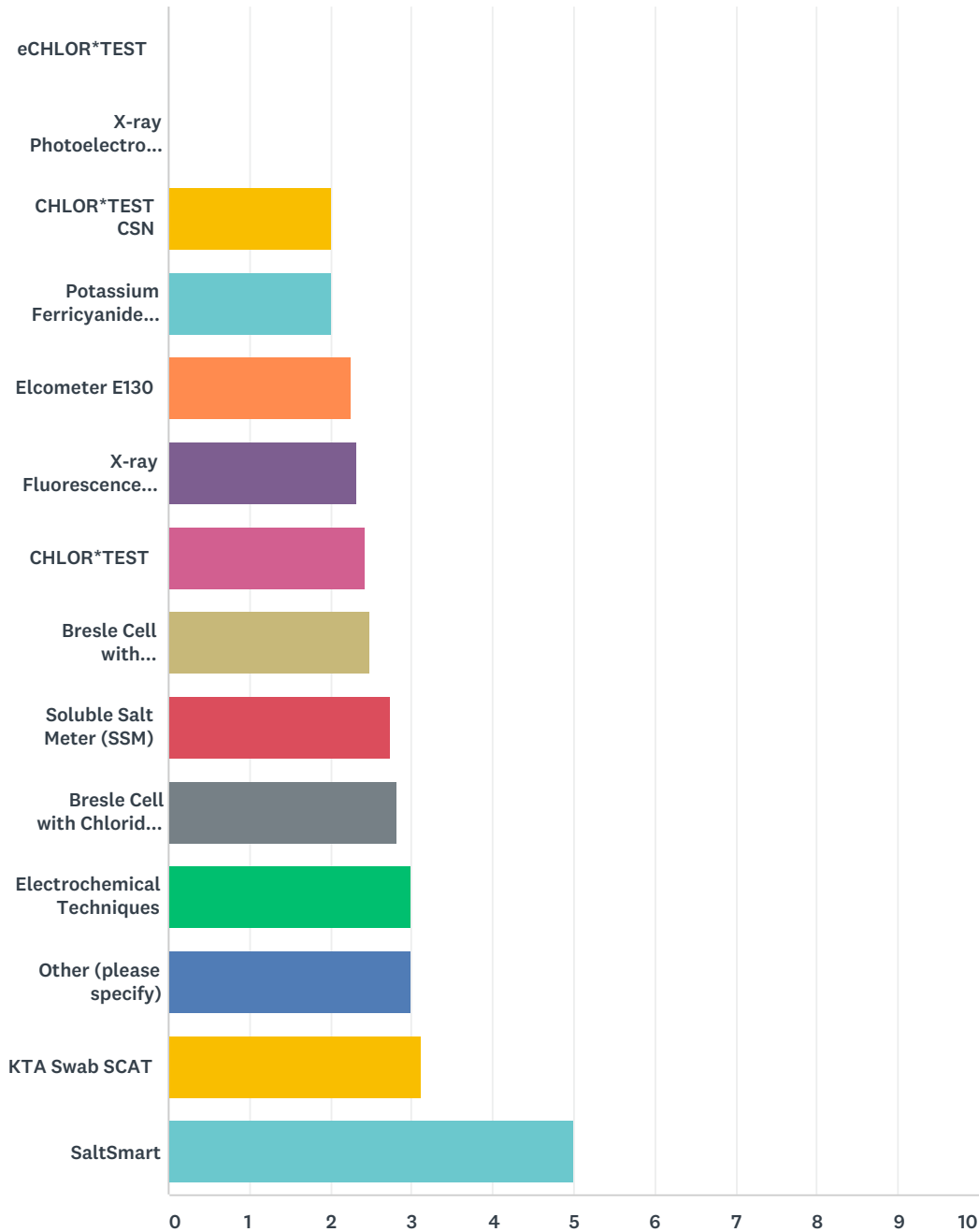
	EXTREMELY EASY TO USE	(NO LABEL)	REASONABLE FOR FIELD USE	(NO LABEL)	VERY DIFFICULT FOR FIELD USE	TOTAL	WEIGHTED AVERAGE
eCHLOR*TEST	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00
X-ray Photoelectron Spectroscopy (XPS)	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

SaltSmart	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	1	2.00
Soluble Salt Meter (SSM)	0.00% 0	75.00% 3	25.00% 1	0.00% 0	0.00% 0	4	2.25
CHLOR*TEST	19.05% 4	33.33% 7	38.10% 8	9.52% 2	0.00% 0	21	2.38
CHLOR*TEST CSN	25.00% 1	25.00% 1	25.00% 1	25.00% 1	0.00% 0	4	2.50
Elcometer E130	0.00% 0	50.00% 2	50.00% 2	0.00% 0	0.00% 0	4	2.50
KTA Swab SCAT	22.22% 2	11.11% 1	44.44% 4	22.22% 2	0.00% 0	9	2.67
Bresle Cell with conductivity measurement	16.67% 1	16.67% 1	33.33% 2	33.33% 2	0.00% 0	6	2.83
Bresle Cell with Chloride ion measurement	0.00% 0	27.27% 3	36.36% 4	36.36% 4	0.00% 0	11	3.09
Other (please specify)	0.00% 0	16.67% 1	66.67% 4	0.00% 0	16.67% 1	6	3.17
Potassium Ferricyanide Test	0.00% 0	0.00% 0	0.00% 0	100.00% 1	0.00% 0	1	4.00
X-ray Fluorescence (XRF)	0.00% 0	0.00% 0	0.00% 0	33.33% 1	66.67% 2	3	4.67
Electrochemical Techniques	0.00% 0	0.00% 0	0.00% 0	0.00% 0	100.00% 2	2	5.00

Q23 In your opinion, how effectively do each of the following salt detection methods measure contamination?

Answered: 36 Skipped: 7



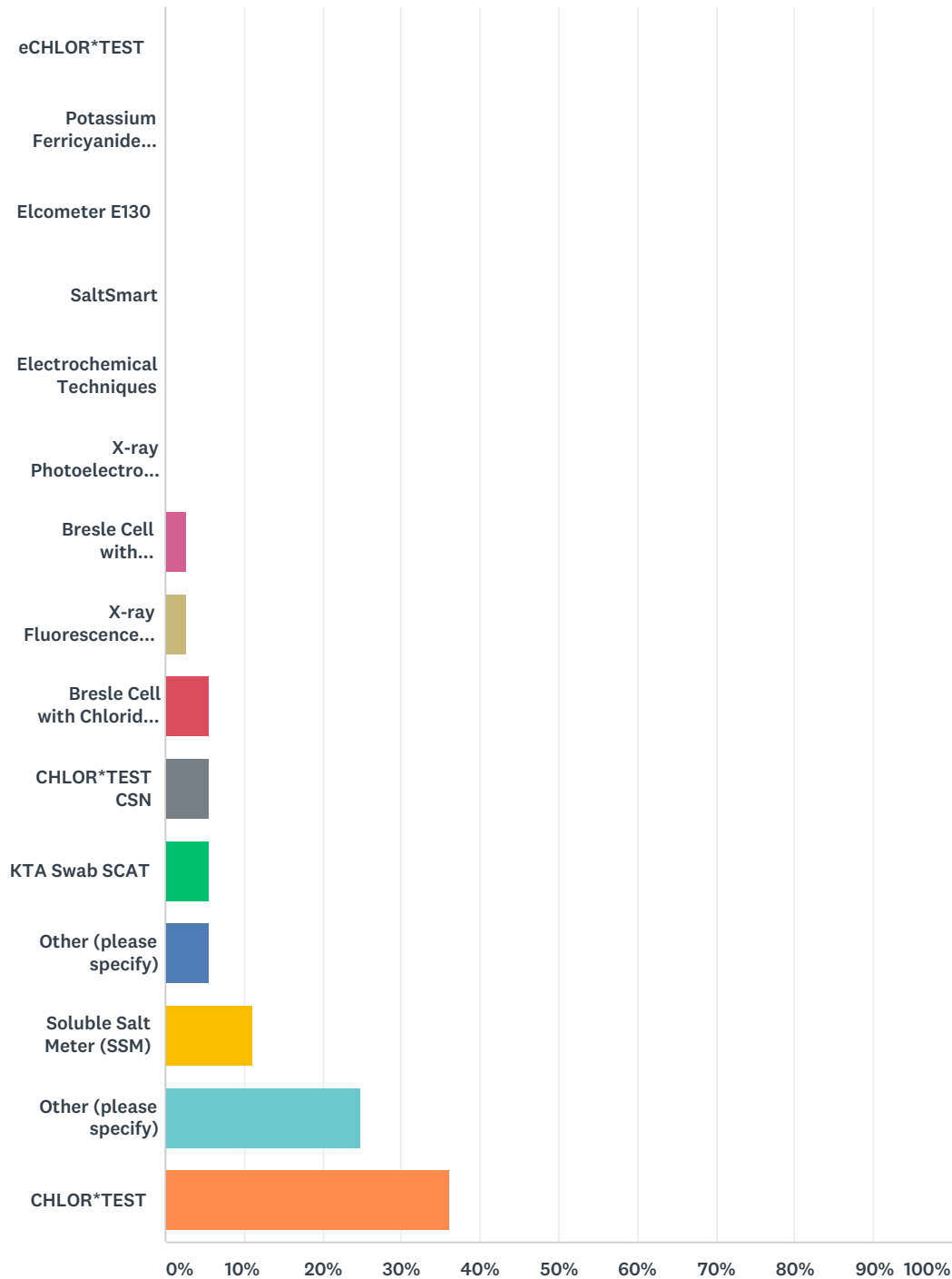
	HIGHLY EFFECTIVE	(NO LABEL)	SOMEWHAT EFFECTIVE	(NO LABEL)	INEFFECTIVE	TOTAL	WEIGHTED AVERAGE
eCHLOR*TEST	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00
X-ray Photoelectron Spectroscopy (XPS)	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

CHLOR*TEST CSN	50.00% 2	0.00% 0	50.00% 2	0.00% 0	0.00% 0	4	2.00
Potassium Ferricyanide Test	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	1	2.00
Elcometer E130	25.00% 1	50.00% 2	0.00% 0	25.00% 1	0.00% 0	4	2.25
X-ray Fluorescence (XRF)	66.67% 2	0.00% 0	0.00% 0	0.00% 0	33.33% 1	3	2.33
CHLOR*TEST	14.29% 3	33.33% 7	47.62% 10	4.76% 1	0.00% 0	21	2.43
Bresle Cell with conductivity measurement	33.33% 2	16.67% 1	33.33% 2	0.00% 0	16.67% 1	6	2.50
Soluble Salt Meter (SSM)	25.00% 1	25.00% 1	25.00% 1	0.00% 0	25.00% 1	4	2.75
Bresle Cell with Chloride ion measurement	0.00% 0	45.45% 5	36.36% 4	9.09% 1	9.09% 1	11	2.82
Electrochemical Techniques	0.00% 0	0.00% 0	100.00% 2	0.00% 0	0.00% 0	2	3.00
Other (please specify)	16.67% 1	0.00% 0	66.67% 4	0.00% 0	16.67% 1	6	3.00
KTA Swab SCAT	11.11% 1	22.22% 2	33.33% 3	11.11% 1	22.22% 2	9	3.11
SaltSmart	0.00% 0	0.00% 0	0.00% 0	0.00% 0	100.00% 1	1	5.00

Q24 Which salt detection method do you prefer?

Answered: 36 Skipped: 7



ANSWER CHOICES	RESPONSES	
eCHLOR*TEST	0.00%	0
Potassium Ferricyanide Test	0.00%	0
Elcometer E130	0.00%	0

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

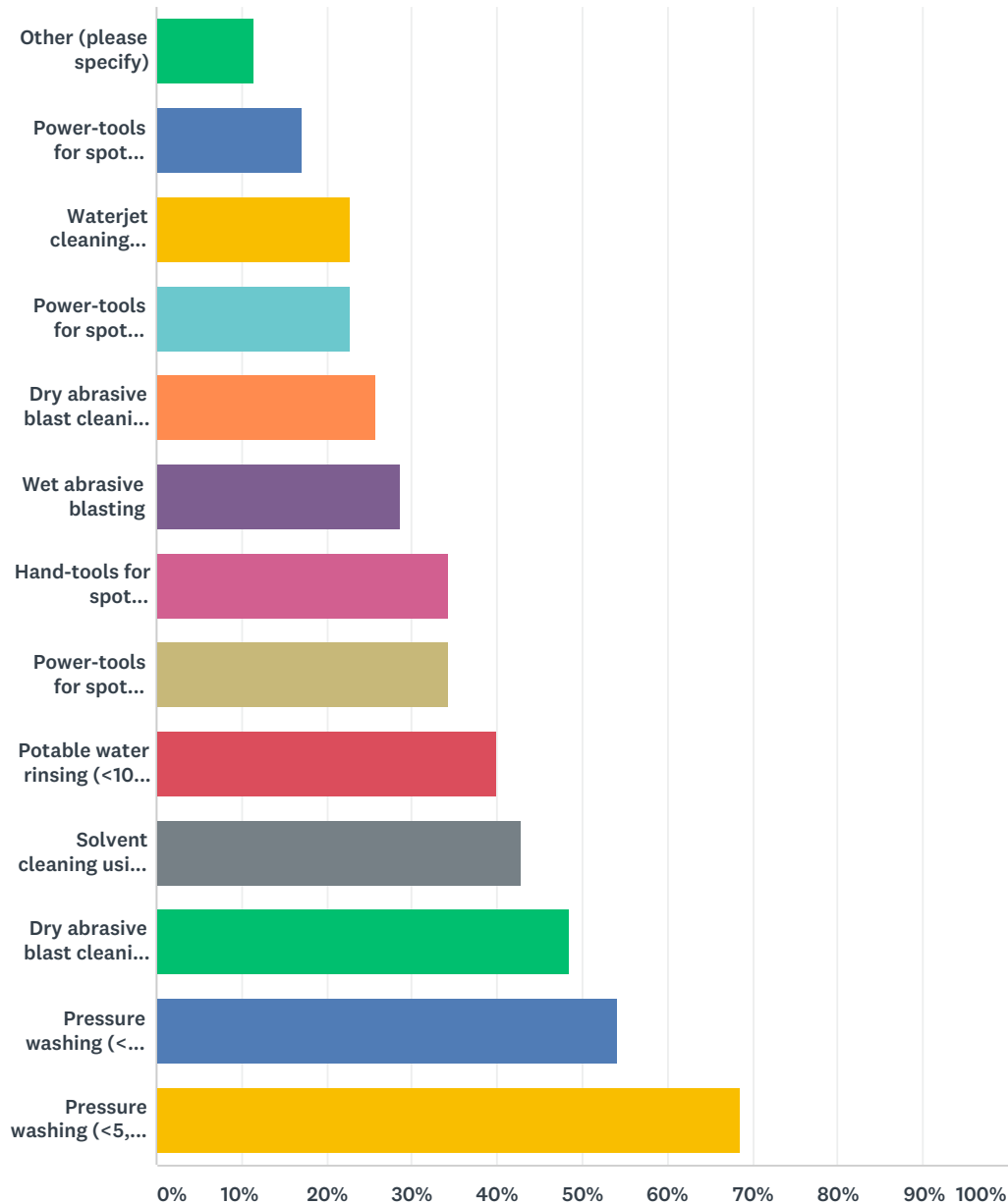
SaltSmart	0.00%	0
Electrochemical Techniques	0.00%	0
X-ray Photoelectron Spectroscopy (XPS)	0.00%	0
Bresle Cell with conductivity measurement	2.78%	1
X-ray Fluorescence (XRF)	2.78%	1
Bresle Cell with Chloride ion measurement	5.56%	2
CHLOR*TEST CSN	5.56%	2
KTA Swab SCAT	5.56%	2
Other (please specify)	5.56%	2
Soluble Salt Meter (SSM)	11.11%	4
Other (please specify)	25.00%	9
CHLOR*TEST	36.11%	13
TOTAL		36

Q25 What do you believe are the most significant challenges for soluble salt detection technologies?

Answered: 32 Skipped: 11

Q26 With which of the following salt remediation methods are you familiar?

Answered: 35 Skipped: 8



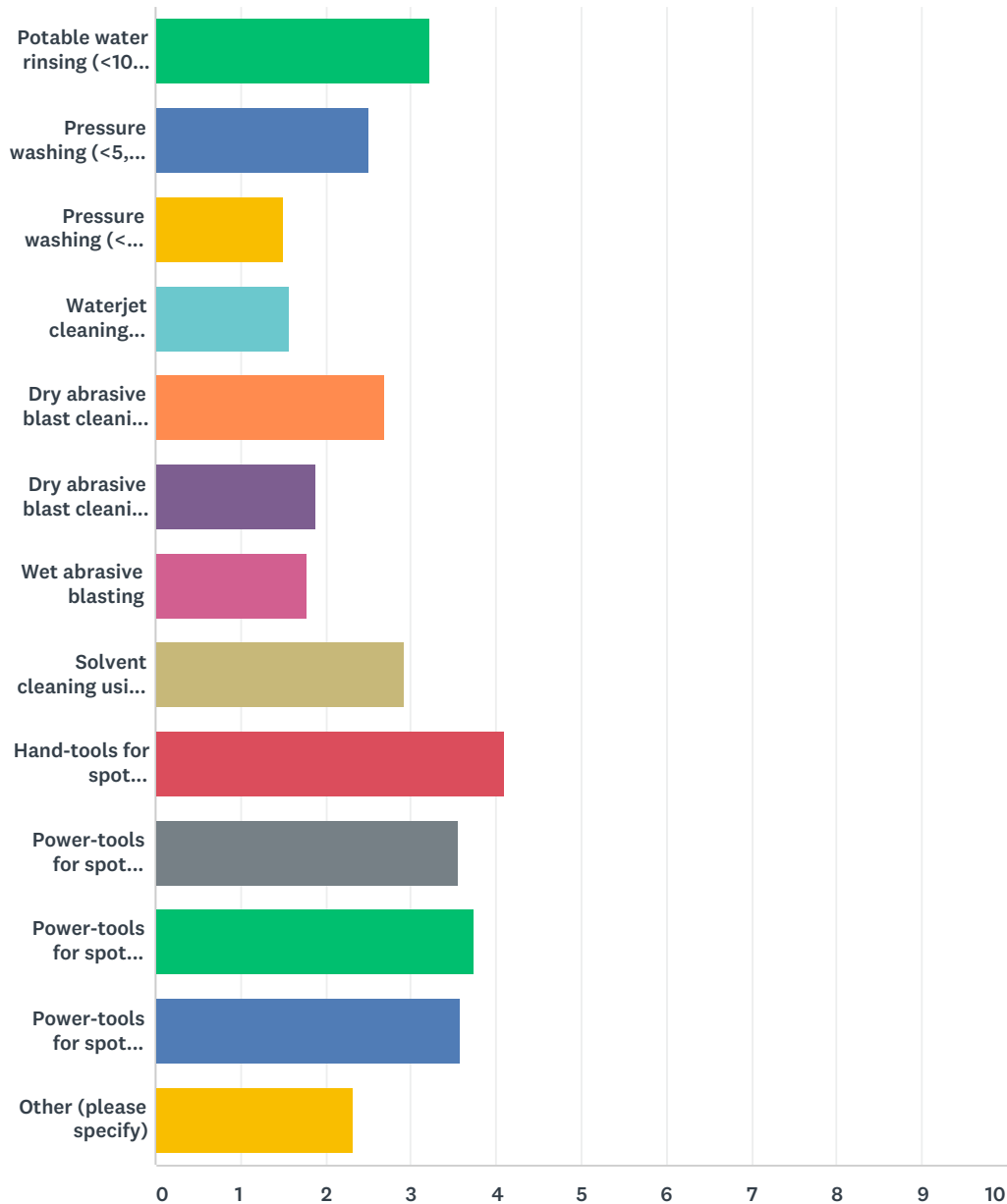
ANSWER CHOICES	RESPONSES	
Other (please specify)	11.43%	4
Power-tools for spot preparation per SSPC SP-15	17.14%	6
Waterjet cleaning (>10,000 psi, with or without additives)	22.86%	8
Power-tools for spot preparation per SSPC SP-11	22.86%	8
Dry abrasive blast cleaning modified to address salts (e.g, through the use of a specific abrasive blend)	25.71%	9

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

Wet abrasive blasting	28.57%	10
Hand-tools for spot preparation per SSPC SP-2	34.29%	12
Power-tools for spot preparation per SSPC SP-3	34.29%	12
Potable water rinsing (<100 psi)	40.00%	14
Solvent cleaning using a solvent other than water	42.86%	15
Dry abrasive blast cleaning without any particular modifications	48.57%	17
Pressure washing (< 5,000 psi) with soluble salt remover (e.g., Chlor-Rid®, HoldTight®, Salt-X, Salt-a-Way, etc)	54.29%	19
Pressure washing (<5,000 psi, water only)	68.57%	24
Total Respondents: 35		

Q27 How effectively do you think each of the following methods remove salt from a steel structure?

Answered: 34 Skipped: 9



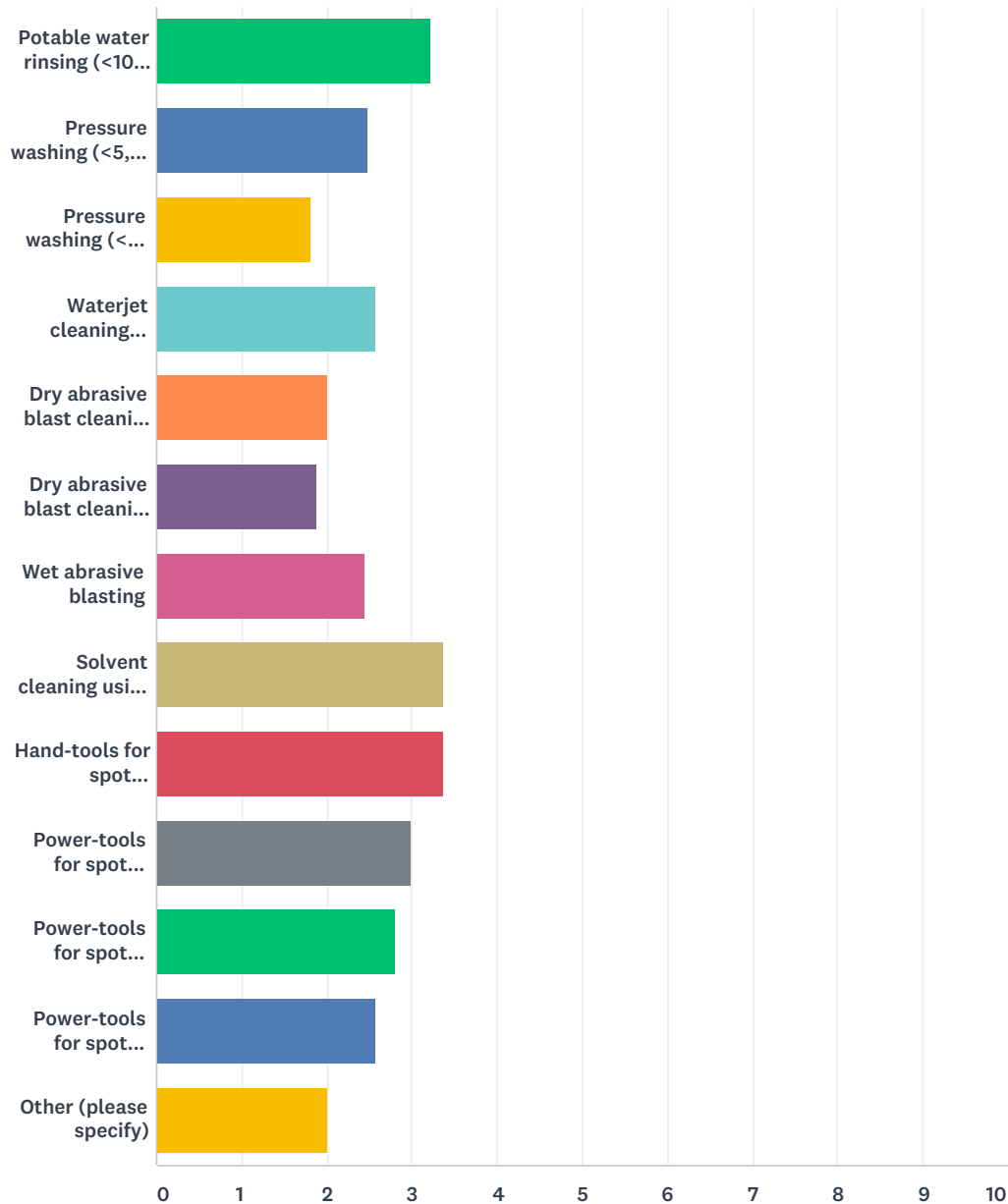
	REMOVES 80-100% OF THE SALT	(NO LABEL)	REMOVES 40-60% OF THE SALT	(NO LABEL)	REMOVES LESS THAN 20% OF THE SALT	TOTAL	WEIGHTED AVERAGE
Potable water rinsing (<100 psi)	15.38% 2	15.38% 2	30.77% 4	7.69% 1	30.77% 4	13	3.23
Pressure washing (<5,000 psi, water only)	17.39% 4	26.09% 6	47.83% 11	4.35% 1	4.35% 1	23	2.52

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

Pressure washing (< 5,000 psi) with soluble salt remover (e.g., Chlor-Rid®, HoldTight®, Salt-X, Salt-a-Way, etc)	61.11% 11	27.78% 5	11.11% 2	0.00% 0	0.00% 0	18	1.50
Waterjet cleaning (>10,000 psi, with or without additives)	85.71% 6	0.00% 0	0.00% 0	0.00% 0	14.29% 1	7	1.57
Dry abrasive blast cleaning without any particular modifications	25.00% 4	12.50% 2	37.50% 6	18.75% 3	6.25% 1	16	2.69
Dry abrasive blast cleaning modified to address salts (e.g, through the use of a specific abrasive blend)	25.00% 2	62.50% 5	12.50% 1	0.00% 0	0.00% 0	8	1.88
Wet abrasive blasting	66.67% 6	11.11% 1	11.11% 1	0.00% 0	11.11% 1	9	1.78
Solvent cleaning using a solvent other than water	35.71% 5	7.14% 1	14.29% 2	14.29% 2	28.57% 4	14	2.93
Hand-tools for spot preparation per SSPC SP-2	0.00% 0	18.18% 2	9.09% 1	18.18% 2	54.55% 6	11	4.09
Power-tools for spot preparation per SSPC SP-3	9.09% 1	27.27% 3	9.09% 1	9.09% 1	45.45% 5	11	3.55
Power-tools for spot preparation per SSPC SP-15	0.00% 0	25.00% 1	25.00% 1	0.00% 0	50.00% 2	4	3.75
Power-tools for spot preparation per SSPC SP-11	0.00% 0	14.29% 1	28.57% 2	42.86% 3	14.29% 1	7	3.57
Other (please specify)	0.00% 0	66.67% 2	33.33% 1	0.00% 0	0.00% 0	3	2.33

Q28 How practical is each removal method for remediating salts during full coating removal?

Answered: 34 Skipped: 9



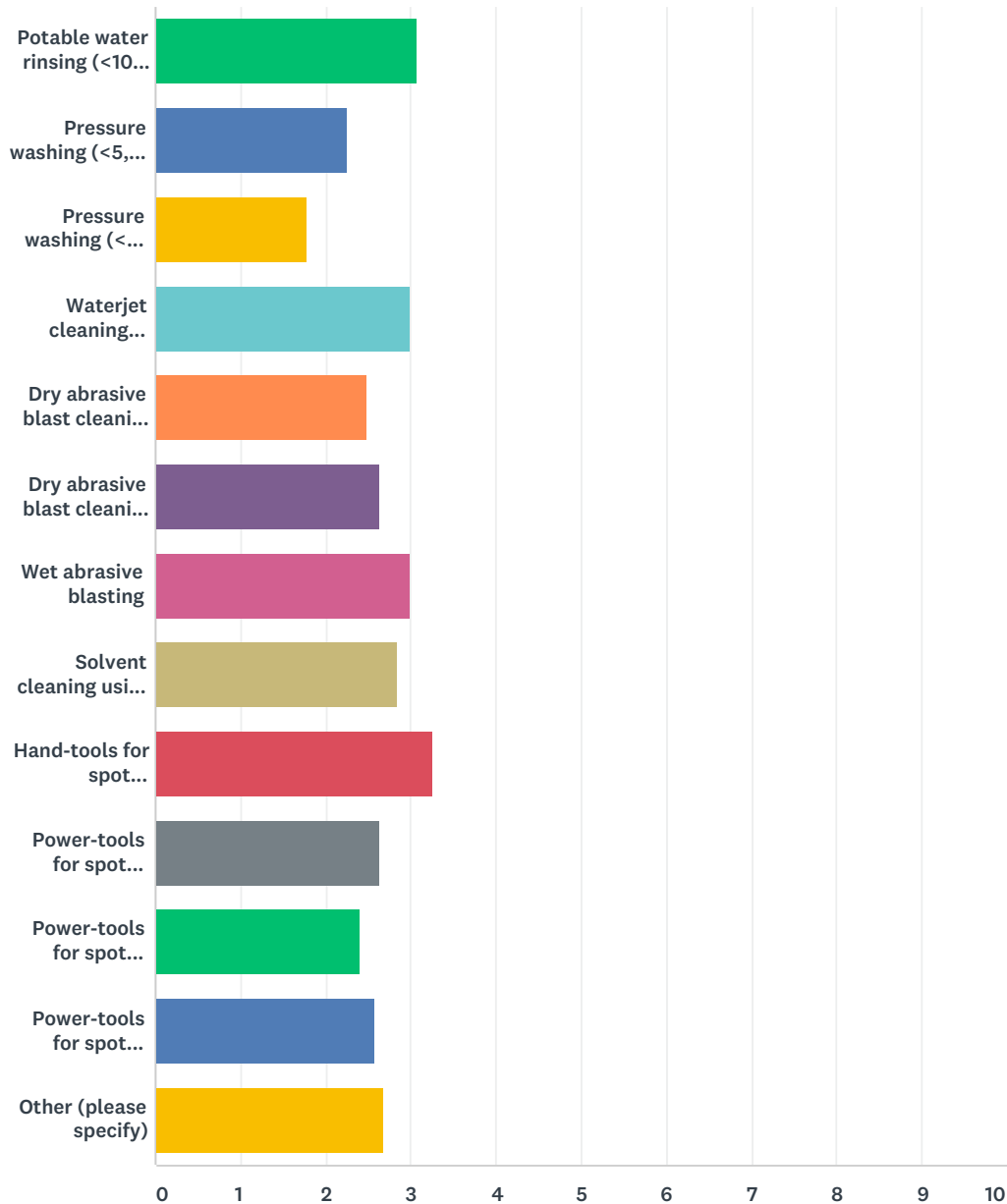
	VERY PRACTICAL	(NO LABEL)	SOMEWHAT PRACTICAL	(NO LABEL)	NOT PRACTICAL/NOT APPLICABLE	TOTAL	WEIGHTED AVERAGE
Potable water rinsing (<100 psi)	23.08% 3	0.00% 0	23.08% 3	38.46% 5	15.38% 2	13	3.23
Pressure washing (<5,000 psi, water only)	34.78% 8	17.39% 4	26.09% 6	8.70% 2	13.04% 3	23	2.48

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

Pressure washing (< 5,000 psi) with soluble salt remover (e.g., Chlor-Rid®, HoldTight®, Salt-X, Salt-a-Way, etc)	61.11% 11	5.56% 1	22.22% 4	11.11% 2	0.00% 0	18	1.83
Waterjet cleaning (>10,000 psi, with or without additives)	14.29% 1	28.57% 2	42.86% 3	14.29% 1	0.00% 0	7	2.57
Dry abrasive blast cleaning without any particular modifications	40.00% 6	26.67% 4	26.67% 4	6.67% 1	0.00% 0	15	2.00
Dry abrasive blast cleaning modified to address salts (e.g, through the use of a specific abrasive blend)	37.50% 3	37.50% 3	25.00% 2	0.00% 0	0.00% 0	8	1.88
Wet abrasive blasting	22.22% 2	22.22% 2	44.44% 4	11.11% 1	0.00% 0	9	2.44
Solvent cleaning using a solvent other than water	0.00% 0	21.43% 3	35.71% 5	28.57% 4	14.29% 2	14	3.36
Hand-tools for spot preparation per SSPC SP-2	9.09% 1	18.18% 2	27.27% 3	18.18% 2	27.27% 3	11	3.36
Power-tools for spot preparation per SSPC SP-3	18.18% 2	18.18% 2	27.27% 3	18.18% 2	18.18% 2	11	3.00
Power-tools for spot preparation per SSPC SP-15	20.00% 1	20.00% 1	20.00% 1	40.00% 2	0.00% 0	5	2.80
Power-tools for spot preparation per SSPC SP-11	28.57% 2	14.29% 1	28.57% 2	28.57% 2	0.00% 0	7	2.57
Other (please specify)	33.33% 1	33.33% 1	33.33% 1	0.00% 0	0.00% 0	3	2.00

Q29 How practical is each removal method for remediating salts during partial coating removal (spot painting or overcoating)?

Answered: 34 Skipped: 9



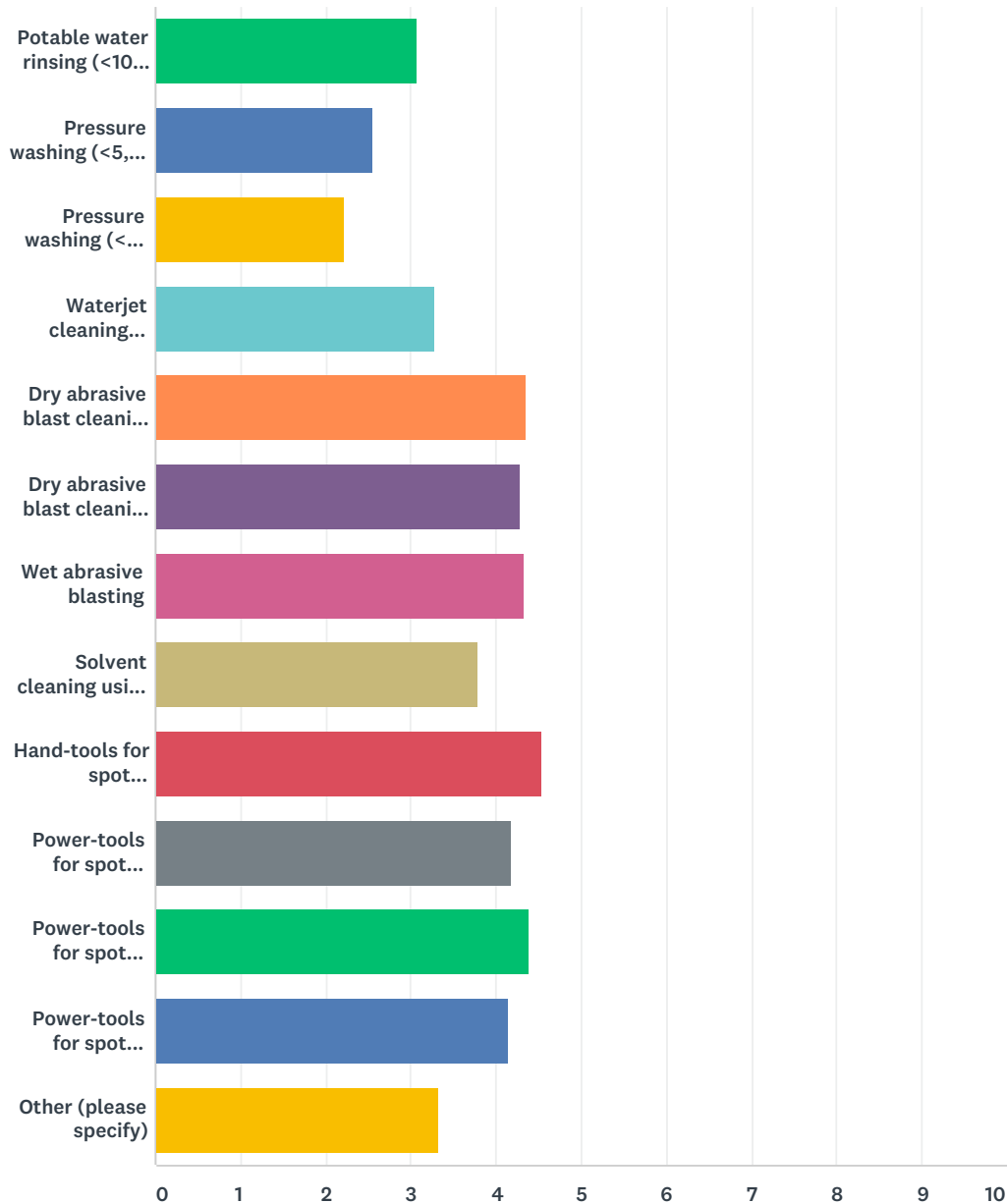
	VERY PRACTICAL	(NO LABEL)	SOMEWHAT PRACTICAL	(NO LABEL)	NOT PRACTICAL/NOT APPLICABLE	TOTAL	WEIGHTED AVERAGE
Potable water rinsing (<100 psi)	16.67% 2	16.67% 2	16.67% 2	41.67% 5	8.33% 1	12	3.08
Pressure washing (<5,000 psi, water only)	43.48% 10	13.04% 3	26.09% 6	8.70% 2	8.70% 2	23	2.26

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

Pressure washing (< 5,000 psi) with soluble salt remover (e.g., Chlor-Rid®, HoldTight®, Salt-X, Salt-a-Way, etc)	61.11% 11	16.67% 3	11.11% 2	5.56% 1	5.56% 1	18	1.78
Waterjet cleaning (>10,000 psi, with or without additives)	14.29% 1	28.57% 2	14.29% 1	28.57% 2	14.29% 1	7	3.00
Dry abrasive blast cleaning without any particular modifications	31.25% 5	31.25% 5	12.50% 2	6.25% 1	18.75% 3	16	2.50
Dry abrasive blast cleaning modified to address salts (e.g, through the use of a specific abrasive blend)	25.00% 2	12.50% 1	50.00% 4	0.00% 0	12.50% 1	8	2.63
Wet abrasive blasting	22.22% 2	11.11% 1	33.33% 3	11.11% 1	22.22% 2	9	3.00
Solvent cleaning using a solvent other than water	23.08% 3	23.08% 3	7.69% 1	38.46% 5	7.69% 1	13	2.85
Hand-tools for spot preparation per SSPC SP-2	9.09% 1	18.18% 2	27.27% 3	27.27% 3	18.18% 2	11	3.27
Power-tools for spot preparation per SSPC SP-3	36.36% 4	0.00% 0	27.27% 3	36.36% 4	0.00% 0	11	2.64
Power-tools for spot preparation per SSPC SP-15	20.00% 1	40.00% 2	20.00% 1	20.00% 1	0.00% 0	5	2.40
Power-tools for spot preparation per SSPC SP-11	28.57% 2	14.29% 1	28.57% 2	28.57% 2	0.00% 0	7	2.57
Other (please specify)	0.00% 0	33.33% 1	66.67% 2	0.00% 0	0.00% 0	3	2.67

Q30 How practical is each removal method for remediating salts during bridge cleaning (without painting)?

Answered: 34 Skipped: 9



	VERY PRACTICAL	(NO LABEL)	SOMEWHAT PRACTICAL	(NO LABEL)	NOT PRACTICAL/NOT APPLICABLE	TOTAL	WEIGHTED AVERAGE
Potable water rinsing (<100 psi)	15.38% 2	23.08% 3	23.08% 3	15.38% 2	23.08% 3	13	3.08
Pressure washing (<5,000 psi, water only)	40.91% 9	18.18% 4	9.09% 2	9.09% 2	22.73% 5	22	2.55

NCHRP Project 10-97 Soluble Salt Detection and Remediation Survey

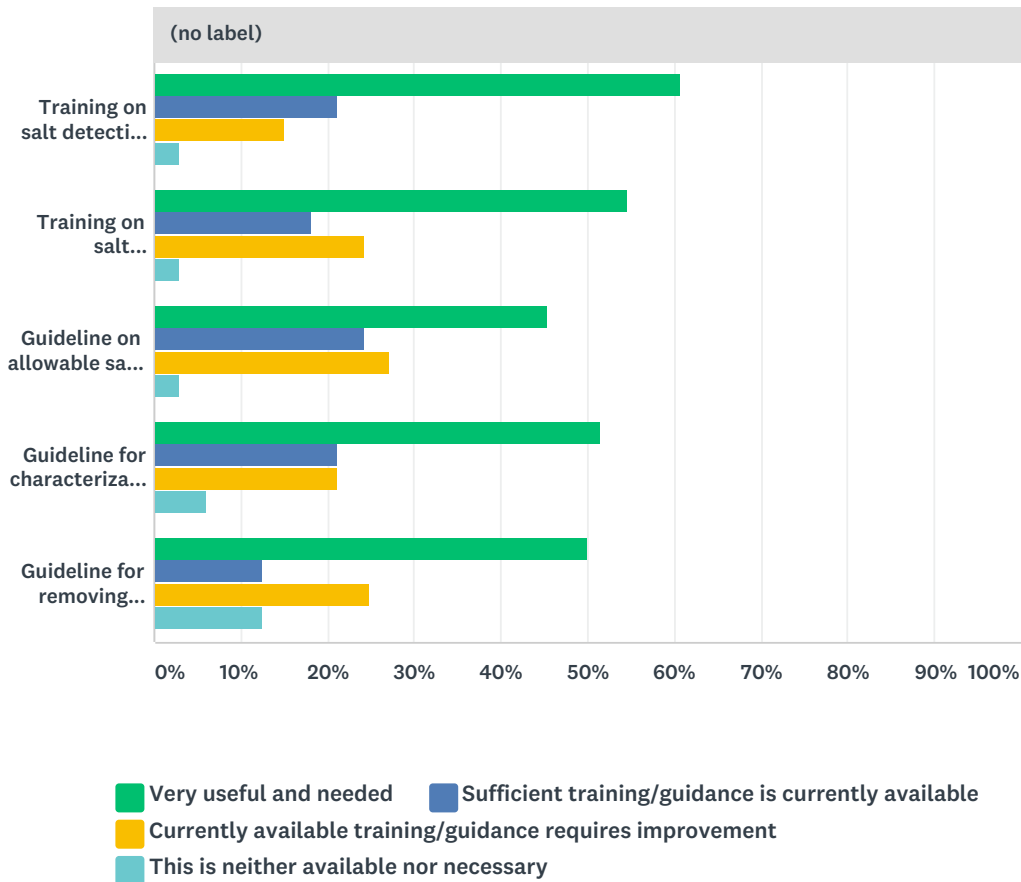
Pressure washing (< 5,000 psi) with soluble salt remover (e.g., Chlor-Rid®, HoldTight®, Salt-X, Salt-a-Way, etc)	50.00% 9	16.67% 3	5.56% 1	16.67% 3	11.11% 2	18	2.22
Waterjet cleaning (>10,000 psi, with or without additives)	42.86% 3	0.00% 0	0.00% 0	0.00% 0	57.14% 4	7	3.29
Dry abrasive blast cleaning without any particular modifications	7.14% 1	7.14% 1	0.00% 0	14.29% 2	71.43% 10	14	4.36
Dry abrasive blast cleaning modified to address salts (e.g, through the use of a specific abrasive blend)	14.29% 1	0.00% 0	0.00% 0	14.29% 1	71.43% 5	7	4.29
Wet abrasive blasting	11.11% 1	0.00% 0	0.00% 0	22.22% 2	66.67% 6	9	4.33
Solvent cleaning using a solvent other than water	7.14% 1	21.43% 3	0.00% 0	28.57% 4	42.86% 6	14	3.79
Hand-tools for spot preparation per SSPC SP-2	0.00% 0	0.00% 0	9.09% 1	27.27% 3	63.64% 7	11	4.55
Power-tools for spot preparation per SSPC SP-3	0.00% 0	9.09% 1	18.18% 2	18.18% 2	54.55% 6	11	4.18
Power-tools for spot preparation per SSPC SP-15	0.00% 0	0.00% 0	20.00% 1	20.00% 1	60.00% 3	5	4.40
Power-tools for spot preparation per SSPC SP-11	0.00% 0	14.29% 1	14.29% 1	14.29% 1	57.14% 4	7	4.14
Other (please specify)	0.00% 0	33.33% 1	33.33% 1	0.00% 0	33.33% 1	3	3.33

Q31 What are significant challenges are associated with soluble salt remediation methods?

Answered: 29 Skipped: 14

Q32 How do you feel about the availability and usefulness of the following types of training and guidance?

Answered: 33 Skipped: 10



(no label)					
	VERY USEFUL AND NEEDED	SUFFICIENT TRAINING/GUIDANCE IS CURRENTLY AVAILABLE	CURRENTLY AVAILABLE TRAINING/GUIDANCE REQUIRES IMPROVEMENT	THIS IS NEITHER AVAILABLE NOR NECESSARY	TOTAL
Training on salt detection methods	60.61% 20	21.21% 7	15.15% 5	3.03% 1	33
Training on salt remediation methods	54.55% 18	18.18% 6	24.24% 8	3.03% 1	33
Guideline on allowable salt levels after remediation	45.45% 15	24.24% 8	27.27% 9	3.03% 1	33
Guideline for characterization salt contamination prior to painting	51.52% 17	21.21% 7	21.21% 7	6.06% 2	33
Guideline for removing soluble salts during periodic cleaning	50.00% 16	12.50% 4	25.00% 8	12.50% 4	32

Q33 With what company or organization are you affiliated?

Answered: 34 Skipped: 9

Q34 Feel free to provide any additional comments you may have below:

Answered: 13 Skipped: 30

Appendix B – Survey of Industry Opinion on the Impact of Soluble Salts and Related Needs

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Q1 What industry are you primarily associated with?

Answered: 65 Skipped: 0

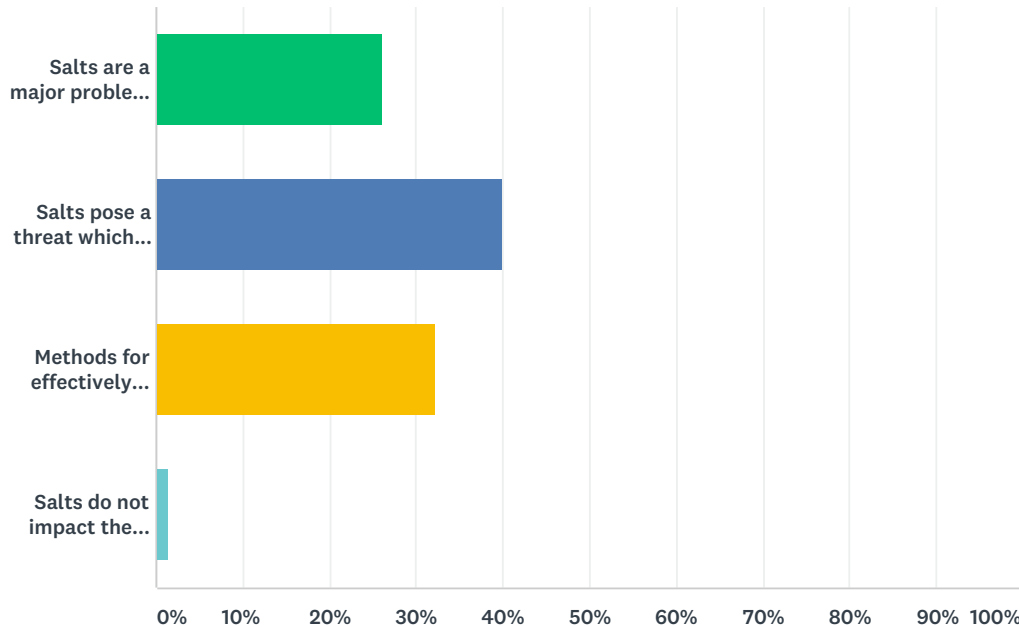
#	RESPONSES	DATE
1	General Protective coatings	9/26/2017 9:57 AM
2	Oil & Gas Oil and Gas	9/25/2017 11:54 PM
3	Other Aerospace	9/20/2017 8:39 PM
4	Offshore Offshore corrosion protection	9/20/2017 10:39 AM
5	Oil & Gas Oil and Ga	9/19/2017 10:32 PM
6	Other Electric and Irrigation Class Water Storage and Delivery	9/19/2017 7:06 PM
7	Shipbuilding/Marine MArine - Shipbuilding	9/19/2017 1:41 PM
8	General Industrial Coatings	9/19/2017 12:46 PM
9	Oil & Gas oil and gas	9/19/2017 11:26 AM
10	General consulting	9/19/2017 11:13 AM
11	General We are multi faceted with operations through N America with Shop and field facilites	9/19/2017 11:08 AM
12	Oil & Gas Tanks and Pipeline	9/19/2017 9:35 AM
13	General coating inspection	9/19/2017 8:54 AM
14	Shipbuilding/Marine marine	9/19/2017 6:14 AM
15	Oil & Gas Oil and Gas	8/30/2017 1:00 PM
16	General Test Equipment	8/28/2017 12:19 PM
17	General Coatings	8/24/2017 12:32 PM
18	General Protective Coatings	8/22/2017 12:46 PM
19	General Inspection	8/22/2017 4:34 AM
20	Bridge Bridge	8/21/2017 2:53 PM
21	Bridge Highways, Transportation	8/21/2017 8:51 AM
22	Oil & Gas Pipeline coatings	8/20/2017 4:22 PM
23	Oil & Gas Shipbuilding/Marine Marine and Oil & Gas	8/20/2017 6:53 AM
24	Oil & Gas Oil & Gas	8/20/2017 3:12 AM
25	Oil & Gas pipeline	8/19/2017 10:33 PM
26	Bridge Transportation (Owner)	8/19/2017 8:17 PM
27	Offshore Offshore renewable Energy	8/19/2017 3:05 PM
28	Offshore Off-shore	8/19/2017 2:32 PM
29	Oil & Gas Oil & Gas	8/18/2017 4:56 AM
30	Shipbuilding/Marine Marine	8/17/2017 5:10 PM
31	Oil & Gas Oil & Gas Industry	8/17/2017 6:21 AM
32	Oil & Gas Oil and gas	8/16/2017 1:08 PM
33	Oil & Gas Oil and gas	8/16/2017 8:15 AM
34	General Protective Coatings Installation	8/15/2017 8:54 PM
35	General Paint	8/15/2017 5:38 PM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

36	Oil & Gas	Corrosion industry in oil and gas and others	8/14/2017 9:53 PM
37	Oil & Gas	Oil and Gas	8/3/2017 7:50 PM
38	Other	Research in coatings	7/27/2017 12:20 AM
39	General	coating	7/26/2017 10:44 AM
40	Oil & Gas	oil	7/24/2017 8:50 AM
41	Shipbuilding/Marine	Marine, Ship Construction and Overhaul	7/24/2017 8:43 AM
42	Shipbuilding/Marine	Marine	7/20/2017 5:06 PM
43	Bridge	Bridge and Highway Construction	7/20/2017 8:49 AM
44	Offshore	Shipbuilding/Marine Ship building and offshore	7/20/2017 7:59 AM
45	General	Paint & Coatings	7/19/2017 7:31 PM
46	General	Polyurea Coatings	7/19/2017 6:08 PM
47	Bridge	Bridge Coatings Contractor	7/19/2017 2:25 PM
48	Other	Fusion Bonded Epoxy Coating and paints to Reinforcement Bar and Pipe	7/19/2017 1:00 PM
49	Bridge	Transportation and water	7/19/2017 12:48 PM
50	General	Coatings Inspection	7/19/2017 12:27 PM
51	General	coating and corrosion control	7/19/2017 12:07 PM
52	General	Coatings	7/19/2017 11:23 AM
53	Shipbuilding/Marine	Marine Coatings	7/19/2017 11:16 AM
54	General	Industrial Coatings Contractor	7/19/2017 10:37 AM
55	Shipbuilding/Marine	marine and industrial coating projects	7/19/2017 10:32 AM
56	Shipbuilding/Marine	Navy Marine	7/19/2017 10:23 AM
57	Other	Aerospace	7/19/2017 10:07 AM
58	Bridge	bridges and military	7/19/2017 9:51 AM
59	Shipbuilding/Marine	Marine / Navy Vessels & Submarines	7/19/2017 9:34 AM
60	Other	POWER	7/19/2017 9:20 AM
61	Oil & Gas	Petrochemical and Refinery (Oil & Gas)	7/19/2017 9:10 AM
62	General	Paint Industry	7/19/2017 7:38 AM
63	Bridge	bridges	7/19/2017 5:06 AM
64	Shipbuilding/Marine	Coating of Industrial and Marine structures.	7/19/2017 2:38 AM
65	Offshore	Offshore	7/19/2017 1:26 AM

Q2 In your opinion, how significantly do soluble salts impact steel structures in your industry?

Answered: 65 Skipped: 0

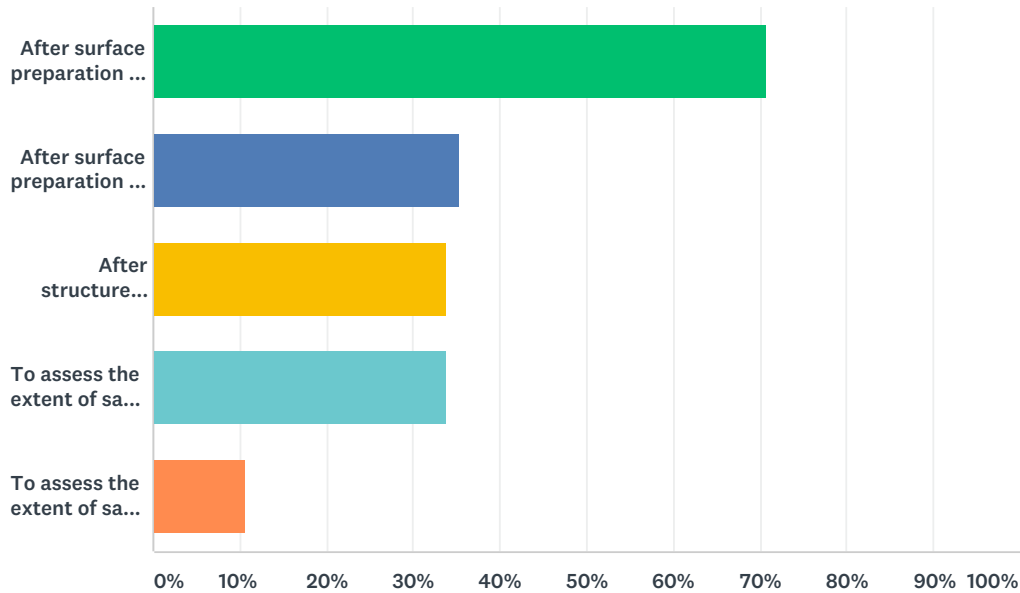


ANSWER CHOICES	RESPONSES	
Salts are a major problem which is neither understood or managed well	26.15%	17
Salts pose a threat which can be managed with additional funding and training	40.00%	26
Methods for effectively managing the effects of salts are in place and adequately funded	32.31%	21
Salts do not impact the performance of steel structures that I work with	1.54%	1
TOTAL		65

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Q3 Under which scenarios do you believe salt detection methods are used in your industry?

Answered: 65 Skipped: 0



ANSWER CHOICES	RESPONSES	
After surface preparation for re-painting (e.g., complete removal and re-coat) projects	70.77%	46
After surface preparation for maintenance painting projects (e.g., spot painting)	35.38%	23
After structure cleaning or washing activities	33.85%	22
To assess the extent of salt contamination as part of a routine condition survey	33.85%	22
To assess the extent of salt contamination as part of a special study	10.77%	7
Total Respondents: 65		

#	OTHER (PLEASE SPECIFY)	DATE
1	After surface preparation for both new structures and maintenance	9/26/2017 9:57 AM
2	After surface preparation for painting new steel	9/25/2017 11:54 PM
3	After surface prep for initial painting (New construction)	9/19/2017 1:41 PM
4	Depends on the environment	8/28/2017 12:19 PM
5	Only when it is specifically specified.	8/24/2017 12:32 PM
6	Normally, we can carry out salt detection tests after surface preparation and in sepcial cases prior to surface preparation.	8/20/2017 3:12 AM
7	Prior to coating New Structural Steel	8/19/2017 8:17 PM
8	During new construction, at relevant areas	7/20/2017 5:06 PM
9	Priot to any surface cleaning, after surface cleaning, and at time after coating is applied.	7/19/2017 1:00 PM
10	Blast grit testing.	7/19/2017 11:16 AM
11	before and after surface prep	7/19/2017 9:51 AM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

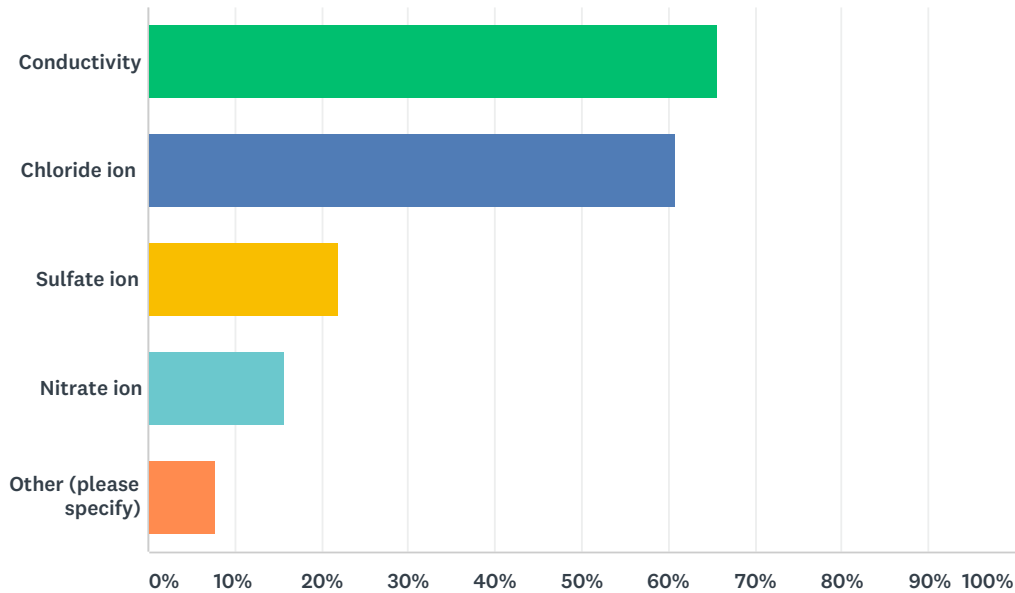
12

Prior to Prepping substrate

7/19/2017 9:20 AM

Q4 What indicator of soluble salts do you typically measure?

Answered: 64 Skipped: 1

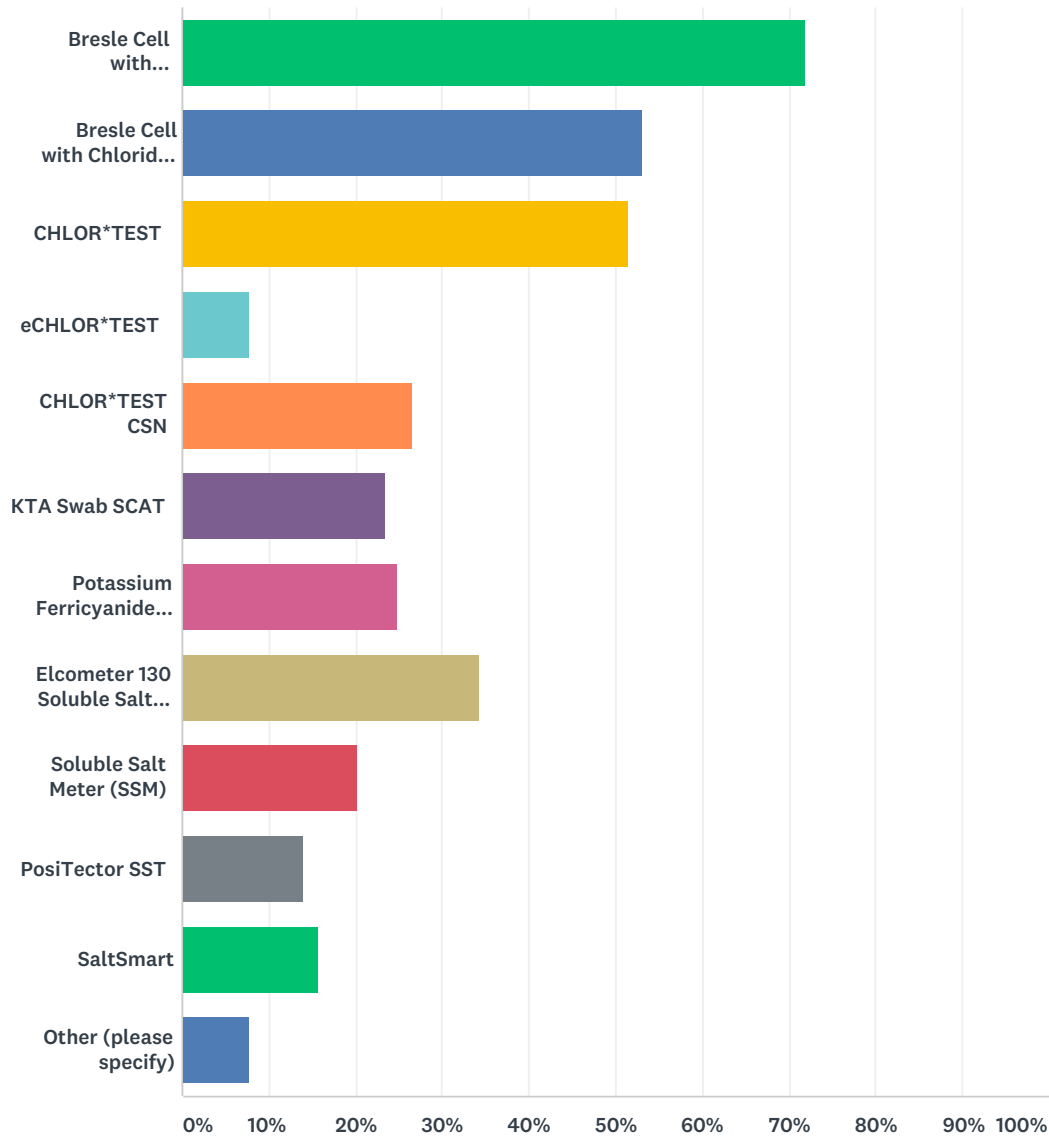


ANSWER CHOICES	RESPONSES	
Conductivity	65.63%	42
Chloride ion	60.94%	39
Sulfate ion	21.88%	14
Nitrate ion	15.63%	10
Other (please specify)	7.81%	5
Total Respondents: 64		

#	OTHER (PLEASE SPECIFY)	DATE
1	All of the above	9/26/2017 9:57 AM
2	Potassium Ferricyanide Test Paper is Qualative not Quantative	9/19/2017 7:06 PM
3	chloride, sulfate and nitrate are not salts, they are ions.	8/28/2017 12:19 PM
4	Potassium ferricyanide	8/14/2017 9:53 PM
5	CSN	7/19/2017 11:23 AM

Q5 With which of the following salt detection methods are you familiar?

Answered: 64 Skipped: 1



ANSWER CHOICES	RESPONSES	
Bresle Cell with conductivity measurement	71.88%	46
Bresle Cell with Chloride ion measurement	53.13%	34
CHLOR*TEST	51.56%	33
eCHLOR*TEST	7.81%	5
CHLOR*TEST CSN	26.56%	17
KTA Swab SCAT	23.44%	15
Potassium Ferricyanide Test	25.00%	16
Elcometer 130 Soluble Salt Profiler	34.38%	22

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

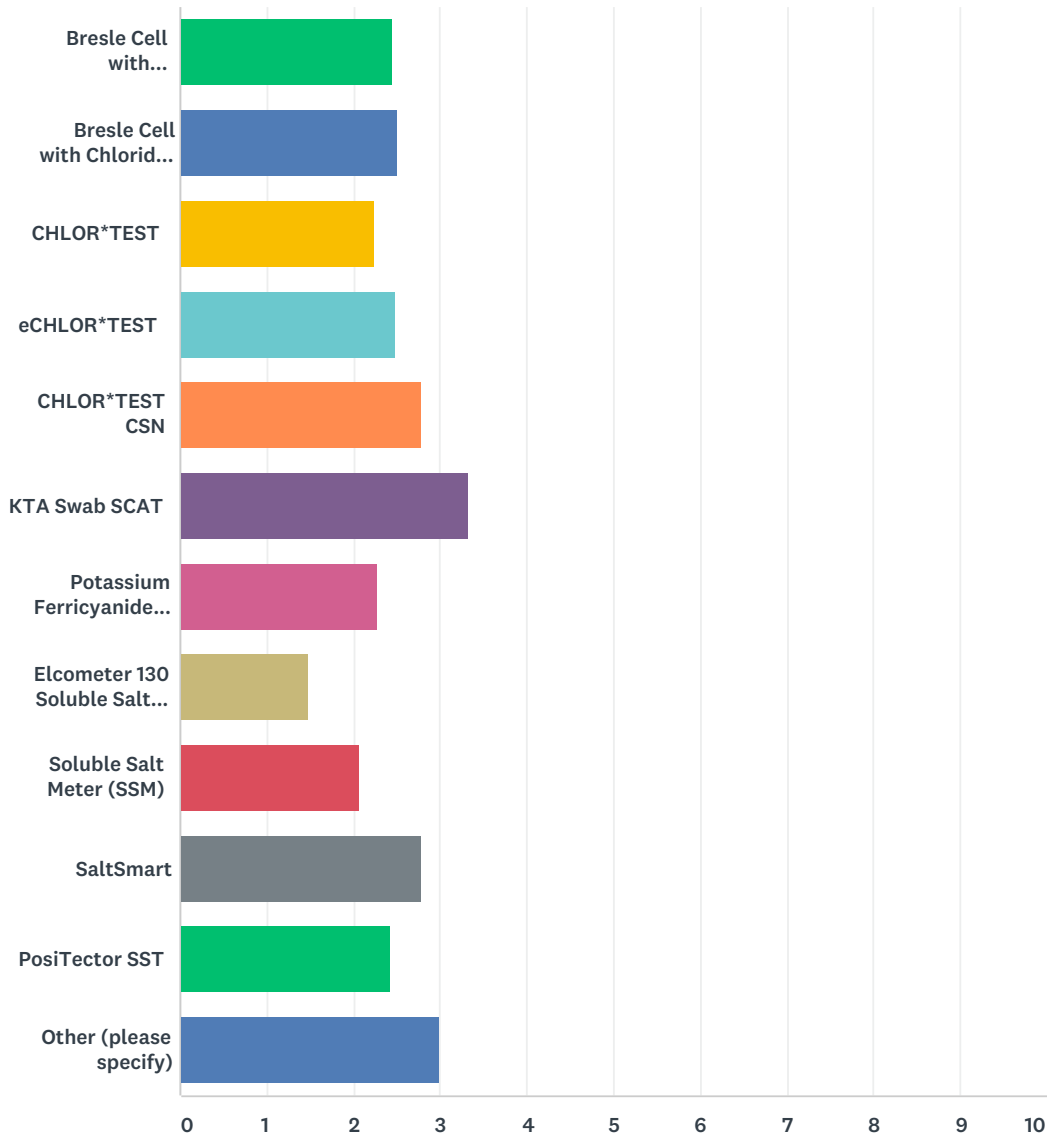
Soluble Salt Meter (SSM)	20.31%	13
PosiTector SST	14.06%	9
SaltSmart	15.63%	10
Other (please specify)	7.81%	5
Total Respondents: 64		

#	OTHER (PLEASE SPECIFY)	DATE
1	I do not know.	7/27/2017 12:22 AM
2	ASTM D512	7/19/2017 1:03 PM
3	1	7/19/2017 11:24 AM
4	nitrate test tubes [reductase test]	7/19/2017 11:17 AM
5	RPCT salt meter	7/19/2017 10:34 AM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Q6 In your opinion, how easy are each of the following salt detection methods to use?

Answered: 63 Skipped: 2



	EXTREMELY EASY TO USE	(NO LABEL)	REASONABLE FOR FIELD USE	(NO LABEL)	VERY DIFFICULT FOR FIELD USE	TOTAL	WEIGHTED AVERAGE
Bresle Cell with conductivity measurement	31.11% 14	13.33% 6	40.00% 18	11.11% 5	4.44% 2	45	2.44
Bresle Cell with Chloride ion measurement	24.24% 8	15.15% 5	48.48% 16	9.09% 3	3.03% 1	33	2.52
CHLOR*TEST	32.26% 10	22.58% 7	35.48% 11	9.68% 3	0.00% 0	31	2.23

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

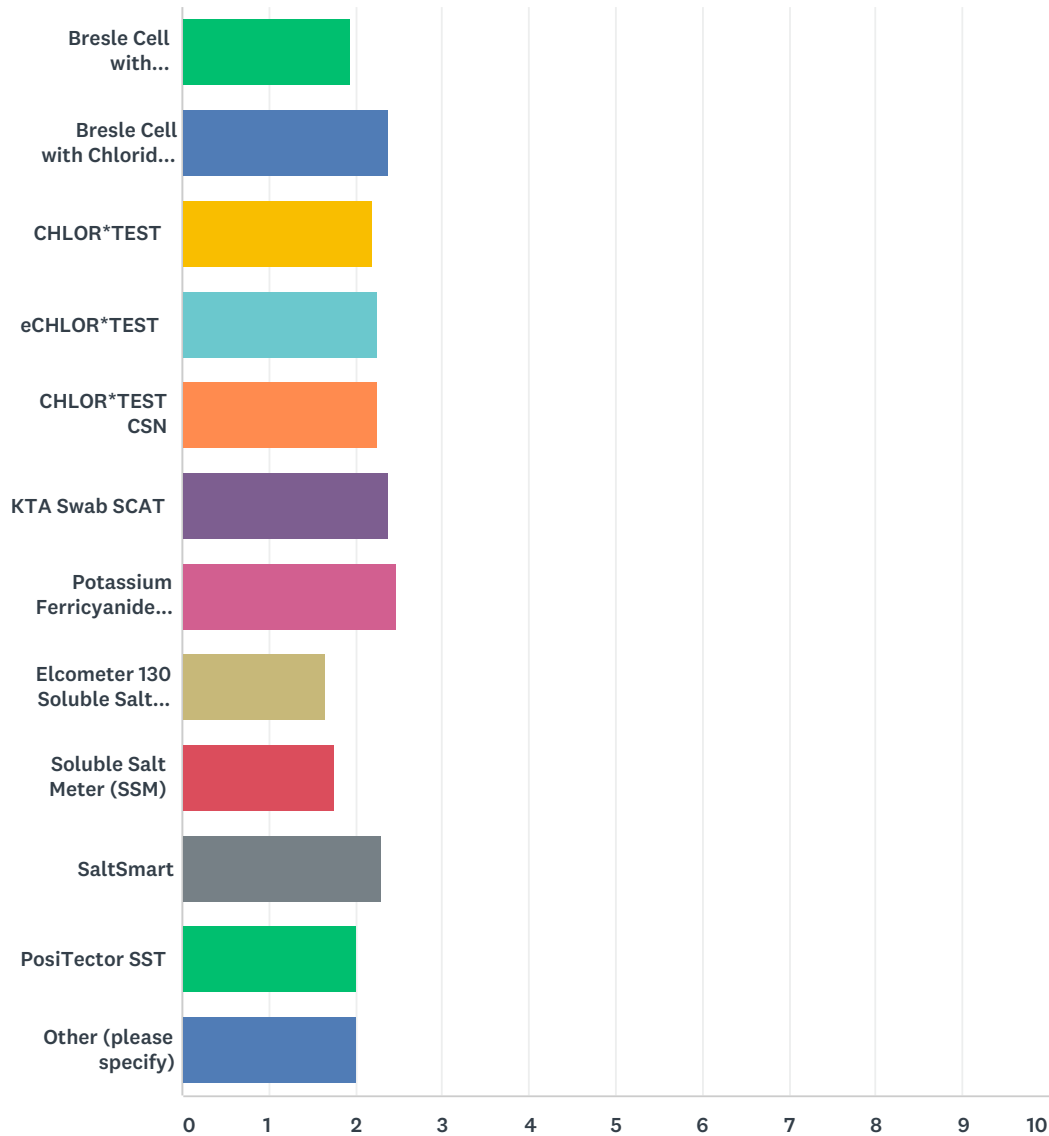
eCHLOR*TEST	0.00% 0	50.00% 2	50.00% 2	0.00% 0	0.00% 0	4	2.50
CHLOR*TEST CSN	21.43% 3	14.29% 2	28.57% 4	35.71% 5	0.00% 0	14	2.79
KTA Swab SCAT	8.33% 1	16.67% 2	25.00% 3	33.33% 4	16.67% 2	12	3.33
Potassium Ferricyanide Test	40.00% 6	6.67% 1	40.00% 6	13.33% 2	0.00% 0	15	2.27
Elcometer 130 Soluble Salt Profiler	57.14% 12	38.10% 8	4.76% 1	0.00% 0	0.00% 0	21	1.48
Soluble Salt Meter (SSM)	41.67% 5	25.00% 3	25.00% 3	0.00% 0	8.33% 1	12	2.08
SaltSmart	22.22% 2	22.22% 2	33.33% 3	0.00% 0	22.22% 2	9	2.78
PosiTector SST	14.29% 1	42.86% 3	28.57% 2	14.29% 1	0.00% 0	7	2.43
Other (please specify)	0.00% 0	60.00% 3	0.00% 0	20.00% 1	20.00% 1	5	3.00

#	FEEL FREE TO ADD COMMENTS HERE	DATE
1	But ISO 8502-06 leaves a lot of room for interpretation, especially wrt sampling-time :-(9/20/2017 10:41 AM
2	Flash rusting of abrasive blast cleaned steel which does not have contact with water is a clear indicator of soluble salt contamination. Flash rusting is a red warning flag indicating the presence of soluble salt contamination.	9/19/2017 7:09 PM
3	Why include SaltSmart since it no longer exists?	8/28/2017 12:21 PM
4	Most of the time we notice that there is a difference in the test value for chloride ion in various test methods, hence we normally try to stick with International standard requirements.	8/20/2017 3:16 AM
5	I trust the Bresle much more than saltsmart	8/19/2017 8:18 PM
6	If you dont have clever eyes you cannot find salt	8/17/2017 5:11 PM
7	All of the above mentioned tests are very subjective. The higher the contaminant load the greater the possibility for a false negative. Except for the conductivity tests all others should be tested within the first five minutes of a blast.	8/14/2017 10:00 PM
8	I do not know	7/27/2017 12:23 AM
9	ASTM D512 is for labratory use only	7/19/2017 1:04 PM
10	wet surfaces can be a challenge	7/19/2017 11:18 AM
11	all methods need to stress using protective gloves to not contaminate surface, thereby skewing results	7/19/2017 10:35 AM
12	These are extremely easy to use only through years of working with them. All testing methods shall be monitored for accuracy	7/19/2017 9:42 AM
13	Often misinterpretation of results occurs.	7/19/2017 2:40 AM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Q7 In your opinion, how effectively do each of the following salt detection methods measure contamination?

Answered: 63 Skipped: 2



	HIGHLY EFFECTIVE	(NO LABEL)	SOMEWHAT EFFECTIVE	(NO LABEL)	INEFFECTIVE	TOTAL	WEIGHTED AVERAGE
Bresle Cell with conductivity measurement	40.91% 18	34.09% 15	18.18% 8	2.27% 1	4.55% 2	44	1.95
Bresle Cell with Chloride ion measurement	21.21% 7	36.36% 12	30.30% 10	6.06% 2	6.06% 2	33	2.39
CHLOR*TEST	26.67% 8	33.33% 10	36.67% 11	0.00% 0	3.33% 1	30	2.20
eCHLOR*TEST	25.00% 1	25.00% 1	50.00% 2	0.00% 0	0.00% 0	4	2.25
CHLOR*TEST CSN	18.75% 3	37.50% 6	43.75% 7	0.00% 0	0.00% 0	16	2.25

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

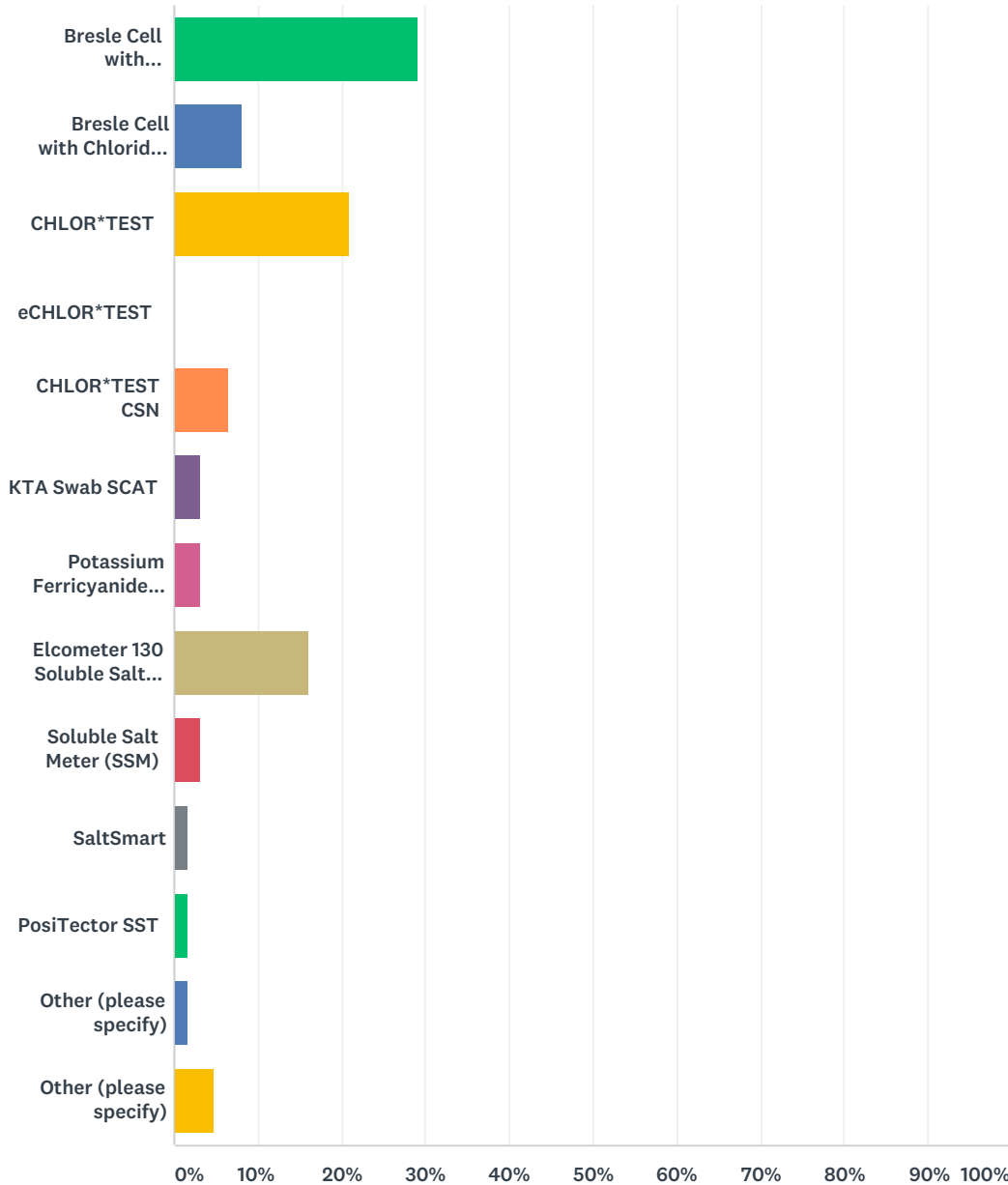
KTA Swab SCAT	30.77% 4	30.77% 4	7.69% 1	30.77% 4	0.00% 0	13	2.38
Potassium Ferricyanide Test	26.67% 4	13.33% 2	53.33% 8	0.00% 0	6.67% 1	15	2.47
Elcometer 130 Soluble Salt Profiler	50.00% 10	35.00% 7	15.00% 3	0.00% 0	0.00% 0	20	1.65
Soluble Salt Meter (SSM)	33.33% 4	58.33% 7	8.33% 1	0.00% 0	0.00% 0	12	1.75
SaltSmart	10.00% 1	50.00% 5	40.00% 4	0.00% 0	0.00% 0	10	2.30
PosiTector SST	28.57% 2	42.86% 3	28.57% 2	0.00% 0	0.00% 0	7	2.00
Other (please specify)	40.00% 2	40.00% 2	0.00% 0	20.00% 1	0.00% 0	5	2.00

#	FEEL FREE TO ADD COMMENTS HERE	DATE
1	Recently did a project where Bresle-Testing was performed next to the Chlor*Test CSN kit. Bresse-Values were in the range of 15 - 35 mg/m2 while CSN-test ALWAYS produced ZERO salts?!	9/20/2017 10:42 AM
2	Potassium Ferricyanide detects readily but is a QUALATATIVE method not Quantative	9/19/2017 7:10 PM
3	values vary for each method (Chloride ion)	8/20/2017 3:18 AM
4	need better explanations on how to convert PPM's	8/19/2017 10:35 PM
5	Bresle is consistent, saltsmart is ok	8/19/2017 8:19 PM
6	I do not know	7/27/2017 12:24 AM
7	I believe what is achieved is subjective.	7/19/2017 2:40 AM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Q8 Which salt detection method do you prefer?

Answered: 62 Skipped: 3



ANSWER CHOICES	RESPONSES	
Bresle Cell with conductivity measurement	29.03%	18
Bresle Cell with Chloride ion measurement	8.06%	5
CHLOR*TEST	20.97%	13
eCHLOR*TEST	0.00%	0
CHLOR*TEST CSN	6.45%	4
KTA Swab SCAT	3.23%	2

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Potassium Ferricyanide Test	3.23%	2
Elcometer 130 Soluble Salt Profiler	16.13%	10
Soluble Salt Meter (SSM)	3.23%	2
SaltSmart	1.61%	1
PosiTector SST	1.61%	1
Other (please specify)	1.61%	1
Other (please specify)	4.84%	3
TOTAL		62

#	OTHER (PLEASE SPECIFY)	DATE
1	SCM400	9/19/2017 11:29 AM
2	Any without patches	7/20/2017 8:00 AM
3	Would prefer to try the Positector SST	7/19/2017 11:20 AM

Q9 What piece of advice on soluble salt detection would you share with someone new to the business?

Answered: 42 Skipped: 23

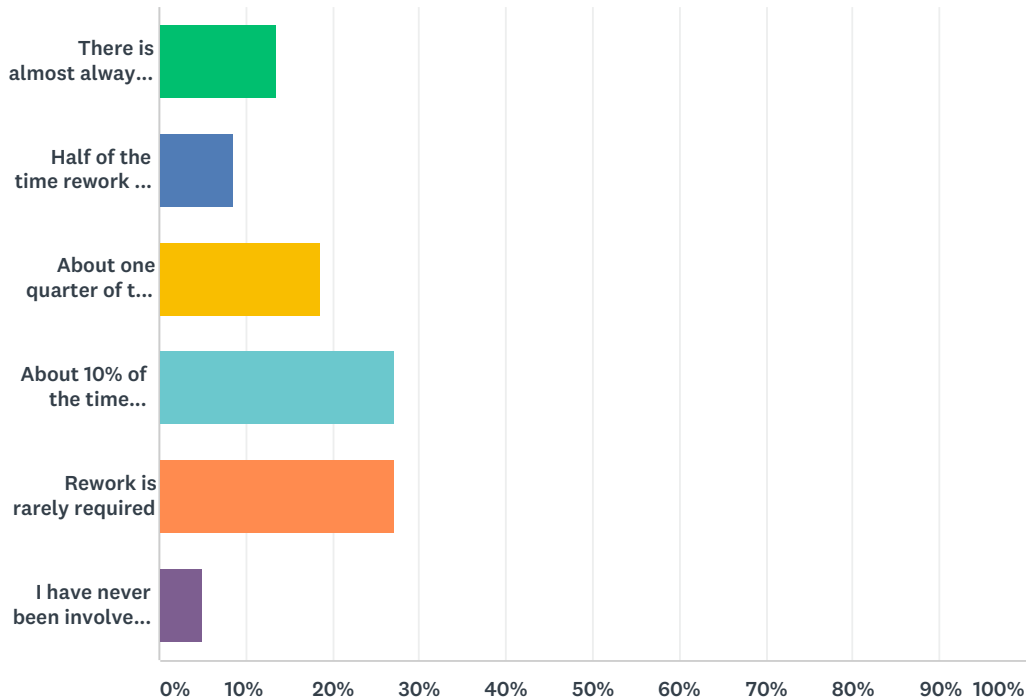
#	RESPONSES	DATE
1	Ensure that high levels of cleanliness are maintained.	9/26/2017 10:00 AM
2	Make sure you perform the tests as per the specifications and the standards referenced in there. ISO 8502-06 & 09 only really are valid for Bresse-Sampling + conductivity measurement. Regardless of the 'equivalence' claimed by other manufacturers of electronic testers. And make sure you sample for AT LEAST 5 - 10 minutes when using a Bresle-Patch (should be agreed between parties involved as per ISO 8502-6)	9/20/2017 10:45 AM
3	Amounts of soluble salts are almost irrelevant. If detectable using potassium Ferricyanide test paper the soluble salts WILL cause a premature coating failure if not decontaminated. Soluble salts contamination is the single largest problem facing the maintenance painting industry in the 21 century.	9/19/2017 7:14 PM
4	Understand what your potential salt - chloride contamination level is expected to be, prior to your surface prep	9/19/2017 1:43 PM
5	always cleaning before blasting	9/19/2017 11:29 AM
6	That zero is virtually impossible to achieve for recoat work.	9/19/2017 11:20 AM
7	salt detection should be conducted prior to specification preparation. If present test after washing with salt removal additive. Confirm acceptable salt level after blast cleaning. Consider the environment to determine if testing is required prior to each coat of paint.	9/19/2017 9:00 AM
8	Identifying testing frequency and threshold implications is critical for quality control.	8/30/2017 1:02 PM
9	Specific ion tests will not find all salts which is why it was developed in the first place. They only identify the anion and not what the salt is. Only a total SA:LT test will find all salts.	8/28/2017 12:26 PM
10	Test, clean - then retest. Check specification requirements for proposed coating. Repeat as needed.	8/24/2017 12:39 PM
11	For whatever reason, this seems to be often over looked. With a device like the Elcometer 130 SSP, this test is extremely easy and quick! There's no reason this shouldn't be implemented on every coating project as it will save headaches down the road.	8/22/2017 12:48 PM
12	Be careful, most test methods measure the average salt concentration for the area that is actually tested, not the maximum salt concentration. The Elcometer 130 SSP shows you the average and the maximum concentration values - which really helps you assess the surface condition. Even if you "pass" the Bresle test, you may have areas of high concentration that will cause rust spots later on.	8/22/2017 4:40 AM
13	Testing prior to work prevents rework	8/21/2017 8:52 AM
14	Watch for pipelines coming from manufacturers along the coast	8/20/2017 4:24 PM
15	Interpretation of the data and results	8/20/2017 6:54 AM
16	I would advice, instead of spending time and money in detecting all the soluble salts on the surface, go for the soluble salt which would effect the structural integrity most and would cause a failure. Most of the time it is either provided by the assest owner or coating specification or by corrosion survey team.	8/20/2017 3:30 AM
17	learn how to convert from PPM's to the measure needed in your spec. Take measurements before and after blast for accuracy and assurance of salt removal prior to coating.	8/19/2017 10:37 PM
18	Practice handling these instruments all the way through the process.	8/19/2017 8:20 PM
19	Never trust in the applicator when them choose the area where do the test. If you are inspector, you have to choose the area.	8/19/2017 2:40 PM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

20	Salinity depends on the circumstances of the environment, doesn't guarantee a land free of salinity especially in the waters.	8/18/2017 5:04 AM
21	You think that everything is ok but salt is hiding somewhere there find it remove it	8/17/2017 5:13 PM
22	Don't rush the test	8/16/2017 8:17 AM
23	If the substrate cannot be tested within the first five minutes of the surface preparation a clean wire brush, preferably stainless steel should be used to break any visible or non-visible oxidation developed from the hygroscopic contaminants. False negatives run high if this procedure is ignored.	8/14/2017 10:08 PM
24	Is coating over any level of salt residue, O.K. for effective Corrosion Protection ?	7/24/2017 8:48 AM
25	Try keep it simple - fewer steps = less risks of error. Use a conductivity meter that can read on <3ml sample. Watch out for correct units!	7/20/2017 5:11 PM
26	If the blasted steel has area that begin to look different from the original blasted metal, we start checking for salt contamination. Also, you need to ask questions about the reasons for the coatings failures on repaint projects and the areas that were failing.	7/19/2017 7:37 PM
27	When a polyurea coating is going to be used in an immersion service condition, it is highly recommended to test for Soluble Salts. If not, blisters can be expected.	7/19/2017 6:11 PM
28	Check for soluble salt prior to and after treatment if needed	7/19/2017 1:12 PM
29	Make sure the liquid in the Bresle or Chlor*Test are messaged sufficiently long to get any salts into solution. I prefer at least 1 minute of messaging.	7/19/2017 12:50 PM
30	Try different methods that might suit your particular needs	7/19/2017 12:10 PM
31	If we washed the bridges on a regular schedule, we would increase the coating life and save all of us money over the long run.	7/19/2017 11:26 AM
32	Make it a part of your process	7/19/2017 11:20 AM
33	Understand the negative effects of invisible contamination	7/19/2017 10:38 AM
34	Do not contaminate surface. Use distilled/deionized water. Take background conductivity of water+patch or collection device; then subtract from final reading. Instructions and industry training never preach this.	7/19/2017 10:36 AM
35	Be mindful of surface temperatures when collecting samples as this may effect readings if the instrument does not have soft ware to account for temperature.	7/19/2017 10:26 AM
36	Provides company warranty data and protects the customers investment	7/19/2017 10:16 AM
37	follow the step by step methods as specified	7/19/2017 9:55 AM
38	To review and understand the ASTM 4417 prior to use of testing. To also understand the manufacturer instructions on the use of their product.	7/19/2017 9:47 AM
39	Be sure you do not contaminate testing equipment while handling.	7/19/2017 9:23 AM
40	Surface preparation is vital to any coating longevity. Testing for chloride, sulfate and nitrates should be performed on any surface prep. and coating material application.	7/19/2017 9:17 AM
41	Careful placement with gloved hand of patch is required or the blister will leak and ruin your measurement.	7/19/2017 2:42 AM
42	During the washing of the structure take care with the ambient temperature. Best Method funded. 1 washing with normal water / 2 washing with demineralized water and vanaban 6% / rinsing with demineralized water	7/19/2017 1:33 AM

Q10 In your experience, how often do you estimate that work is out of compliance with the soluble salt requirement?

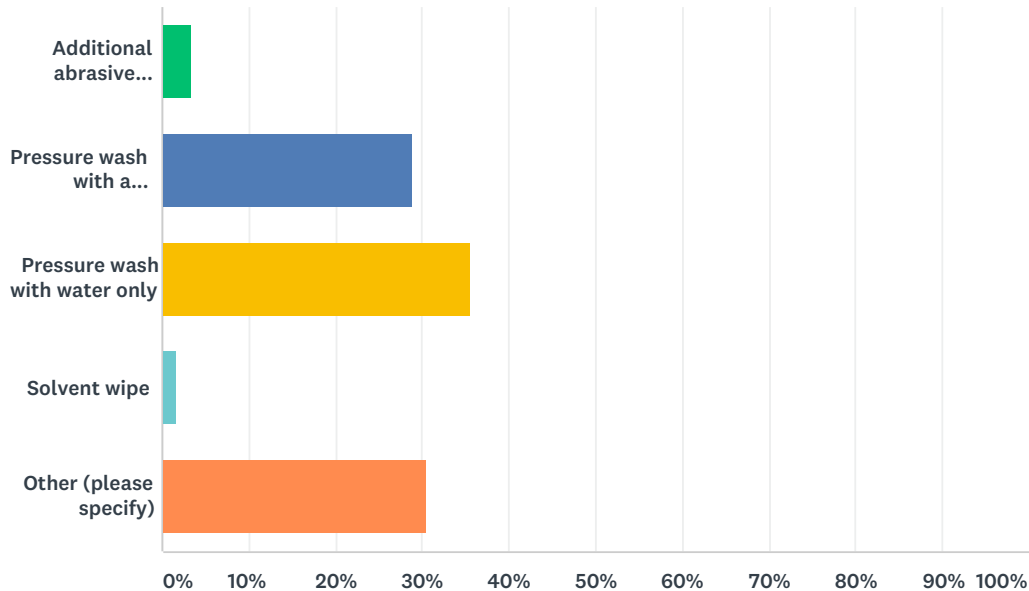
Answered: 59 Skipped: 6



ANSWER CHOICES	RESPONSES	
There is almost always re-work	13.56%	8
Half of the time rework is required	8.47%	5
About one quarter of the time rework is required	18.64%	11
About 10% of the time requires rework	27.12%	16
Rework is rarely required	27.12%	16
I have never been involved in a job requiring rework due to excessive soluble salt contamination	5.08%	3
TOTAL		59

Q11 If non-compliant, what methods have you observed to be effective to remove remaining soluble salts?

Answered: 59 Skipped: 6



ANSWER CHOICES	RESPONSES	
Additional abrasive blasting	3.39%	2
Pressure wash with a salt-removal additive	28.81%	17
Pressure wash with water only	35.59%	21
Solvent wipe	1.69%	1
Other (please specify)	30.51%	18
TOTAL		59

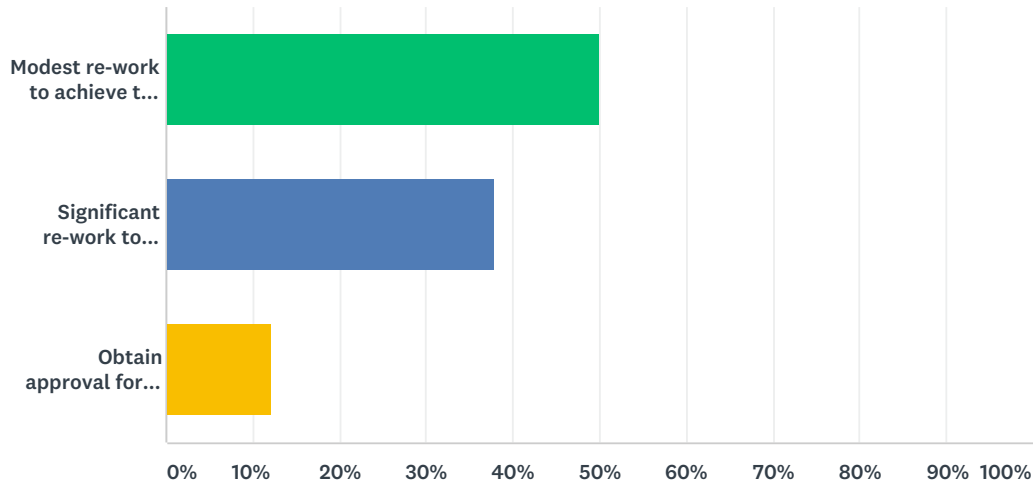
#	OTHER (PLEASE SPECIFY)	DATE
1	HOT water (potable or demineralized) washing	9/20/2017 10:53 AM
2	Prefer water only but only after testing water for salts first	9/19/2017 11:24 AM
3	chlorid	8/19/2017 10:39 PM
4	Additive wash, then water wash	8/19/2017 8:22 PM
5	Washing media we will do with bath soap before in Surface Preparation..	8/18/2017 5:17 AM
6	Double plastin or preblasting before main washing.Visual inspection marking blasting washing and blasting no way other than this	8/17/2017 5:16 PM
7	Blasting or power tooling after applying Chlor rid	8/15/2017 8:57 PM
8	Technology to react and remove FeS and ironically bonded iron salts.	8/14/2017 10:27 PM
9	Low Pressure, High Volume washing with fresh or D.I. Water.	7/24/2017 8:51 AM
10	Wash with additive, scrub, clean rinse, reblast	7/20/2017 8:55 AM
11	Pressure wash with HOLDTIGHT 102 or Chlor*Rid at low pressure (1500 psi)	7/19/2017 7:49 PM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

12	This answer should allow multiple selections. B, C, D	7/19/2017 2:27 PM
13	Acid wash followed by di water rinse but pressure wash can be efective if de-icing salts are the issue.	7/19/2017 1:17 PM
14	combination , we utilize very hot water pressure wash first then blast and re test	7/19/2017 10:41 AM
15	PPG-DX579	7/19/2017 10:38 AM
16	Pressure wash	7/19/2017 7:40 AM
17	I've seen Inspectors keep testing until an acceptable measurement is acquired.	7/19/2017 2:47 AM
18	See previous recommandation	7/19/2017 1:35 AM

Q12 When you do not achieve the soluble salt requirement, what is the typical course of action?

Answered: 58 Skipped: 7



ANSWER CHOICES	RESPONSES	
Modest re-work to achieve the requirement	50.00%	29
Significant re-work to achieve the requirement	37.93%	22
Obtain approval for the non-conformity	12.07%	7
TOTAL		58

#	FEEL FREE TO ADD ANY COMMENTS:	DATE
1	My specifications require decontamination of all rusted and blistered areas. Low Pressure Water Cleaning (LP WC) using a minimum 3,500 psi washer with a zero degree nozzle and rotating tip with various concentrations of chemical decontaminate in the wash water are required. Repeated washings may be needed until the Contractor understands the procedure required for successful decontamination.	9/19/2017 7:22 PM
2	Blasting is typically more modest, but power tooling is significant.	8/15/2017 8:57 PM
3	Technology to react and remove FeS and ironically bonded iron salts.Re	8/14/2017 10:27 PM
4	One or two re-washes, then Obtain Approval as is.	7/24/2017 8:51 AM
5	Depends on job, area, deviation; either modest or significant re-wash	7/20/2017 5:16 PM
6	Contractors know how to play the system. They play on authorities to allow them to fore go do the right thing. You would not only rinse a plate and begin eating off of it. You would scrub off the old food with soap and clean rinse before placing anything on the plate.	7/20/2017 8:55 AM
7	We have achieve the required results every time.	7/19/2017 7:49 PM
8	With the Chlor-Rid products, I've always been able to bring the salt levels down to be compliant.	7/19/2017 6:13 PM
9	I have seen many different approaches. For highly pitted steel surfaces; if fresh water wash does not work, add'l blasting followed another wash may achieve desired results. There are also companies that have the ability to wash your substrates with De - Ionized water.	7/19/2017 10:11 AM
10	My opinion is that washing w/ potable water is the best and most cost effective way to reduce/remove soluble salt contamination.	7/19/2017 9:22 AM

Q13 What piece of advice on soluble salt remediation would you share with someone new to the business?

Answered: 39 Skipped: 26

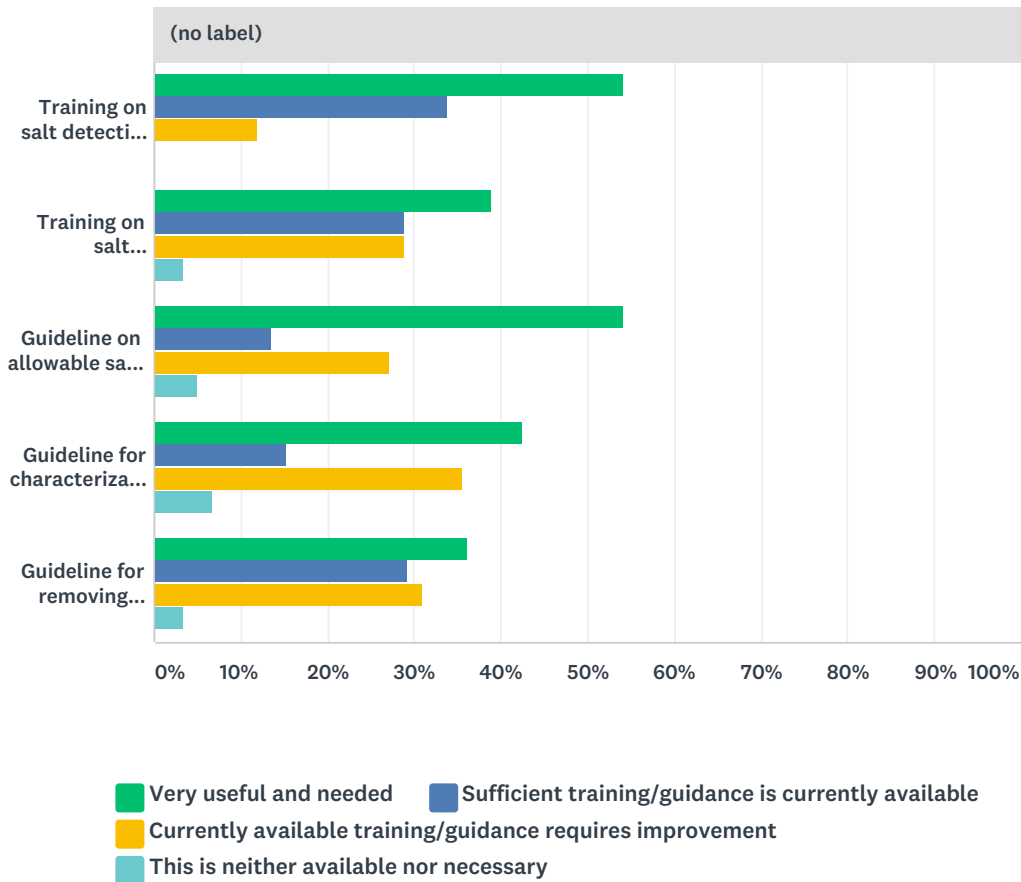
#	RESPONSES	DATE
1	Check the surface for salt contamination before surface preparation as washing may prevent contamination of the cleaned surface.	9/26/2017 10:01 AM
2	Take some recognized training (SSPC, NACE, Frosio, ...) And get thoroughly familiar with the different methods. Make sure you KNOW the standards. People without a chemistry background probably shouldn't be testing for contamination because often they lack understanding of the chemistry of things... (seeing lots of inspectors out there that do not stop to think about many of the factors that could affect measurement accuracy, sampling efficiency, etc...)	9/20/2017 10:53 AM
3	Read my article in Coatings Pro, September 2011, "Coating the Reactivator Tank: A Step into the Future"	9/19/2017 7:22 PM
4	If you suspect a salt problem, pre-clean (pressure wash) prior to surface prep	9/19/2017 1:45 PM
5	check twice minimum	9/19/2017 11:39 AM
6	Always pressure wash or steam first if possible.	9/19/2017 11:24 AM
7	If roadway deicing salts are used on the structure salt remediation should be mandatory. Check pitted areas for salt contamination after blasting.	9/19/2017 9:03 AM
8	Water quality and water pressure are the key to removing salts. A good non-ionic salt remover can be helpful when necessary.	8/28/2017 12:29 PM
9	If left on the surface, you've just built in a failure.	8/24/2017 12:42 PM
10	There are many ways to remediate and each one is specific to your environment	8/20/2017 4:26 PM
11	Frequency of the measurements. Representativity and objectivity	8/20/2017 6:57 AM
12	Water wash followed by scrubbing with a hard nylon or PE brush on the affected area, then pressure water wash. Make sure the water used for cleaning purpose doesn't add up to the soluble salt level, hence it is good to check the water prior to its use.	8/20/2017 3:37 AM
13	I work mostly in North Dakota so I have very little likelihood of high salt presence, although my specs require that I test for it.	8/19/2017 10:39 PM
14	Don't let the work pass until the numbers are reached. Process control is critical. Once it is painted, it's on the owner	8/19/2017 8:22 PM
15	Sometimes, it is very difficult to remove the salts after washing and blasting. The best way to remove remaining salts is re-wash and leave it at least 12 hours before re-blasting. The chloride ions will chemically bond to the rust and will be easier to remove it with blasting.	8/19/2017 2:41 PM
16	Ensure the situation and environmental conditions in good condition, and the media that we will do free of pollution (dirt that stick).	8/18/2017 5:17 AM
17	Don't trust primers first remove them. Wash blast wash everytime use surface tolerant epoxy paints don't take risk	8/17/2017 5:16 PM
18	Be thorough	8/16/2017 8:19 AM
19	Reaction and removal of FeS (iron salts), this will result in the reaction of the ironically bonded iron salts.	8/14/2017 10:27 PM
20	The potential for blistering if disregarded, and insuring costs for reduction/removal are negotiated.	7/24/2017 8:51 AM
21	Check conductivity of water and grit prior to or during surf prep	7/20/2017 5:16 PM
22	Pre-soak, scrub, and wash; mind the tight areas, crevasses, and joints.	7/20/2017 8:55 AM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

23	Do not drive the soluble salts down into the metal with your blasting. Use a procedure that addresses soluble salts and areas of concern before you blast. You are not going to blast soluble salts off the surface. I have had customers blast a surface 5 or more times and still be to high to pass our requirements.	7/19/2017 7:49 PM
24	Follow the directions.	7/19/2017 6:13 PM
25	Industry levels vary greatly for what is considered acceptable and seems no one has the answer. From 2ppm all the way up to 500ppm+ depending on what is to be applied which needs more study.	7/19/2017 1:17 PM
26	Perform the tests in enough locations that are representative of the structure and specifically at locations that are adjacent to the roadway on bridges.	7/19/2017 12:54 PM
27	Be persistant	7/19/2017 12:11 PM
28	Be reasonable	7/19/2017 11:27 AM
29	Make it a part of your education	7/19/2017 11:23 AM
30	find the methods that work best for the situation, they may vary	7/19/2017 10:41 AM
31	Fresh water under pressure is effective; but pitted surfaces can still retain harmful salts even after high and ultra-high pressures are used	7/19/2017 10:38 AM
32	Corrosion protection provided by PPG DX579 Metal Cleaner and DX520 Metal Conditioner	7/19/2017 10:38 AM
33	Keep your instruments safe from damage.	7/19/2017 10:28 AM
34	Fresh water washing is the best method of removal.	7/19/2017 10:11 AM
35	follow the specification requirements since there are different methods per projects	7/19/2017 9:59 AM
36	If you are unsure, ask. There are many seasoned veterans in the coating world.	7/19/2017 9:33 AM
37	It is imperative to test for substrate contamination prior to surface preparation.	7/19/2017 9:22 AM
38	Trust your measurement, unless you have knowingly made a mistake. Then have the courage to standby your measurement.	7/19/2017 2:47 AM
39	Washing is the best way	7/19/2017 1:35 AM

Q14 How do you feel about the availability and usefulness of the following types of training and guidance?

Answered: 59 Skipped: 6



(no label)					
	VERY USEFUL AND NEEDED	SUFFICIENT TRAINING/GUIDANCE IS CURRENTLY AVAILABLE	CURRENTLY AVAILABLE TRAINING/GUIDANCE REQUIRES IMPROVEMENT	THIS IS NEITHER AVAILABLE NOR NECESSARY	TOTAL
Training on salt detection methods	54.24% 32	33.90% 20	11.86% 7	0.00% 0	59
Training on salt remediation methods	38.98% 23	28.81% 17	28.81% 17	3.39% 2	59
Guideline on allowable salt levels after remediation	54.24% 32	13.56% 8	27.12% 16	5.08% 3	59
Guideline for characterization salt contamination prior to painting	42.37% 25	15.25% 9	35.59% 21	6.78% 4	59
Guideline for removing soluble salts during periodic cleaning	36.21% 21	29.31% 17	31.03% 18	3.45% 2	58

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

#	OTHER (PLEASE SPECIFY)	DATE
1	Training WHERE to test is crucially important. If in tact paint is removed there will be no evidence of soluble salts even though a nearby area with failed coating may be heavily contaminated. Test the rusty areas first!!!!	9/19/2017 7:36 PM
2	Show client a cost vs benefit of anticipated coating life	9/19/2017 11:30 AM
3	Much of the training/information currently available is just wrong or misleading. Our industry prefers marketing hype to Science.	8/28/2017 12:35 PM
4	There really needs to be a way to compare the performance of each piece of test equipment.	8/22/2017 4:42 AM
5	In my opinion Contractors are allowed to get away with alot. The more they ask for, the more they are allowed, the less likely a client get the job they paid for.	7/20/2017 8:58 AM
6	In my training classes, we always focus on the importance to test and treat for soluble salts.	7/19/2017 6:15 PM
7	SSPC committee(s) discussing this issue are leaning on bests guesses and existing rules of thumb. There needs to be integration of research and validation of allowable levels and testing locations/frequency.	7/19/2017 2:29 PM

We'd appreciate your thoughts on Soluble Salt Detection and Remediation!

Q15 Feel free to provide any additional comments you may have below:

Answered: 20 Skipped: 45

#	RESPONSES	DATE
1	None	9/26/2017 12:01 AM
2	Would be interesting to put together a training program, say 1/2 day training similar to 'Successfully using PA2', together with SSPC. Interested? Feel free to get back to me : ga@sciconworldwide.com Good survey and looking forward to the results.	9/20/2017 10:55 AM
3	Feel free to contact me regarding any of the responses. John Brodar P.E. AZ Mechanical 27326, CA Corrosion CR1077, NACE 4066 Cathodic Protection Specialist Coatings Specialist Corrosion Specialist jmbrodar@srpnet.com 602-236-5613 home 480-962-8238	9/19/2017 7:40 PM
4	Hi Pete	9/19/2017 1:46 PM
5	If not already, suggest contact with Johnny Eliasson of Chevron Marine who has studied extensively the cost/ performance benefits relating to their fleet.	9/19/2017 11:34 AM
6	CSN field testing is extremely expensive on large bridge projects. Pressure washing should include a salt remediation additive to the wash water. Conductivity testing after blast cleaning should be conducted	9/19/2017 9:07 AM
7	Hi Peter - Tom Swan. Good luck with knocking any sense into this industry. I know Mark Schilling tried for years with no success. I have a flat spot on my far head from trying,	8/28/2017 12:39 PM
8	It is a massive grey area where there is very little or absolutely confusing information available for Soluble salt acceptable levels, acceptable detection methods, its effects on long or short term, to identify the corrosion caused due to a particular soluble salt level, cost and time required to be dedicate for its removal, etc. Wish you all the best...	8/20/2017 3:48 AM
9	The instrument is critical to the entire coating system lifecycle. If it is not consistent, user-friendly and trustworthy- throw it in the trash.	8/19/2017 8:25 PM
10	Use standard and calibrated inspection equipment.	8/18/2017 5:29 AM
11	This salt topic should stand as a must on data sheets & survey standarts	8/17/2017 5:18 PM
12	Would love to follow up with a more in depth discussion on this topic. I am the inventor of the technology to remove non-water soluble FeS, ironically bonded iron salts and other water soluble contaminants.	8/14/2017 10:33 PM
13	I find your survey is too simplified to properly reflect differencies between the wide range of jobs where measuring of salts is or should be done.	7/20/2017 5:32 PM
14	The Contractor's equipment is more times than not is contaminated with Salt. The Contractor uses the same equipment and most times the same abrasive on tested and non-tested projects. In my experience it is extremely unlikely that the equipment is ever cleaned prior to use. The NYSDOT does not currently specify salt testing and the Contractors I have encountered will not wash at all if not made to do so.	7/20/2017 9:03 AM
15	If you'd like to contact me, feel free to anytime. My contact info is: bennya@specialty-products.com	7/19/2017 6:16 PM
16	They never go away unless removed.	7/19/2017 11:28 AM
17	This needs to be announced to the industry and especially the smaller wanna be contractors. In industries locally we have heavy fallout and most contractors do not perform proper testing.	7/19/2017 10:43 AM
18	The most interesting thing I have learned is that porosity in steel can retain ionic species which, after UHPWJ can still create premature rust-back; thereby requiring a repeated pass with UHPWJ. Good luck with the study, Pedro and Fly Eagles Fly! Gordo	7/19/2017 10:42 AM
19	There are plenty of resources for first timers and seasoned persons. We can always learn about new techniques and new products.	7/19/2017 9:39 AM
20	ISO 8502-6 and 8502-9 are good guidelines	7/19/2017 1:39 AM

Appendix C – Creating Standards for Equipment Testing

The project intended to evaluate the measurement capability of various commercial methods of indicating surface salts. Although simple in concept, the terminology “soluble salts,” is not used uniformly across industry. This appendix discusses the various “soluble salt” metrics and presents the procedure for preparing and characterizing the salt solutions used in the laboratory testing of detection methods.

It is important to understand the implications of nuances in the language of “surface salt” specifications. Sodium chloride (NaCl) is the most common salt of concern in corrosion control and protective coatings longevity. It is the major constituent and corrosive element found within marine atmospheres and common “road deicing salts.” As a result, many standards have been established to control or limit residual “soluble salts” or “chlorides.” Unfortunately, these practices have also evolved to create poor descriptors of the exact concern. Common examples include:

- Specifications where it is unclear if the specified levels of “Soluble Salts” in terms of weight per unit surface area (e.g., $\mu\text{g}/\text{cm}^2$) are based on chlorides alone, sodium chloride, or a combination of several salts (such as within the NACE SP0508). Based on the molecular weights of the elements, chlorides comprise 60.7% of the weight of sodium chloride. Therefore, $8.24 \mu\text{g NaCl}/\text{cm}^2$ is the same as $5.0 \mu\text{g Cl}^-/\text{cm}^2$.
- Detection methods intending to simplify measurement options by measuring the conductivity of salts extracted from that surface into a known volume of water. These methods must assume some equivalence between a “soluble salt concentration” and the measured conductivity. If the salts on the surface are pure NaCl and the solutions remain relatively dilute, such equivalence can be determined. However, the surface salts are likely of an unknown composition; therefore the equivalence may not hold. Because the composition of the surface “salt” is rarely known, ISO 8502-9 provides a conversion formula that incorporates a constant to represent the specific conductance of salt concentration under “normal conditions.” This constant is reportedly based on calculation of the total conductivity from the specific conductivities of the individual ions extracted from ten rusty steel specimens. ISO 8502-9 notes that this constant may vary by $\pm 12\%$ in “extreme” conditions.
- Industry has selected test techniques that are ion-specific for chlorides. Measurements using these methods may suggest that there are no salts on a surface even though the surface is contaminated with non-chloride bearing soluble salts.

The current effort is focused on using standard solutions derived from reagent grade chemicals to form solutions containing only sodium chloride or salt mixtures (sodium chloride, sodium sulfate, and sodium bicarbonate as per the NACE SP0508 standard). The following shows how these solutions result in a variety of equivalent, expressions of contamination level.

Salt Solutions Derived from NaCl Only

Example 1 – Creating a Solution that would register as 5 $\mu\text{g}/\text{cm}^2$ (expressed as chlorides alone) or 75 $\mu\text{S}/\text{cm}$ conductivity in a Bresle test of 3 mL extract volume.

- A. Create a stock solution via addition of 25.75 grams of NaCl into 1,000 ml of deionized water. This results in a concentration of 25.75 g/L NaCl.
- B. Using a micro-pipette, add 4 μL of the stock solution into a 3 mL volume of water to simulate the extract. This results in a concentration of $25.75 \text{ g/L} \times (4 \times 10^{-3} \text{ mL}/3 \text{ mL}) = 0.03433 \text{ g/L NaCl}$.
- C. The total weight of salt in this solution is $25.75 \text{ g/L} \times 4 \mu\text{L} = 103 \mu\text{g}$ of NaCl. 60.7% of this weight (62.5 μg) is Cl^- alone.
- D. The test method seeks to extract this salt from a wetted area of 12.5 cm^2 . Thus, this represents a surface salt contamination of $103 \mu\text{g NaCl}/12.5 \text{ cm}^2$ or $8.24 \mu\text{g}/\text{cm}^2$ expressed as NaCl, or $8.24 \times 60.7\% = 5.00 \mu\text{g}/\text{cm}^2$ expressed as Cl^- .
- E. To express this same concentration as a conductivity, convert the salt concentration to its molecular concentration. From paragraph B (above), the extract solution salt concentration is 0.03433 g/L NaCl. Divided by the molecular weight of NaCl (mw = 58.44 g/g-mole), the concentration is $(0.03433 \text{ g/L} / 58.44 \text{ g/g-mole}) = 5.9 \times 10^{-4} \text{ moles/L}$, or $5.9 \times 10^{-7} \text{ moles}/\text{cm}^3$.
- F. Given that $\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-$, there is a one-to-one molecular equivalence between NaCl and the individual ions, Na^+ and Cl^- . The molecular conductivity (aka specific conductance²⁹) of Na^+ ions is $50.11 \text{ S}\cdot\text{cm}^2/\text{mole}$ and for Cl^- the value is $76.34 \text{ S}\cdot\text{cm}^2/\text{mole}$. Given their molecular concentration and these conductivities, the solution conductivity would be $(5.9 \times 10^{-7} \text{ moles}/\text{cm}^3 \times 50.11 \text{ S}\cdot\text{cm}^2/\text{mole} + 5.9 \times 10^{-7} \text{ moles}/\text{cm}^3 \times 76.34 \text{ S}\cdot\text{cm}^2/\text{mole} =) 74.3 \mu\text{S}/\text{cm}$.
- G. If testing the chloride ion content of this solution using an ion specific technique, one would expect a value of $0.03433 \text{ g/L NaCl} \times 60.7\% = 0.02084 \text{ g/L Cl}^-$ or 20.8 ppm.
- H. Therefore, in this example the following are ALL equivalent values: $5.00 \mu\text{g Cl}^-/\text{cm}^2$; $8.24 \mu\text{g NaCl}/\text{cm}^2$; $74.3 \mu\text{S}/\text{cm}$; and 20.8 ppm Cl^- content of extract.

Solutions representing other surface concentrations of Cl^- and other conductivities can be made by linear modifications to the amount of salt added in the stock solution in paragraph A. This adjustment will have a proportional adjustment on all other values listed in paragraph H, above. Note the solution conductivity calculation will be largely valid at these relatively dilute salt solutions.

Salt Solutions Derived from NACE SP0508 Solution

Example 2 – Creating a Solution that would register as 5 $\mu\text{g Cl}^-/\text{cm}^2$ (expressed as chlorides alone) in a Bresle test of 3 mL extract volume. Assume that the salt is represented by the NACE SP0508 salt, which is a mixture of three salts NaCl (53.6 wt. %), Na_2SO_4 (24.3 wt. %), and NaNO_3 (22.1 wt. %).

²⁹ See <https://pubs.usgs.gov/wsp/2311/report.pdf> as a reference for these values

- A. As the target criteria in this example is still $5 \mu\text{g Cl}^-/\text{cm}^2$, and the only source of chlorides is the NaCl, the solution will still require the exact same amount of Cl, derived from NaCl as Example 1. Therefore, create a stock solution via addition of 25.75 grams of NaCl into 1,000 ml of deionized water. Based on the ratio of the other two salts to NaCl in the NACE salt, also add $(25.75 \text{ grams} \times 24.3/53.6 =)$ 11.67 grams Na_2SO_4 , and $(25.75 \text{ grams} \times 22.1 / 53.6 =)$ 10.62 grams NaNO_3 .
- B. As in Example 1, this will yield a $5 \mu\text{g Cl}^-/\text{cm}^2$ reading for chlorides alone.
- C. The total salt concentration will be much higher than Example 1 due to the other components of the salt mixture. In this example the total salts will be 42.44 g/L versus 25.75 g/L in Example 1.
- D. As in Example 1, the total chlorides will remain at 20.8 ppm.
- E. To calculate the expected conductivity of the extract solution, we account for the molar equivalent of all of the salts.

Salt	Concentration, g/L	Molecular Wt, g/g-mole	Concentration, mole/L
NaCl	27.75	58	0.392
Na_2SO_4	11.67	142	0.072
NaNO_3	10.62	85	0.110

We then summarize the total ionic molar concentration from each of the three salts. We also recall that for testing of the salt-sensing instrumentation based on Bresle patches, we inject (or dilute) this solution at a ratio of $4 \mu\text{L} / 3 \text{ mL}$ of water.

Salt	$[\text{Na}^+]$ mole/L	$[\text{Cl}^-]$ mole/L	$[\text{SO}_4^{2-}]$ mole/L	$[\text{HCO}_3^-]$ mole/L
NaCl	0.444	0.444		
Na_2SO_4	$(2 \times 0.082) = 0.164^{30}$		0.082	
NaNO_3	0.125			0.125
TOTAL Concentration =>	0.733	0.444	0.082	0.125
Total Diluted Concentration =>	$(0.004 \text{ mL} / 3 \text{ mL} * 0.733) = 9.78 \times 10^{-4}$	5.92×10^{-4}	1.10×10^{-4}	1.67×10^{-4}

We can then sum the molar conductivity provided by each ionic species in the solution. This also give us the total solution conductivity.

Ion	Ionic Concentration, mole/L	Molar Conductivity, $\text{S} \cdot \text{cm}^2/\text{mole}$	Conductivity, $\mu\text{S}/\text{cm}$
Na^+	9.78×10^{-4}	50.11	49.0
Cl^-	5.92×10^{-4}	76.34	45.2
SO_4^{2-}	1.10×10^{-4}	159.6	17.5
NO_3^-	1.67×10^{-4}	71.4	11.9
Total Conductivity			123.6

³⁰ Each mole of Na_2SO_4 provides 2 moles of Na^+

- A. In this example, the following are ALL equivalent values: $5.00 \mu\text{g Cl}^-/\text{cm}^2$; $8.24 \mu\text{g NaCl}/\text{cm}^2$; and 20.8 ppm Cl⁻ content of extract. However, the total solution conductivity will be $123.6 \mu\text{S}/\text{cm}$. In example 1, the total solution conductivity was $74.3 \mu\text{S}/\text{cm}$. If we made a NACE solution to have a total conductivity of only $74.3 \mu\text{S}/\text{cm}$, then all the other measurements would decrease proportionately. They would decrease by a factor of $(74.3 / 123.6 =) 0.60$, giving a surface salt as chlorides alone of $3.00 \mu\text{g Cl}^- / \text{cm}^2$.

These examples are intended to illustrate the necessity of clearly stating specification values and assumptions concerning the type of salt contamination. Note that different test procedures also rely on different dilution ratios (a function of the volume of extraction fluid and test area) – these factors also change the outcome of the calculations and must be considered.

The following two screenshots show the Excel spreadsheet used to calculate the various values associated with the four contaminated panel conditions used in the detection method evaluation.

Conditions 3 and 5

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Conditions 4 and 6

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Appendix D – Database of Detection Data Collected During this Project (Excel Spreadsheet)