EFFECTS OF CHLORIDE CONTAMINATION
ON COATINGS PERFORMANCE
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Research Report
KTC-10-10/SPR366-08-1F
Effects of Chloride Contamination on Coatings Performance

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16. Abstract  
Research indicates that chloride concentration as determined by currently available field test methods does not reliably predict protective coating performance on KYTC bridges. Laboratory testing of chloride charged panels also failed to relate chloride concentration to coating performance. The coatings industry provides recommendations for acceptable chloride levels for various exposure conditions but bridges are different than other structural steel and the exposure conditions for bridges are not adequately addressed. Effective chloride remediation strategies and protective coatings that perform best in the presence of chlorides need to be identified.

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EXECUTIVE SUMMARY

The Kentucky Transportation Cabinet (KYTC) applies de-icing salts on roads and bridges during the winter. This can result in significant chloride (i.e. soluble salt) concentrations on bridge elements. Locations under deck joints (including bearings and beam ends) are subjected to high chloride concentrations due to joint leakage. In the winter, traffic on wet, salt-treated bridge decks can also generate airborne misting (aerosols) that can spread outward and upward due to vehicle and wind generated turbulence and subsequently deposit on outer faces of fascia girders or truss members (on truss bridges). Those areas of bridges exposed to the aerosol are typically referred to as the “splash zones” of bridges.

A literature search revealed that there is a certain level of agreement in the industry as to the acceptable level of chloride contamination of steel for various types of coatings and service conditions. That search also reveals that the service conditions as described do not reflect the conditions present in splash zones and beneath joints of bridges.

Deicing salts on bridges promote the corrosion of steel (and reinforced concrete) bridge elements and also accelerate the deterioration of protective coatings for structural steel. Deterioration of concrete piers under bridge deck joints that leak and the failure of steel protective coatings in the splash zones and under leaking joints point to the deleterious effect of soluble salts. This study attempts to assess the presence and quantity of chloride salts on a limited number of Kentucky bridges and to determine the relationship between chloride salt concentration and the failure of steel protective coatings.

It is obvious from observations of coating performance of in-service steel bridges that protective coatings usually fail first in splash zones and below leaking joint. Time of wetting and the presence of water soluble chlorides would appear to be the primary contributing factors to failure in these isolated areas. Undocumented information from recent KYTC bridge painting projects, indicate the presence of elevated chloride levels in spot failures.

Using commercially available chloride testing methods, KTC assessed the chloride concentration at various locations of thirteen bridges. The areas tested were in locations where higher concentrations of chlorides would be expected (e.g. splash zones and below leaking joints). Chloride concentrations in those areas ranged from 0 to 432 µg/cm² with an average of 59 µg/cm².

Steel test panels were cleaned in the laboratory and charged with graduated concentrations of chlorides. After being contaminated, the panels were coated with high performing coatings and then subjected to 5,000 hours of accelerated weathering and evaluated for coating performance. Results of laboratory testing indicate little correlation between the chloride concentration and coating performance.
The conclusion drawn from the field measurements, laboratory testing, and the dearth of substantive literature concerning chloride impact on protective coating is that the currently available methodologies for assessing chloride levels are insufficient.
1. INTRODUCTION

Kentucky Transportation Cabinet (KYTC) roads typically receive repeated de-icing salt applications during the winter. This can result in significant chloride (i.e. soluble salt) concentrations on bridges. Superstructure elements under deck joints (including bearings and beam ends) are subjected to chloride contamination from water runoff seeping through leaking joints. Wet, salt-treated bridge decks (or underlying roadways in the case of overpass bridges) can result in airborne mists (aerosols) that can spread due to vehicle and wind generated turbulence. Those mists often contain chlorides which are subsequently deposited on exposed bridge elements including outer faces of fascia girders and splash zones of lower chord and connecting members of truss bridges. Severe chloride contamination occurring during winter months may prove extremely detrimental to winter painting projects as the chloride deposits may occur while painting operations are on-going. That thwarts most common chloride remediation efforts employed by painters and will likely result in poorer completed painting projects (compared to painting projects performed in other seasons). These surface chloride concentrations may subsequently decrease when the bridge members are flushed by spring rains.

At some bridge locations, deicing salts may infuse into crevices, permeable coatings or rust and remain unaffected by subsequent rainfall. In those cases, the retained chlorides can be hard to remove by methods commonly used to prepare bridge steel substrates for maintenance painting. If the retained chlorides are not purged from those substrates (typically consisting of abrasily blasted steel for total removal maintenance painting or existing paint and tool-cleaned exposed steel for overcoating) prior to paint application, they will prove to be problematic. Chloride contamination promotes premature coatings failure and corrosion thereby reducing the effectiveness of bridge maintenance painting projects.

In part, this study was created to address concerns about the effects of chloride contamination from winter painting. From 2004 to 2009, KYTC discontinued seasonal restrictions on bridge painting allowing contractors to paint in winter when chloride concentrations on bridges are high. However, shortly after this study was begun, KYTC officials became alarmed at significant coating deterioration and corrosion on recent winter-painted bridges. The most prominent examples were several overpass and mainline bridges along I-64 between Louisville and Frankfort. KYTC painting personnel conducted several field investigations in conjunction with KTC researchers and detected elevated chloride levels at many locations. Based on those findings, KYTC officials reinstated the seasonal restrictions on bridge painting operations obviating the need for any research related to chloride problems during winter painting operations.

Besides the winter painting issue, KYTC officials were concerned that excessive retained chlorides on bridge substrates prior to painting would reduce paint durability regardless of when painting operations occurred. KYTC officials wished to determine acceptable chloride limits on bridge steel prior to painting. This second issue became the focus of this study after KYTC eliminated the need to study the effect of chlorides on winter painting operations. Existing KYTC maintenance painting practices/specifications...
and the types of coatings systems used for bridge maintenance painting were factored into the study.

1.1 BACKGROUND

In 2002 the Kentucky Transportation Center (KTC) conducted research on chloride contamination including field measurements and actions to reduce surface chlorides including pressure washing and chemical treatments (1). That work indicated spring rainfalls were effective in flushing chlorides from exposed surfaces of bridge members. At that time, KYTC employed seasonal restrictions on bridge maintenance painting primarily intended to limit weather-related problems with coatings due to temperature and moisture. When KYTC imposed requirements for containment of structural elements during painting, contractors pressed for year-around painting. In response KYTC officials permitted that as long as atmospheric conditions within the containment were suitable for coatings application. For several years winter painting was widely used until the occurrence of the unanticipated problem of premature coatings failures. The premature coating failures may have had several contributing factors, but chloride contamination was almost certainly a prime factor. While, KYTC no longer permits winter painting, long-term performance monitoring of KYTC bridge coatings has shown that coatings often fail prematurely in areas susceptible to chloride contamination (2).

Chloride contamination is a major problem throughout the structural painting industry. For bridges, the problem is most severe in marine and more northern environments. In Kentucky, wide-spread use of deicing salts, even when bad weather is threatening, creates sufficient contamination to cause premature coatings failure and corrosion. Unfortunately chlorides may be invisible or when visible, they can be confused with concrete efflorescence. Prior to mechanical surface preparation (e.g. abrasive blast cleaning) chlorides may lie on coating surfaces, in crevices, within surface rust or on steel substrates covered by rust. Mechanical surface preparation is usually insufficient to eliminate the problem and, in many cases, exacerbates it by driving surface chlorides into pits that are difficult to remove. If enough surface chlorides remain prior to painting, they will cause premature coatings failure and corrosion. A pressing issue is determining what concentrations of surface chlorides are problematic. Another is determining a method to properly test bridge substrates to determine if they are sufficiently chloride-free to allow for proper maintenance painting. Both of these issues were to be addressed in this study.

To detect/measure retained surface chlorides, most DOTs require inspectors to perform sample tests on substrates that have been subjected to mechanical surface preparation prior to painting. Extraction tests such as the CHLOR*TEST™ and Bresle Test are used to remove surface soluble chlorides over small areas and measure their concentration (per unit area) based upon either titration or conductivity (3). Those tests extract 50 - 60 percent of the soluble chlorides (4). Specifications addressing permissible chloride surface concentrations limit them to low levels prior to painting (5 - 30 µg/cm²). KYTC maintenance painting specifications have not typically addressed chloride assessment or remediation. For remediation of surface chlorides, some bridge owners have specified the use of pressure/hot washing and/or chemical chloride stabilizers prior
to mechanical surface preparation. In a few instances, they have employed high pressure water jetting for effective chloride removal and surface preparation.

1.2 WORK PLAN

The study objectives approved by the KYTC Study Advisory Committee were:

1. Develop a reliable procedure to quantitatively charge anticipated levels of surface chlorides on coatings test panels;

2. Determine the relative effectiveness/utility of common surface chloride extraction tests;

3. Determine acceptable surface chloride levels for representative KYTC qualified coating systems using commonly specified surface preparation methods;

4. Conduct sampling of surface chloride concentrations on problem locations (e.g. under deck joints) on KYTC bridges in winter months;

5. Provide KYTC with recommendations on surface chloride tests and acceptable concentrations for representative KYTC qualified coatings systems.

Prior to the onset of this work, KTC researchers conducted a literature search to locate existing guidance for acceptable surface chloride levels, measurement, and remediation. CHLOR*TEST™ and Bresle Test were used concurrently, to measure surface chloride surface concentrations on some KYTC bridges. The resulting field data established typical chloride levels on KYTC bridges, and provided data to establish rational chloride surface contamination levels for laboratory work. Researchers then developed a method for uniformly charging known levels of chlorides on structural steel specimens of structural steel which were subsequently subjected to accelerated corrosion/weathering tests.

2. WORK ADDRESSING STUDY TASKS

2.1 SUMMARY OF LITERATURE SEARCH

Literature published over the last 20 years provided a wide variety of opinions on the service conditions to which bridge steel was subjected. A range of recommendations were provided on acceptable levels of chloride contamination on bridge substrates prior to repainting. One of the service variables is the type of exposure condition. Bridges are often grouped into the atmospheric exposure or “industrial exposure groups. In areas impacted by frequent deicing treatments, snow and ice, approximately 33 percent of the service life of a bridge may be similar to salt water immersion conditions. Much of the research conducted assumes that coatings applied in sea water immersion conditions are not relatable to those used for bridge maintenance painting.
A 1991 SSPC publication (5) recognized different bridge conditions for chloride contamination and recommended a safe chloride level of 30 µg/cm² for organic coatings in *atmospheric exposure conditions* and 10 µg/cm² for organic coatings in *immersion like zones*. A 2001 technical report (6) compiled findings from several sources with general agreement of a safe chloride contamination level of 7 to 10 µg/cm². A 2005 guidance document (7) recommended safe chloride levels of 0 - 10 µg/cm² for organic coatings in *atmospheric exposure* and 0 – 3 µg/cm² in *sea water immersion exposure*.

A review of published literature indicates that bridges in areas where de-icing chemicals are used might be considered “sea water immersion exposure” at least for the splash zones and beneath joints. KYTC typically has specified organic coatings for both new steel and maintenance coating projects, therefore the only safe levels of chlorides would be in the 0 - 10 µg/cm² range.

### 2.2 FIELD CHLORIDE MEASUREMENT ON BRIDGES

KTC researchers performed bridge surface chloride testing in KYTC District 5 (Louisville – March 2008) and District 7 (Lexington – May 2008). In most cases, the tests were performed on outer faces of fascia beam ends at bridge abutments (i.e. on top of the exposed paint) (Figure 1). These were locations where high chloride contamination could be anticipated due to leaking joints. Some of the test areas exhibited failed coatings and surface rust while the coatings were intact at others. Some tests were performed at the paint/steel substrate by carefully removing the overlying paint (Figure 2). In some instances, faint rusting was observed forming at the paint/substrate interface with no outward signs on the exposed surface of the paint (Figure 3).

To conduct the field and laboratory chloride measurements, KTC researchers used the CHLOR*TEST™ and the Bresle Test methods. Both methods employ aqueous extraction liquids to lift salts from test surfaces. The CHLOR*TEST™ method utilizes an acidic extraction solution while the Bresle Test relies on de-ionized water. The surface test area for the CHLOR*TEST™ method is approximately 9.6 cm² compared to 12.5 cm² for the Bresle Test.

The CHLOR*TEST™ method utilizes a flanged polymer sleeve to apply the extraction solution to the test surface (Figure 4). The sleeve is filled with a premeasured extraction solution prior to attachment to the test surface and the glued face of the sleeve flange is pressed against the test surface forming a water-tight seal. Once the solution is in contact with the test surface, the flexible polymer sheath/patch is manipulated for a fixed time interval to agitate the solution in contact with the test surface to promote better extraction of the existing salts (Figure 5). The solution dissolves and removes salts from the area tested, and the resulting solution is evaluated for the amount of salts. With the CHLOR*TEST™ the extract solution is transferred from the sleeve after it is detached from the test surface. The solution is poured back into its original bottle and a titration tube is placed in the solution (Figure 6). The solution is drawn up the tube by capillary action and the surface chloride level read directly off a scale marked along the side of the tube in µg/cm².
The Bresle method uses a flanged polymer patch with a glued flange similar to the one used with the CHLOR*TEST™ method to apply the extraction solution (Figure 7). A hypodermic needle is used to both charge and remove 3 mL of extraction solution from the patch (Figure 8). Once the solution is in contact with the test surface, the flexible polymer sheath/patch is manipulated for a fixed time interval to agitate the solution in contact with the test surface to promote better extraction of the existing salts (Figure 9). Once the Bresle solution is removed from the patch, a Horiba Conduct 173 Conductivity Meter was used to measure the chloride. Several drops of the solution are placed in a small receptacle in the meter (Figure 10). The meter subsequently measures the conductivity of the solution and provides readout of chloride conductivity in microsiemens per centimeter (µS/cm). Note the use of a KTC devised tool to insure patch seal on a rough pitted surface (Figure 8). The conductivity method was specified for field chloride measurements on some KYTC maintenance painting projects just prior to the onset of this study.

A comparison of the two methods can be found in SSPC TECHNOLOGY GUIDE 15 (8). Since the results are in different units, all test results in this report have been converted to µg/cm² using a conversion equation in GUIDE 15:

\[ E = \frac{0.5 \times S \times V}{A} \]

Equation 1

E is surface concentration of total chloride in µg/cm²
S is conductivity in µS/cm
V is volume of extract solution in mL
A is the test area in cm²

Chloride tests were conducted on 14 bridges in District 5 and District 7. In District 5, testing was performed on various ramps and mainline bridges on I-64 Riverside Parkway in Jefferson County, the I-64 westbound bridge over the Kentucky River in Franklin County, and the US 127 bridge over the Kentucky River also in Franklin County. In District 7, tests were performed on the US 25 bridge over Interstate 75 and on the KY 4 bridge over Lansdowne Drive. Both of those bridges were in Fayette County.

On the I-64 Riverside Parkway bridges, some chloride tests were performed on the surfaces of exposed coatings. Other tests were conducted at coating/steel substrate interfaces after careful removal of the coating just down to the top of the underlying steel (which had been abrasively blasted as part of a recent zone painting project). Chloride concentrations ranged from undetectable to 60 µg/cm². Surface chloride concentrations taken with the CHLOR*TEST™ method varied over the bridges showing no pattern relative to location on the bridge (e.g. bearing versus flange versus web). At 10 locations, surface chloride measurements and chloride measurements at the coating/steel substrate interface were both taken at the same location using the CHLOR*TEST™ method. Three of those measurements indicated higher chloride levels at the coating/steel substrate interface compared to those taken on the coating surfaces.
Chloride levels measured with the Bresle test in the same locations on the I-64 Riverside Parkway bridges indicated lower chloride concentrations, ranging from undetectable to 4 µg/cm². The Bresle test results also revealed no chloride concentration patterns on the bridges and indicated that chloride levels were higher at the coating/steel substrate interface after removal of the paint in 2 of 10 tests. It is possible that chlorides migrate through a coating and when the coating surface is subsequently flushed by rain, the surface chloride concentration may be less than that found at the coating/steel substrate interface. Chlorides may also accumulate at the coating/steel substrate interfaces over time.

Field chloride measurements on all bridges other than the I 64 Riverside Parkway were conducted using the Bresle Test and all of those were conducted on surfaces of the existing coatings. Chloride levels ranged from 2 µg/cm² to 432 µg/cm². A few test locations had undetectable/low chloride levels. The average of all field chloride tests was approximately 60 µg/cm². The results of the surface chloride tests on the bridges in Districts 5 and 7 are presented in Tables 1 thru 5. Of the 44 field chloride tests, only seven had chloride concentrations greater than 100 µg/cm².

3. LABORATORY TESTING

Laboratory tests were performed to study the impact of chloride contamination on protective coatings used by KYTC. Chloride concentration levels used in these tests were based upon the previous KTC field measurements on KYTC bridges and recommendations by KYTC coatings personnel. KTC researchers used the Bresle test method because KYTC coatings inspection personnel were using that method on maintenance painting projects in conjunction with Horiba Conduct 173 Conductivity Meters. KTC also used those meters in conducting their Bresle tests. The primary test levels chosen for laboratory evaluation were in µS/cm with the corresponding chloride concentrations (µg/cm²) determined by Equation 1. The conductivity levels and (corresponding chloride concentrations) tested ranged from: 0µS/cm (0µg/cm²) to 800µS/cm (98µg/cm²). The test panel chloride charging levels and post charging tests are reported in Table 6. The CHLOR*TEST™ test kit used titration tubes that read only to 60 µg/cm². Consequently that test could not be used to measure the highest chloride concentration level accurately.

To perform the necessary tests, 4 in x 6 x 3/16 in low-carbon steel test panels were used with one face abrasively blasted to an SSPC-VIS 1 SP5 white metal blast and a 2-4 mil anchor profile. The previously specified chloride concentrations were uniformly placed on these prepared surfaces. The chloride solution levels were obtained using 96 percent pure calcium chloride in varying quantities dissolved in de-ionized water (Table 6). To achieve the appropriate chloride concentrations on the test panels, small amounts (0.2 ml) of various calcium chloride solutions were evenly spread over the prepared faces of the test panels to provide uniform chloride concentrations. The panels were dried rapidly to remove water and prevent flash rusting. The chloride contaminated panels were then sealed in moisture proof bags to prevent rusting in storage prior to painting.
A total of six coatings systems were used for the laboratory testing. Five manufacturers provided the coatings systems. The coating systems included three zinc-based primers systems (1- three coat and 2 - two coat) and three non-zinc systems (1- two coat calcium sulfonate, 1- one coat calcium sulfonate, and 1-one coat waterborne acrylic). KYTC Division of Materials personnel sampled and analyzed the coatings to assure their conformance to manufacturer specifications. Four of the systems applied were on the KYTC List of Approved Materials (Structural Steel Coatings). The other two systems had been previously subjected to accelerated weathering/corrosion testing by KTC and had exhibited satisfactory performance. The generic coating systems tested are listed in Table 7.

To achieve high confidence in the test results, each coating system was applied to five panels at each chloride concentration. The panels were examined and the three best panels from each coatings system at each chloride level were selected for accelerated weathering/corrosion testing.

The coatings were applied per manufacturer’s recommendations at the KTC paint lab. During coating application ambient condition readings were taken periodically to ensure conformity with manufacturer requirements. All coatings were applied by spraying within the recoat time specified by the manufacturer. During painting, frequent wet film measurements were taken to ensure that the dry-film coating thicknesses would be within manufacturer requirements.

The painted panels were cured for 20-25 days at room temperature (70 – 75°F) and humidity (50 – 55%) prior to the onset of laboratory testing. Test coupons were photographed prior to testing. Measurements were taken of the initial gloss using a 60° gloss meter in conformance with ASTM D523 - 08 Standard Test Method for Specular Gloss. After curing, the panels were subjected to weathering/corrosion testing per ASTM D5894 - 05 Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet) which incorporates accelerated weathering (cyclic UV/humidity) and corrosion (cyclic condensation/evaporation).

During the accelerated weathering portion of the ASTM D 5894 test, a Q-Panel QUV Accelerated Weathering Tester was employed. A single QUV test cycle consisted of a four-hour UV exposure cycle with UVA-340 lamps set at normal irradiance at 60°C alternated with a four-hour condensation cycle at 50°C.

Corrosion tests were performed in a Q-Panel Q-Fog Cyclic Corrosion Tester. The test employed an electrolyte solution of de-ionized water with 0.05% sodium chloride, and 0.035% ammonium sulfate (by weight). A single Q-Fog test cycle consisted of a one-hour condensation of the electrolyte followed by a one-hour drying period (evaporation). Prohesion tests were performed at room temperature (approximately 20°C). Figure 11 shows test panels in the Q-Fog test chamber. Test panels were evaluated for rust through and consequently they were not scribed. The panel edges were taped to protect against premature coating failure and contamination of the evaluation area.
The test cycle began with the accelerated weathering (QUV) cyclic tests. Panels were tested in the QUVs for one-week periods (168 hours) and then moved to the (Q-Fog) chamber for a week-long test. Thereafter, the panels were alternated between the QUV and Prohesion chambers for another week-long test blocks. The tests were briefly stopped at 6-week intervals (1,008 hours) to evaluate the panels for rust through and to take photographs. The tests were run for five 6-week intervals (1,008 hours) and completed after a total of 5,040 hours of testing.

Performance of the protective coatings was evaluated using ASTM D 610 – 01/SSPC Guide to Visual Standard No. 2 Guide to Standard Method of Evaluating Degree of Rusting of Painted Steel Surfaces. Though the evaluations are subjective, panels were rated by two SSPC Bridge Coatings Inspection Certified coating inspectors who generally agreed on the ratings. The rust ratings for the test panels at each chloride charging level were averaged for each coating type at each evaluation point in the test program. An arbitrary failure rust rating of 7 was chosen. A rust rating of 7 indicates from 0.1 percent to 0.3 percent of the test surface has rusted.

4. TEST RESULTS

4.1 FIELD TESTS

Chloride tests on KYTC bridges produced significant surface chloride concentrations in splash zone areas and near leaking joints (even after spring rains). Tests on coatings surfaces revealed chloride levels as high as 432 µg/cm². At many test locations surface chloride concentrations were present in the 30 - 70 µg/cm² range.

Twenty locations on the I-64 Riverside Parkway bridges were tested for chloride levels both at the coated surface and also at the coating/steel substrate interface. At 25 percent of those locations, the chloride levels were higher at the coating/steel substrate interface than on the coating surface. The coating appeared to be intact at those test locations with no outward signs of surface distress or corrosion. In some cases, when the coating was removed down to the coating/steel substrate interface, small spots of ferrous rust were observed.

In the KTC field tests; there was general agreement between the two chloride test methods where undetectable chloride levels were indicated at the same locations. Where measurable levels of chlorides were detected, the Bresle test results were consistently lower than those obtained from the CHLOR®TEST™.

4.2 LABORATORY TESTS

Chloride test results for both test methods on the unpainted laboratory test panels charged to specific chloride levels were reasonably consistent with each other and with the
targeted chloride charging levels on the plates (Table 6). Chloride extraction from the laboratory panels for the two methods was approximately 100 percent as opposed to the 50 – 60 percent commonly reported in the literature.

Performance can generally be grouped by coating type. Coating systems with zinc primers (i.e. zinc-based coatings) tended to perform better than non-zinc coatings systems. Most test panels with zinc-based coatings had no rust through at any chloride level after 5,000 hours of testing (Figure 12). Some zinc-based coatings systems had individual panels that exhibited minor rust through at 5,000 hours, but the average ratings of all three panels were above the arbitrary failure rating of 7. One set of panels with a zinc-based coating system had two panels fail rapidly at 2,000 hours (ratings of 3 and 4). The third panel of the same set completed the 5,000-hr testing with a rating of 9. That set of panels had the highest chloride contamination level (i.e., 98 µg/cm²). While generally not falling to the failure rating of 7, the amount of rust breakthrough that did occur with zinc-based systems cannot be consistently related to chloride levels (Figures 13-15).

Non-zinc coatings systems (i.e., inhibitive and barrier coatings systems) began showing significant rust-through at 3,000 hours and failures of many test panels at 5,000 hours. However, none of the individual panels of the non-zinc based coatings systems had rust ratings lower than 6. A typical set of panels with a non-zinc coating after 5,000 hours testing is shown in Figure 16. Chloride contamination levels had no consistent relationship to coating performance for the non-zinc based coatings systems (Figures 17-19).

Rust blistering was observed predominantly at the top and bottom of the panels where moisture from the condensation cycle is trapped in mounting bracket on the QUV Weathering Tester. Also, during the tests rust blisters tended to occur early and enlarge during the tests rather than increase in number (Figure 20).

Corrosion tests on the painted test panels did not indicate a relationship between panel contamination levels and test performance (in terms of passing the tests with a condition rating greater than 7) especially for the zinc-based coatings systems. For the zinc-based systems, chloride contamination levels of 24 and 49µg/cm² performed as well as those with no chloride contamination (in terms of test survival). The non-zinc systems’ performance (in terms of surviving the tests) was less than that of the zinc-based systems for all chloride contamination levels. Generally, the non-zinc systems performed worse at higher chloride contamination levels.

5. CONCLUSIONS

As previously noted, past research indicated that spring rains were effective in removing surface chloride contamination. That was contradicted by the chloride field test values obtained in this study. High surface concentrations of chlorides may result in their permeation into porous coatings leading to elevated chloride levels at the coating/steel substrate interface. That can result in premature coatings failure and corrosion.
Obviously, rainfall cannot be relied upon to purge accumulations of winter deicing salts from bridges.

Field tests indicate some variability in the two test methods used. That may be due to: differences in chloride concentration over the test area, differences in the efficiency of the extraction mediums and variances in coatings properties that may affect chloride retrieval. Areas of bridges where CHLOR*TEST™ surface tests indicated low chloride levels in the previous KTC study subsequently failed within 6 years (8).

The two test methods appear to accurately extract and measure chloride levels in laboratory tests. That was probably due to the facts that there were no deep corrosion pits, no coatings, and the chlorides were laying on the test surface and easy to dissolve and extract. While the measurements of chloride contamination were accurate, the subsequent KTC laboratory tests that simulated field exposure of the coatings, did not consistently relate high chloride contamination levels to poor coatings performance. While the two test methods used may accurately measure chloride levels, test results and field observations reveal that they may not be reliable indicators of subsequent coating performance (which is the reason that KYTC was trying to measure chlorides on bridge painting projects).

KTC researchers have participated in numerous evaluations of coatings on KYTC bridges. Based on those observations, time of wetness (TOW) and the presence of chlorides appear to be the primary causes of coatings failures on Kentucky bridges. Under deck joints, both TOW and chloride contamination may be severe. Generally, coatings tend to degrade more rapidly at these highly stressed bridge locations than elsewhere. To address this situation, some DOTs have used zinc-based coatings systems at joint locations and barrier systems on the remainder of the bridge steel (which is subjected to lower coatings stresses). This study did not address TOW, but it needs to be considered when taking steps to extend/maximize bridge coating performance. In specifying acceptable chloride contamination levels on substrates, most industry sources do not address TOW. Based upon our test results, TOW should be given greater consideration in planning bridge painting projects.

Laboratory testing indicates that zinc-based coating systems provide better protection against corrosion than non-zinc systems when applied over chloride contaminated surfaces as seen in Figure 21. Chloride concentrations could not be directly related to the rate of corrosion or rust breakthrough failures. KTC researchers are unsure if the uniform application of the chlorides possibly contributed to this unexpected result. The uniform chloride concentration across the panels may have suppressed the formation of anodic and cathodic sites on the test panels. In any case, the testing indicated there was no clear correlation between chloride contamination and coatings performance for the test regimen. That regimen is used to test (stress) coatings for the KYTC coatings qualifications and sufficiently replicates field service at most bridge locations.

Based upon field test experience with the CHLOR*TEST™ and the Bresle Test methods and the results of the laboratory chloride contamination tests, KTC researcher
believe that a different approach needs to be used to address bridge locations where TOW and chloride contamination are problematic. The focus needs to be changed from detection and measurement of chloride levels to a knowledge-based approach of identifying bridge areas that are/or likely to be susceptible to chloride build-up, extended TOW and consequently premature coatings failure (compared to the majority of a bridge). Subsequent to that identification, chloride remediation and special coatings treatments can be used to address areas of accelerated coatings deterioration with the ultimate objective of achieving a coatings application that will wear uniformly over a bridge.

“Study objective 5. Provide KYTC with recommendations on surface chloride tests and acceptable concentrations for representative KYTC qualified coatings systems” could not be completed. Measurement of chloride contamination levels cannot be consistently related to coating performance.

6. RECOMMENDATIONS

Based upon the findings of this study, the following recommendations are provided:

1) Employ the routine maintenance practice of washing splash zones and beneath joints of bridges after snow and ice season is over. Spring rains do not provide consistent, reliable means of eliminating chloride residues on bridges from deicing salt applications. Other DOTs wash bridges and KYTC should do so as well, especially steel bridges on routes that receive heavy salt applications in winter months. A research study should be performed to investigate washing more thoroughly and develop effective washing procedures.

2) On maintenance painting projects, use commercially available chloride field test methods only to “qualitatively” assess bridges for chlorides prior to painting. Findings of this study have not shown a clear relationship between chloride contamination on blast cleaned steel and durability of the applied coatings. There is a concern about the ability of those methods to accurately assess chloride levels where deep pits may concentrate high amounts of chlorides (e.g. hot spots). We have observed localized/spot rusting initiating at the coating/substrate interface under seemingly intact coatings. Some localized failures may be due to pitting-related chloride “hot spots” but, this has not been proven.

3) Develop chloride remediation methods which may include but are not limited to pressure washing, hot water washing, steam cleaning, washing with chloride-neutralizing additives, water jetting, blast/wait/re-blast sequencing, blasting with soft/fine abrasives, electrochemical extraction or combinations of these. Those methods would be used to spot treat areas of bridges especially susceptible to chloride contamination.

4) Indentify and specify coating systems that have been tested and shown to have superior durability in accelerated coatings deterioration sites on bridges. This extended durability would include resistance to atmospheric exposure that degrades coatings, making them less protective, resistance to surface chlorides and tolerance to extended
TOW. Some work has been done in this study that indicated zinc-based coatings systems provide superior performance for total removal painting projects. Further research is needed for overcoating systems that may not employ zinc primers (e.g. active barrier coatings systems). New coating concepts need to be developed to address bridge exposures that replicate immersion service.

5) For bridge maintenance painting projects, identify areas on common bridge types that are susceptible to accelerated coatings failure due to extended TOW and chloride contamination. Provide recommendations for remediation of corroded areas, areas with high measured chlorides, and areas typically subject to high surface chloride contamination from deicing salts. Remediation would go beyond the normal abrasive blasting widely used on KYTC bridge maintenance painting projects. Provide recommendations for surface treatment of substrates at bridge locations subjected to extended TOW.

6) Develop surface preparation/coating application specifications/recommended coatings for experimental bridge maintenance painting projects incorporating this new approach to achieving enhanced coatings performance.

7. REFERENCES

Table 1. Riverside Parkway (I-64) in Louisville. *Titration tubes limited to 60 µg/cm²
<table>
<thead>
<tr>
<th>Location / Chloride Analysis</th>
<th>Bresle Test converted to µg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southbound – North Abutment (Back of Lower Diaphragm)</td>
<td>32.4</td>
</tr>
<tr>
<td>Southbound – North Abutment (Top of Bottom Flange)</td>
<td>432</td>
</tr>
<tr>
<td>Southbound – North Abutment (Plate on Bottom Flange)</td>
<td>336</td>
</tr>
<tr>
<td>Northbound – North Abutment (Angle of Bottom Member)</td>
<td>230.4</td>
</tr>
<tr>
<td>Northbound – North Abutment (Vertical Stiffener)</td>
<td>31.2</td>
</tr>
<tr>
<td>Northbound – North Abutment (Top of angled member)</td>
<td>139.2</td>
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Table 2. US 127 over KY River

<table>
<thead>
<tr>
<th>Location / Chloride Analysis</th>
<th>Bresle Test converted to µg/cm²</th>
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<tbody>
<tr>
<td>Eastbound – East Abutment (North Corner – Bottom of Rocker)</td>
<td>5.9</td>
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<tr>
<td>Eastbound – East End (South Facing Girder – Top of Bottom Flange)</td>
<td>11.8</td>
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<tr>
<td>Eastbound – East End (Vertical Stiffener at Abutment)</td>
<td>5.0</td>
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<tr>
<td>Westbound – East End (Bottom Floor Beam)</td>
<td>138.0</td>
</tr>
<tr>
<td>Westbound – East End (North Facing Girder)</td>
<td>200.0</td>
</tr>
<tr>
<td>Westbound – East End (Bottom Flange of Girder next to Abutment)</td>
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Table 3. I-64 over KY River

<table>
<thead>
<tr>
<th>Location / Chloride Analysis</th>
<th>Bresle Test converted to µg/cm²</th>
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<tbody>
<tr>
<td>Southbound – West Abutment (South Facing Beam)</td>
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</tr>
<tr>
<td>Southbound – West Abutment (South Facing Beam)</td>
<td>11.8</td>
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<tr>
<td>Southbound – West Abutment (Shoe at Beam #3)</td>
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<tr>
<td>Northbound – East Abutment (North Facing Beam)</td>
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<tr>
<td>Northbound – East Abutment (Shoe at Beam #4)</td>
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<tr>
<td>Northbound – East Abutment (South Facing Beam)</td>
<td>57.6</td>
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Table 4. US 25 over I-75
Table 5. KY 4 over Lansdowne Drive in Lexington

<table>
<thead>
<tr>
<th>Location / Chloride Analysis</th>
<th>Bresle Test converted to µg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound – West Abutment (Top of Lower Flange on Beam #3)</td>
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<td>Westbound – West Abutment (South Fascia, Top of Lower Flange on Beam #1)</td>
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<td>Westbound – West Abutment (North Fascia, Bottom of Top Flange)</td>
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<td>Eastbound – East Abutment (South Fascia, Top of Bottom Flange)</td>
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<td>Eastbound – East Abutment (Top of Bottom Flange on Beam #3)</td>
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<tr>
<td>Westbound – East Abutment (Top of Bottom Flange on Beam #3)</td>
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Table 6. Test Panels Charged with Chlorides

* solutions were lost before tests could be performed

<table>
<thead>
<tr>
<th>Test Panels Charged with Chlorides in µS/cm</th>
<th>Targeted Chlorides in µg/cm²</th>
<th>Actual Readings on Panels Using Bresle Test in µS/cm</th>
<th>Actual Readings on Panels Using in CHLOR*TEST µg/cm²</th>
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<tbody>
<tr>
<td>25</td>
<td>3</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
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<tr>
<td>100</td>
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<td>560</td>
<td>57.5</td>
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<tr>
<td>800</td>
<td>98</td>
<td>790</td>
<td>60+</td>
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Table 7. Coating systems that were applied on panels with various chloride concentrations.
9. FIGURES

Figure 1. Third Street exit ramp from I 64. Typical location of chloride testing.

Figure 2. Coating being removed to perform the CHLOR*TEST™ at the coating/steel substrate interface on the Third Street Exit Ramp of the I-64 Riverside Parkway in Louisville.
Figure 3. Rust exposed after removal of apparently sound coating (Approx. x 2 Mag.).

Figure 4. CHLOR*TEST™ sleeve with extraction solution on painted surface
Figure 5. The fluid being massaged during chloride extraction using the CHLOR*TEST™

Figure 6. Measuring CHLOR*TEST™ extraction solution with titration tube
Figure 7. Injection of De-ionized water (extraction fluid) into a Bresle Test patch.

Figure 8. The de-ionized water being extracted from the Bresle patch at the Lansdowne Drive bridge site.
Figure 9. The de-ionized water being massaged in the Bresle patch at the Lansdowne Drive bridge site.

Figure 10. The extracted fluid from the Bresle patch at the Lansdowne Drive bridge site being tested and read with a Horiba conductivity meter.
Figure 11. The chloride contaminated painted panels in the salt/fog test chamber at the University of Kentucky Transportation Center Research Lab.

Figure 12. Three panels with a zinc-based coating over a 800 $\mu$S/cm (98 $\mu$g/cm$^2$) chloride contaminated surface after 5,000 hours testing.
Figure 13. Rust rating of N system panels at various chloride concentrations.

Figure 14. Rust rating of P system panels at various chloride concentrations.
Figure 15. Rust rating of Q system panels at various chloride concentrations.

Figure 16. Three panels with a non-zinc based coating over a 800 µS/cm chloride charged surface after 5,000 hours testing.
Figure 17. Rust rating of R system panels at various chloride concentrations.

Figure 18. Rust rating of S system panels at various chloride concentrations.
Figure 19. Rust rating of T system panels at various chloride concentrations.
Figure 20. One group of three panels showing the expansion of corrosion cells as opposed to the formation of new corrosion cells.
Figure 21. Comparison of Coatings Performance at Various Chloride Contamination Levels for 5,000 Hours of ASTM D 5894 Testing.