UNIVERSITY OF KENTUCKY College of Engineering

Kentucky Transportation Center

Research Report
KTC-14-03/SPR11-424-1F
DOI: http://dx.doi.org/10.13023/KTC.RR.2014.03

Evaluation of Deterioration of Structural Concrete Due to Chloride Intrusion and Other Damaging Mechanisms

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Research Report
KTC-14-03/SPR10-406-1F

EVALUATION OF DETERIORATION OF STRUCTURAL CONCRETE DUE TO CHLORIDE INTRUSION AND OTHER DAMAGING MECHANISMS

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In cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

September 2015

<table>
<tr><td>1. Report No.
KTC-14-03/SPR10-406-1F</td><td>2.Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle Evaluation of Deterioration of Structural Concrete Due to Chloride Intrusion and Other Damaging Mechanisms</td><td>5. Report Date September 2015</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s), Sudhir Palle, Brian Howell, Theodore Hopwood II and Bobby W. Meade</td><td>8. Performing Organization Report No KTC-14-03/SPR10-406-1F</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, KY 40506-0043</td><td>10. Work Unit No. (TRAIS)</td></tr>
<tr><td>11. Contractor Grant No.
KYSPR 10-406</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Kentucky Transportation Cabinet
State Office Building
Frankfort, KY 40622</td><td>13. Type of Report and Period Covered
Final</td></tr>
<tr><td>14. Sponsoring Agency Code</td></tr>
<tr><td colspan="3">15. Supplementary Notes
Prepared in cooperation with the Kentucky Transportation Cabinet. Study Title: Evaluation of Deterioration of Structural Concrete Due to Chloride Intrusion and Other Damaging Mechanisms</td></tr>
<tr><td colspan="3">16. Abstract

Kentucky's bridges continue to age and experience distress. The intrusion of chlorides into concrete remains the primary mechanism for deterioration. It leads to reinforcing steel corrosion that damages the adjoining concrete structure. This study found problematic chloride concentrations in Kentucky concrete bridge elements (decks, pier caps, abutments). Chloride levels have been found at concentrations sufficient to initiate reinforcing steel corrosion. In some cases, chloride concentrations were sufficient to cause accelerated corrosion and produce major section loss of reinforcing steel. Advanced stages of corrosion such as these typically require costly repairs and maintenance to extend the service life of bridges.

Field inspections and laboratory analyses conducted during this study verified the ongoing problem of concrete deterioration across bridges within Kentucky's transportation network.</td></tr>
<tr><td colspan="2">17. Key Words
alkali-silica reaction, bridges, carbonation, chlorides, concrete, corrosion, deicing, deterioration, reinforcing steel, salt,</td><td>18. Distribution Statement
Unlimited with the approval of the Kentucky Transportation Cabinet</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
96

22. Price</td></tr>
</table>

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ACKNOWLEDGEMENTS

The authors would like to thank the KYTC Study Advisory Committee members who assisted on this study. They include: Kevin Sandefur, SAC Chair (Division of Bridges); Derrick Castle (Division of Materials); Trevor Booker (Division of Materials); Anne Irish (Division of Maintenance); and Jeff Smith (FHWA).

EXECUTIVE SUMMARY

The Kentucky Transportation Cabinet (KYTC) maintains an inventory of about 8,600 bridges (based on the 2012 NBI inventory), which continue to experience system-wide aging as evidenced by the approximately 53% of bridges that are over 40 years old. KYTC officials are charged with maintaining the structural and functional capacity of this existing bridge network, which is a challenging task given that the complete replacement of every aging bridge would be cost prohibitive in today's fiscally constrained environment. To this end, bridge preservation continues to serve a key role in maintaining the operational integrity of the state's bridge inventory. One of the key tenets of bridge preservation is understanding how deterioration mechanisms work and devising appropriate mitigation measures in response. For this study, Kentucky Transportation Center (KTC) researchers examined deterioration mechanisms across a sample of Kentucky bridges through field inspections and laboratory testing. Data from these observations were used to determine the potential for concrete damage on Kentucky's bridges.

KTC researchers examined three potential mechanisms for concrete deterioration of bridges – chloride intrusion, carbonation, and alkali-silica reaction (ASR). Initially, researchers surveyed KYTC district bridge maintenance officials and determined that ASR was not an issue. Cores taken from 10 KYTC bridge decks did not show indications of carbonation. After obtaining these results, KTC researchers focused the project on chloride intrusion.

Chloride intrusion occurs when anti-deicing agents are applied to roadways to prevent icing and to clear roads and bridges of ice and snow. KYTC primarily uses sodium chloride (solid and liquid) and liquid calcium chloride for anti-icing/deicing. Each of those materials can infiltrate the pores within structural (i.e. reinforced) concrete. Once intrusion occurs, the chlorides may disrupt the naturally protective layer surrounding the steel reinforcing bars (rebars) embedded in the concrete. When high concentrations of chlorides infiltrate reinforced concrete, they promote aggressive corrosion of the steel. The resulting steel corrosion products expand, which creates internal structural stresses in structural concrete that lead to spalling and cracking.

For this study, KTC researchers visually inspected 24 bridges on Interstate 65 (I-65) in downtown Louisville. They subsequently collected and tested core samples from decks and substructure elements (pier caps and abutments) of an additional 24 bridges located in Districts 4, 5, 7, 8, and 9. Visual inspections indicated deterioration on all 24 Louisville bridges including concrete cracking and spalling, efflorescence stains, exposed/corroded rebars and failed joint seals. During the field sampling and laboratory testing phase, KTC researchers collected 309 concrete powder samples from 24 bridges and analyzed them for chloride contamination levels. Laboratory test results revealed high levels of chloride contamination in many of those samples. In fact, many of the samples had chloride levels in excess of 1.2 lbs. chloride/cubic yard concrete (0.032% by weight), which is the required threshold for reinforcing steel corrosion. Sample results showed approximately 40%, 49%, and 51% of the collected samples for abutments, decks, and piers, respectively, exceeded this threshold. Nearly 19% of

abutment samples exceeded the chloride levels known to promote major section loss in reinforcing steel.

As shown in this study, chloride intrusion poses a significant challenge to the health of Kentucky's bridge infrastructure. KYTC must focus on minimizing chloride intrusion into reinforced concrete and on mitigating its detrimental effects as key components in preserving its bridge inventory.

Proposed KYTC actions for addressing chloride problems include:

1) Pre-Construction/Design Phase (New Bridges)

a) Analyze the use of porosity-reducing admixtures, low water-cement ratios, and concrete formulations to reduce permeability and reduce rates of chloride intrusion.

b) Analyze the use of stainless steel, carbon fiber, nanotechnology materials, and other non-traditional materials for use as reinforcement bars in bridge concrete structures.

c) New bridges should be sealed before the first snow and ice season.

2) Rehabilitation and Maintenance (Existing Bridges)

a) Apply deck/crack sealants to the bridge deck surface to reduce chloride intrusion.

b) Periodically (annually/biannually) clean bridges to thoroughly wash chloride residuals from the surfaces of bridge decks, pier caps, and abutments and reduce the potential for future steel corrosion.

c) Consider the use of electrochemical chloride extraction, an in-situ technique using direct current, to remove chloride within the depth of the reinforcing steel mats. In most cases, traffic will need to be rerouted for treatment of bridge decks but is not typically required for pier cap treatment.

d) Adopt the use of cathodic protection, a permanently installed system using a 'sacrificial' anode to prevent the corrosion of reinforcing steel.

3) Restoration (Existing Bridges)

a) Repair any cracks on bridges once they have been identified at the earliest available opportunity using approved crack sealants.

b) Repair any deck joint seal leakages within bridges following inspection and at the earliest available opportunity with joint sealants.

c) Repair any spalls on bridges at the earliest available opportunity and replace underlying corroded steel, if needed.

d) Resurface bridge decks with a latex modified concrete overlay to enhance concrete impermeability and decrease chloride intrusion.

1. INTRODUCTION

Deterioration of bridge concrete presents a major challenge to highway agencies. Deteriorating bridges bring increased maintenance needs, which are the result of an aging infrastructure. The Kentucky Transportation Cabinet (KYTC) is not immune to these challenges and continues to see an increase in the overall age of its bridge inventory. As of 2012, over 53% (4,580 structures) of the Kentucky Transportation Cabinet's state-maintained bridge inventory (8,599 structures) was over 40 years old (Figure 1). The number of KYTC bridges classified as structurally deficient or functionally obsolete totaled 517 (~6%) and 1,536 (~18%), respectively (1). Due to budgetary limitations, these circumstances present major challenges for KYTC because adequate funding will likely be unavailable to replace all bridges that will become structurally deficient functionally obsolete in the near future. As such, bridge preservation and maintenance will play an increasingly important role in extending bridge service lives and maintaining the integrity of the KYTC bridge inventory.

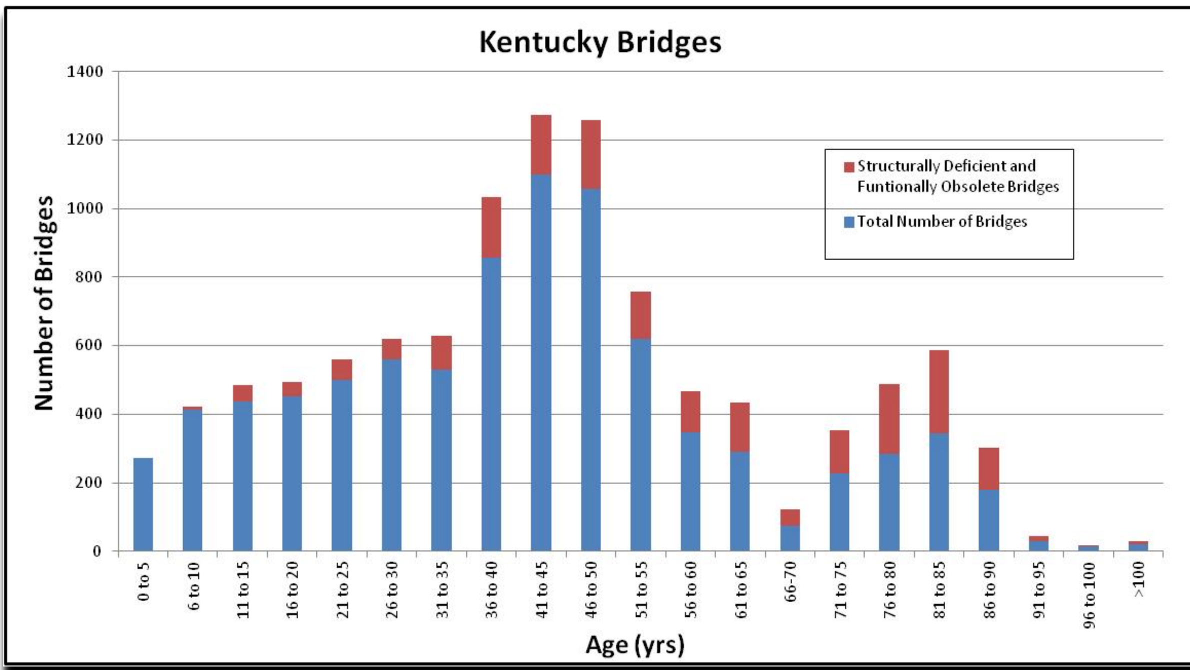

Figure 1. Kentucky Bridges by Year

As part of this study, the KYTC requested that the Kentucky Transportation Center (KTC) address several potential structural (i.e., reinforced) concrete deterioration mechanisms that can impact KYTC bridges. Those investigated were chloride intrusion, carbonation, and alkali-silica reactions. KTC researchers initially conducted interviews with bridge maintenance officials at the district level to gather information on the location and magnitude of these phenomena. After concluding these interviews, a limited number of bridges were selected for concrete sampling and follow-up laboratory testing and analysis.

1.1. BACKGROUND

Over 90 percent of the major elements (deck, superstructure and substructure) on KYTC bridges are made from structural concrete. Distress in concrete results from a variety of mechanisms, including weather-related impacts as well as chemical reactions within the concrete structure itself. Several of the common mechanisms include chloride intrusion, carbonation, and alkali-silica reactions (ASR). This study addressed the susceptibility of reinforced concrete on KYTC bridges to these types of deterioration.

The corrosion of reinforcing steel in concrete is a major problem for bridges, especially decks, piers and abutments. It is caused when conditions within the concrete change over time, leading to the onset of various chemical reactions. Fresh concrete typically has a pH that ranges from 12 to 13. The reinforcing steel placed into the alkaline concrete initially develops a passive layer that inhibits the corrosion process. However, this passive layer begins to break down and become less protective if chloride ions are present (2). Corrosion of embedded steel reinforcing bars can occur once chloride penetration or intrusion into the concrete exceeds a minimum threshold level, defined as 0.032% chloride by weight of concrete – equivalent to 1.2 lbs. chloride per cubic yard of concrete (3).

Chlorides typically enter concrete from deicing materials that are applied to prevent icing or to remove snow and ice. Traditional deicing practices consist of spreading solid salt applied to snow and ice on roadways and bridges. Salt lowers the

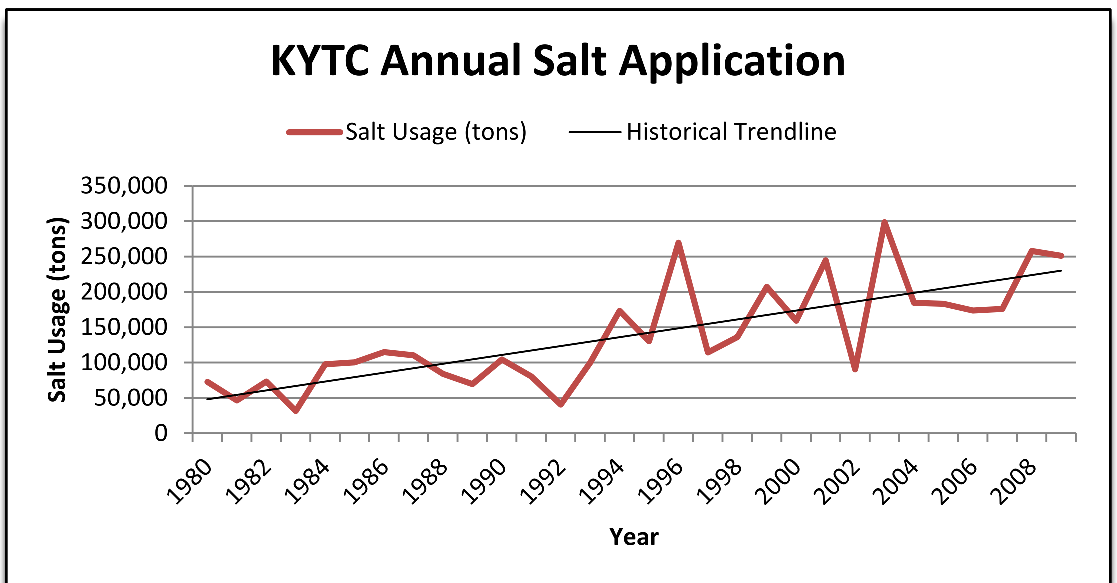

Figure 2. KYTC Annual Salt Applications

freezing point of water, facilitating the melting of snow and ice. Since 1980, KYTC has continuously increased its application of salts on roadways and bridges (Figure 2) (4).

Beginning in the 1990s, KYTC added new anti-deicing materials to its winter roadway treatment program, including salt brine and liquid calcium chloride – in addition to the traditional solid salt applications. In fact, KYTC has significantly increased its use of liquid deicing materials over the last decade (5). Figure 3 illustrates the aggregated deicing material application rates across Kentucky from fiscal year 2005 through 2013.

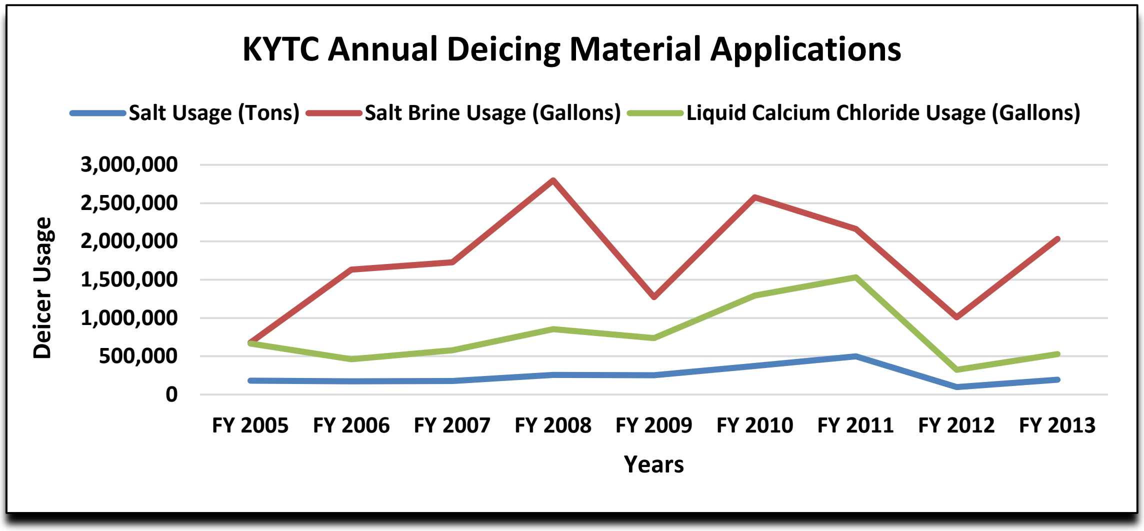

Figure 3. KYTC Annual Deicing Material Applications

The steady rise in the use of deicing materials has prompted concerns about chloride intrusion levels in bridge concrete. Any increase in chloride levels in the concrete at the level of the reinforcing steel increases the likelihood of accelerated deterioration. Additionally, the last ten years have seen the highest recorded use rates of deicing chemicals. The increase in salt (solid sodium chloride) usage has been compounded by the increased use of liquid deicing agents (Figure 3). Consequently, bridges now receive greater exposure to potential chloride intrusion than ever before, but the resulting detrimental effects may not be fully evident in the immediate future. Appendix A provides salt usage (tons) for KYTC from 1979-2009. Appendix B provides total usage of salt, salt brine (gallons) and liquid calcium chloride (gallons_ from 2004-2009 for each KYTC district.

Carbonation is another concrete deterioration mechanism that can lead to the corrosion of reinforcing steel in structural concrete. Carbonation occurs when carbon dioxide in the atmosphere permeates a concrete structure. Carbon dioxide (CO_2) reacts with calcium hydroxide ($CaCO_3$) within the concrete cement and produces calcium carbonate ($CaCO_3$). Calcium carbonate reduces the alkalinity, or pH level, within the concrete. If the pH drops below 10.0 the natural passive layer of protection for the steel reinforcing bars dissolves and facilitating the onset of reinforcing steel corrosion (Ref 2).

A third potential mechanism for concrete deterioration on KYTC bridges is alkali-silica reactions, commonly referred to as ASR. This reaction occurs when alkali hydroxides present in the cement react with certain types of aggregates containing silica materials. The reactant product formed is an alkali-silica gel that expands upon contact with water. This expansion exerts pressure within the concrete and may lead to concrete cracking and swelling. The most effective way to avoid ASR is to select aggregates without inherent reactive properties (6).

To identify what drives concrete deterioration on bridges, investigations must determine what mechanisms are present, the extent to which they are occurring, and available methods to test for their occurrence and severity. Chlorides have been applied to KYTC bridges for decades. In the early 2000s, KYTC personnel performed a limited number of chloride concentration tests on several decks of I-264 bridges at the upper reinforcing mat level. The test data indicated low chloride levels. Since then, the concentrations of chlorides in KYTC bridges had not been assessed on a widespread basis. As proactive methods of addressing concrete distress are being considered by KYTC, more complete information on chloride penetration into structural concrete (including decks) must be obtained. Current methods to evaluate the various types of distress include field sampling of concrete at the depth of the reinforcing steel and chloride extraction/measurement by laboratory analyses.

1.2 WORK PLAN

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

1. Identify the structural concrete deterioration mechanisms encountered by highway agencies and their impacts on structures. Determine effective methods for evaluating the presence/extent of concrete deterioration.

2. Acquire and become familiarized with relevant test instrumentation/tests/analyses to evaluate concrete deterioration.

3. Perform in-situ tests of bridge concrete and laboratory analyses/examination of extracted concrete specimens. Determine critical properties/concrete damage assessment of selected bridges/structures throughout Kentucky with various ages and amounts/types of distress. Tests will be performed on bridge decks, barrier walls, retaining walls, abutments, beams and piers.

4. Prepare a summary of findings and provide recommendations/guidance for extended testing and protection of bridge concrete.

The tasks that addressed the study objectives were:

<u>Task 1.</u> KTC was to conduct a literature search of the various types of concrete deterioration including those normally associated with bridges. KTC would identify procedures for testing/evaluating concrete for various types of structural concrete deterioration including chloride ingress/rebar corrosion, carbonation and alkali-silica reactions (ASR) relevant to KYTC bridges.

<u>Task 2.</u> KTC was to contact equipment manufacturers and concrete laboratories about test methods/equipment to conduct in-situ and laboratory evaluations of concrete properties and chloride penetration and nondestructive tests of concrete damage including cracking, rebar corrosion, carbonation and ASR damage. KTC was to acquire and become familiarized with relevant test instrumentation. KTC would also identify Kentucky bridges for testing.

Task 3. KTC was to acquire test equipment to perform in-situ tests of concrete properties/concrete damage assessment of selected bridges throughout Kentucky with various ages and amounts/types of distress. Tests would be performed on bridges decks, barrier walls, retaining walls, abutments, beams and piers. The work would both evaluate the tests employed and the results obtained to characterize typical bridge distress in Kentucky

Task 4. Based upon findings in Task 3, KTC was to prepare a summary of findings and provide recommendations/guidance for extended testing of bridge concrete.

Task 5. KTC was to prepare a final report to document study conclusions and provide recommendations.

2. LITERATURE REVIEW

In general, state departments of transportation (DOTs) continue to place emphasis on the maintenance of existing transportation infrastructure including bridge preservation. Consequently, numerous research studies have been conducted on bridge preservation in recent years, with a particular focus on various concrete deterioration mechanisms. Three of the most common types of concrete deterioration in bridges include chloride intrusion, carbonation, and alkali-silica reactions (ASR).

Chloride intrusion, or ingress into concrete (relevant to KYTC), typically occurs when state DOTs apply winter deicing materials. When chlorides enter porous concrete, they disrupt the passive, protective layer surrounding the steel reinforcement bars within the concrete. Over time, the breakdown of the passive layer leads to corrosion of the steel reinforcement bar. Research has established the following chloride threshold values for corrosion (7):

- 1.2 lbs. chloride/ yd^3 concrete - initiate corrosion
- 3.0 lbs. chloride/ yd^3 concrete - rapid acceleration of corrosion
- 7.0 lbs. chloride/ yd^3 concrete - major loss of steel section

Once corrosion begins, several factors work in concert with chloride intrusion to influence the rate of deterioration including temperature, humidity, moisture content and electrical resistance (Ref 3).

Chlorides are the key ingredients in several different deicing materials. Rock salts, or sodium chloride (NaCl) has traditionally been the deicing material used on roadways and bridges. However in recent years, high demand for rock salts stemming from their increased use in winter maintenance operations has produced shortages. Consequently, state DOTs have sought alternative deicing materials to add to their portfolio of deicing materials. Examples of alternative deicing materials include salt brine and liquid calcium chloride, among others. As state DOTs have increasingly shifted toward alternative forms of deicing materials, it has raised additional concerns due to their chemical characteristics. Recent studies have shown that deicing materials composed of either magnesium ions or calcium more readily react with Portland cement concrete than traditional rock salt. This may lead to an increase in expansive cracks, permeability, and loss of compressive strength (Ref. 7).

Carbonation is another mechanism through which the embedded steel reinforcement can corrode. It occurs when atmospheric carbon dioxide (CO_2) enters concrete, neutralizing its alkalinity. Similar to chlorides, this results in deterioration of the concrete's alkaline protective layer for the steel reinforcement bars leading to corrosion. Carbonation is most likely to occur during hot, humid conditions, with relative humidity around 60 percent. Other factors promoting carbonation include insufficient concrete cover above the steel reinforcement, cracks in the concrete and porous concrete (8).

An alkali-silica reaction, or ASR, is an internal reaction within concrete. The nature of this reaction is contingent upon the materials comprising its structure. ASR occurs when alkali hydroxides in cement react with silica minerals found within certain types of aggregates. This reaction forms an expansive gel that promotes cracking of the concrete. The use of non-reactive aggregate materials in concrete or limitation of alkali within the cement mixture can inhibit the process of ASR as a potential failure mechanism (Ref. 6).

3. FIELD INVESTIGATIONS

KTC researchers performed site investigations and conducted field sampling to assess concrete deterioration for a select sample of Kentucky bridges. First, researchers conducted preliminary site investigations for 24 bridges located on I-65 in the downtown Louisville area. This major interstate is one of the most heavily travelled in the state and each of these bridges represents a critical component for this high-volume corridor. The preliminary site investigations involved only visual observations and did not involve collection of concrete samples. KTC researchers discovered widespread evidence of deterioration across many of these bridges. The types of deterioration observed included cracking, spalling, efflorescence, exposed/corroded rebar, and failed joint seals. In fact, every I-65 bridge examined displayed one or more of those types of deterioration. The results from these site investigations can be seen in the pictures found within Appendix C. Samples were not collected due to the high traffic volumes on the bridges. Rather, KTC researchers decided to focus material sampling efforts on less travelled, but equally suitable, bridges experiencing the same types of distress.

During the sampling phase, KTC researchers identified five KYTC Department of Highways districts in which to conduct further analysis and selected 24 additional bridges within these districts to serve as case studies. Districts 4, 5, 7, 8, and 9 were selected. Collectively, they represented the full range of deicing material usage among all KYTC districts from high to low. Accordingly, Districts 5 and 7 had some of the highest deicing material application rates among all KYTC districts. This stems from their including the state's two largest urban areas – Louisville and Lexington. District 9 represented a middle-of-the-road tier for deicing material usage among state highway districts. At the other end, Districts 4 and 8 represented primarily rural areas and ranked consistently among the lowest users of deicing materials. KTC researchers consulted with district engineers responsible for bridge maintenance activities in each of these districts and obtained their input for bridge selection. KYTC district engineers identified bridges within their districts categorized as either priority A or priority C and provided these recommendations to KTC. Priority A and C segments represent roadways and bridges with the highest and lowest priority schedule for treatment in snow and ice removal operations, respectively. KTC researchers consolidated the recommendations from the district engineers into a single bridge list and chose 24 bridges for extracting concrete samples.

KTC researchers surveyed the district engineers all of the KYTC districts in an effort to examine concrete deterioration mechanisms of concern for Kentucky's bridges. Among the three deterioration types discussed, KYTC officials stated that chloride intrusion resulting from snow and ice removal operations was the cause of concrete deterioration on bridges. Conversely, district officials did not see evidence of carbonation or alkali-silica reactions on Kentucky's bridges and did not view either of these concrete deterioration mechanisms as a concern. As such, KTC shifted its primary focus to assessing chloride intrusion within the concrete of bridge structures. Nevertheless, KTC also conducted an analysis of carbonation deterioration mechanisms for a limited number of concrete samples. The procedures for both of these analyses are discussed further in Section 3.0 Laboratory Testing below. Aggregates used by KYTC do not typically promote ASRs. Therefore, KTC did not assess this deterioration method further.

KTC researchers obtained both powder and core concrete samples from all/some of the 24 bridges during the period of April to July 2011. In each of these cases, the samples were extracted from select locations along the bridge deck including the wheel path and drain line (i.e., near curb) as well as the substructure. Powder samples were also taken from the top horizontal surfaces of abutment seats and pier caps of most of the bridges. Appendix D includes the full list of sampling locations.

KTC researchers used a hammer drill with a one-inch drill bit to collect powder samples. At each sample location the drill was placed perpendicular to the concrete surface directly above a steel rectangular plate that had been placed flush against the concrete surface. The steel plate had a circular hole in the middle with a diameter slightly larger than the drill bit, which allowed the drill to penetrate the concrete. KTC researchers drilled through the hole to a depth approaching the KYTC specified depth for concrete cover (2 inches). Once this depth was reached, researchers extracted the concrete powder and cleaned the hole thoroughly with compressed air. Then, the researchers drilled down an additional 0.5 inch. The final 0.5-inch section was the region of interest, and the region the sample was collected from. The 0.5-inch sample consisted of concrete powder that accumulated on top of the steel plate lying on the bridge deck. Figure 4 depicts KTC researchers taking a sample from a bridge deck.

Figure 4. Drilling for Powder Sample

The concrete powder samples were placed in a sealed plastic bag, labelled for identification and taken to the laboratory for chloride analysis. KTC researchers also collected concrete core samples to test for carbonation from the decks of 10 bridges using a core drill with a 2-inch barrel. KTC researchers wanted to take cores from the pier caps and abutments as well including samples from vertical surfaces, but were not able to do so with the available equipment. A pachometer was used to locate the steel reinforcement and cores were taken 3 inches deep unless steel reinforcements were encountered. Each of these core samples was sealed inside a plastic bag and labeled before transporting them to the laboratory.

3. LABORATORY TESTING

KTC researchers conducted laboratory tests on the concrete samples, both powder and core, to determine the amount of chloride contamination and carbonation present, respectively. For the powder samples, KTC researchers employed the Germann Rapid Chloride Test (RCT) to determine the amount of acid-soluble chlorides in the hardened concrete. This test provides very similar results to standard titration methods such as AASHTO T260 (Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials), the industry-accepted practice for testing of chlorides in concrete. Various laboratories in Europe and the United States – including the Federal Highway Administration – have conducted tests on chloride-contaminated concrete samples using both the RCT and AASHTO T260 and produced similar results. In fact, the Rapid Chloride Test has been shown to have an average deviation of ± 4% to known chloride concentrations in concrete. Therefore, KTC researchers determined the Rapid Chloride Test represented a scientifically viable and useful proxy for AASHTO T260 and was employed in this study. For a more detailed comparison of RCT and AASHTO T260, refer to Appendix E. The RCT test method was followed with the exception that the powder samples were mixed with the premeasured extraction solution and stored overnight (at least 12 hours) to ensure 100% chloride extraction for the follow-on measurement procedure (9).

To test for carbonation, KTC researchers employed the Germann Instruments Rainbow Indicator Test. This test determines the pH level within a fresh cut concrete sample or core. Core samples were cut in half to expose a fresh surface and then sprayed with the Rainbow Indicator solution. The ensuing color change indicated the pH of the cement (Figure 5).

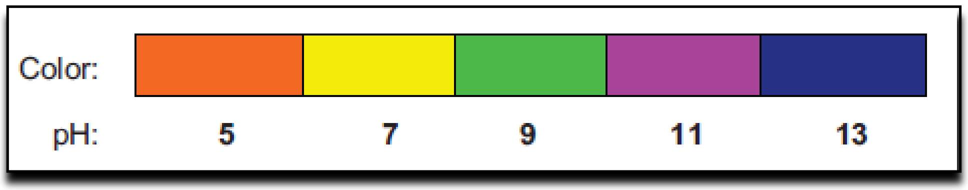

Figure 5. Rainbow Indicator Concrete Color and pH (Provided by Germann)

KTC researchers extracted 11 core concrete samples from 10 of the 24 test bridge decks. The samples were taken to the laboratory and wiped free of dust and sediment. They were split vertically by saw cutting immediately before testing. Each of the samples received a uniform spray application of the Rainbow Indicator across the freshly cut surface. After a prescribed 30-minute dwell period, the concrete samples were visually examined for changes in the cement color. The color scale in Figure 5 was used to determine the pH of each sample.

4. TEST RESULTS

The Rapid Chloride Test results for the concrete samples confirmed the presence of chlorides in the bridges tested. As has been described in numerous publications, the following chloride concentration levels in concrete are known to corrode the reinforcing steel:

- Initiate corrosion: 1.2 lb. chloride / cubic yard concrete = 0.032% by weight
- Accelerate corrosion: 3.0 lb. chloride / cubic yard concrete = 0.079% by weight
- Cause major section loss: 7.0 lb. chloride / cubic yard concrete = 0.184% by weight

In total, KTC researchers collected and tested 309 concrete samples from the 24 bridges. The samples were extracted from locations along the wheel paths and drain lines (near curb) on bridge decks as well as the abutments and piers. Chloride intrusion was detected in each of the bridge elements tested ranging from non-problematic concentrations to those that could cause major section loss in the reinforcing steel. The results for each bridge are provided in tables in Appendix D. The complete chloride field sample results are shown in the graph in Appendix F. On average, the abutments exhibited the highest concentrations of chlorides in the concrete. The maximum, minimum, and average chloride levels for each element are provided in Table 1 below.

	Deck	Abutment	Pier
Maximum	0.188	0.752	0.118
Minimum	0.004	0.003	0.004
Average	0.045	0.088	0.043

Table 1. Chloride % by Concrete Weight

Over 52 % of the concrete samples had chloride concentrations sufficient to initiate reinforcing steel corrosion (or cause more severe damage). Bridge elements on which corrosion had initiated – but had not yet reached levels that would cause advanced stages of corrosion included: 33.3% of deck wheel paths (39 of 117 samples), 30.1% of deck drain lines (28 of 93 samples), 16.7% of abutments (12 of 72 samples) and 40.7% of pier caps (11 of 27 samples).

Chloride levels exceeding the accelerated corrosion stage (0.079% by weight) and major section loss stage (0.184% by weight) were also encountered in significant numbers. Obviously, these corrosion levels have a greater capacity to cause severe infrastructure damage over time and consequently, represent the areas of greatest concern. Bridge elements exhibiting an accelerated level of corrosion – but not yet major section loss – ranged from 11.1% for pier caps (3 of 27 samples) and 11.8% for deck drain lines (11 of 93 samples) to a high of 21.4% for the deck wheel paths (25 of 117 samples). The highest levels of chloride intrusion were found in samples collected from abutments. Nearly 20% of the total samples (14 of 72 samples) taken from abutments exceeded the chloride level threshold associated with major section loss. In Table 2 and Figure 6 below, the chloride levels for each of the bridge section types are shown along with a chart that represents the corresponding corrosion stage baselines, respectively.

	Total	Initiate Corrosion (0.032% ≤ x < 0.079%)	% of Samples	Accelerated Corrosion (0.079% ≤ x < 0.184%)	% of Samples	Major Section Loss (> 0.184%)	% of Samples
Deck (Wheel Path)	117	39	33.3%	25	21.4%	0	0%
Deck (Drain Line)	93	28	30.1%	11	11.8%	1	1.1%
Abutment	72	12	16.7%	3	4.2%	14	19.4%
Pier Caps	27	11	40.7%	3	11.1%	0	0%

Table 2. Chloride Levels by Bridge Element Type

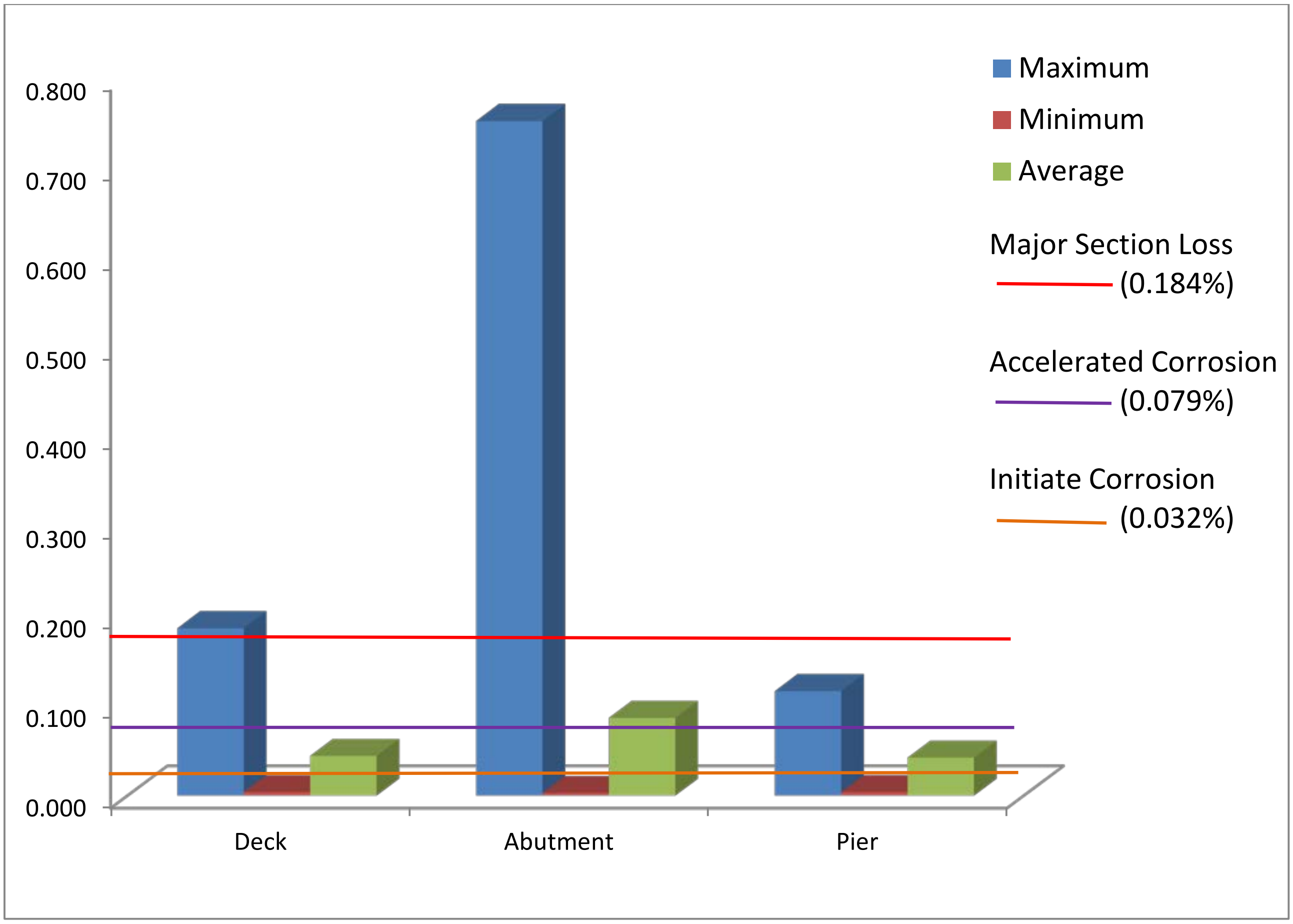

Figure 6. Chloride Percentages (Max., Min., Avg.) and Corrosion Baselines

The carbonation tests yielded 10 concrete core samples all with pH levels of 11 or higher. Consequently, the process of carbonation did not occur in the samples analyzed within this study. It should be noted that the cores were taken from bridge decks that contain more impermeable concrete than the piers or abutments and that only horizontal deck surfaces were tested. Specimens from substructure locations would be better choices for evaluating carbonation. The resulting carbonation test results are contained in the sample pictures found in Appendix G in comparison with the color/concrete pH chart in Figure 5.

5. CONCLUSIONS

This research study revealed that deterioration of concrete structures in bridges remains an ongoing problem for most of Kentucky's bridges. It primarily occurs due to the intrusion of chlorides, which leads to the onset of reinforcing steel corrosion. The severity of chloride intrusion varies by bridge element type with abutments showing higher chloride concentrations in concrete at the reinforcing mat level. That probably relates to leaking deck joints. In some cases, chlorides may already be causing significant levels of reinforcing steel corrosion. In advanced stages, expanding corrosion products from reinforcing steel produce visible damage in the concrete cover. Upon conducting the visual inspections of the I-65 bridges in Louisville, KTC researchers observed damage to the concrete cover on all of the 24 bridges they inspected.

Chloride content analysis of concrete cover at specific depths is commonly performed to determine whether chloride contamination is present in harmful concentrations at the level of the reinforcing steel mat prior to the onset of visible corrosion damage. When visible damage is detected, the effects of corrosion are already well advanced severely limiting the usefulness of preventive treatment options such as sealants.

The field sampling/chloride analyses of bridge concrete, indicated that chloride-induced corrosion of reinforcing steel in concrete could pose a widespread maintenance problem to KYTC in the next 10-15 years. Nearly half of the samples had chloride contents at the depth of the upper reinforcing steel mat that could result in reinforcing steel corrosion. It should be noted that nearly all of the samples were taken at locations that didn't have significant visible concrete distress or patching. The bridge deck chloride content tests from the combination of wheel path and drainage line samples, indicated the potential for initial stages of corrosion in 32% of the sample locations, and the potential for accelerated corrosion in another 17% of the sample locations. That is, nearly half of all bridge deck samples (49%) had sufficient chloride contents in the concrete that would initiate corrosion the underlying reinforcing steel in the foreseeable future. Similarly, the percentage of pier cap samples with chloride levels sufficiently high to initiate or accelerate corrosion were 41% and 11%, respectively.

In both the pier caps and bridge decks, major section loss of the steel reinforcement bars did not appear to be an issue (yet) as neither group showed more than 1% of their respective samples reaching the required threshold. However, samples collected from the bridge abutments demonstrated the highest levels of chloride intrusion and consequently, the most severe deterioration. Nearly 19% of the abutment samples contained chloride levels associated with major section loss of steel, a chloride level requiring 7.0 lb. chloride/cubic yard concrete or 0.184% by weight. This level of deterioration represents the most severe stage of corrosion degradation. Most likely, the abutment samples' tendency to experience higher levels of corrosion than bridge deck samples may be explained due to their location under leaking deck joints and their composition (more permeable concrete than used in bridge decks), which enables higher rates of chloride intrusion. On the other hand, bridge pier caps also use a concrete-grade mix similar to abutments, but those investigated in this study experienced less severe levels of corrosion. This may be explained by abutment structures' greater ability to experience lateral movement than pier caps (in the form of expansion joints). This establishes additional pathways for increased chloride exposure as snow and ice melts during deicing operations.

KTC researchers conducted an analysis across a cross-section of districts, each with different rates of deicing material usage. Districts 4 and 8 displayed low levels of usage; Districts 5 and 7 displayed high levels of usage; and District 9 constituted a middle tier between the two groups. Although the district with the highest rate of usage (District 7) had with the highest number of samples with corrosion (~71%), a direct correlation between the rate of deicing material application and level of corrosion could not be ascertained from this limited analysis due to several mitigating factors. First, the limited sample size of this study was not statistically sufficient to infer general corrosion characteristics with respect to the total population of bridges within the districts. Second, and more importantly, interviews conducted with KYTC officials yielded insights into present deicing material application practices and limitations in their ability to quantify use rates. In many cases, officials stated that deicing dump truck operators would increase the deicing material rate of application when driving across bridge decks. In these cases, truck operators had the ability to press a button and increase the spreader's application rate. They would do this frequently when travelling across bridge decks. However, quantifying this increased rate of application, the frequency at which it occurs, and the starting and stopping points for increased output (as the spreader moves across the bridge deck) could not be determined. Thus, our ability to quantify the amount of deicing materials applied to individual bridges (or by district) is limited. Nevertheless, this study revealed that elevated chlorides negatively impact bridges by promoting corrosion of the reinforcing steel (decks, pier caps and abutments). That was observed in all five KYTC districts studied.

6. RECOMMENDATIONS

Kentucky has thousands of bridges in its inventory spanning a wide range of ages and various levels of serviceability. In this same context, different deterioration treatment solutions are most appropriate for specific periods in a bridge's life cycle. Consequently, KTC recommends a comprehensive, solutions-based portfolio approach for adoption within the KYTC bridge preservation program. This toolbox of solutions should be tailored to Kentucky's bridges on a case-by-case basis and rely on long-term cost analyses, engineering studies, and other assessments, as required by KYTC. We hereby recommend the following solutions:

1) Pre-Construction/Design Phase (New Bridges)

a) Analyze the use of porosity-reducing admixtures, low water-cement ratios, and concrete formulations to reduce permeability and reduce rates of chloride intrusion.

b) Analyze the use of stainless steel, carbon fiber, nanotechnology materials, and other non-traditional materials for use as reinforcement bars in bridge concrete structures.

c) New bridges should be sealed before the first snow and ice season.

2) Rehabilitation and Maintenance (Existing Bridges)

a) Apply deck/crack sealants to the bridge deck surface to reduce chloride intrusion. Deck sealants should meet KYTC-designated acceptance criteria and project performance standards prior to selection. KYTC should employ industry-wide best practices to test deck sealant performance, as needed. This may include common acceptance tests, such as AASHTO T259, ASTM C642, and NCHRP 244 Series II. Any deck sealant will need to be applied strictly in accordance with the manufacturer's recommendations and reapplied as specified by the manufacturer. Deck sealants should only be applied to bridge decks not yet displaying signs of corrosion to maximize effectiveness, (i.e. those containing less than 1.2 lb. chloride / cubic yard concrete [or 0.032% by chlorides weight by concrete weight]).

b) Periodically clean bridges to thoroughly wash chloride residuals from the surfaces of bridge decks, pier caps, and abutments and reduce the potential for future steel corrosion. Cleaning should occur on an annual or semi-annual basis. This treatment is most effective at removing chlorides on the concrete surface, while reducing the potential for future ingress of chlorides and subsequent deterioration of the reinforcement steel. However, this treatment will not remove chlorides already within the concrete.

c) Consider the use of electrochemical chloride extraction, an in-situ technique using direct current, to remove chloride within the depth of the reinforcing steel mat and typically lasting anywhere from 4 to 8 weeks. In most cases, traffic will need to be rerouted for treatment of bridge decks but is not typically required for pier cap treatment.

d) Adopt the use of cathodic protection, a permanently installed system using a 'sacrificial' anode to prevent the corrosion of reinforcing steel. This system requires routine, periodic maintenance but does not impact traffic patterns on the bridge. According to NCHRP Report 398 (2009), recent surveys coupled with an NBI analysis revealed that 20 states reported the use of cathodic protection systems including Arizona, California, Colorado, Connecticut, Florida, Illinois, Indiana, Iowa, Maryland, Missouri, New York, North Carolina, Oregon, Pennsylvania, South Dakota, Texas, Utah, Vermont, Virginia, and Washington.

3) Restoration (Existing Bridges)

a) Repair any cracks on bridges once they have been identified at the earliest available opportunity using approved crack sealants.

b) Repair any deck joint seal leakages within bridges following inspection and at the earliest available opportunity with joint sealants. Joint sealants should meet KYTC-designated acceptance criteria and project performance standards prior to selection. KYTC should employ industry-wide best practices in testing joint sealant performance. Any joint sealant should be applied in strict accordance with the manufacturer's recommendations and reapplied as specified by the manufacturer.

c) Repair any spalls on bridges at the earliest available opportunity and replace underlying corroded steel, if needed.

d) Resurface bridge decks with a latex modified concrete overlay to enhance concrete impermeability and decrease chloride intrusion.

7. REFERENCES

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8. APPENDIX A – STATEWIDE SALT USAGE REPORT

Kentucky Transportation Cabinet (Statewide)
July 1, 1979 - June 30, 2009 (Usage in Tons)

Year	Usage	Year	Usage	Year	Usage
1980	72,837	1990	104,412	2000	159,282
1981	46,401	1991	80,288	2001	244,979
1982	73,275	1992	40,804	2002	90,678
1983	31,595	1993	100,013	2003	298,815
1984	97,593	1994	173,104	2004	184,746
1985	100,397	1995	130,317	2005	183,360
1986	114,932	1996	269,589	2006	173,715
1987	110,355	1997	114,491	2007	175,987
1988	84,234	1998	135,959	2008	257,956
1989	69,711	1999	207,031	2009	251,248

9. APPENDIX B – KYTC DISTRICT SALT AND LIQUID CHLORIDES USAGE REPORT

Kentucky Transportation Cabinet (by District)
July 1, 2004 - June 30, 2009

District	Salt Usage	Salt Brine Usage	Liquid Calcium Chloride Usage
One	61,457 Tons	1,291,831 Gallons	194,665 Gallons
Two	67,401 Tons	965,554 Gallons	334,096 Gallons
Three	55,813 Tons	502,940 Gallons	190,027 Gallons
Four	69,157 Tons	152,965 Gallons	162,811 Gallons
Five	124,329 Tons	689,735 Gallons	488,751 Gallons
Six	188,292 Tons	1,009,984 Gallons	258,257 Gallons
Seven	134,201 Tons	1,662,584 Gallons	462,112 Gallons
Eight	51,911 Tons	335,763 Gallons	152,749 Gallons
Nine	93,375 Tons	398,372 Gallons	286,538 Gallons
Ten	68,479 Tons	285,010 Gallons	341,593 Gallons
Eleven	53,140 Tons	545,484 Gallons	91,615 Gallons
Twelve	74,710 Tons	267,700 Gallons	338,887 Gallons
Total	1,042,266 Tons	8,107,921 Gallons	3,302,099 Gallons

*** Based on the OMS System Reports.**

10. APPENDIX C - CONCRETE CONDITION OF I-65 BRIDGES IN LOUISVILLE AREA

During Long Term Monitoring of bridge coating conditions some attention was given to the condition of concrete bridge elements as well. There are several bridges that show varying degrees of deterioration. Some of which should warrant further investigation. The following is a brief description and photos of bridges on I-65 in the Louisville area beginning just north of the Watterson Expressway at Phillips Lane and continuing to just south of the I-65/64 interchange at E. Main St. The photos show transverse cracking on decks and joint seal failures that provide a path for chlorides to wreak havoc on pier caps and abutments causing failure of bearings and staining.

Figure 7. I-65 over Phillips Lane, Transverse cracking and efflorescence on bottom of deck

Figure 8. I-65 over Phillips Lane, Transverse cracking on the deck, efflorescence, staining on back wall (note failed joint seal)

Figure 9. I-65 over Manning Street, Joint seal failure #1

Figure 10. I-65 over Manning Street, Joint seal failure #2

Figure 11. I-65 over Manning Street, Cracking and efflorescence on bottom of deck

Figure 12. I-65 over Manning Street, Cracking and efflorescence on bottom of deck

Figure 13. I-65 over East Entrance to KY Fair & Expo Center, Transverse cracking with evidence of efflorescence

Figure 15. I-65 over East Entrance to KY Fair & Expo Center, Joint failure

Figure 14. I-65 over East Entrance to KY Fair & Expo Center, Spalling and exposed rebar

Figure 16. I-65 over East Entrance to KY Fair & Expo Center, Cracking on back wall (possible spalling repair)

Figure 17. I-65 over Fairgrounds entrance from Bradley Ave., Large pieces of concrete from back wall near joint seal area

Figure 19. I-65 over Fairgrounds entrance from Bradley Ave., Joint seal failure and cracking

Figure 18. I-65 over Fairgrounds entrance from Bradley Ave., Joint seal area

Figure 20. I-65 over Fairgrounds entrance from Bradley Ave., Joint seal failure (lying on abutment)

Figure 21. I-65 over Crittenden Drive, Staining from leaking joint seal

Figure 22. I-65 over Crittenden Drive, Joint seal failure

Figure 23. I-65 over Crittenden Drive, Deterioration at longitudinal joint between the north and south bound bridges

Figure 24. I-65 over Crittenden Drive, Deterioration at longitudinal joint between the north and south bound bridges

Figure 25. I-65 over Southern Railway (northwest of Crittenden), Transverse and longitudinal efflorescence

Figure 26. I-65 over Southern Railway (northwest of Crittenden), Transverse and longitudinal efflorescence

Figure 27. I-65 over Eastern Parkway, Joint seal failure

Figure 28. I-65 over Eastern Parkway, Deterioration adjacent to joint

Figure 29. I-65 over Eastern Parkway, Pier cap deterioration

Figure 30. I-65 over Eastern Parkway, Pier cap deterioration

Figure 31. I-65 over East Burnett Ave., East Hill St., & CSX RR; Deterioration of the abutment seats #1

Figure 282. I-65 over East Burnett Ave., East Hill St., & CSX RR; Deterioration of the abutment seats #2

Figure 293. I-65 over East Burnett Ave., East Hill St., & CSX RR; Abutement deterioration with spalling and exposed rebar

Figure 315. I-65 over East Burnett Ave., East Hill St., & CSX RR; Piers show evidence of staining from leaking joint

Figure 304. I-65 over East Burnett Ave., East Hill St., & CSX RR; Abutment deterioration with uneven settling

Figure 326. I-65 over East Burnett Ave., East Hill St., & CSX RR; Several areas cracking and spalling with exposed rebar

Figure 337. I-65 over East Ormsby Ave., Large amount of debris created due to missing joint seal

Figure 38. I-65 over East Ormsby Ave., Transverse cracking on bottom of deck

Figure 39. I-65 over East Ormsby Ave.; Cracking, spalling, and exposed rebar on pier #1

Figure 40. I-65 over East Ormsby Ave.; Cracking, spalling, and exposed rebar on pier #2

Figure 41. I-65 over Oak St.; Rust staining, deteriorating concrete, and exposed rebar #1

Figure 42. I-65 over Oak St.; Rust staining, deteriorating concrete, and exposed rebar #2

Figure 43. I-65 over Oak St.; Joint seal failure

Figure 344. I-65 over Oak St.; Numerous small cracks on bottom of deck

Figure 355. I-65 over S. Floyd St., Cracking and efflorescence on bottom of deck

Figure 366. I-65 over S. Floyd St., Staining on back wall and abutment

Figure 377. I-65 over E. Saint Catherine St., Staining of back wall and abutment

Figure 48. I-65 over E. Saint Catherine St., Transverse deck cracking and efflorescence

Figure 49. I-65 over E. Kentucky St. and S. Brooke St., Spalling and exposed rebar

Figure 381. I-65 over E. Kentucky St. and S. Brooke St., Severe spalling #1

Figure 50. I-65 over E. Kentucky St. and S. Brooke St., Spalling and exposed rebar

Figure 52. I-65 over E. Kentucky St. and S. Brooke St., Severe spalling #2


Figure 53. I-65 over Caldwell St., Abutment seat deterioration


Figure 54. I-65 over Caldwell St., Evidence of failing joint seal


Figure 55. I-65 over Caldwell St., Transverse cracking and efflorescence #1


Figure 396. I-65 over Caldwell St., Transverse deck cracking and efflorescence #2


Figure 57. I-65 over College St., Spalling, exposed rebar and joint failure


Figure 58. I-65 over College St., Deck joint seal failure


Figure 59. I-65 over E. Jacobs St., Broadway, and E. Gray St.; Drain and joint seal leaking #1


Figure 60. I-65 over E. Jacobs St., Broadway, and E. Gray St.; Drain and joint seal leaking with spalling of concrete

Figure 61. I-65 over E. Jacobs St., Broadway, and E. Gray St.; Joint failure

Figure 62 I-65 over E. Jacobs St., Broadway, and E. Gray St.; Leaking joint seal, damaged drain, and exposed rebar

Figure 63. I-65 over Muhammad Ali Blvd. and S. Brooke St., Staining on abutment and piers

Figure 64. I-65 over Muhammad Ali Blvd. and S. Brooke St., Spalling and exposed rebar

Figure 65. I-65 over Muhammad Ali Blvd. and S. Brooke St.; Staining, cracking, and spalling

Figure 66. I-65 over Muhammad Ali Blvd. and S. Brooke St., Cracking, spalling, and efflorescence on pier

Figure 67. Access ramp from S. 1st St. to I-65 South, Cracks and efflorescence on abutment #1

Figure 68. Access ramp from S. 1st St. to I-65 South, Cracks and efflorescence on abutment #2

Figure 69. Access ramp from S. 1st St. to I-65 South, Cracking and efflorescence on bottom of deck #1

Figure 401. I-65 over S. Floyd St., Cracking and efflorescence of bottom of deck #1

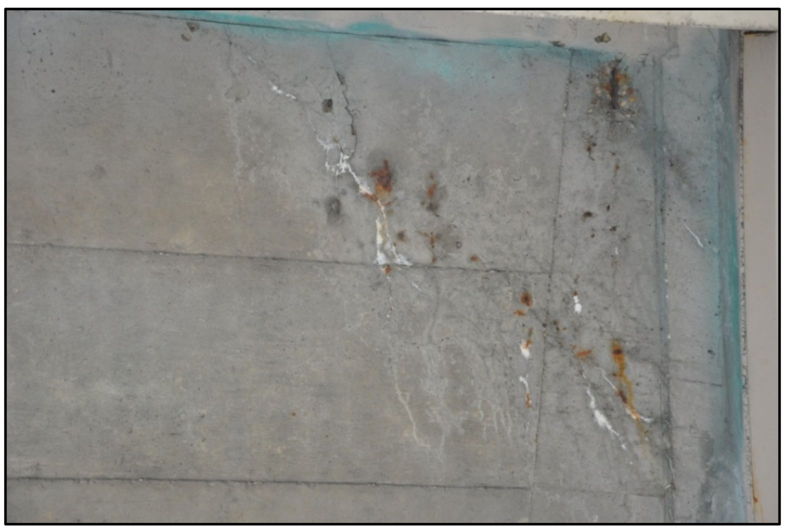


Figure 70. Access ramp from S. 1st St. to I-65 South, Cracking and efflorescence on bottom of deck #2

Figure 72. I-65 over S. Floyd St., Cracking and efflorescence of bottom of deck #2

Figure 73. I-65 over S. Floyd St., Cracking and efflorescence

Figure 74. I-65 over S. Floyd St., Cracking and staining

Figure 75. I-65 over Liberty St.; Staining, spalling, exposed rebar, and efflorescence #1

Figure 76. I-65 over Liberty St.; Staining, spalling, exposed rebar, and efflorescence #2


Figure 77. I-65 over Liberty St.; Cracked concrete


Figure 79. I-65 access ramp over Liberty St., Joint seal failure with cracking and staining


Figure 78. I-65 over Liberty St.; Joint seal failure


Figure 80. I-65 access ramp over Liberty St., Leaking seals

Figure 81. I-65 access ramp over Liberty St., Spalling and exposed rebar

Figure 82. I-65 access ramp over Liberty St., Minor spalling and exposed rebar

Figure 83. I-65 over Preston St. and Jefferson St., Staining of abutment wall

Figure 84. I-65 over Preston St. and Jefferson St., Spalling and exposed rebar

Figure 85. I-65 over Preston St. and Jefferson St., Spalling and exposed rebar #1

Figure 86. I-65 over Preston St. and Jefferson St., Spalling and exposed rebar #2

Figure 87. I-65 over S. Jackson St., Staining and cracking

Figure 88. I-65 over S. Jackson St., Abutment deterioration

Figure 89. I-65 over S. Jackson St., Cracking and efflorescence on bottom of deck #1

Figure 410. I-65 over S. Jackson St., Cracking and efflorescence on bottom of deck #2

Figure 91. I-65 over E. Market St., Cracking and exposed rebar on abutment #1

Figure 92. I-65 over E. Market St., Cracking and exposed rebar on abutment #2

Figure 93. I-65 over E. Market St., Cracking and efflorescence on bottom of deck #1

Figure 94. I-65 over E. Market St., Cracking and efflorescence on bottom of deck #2

Figure 95. I-65 over E. Main St., Staining on piers

Figure 96. I-65 over E. Main St., Spalling and exposed rebar

Figure 97. I-65 over E. Main St., Deterioration at joint area #2 (notice patch over conduit)

11. APPENDIX D – SAMPLING FROM BRIDGE SITES

District 4

Bridge: #014B00020N
Route: KY 737 over Rough River
County: Breckinridge

Observation and Comments: This is a two-lane bridge with guard rails at each end. There is very little traffic and the speed limit is 55 mph. There is no shoulder and very little slope to the deck. The abutments are easily accessible but the pier caps are over water and cannot be reached without other equipment. The coating on the steel portion of this bridge is in poor condition. Nine concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass 35', 36', and 37' from the north end and 9' from the curb, three samples were taken in the drain path 55', 56' and 57' from the north end and 9' from the curb, and three samples were taken at the abutment under the north end. A table displaying the site sample locations and chloride concentrations along with site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	35 ft. from north end, 4 ft. from curb (wheel path)	0.1213
2	36 ft. from north end, 4 ft. from curb (wheel path)	0.0860
3	37 ft. from north end, 4 ft. from curb (wheel path)	0.0791
4	55.5 ft. from north end, 9 ft. from curb (drain path)	0.0774
5	57 ft. from north end, 9 ft. from curb (drain path)	0.0969
6	58.5 ft. from north end, 9 ft. from curb (drain path)	0.0718
7	North End Abutment	0.0684
8	North End Abutment	0.0721
9	North End Abutment	0.0528

Table 3. Bridge #014B00020N Chloride Samples

Bridge: #043B00026R
Route: Western KY Pkwy over KY 187
County: Grayson

Observation and Comments: These bridges have two lanes each in the east and west bound directions. There is moderate traffic with a speed limit of 70 mph. There are 4' shoulders and the west end of the deck is slightly elevated on both bridges. The abutments are easily accessible but the pier caps cannot be reached without other equipment. The bridges are total concrete. Nine concrete powder samples were taken on the east end of the west bound fast lane at 2", 4", and 6" depths. No pictures were taken of these bridges because they were added to the list by the district after initial evaluation had been completed. A table displaying the site sample locations and chloride concentrations along with the site location are shown below.

Sample Number	Sample Location	Chloride % by Weight* Concrete
1	6 ft. from barrier wall, 12.5 ft. from East end (2" depth)	0.0051
2	6 ft. from barrier wall, 12.5 ft. from East end (4" depth)	0.0036
3	6 ft. from barrier wall, 12.5 ft. from East end (6" depth)	0.0038
4	6 ft. from barrier wall, 12 ft. from East end (2" depth)	0.0111
5	6 ft. from barrier wall, 12 ft. from East end (4" depth)	0.0062
6	6 ft. from barrier wall, 12 ft. from East end (6" depth)	0.0037
7	6 ft. from barrier wall, 11.5 ft. from East end (2" depth)	0.0071
8	6 ft. from barrier wall, 11.5 ft. from East end (4" depth)	0.0038
9	6 ft. from barrier wall, 11.5 ft. from East end (6" depth)	0.0040

Table 4. Bridge #043b00026R Chloride Samples

Bridge: #047B00116N
Route: KY 1868 over Nolin River
County: Hardin

Observation and Comments: This is a two-lane concrete bridge. There is very little traffic and the speed limit is 55 mph. There is no shoulder and no slope to the deck. The abutments are easily accessible but the pier caps are over water and cannot be reached without other equipment except for the two pier caps on each end. Twelve concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass and three samples at the drain line at 104' from the west end of the bridge. Three samples were taken at the west end abutment and three samples were taken at the west end pier cap. Also, one 2" core was taken in the wheel pass on the west end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	114 ft. from West end, 8.75 ft. from barrier wall (EB lane)	0.0222
2	115 ft. from West end, 8.75 ft. from barrier wall (EB lane)	0.0092
3	116 ft. from West end, 8.75 ft. from barrier wall (EB lane)	0.0164
4	116 ft. from West end, 9 ft. from barrier wall	0.0155
5	117 ft. 9 in from West end, 9 ft. from barrier wall	0.0110
6	119 ft. 3 in from West end, 9 ft. from barrier wall	0.0162
7	West end Abutment (EB side)	0.0413
8	West end Abutment (EB side)	0.0608
9	West end Abutment (EB side)	0.0540
10	Pier cap, First pier from West end under EB lane	0.0198
11	Pier cap, First pier from West end under EB lane	0.0176
12	Pier cap, First pier from West end under EB lane	0.0225

Table 5. Bridge #047B00116N Chloride Samples

Bridge: #090B00012L (WB) & #090B00012R (EB)
Route: Bluegrass Pkwy over KY 52 (Both Directions)
County: Nelson

Observation and Comments: These concrete bridges have two lanes each in the east and west bound directions. There is moderate traffic with a speed limit of 70 mph. There are 4' shoulders on both bridges. The abutments are easily accessible but the pier cap is inaccessible without a ladder. Fifteen concrete powder samples were taken for testing of chloride levels on the east end of the west bound bridge. Three samples each were taken in the wheel pass at 2" depths and 6" depths at the same location. Three samples each were taken in the drain line at 2" depths and 6" depths at the same location. Three samples were taken at the abutment. Twelve powder concrete samples were taken for testing of chloride levels on the east end of the east bound bridge. Three samples were taken in the wheel pass, three samples in the drain line, three samples at the abutment, and three samples on the pier cap. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	16 ft. from East end, 12.5 ft. from curb	0.1105
2	15 ft. from East end, 12.5 ft. from curb	0.1041
3	14 ft. from East end, 12.5 ft. from curb	0.1412
4	16 ft. from East end, 12.5 ft. from curb (6" depth)	0.0327
5	15 ft. from East end, 12.5 ft. from curb (6" depth)	0.0322
6	14 ft. from East end, 12.5 ft. from curb (6" depth)	0.0334
7	28 ft. from East end, 10" from curb	0.1493
8	29 ft. from East end, 10" from curb	0.0843
9	30 ft. from East end, 10" from curb	0.0836
10	28 ft. from East end, 10" from curb (6" depth)	0.0274
11	29 ft. from East end, 10" from curb (6" depth)	0.0284
12	30 ft. from East end, 10" from curb (6" depth)	0.0282
13	East end Abutment	0.0435

14	East end Abutment	0.0238
15	East end Abutment	0.0253

Table 6. Bridge #090B00012L Chloride Samples (WB)

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	8 ft. from East end, 7 ft. from curb (wheel path @ Left. Ln)	0.0299
2	9 ft. from East end, 7 ft. from curb (wheel path @ Left. Ln)	0.0967
3	10 ft. from East end, 7 ft. from curb (wheel path @ Left. Ln)	0.0446
4	8 ft. from East end, 9" from curb (drain path @ Left. Ln)	0.0284
5	9 ft. from East end, 9" from curb (drain path @ Left. Ln)	0.0208
6	10 ft. from East end, 9" from curb (drain path @ Left. Ln)	0.0159
7	East end Abutment	0.5108
8	East end Abutment	0.7522
9	East end Abutment	0.3425
10	East end pier	0.0298
11	East end pier	0.0279
12	East end pier	0.0214

Table 7. Bridge #090B00012R Chloride Samples (EB)

Bridge: #090B00029N

Route: KY 49 over Bluegrass Pkwy
County: Nelson

Observation and Comments: This is a two lane concrete bridge. There is very little traffic and the speed limit is 55 mph. The shoulder is raised approximately 2' and there is no slope to the deck. The abutments are easily accessible and the pier caps are accessible from the Bluegrass Parkway. Nine concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 35', 36' and 37' from the north end of the bridge and 6' – 8" from the curb. Three samples were taken in the drain line at 55', 56', and 57' from the north end of the bridge and 1' from the curb. Also, three samples were taken at the north end abutment. A 2" core was taken in the wheel pass on the north end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	35 ft. from North end, 9 ft. from curb (wheel path)	0.0120
2	36 ft. from North end, 9 ft. from curb (wheel path)	0.0073
3	37 ft. from North end, 9 ft. from curb (wheel path)	0.0668
4	50 ft. from North end, 1 ft. from curb (drain)	0.1063
5	51 ft. from North end, 1 ft. from curb (drain)	0.0744
6	52 ft. from North end, 1 ft. from curb (drain)	0.1045
7	North end Abutment (NB)	0.0751
8	North end Abutment (NB)	0.2116
9	North end Abutment (NB)	0.1296
10	Center Pier, West end	0.0387
11	Center Pier, West end	0.0735
12	Center Pier, West end	0.0380

Table 8. Bridge #090B00029N Chloride Samples

District 5

Bridge: #056B00062L
Route: I-71 SB over Chamberlin Lane
County: Jefferson

Observation and Comments: This is a two lane bridge with a latex overlay. There is heavy traffic and the speed limit is 70 mph. There is an 8' shoulder on the bridge and very little slope to the deck. It is a single span over a road with easy access to the abutments and pier caps. Twelve concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 18', 19' and 20' and 13' from the curb on the south end of the bridge. Three samples were taken in the drain line at 18', 19', and 20' and 1' from the curb on the south end of the bridge. Three samples were taken at the abutment and three samples were taken on a pier cap on the north end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	18 ft. from South end, 13 ft. from curb (wheel path)	0.0602
2	19 ft. from South end, 13 ft. from curb (wheel path)	0.0821
3	20 ft. from South end, 13 ft. from curb (wheel path)	0.0400
4	18 ft. from South end, 1 ft. from curb (drain)	0.0108
5	19 ft. from South end, 1 ft. from curb (drain)	0.0074
6	20 ft. from South end, 1 ft. from curb (drain)	0.0120
7	SB North Abutment	0.0078
8	SB North Abutment	0.0088
9	SB North Abutment	0.0093
10	SB North end Pier	0.1183
11	SB North end Pier	0.0992
12	SB North end Pier	0.0691

Table 9. Bridge #056B00062L Chloride Samples

Bridge: #056B00062R
Route: I-71 NB over Chamberlin Lane
County: Jefferson

Observation and Comments: This is a two lane bridge with a latex overlay. There is heavy traffic and the speed limit is 70 mph. There is an 8' shoulder on the bridge and very little slope to the deck. It is a single span over a road with easy access to the abutments and pier caps. Twelve concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 23', 24' and 25' and 13' from the curb on the south end of the bridge. Three samples were taken in the drain line at 23', 24', and 25' and 1' from the curb on the south end of the bridge. Three samples were taken at the abutment and three samples were taken on a pier cap on the north end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown on the following page.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	23 ft. from South end, 13 ft. from curb (wheel path)	0.0255
2	24 ft. from South end, 13 ft. from curb (wheel path)	0.0279
3	25 ft. from South end, 13 ft. from curb (wheel path)	0.0274
4	23 ft. from South end, 1 ft. from curb (drain)	0.0173
5	24 ft. from South end, 1 ft. from curb (drain)	0.0082
6	25 ft. from South end, 1 ft. from curb (drain)	0.0087
7	NB North Abutment	0.0084
8	NB North Abutment	0.0104
9	NB North Abutment	0.0144
10	NB North end Pier	0.0246
11	NB North end Pier	0.0597
12	NB North end Pier	0.0251

Table 10. Bridge #05600062R Chloride Samples

Bridge: #093B00023N
Route: KY 1315 over Floyds Creek
County: Oldham

Observation and Comments: This is a two lane bridge with a latex overlay. Traffic is light and the speed limit is 55 mph. There is no shoulder on the bridge and no slope to the deck. It is over a creek with easy access to the abutments and pier caps. Twelve concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 24', 25' and 26' and 4' from the curb on the south end of the bridge. Three samples were taken on the drain line at 32', 33' and 34' and 1' from the curb on the south end of the bridge. Three samples were taken on a pier cap and three samples were taken at the north end abutment. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	24 ft. from South end, 4 ft. from curb	0.0080
2	25 ft. from South end, 4 ft. from curb	0.0590
3	26 ft. from South end, 4 ft. from curb	0.0092
4	32 ft. from South end, 1 ft. from curb	0.0303
5	33 ft. from South end, 1 ft. from curb	0.0142
6	34 ft. from South end, 1 ft. from curb	0.0196
7	North end Abutment	0.2000
8	North end Abutment	0.2256
9	North end Abutment	0.1788
10	North end Pier	0.0688
11	North end Pier	0.0637
12	North end Pier	0.0339

Table 11. Bridge #093B00023N Chloride Samples

Bridge: #108B00015N
Route: KY 1060 over Plum Creek
County: Spencer

Observation and Comments: This is a two lane bridge with light traffic and a speed limit of 35 mph. There is no shoulder on the bridge and no slope to the deck. It is over a creek with easy access to the abutments and pier caps. Twelve concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 47', 79' and 84' and 3' from the curb on the south end of the bridge. Three samples were taken on the drain line at 47', 79' and 84' and 1' from the curb on the south end of the bridge. Three samples were taken on a pier cap and three samples were taken at the north end abutment. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	47 ft. from South end, 3 ft. wheel path	0.0263
2	79 ft. from South end, 3 ft. wheel path	0.0045
3	83 ft. from South end, 3 ft. wheel path	0.0045
4	47 ft. from South end, 1 ft. from gutter line	0.0062
5	79 ft. from South end, 1 ft. from gutter line	0.0162
6	83 ft. from South end, 1 ft. from gutter line	0.0123
7	North end Abutment	0.0146
8	North end Abutment	0.0223
9	North end Abutment	0.0122
10	North end Pier 1	0.0864
11	North end Pier 1	0.0610
12	North end Pier 1	0.0142

Table 12. Bridge #108B00015N Chloride Samples

District 7

Bridge: #034B00028L (EB) & #034B00028R (WB)
Route: KY 4 (New Circle) over Tates Creek (Both Directions)
County: Fayette

Observation and Comments: These concrete bridges have two lanes each in the east and west bound directions. There is heavy traffic with a speed limit of 55 mph. There are small shoulders on both bridges and virtually no slope to the decks. The abutments are easily accessible as are the pier caps. Twelve concrete powder samples were taken for testing of chloride levels on the outer loop of KY 4 (EB). Three samples were taken in the wheel pass at 29', 30' and 31' and 6' from the curb. Three samples were taken in the drain line at 29', 30' and 31' and 1' from the curb. Three samples were taken at the abutment and on a pier cap. All samples were taken from the Nicholasville Road (US 27) end of the bridge. Nine concrete powder samples were taken for testing of chloride levels on the inner loop of KY 4 (WB). Three samples were taken in the wheel pass at 23', 24' and 25' and 7' from the curb. Three samples were taken in the drain line at 23', 24' and

25’ and 1’ from the curb. Three samples were taken at the abutment with no samples taken on the pier due to safety concerns. All samples were taken from the Nicholasville Road (US 27) end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	29 ft. from West end, 6 ft. from curb	0.067
2	30 ft. from West end, 6 ft. from curb	0.054
3	31 ft. from West end, 6 ft. from curb	0.060
4	29 ft. from West end, 1 ft. from curb	0.056
5	30 ft. from West end, 1 ft. from curb	0.188
6	31 ft. from West end, 1 ft. from curb	0.024
7	West end Pier	0.004
8	West end Pier	0.005
9	West end Pier	0.004
10	West end Abutment	0.338
11	West end Abutment	0.325
12	West end Abutment	0.350

Table 13. Bridge #034B00028L Chloride Samples (EB)

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	23 ft. from West end, 7 ft. from curb	0.117
2	24 ft. from West end, 7 ft. from curb	0.089
3	25 ft. from West end, 7 ft. from curb	0.118
4	23 ft. from West end, 1 ft. from curb	0.051
5	24 ft. from West end, 1 ft. from curb	0.028
6	25 ft. from West end, 1 ft. from curb	0.039
7	West end Abutment	0.485
8	West end Abutment	0.339
9	West end Abutment	0.211

Table 14. Bridge #034B00028R Chloride Samples (WB)

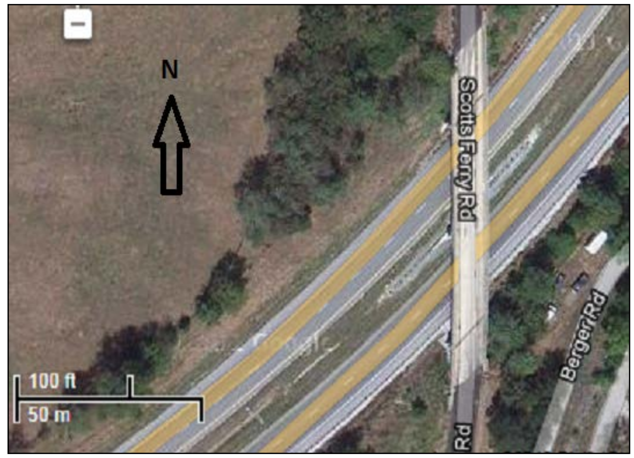

E New Circle Rd
4
4
4
N
1974
4
E New Circle Rd
4
50 ft
20 m
1974

Bridge: #120B00026N
Route: Scott Ferry Rd over Bluegrass Pkwy
County: Woodford

Observation and Comments: This is a two lane bridge with light traffic and a speed limit of 55 mph. There is no shoulder on the bridge and a slope on the deck from north to south. It is over the Bluegrass Parkway with easy access to the abutments and pier cap. Nine concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 63', 64' and 65' and 5' from the curb on the south end of the bridge. Three samples were taken on the drain line at 63', 64' and 65' and 1' from the curb on the south end of the bridge. Three samples were taken on the south end abutment. A 2" core sample was taken 59' from the south end of the bridge. No samples were taken on the pier cap due to safety issues concerning the use of a ladder for access. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	63 ft. from South end, 5 ft. from curb	0.078
2	64 ft. from South end, 5 ft. from curb	0.098
3	65 ft. from South end, 5 ft. from curb	0.110
4	63 ft. from South end, 1 ft. from curb	0.013
5	64 ft. from South end, 1 ft. from curb	0.045
6	65 ft. from South end, 1 ft. from curb	0.033
7	South end Abutment	0.051
8	South end Abutment	0.046
9	South end Abutment	0.063

Table 15. Bridge #120B00026N Chloride Samples



Bridge: #011B00038L
Route: US 127 over Norfolk Southern Rail
County: Boyle

Observation and Comments: This is a two lane steel bridge. There is heavy traffic and the speed limit is 55 mph. There are very large shoulders and the deck slopes and tilts. The abutments are easily accessible but the pier caps are over heavy vegetation. Nine concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass, three samples at the drain line and three samples at the abutment. All samples were taken on the north end of the bridge. No samples were taken at the piers due to safety concerns.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	3 ft. from North end, 13.5 ft. from curb (wheel path)	0.0727
2	4 ft. from North end, 13.5 ft. from curb (wheel path)	0.0489
3	5 ft. from North end, 13.5 ft. from curb (wheel path)	0.0724
4	3 ft. from North end, 1 ft. from curb (drain)	0.0087
5	4 ft. from North end, 1 ft. from curb (drain)	0.0043
6	5 ft. from North end, 1 ft. from curb (drain)	0.0052
7	North end Abutment	0.1624
8	North end Abutment	0.2049
9	North end Abutment	0.2075

Table 16. Bridge #011B00038L Chloride Samples

Bridge: #040B00029N
Route: KY 1355 over Sugar Creek
County: Garrard

Observation and Comments: This is a two lane bridge with very little traffic and a speed limit of 55 mph. There are small shoulders and there is no slope to the deck. The access to the abutments and the piers are difficult due to steep slopes, vegetation and water. Twelve concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 12', 13' and 14' and 4' from the curb. Three samples were taken on the drain line at 12', 13' and 14' and 1' from the curb. These six samples were taken from the west end of the bridge. Three samples were taken at the abutment on the east end of the bridge and three samples were taken on the pier cap. Two 2" cores were taken at 3" depths on the east end of the bridge. One sample was taken over a crack on the deck and the other in the wheel pass. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown on the following page.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	12 ft. from West end, 4 ft. from curb (wheel path)	0.0653
2	13 ft. from West end, 4 ft. from curb (wheel path)	0.0235
3	14 ft. from West end, 4 ft. from curb (wheel path)	0.0350
4	12 ft. from West end, 1 ft. from curb (drain)	0.0489
5	13 ft. from West end, 1 ft. from curb (drain)	0.0378
6	14 ft. from West end, 1 ft. from curb (drain)	0.0644
7	East end Abutment	0.0090
8	East end Abutment	0.0083
9	East end Abutment	0.0101
10	South end Center Pier	0.0491
11	South end Center Pier	0.0596
12	South end Center Pier	0.0297

Table 17. Bridge #040B00029N Chloride Samples

Bridge: #040B00030N
Route: KY 1355 over Sugar Creek W. Fork
County: Garrard

Observation and Comments: This is a two lane bridge with very little traffic and a speed limit of 55 mph. There are small shoulders and there is no slope to the deck. The access to the abutments and the piers are difficult due to steep slopes, vegetation and water. Nine concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 2', 3' and 4' and 4' from the curb. Three samples were taken on the drain line at 2', 3' and 4' and 1' from the curb. Three samples were also taken at the abutment. A 2" core sample at a 3" depth was also taken. All samples were taken on the east end of the bridge. No samples were taken from the pier cap due to safety concerns using a ladder at this location. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	2 ft. from East end, 4 ft. from curb (wheel path)	0.1043
2	3 ft. from East end, 4 ft. from curb (wheel path)	0.1569
3	4 ft. from East end, 4 ft. from curb (wheel path)	0.0617
4	2 ft. from East end, 1 ft. from curb (drain)	0.0696
5	3 ft. from East end, 1 ft. from curb (drain)	0.0917
6	4 ft. from East end, 1 ft. from curb (drain)	0.0574
7	East end Abutment	0.0044
8	East end Abutment	0.0039
9	East end Abutment	0.0048

Table 18. Bridge #040B00030N Chloride Samples

District 8

Bridge: #100B00074R (EB) & #100B00074L (WB)
Route: Cumberland Pkwy over Fishing Creek (Both Directions)
County: Pulaski

Observation and Comments: These steel bridges have two lanes each in the east and west bound directions. There is heavy traffic with a speed limit of 55 mph. There are small shoulders on both bridges and virtually no slope to the decks. The abutments are easily accessible as are the pier caps. Fifteen concrete powder samples were taken for testing of chloride levels in the east bound lane. Three samples were taken in the wheel pass at 22', 23' and 24' and 6' from the curb. Three samples were taken in the drain line at 22', 23' and 24' and 1' from the curb and three samples were taken at the abutment. Samples in this group were taken from the west end of the bridge. Three samples were taken in the wheel pass at 30', 31' and 32' and 6' from the curb. Three samples were taken in the drain line at 30', 31' and 32' and 1' from the curb. Samples in this group were taken from the east end of the bridge.

Fifteen powder concrete powder samples were taken for testing of chloride levels in the west bound lane. Three samples were taken in the wheel pass and three samples were taken in the drain line. Samples in this group were taken from the west end of the bridge. Three samples were taken in the wheel pass at 30', 31' and 32' and 6' from the curb. Three samples were taken in the drain line at 30', 31' and 32' and 1' from the curb and three samples were taken at the abutment. Samples in this group were taken from the east end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

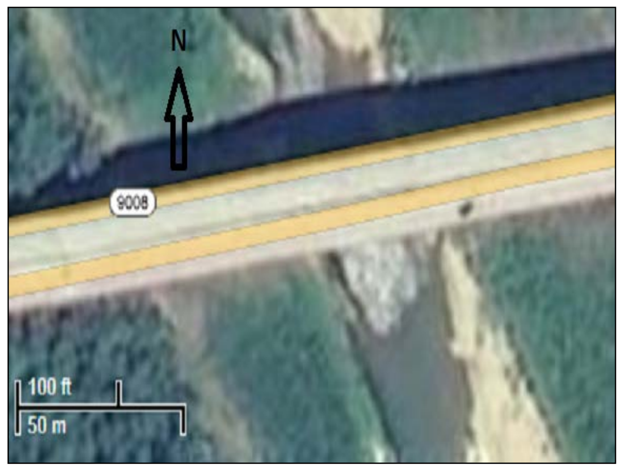
Sample Number	Sample Location	Chloride % by Concrete Weight*
1	22 ft. from West end, 6 ft. from curb (wheel path)	0.0060
2	23 ft. from West end, 6 ft. from curb (wheel path)	0.0079
3	24 ft. from West end, 6 ft. from curb (wheel path)	0.0082
4	22 ft. from West end, 1 ft. from curb (drain)	0.0186

5	23 ft. from West end, 1 ft. from curb (drain)	0.0135
6	24 ft. from West end, 1 ft. from curb (drain)	0.0301
7	West end Abutment	0.0479
8	West end Abutment	0.0299
9	West end Abutment	0.0307
10	30 ft. from East end, 6 ft. from curb (wheel path)	0.0154
11	31 ft. from East end, 6 ft. from curb (wheel path)	0.0224
12	32 ft. from East end, 6 ft. from curb (wheel path)	0.0197
13	30 ft. from East end, 1 ft. from curb (drain)	0.0231
14	31 ft. from East end, 1 ft. from curb (drain)	0.0121
15	32 ft. from East end, 1 ft. from curb (drain)	0.0176

Table 19. Bridge #100B00074R Chloride Samples (EB)

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	34 ft. from West end, 5.5 ft. from curb (wheel path)	0.0592
2	35 ft. from West end, 5.5 ft. from curb (wheel path)	0.0316
3	36 ft. from West end, 5.5 ft. from curb (wheel path)	0.0205
4	34 ft. from West end, 1 ft. from curb (drain)	0.0291
5	35 ft. from West end, 1 ft. from curb (drain)	0.0427
6	36 ft. from West end, 1 ft. from curb (drain)	0.0271
7	East end Abutment	0.0232
8	East end Abutment	0.0106
9	East end Abutment	0.0170
10	7 ft. from East end, 6 ft. from curb (wheel path)	0.0541
11	8 ft. from East end, 6 ft. from curb (wheel path)	0.0553
12	9 ft. from East end, 6 ft. from curb (wheel path)	0.0546
13	7 ft. from East end, 1 ft. from curb (drain)	0.0342
14	8 ft. from East end, 1 ft. from curb (drain)	0.0242
15	9 ft. from East end, 1 ft. from curb (drain)	0.0330

Table 20. Bridge #100B00074L Chloride Samples (WB)



Bridge: #100B00019N
Route: KY 192 over Pitman Creek
County: Pulaski

Observation and Comments: This is a two lane bridge with light traffic and a speed limit of 55 mph. There are small shoulders and there is no slope to the deck. The abutments are easy to access while there is no access to the piers. Fifteen concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 10', 11' and 12' and 5' from the curb. Three samples were taken on the drain line at 10', 11' and 12' and 1' from the curb. Three samples were also taken at the abutment. These nine samples were taken from the east end of the bridge. Six samples were also taken from the west end of the bridge. Three samples were taken on the wheel pass at 10', 11' and 12' and 6' from the curb. Three samples were taken on the drain line at 10', 11' and 12' and 1' from the curb. No samples were taken from the piers. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown on the following page.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	10 ft. from East end, 5 ft. from curb (wheel path)	0.0618
2	11 ft. from East end, 5 ft. from curb (wheel path)	0.0225
3	12 ft. from East end, 5 ft. from curb (wheel path)	0.0658
4	10 ft. from East end, 1 ft. from curb (drain)	0.0808
5	11 ft. from East end, 1 ft. from curb (drain)	0.0655
6	12 ft. from East end, 1 ft. from curb (drain)	0.0872
7	10 ft. from West end, 1 ft. from curb (drain)	0.0413
8	11 ft. from West end, 1 ft. from curb (drain)	0.0436
9	12 ft. from West end, 1 ft. from curb (drain)	0.0379
10	10 ft. from West end, 6 ft. from curb (wheel path)	0.0387
11	11 ft. from West end, 6 ft. from curb (wheel path)	0.0513
12	12 ft. from West end, 6 ft. from curb (wheel path)	0.0414
13	East end Abutment	0.0045
14	East end Abutment	0.0034
15	East end Abutment	0.0061

Table 21. Bridge #100B00019N Chloride Samples

Bridge: #100B00055N
Route: KY 1003 over Buck Creek
County: Pulaski

Observation and Comments: This is a two lane bridge with light traffic and a speed limit of 55 mph. There are small shoulders and there is no slope to the deck. The abutments are easy to access while there is no access to the piers. Fifteen concrete powder samples were taken on this bridge for testing of chloride levels. Three samples were taken on the wheel pass at 17', 18' and 19' and 4' from the curb. Three samples were taken on the drain line at 17', 18' and 19' and 1' from the curb and three samples at the abutment on the north end of the bridge. Six samples were also taken from the south end of the bridge. Three samples were taken on the wheel pass at 10', 11' and 12' and 4' from the curb. Three samples were taken on the drain line at 10', 11' and 12' and 1' from the curb. No samples were taken from the piers. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	10 ft. from South end, 4 ft. from curb (wheel path)	0.0799
2	11 ft. from South end, 4 ft. from curb (wheel path)	0.1076
3	12 ft. from South end, 4 ft. from curb (wheel path)	0.1000
4	10 ft. from South end, 1 ft. from curb (drain)	0.0214
5	11 ft. from South end, 1 ft. from curb (drain)	0.0582
6	12 ft. from South end, 1 ft. from curb (drain)	0.0309
7	17 ft. from North end, 4 ft. from curb (wheel path)	0.1311
8	18 ft. from North end, 4 ft. from curb (wheel path)	0.0799
9	19 ft. from North end, 4 ft. from curb (wheel path)	0.1368
10	17 ft. from North end, 1 ft. from curb (drain)	0.0796
11	18 ft. from North end, 1 ft. from curb (drain)	0.0730
12	19 ft. from North end, 1 ft. from curb (drain)	0.0746
13	End Abutment	0.0153
14	End Abutment	0.0096
15	End Abutment	0.0091

Table 22. Bridge #100B00055N Chloride Samples

District 9

Bridge: #103B00029N
Route: KY 1722 over I-64
County: Rowan

Observation and Comments: This is a two lane bridge with very little traffic. There are small shoulders and there is no slope to the deck. There is access to the east end abutment only. Piers are easily accessible but would need some other equipment to reach them due to the bridge being over I-64. Fifteen concrete powder samples were taken on this bridge for testing of chloride levels. Six samples were taken from the west end of the bridge, six samples were taken from the east end of the bridge and three samples were taken from the east end abutment. Measurements of the location of the sample points were not taken. No samples were taken on the piers. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	11 ft. from South end, 4.5 ft. from curb (wheel path)	0.026
2	12 ft. from South end, 4.5 ft. from curb (wheel path)	0.024
3	13 ft. from South end, 4.5 ft. from curb (wheel path)	0.027
4	11 ft. from South end, 1 ft. from curb	0.017
5	12 ft. from South end, 1 ft. from curb	0.021
6	13 ft. from South end, 1 ft. from curb	0.018
7	15 ft. from North end, 1 ft. from curb	0.086
8	16 ft. from North end, 1 ft. from curb	0.051
9	17 ft. from North end, 1 ft. from curb	0.116
10	North Abutment Footer	0.005
11	North Abutment Footer	0.013
12	North Abutment Footer	0.006

Table 23. Bridge #103B00029N Chloride Samples

Bridge: #006B00064N
Route: KY 1325 over Flat Creek
County: Bath

Observation and Comments: This is a two lane bridge with very little traffic. The bridge has a large deck and with very little slope. There is easy access to the abutments. There is no access to the piers due to their height and being over water. Fifteen concrete powder samples were taken on this bridge for testing of chloride levels. Six samples were taken from the south end of the bridge in the wheel pass at 10', 11' and 12' and 12' from the curb and in the drain line at 10', 11' and 12' and 1' from the curb. Three samples were taken at the abutment at the same end of the bridge. Six samples were taken from the north end of the bridge in the wheel pass at 4', 5' and 6' and 14' from the curb and in the drain line at 24', 25' and 26' and 1' from the curb. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown on the following page.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	4 ft. from North end, 14 ft. from curb (wheel path)	0.0098
2	5 ft. from North end, 14 ft. from curb (wheel path)	0.0689
3	6 ft. from North end, 14 ft. from curb (wheel path)	0.0420
4	24 ft. from North end, 1 ft. from curb (drain)	0.0232
5	25 ft. from North end, 1 ft. from curb (drain)	0.0306
6	26 ft. from North end, 1 ft. from curb (drain)	0.0361
7	South end Abutment	0.0113
8	South end Abutment	0.0166
9	South end Abutment	0.0132
10	10 ft. from South end, 12 ft. from curb (wheel path)	0.0201
11	11 ft. from South end, 12 ft. from curb (wheel path)	0.0214
12	12 ft. from South end, 12 ft. from curb (wheel path)	0.0201
13	10 ft. from South end, 1 ft. from curb (drain)	0.1316
14	11 ft. from South end, 1 ft. from curb (drain)	0.0785
15	12 ft. from South end, 1 ft. from curb (drain)	0.1195

Table 24. Bridge #006B00064N Chloride Samples

Bridge: #081B00049N
Route: KY 11 over Strodes Rd and TTI Rail
County: Mason

Observation and Comments: This is a two lane bridge with moderate traffic. The bridge has a large deck and with very little slope. There is easy access to the abutments. There is no access to the piers. Fifteen concrete powder samples were taken on this bridge for testing of chloride levels. Six samples were taken from the south end of the bridge in the wheel pass at 30', 31' and 32' and 12' from the curb and in the drain line at 30', 31' and 32' and 1' from the curb. Six samples were taken from the north end of the bridge in the wheel pass at 10', 11' and 12' and 13'- 6" from the curb and in the drain line at 10', 11' and 12' and 1' from the curb. Three samples were taken at the abutment at the same end of the bridge. Also, a 2" core sample was taken at the north end of the bridge at a 3" depth. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	10 ft. from North end, 13.5 ft. from curb (wheel path)	0.0244
2	11 ft. from North end, 13.5 ft. from curb (wheel path)	0.0503
3	12 ft. from North end, 13.5 ft. from curb (wheel path)	0.0169
4	10 ft. from North end, 1 ft. from curb (drain)	0.0125
5	11 ft. from North end, 1 ft. from curb (drain)	0.0124
6	12 ft. from North end, 1 ft. from curb (drain)	0.0199
7	North end Abutment	0.0101
8	North end Abutment	0.0103
9	North end Abutment	0.0106
10	30 ft. from South end, 12 ft. from curb (wheel path)	0.0492
11	31 ft. from South end, 12 ft. from curb (wheel path)	0.0903
12	32 ft. from South end, 12 ft. from curb (wheel path)	0.0751
13	30 ft. from South end, 1 ft. from curb (drain)	0.0280
14	31 ft. from South end, 1 ft. from curb (drain)	0.0165
15	32 ft. from South end, 1 ft. from curb (drain)	0.0110

Table 25. Bridge #081B00049N Chloride Samples

Bridge: #081B00065N
Route: KY 9 over TTI Rail
County: Mason

Observation and Comments: This is a two lane bridge with heavy and a speed limit of 55 mph. The bridge has wide shoulders and a slope to the deck. There is easy access to the abutments and no access to the piers. Fifteen concrete powder samples were taken on this bridge for testing of chloride levels. Six samples were taken from the south end of the bridge in the wheel pass at 5', 6' and 7' and 13'- 6" from the curb and in the drain line at 5', 6' and 7' and 1' from the curb. Six samples were taken from the north end of the bridge in the wheel pass at 15', 16' and 17' and 13'- 6" from the curb and in the drain line at 15', 16' and 17' and 1' from the curb. Three samples were taken at the abutment at the same end of the bridge. A table displaying the site sample locations and chloride concentrations along with various site pictures are shown below.

Sample Number	Sample Location	Chloride % by Concrete Weight*
1	5 ft. from South end, 13.5 ft. from curb (wheel path)	0.0229
2	6 ft. from South end, 13.5 ft. from curb (wheel path)	0.0122
3	7 ft. from South end, 13.5 ft. from curb (wheel path)	0.0174
4	5 ft. from South end, 1 ft. from curb (drain)	0.0160
5	6 ft. from South end, 1 ft. from curb (drain)	0.0364
6	7 ft. from South end, 1 ft. from curb (drain)	0.0154
7	North end Abutment	0.0099
8	North end Abutment	0.0111
9	North end Abutment	0.0083
10	15 ft. from North end, 13.5 ft. from curb (wheel path)	0.0088
11	16 ft. from North end, 13.5 ft. from curb (wheel path)	0.0340
12	17 ft. from North end, 13.5 ft. from curb (wheel path)	0.0185
13	15 ft. from North end, 1 ft. from curb (drain)	0.0165
14	16 ft. from North end, 1 ft. from curb (drain)	0.0284
15	17 ft. from North end, 1 ft. from curb (drain)	0.0124

Table 26. Bridge #081B00065N Chloride Samples

* Chloride contents determined from powder samples taken from 1.5 to 2.0 in. depth in concrete.

12. APPENDIX E – RAPID CHLORIDE TEST

GI

RCT and RCTW

Purpose

The **RCT** and **RCTW** systems are used to accurately and quickly determine the chloride ion content from powder samples of concrete obtained on-site or in the laboratory. The test results can be used for:

- Establishing the chloride ion profile for service life estimation
- Establishing the depth of removal of a chloride ion contaminated surface layer
- Diagnosing a structure for corrosion activity, in combination with other test systems such the **Mini Great Dane**, the **GalvaPulse**, and the **Rainbow Indicator**
- Monitoring the chloride ion content during electrochemical removal of chlorides
- Measuring the chloride ion content of fresh concrete or its constituents

Principle

A powder sample of hardened concrete is obtained by drilling or grinding from the structure, or a sample is obtained from the fresh concrete. The sample is mixed into a distinct amount of extraction liquid and shaken for five minutes. The extraction liquid removes disturbing ions, such as sulfide ions, and extracts the chloride ions in the sample.

A calibrated electrode is submerged into the solution to determine the amount of chloride ion, which is expressed as percentage of concrete mass.

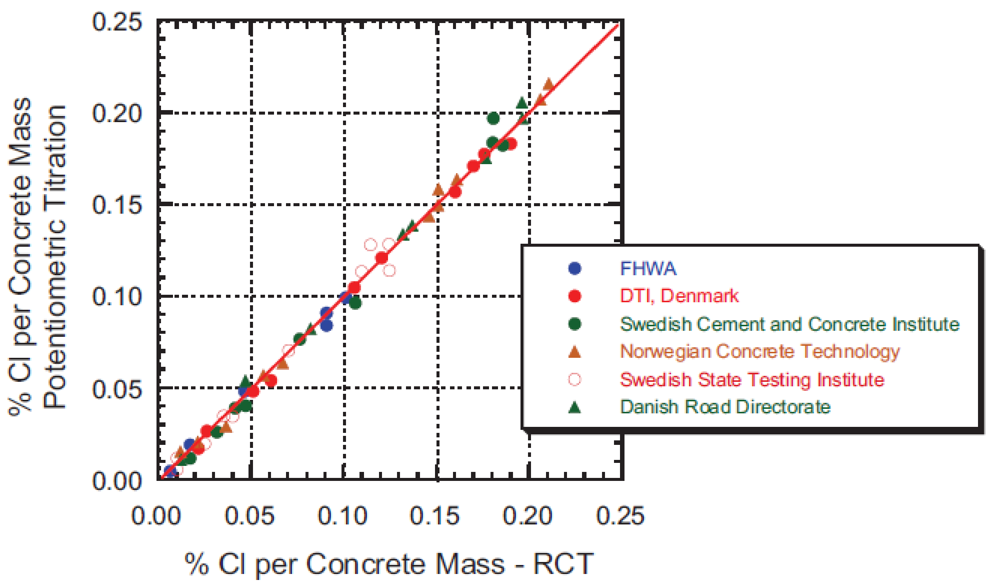
Two extraction methods are used:

- The **RCT** (**R**apid **C**hloride **T**est) is used to determine the amount of acid-soluble chlorides
- The **RCTW** (**R**apid **C**hloride **T**est **W**ater) is used to determine the amount of water-soluble chlorides

The two methods use different kinds of extraction liquids. The type of method to use will depend on the specification criteria for maximum allowable chloride ion content in either hardened or fresh concrete.

Accuracy

Numerous correlations have been made between **RCT** test results and chloride ion content determined by standard laboratory potentiometric titration methods such as AASHTO T 260, ASTM C114, DS 423.28 or NS 3671. The following graph shows the results of such correlations made by various laboratories in the Scandinavian countries and in the U.S.



RCT and RCTW

In one comparison, the Swedish National Testing Institute produced concrete powders containing known amount of chloride ion introduced into the concrete by diffusion. The concretes were made with different binders as illustrated in the table below. Parallel testing was done in accordance with, AASHTO T 260 and with the RCT system. The RCT readings were taken after the powder samples were kept in the extraction liquid overnight to obtain full extraction of acid-soluble chlorides. Alternatively, if the result is obtained after 5 minutes of shaking of the vial, a correction factor has to be applied to the measured chloride ion content.

The following table compares the known chloride ion content with the values determined by the RCT and by AASHTO T 260.

	% Cl^- per Mass of Concrete		
	Known Amount	AASHTO T 260	RCT
Portland Cement (CEM I)	0.023 0.071 0.328	0.024 0.070 0.314	0.022 0.072 0.321
Fly Ash Cement (CEM II/B-V)	0.020 0.057 0.244	0.019 0.052 0.229	0.019 0.061 0.238
Slag Cement (CEM III/B)	0.020 0.056 0.244	0.019 0.052 0.231	0.019 0.059 0.238

The accuracy of the RCT results compared with the known amount of chlorides is as good as with the AASHTO T 260 potentiometric titration method. The average deviation of the RCT results from the known amount of chlorides is within ± 4 %.

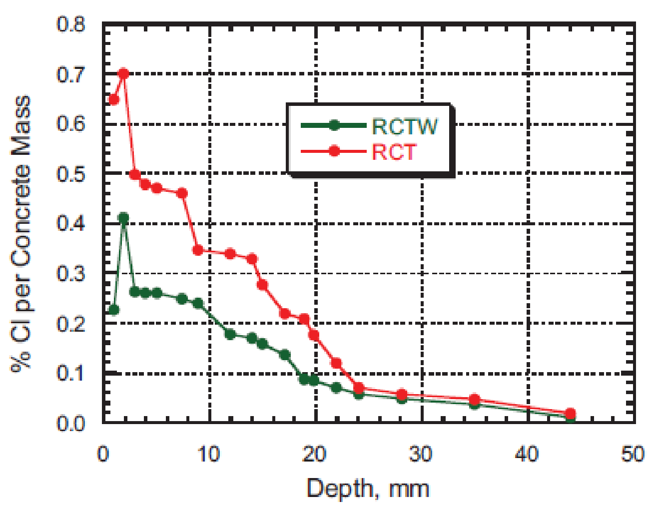
For repeated testing with the RCT on the same concrete powder, the coefficient of variation of test results is on average 5 %.

The precision and accuracy of the RCTW test for water-soluble chlorides is similar to RCT results.

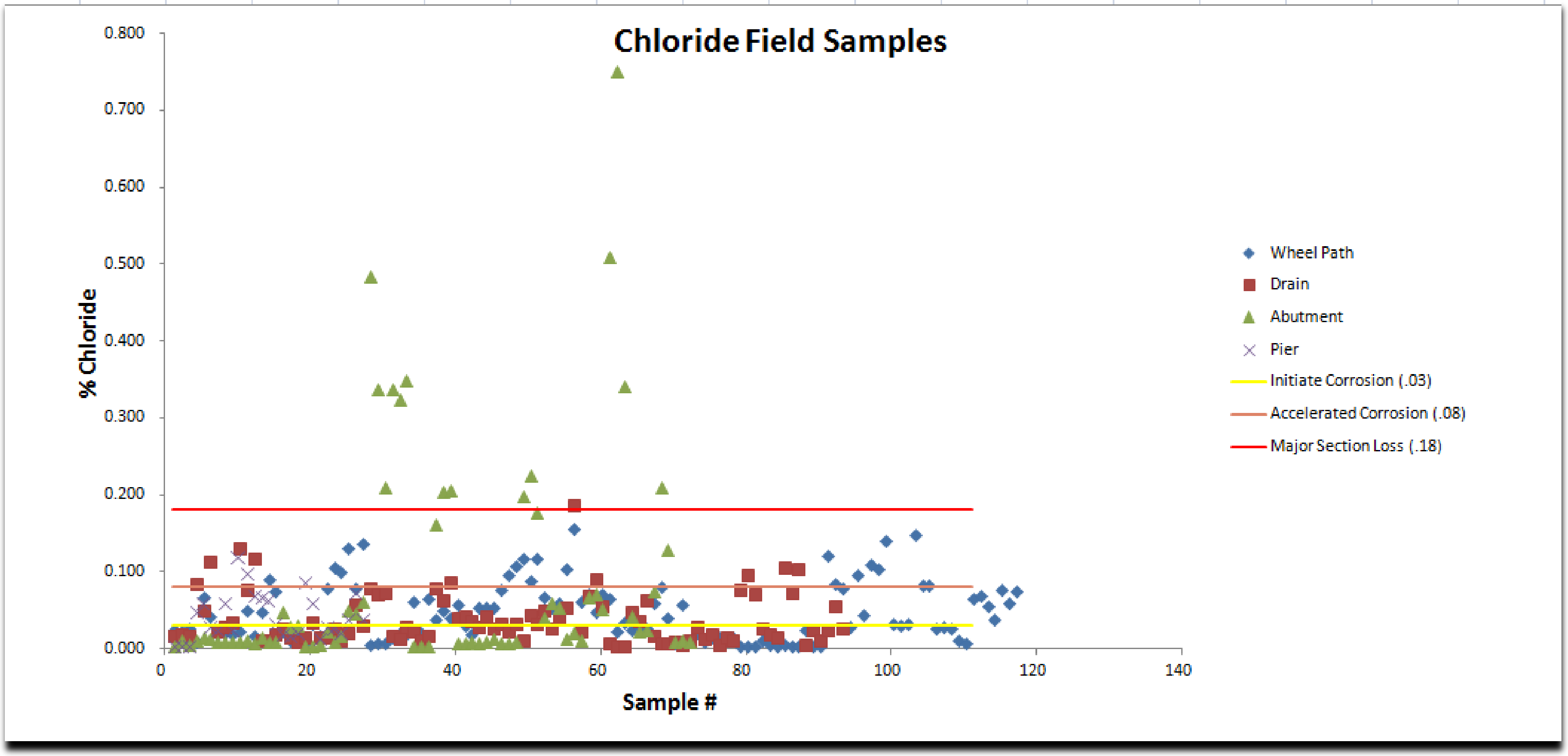
Testing Examples

Examples of chloride ion profiles measured with the RCT are illustrated on pages 99 and 100.

The graph to the right show two other profiles that were obtained from on-site profile grinding on a highway bridge column exposed to deicing salts for 4 years. Concrete powder samples were obtained at depth increments of 1 to 2 mm and were analyzed for acid-soluble chlorides with the RCT and for water-soluble chlorides with the RCTW. The depth of carbonation was measured to be 2 mm using the Rainbow Indicator, corresponding to the initial peaks of the chloride ion profiles obtained.



13. APPENDIX F – CHLORIDE FIELD SAMPLES



14. APPENDIX G – CARBONATION TESTS ON CORE SAMPLES

A. Bridge #081B00065N, 9AA over TTI RR

Figure 98. Bridge #081B00065N Core Sample, Pre-Spray

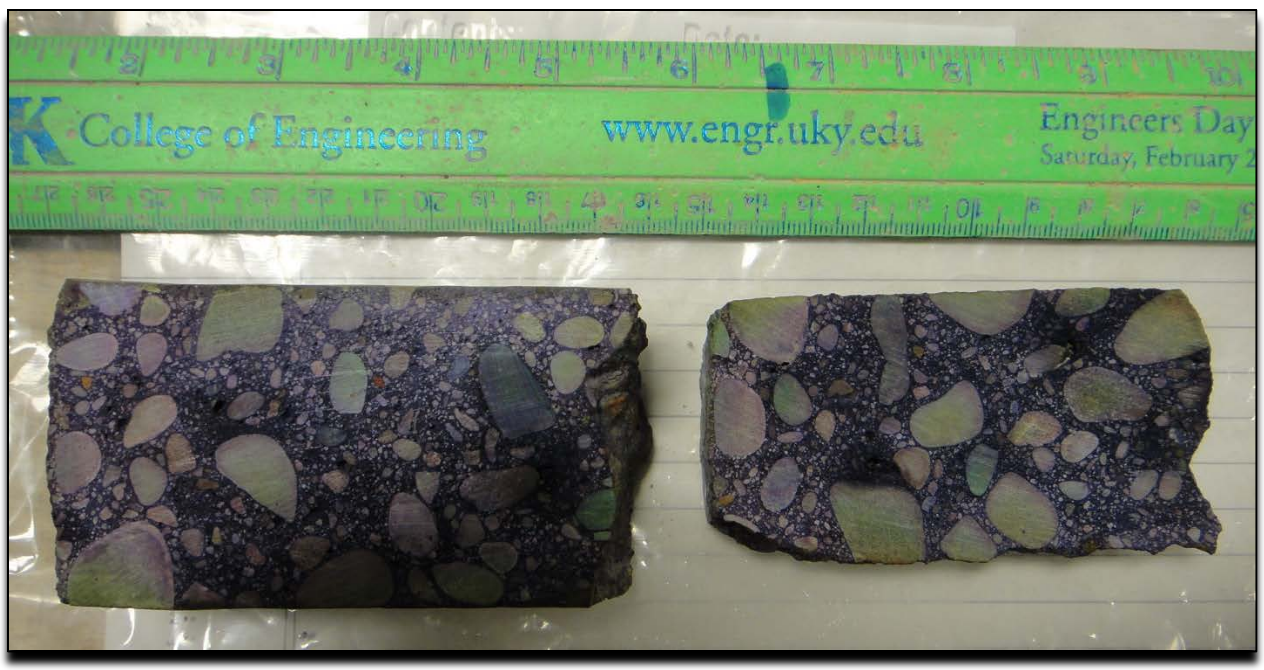


Figure 99. Bridge #081B00065N Core Sample, Post-Spray

B. Bridge #040B00029N, KY 1355 over Sugar Creek

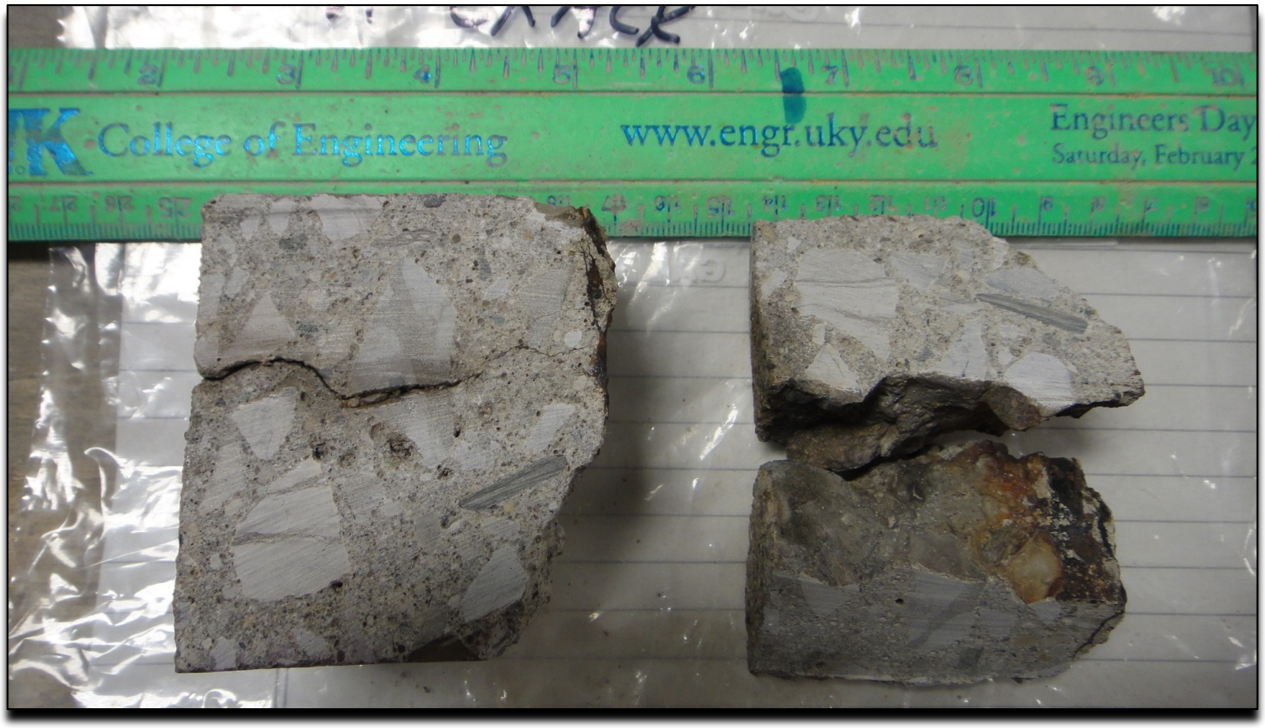


Figure 100. Bridge #040B00029N Core Sample, Pre-Spray

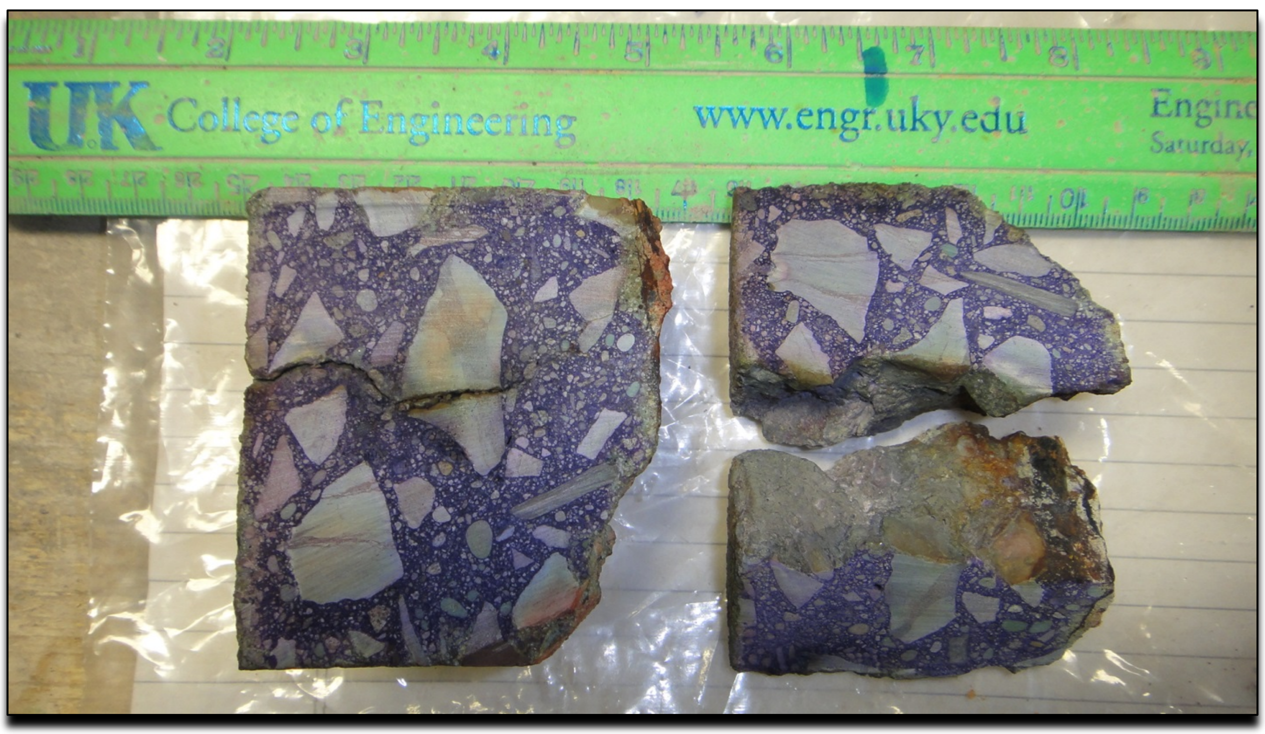


Figure 101. Bridge #040B00029N Core Sample, Post-Spray

C. Bridge #040B00030N, KY 1355 over West Sugar Creek

Figure 102. Bridge #040B00030N Core Sample, Pre-Spray

Figure 103. Bridge #040B00030N Core Sample, Post-Spray

D. Bridge #047B00116N, KY 1868 over Nolan River

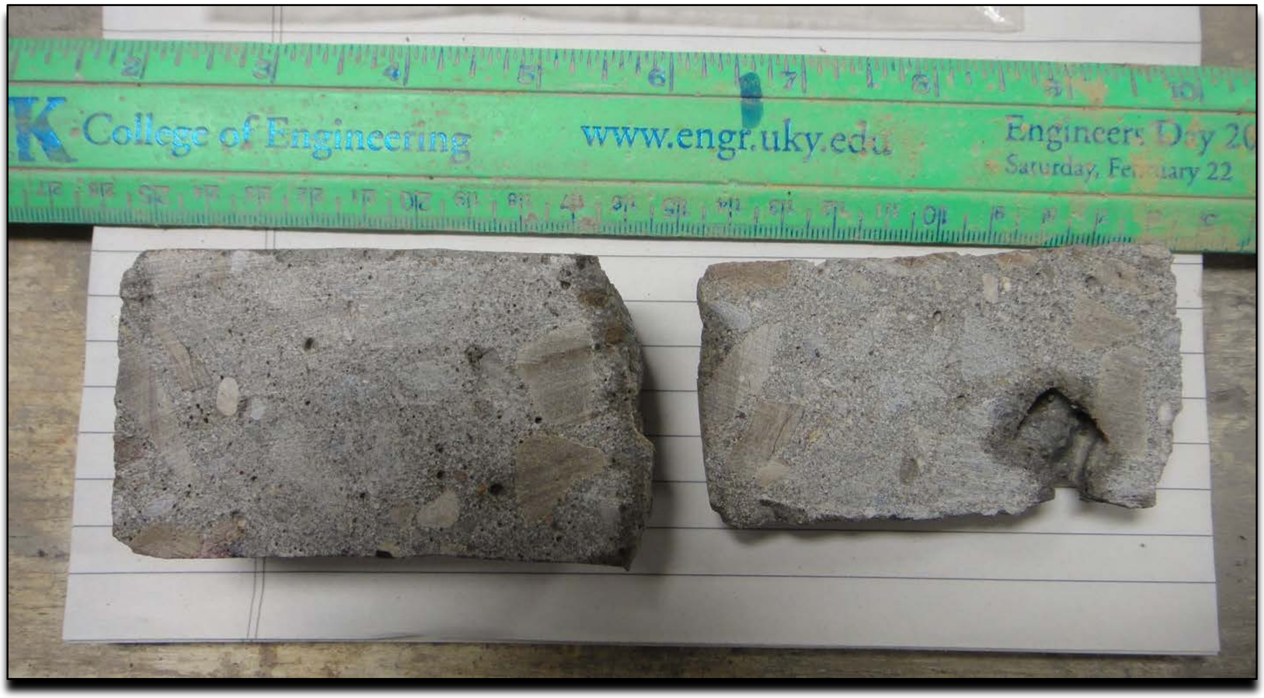


Figure 104. Bridge #047B00116N Core Sample, Pre-Spray

Figure 105. Bridge #047B00116N Core Sample, Post-Spray

E. Bridge #081B00049N, KY 11 over TTI RR

Figure 106. Bridge #081B00049N Core Sample, Pre-Spray

Figure 107. Bridge #081B00049N Core Sample, Post-Spray

F. Bridge #090B00029N, KY 49 over Bluegrass Parkway

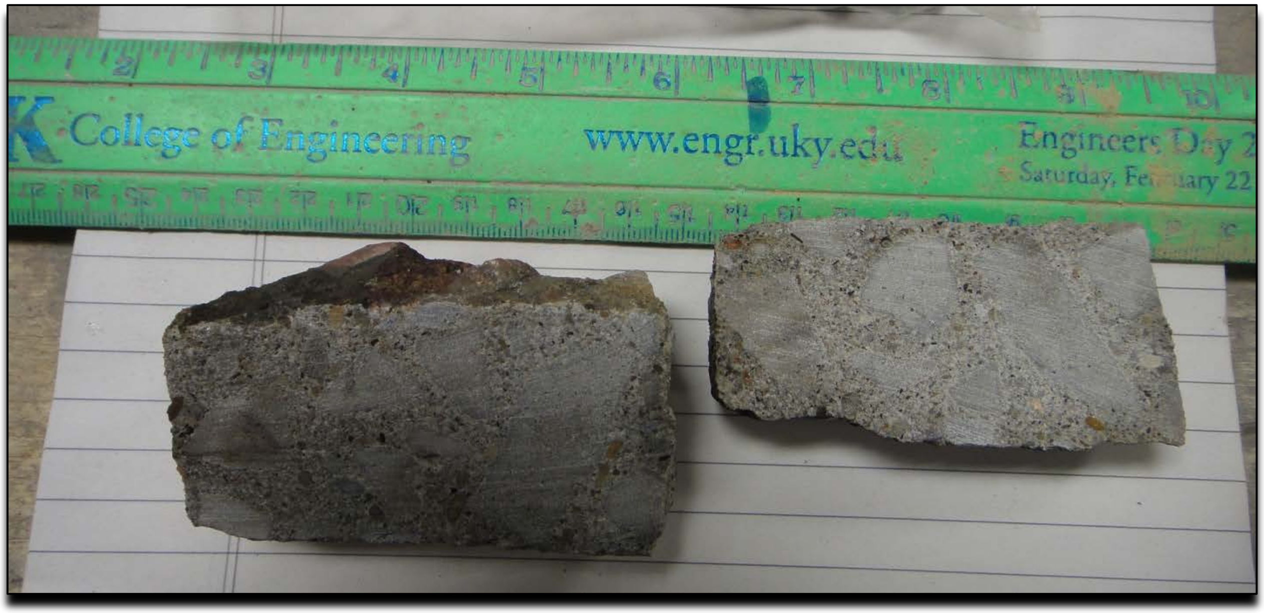


Figure 108. Bridge #090B00029N Core Sample, Pre-Spray

Figure 109. Bridge #090B00029N Core Sample, Post-Spray

G. Bridge #006B00064N, KY 1325 over Flat Creek

Figure 110. Bridge #006B00064N Core Sample, Pre-Spray

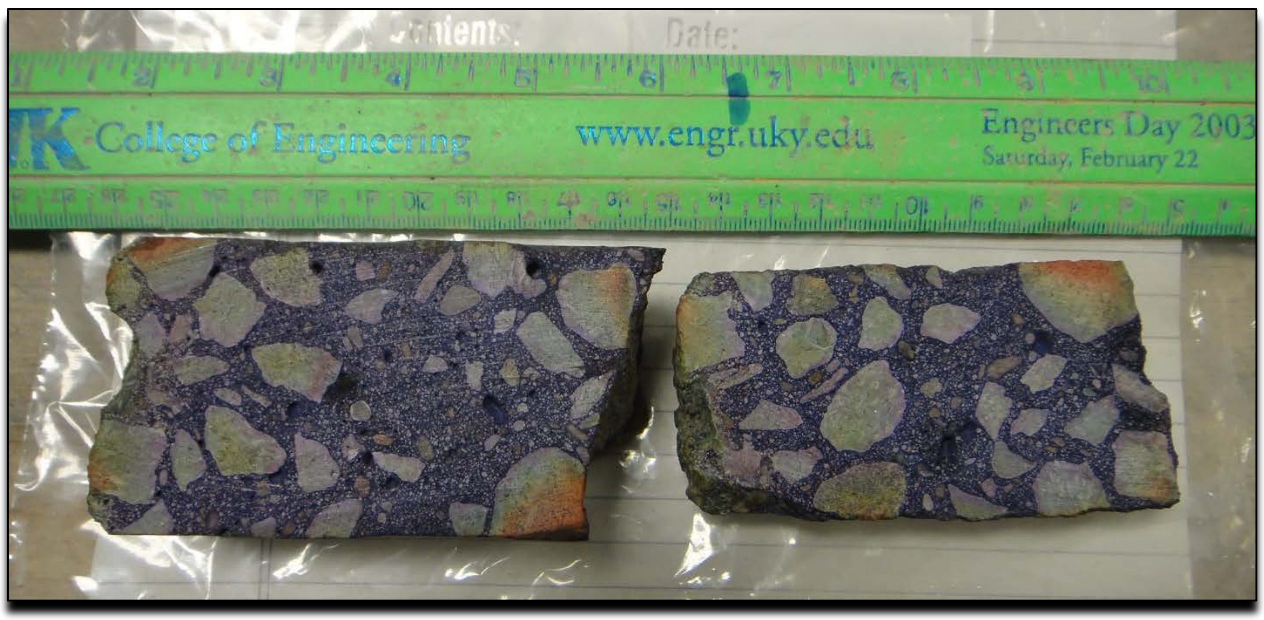


Figure 111. Bridge #006B00064N Core Sample, Post-Spray

H. Bridge #103B00029N, KY 1722 over Interstate 64

Figure 112. Bridge #103B00029N Core Sample, Pre-Spray

Figure 113. Bridge #103B00029N Core Sample, Post-Spray

I. Bridge #120B00026N, Scott's Ferry over Bluegrass Parkway

Figure 114. Bridge #120B00026N Core Sample, Pre-Spray

Figure 115. Bridge #120B00026N Core Sample, Post-Spray

J. Bridge #043B00026R, Western Kentucky Parkway over KY 187

Figure 116. Bridge #043B00026R Core Sample, Pre-Spray

Figure 117. Bridge #043B00026R Core Sample, Post-Spray