PRR-155

# Effectiveness of Concrete Deck Sealers and Laminates for Chloride Protection of New and In Situ Reinforced Bridge Decks in Illinois


## FINAL REPORT
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16. Abstract

Preventative maintenance of our infrastructure elements is increasingly vital as the resources to repair and replace these elements become scarce. One form of preventative maintenance is to protect structures from damages inflicted from deicing and anti-icing practices. A low cost preventative maintenance strategy is the use of protective coatings for bridge decks. Bridge deck concrete is often flawed by cracks. These cracks provide ingress for chloride ions to the reinforcement of the deck and structure. In order to prevent the further ingress of chloride ions, sealers and laminates are often considered practical methods of protection. This research project developed a protocol to evaluate concrete sealer and laminate effectiveness in protecting bridge deck concrete from chloride ion ingress. The protocol developed includes criteria for selecting products for evaluation, sample locations, sample depths, duration of study as well as the method of analysis of the chloride ions present in the concrete dust collected. The results demonstrate not only the relative effectiveness of the various sealers and laminates, but also the durability of each product as compared to control structures without a sealer or laminate applied. The durability and cost of the products can be used to develop the relative cost-effectiveness of each product. The cost-effectiveness values were utilized to develop the recommended policy for the use of bridge deck sealers and laminates for preventative maintenance.

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Final Report

# Effectiveness of Concrete Deck Sealers and Laminates for Chloride Protection of New and In Situ Reinforced Bridge Decks in Illinois

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October 2009

# ABSTRACT

Preventative maintenance of our infrastructure elements is increasingly vital as the resources to repair and replace these elements become scarce. One form of preventative maintenance is to protect structures from damages inflicted from deicing and anti-icing practices. A low cost preventative maintenance strategy is the use of protective coatings for bridge decks. Bridge deck concrete is often flawed by cracks. These cracks provide ingress for chloride ions to the reinforcement of the deck and structure. In order to prevent the further ingress of chloride ions, sealers and laminates are often considered a practical method of protection. This research project developed a protocol to evaluate concrete sealer and laminate effectiveness in protecting bridge deck concrete from chloride ion ingress. The protocol developed includes criteria for selecting products for evaluation, sample locations, sample depths, duration of study as well as the method of analysis of the chloride ions present in the concrete dust collected. The results demonstrate not only the relative effectiveness of the various sealers and laminates, but also the durability of each product as compared to control structures without a sealer or laminate applied. The durability and cost of the products can be used to develop the relative cost-effectiveness of each product. The cost-effectiveness values were utilized to develop the recommended policy for the use of bridge deck sealers and laminates for preventative maintenance.

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# DISCLAIMER

The contents of this paper reflect the view of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views, or policies, of the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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# INTRODUCTION

Protecting and extending the service life of our infrastructure is a goal of the Illinois Department of Transportation (IDOT). Deterioration of reinforced concrete bridges is a major concern. One of the major factors affecting bridge decks is the penetration of chloride ions into the bridge deck concrete. Once the chloride ions penetrate to the level of the reinforcing steel, they start a corrosion cell with the steel. The corrosion of the reinforcing steel leads to a loss of strength and ultimately the deterioration of the bridge deck. A variety of different values have been documented to represent the thresholds of chloride at which corrosion/deterioration occurs. Due to the various factors of concrete mix design (water/cement ratios, admixtures, air content, supplemental material usage, density and age), coverage depths, type of reinforcing steel, use of epoxy coatings and other construction factors, the numbers vary widely. In addition, the amount of carbonation and resultant change in the pH of the concrete affects the corrosion thresholds of concrete and reinforcing steel. The following values are reported consistently; 1.2 lbs/$yd^3$ (315 ppm) the chloride level to initiate corrosion, 3.0 lbs/$yd^3$ (790 ppm) the level of chloride need to rapidly accelerate corrosion and >7.0 lbs/$yd^3$ (1840 ppm) the level that causes major loss of steel section. These values assume an average density of concrete of 3,800 lbs/$yd^3$ in order to convert to parts per million (Newman, 2001).

An increasing number of chloride ions are being placed on bridge deck surfaces in the form of anti-icing and deicing chemicals for winter maintenance. These chloride ions penetrate the concrete by capillary absorption, hydrostatic pressure, and diffusion. Capillary absorption occurs when the concrete surface is subjected to continuous wetting and drying cycles. When water containing chloride ions hits dry pavement it is then drawn into the pore structure of the concrete through capillary suction. Hydrostatic pressure is rarely a factor on bridge structures. Diffusion is the most common method for chloride ion penetration. In order for diffusion to occur, water must be present to move the chlorides from different concentration gradients. Since the chloride-containing chemicals are used for anti-icing and/or deicing situations, water is present. Therefore, capillary absorption and diffusion work in conjunction to ingress chloride ions to the level of reinforcing steel in concrete structures.

Since the 1960’s, IDOT implemented a “bare road policy” for its winter maintenance programs. IDOT uses rock salt, liquid calcium chloride, liquid sodium chloride, and variations of these chemical compositions for this strategy. Most recently, traffic and highway operation demands have shown that anti-icing is very effective in crash reduction. Because frost is so difficult to predict, the new strategy in Illinois involves routinely applying salt brine (23% sodium chloride) 2-3 times a week, during normal work hours, on bridges and culverts known to frost between September and April. This practice prevents early morning frost from forming on decks and saves a great deal of overtime that would be used for early morning call outs to spread salt on frosty decks after frost has formed and a hazardous situation exists. The use of salt brine in addition to Illinois traditional salt use practices has improved the safety of our roadways. Unfortunately, this focused increase on safety has also increased the level of chlorides available to cause deleterious effects on the bridge decks.

Recent research studying the deleterious effects of deicing and anti-icing chemicals on concrete found that sodium chloride-containing deicers and anti-icers are the least harmful to Portland cement concrete, Sutter (2009). The researchers found that the sodium chloride, while corrosive to steel, does not form expansive/deleterious chemicals in reaction with Portland cement concrete. Deicing chemicals that contain the ions magnesium and calcium do react with the Portland cement concrete to form oxychloride phases, which are expansive and potentially damaging. These expansive products result in expansive cracks, increased permeability, and significant loss in compressive strength. Areas of Illinois that experience temperatures below 14° F (effective temperature of sodium chloride) supplement with the use of calcium chloride in order to adequately clear the roadways. Michigan Technological Transportation Institute (MTI) researchers found that sodium chloride has a higher rate of ingress and therefore penetrates into concrete deeper and faster than magnesium chloride and calcium chloride containing deicers. This was thought to be due to the fact that there was no chemical interaction with the concrete in order to slow the movement of the ions through the concrete.

Due to shortages of rock salt, more and more alternate chemicals are finding their way into Illinois. These chemicals are relative unknowns in terms of deicing and anti-icing capabilities as well as their potential deleterious effects on concrete.

Over the years, Illinois has implemented new construction practices and mix designs in order to improve the durability and performance of reinforced concrete. One practice is to utilize epoxy coated steel to prevent steel corrosion. In addition, Illinois introduced high performance concrete mix designs and innovative construction practices to optimize the performance life of concrete. The new mix designs utilize supplementary cementious materials such as coal fly ash and ground granulated blast furnace slag to improve the density and porosity of concrete. Unfortunately, high performance concrete mixes in Illinois have been susceptible to cracking. These cracks provide a quick route of ingress for sodium chloride and calcium chloride, therefore allowing the salt to attack any defect in epoxy coated steel and start a corrosion cell.

IDOT specifies concrete sealers for bridge seats and other substructure elements. This research will select products which are appropriate to apply to bridge deck concrete from the IDOT Concrete Sealer Approved Product List to reduce or retard the ingress of chloride ions.

## SUPPORTING RESEARCH

A number of research projects investigating a variety of penetrating sealers have found silane and siloxane-based materials perform best in salt-ponding studies. Many different NCHRP studies have evaluated the performance of concrete sealers under laboratory conditions. NCHRP Synthesis 209, Cady (1994), NCHRP Report 244, Pfeifer and Scali (1981) and most recently NCHRP project 20-07, Krauss et. al. (2009), which attempt to update and revise the strategies for evaluating the concrete sealers utilizing the best available technology are vast resources of lab testing protocols. Synthesis 209 found that sealing concrete is the lowest first-cost method for protecting concrete structures against future deterioration and corrosion, and potentially the lowest life-cycle cost procedure to extend the service life of concrete bridges.

Several other states have conducted research utilizing a variety of different field conditions. Minnesota performed testing on a variety of sealers as well as a control on one structure Hagen (1995). South Dakota, Soriano (2003), looked at various penetrating sealers and crack sealers in order to answer the questions; what to apply, when to apply and how to apply. They found that penetrating sealers, such as silanes and siloxanes, were superior to linseed oil based protective coat and that certain characteristics of crack sealers perform optimally. They also found that the earlier sealers are applied the more benefit in protection from water and chloride ingress. Minnesota's research, Johnson et. al. (2009), focused on surface preparation methods and the resulting penetration of the sealers studied. Other states have utilized various bridges, conditions, products and means of evaluating the performance of concrete sealers and laminates in the field. All research findings point towards sealers and laminates providing protection for bridge deck concrete. This research will utilize the previous research and apply the findings to specific conditions, structures, sealers and laminates currently available in Illinois.

## RESEARCH OBJECTIVES

The objective of this research was to develop recommendations and a policy for using sealers and laminates to protect reinforced bridge decks from chloride ion ingress. The method used included determining the effectiveness of various sealers and laminates under the specific conditions (weather conditions, construction practices and maintenance practices) found in Illinois. The effectiveness measure was based upon the ability of the sealers and laminates to deter the ingress of chloride ions in relation to control structures on which no sealer or laminate had been applied. The control structures were located in similar geographical locations. This was done in order to ensure that the structures were subjected to similar weather conditions, deicing and anti-icing activities as well as similar Average Daily Traffic (ADT). Sealers and laminates were applied to both new construction and in-situ structures. The effectiveness was determined over a six-year period in order to capture the durability of the product over time. The durability factor in conjunction with the installation costs of the various products was utilized to develop the recommendations/policy.

In order to continually add products appropriate for use on bridge decks to the Concrete Sealer Approved Product List, a series of laboratory tests was conducted to attempt to correlate the field work with tests done in the lab setting.

## SNOW AND ICE REMOVAL POLICY AND PRACTICES

In order to better understand the need for sealing/protection from the ingress of chloride ions from anti-icing and deicing practices, it is important to understand the policy guiding the application of these chemicals. Policy changes and improvements are continual, but the basics of the IDOT policy follow and demonstrate the vast amount of sodium and calcium chloride chemicals used to provide "bare pavement" for the traveling public. IDOT's policy for frost prevention, found in Table 5, calls for the use of 23% sodium chloride brine 2-3 times a week in frost prone areas. The Central Bureau of Operations maintains the policy for deicing and anti-icing practices in Illinois. This policy may be obtained by contacting the Weight Enforcement Engineer at the Central Bureau of Operations. The following Tables 1-5 summarize the policy for various events.

**Table 1**
**Light Snow Storm**

| | | INITIAL OPERATIONS | | | ONGOING OPERATIONS | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Spread Rate Range (Per Lane Mile) | | | Spread Rate Range (Per Lane Mile) | | |
| *PAVEMENT TEMPERATURE RANGE AND TREND* | Initial Surface Conditions | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | COMMENTS |
| *Above 32 F - Steady or Rising* | **Dry, wet, slush or light snow cover** | **NONE See comments** | | | **NONE See comments** | | | Monitor pavement temperatures closely for drops to and below 32 F |
| *Above 32 F - 32 or lower is imminent* | **Dry** | **Apply pre wet salt** | **100 to 150 lbs.** | **See Comment #1** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 200 lbs.** | #1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100%<br><br>#2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates. |
| *20 to 32 F temperatures staying in this range* | **Wet, slush or light snow cover** | **Apply pre wet or dry salt** | **100 to 150 lbs.** | **150 to 250 lbs.** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 250 lbs.** | |
| *5 to 20 F temperatures staying in this range* | **Dry, Wet, Slush or light snow cover** | **Apply salt pre-wetted with calcium chloride** | **150 to 250 lbs.** | **See Comment #3** | **Reapply chemicals as needed, plow as needed** | **150 to 250 lbs.** | **See Comment #3** | # 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider. |
| *Below 5 F Steady or falling temperatures* | **Dry or light snow cover** | **Plow as needed see comments** | | | **Plow as needed see comments** | | | Abrasives or abrasive mixes can be used to enhance traction as required. |

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

## Table 2
## Light Snow Storm with Period(s) of Moderate or Heavy Snow

| | | INITIAL OPERATIONS | | | ONGOING OPERATIONS | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Spread Rate Range (Per Lane Mile) | | | Spread Rate Range (Per Lane Mile) | | |
| *PAVEMENT TEMPERATURE RANGE AND TREND* | Initial Surface Conditions | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | COMMENTS |
| *Above 32 F - Steady or Rising* | **Dry, wet, slush or light snow cover** | **NONE See comments** | | | **NONE See comments** | | | Monitor pavement temperatures closely for drops to and below 32 F |
| *Above 32 F - 32 or lower is imminent* | **Dry** | **Apply pre wet salt** | **100 to 150 lbs.** | **See Comment #1** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 200 lbs.** | #1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100%<br><br>#2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates. |
| *20 to 32 F temperatures staying in this range* | **Wet, slush or light snow cover** | **Apply pre wet or dry salt** | **100 to 150 lbs.** | **150 to 250 lbs.** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 250 lbs.** | |
| *5 to 20 F temperatures staying in this range* | **Dry, Wet, Slush or light snow cover** | **Apply salt pre-wetted with calcium chloride** | **150 to 250 lbs.** | **See Comment #3** | **Reapply chemicals as needed, plow as needed** | **150 to 250 lbs.** | **See Comment #3** | # 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider. |
| *Below 5 F Steady or falling temperatures* | **Dry or light snow cover** | **Plow as needed see comments** | | | **Plow as needed see comments** | | | Abrasives or abrasive mixes can be used to enhance traction as required. |

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

## Table 3
## Moderate or Heavy Snow Storm

| | | INITIAL OPERATIONS | | | ONGOING OPERATIONS | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Spread Rate Range (Per Lane Mile) | | | Spread Rate Range (Per Lane Mile) | | |
| *PAVEMENT TEMPERATURE RANGE AND TREND* | Initial Surface Conditions | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | COMMENTS |
| *Above 32 F - Steady or Rising* | **Dry, wet, slush or light snow cover** | **NONE See comments** | | | **NONE See comments** | | | Monitor pavement temperatures closely for drops to and below 32 F |
| *Above 32 F - 32 or lower is imminent* | **Dry** | **Apply pre wet salt** | **100 to 150 lbs.** | **See Comment #1** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 200 lbs.** | #1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100%<br><br>#2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates. |
| *20 to 32 F temperatures staying in this range* | **Wet, slush or light snow cover** | **Apply pre wet or dry salt** | **100 to 150 lbs.** | **150 to 250 lbs.** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 250 lbs.** | |
| *5 to 20 F temperatures staying in this range* | **Dry, Wet, Slush or light snow cover** | **Apply salt pre-wetted with calcium chloride** | **150 to 250 lbs.** | **See Comment #3** | **Reapply chemicals as needed, plow as needed** | **150 to 250 lbs.** | **See Comment #3** | # 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider. |
| *Below 5 F Steady or falling temperatures* | **Dry or light snow cover** | **Plow as needed see comments** | | | **Plow as needed see comments** | | | Abrasives or abrasive mixes can be used to enhance traction as required. |

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

## Table 4
## Freezing Rain or Sleet Storm

| | | INITIAL OPERATIONS | | | ONGOING OPERATIONS | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Spread Rate Range (Per Lane Mile)** | | | **Spread Rate Range (Per Lane Mile)** | | |
| *PAVEMENT TEMPERATURE RANGE AND TREND* | Initial Surface Conditions | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | **Suggested Actions** | **Pre-wet* Solid Salt** | **Dry Salt** | COMMENTS |
| *Above 32 F - Steady or Rising* | **Dry, wet, slush or light snow cover** | **NONE See comments** | | | **NONE See comments** | | | Monitor pavement temperatures closely for drops to and below 32 F |
| *Above 32 F - 32 or lower is imminent* | **Dry** | **Apply pre wet salt** | **100 to 150 lbs.** | **See Comment #1** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 200 lbs.** | #1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100%<br><br>#2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates. |
| *20 to 32 F temperatures staying in this range* | **Wet, slush or light snow cover** | **Apply pre wet or dry salt** | **100 to 150 lbs.** | **150 to 250 lbs.** | **Reapply chemicals as needed, plow as needed** | **100 to 150 lbs.** | **150 to 250 lbs.** | |
| *5 to 20 F temperatures staying in this range* | **Dry, Wet, Slush or light snow cover** | **Apply salt pre-wetted with calcium chloride** | **150 to 250 lbs.** | **See Comment #3** | **Reapply chemicals as needed, plow as needed** | **150 to 250 lbs.** | **See Comment #3** | # 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider. |
| *Below 5 F Steady or falling temperatures* | **Dry or light snow cover** | **Plow as needed see comments** | | | **Plow as needed see comments** | | | Abrasives or abrasive mixes can be used to enhance traction as required. |

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

## Table 5
## Frost Control

| | | INITIAL OPERATIONS | | | | ONGOING OPERATIONS | | |
|---|---|---|---|---|---|---|---|---|
| | | | Spread Rate Range (Per Lane Mile) | | | Spread Rate Range (Per Lane Mile) | | |
| PAVEMENT TEMPERATURE FORECAST *and RELATION TO DEW POINT TEMPERATURE RANGE AND TREND* | **Traffic Conditions** | **Suggested Actions** | *** Liquid Salt Solution** | **Pre-wet Solid Salt** | **Suggested Actions** | **Pre-wet Solid Salt**** | **Dry Salt** | COMMENTS |
| *Above 32 F - Steady or Rising* | **All** | **See comments** | | **N/A** | **See comments** | | | Monitor pavement temperature and weather forecasts closely for drops to and below 32 F and frost potential |
| *28 to 32 F temperatures staying in range and equal to or below dew point* | | **Apply salt brine to bridge decks and frost prone locations 2 to 3 times weekly** | **20 to 50 gal. per mile** | | **Apply chemicals as needed.** | **75 to 150 lbs.** | **100 to 200 lbs.** | |
| *20 to 28 F temperatures staying in this range and equal to or below dew point* | | **Apply salt brine to bridge decks and frost prone locations 2 to 3 times weekly** | **30 to 60 gal. per mile** | | **Apply chemicals as needed.** | **150 to 350 lbs.** | **150 to 400 lbs.** | It is not advisable to apply Liquid Salt Solution when pavement temperatures drop below 20 F |
| *10 to 20 F temperatures staying in this range and equal to or below dew point* | | **N/A** | | | **Apply chemicals as needed.** | **250 to 500 lbs.** | **500 lbs.** | |

*Application rate for 28% solution
**Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

# CLIMATE DATA

The following climate information is from the Illinois's Climatology Office website (http://www.isws.uiuc.edu/atmos/statecli/index.htm). The website provides maps and graphs that summarize the trends of various conditions throughout Illinois. There is also a copy of a report regarding the severe weather experienced in 2007, including cost estimates of damages and losses due to the inclement conditions.

As the sun gradually lowers in the sky in the Northern Hemisphere during the fall, cold arctic and polar air masses intrude farther and farther south into the United States. Disturbances forming along the boundary between the cold polar air and the relatively warm, tropical air sometimes turn into winter storms. These are usually large, intense low-pressure systems that may cover tens of thousands of miles. Illinois's location in the Midwest and its great north to south extent place it in the path of many of these storms. When conditions are right, these storms can strike Illinois hard, leaving snow and ice over all or parts of the state.

Severe winter storms in Illinois produce more total damage than any other form of short-term severe weather including tornadoes, lightning and hail. Central Illinois has the distinction of being in the nation's primary area for severe freezing rain (ice) storms. However, any part of the state is apt to have a severe snow storm or ice storm.

Illinois, on the average, experiences five severe winter storms during the November-April period. These storms may be those with only heavy snow, or with snow and ice mixed, or with ice (glaze) only.

The 2007-2008 winter conditions across the State led to record quantities of deicing and anti-icing chemicals used to combat the precipitation and cold temperatures. The increased quantity of chemicals was reflected in the results of the samples collected and analyzed after that winter.

The following maps and charts (Figures 1-7) serve as a visual clue as to the average conditions found in Illinois. The temperatures and precipitation of this region play a large role in the deterioration of our infrastructure and continue to be factors that contribute in large part to the need for preventative maintenance strategies to be employed.

| YEAR | SNOWFALL INCHES/YEAR |
|---|---|
| 2002 | **12.1** |
| 2003 | **18.9** |
| 2004 | **13.4** |
| 2005 | **14.0** |
| 2006 | **13.7** |
| 2007 | **18.1** |

**Snowfall in Inches/Year**

**Figure 1**

**Figure 2**

Annual Average Low Temperature (°F)


**Figure 3**

Average Number of Days With Precipitation At or Above 1.00 inches

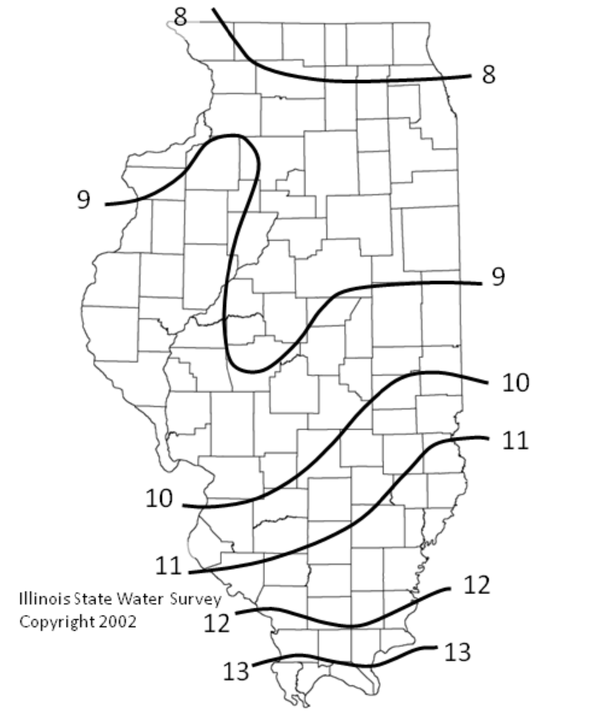



**Figure 4**

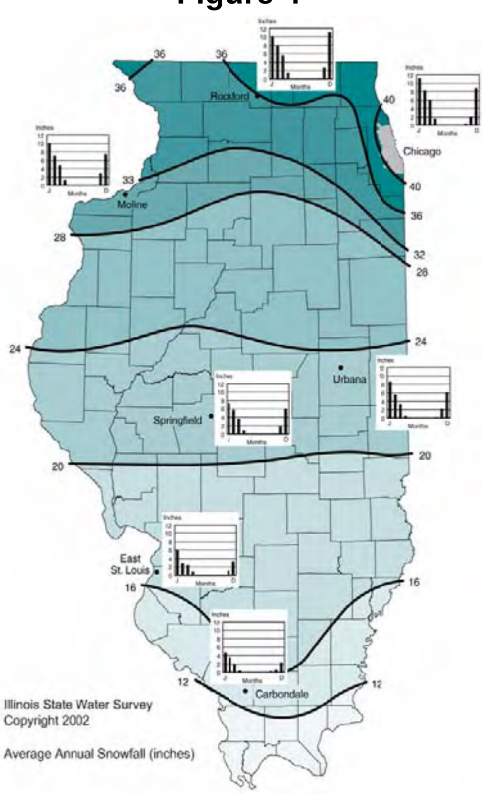



**Figure 5**

Average Number of Days At or Below 32F

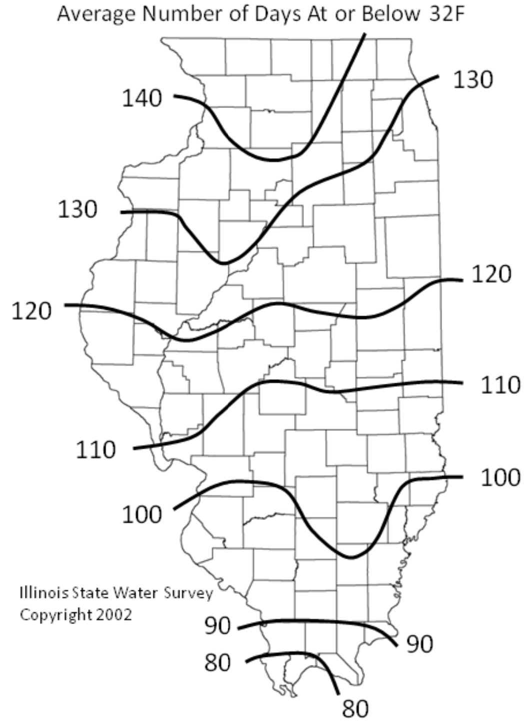


**Figure 6**


**Figure 7**


## SEALERS AND LAMINATES

Table 6 lists the various sealers and laminates utilized in this research. The table includes the product name, manufacturer, generic type of sealer and the recommended application rate. Data is from the product data sheets supplied by the manufacturers.

## Sealer and Laminate Products and Application Rates
## Table 6

| ***Product*** | ***Manufacturer*** | ***Type*** | ***Application Rate (x2=two applications)*** |
|---|---|---|---|
| Protective Coat | Various | Std. Spec. Art. 1023.01 | 450 $ft^2$/gal x2 |
| Tri-Siloxane TK-290 W.B. | TK Products Inc. | Penetrating Silane/Siloxane (10% and 20%) | 150 $ft^2$/gal |
| Tri-Siloxane TK-290 | TK Products Inc. | Penetrating Siloxane 16% | 150 $ft^2$/gal |
| TK 9000 | TK Products Inc. | Crack Sealer (100% solids-epoxy resin) | Directly into cracks |
| ChemTec One | Chem Tech Int'l | Penetrating Silicate | 100 $ft^2$/gal x2 |
| Latex Concrete Overlay | | Concrete Overlay | 3 ½ inch overlay |
| Mark 163 "Flexogrid" | Poly Carb, Inc. | Laminate material (hybridized copolymer) | ¼ inch to 3/8 inch in x2 |
| Mark 154 | Poly Carb, Inc. | Laminate material | ¼ inch to 3/8 inch in x2 |
| Mark 135 "Safe-T-Seal" | Poly Carb, Inc. | Laminate material (crack welder) | Paint rollers/sand dusted |
| Mark 135.3 | Poly Carb, Inc. | Laminate material | Paint rollers/sand dusted |
| Thin Polymer Overlay | Poly Carb, Inc. | Laminate Material | ¼ inch to 3/8 inch x2 |
| Sil-Act Multigard | Advanced Chemical Technologies | Penetrating Silane 100% Mix with water to apply | 100 $ft^2$/gal |
| WB 244 | Tamms Industries | Penetrating Silane/Siloxane <20% | 150 $ft^2$/gal |
| Dural 335 | Tamms Industries | Healer / Sealer (100% epoxy resin) | 150-300 $ft^2$/gal |
| Microsilica Overlay | | Concrete Overlay | Hand poured/finished |
| Deck A Pell (15%) | Chemprobe Technologies, Inc. | Penetrating Silane/Siloxane (15%) | 150 $ft^2$/gal |
| Dur A Pell 100 "S" | Chemprobe Technologies, Inc. | Penetrating Silane ≥ 95% | 300 $ft^2$/gal |
| Dur A Pell 20 | Chemprobe Technologies, Inc. | Penetrating Silane/Siloxane 20% | 150 $ft^2$/gal |
| Water Repellent # 2 | Weatherall Company Inc. | Penetrating Silane/Siloxane | 80-100 $ft^2$/gal |
| Clear Masonry Sealer | Weatherall Company Inc. | Penetrating Silane/Siloxane | 325 $ft^2$/gal |
| Duraguard 401 | ChemMasters | HMWM Healer/Sealer | 100-150 $ft^2$/gal |

IDOT maintains a Concrete Sealer Approved Product List. The most current list may be found at the following link, http://www.dot.state.il.us/materials/concretesealers.pdf on the IDOT website. The list is subject to change due to manufacturers and products entering and leaving the market. The majority of products evaluated in this research were chosen from products found on the list in 2002. Some of the products evaluated are not found on the current list. These products may still be commercially available despite not being on the current list. The Concrete Sealer Approved Product List categorizes material as either penetrating or film forming. It further describes the general chemistry as silane, siloxane, epoxy, and silica or oxoaluminum stearate. The silicone-based sealers can be separated into hydrophobic sealers, ("water-repellants") and pore blockers. Silanes, siloxanes and siliconates are all hydrophobic. They repel water by lowering the surface tension of the concrete below the surface tension of water. These products still allow vapor transmission. The silicate sealers are pore blockers. The pore blockers penetrate into the capillary structure of the concrete and fill the pores, thus blocking moisture and subsequent chloride ingress. These products inhibit vapor transmission and can possibly lead to freeze thaw damage. There are a variety of materials found on the list, including products that are combinations of the various chemistries.

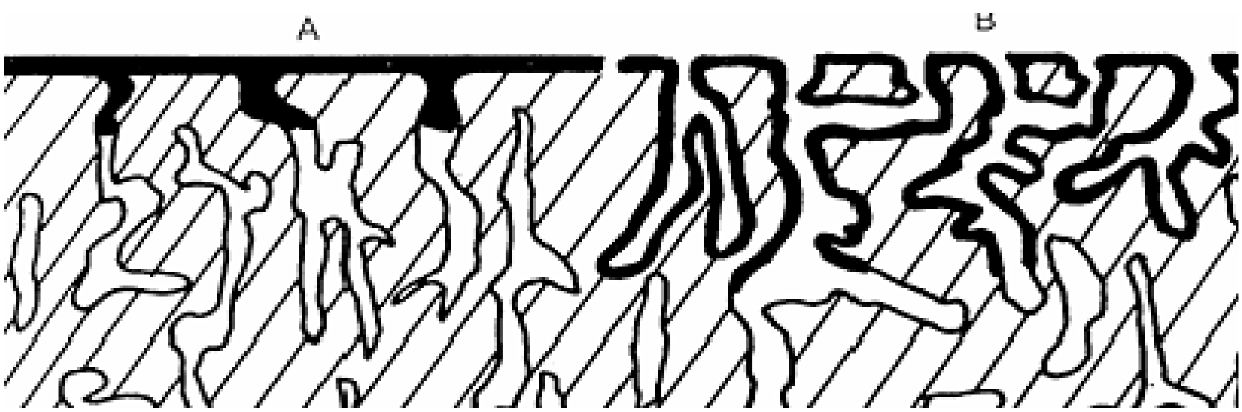



**Figure 8**

Figure 8 depicts the concrete pore structure and the resultant sealing of the generic types of sealers. Type A is a pore blocking, film forming sealer and Type B is a penetrating, hydrophobic sealer.

The application of all products requires a clean, dry and sound concrete surface. This includes the removal of all curing compounds, foreign matter and efflorescence. The initial moisture content of the deck should be kept as low as possible during the time of application to ensure the best penetration of the various products. The application temperatures typically range from 40°F to 100°F. The majority of the products require a 28-day concrete cure prior to application of product. Some products are applied in one application, while others require two applications. The penetrating products are typically spray applied utilizing a simple garden hose sprayer application. The products may be applied to both new and existing concrete if the above criteria are met. Caution should be taken with the silane products as the silanes are more volatile and can be less effective if applied on hot or windy days.

## SAMPLING PROTOCOL

The following guidelines and procedures were followed for sample locations, drilling and sample collection. These procedures were used each sampling time in order to provide clarity and consistency for each bridge structure, and from one bridge structure to another. The guidelines were also developed to assist District personnel that expressed an interest in collecting bridge deck concrete for chloride ion ingress testing.

Samples were collected pre-sealing. The bridge structures were drilled and sampled immediately prior to the application of the bridge deck sealer or laminate. This set of samples provided a baseline on which to quantify the amount of chloride ion diffusion into the deck at future sampling points in year 1, 2, 3, 4 and 5.

Samples were collected for 5 years from the year of application. The bridge deck structures were drilled and sampled at the yearly anniversary date of the pre-sealing sampling for anniversaries 1, 2, 3, 4, and 5. These samples were compared to the pre-sealing samples and used to evaluate the performance of the bridge deck sealer. The following distinct locations were used for chloride ion sampling. The samples were drilled in sound areas, away from cracks, patches or stains. Figure 9 demonstrates the sampling locations.

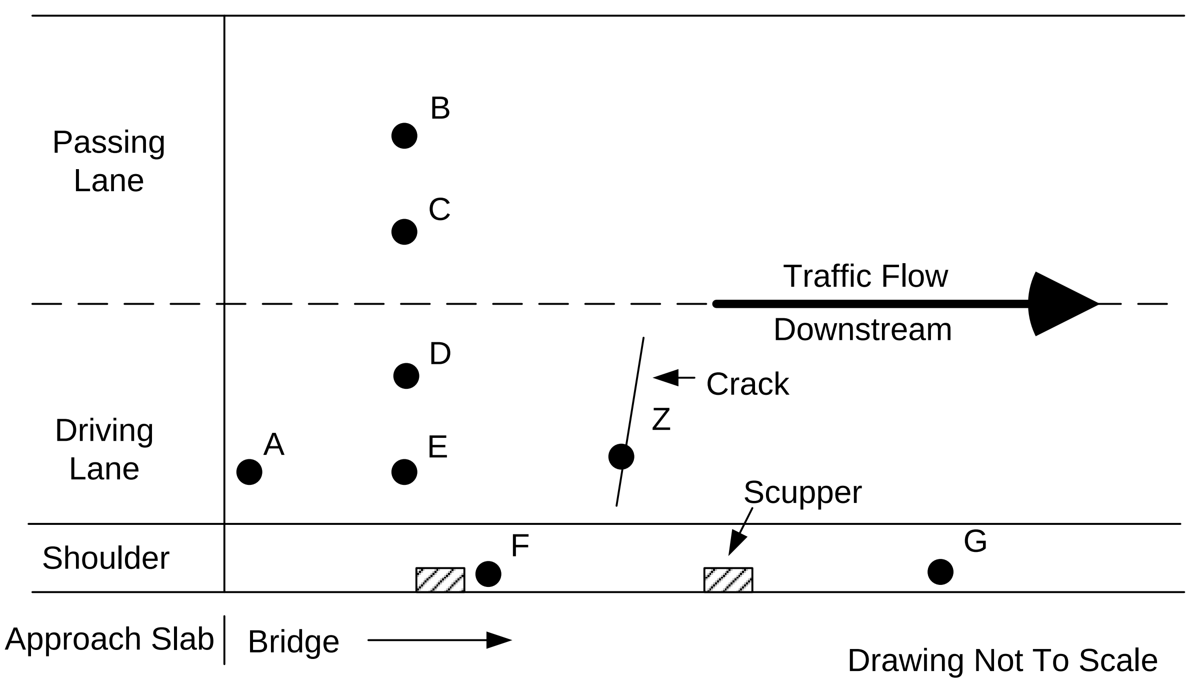



**Figure 9**

The sample locations were chosen to isolate areas of the deck that would have the greatest chloride ion ingress potential and or places where bridge deck wear due to tire traffic would be increased. The sample locations were typically isolated to the first 15 feet of the structure to simplify traffic control requirements.

Location A – The first sample location was in the driving lane, outside wheel-path, and 6 inches downstream of the bridge / approach slab joint.

Location B – The second sample location was in the passing lane, outside wheel-path, and 5 feet downstream of the bridge / approach slab joint.

Location C – The third sample location was in the passing lane, inside wheel-path, and 5 feet downstream of the bridge / approach slab joint.

Location D – The fourth sample location was in the driving lane, inside wheel-path, and 5 feet downstream of the bridge / approach slab joint.

Location E – The fifth sample location was in the driving lane, outside wheel-path, and 5 feet downstream of the bridge / approach slab joint.

Location F – The sixth sample location was in the driving lane shoulder, 6 inches downstream of the first scupper, and 6 inches from the base of the parapet wall.

Location G – The seventh sample location was in the driving lane shoulder, 5 feet downstream of the last scupper, and 6 inches from the base of the parapet wall.

Location Z – The eighth sample location was randomly located along a crack found on the bridge deck. Typically this location was in the driving lane, in close proximity to location E.

Additional samples were collected at specialized areas or areas of increased distress. The location of these samples on the bridge deck surface were clearly identified and reported. The samples were properly labeled according to the lettering and numbering system outlined below.

Subsequent samplings of location A were done at distinct locations 3 inches from the previous location, however maintaining the same 6 inch distance from the bridge / approach slab joint.

Subsequent samplings of locations B, C, D, E, and G were done at distinct locations 3 inches downstream from the previous location.

Subsequent samplings of location F were done at distinct locations 3 inches from the previous location, however maintaining the 6 inch distance from the first scupper. The resulting pattern of sampling holes for this location formed a semi-circle around the scupper.

The same sampling location from year to year was critical in order to obtain comparable results.

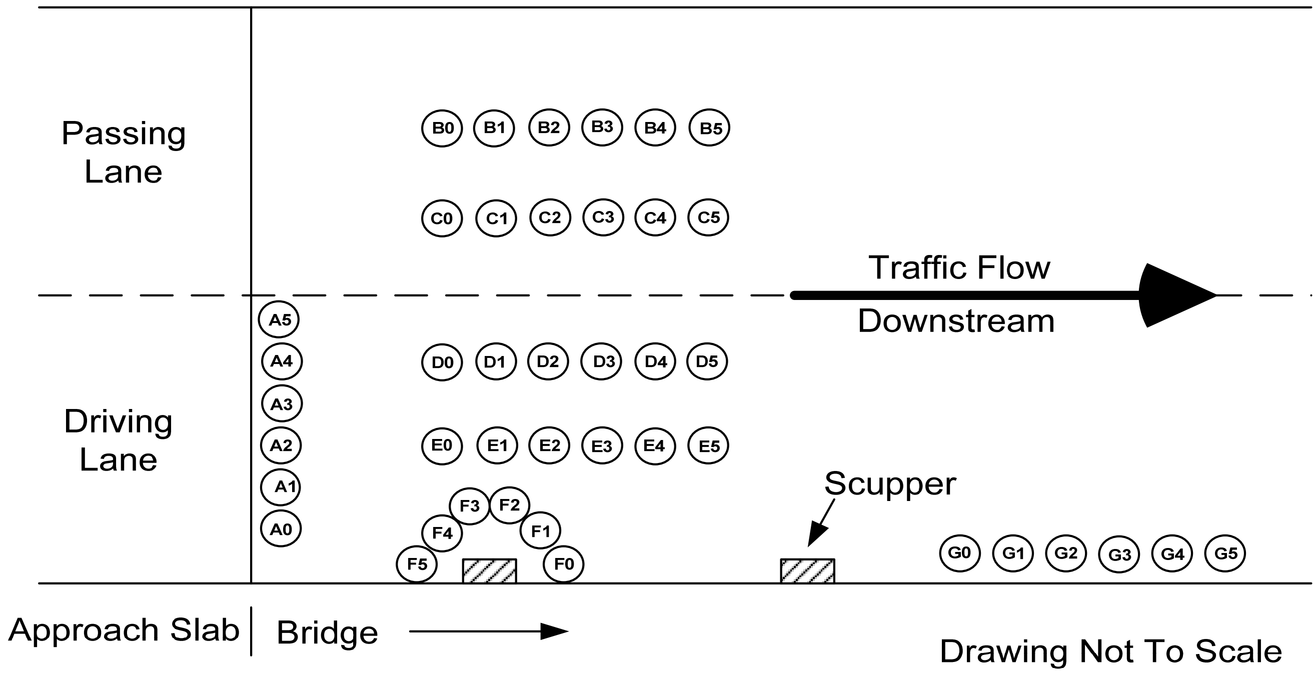



**Figure 10**

Figure 10 depicts the pattern of locations that resulted at the end of the 5 year sampling period. Each location is labeled with the numbers 0 through 5 depicting the location of the pre-sealing location through the 5th year's location.

The following procedure was used to drill and collect the proper number of samples from each sampling location.

A rotary impact drill with both a 1 inch and ¾ inch diameter masonry bits was used to make the sampling hole.

The impact drill was equipped with the 1 inch masonry bit. The drill was operated at the proper location and a hole created to a depth of ½ inch. The material was removed and the hole thoroughly cleaned with compressed air. The material removed from this portion of the hole was considered waste material.

Next, the impact drill was equipped with the ¾ inch masonry bit. The drill bit was placed in the same hole and drilled down an additional 1 inch. The drill bit was carefully removed from the hole and at least 10 grams of the pulverized material were collected. This material was placed into the properly labeled container. (Empty film canisters work excellent for sample containers.) Once the sample was collected, the hole was thoroughly cleaned with compressed air.

This last process was repeated an additional 2 times, for a total of 3 samples from the same hole. If reinforcing steel was encountered during the drilling of a sample, a new adjacent location was selected and collected.

Once the sampling process was completed the resulting hole was filled with non-shrink grout.

A diagram of the sampling hole may be seen in Figure 11.

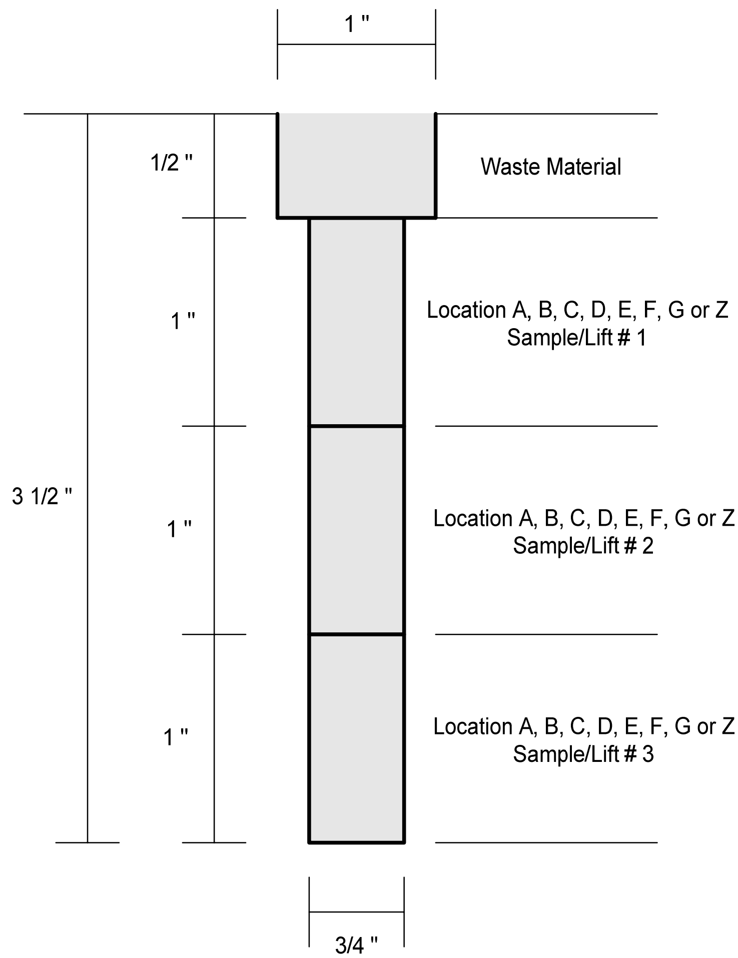



**Figure 11**

Each individual sample was placed in a separate container and properly labeled for testing. The label for each sample contained the following information shown in Figure 12. The label was permanently affixed to the outside of the sample container and clearly legible.

Location __________ Sample # ________
Structure # ______________________________
Date Sampled ___________________________
District ________ County ______________
Marked Route ___________________________

**Figure 12**

Chloride ion analysis was performed on each individual sample by the Bureau of Materials and Physical Research (BMPR) Analytical Chemistry Lab. The samples were prepared in accordance with AASHTO T260. The acid soluble chloride ion content was determined by a *Metrohm* automated titrator. The results were reported in ppm. These results were then entered into an Access database. The results were analyzed using an Excel spreadsheet. These are available upon request.

## BENEFITS

The primary benefit of utilizing sealers and laminates is the extension of the effective life of bridge deck concrete. Much has been documented regarding the cracking of concrete during early stages of cure. These cracks continue to be prevalent in current High Performance Concrete (HPC) mix designs that attempt to decrease the pore size and increase the density of the resultant concrete. Whether the use of cementitious replacements, engineering restraints or varying the construction practices, cracks are a fact of current concrete pours. These cracks provide immediate access into concrete decks and ultimately the reinforcement. The use of epoxy coated bars make corrosion less of a concern but damage to the epoxy coating may still allow access of the chlorides to the steel reinforcement. Freeze thaw damage is a concern when chlorides enter into the concrete paste. Some chloride containing chemicals have free ions that can form expansive reaction products with Portland cement paste. These expansive forces cause additional stresses and damage to the concrete deck. Penetrating sealers prevent the ingress of additional water and chloride ions, and crack sealers and laminates provide filling of the cracks and in some situations a whole new wearing surface. The long term benefits are more years of life for each structure, fewer repairs and fewer full deck replacements. Sealers are a low cost improvement that can easily be applied by IDOT's Maintenance, Operations and Day Labor forces.

## COSTS

The following is a relative scale of prices for the various types of sealers and laminates evaluated. Prices in this area are dynamic and difficult to tie down. The following values are based upon estimates gathered in 2008 and are only for the material costs and should not be considered final. The relative costs are sorted by lowest to highest in cost per square foot.

## Sealer and Laminate Costs
## Table 7

| Product | Manufacture | Type | Carrier | Application Rate | Cost Estimate Per/Sq. Ft. *Dual application rates included |
|---|---|---|---|---|---|
| Clear Masonry Sealer | Weatherall Company Inc. | Penetrating Silane/Siloxane | Water | 325 $ft^2$/gal | $0.10 |
| Protective Coat | Std. Spec. Article 1023.01 | Boiled Linseed Oil/Mineral Spirits | Solvent | 450 $ft^2$/gal x2 | $0.12 |
| Tri-Siloxane TK-290 W.B. | TK Products Inc. | Penetrating Silane/Siloxane (10% and 20%) | Water | 150 $ft^2$/gal | $0.13 |
| Tri-Siloxane TK-290 | TK Products Inc. | Penetrating Siloxane (16%) | Water | 150 $ft^2$/gal | $0.13 |
| Sil-Act Multigard | Advanced Chemical Technologies | Penetrating Silane 100% apply with water | Water | 100 $ft^2$/gal | $0.13 |
| ChemTec One | Chem Tech Int'l | Penetrating Silica | Water | 100 $ft^2$/gal x2 | $0.14 |
| WB 244 | Tamms Industries | Penetrating Silane/Siloxane (<20%) | Water | 150 $ft^2$/gal | $0.17 |
| Deck A Pell 15% | Chemprobe Technologies, Inc. | Penetrating Silane/Siloxane (15%) | Solvent | 150 $ft^2$/gal | $0.19 |
| Dural 335 (found in Failed file) | Tamms Industries | Healer / Sealer (100% epoxy resin) | Epoxy | 300 $ft^2$/gal | $0.20 |
| Dur A Pell 20 | Chemprobe Technologies, Inc. | Penetrating Silane/Siloxane (20%) | Water | 150 $ft^2$/gal | $0.20 |
| TK 9000 | TK Products Inc. | Crack Sealer (100% epoxy resin) | Epoxy | | $0.23/ft of crack length |
| Dur A Pell 100 S | Chemprobe Technologies, Inc. | Penetrating Silane (>= 95%) | Solvent | 300 $ft^2$/gal | $0.29 |
| Water Repellent # 2 | Weatherall Company Inc. | Penetrating Silane/Siloxane | Solvent | 100 $ft^2$/gal | $0.40 |
| Duraguard 401 | ChemMasters | HMWM Healer / Sealer | HMWM | 150 $ft^2$/gal | $0.47 |
| Mark 135 "Safe-T-Seal" | Poly Carb, Inc. | Laminate material (crack welder) | Epoxy | Paint rollers/sand dusted | $0.65/Sq. ft Includes sand |
| Mark 135.3 | Poly Carb, Inc. | Laminate material | Epoxy | Paint rollers/sand dusted | $0.65/Sq. ft Includes sand |
| Mark 154 | Poly Carb, Inc. | Laminate material | Epoxy | ¼ inch to 3/8 inch x2 | $2.15 Sq. ft Includes aggregate |
| Mark 163 "Flexogrid" | Poly Carb, Inc. | Laminate material (hybridized copolymer) | Epoxy | ¼ inch to 3/8 inch x2 | $2.80/Sq. ft includes aggregate |
| Thin Polymer Overlay | Poly Carb, Inc. | Laminate Material | Epoxy | ¼ inch to 3/8 inch x2 | >$2.15/Sq. ft. includes aggregate |
| Microsilica Overlay | | Concrete Overlay | NA | Hand poured/ finished | |
| Latex Portland cement concrete overlay | | Concrete Overlay | NA | 3 ½ inch overlay | $13.89/Sq. ft. |

The costs of the products range from $0.10 to $0.40 per square foot for the spray applied penetrating sealers. The laminate systems vary depending upon type of system, surface preparation requirements and aggregate sources.

# RESULTS

The following graphs summarize the results of the various sealers versus the control structure in the same geographic region. The control structure does not have a sealant or laminate applied to the deck surface. The control structure is of similar age, construction practices, traffic volumes and anti-icing/deicing practices as the sample structures on the same graphs. The graphs represent each consecutive year of sampling, each depth (lift) of sample and all products that fall under the same age and construction. The lifts, found demonstrated in Figure 11, represent each depth of concrete dust collected and tested for chloride ion content. The first lift represents samples from ½ inch to 1 ½ inches, the second lift represents 1 ½ inches to 2 ½ inches, the third lift represents 2 ½ inches to 3 ½ inches. The scale of the ppm of chloride changes to accommodate the increased levels over time. The results listed are averages for each sample location on each bridge on which the product was applied. The graphs listed as control structures were collected on structures with no sealer or laminate applied to the deck surface. These structures were evaluated to demonstrate the level of chloride ingress expected on structures that are not protected. These controls were not compared directly to structures in the same geographical region with product applied.

The background levels of chloride were taken for each sample location and on each structure. The background levels, denoted by the red bar, included in the graphs are for the control structure but represent all structures on the graph. The red bar is a representation of the starting point of the chloride ion levels in the concrete prior to sealer product application and the subsequent use of deicing chemicals. The following Figure 13 represents the IDOT Districts as utilized in the following graphs.

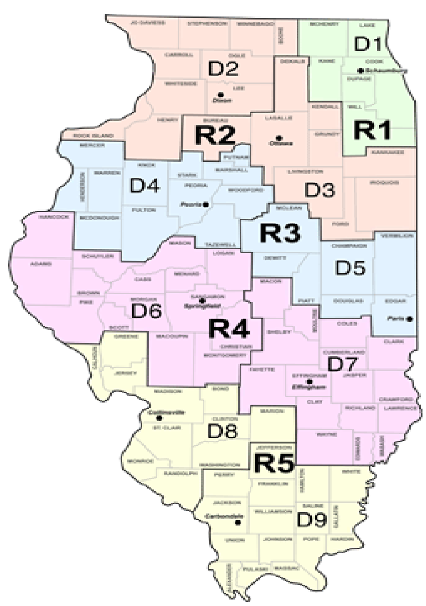
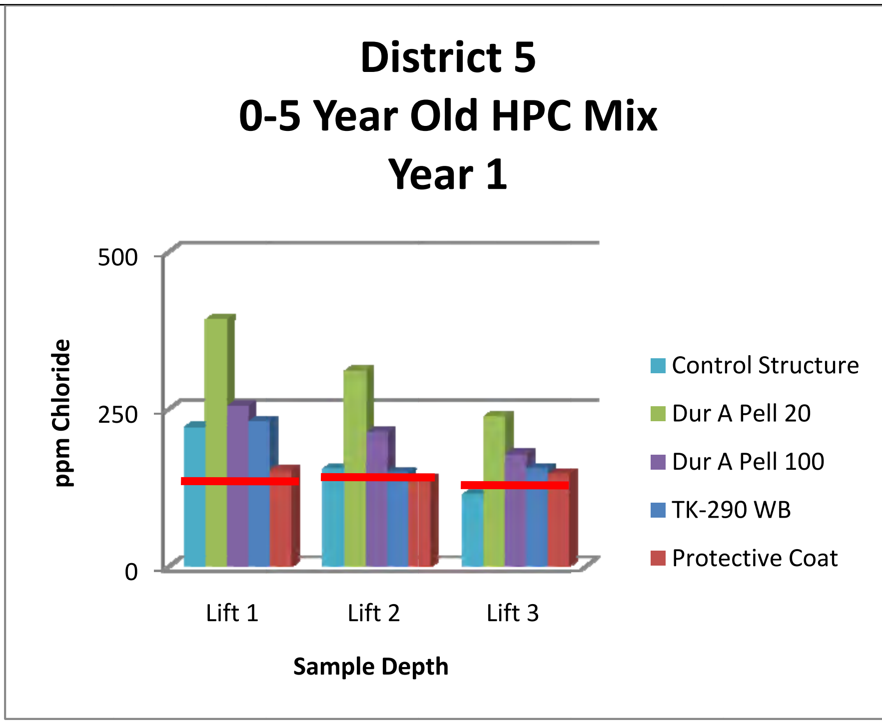


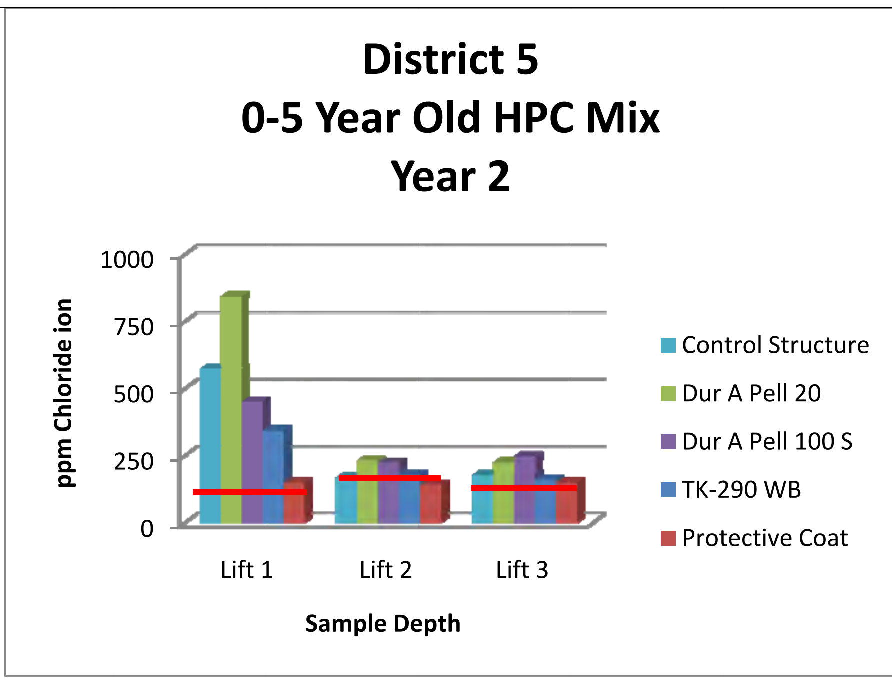

**Figure 13**




**Graph 1** depicts that after one year the Dur A Pell 20 product allowed significantly more ingress of chloride ions into the bridge deck as compared to the other products and the control structure.

Baseline values denoted by:

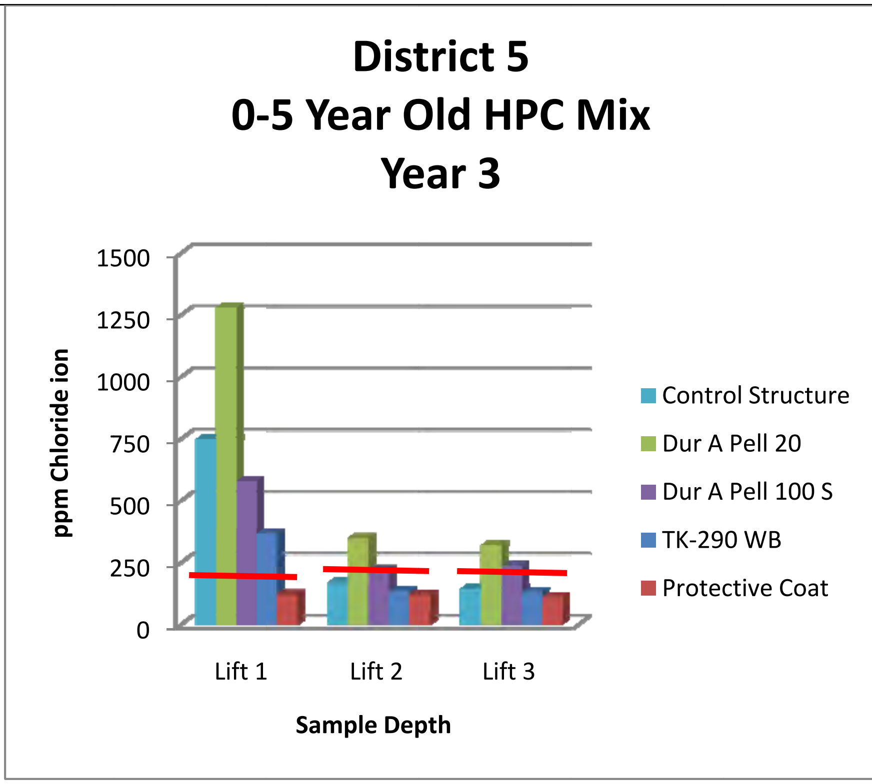
**Graph 1**




**Graph 2** depicts that after two years the Dur A Pell 20 product allowed significantly more ingress of chloride ions into the top 1½ inch of the bridge deck as compared to the other products and the control structure. After two years the other products are starting to show similar levels of ingress.

Baseline values denoted by:

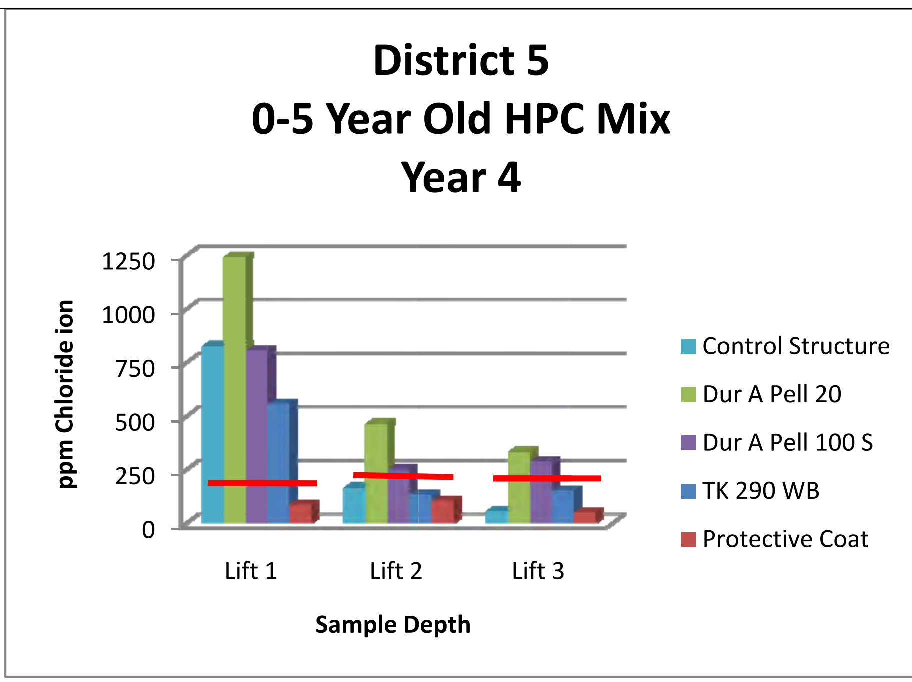
**Graph 2**




**Graph 3** depicts that after three years the Dur A Pell 20 product allowed significantly more ingress of chloride ions into the top 1½ inch of bridge deck as compared to the other products and the control structure. After three years the other products show similar levels of ingress. The Dur A Pell products are both showing more ingress than the control. The TK product and protective coat are showing improvement over the control.

Baseline values denoted by:

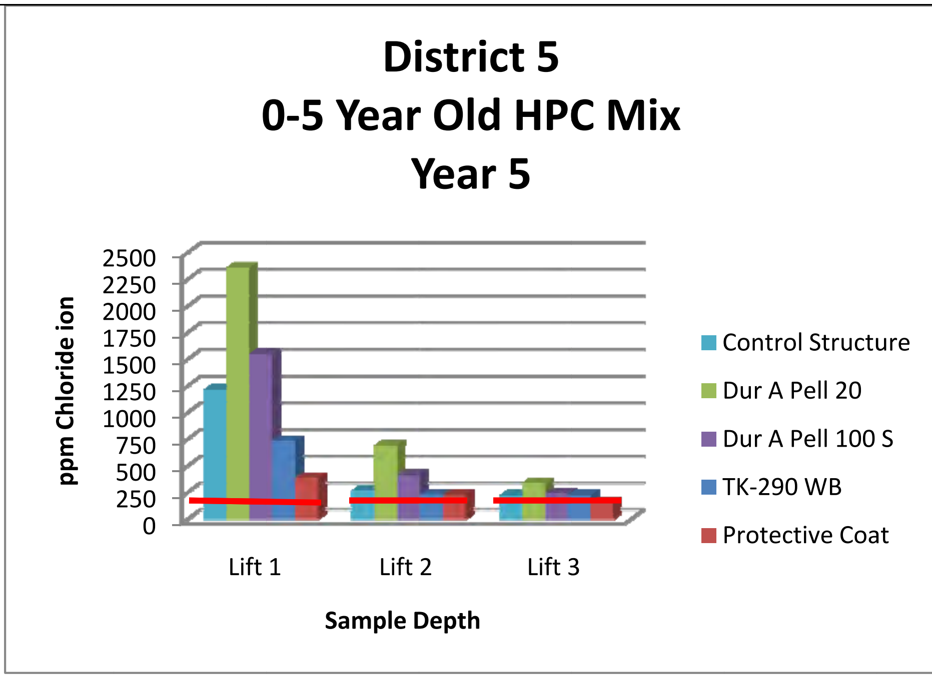
**Graph 3**




**Graph 4** depicts that after four years the only product that is showing less ingress at all depths is protective coat. The TK290 WB product is less than the control at all depths except lift 3.

Baseline values denoted by:

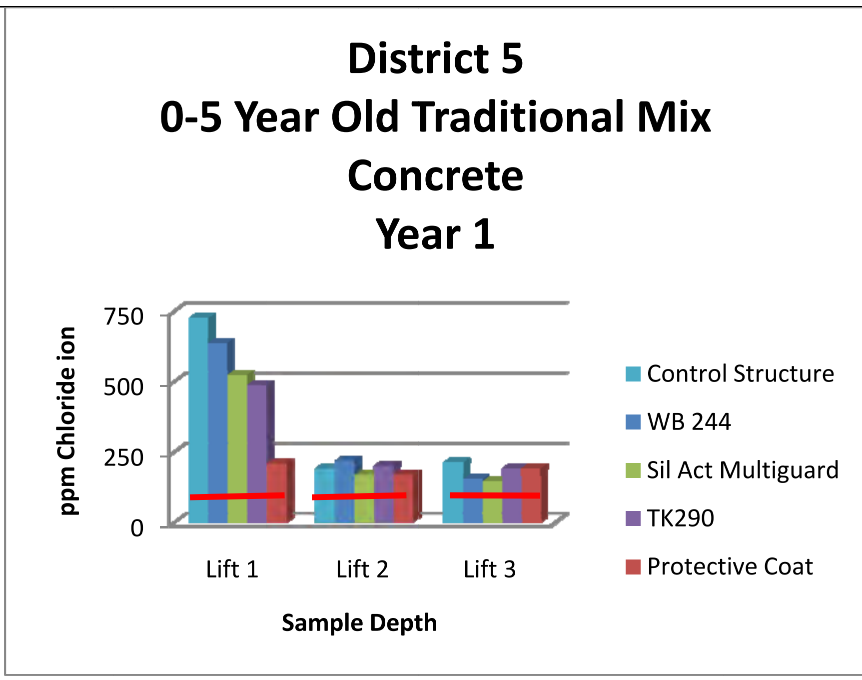
**Graph 4**




**Graph 5** depicts that after five years the Dur A Pell products are both in excess of the control. The TK products and the protective coat are both performing better than the control structure that is unprotected.

Baseline values denoted by: ▬

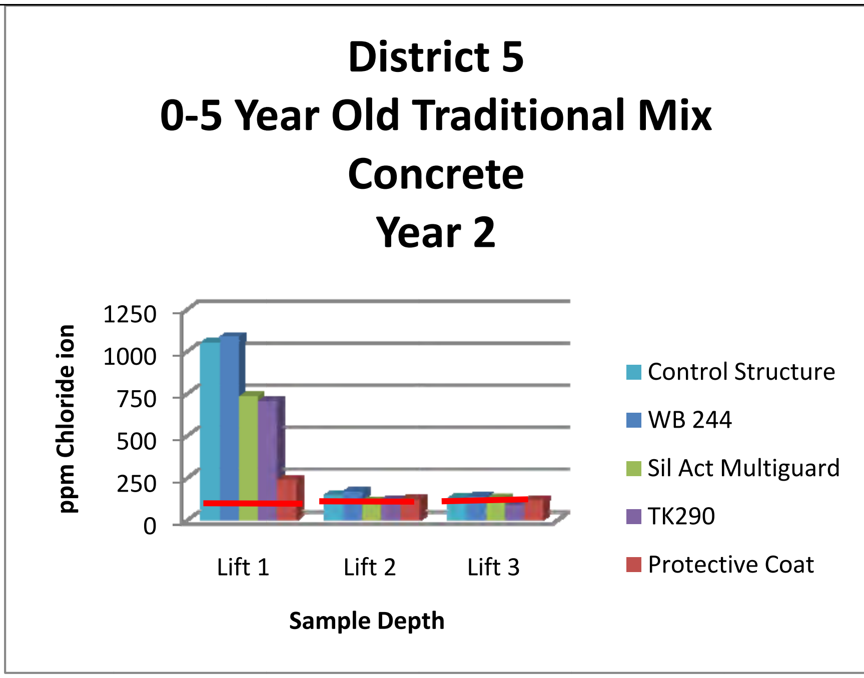
**Graph 5**




**Graph 6** depicts that after one year all products are protecting the decks more than the control structure without sealant.

Baseline values denoted by: ▬

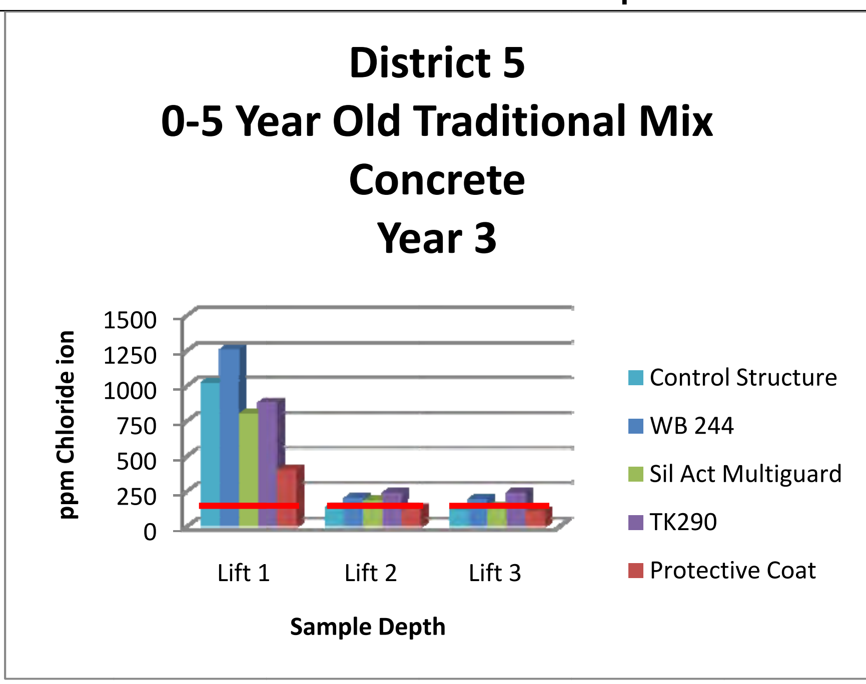
**Graph 6**




**Graph 7** depicts that after two years the WB 244 product is allowing more ingress than the other products and the control.

Baseline values denoted by:

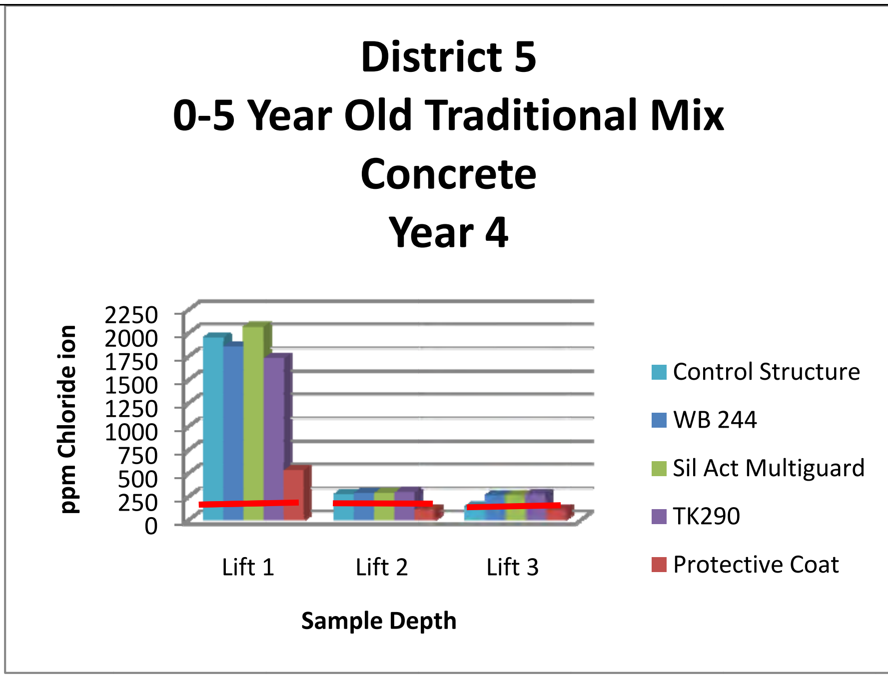
**Graph 7**




**Graph 8** depicts that after three years the majority of ingress is still isolated to the first lift and that the WB 244 product is the only one with ingress greater than the control. Protective coat is the only product to have less ingress than the control in all lifts.

Baseline values denoted by:

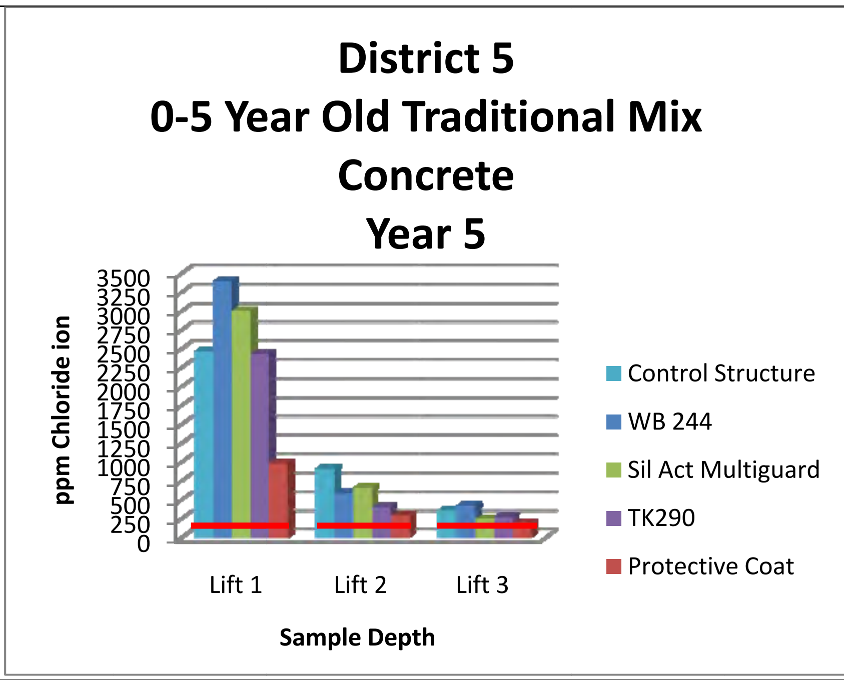
**Graph 8**




**Graph 9** depicts that after four years the only product that is showing less ingress at all depths is protective coat. The remaining products are maintaining ingress roughly the same or greater than the control.

Baseline values denoted by:

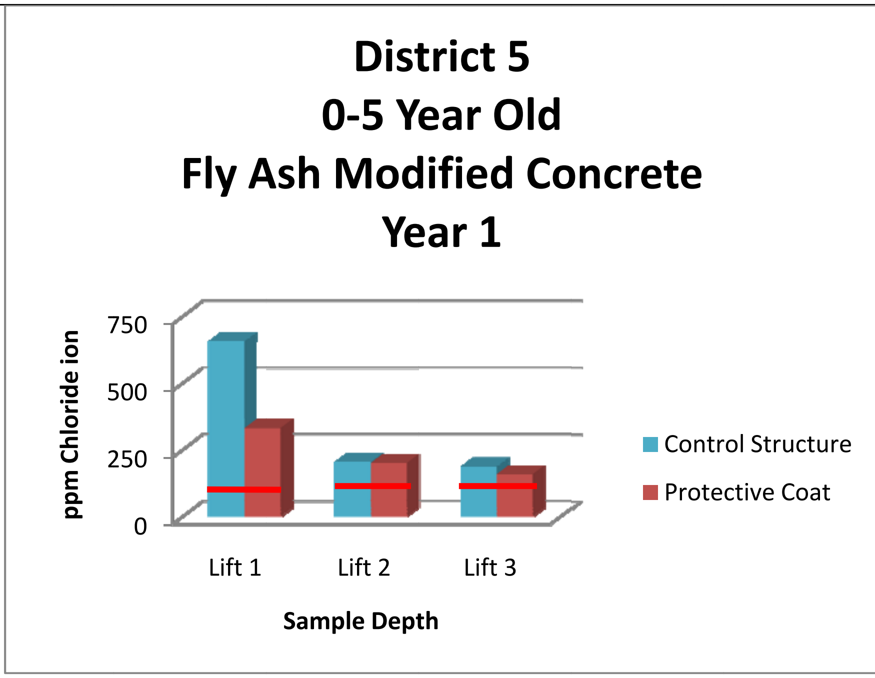
**Graph 9**




**Graph 10** depicts that after five years the only products that are showing less ingress at all lifts are protective coat and TK 290. The other products are providing protection from ingress at depths two and three after 5 years demonstrating that limited salts are getting to the level where corrosion of steel would be a concern.

Baseline values denoted by:

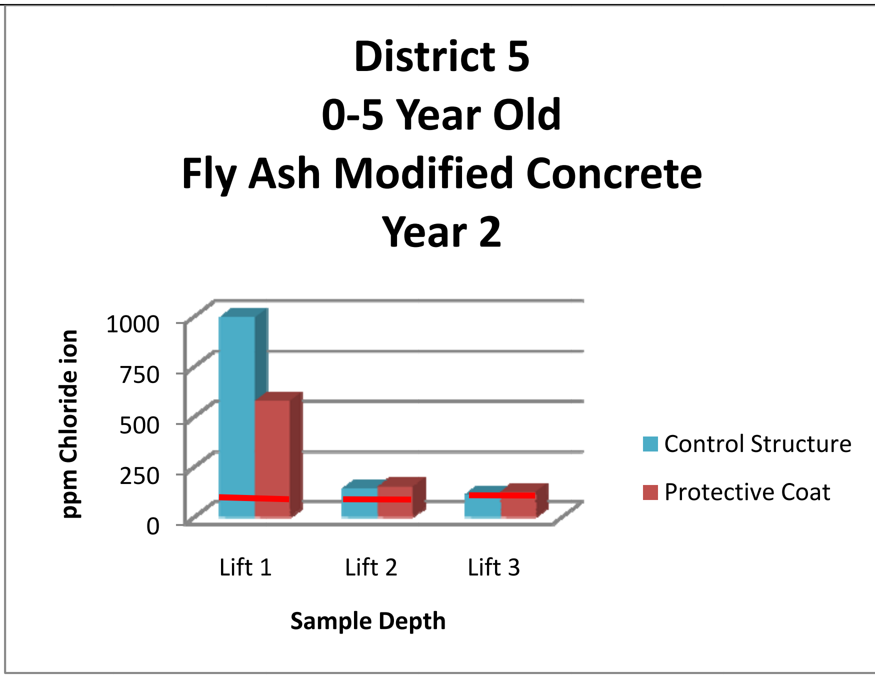
**Graph 10**




**Graph 11** depicts that after one year the protective coat is providing protection from ingress.

Baseline values denoted by:

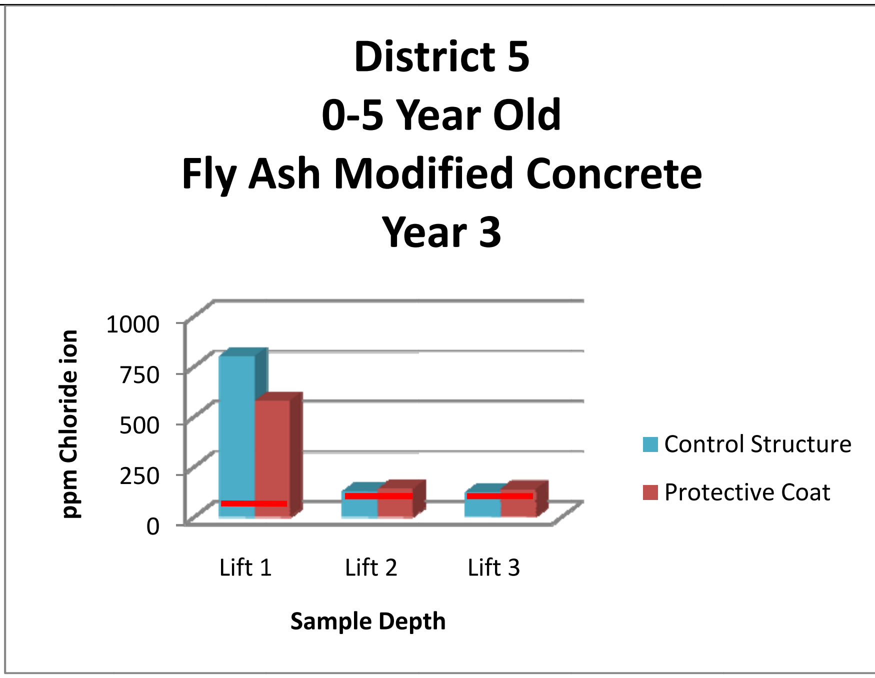
**Graph 11**




**Graph 12** depicts that after two years the protective coat is providing good protection at the upper lift as compared to the control.

Baseline values denoted by:

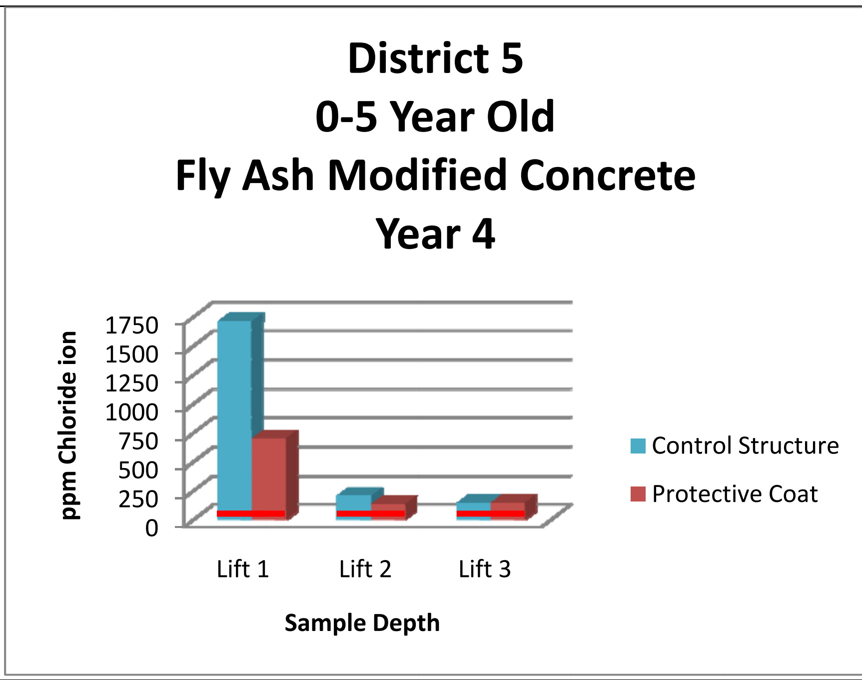
**Graph 12**




**Graph 13** depicts that after three years protective coat is staying at the same levels of protection as year 2.

Baseline values denoted by:

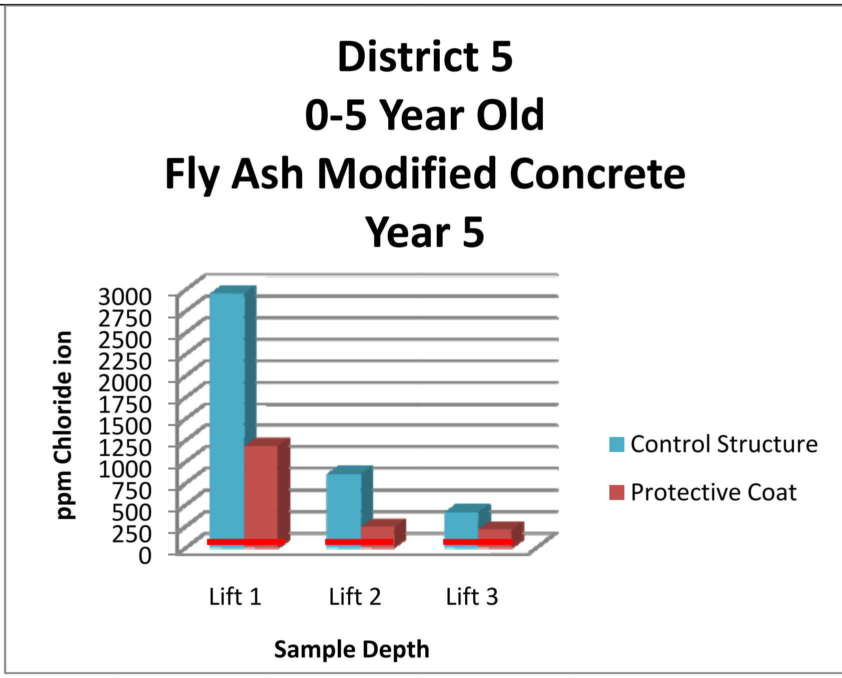
Graph 13




**Graph 14** depicts that after four years protective coat is limiting chloride ion ingress to levels comparable with or below the control structure at all depths.

Baseline values denoted by:

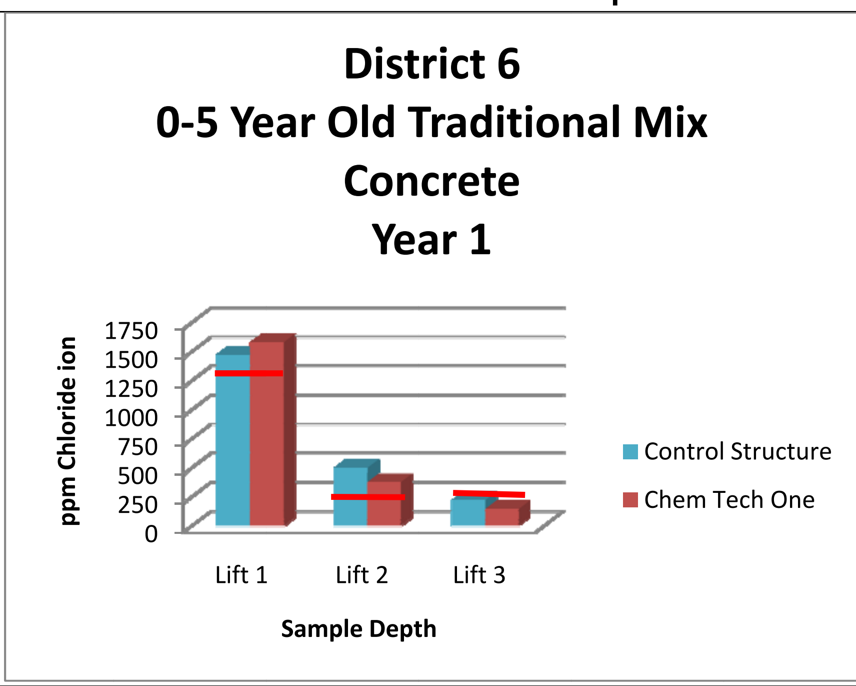
Graph 14




**Graph 15** depicts that after five years the protective coat is starting to show chloride ingress in the first depth. The product is starting to show signs of allowing chlorides to ingress.

Baseline values denoted by:

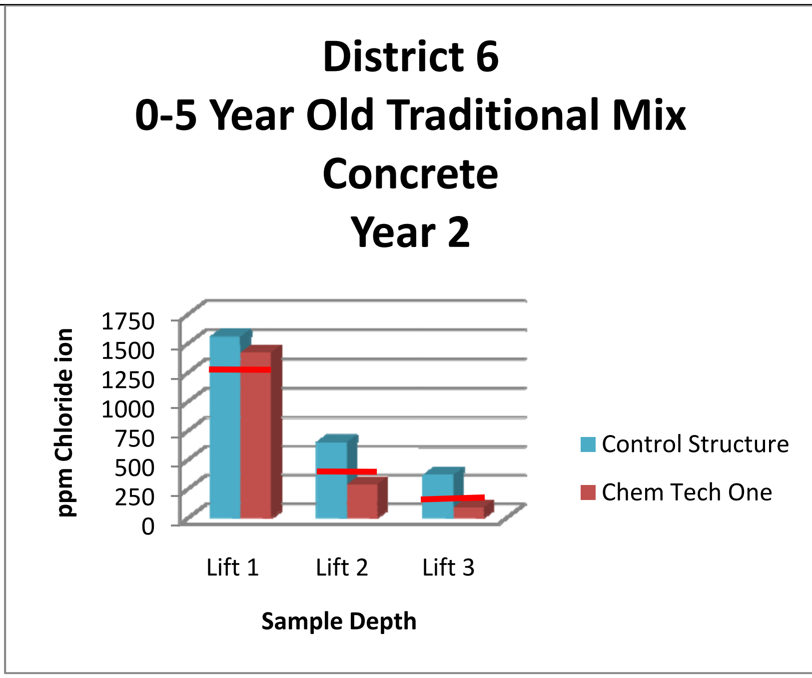
**Graph 15**




**Graph 16** depicts that after one year the Chem Tech One is collecting more chlorides in the first lift than the control structure.

Baseline values denoted by:

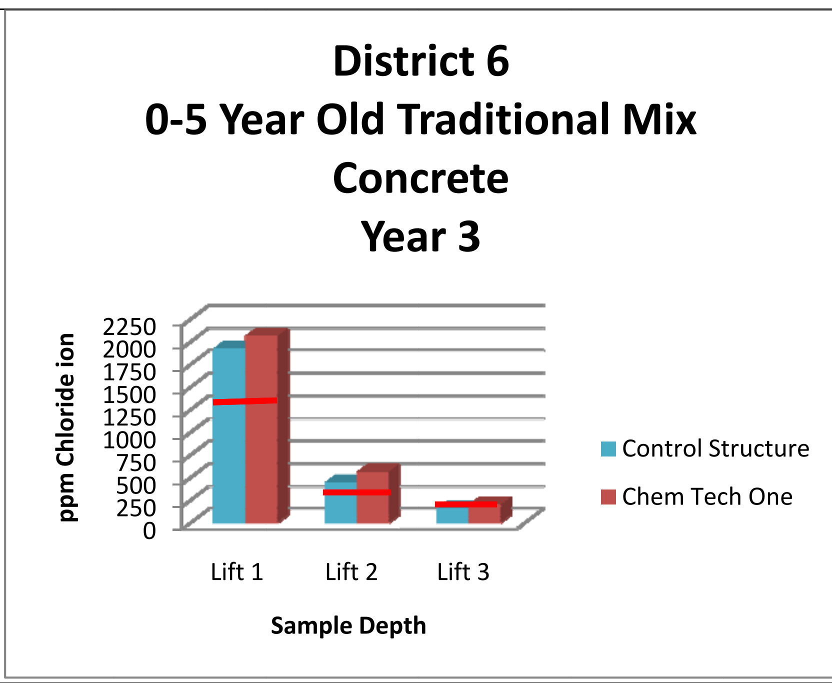
**Graph 16**




**Graph 17** depicts that after two years the chloride levels for the Chem Tech One product are down from year 1 and are less than the control at all levels.

Baseline values denoted by:

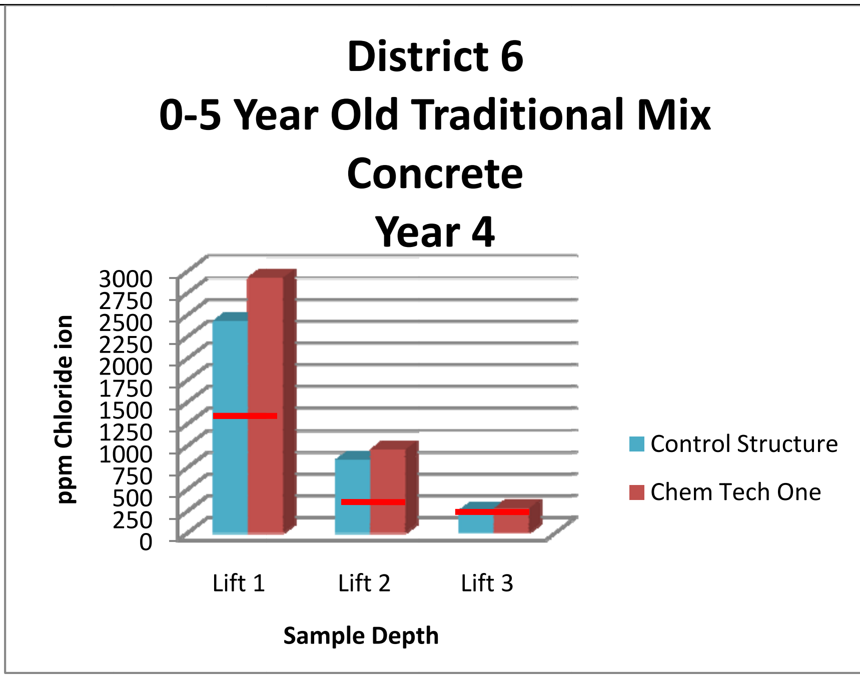
**Graph 17**




**Graph 18** depicts that after three years the Chem Tech One product is showing more ingress at all depths than the control.

Baseline values denoted by:

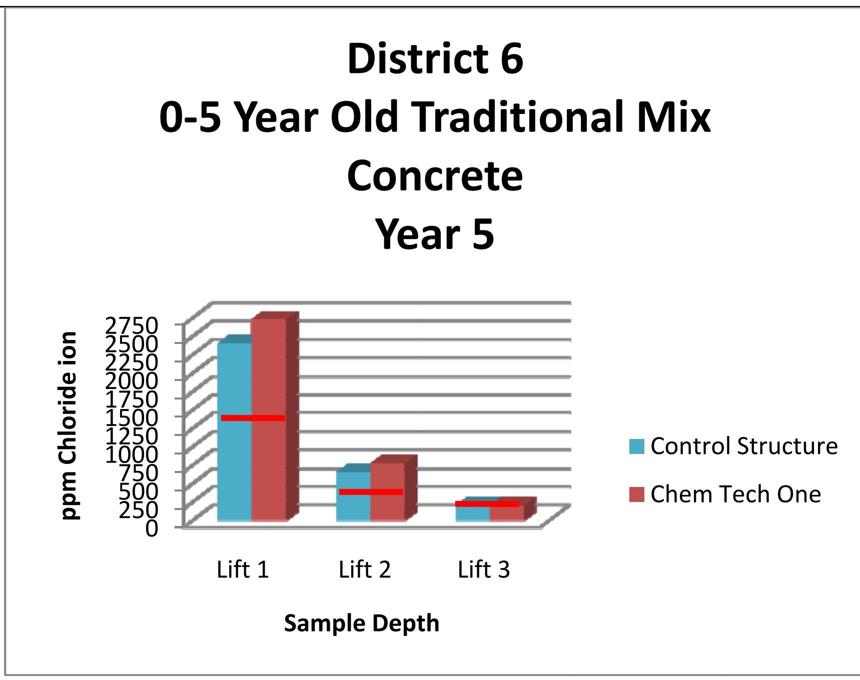
**Graph 18**




**Graph 19** depicts that after four years the Chem Tech One product is allowing more ingress than the control at all lifts.

Baseline values denoted by:

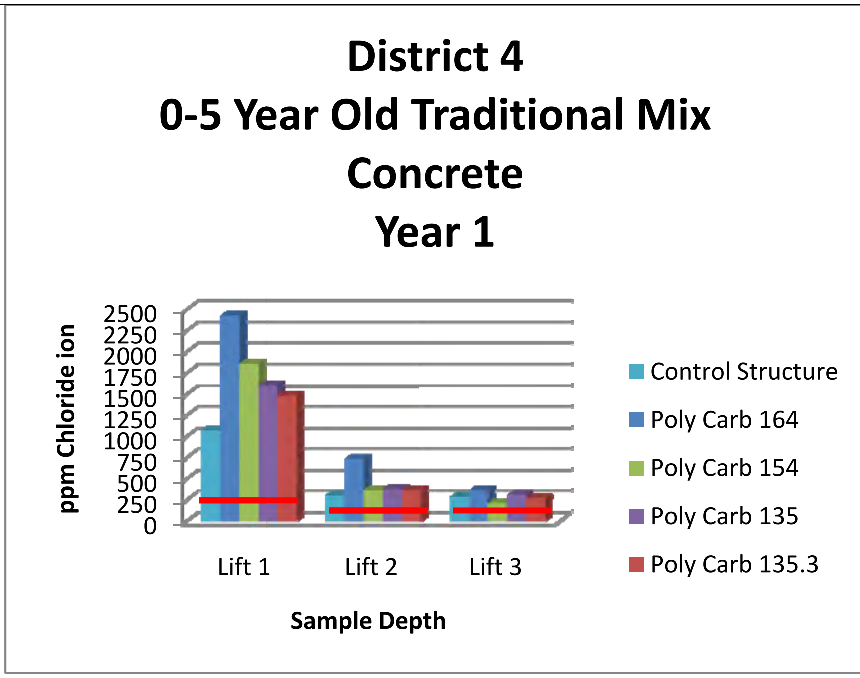
**Graph 19**




**Graph 20** depicts that after five years the Chem Tech One product is not preventing chloride ion ingress. The sealer is not providing an increase in protection over the control section without product.

Baseline values denoted by:

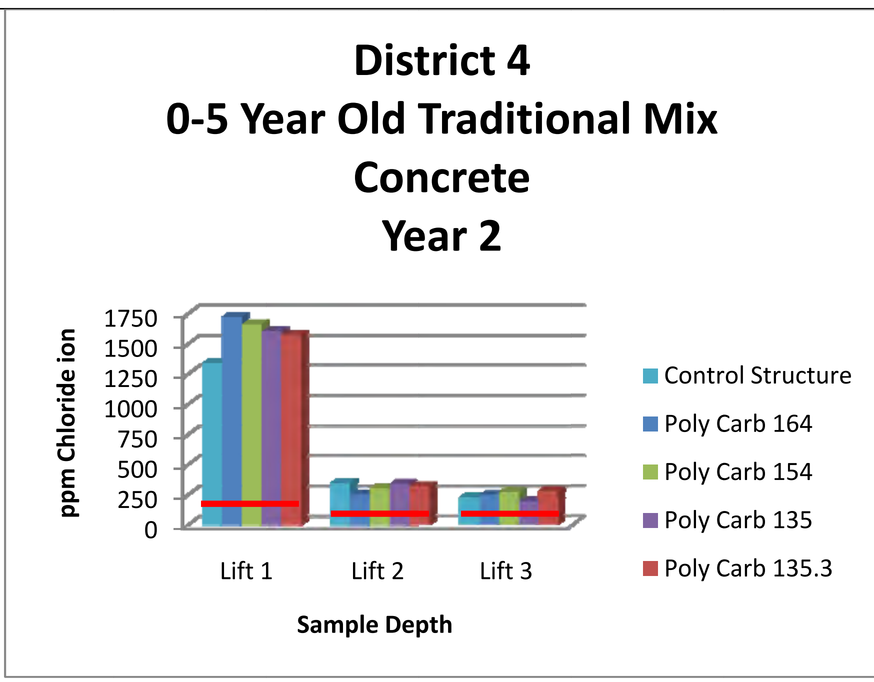
**Graph 20**




**Graph 21** depicts that after one year the Poly Carb products are all showing more chloride ingress at the first lift than the control.

Baseline values denoted by:

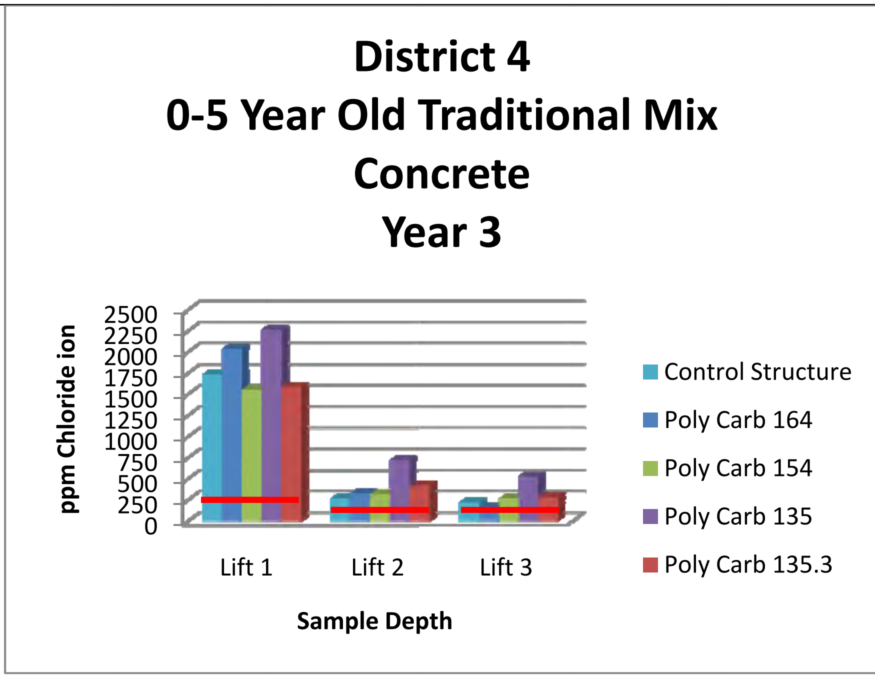
**Graph 21**




**Graph 22** depicts that after two years the Poly Carb products are all showing more chloride ingress at the first lift than the control. The amounts are starting to level off.

Baseline values denoted by:

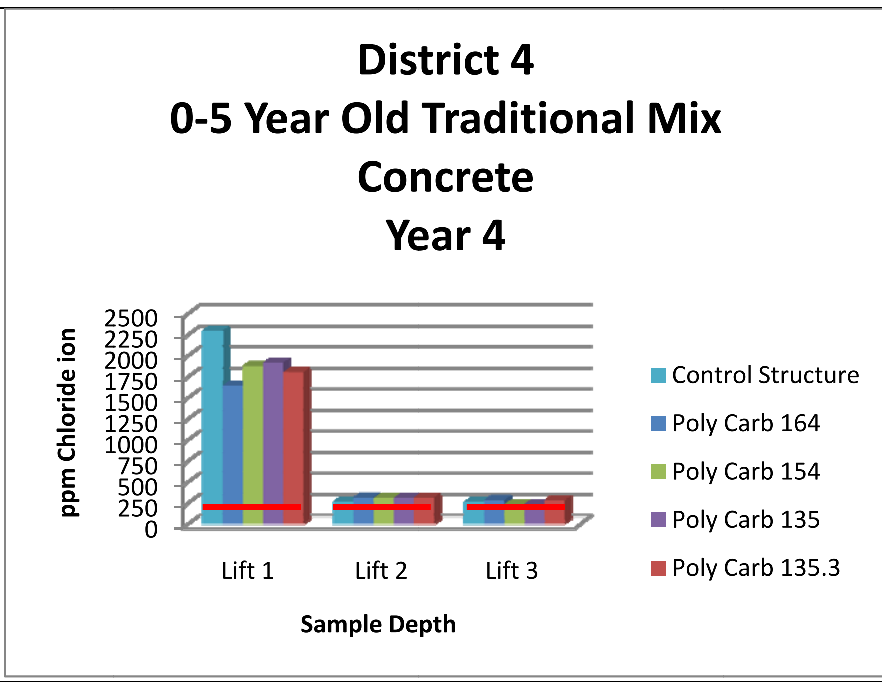
**Graph 22**




**Graph 23** depicts that after three years the Poly Carb product 135 is standing out as showing ingress at all lifts. The chloride ingress levels for the remaining products have stabilized.

Baseline values denoted by:

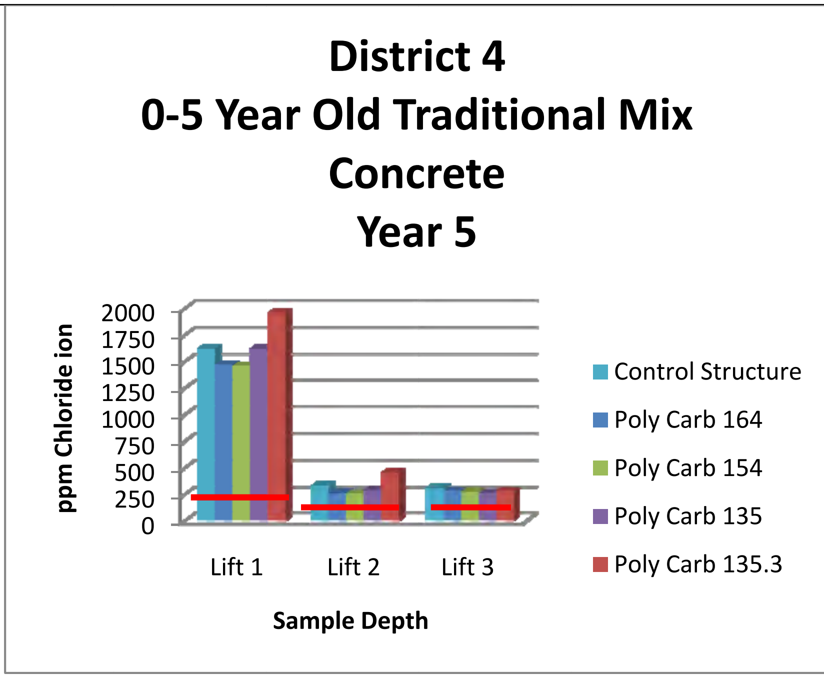
Graph 23




**Graph 24** depicts that after four years the Poly Carb products are all showing chloride ingress at the first lift but limited ingress in the second and third lifts.

Baseline values denoted by:

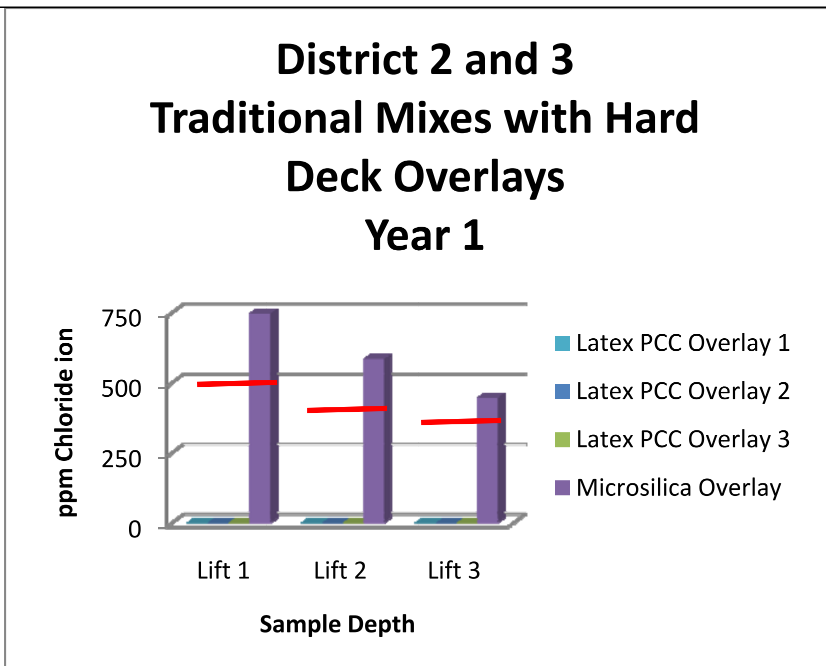
Graph 24




**Graph 25** depicts that after five years the Poly Carb product 135.3 is showing more ingress at lifts one and two. The other products are all showing chloride ingress at the first lift but limited ingress in the second and third.

Baseline values denoted by:

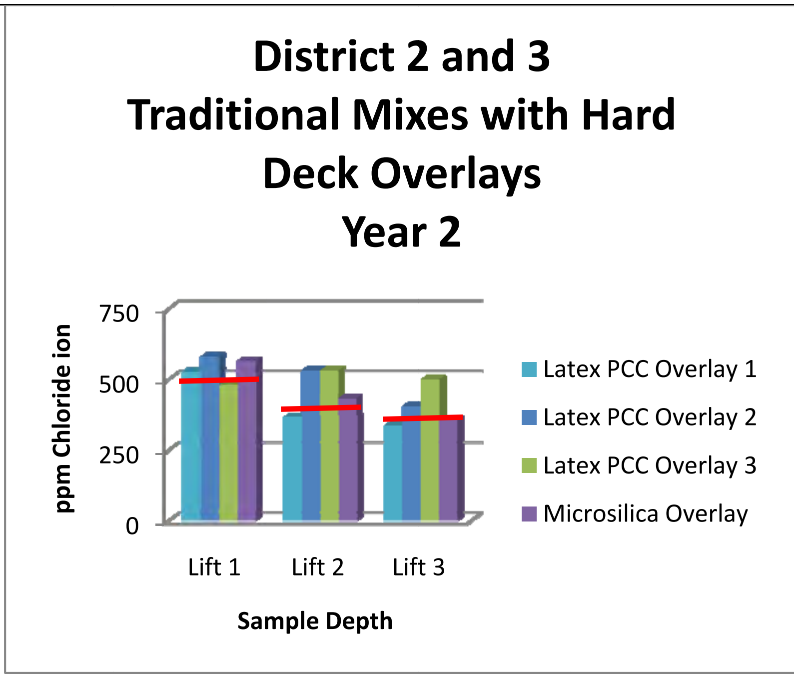
**Graph 25**




**Graph 26** The Microsilica overlay was the only deck sampled due to construction and traffic control limitations.

Baseline values denoted by:

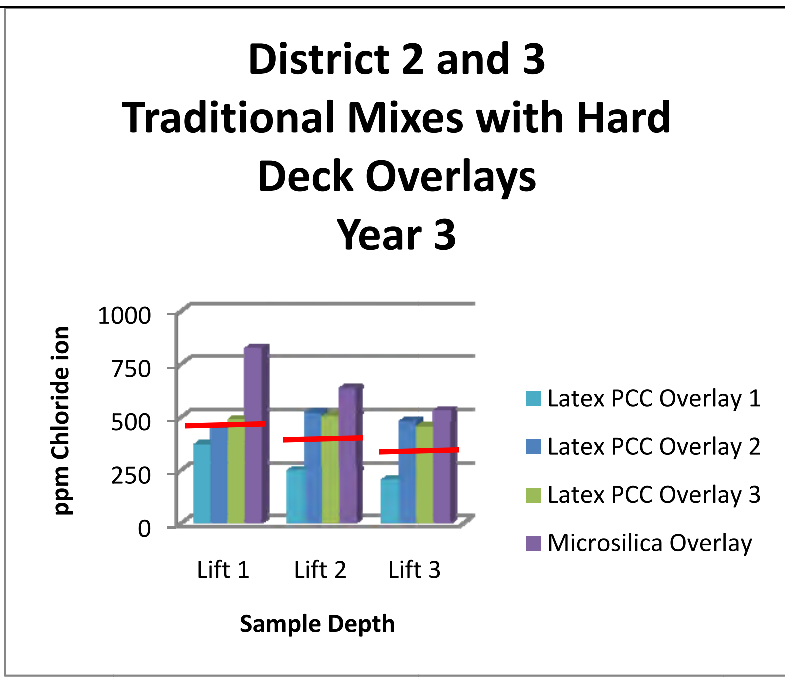
**Graph 26**




**Graph 27** depicts that after two years all of the overlays were at the same levels of chloride ingress at each lift.

Baseline values denoted by:

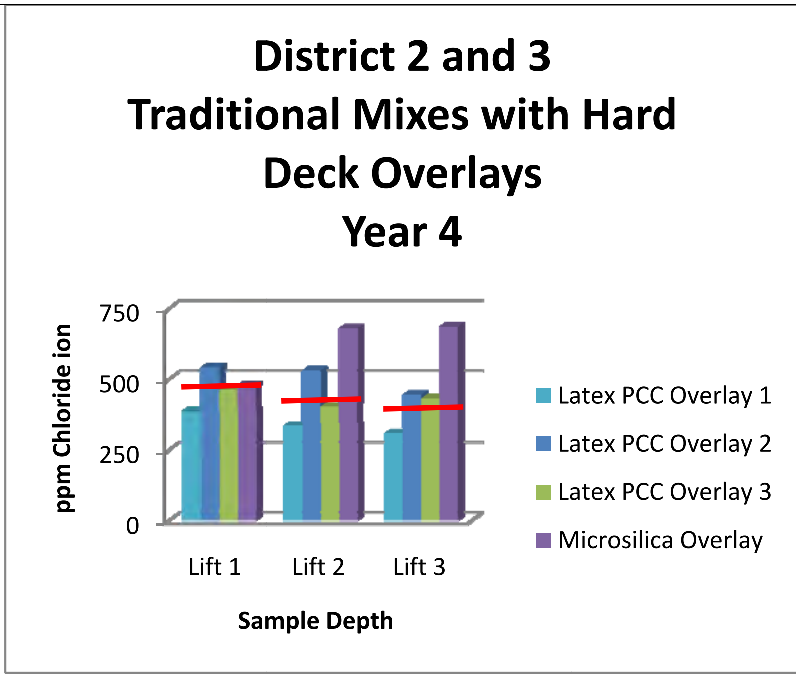
**Graph 27**




**Graph 28** depicts that after three years all of the overlays are at the same or lower levels of chloride ingress at each depth as when they were installed. The subtle changes are likely due to testing variability.

Baseline values denoted by:

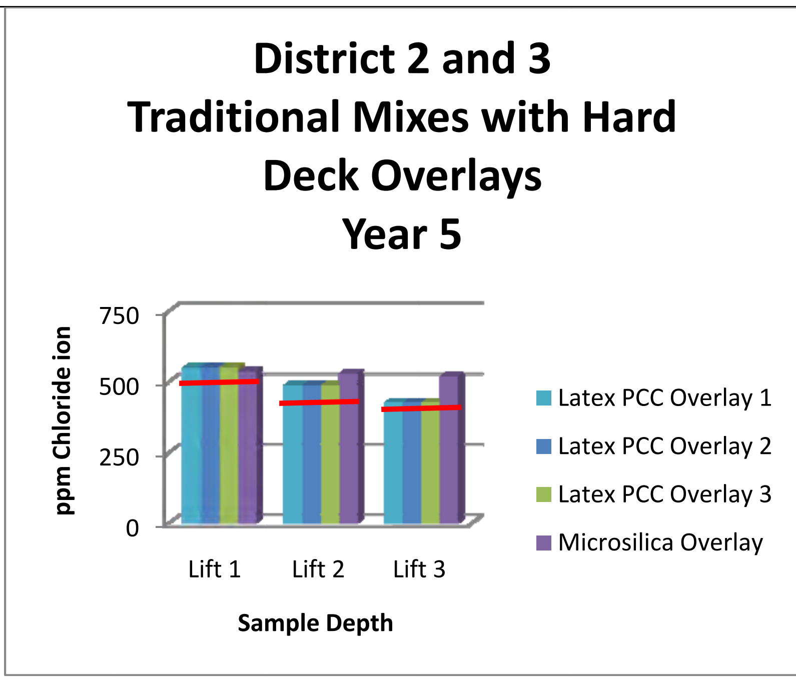
**Graph 28**




**Graph 29** depicts that after four years each of the overlays are at similar levels of chloride ingress at each depth as previously found for the particular overlay.

Baseline values denoted by:

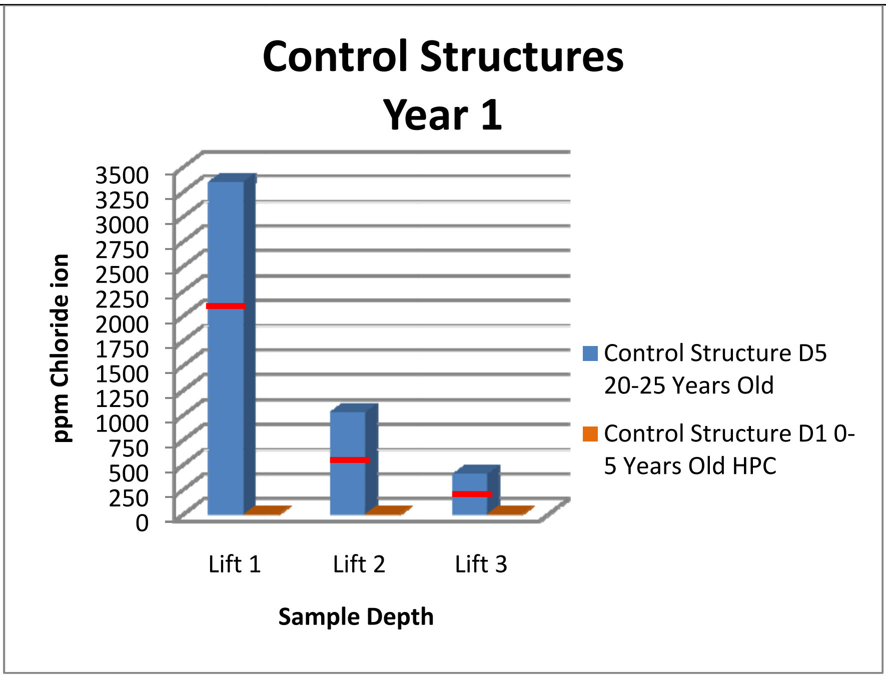
**Graph 29**




**Graph 30** depicts that after five years all of the overlays are at very similar levels of chloride ingress at each depth.

Baseline values denoted by:

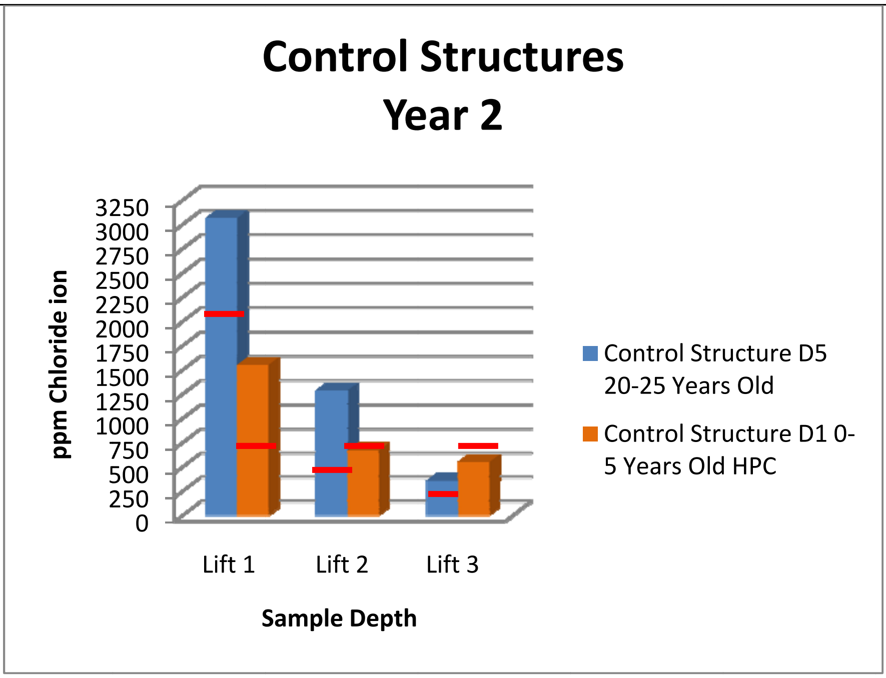
**Graph 30**




**Graph 31** depicts that after one year one control structure was sampled and one was not. It also shows that structures in service 20-25 years have significant chlorides if left unprotected.

Baseline values denoted by:

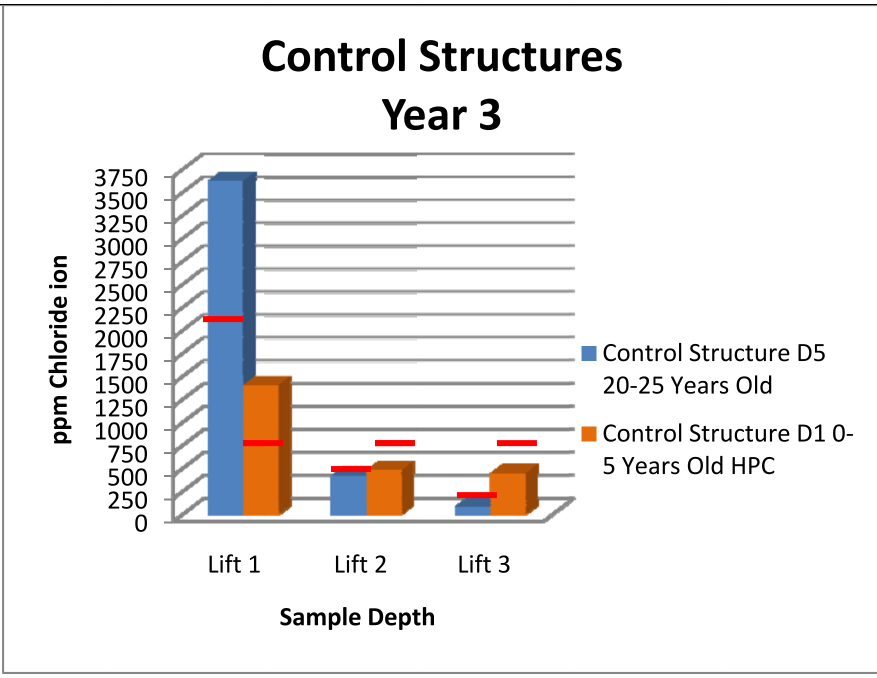
Graph 31




**Graph 32** depicts that after two years both control structures were sampled. Structures in service 0-5 years without a sealant have significant chloride ion ingress.

Baseline values denoted by:

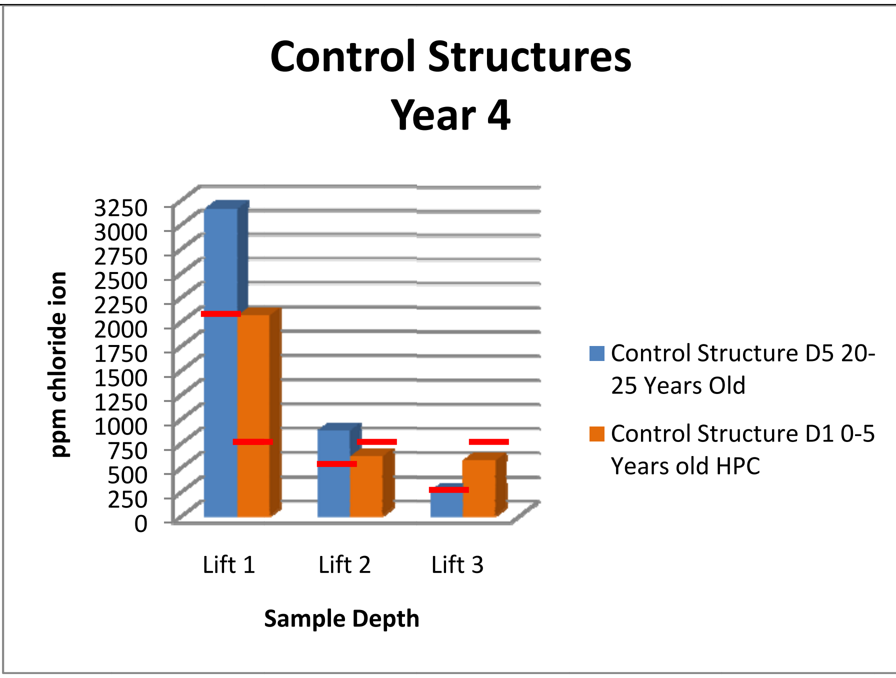
Graph 32




**Graph 33** depicts that after three years the control structures continue to see increases in chloride ions.

Baseline values denoted by:

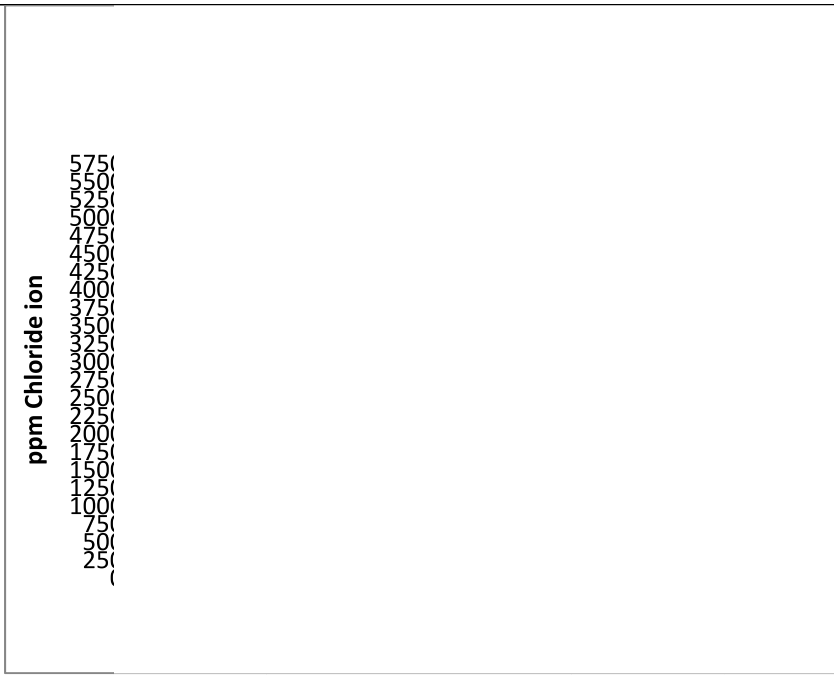
Graph 33




**Graph 34** depicts that after four years both control structures continue to ingress chloride ions in all lifts.

Baseline values denoted by:

Graph 34




**Graph 35** depicts that after five years both control structures continue to significantly ingress chloride ions at all lifts of the concrete. This demonstrates the need for sealants on both new construction and existing structures.

Baseline values denoted by:

**Graph 35**

The results demonstrate that bridge decks in Illinois are seeing significant chloride ion ingress if not protected. They also show that significant improvements are made if a sealer or laminate is used. The type of sealer or laminate is shown to be significant in terms of long term protection from ingress. As control structures continue to increase in chloride ion ingress at all levels, the decks with a sealer or laminate show significantly less chloride ion ingress at the second and third lifts which indicate the levels of chloride in potential contact with reinforcement bar. Preventing the electrolyte, chloride ion, from accessing the reinforcement steel will significantly diminish the potential for a corrosion cell to form. Elimination of the corrosion cell leads to greater strength and durability of the concrete infrastructure.

## Sealer and Laminate Performance and Durability
## Table 8

| | | | | |
|---|---|---|---|---|
| | | | | |
| Latex Portland cement concrete overlay | No significant change in chloride levels after 5 years. No increase in the interface of the existing and laminate overlay. | Concrete Overlay | 5+ years | Use if practical |
| | | | | |
| Tri-Siloxane TK-290 W.B. | After 5 years showing increase in penetration in the first depth. The second and third lifts just starting to hint at ingress. Beginning durability issues after 5 years. | Penetrating Silane/ Siloxane (10% and 20%) | 5 years | Use for all new and existing concrete. Reapply after 5 years. Caution with water-based reapplication issues. |
| | lift earlier than most. Didn’t | | | |
| Dur A Pell 20 | After 5 years allowed significant increase in first lift. Some ingress in lift two after 4 years. | Penetrating Silane/ Siloxane (20%) | 4 years | Use for all new and existing concrete. Reapply after 4 years. |
| | years both lifts 1 and 2 | | | Use for all new and existing concrete. Reapply after 4 |
| Sil-Act Multigard | After 4 years the first depth shows major ingress, second depth slight ingress. After 5 years more than in year 4. | Penetrating Silane | 4 years | Use for all new and existing concrete. Reapply after 4 years. |
| | ingress in first lift. After 5 years more in lift 1 and increases in lift 2. | | | Use for all new and existing concrete. Reapply after 4 |
| Mark 154 | The thin polymer overlay systems show increased chlorides in the first lift and very little ingress in lifts 2 and 3. May be trapping chlorides in the interface of the existing deck and laminate? | Laminate material | 4 years | When used, monitor for de-lamination and chloride buildup in the first lift. Protects from chloride ingress to steel but may cause surface freeze thaw issues? |
| | The thin polymer overlay systems show increased and 3. May be trapping chlorides in the interface of | | | When used, monitor for de-lamination and chloride buildup in the first lift. Protects from chloride ingress to steel but may |

| Product | Description of Performance | Type | Durability/ Service Life | Recommendations |
|---|---|---|---|---|
| Mark 135.3 | The thin polymer overlay systems show increased chlorides in the first lift and very little ingress in lifts 2 and 3. May be trapping chlorides in the interface of the existing deck and laminate? | Laminate material | 4 years | When used, monitor for de-lamination and chloride buildup in the first lift. Protects from chloride ingress to steel but may cause surface freeze thaw issues? |
| Thin Polymer Overlay | The thin polymer overlay systems show increased chlorides in the first lift and very little ingress in lifts 2 and 3. May be trapping chlorides in the interface of the existing deck and laminate? | Laminate Material | 4 years | When used, monitor for de-lamination and chloride buildup in the first lift. Protects from chloride ingress to steel but may cause surface freeze thaw issues? |
| Mark 163 "Flexogrid" | The thin polymer overlay systems show increased chlorides in the first lift and very little ingress in lifts 2 and 3. May be trapping chlorides in the interface of the existing deck and laminate? | Laminate material (hybridized copolymer) | 4 years | When used, monitor for de-lamination and chloride buildup in the first lift. Protects from chloride ingress to steel but may cause surface freeze thaw issues? |
| Deck A Pell (15%) | After 4 years shows major ingress. Year 5 shows significantly more. | Penetrating Silane/ Siloxane (15%) | 3 years | If used on new and existing decks, reapply after 3 years. |
| ChemTec One | After 2 years all three lifts show ingress. | Penetrating Silica | 1 year | Not Recommended. Potential Freeze Thaw damage. |
| *Water Repellent # 2 | Currently under evaluation in District 4. Will add addendum when complete. First year shows ingress. | Penetrating Silane/ Siloxane | 2+ year | No recommendations yet due to increases seen early. |
| *Dural 335 | Currently under evaluation in District 4. Will add addendum when complete. First year shows ingress. | Healer / Sealer (100% epoxy resin) | 2+ year | No recommendations yet due to increases seen early. |
| *Clear Masonry Sealer | Currently under evaluation in District 4. Will add addendum when complete. First year shows ingress. | Penetrating Silane/ Siloxane | 2+ year | No recommendations yet due to increases seen early. |
| *Duraguard 401 | Currently under evaluation in District 4. Will add addendum when complete. First year shows ingress. | HMWM Healer / Sealer | 2+ years | No recommendations yet due to increases seen early. |
| *TK 9000 | Currently under evaluation in District 8. Product performing well after 2 years. Addendum will be added later when complete. | Crack Sealer (100% epoxy resin) | 2+ years | Early success but still under evaluation. |

*Still under evaluation

Laboratory testing was done in order to establish potential tests for future material testing and to create acceptance criteria based upon those results. The tests included, specific gravity, pH, dry to touch time, total solids, IR scan, viscosity, chloride ion content and chloride ion ingress after ponding. The physical and chemical testing provided a tool for future product evaluation. The ponding results were inconsistent and difficult to draw conclusions or trends. More testing will need to be done to improve this area of evaluation and material specification.

# CONCLUSIONS

This research shows that the use of protective coat, penetrating sealers and laminates deters the ingress of chloride ions into Portland cement concrete. Because this research is unique to Illinois, the results of this research demonstrate some anomalies from previous research performed in other states. Illinois' unique anti-icing and deicing materials and application practices, construction practices and sealers available may account for some of the differences.

The best overall performers are hard deck overlays. The modified concrete overlays did not allow ingress of chloride to the original concrete surface. The change in chloride level seen in the graphs was due to variability in the sampling and testing methods. Of the sealers, protective coat performed better than all silanes and siloxanes. The product combination of silane and siloxane performed better than the silanes and siloxanes alone.

Previous research by: Pincheira and Dorshorst (2005); Basheer (1998); Weyers (1995) and Whiting (2005), found that typically silanes penetrate deeper than siloxanes and protective coat (linseed oil). This research found that protective coat and a water-based silane/siloxane mixture demonstrated the best durability over the 5 years of study. This durability indicates not only a positive mechanism of deterring chloride ingress but also the ability of the products to withstand wear due to the tire traffic. The bulk of the test locations were in the wheel paths which would see the most significant loss from traffic wearing.

Previous research found that solvent-based silanes and siloxanes tended to penetrate deeper than their water-based counterparts with the same solids content. While one water-based sealer performed slightly better than the others, solvent-based sealers did perform better overall than the water-based counterparts in this research.

Basheer (1998), Whiting (2005) and Soriano (2002) all demonstrated that silanes with higher solids content (40% or higher) penetrated slightly deeper than the same sealants with lower solids content. This research did not specifically take into account the solids content of the materials chosen for evaluation. The products which performed well for 4 years had varied solids contents, ranging from 15% to 95%.

Silanes display the least amount of salt-water absorption of the sealants tested. A slight benefit in absorption performance was also seen by Soriano (2002) with silanes of higher solids content (100% vs. 40%). All of this data indicates that a high solids content, solvent-based silane should be chosen for use.

Water-based products may need to be used if environmental restrictions are present. The majority of the products evaluated were below the currently proposed limits (400 g/L) for waterproofing concrete/masonry sealers. Caution may be required when reapplying water-based products. Research by Whiting (2005) found that water-based products did not readily penetrate upon reapplication to surfaces previously treated. This may be due to the "water-repellent" nature of the residual products repelling the water carrier and inhibiting reapplication.

The Illinois Pollution Control Board recently adopted new VOC regulations that restrict the use of solvent carriers and require formulation changes in some products currently available in order to comply. The new VOC limits for waterproofing concrete/masonry sealers as of July 1, 2009 are 400g/L. Protective coat formulations used in Illinois currently will meet the new standards.

Hard deck overlays provide exceptional chloride ion protection for greater than 5 years. The price of the hard deck overlays and the additional load added to structures limit their use. A lower cost alternative, for 5 years of protection, is protective coat and/or a water-based silane/siloxane combination product. These products were applied to new HPC concrete and outperformed all other products evaluated.

Wright's (1993) research showed that aging linseed oil with ultraviolet light exposure caused linseed oil's ability to reduce chloride ingress to be much better than that of silane. Wright's field results indicated linseed oil to be the most effective product compared to the silane and siloxane. It is perhaps this phenomenon that was observed in this research that allowed for protective coat to perform so successfully. The protective coat evaluated in this research was applied during early season construction and therefore exposed to more UV and heat during the first year of service than what is typical. Typically protective coat was used in Illinois for concrete that was finished late in the construction season and thus "green" for the first deicing chemical applications. This late season application may not have allowed for the UV and heat exposure to enhance the linseed oil's performance.

Previous concerns regarding the loss of skid resistance with the use of protective coat were considered in this research. The BMPR supplied skid resistance testing on two different structures in District 6 on which the contractor applied protective coat on a newly installed bridge deck. The friction number was determined using a treaded tire and a smooth tire. The friction number was taken before application, after application and one week later. The average friction numbers were reported. The resultant skid numbers after initial installation and one week later exceeded the minimum requirements of $FN_t > 35$ and $FN_s > 25$ as found in the BMPR Pavement Technology Advisory "Testing Pavement Friction" PTA-T3. The decrease in friction after protective coat application was on average 24% on concrete and there was no decrease seen on HMA on the approach pavement.

## RECOMMENDATIONS/POLICY

1. **Policy**. The use of a sealant or laminate to protect bridge decks from the ingress of chloride ions is a practice IDOT should implement for all new bridge deck construction, new overlays and existing bridge decks which the State would like to buy more service time. The type of sealer or laminate utilized should be based upon cost, availability and durability.
    a. Hard deck overlays should be considered whenever feasible. The overlays shall be used in compliance with the appropriate specification for the selected overlay.

b. Protective coat is currently the most cost effective product included in this study. Protective coat is readily available and found in the Standard Specifications for Road and Bridge Construction, Article 1023.01. Protective coat should be considered on all new bridge deck construction (including hard deck overlays) and existing structures where chloride ions are used for deicing and anti-icing. Protective coat is applied by cleaning the surface of all dirt, oil, grease, curing compounds and other substances that would prevent proper penetration of the material. Prior to application, the surface shall be thoroughly dry. New concrete shall be cured for a minimum of 14 days prior to application. Application can be by tank sprayer, broom, roller or the use of spray bars for larger jobs. Two coats are recommended. Do not over apply. Any excess material must be removed with rags or paint rollers. Over-application may result in a slippery surface. Do not apply in temperatures below 40 ° F. Early season application is recommended when possible due to improved performance under early UV and heat exposure.

c. Penetrating sealers are slightly more expensive than protective coat and range in price depending upon the chemistry of the product. The higher the solids content of the active ingredients, the higher the resultant price. Penetrating sealers are currently available and found on IDOT's Concrete Sealer Approved Product List. Considerations when choosing a penetrating sealer are: chemical composition, carrier solvent, and application conditions. This research found combination products perform best, followed by silanes and siloxanes. The carrier solvent was not a significant finding of this research but other research found solvent-based products perform superiorly.

2. **Recommendations.** In order to implement the new policy suggestions, specifications and approval criteria need to be created in order to support the testing and approval of products.

   a. IDOT should revise the current Concrete Sealer Approved Product List to subcategorize material for bridge deck applications based upon sealer type and application. Such categories to consider; penetrating sealers vs. crack fillers, silanes vs. siloxanes vs. combinations or other active ingredients, solids content, VOC and carrier solvent.
   b. IDOT should develop a Special Provision for the use of protective coat.
   c. IDOT should develop a Special Provision for the use of penetrating sealers on bridge decks.
   d. IDOT should develop a laboratory testing protocol that utilizes the "Proposed Testing Protocol for Surface Applied Concrete Sealers" from NCHRP Project 20-07 and the current IDOT protocol for the Concrete Sealer Approved Product List. Chloride ion ingress and depth of penetration should be the focus.
   e. Work with the Bureau's of Bridges and Structures and Operations, including Maintenance and Day Labor, to develop an application procedure as well as a reapplication protocol. Work with industry and other states with current programs to find the best fit to our current operations and work schedules and work force.

f. Evaluate crack sealers in an experimental feature through IDOT's new products evaluation group.

3. **Maintenance.** Establish a maintenance strategy for the various products that optimizes the durability of products available. Utilize personnel from the Bureau of Operations to re-apply products.
    a. Work with manufacturers to develop best practices for re-application of the various products.
    b. Make sure practices consider surface preparation, absorption, dry and/or cure times, application rates, storage, safety and handling.
    c. Re-application should be scheduled for late spring and early summer to optimize personnel and avoid conflicts with other maintenance activities as well as optimize the performance of the products.
    d. Invest in new application equipment or modification of current equipment to re-apply the materials.
    e. Solicit manufacturers to provide training and support to maintenance personnel.
    f. Develop a procurement contract for the various available products to ensure best, bulk pricing.

## FUTURE RESEARCH SUGGESTIONS

Future research should consider a laboratory testing protocol that accurately depicts field performance. This research would need to connect various laboratory test procedures to the importance of predicting success in the field. For example, the depth of penetration could be utilized to determine durability and/or longevity of the sealer application. Various tests should be considered that determine the chemical nature of the material. Different chemical formulations developed in the future may outperform those currently available. A set of testing protocols should be in place to examine this potential. In addition, IDOT should further consider the use of gravity filled crack sealers. The use of penetrating sealers and protective coat as a low cost improvement cannot address large cracks that serve as direct access into the depths of the concrete. Crack sealers should be evaluated for their ability to penetrate and fill cracks as well as their ability to prevent chloride ion ingress. This research evaluated 4 different crack sealers utilizing a modification of the sampling protocol. The work is not finalized on the crack sealers and will be added as an addendum to this report.

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