Laboratory Investigation of Concrete Beam-End Treatments

Final Report
May 2015

IOWA STATE UNIVERSITY
Bridge Engineering Center
Institute for Transportation

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16. Abstract

The ends of prestressed concrete beams under expansion joints are often exposed to moisture and chlorides. Left unprotected, the moisture and chlorides come in contact with the ends of the prestressing strands and/or the mild reinforcing, resulting in corrosion. Once deterioration begins, it progresses unless some process is employed to address it. Deterioration can lead to loss of bearing area and therefore a reduction in bridge capacity.

Previous research has looked into the use of concrete coatings (silanes, epoxies, fiber-reinforced polymers, etc.) for protecting prestressed concrete beam ends but found that little to no laboratory research has been done related to the performance of these coatings in this specific type of application.

The Iowa Department of Transportation (DOT) currently specifies coating the ends of exposed prestressed concrete beams with Sikagard 62 (a high-build, protective, solvent-free, epoxy coating) at the precast plant prior to installation on the bridge. However, no physical testing of Sikagard 62 in this application has been completed. In addition, the Iowa DOT continues to see deterioration in the prestressed concrete beam ends, even those treated with Sikagard 62.

The goals of this project were to evaluate the performance of the Iowa DOT-specified beam-end coating as well as other concrete coating alternatives based on the American Association of State Highway and Transportation Officials (AASHTO) T259-80 chloride ion penetration test and to test their performance on in-service bridges throughout the duration of the project. In addition, alternative beam-end forming details were developed and evaluated for their potential to mitigate and/or eliminate the deterioration caused by corrosion of the prestressing strands on prestressed concrete beam ends used in bridges with expansion joints. The alternative beam-end details consisted of individual strand blockouts, an individual blockout for a cluster of strands, dual blockouts for two clusters of strands, and drilling out the strands after they are flush cut. The goal of all of the forming alternatives was to offset the ends of the prestressing strands from the end face of the beam and then cover them with a grout/concrete layer, thereby limiting or eliminating their exposure to moisture and chlorides.

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LABORATORY INVESTIGATION OF CONCRETE BEAM-END TREATMENTS

Final Report
May 2015

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EXECUTIVE SUMMARY

Background

The ends of prestressed concrete beams located under bridge expansion joints are often exposed to extended periods of moisture and chlorides. This exposure can cause the beam ends to deteriorate prematurely, corrode the prestressing strands, degrade the surrounding concrete, and eventually reduce the capacity of the beam.

Problem Statement

Previous research has investigated the use of concrete coatings (silanes, epoxies, etc.) for protecting prestressed concrete beam ends, but insufficient laboratory research has evaluated the performance of these coatings for this application.

The Iowa Department of Transportation (DOT) currently specifies coating the ends of exposed prestressed concrete beams with Sikagard 62 (a high-build, protective, solvent-free, epoxy coating) at the precast plant prior to installation on the bridge. However, no physical testing of Sikagard 62 for this application has been completed.

Meanwhile, the Iowa DOT continues to see deterioration even in beam ends treated with Sikagard 62. The Iowa DOT therefore wanted to evaluate several available prestressed beam-end treatment alternatives in the laboratory and in the field.

Research Objectives

The objectives of this research were to evaluate the performance of several concrete coating alternatives based on the American Association of State Highway and Transportation Officials (AASHTO) T259-80 chloride ion penetration test and to evaluate them based on their performance on in-service bridges. In addition, alternative beam-end forming details were developed and evaluated for their potential to mitigate the deterioration caused by corrosion of the prestressing strands on prestressed concrete beam ends.

Key Findings

- In laboratory testing, the coatings performed similarly on all three concrete slabs, indicating that concrete mix design did not significantly affect coating performance.
- For the most part, the coated slab sections resisted chloride penetration of the concrete much better than the uncoated control sections. The only exception was the section coated with TEX•COTE XL 70 BRIDGE COTE with Silane.
- Based on the results of the AASHTO T259-80 chloride penetration test, the coatings showing the best to worst performance were as follows: (1) three-way tie between BASF Sonoguard, BASF Hydrozo 100, Sikagard 62 – two coats, (2) Viking Aqua Guard Concrete Sealer, (3)

Sikagard 62 – one coat, (4) TEX•COTE RAINSTOPPER 140, (5) PAULCO TE-3008-1, (6) Evercrete DPS, (7) TEX•COTE XL 70 BRIDGE COTE with Silane.

- In field testing, the inspection results of the coated beam ends varied from product to product and, at times, from one beam to another coated with the same product.
- In general, the performance of all of the products was excellent. No signs of peeling or deterioration of the coating were found on the concrete surfaces. All noticeable problems appeared to be at the prestressing strand locations.
- In the rare case when all prestressing strand ends were covered after the Iowa DOT preparation process, the beam end showed no signs of deterioration. However, in most cases several of the strand ends were visible and appeared rusted immediately before the coating was applied. All visible rust was removed before applying the coatings, but this is believed to be more a superficial fix than a long-term maintenance plan.
- At the precast plant, the strands protruding from the ends of the untrimmed and untreated beam ends were found to be heavily rusted. Before treatment, moisture and rust likely migrated into the beam end via the strands.
- The pre-existing moisture and rust on the strands within the beam ends before application of the coating likely caused most of the failures found on the coated bridge beams. Some coated beam ends only had visible signs of rust on the strand ends, others had visible rust piercing the coating, and a few others had the coating peeling off and missing completely from the strand ends.
- All three grout products provided an adequate bond to the existing concrete and were easy to mix and apply to the vertical voids. However, all three products exhibited shrinkage cracks within a few days of application.

Implementation Readiness and Benefits

With the exception of TEX•COTE XL 70 BRIDGE COTE with Silane, the selected coating products resisted chloride penetration of the concrete much better than the uncoated concrete. Adding a second coat of Sikagard 62 slightly improved chloride ion penetration performance, but likely not enough to warrant the extra time and cost involved in the process.

Single, double, or individual bar blockout are excellent options for separating the face of the beam end and the end of the prestressing strand. Viable alternative beam-end fabrication details include any of the blockout options: single, double, or individual strand.

Foam was found to be the best material for creating the voids. Further investigation is warranted into potential grout products, epoxy products, or both that can adequately fill voided areas without cracking.

Drilling out the strands after each is flush cut to the beam face was found to be nearly impossible and is not considered a viable option.

INTRODUCTION

Like many other state departments of transportation (DOTs), the Iowa Department of Transportation is facing the daunting task of maintaining an inventory of aging bridges. After experiencing years of cost-effective construction and reduced maintenance costs, many of the new structures built in Iowa are prestressed concrete girder bridges, and, when possible, expansion joints are eliminated by utilizing integral abutments. However, when integral abutments are not feasible, the Iowa DOT is faced with protecting and maintaining a concrete superstructure with expansion joints that often expose the ends of the prestressed beams to moisture and chlorides.

Typical prestressed concrete beam construction results in woven prestressing strands protruding from the ends of the beams. On bridges with non-integral abutments, these strands are subsequently cut off so as to not obstruct the construction of the bridge abutment. Beam-end finishing details vary from state to state, some specifying that the strands be simply flush cut and left untouched, others requiring that the beam ends be treated with epoxy or silicone sealer after the strands are cut. Because beam ends on non-integral abutment bridges are not encased in concrete, the final detailing of the beam ends is critical because they are fully exposed to the elements, including potential contamination from moisture and chlorides that may penetrate the joint. Left unprotected, these exposed strands may begin to corrode, eventually leading to cracks and spalling of the concrete. Still, some state DOTs, including Iowa, have found that deterioration of beam ends occurs despite their attempts to protect the beam ends with additional detailing.

Currently, the Iowa DOT specifies prestressed concrete beam ends be coated with Sikagard 62 at the precast plant, although there has been no laboratory investigation into the effectiveness of the coating's performance in this application. Individual precasters often have their own beam-end finishing details in addition to use of the Sikagard 62, although anecdotal evidence suggest that not all beams are actually getting the needed finishing prior to application of the coating and installation in the field. Furthermore, as mentioned previously, the performance of in-service bridge beams that have undergone their detailing process has been found to be highly variable and sometimes substandard. Field inspections have found many bridge beams with exposed strand ends that are heavily corroded and others with spalling and deterioration of the beam ends, resulting in a potential reduction in the bearing capacity of the beam.

Problem Statement

The ends of prestressed concrete beams located under bridge expansion joints are often exposed to extended periods of moisture and chlorides, which subsequently results in premature deterioration of the beam ends. This results in active corrosion of the prestressing strands, which can lead to degradation of the surrounding concrete and, eventually, loss of bearing area and a general reduction in the capacity of the beam. There exists a need to investigate concrete beam-end treatments and techniques for mitigating this problem on new structures and improving long-term beam performance. Although previous research has touched on this topic, insufficient research exists related to physically testing the treatment alternatives and evaluating their in-service performance. The Iowa DOT wishes to evaluate the prestressed beam-end treatment alternatives currently used on its prestressed girder bridges as well as other relevant options currently available through evaluation in the laboratory and in the field.

Research Goal and Objectives

The objective of this work is to conduct laboratory testing to evaluate prestressed concrete beam-end treatment alternatives that will prevent, or at least slow, the deterioration currently occurring at beam ends in jointed prestressed concrete girder bridges. In addition, new beam-end fabrication/forming details were developed and evaluated for their potential to eliminate/mitigate the damage to beam ends that often results from moisture ingress via the exposed strand ends on these beams. The tasks completed to meet the project objectives are as follows:

- Conduct a literature review of the subject
- Select several beam-end treatment alternatives, including the one currently used/specified by the Iowa DOT (i.e., Sikagard 62)
- Conduct laboratory tests to evaluate beam coating alternatives by employment of the AASHTO T259-80 test
- Apply the selected beam coating alternatives on two prestressed concrete girder bridges and monitor for the duration of the project
- Conduct laboratory tests evaluating alternative beam-end fabrication details

Research Approach

This study involved a literature review of the subject, laboratory and field evaluation of several beam-end coating alternatives, and development and laboratory testing of several beam-end fabrication modifications aimed at reducing strand exposure. The literature review presents information on the state of the practice in other states, as well as other research related to the use and performance of prestressed beam-end coatings. Laboratory testing was then completed on several beam-end coating alternatives according to the AASHTO T259-80 test. Resistance to chloride ion penetration is an important criterion for coatings on concrete surfaces, especially those beam ends that are exposed on non-integral abutment bridges. Coatings that exhibit good resistance to chloride ion penetration will be good candidates for field applications on bridge beams in the future. All of the coating alternatives were also applied on separate full-scale prestressed beams at the precast plant and installed in two bridges near Des Moines, Iowa, for monitoring throughout the duration of the project. Lastly, several beam-end details were developed and evaluated for their constructability. These details were developed with the goal of reducing or eliminating the exposure of the prestressing strands to the elements.

LITERATURE REVIEW

A search of relevant literature regarding the treatments and products used to address problems related to prestressed beam ends being exposed to the elements was conducted, the results of which are summarized in this section. One of the more relevant and recent research projects conducted on this subject was completed in 2012 by the Pennsylvania Department of Transportation (PennDOT) (Radlinska et al. 2012). One of the study's initial findings was that, much like the Iowa DOT has found, there is a lack of available laboratory results that would facilitate a direct comparison between the available methods and actual field applications. Based on survey data from state DOTs, the study found that most states do nothing to protect their concrete beam ends, nor have they conducted research on any coatings or beam-end treatments they may utilize. The PennDOT survey also identified coatings and combination systems that often provide the best service life and are a good low cost option based on manufacturers' data. The study found sealers (i.e., silane, siloxane, etc.) to be another good alternative, although these alternatives are restricted to areas that do not have active corrosion or heavy chloride ion concentrations. A third alternative, cathodic systems, were noted to provide the greatest protection, but their high cost and need for continuous monitoring typically limit their use. In addition to the DOT survey, a survey of concrete manufacturers was also completed and indicated that the manufacturers' suggestion for best corrosion prevention was membranes (urethanes, epoxies, etc.) and then sealers.

The PennDOT research also found that coatings used to protect steel beams are first approved by the National Transportation Product Evaluation Program (NTPEP) and subsequently usually have good performance. To date, a similar approval process is not in place for concrete coatings. Based on the survey data and information collected from various manufacturers related to ease of application, frequency of inspection, service life, cure time, etc., the researchers concluded that the top three available products for concrete beam-end treatment were Evercrete Deep Penetrating Sealer (DPS), water-based asphalt emulsion, and TEX•COTE XL 70 BRIDGE COTE.

In 2004, the Wisconsin Highway Research Program (Tabatabai et al. 2005) conducted an extensive experimental study comparing the effectiveness of four different beam-end treatment alternatives: (1) carbon fiber-reinforced polymer (FRP) wrap (two REPLARK 30 fabric and resin layers, in addition to primer and putty), (2) REPLARK 30 polymer resin coating (no fiber), (3) epoxy coating (MASTERSEAL GP epoxy sealer), and (4) sealer (MASTERSEAL SL 40 VOC). The research involved subjecting full-scale beam ends treated with each of the alternatives to controlled saltwater exposure and wet/dry cycles consisting of four days of "wet" exposure followed by three "dry" days. After six months of this alternating wetting and drying, no deterioration was evident. Therefore, corrosion was rapidly induced in the specimens by subjecting them to cyclic wetting and drying with a 6% chloride solution along with an applied constant voltage to the steel. The effectiveness of the coatings was subsequently evaluated based on chloride content, extent of cracking, and observed strand corrosion. Of the four alternatives, the FRP and polymer resin coatings were the most effective, followed by epoxy and then silane. The researchers further concluded that the polymer resin or epoxy coatings were recommended because the FRP was not so much more effective as to offset the additional cost of the FRP wrap.

Research conducted in 2002 published by the Michigan Department of Transportation (Ahlborn et al. 2001) looked at the causes and cures for corrosion-induced deterioration in prestressed concrete I-beam ends. The authors evaluated preventative beam-end measures based on meeting a predetermined set of technical requirements and concluded that the procedure/product either met requirements, did not meet requirements, or no conclusions could be drawn regarding meeting the requirements. The research revealed that penetrating and surface sealers did not meet the requirements, surface coatings were inconclusive, surface-applied corrosion inhibitors were inconclusive, and impressed current cathodic protection met the requirements. Note that nowhere in the research was cost of the alternatives considered.

Much of the research identified in the literature search that was related to concrete coating performance was not particularly relevant to this work because the coatings were often utilized in a repair situation or applied to concrete structures without protruding prestressing strands (e.g., barrier rails). One such research project, conducted by the Kentucky Transportation Center (KTC) in 2006 (Palle and Hopwood 2006), evaluated several coating alternatives on a section of bridge barrier rail and including subjecting each of the alternatives to several laboratory tests to evaluate properties such as adhesion, chloride penetration, and UV degradation.

LABORATORY BEAM-END COATING EVALUATION

Various methodologies exist for attempting to protect concrete beam ends from the damaging effects of moisture and chlorides. Products range from penetrating sealers, surface epoxies, moisture blockers, etc., to more physical alternatives such as FRP wraps and strip seals. For this work, the selection of alternatives for evaluation on laboratory and field specimens began with selecting the current concrete coating product outlined for protecting concrete beam ends by the Iowa DOT, Sikagard 62 (a high-build, protective, solvent-free, epoxy coating). Additional alternatives were then selected based on results from the literature search and input from the project's technical advisory committee (TAC).

Alternative Selection

As noted above, the current product listed by the Iowa DOT, Sikagard 62, was an automatic selection for evaluation for two main reasons: the Iowa DOT currently has no laboratory-based test data for this product in this application and evaluating this product would provide a baseline for performance evaluation in testing additional concrete coatings. As noted above, additional alternatives were selected based on products found in previous research and then cross-referenced with a list of currently available products meeting the application criteria. From there, guidance and input from the TAC and Iowa DOT staff resulted in the selection of the following alternatives for inclusion in the subsequently described experimental evaluation:

- Sikagard 62 (epoxy)
- TEX•COTE XL70 BRIDGE COTE with Silane
- TEX•COTE RAINSTOPPER 140 (40% silane sealer)
- Viking Aqua Guard Concrete Sealer (2 part – water-based epoxy)
- PAULCO TE-3008-1 (2 part – solvent-based epoxy)
- BASF Sonoguard (2 part – polyurethane waterproofer)
- BASF Hydrozo 100 (100% silane penetrating sealer)
- Evercrete Deep Penetrating Sealer (DPS)

Laboratory Ponding Tests and Results

The method for evaluating the performance of the selected concrete coating alternatives was the AASHTO T259-80 test (Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration). Laboratory testing of the selected beam-end coating alternatives consisted of first casting three concrete ponding slabs, one from each of the three precast facilities located in or near Iowa: Coreslab Structures, Omaha, Nebraska; Cretex, Iowa Falls, Iowa; Andrews Prestressed Concrete, Mason City, Iowa. (Note: Prior to completion of testing, the Andrews facility closed for business.) The purpose of obtaining a ponding slab from each of the three precasters was to evaluate if concrete mix design or differences in concrete placement techniques had any effect on the performance of the coating alternatives.

Each slab was cast on-site at the precast plant and then transported to the Iowa State University (ISU) structural engineering laboratory for testing. Illustrated in Figure 1 is a plan view of a typical ponding slab; all three slabs were 5 ft by 7 ft in plane and 6 in. thick. The slab dimensions allowed for 12 squares per slab for application of the 8 selected alternatives, several control (untreated) areas, a ponding barrier, and lifting loops. The dotted lines in Figure 1 denote the location of the edge of each coating alternative; the solid lines within the dams designate the boundaries of the area from which samples were taken for testing. The buffer area between the dotted and solid lines reduces the potential for erroneous readings due to insufficient coverage of the concrete at the interface between two coating alternatives. To assist with the referencing of the slabs and the applied alternatives, each row of squares on the slab was designated with a letter from A to D, and each column was designated with a number from 1 to 3 (see Figure 1).

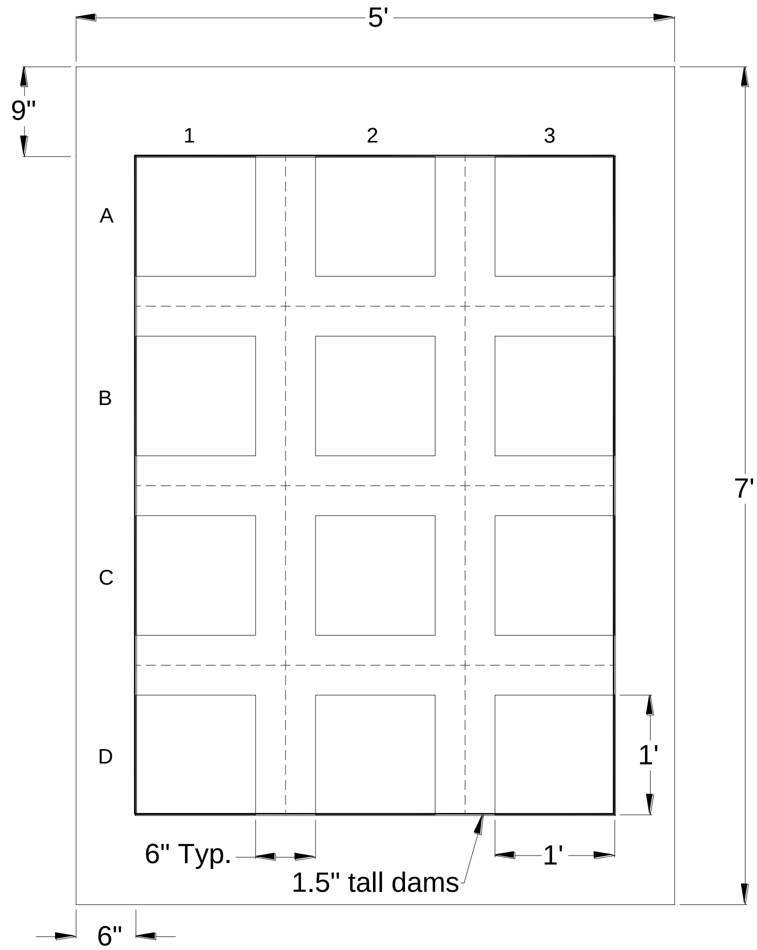

Figure 1. Dimensions of laboratory slabs for ponding tests

To simulate application of the coating alternatives on a vertical beam end, the ponding slabs were stood on edge and each alternative applied to a designated square on each slab according to manufacturer recommendations (see Table 1). Figure 2 shows one slab after application of the coating alternatives (all but D3) and prior to ponding; the other two slabs looked very similar and are not shown in the interest of brevity.

Table 1. Coating alternatives and slab reference IDs

Coating	Slab Reference ID	Number of Coats
TEX•COTE XL70	A1	1
TEX•COTE RAINSTOPPER	A2	1
Sikagard 62 – one coat	A3	1
Viking Aqua Guard	B1	2
PAULCO TE-3008-1	B2	2
BASF Sonoguard	B3	Base/Top
Evercrete DPS	C1	2
Blank*	C2	1
Control 1	C3	1
BASF Hydrozo 100	D1	2
Control 2	D2	1
Sikagard 62 – two coats	D3	2

* Square left blank due to B2 coating overrunning onto C2

Figure 2. Typical ponding slab with coating alternatives applied

The application of two coats of Sikagard 62 to D3 was at the request of Iowa DOT staff to evaluate any potential benefit to using two coats versus the typical one-coat application specified by the manufacturer, and both coats were applied after the photo was taken but prior to ponding.

After the coatings were applied and had been allowed sufficient time to cure, as specified by the manufacturers, the slabs were laid horizontally and subjected to continuous ponding with a 3% chloride solution to a depth of approximately 0.5 in. for 90 days. Each slab was outfitted with aeration tubes to keep the chlorides from settling out of solution and then covered to reduce evaporation; additional solution was periodically added when needed to maintain a proper depth of chloride solution (see Figure 3).

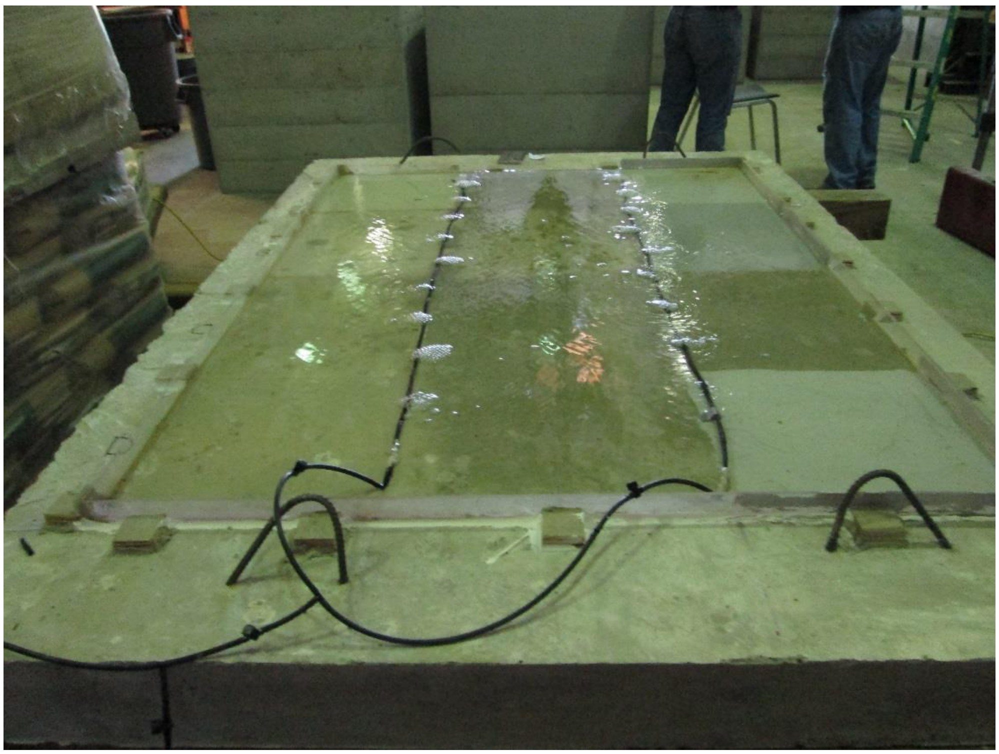

Figure 3. Laboratory specimens ponded with 3% chloride solution prior to being covered

After 90 days of ponding, the slabs were drained, lightly brushed, and vacuumed to remove any chloride residue prior to extracting the needed powder samples. A small area of each coating was then removed, the area was cleaned thoroughly, and then samples were extracted at each location at depths of 0.5 in. and 1.0 in. and taken to a materials testing laboratory at ISU for chloride analysis. Each of the holes where the samples were taken was then filled with caulk to prevent the creation of an alternative entry point for the chloride solution. This process of ponding, drying, sampling, and caulking was then repeated two more times. Listed in Table 2, and shown in Figures 4 through 6, are the results from the three chloride samplings done on the three slabs. The first round of samples from the Cretex slab were unfortunately compromised in the time between collecting the samples and testing the samples and are therefore presented as not applicable (NA).

Table 2. Ponded lab specimens chloride test results (% Cl)

						Andrews						
Sample\Alt	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2***	**C3****	**D1**	**D2*****	**D3**
1	0.35	0.19	0.13	0.09	0.38	0.07	0.20	NA	0.53	0.05	NA	0.08
2	0.25	0.08	0.06	0.07	0.06	0.05	0.06	NA	0.14	0.07	0.12	0.06
3	0.37	0.08	0.06	0.06	0.24	0.06	0.35	NA	0.22	0.05	0.27	0.04

						Core Slab						
Sample\Alt	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2***	**C3**	**D1**	**D2*****	**D3**
1	0.22	0.04	0.03	0.03	0.03	0.03	0.14	NA	0.19	0.03	NA	0.03
2	0.05	0.04	0.05	0.04	0.03	0.04	0.06	NA	0.05	0.03	0.05	0.03
3	0.18	0.03	0.02	0.03	0.03	0.02	0.05	NA	0.07	0.03	0.10	0.03

						Cretex						
Sample\Alt	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2***	**C3****	**D1**	**D2*****	**D3**
1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	0.13	0.06	0.07	0.08	0.04	0.04	0.13	NA	0.14	0.05	0.13	0.04
3	0.19	0.06	0.05	0.03	0.11	0.03	0.08	NA	0.18	0.03	0.20	0.03

* Square C2 was compromised by application of B2 and therefore not evaluated
** 1st control square, no treatment applied
*** 2nd control square, no treatment applied

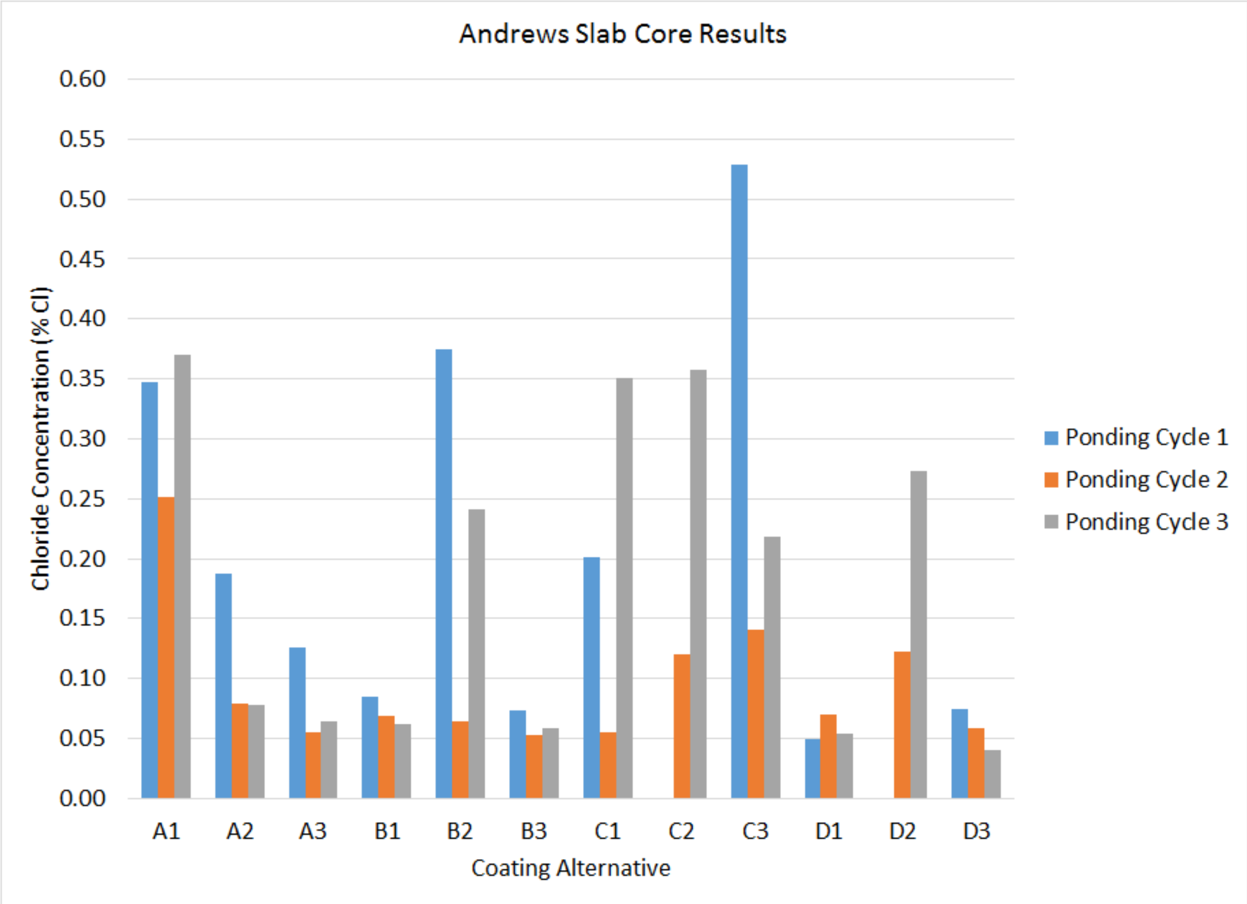

Figure 4. Chloride test results for the Andrews Slab

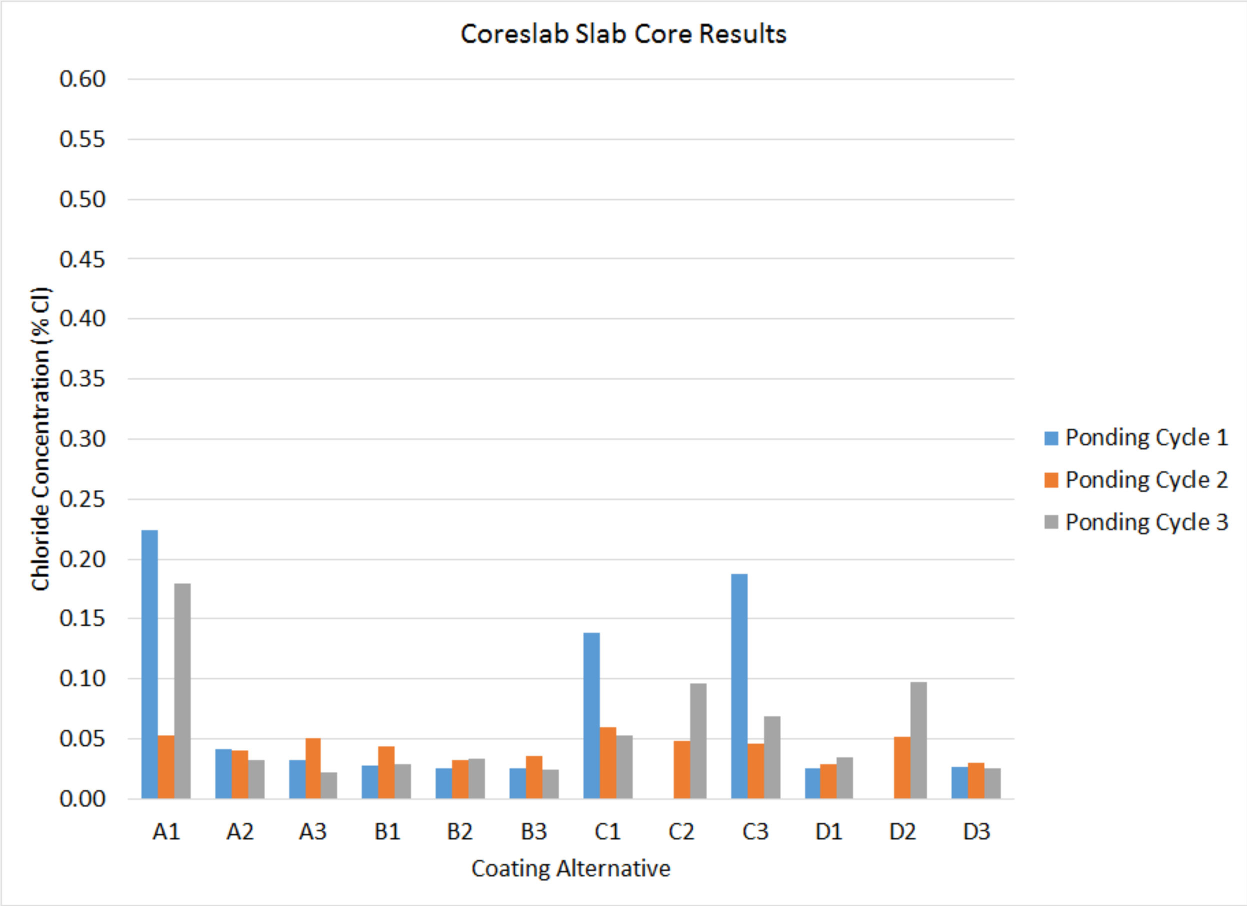

Figure 5. Chloride test results for the Coreslab Slab

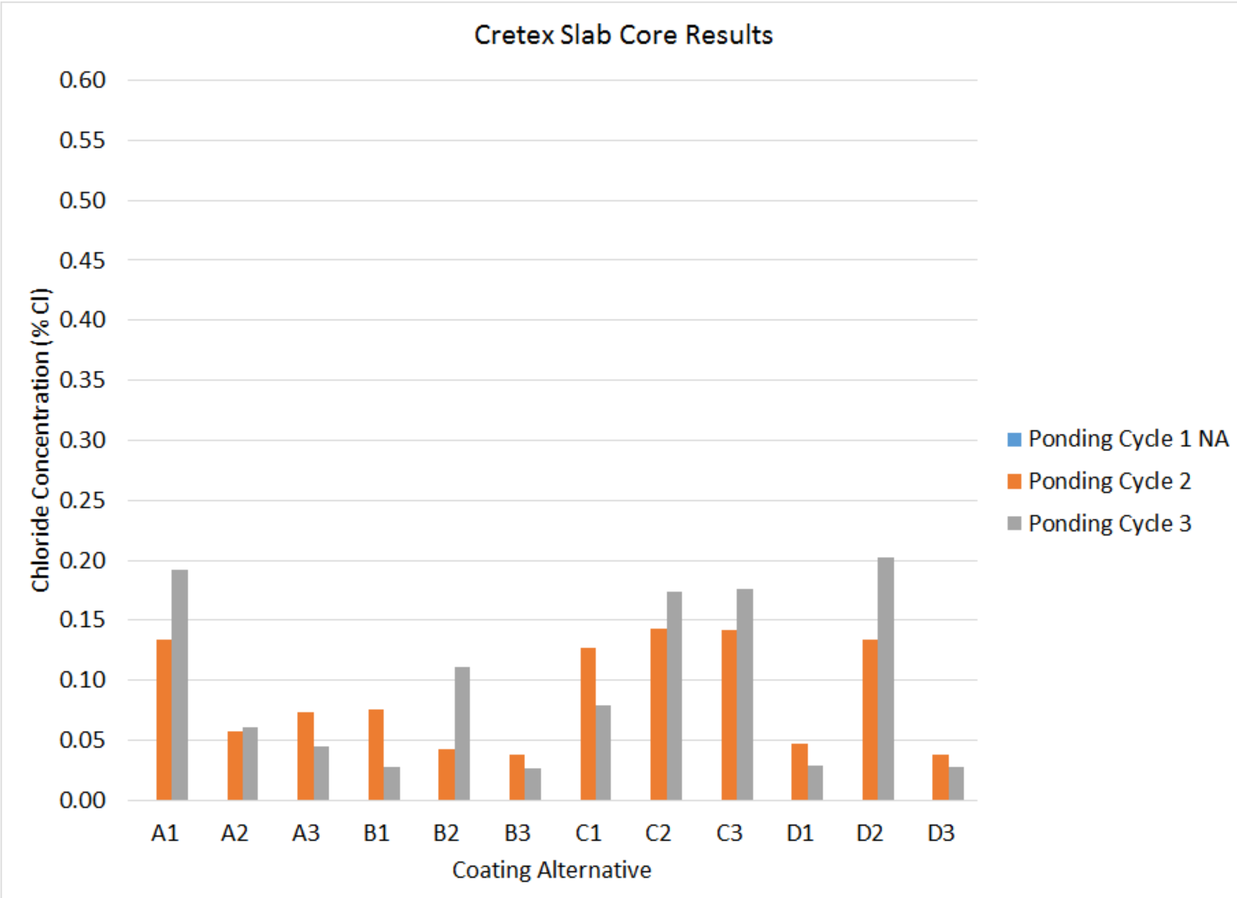

Figure 6. Chloride test results for the Cretex Slab

Table 2 and Figures 4 through 6 provide several useful pieces of information. (Recall that Andrews is no longer a precast supplier, so the presented data is for informational purposes only.) First, in general, all three slabs performed relatively the same, indicating that differences between the suppliers do not have a notable effect on the performance of the concrete coating alternatives. Additionally, visual inspection throughout the project found there to be no issues with adhesion of any of the alternatives to the concrete surfaces provided by all three manufacturers throughout the three ponding cycles. Second, if we compare the performance of the control squares (C3 and D2) with all the squares that had an applied coating, there is a general improvement of the chloride resistance where a coating is used, as expected. The one exception to this is the TEX•COTE XL 70 product; based on the results from the laboratory ponding tests, this was the only alternative to not perform better than the control. Third, although the chloride contents varied up and down slightly from one ponding cycle to the next, the variances were relatively small and showed no notable increase in the chloride content of the concrete over the course of the three ponding cycles. Lastly, using the numbers in Table 2 or Figures 4 through 6 as a guide, the alternatives may be rated as follows in terms of decreasing performance to resist chloride penetration into the concrete: (1) tie: BASF Sonoguard, BASF Hydrozo 100, Sikagard 62 – two coats, (2) Viking Aqua Guard, (3) Sikagard 62 – one coat, (4) TEX•COTE RAINSTOPPER 140, (5) PAULCO TE-3008-1, (6) Evercrete, (7) TEX•COTE XL 70.

FIELD APPLICATION TO BRIDGE GIRDERS

The initial scope of this work called for only a laboratory investigation of the selected beam-end treatment alternatives. However, during the alternative selection process the research team was made aware of two prestressed concrete girder bridges scheduled for fabrication/construction during the research project timeframe. The TAC suggested including a field component to the scope of the project by applying the selected beam-end coating alternatives to the beam ends on these two projects and visually monitoring their performance. Subsequently, the research team reached out to the precaster to establish a timeline of events (i.e., status of beam fabrication, etc.) so that as soon as the beams were cast and had been properly prepared for the coating process the research team could be on-site to apply the alternatives prior to the beams being sent out to the construction site. Note that Sikagard 62 was not applied to these girders.

Before outlining the application of the coating alternatives to the bridge beams and discussing their field performance in the subsequent section, the research team believes it would be remiss to not discuss a couple of details discovered during the literature review and a site visit to the precast plant. Results from previous research indicated that silanes should only be applied to areas that have no active corrosion or heavy chloride ion concentrations. Initial inspection of the 19 beam ends reserved for this research found them to have been prepped according to the Iowa DOT specifications, although there were numerous prestressing strand ends that were visible and showing signs of rust, some significant. A cursory inspection of other beam ends in the precast yard found many beams awaiting the precaster’s beam-end finishing process with uncut prestressing strands protruding from the beam ends. All of those exposed strands were visibly rusted. The potential exists that these exposed strands, which by their very nature have gaps created when the individual strands are woven together, could draw moisture into the end of the beam by capillary action. When these strands are eventually cut in preparation for beam-end treatment, the exposed rusty strands are removed, but the level of corrosion and moisture that has migrated down the strand and is encased in concrete is unknown. Any rust and moisture that does exist within the concrete is subsequently covered up either by the beam-end treatment process and the coating or, in the worst case, by just the coating itself. The presence of moisture and pre-existing rust on the strand within the concrete are potentially a significant source, if not the source, of the rust that is prematurely degrading the beam-end treatment and coatings. Furthermore, most of the coating alternatives, including the DOT-specified Sikagard 62, are designed to protect concrete surfaces, not steel surfaces, from moisture/chloride ingress.

Bridge Girder Treatment

The two bridges selected for inclusion in this testing are the Interstate 35 Bridge (Bridge BD) over E.P. True Parkway in West Des Moines, Iowa, and the US 65 Overflow Bridge (Bridge BC) on the southeast side of Des Moines, Iowa. Bridge BD had the abutment ends of all seven prestressed girders coated at both the north and south abutments; Bridge BC had all five beam ends coated at one abutment. Tables 3 and 4 list the beam numbers and corresponding coatings applied to each of Bridge BD and BC’s beams, respectively.

Table 3. Bridge BD beam-end coating details

Bridge ID	Location	Beam ID	Alternative	Number of Coats
BD	S. Abutment	BD08501E	TEX•COTE XL 70	1
BD	S. Abutment	BD08502	TEX•COTE RAINSTOPPER	1
BD	S. Abutment	BD08503	BASF Sonoguard	Base/Top
BD	S. Abutment	BD08504	PAULCO TE-3008-1	2
BD	S. Abutment	BD08505	Viking Aqua Gaurd	2
BD	S. Abutment	BD08506	BASF Hydrozo 100	2
BD	S. Abutment	BD08507	Evercrete DPS	2
BD	N. Abutment	BD13522E	Viking Aqua Gaurd	2
BD	N. Abutment	BD13523	PAULCO TE-3008-1	2
BD	N. Abutment	BD13524	BASF Sonoguard	Base/Top
BD	N. Abutment	BD13525	BASF Hydrozo 100	2
BD	N. Abutment	BD13526	TEX•COTE XL 70	1
BD	N. Abutment	BD13527	Evercrete DPS	2
BD	N. Abutment	BD13528E	TEX•COTE RAINSTOPPER	1

Table 4. Bridge BC beam-end coating details

Bridge ID	Location	Beam ID	Alternative	Number of Coats
BC	N. Abutment	BC11526E	TEX•COTE RAINSTOPPER	1
BC	N. Abutment	BC11527	TEX•COTE XL70	1
BC	N. Abutment	BC11528	Viking Aqua Guard	2
BC	N. Abutment	BC11529	Evercrete DPS	2
BC	N. Abutment	BC11530E	BASF Sonoguard	Base/Top

Figures 7 through 13 show a representative prestressed concrete beam end after application of each of the seven coating alternatives at the precast plant. As noted previously, all of the girders were prepared for coating application by the precaster as per their own specifications. In addition, immediately prior to application of the coatings, at the recommendation of the Iowa DOT, the research team removed any visible surface rust from the prestressing strand ends using an angle grinder and removed any dust and visible surface debris.

Figure 7. BD08501E – TEX•COTE XL 70

Figure 8. BD08502 – TEX•COTE RAINSTOPPER 140

Figure 9. BD08503 – BASF Sonoguard

Figure 10. BD08504 – PAULCO TE-3008-1

Figure 11. BD08505 – Viking Aqua Guard

Figure 12. BD08506 – BASF Hydrozo 100

Figure 13. BD08507 – Evercrete DPS

Note that approximately one month after application of the coating alternatives to the Bridge BC beams, the precast foreman and the Iowa DOT inspector mentioned that it appeared as though a couple of the Bridge BC beams had not had a coating applied, and others were already showing visible signs of rusting of the prestressing strand ends. Review of the notes and photos from the application date, as well as an on-site visit by the research team, confirmed that all the beams had been coated with the appropriate coating alternative. Still, a couple of the beam ends were showing signs of rust on the beam ends. This observation may be directly related to the previously mentioned condition of the strands prior to treatment of the beam ends, and this condition appears to be a significant factor in the performance of the coatings. During the inspection visit by the research team, all visible rust was again removed using an angle grinder and the appropriate coating reapplied. The beams and respective coatings that were touched up in this way were BC11526E TEX•COTE RAINSTOPPER, BC11527 TEX•COTE XL 70 BRIDGE COTE, and BC11529 Evercrete DPS.

Field Investigation Results

The following outlines the performance of each of the coating alternatives on the bridge girders treated with the selected coating alternatives. The notes and photos below are from the inspection conducted after nearly 18 months of service in the field. Photos of each beam before and/or shortly after applying the coating accompany a photo taken at time of final inspection to clarify the notes presented below. Although the entire ends of the beams were treated with each alternative, the field inspection focused on the bottom flanges of the beams because the top flanges were often encased in the abutment diaphragm/deck and therefore not visible.

Overall, the field performance of all the coating alternatives was generally very good on the concrete surface of the beam end. As noted previously, many of the beam prestressing strands exhibited signs of rusting prior to application of the coatings, and the potential exists that given the beam-end preparation procedure some level of rusting/moisture exists on/within the woven strands within the concrete. That said, most of the issues identified with the coating alternatives, even with Sikagard 62, were found at the locations of the prestressing strand ends. Pre-existing rust/moisture on the strands could be the influential factor at play in these failures, although other unknown factors may also be contributing.

TEX•COTE XL 70 BRIDGE COTE with Silane

This product showed similar levels of performance on the three prestressed beams to which it was applied (see Figures 14 through 21).

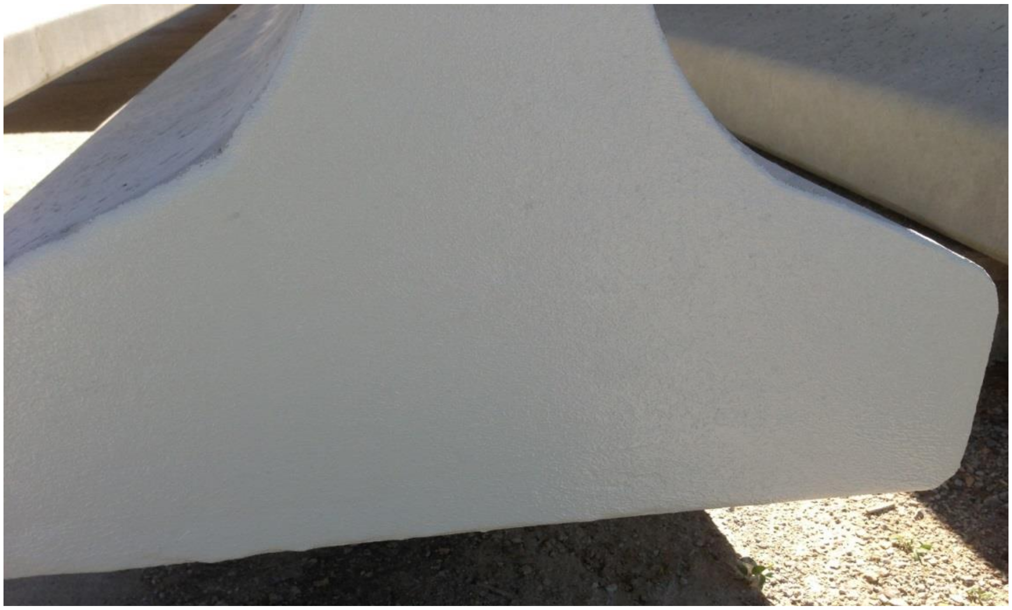

Figure 14. TEX•COTE XL 70 application at plant on BD13526

Figure 15. TEX•COTE XL 70 field condition on BD13526

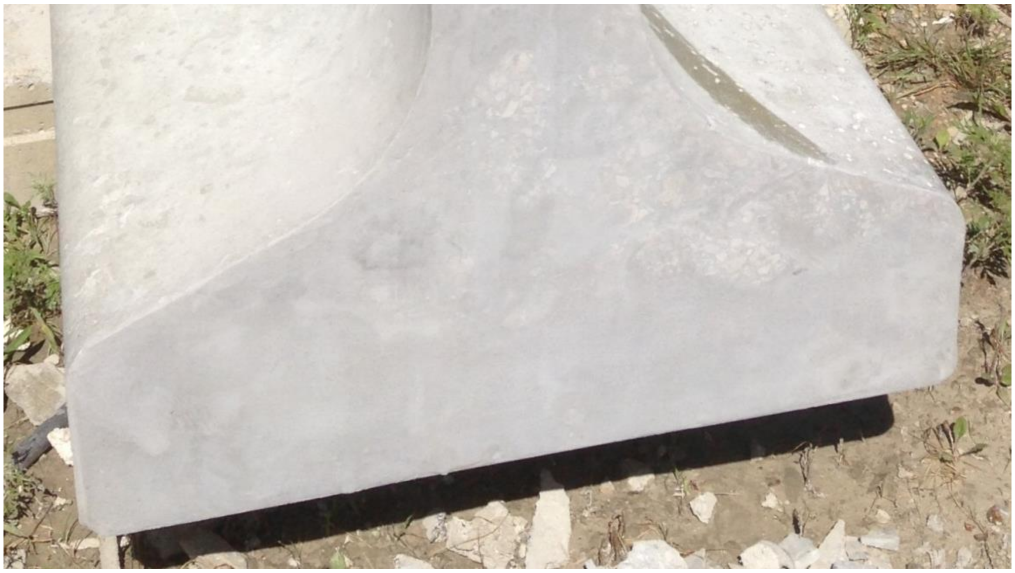

Figure 16. BD08501E prior to application of TEX•COTE XL 70

Figure 17. TEX•COTE XL 70 applied on BD08501E

Figure 18. TEX•COTE XL 70 field performance on BD08501E

Figure 19. BC11527 prior to application of TEX•COTE XL 70

Figure 20. TEX•COTE XL 70 applied on BC11527

Figure 21. TEX•COTE XL 70 field performance on BC11527

Field inspection of beams BD13526 and BD8501E revealed several strand ends where the coating has peeled off completely, exposing the rusty end of the strand. Beam BD8501E had four or five strand ends exposed and showing significant signs of rusting (see Figure 18). On beam BC11527, the precaster noted that within a couple weeks of application several of the strand ends were showing signs of rust. The rusty areas were removed with an angle grinder by the research team and the entire end of the beam recoated with TEX•COTE XL 70. Upon inspection after nearly a year and a half in service, beam BC11527 showed signs of rust appearing through the coating at several strand end locations similar to what was found after the first application, but no chipping or peeling of the coating was evident (see Figure 21).

TEX•COTE RAINSTOPPER 140

All three beams (BD13528, BD08502, and BC11526E) coated with this product showed similar levels of performance. There were numerous strand ends exposed and covered with rust (see Figures 22 through 30).

Figure 22. BD13528 prior to application of TEX•COTE RAINSTOPPER 140

Figure 23. TEX•COTE RAINSTOPPER 140 applied to BD13528

Figure 24. TEX•COTE RAINSTOPPER 140 field performance on BD13528

Figure 25. BD08502 prior to application of TEX•COTE RAINSTOPPER 140

Figure 26. TEX•COTE RAINSTOPPER 140 applied to BD08502

Figure 27. TEX•COTE RAINSTOPPER 140 field performance on BD08502

Figure 28. BC11526E prior to application of TEX•COTE RAINSTOPPER 140

Figure 29. TEX•COTE RAINSTOPPER 140 applied to BC11526E

Figure 30. TEX•COTE RAINSTOPPER 140 field performance on BC11526E

Recall that beam BC11526E had a second coating applied at the plant. Visual inspection by both the plant foreman and the research team revealed that the rust had not penetrated the coating yet, but rust was visible through the coating. The rusty areas were then removed using an angle grinder and the entire surface of the beam retreated with the TEX•COTE RAINSTOPPER 140. Eighteen months after being in service, the most recent field inspection of BC11526E found the strand ends again to be visible and rusty, and in some locations the rust was piercing the coating.

Evercrete DPS

All three beams (BD13527, BD08507, and BC11529) coated with this product showed similar levels of performance and performed similarly to the RAINSTOPPER product. There were numerous strand ends exposed and covered with rust (see Figures 31 through 39).

Figure 31. BD13527 prior to application of Evercrete DPS

Figure 32. Evercrete DPS applied to BD13527

Figure 33. Evercrete DPS field performance on BD13527

Figure 34. BD08507 prior to application of Evercrete DPS

Figure 35. Evercrete DPS applied to BD08507

Figure 36. Evercrete DPS field performance on BD08507

Figure 37. BC11529 before application of Evercrete DPS

Figure 38. Evercrete DPS applied to BC11529

Figure 39. Evercrete DPS field performance on BC11529

Recall that beam BC11529 had a second coating applied at the plant. Visual inspection by both the plant foreman and research team revealed that the rust had not penetrated the coating yet, but rust was visible through the coating. The rusty areas were then removed using an angle grinder and the entire surface of the beam retreated with Evercrete DPS. During the most recent field inspection of BC11529, several strand ends were again found to be visible and rusty, and in some locations the rust was piercing the coating.

BASF Sonoguard

Figures 40 through 48 illustrate the condition of the beams (BD13524, BD08503, BC11530E) coated with BASF Sonoguard. In all cases, except one localized spot on BD13524 that appeared to have one strand end with the coating peeling off, the coating appeared to be performing effectively. The one strand end where the coating was peeling off is likely a result of pre-existing rust within the strand prior to application of the beam-end treatment and coating. Progression of the rust likely resulted in the puncturing of the coating. All other areas on BD13524 and the other two beams exhibited no signs of deterioration of the Sonoguard coating.

Figure 40. BD13524 before application of BASF Sonoguard

Figure 41. BASF Sonoguard applied to BD13524

Figure 42. BASF Sonoguard field performance on BD13524

Figure 43. BD08503 before application of BASF Sonoguard

Figure 44. BASF Sonoguard applied to BD08503

Figure 45. BASF Sonoguard field performance on BD08503

Figure 46. BC11530E before application of BASF Sonoguard

Figure 47. BASF Sonoguard applied to BC11530E

Figure 48. BASF Sonoguard field performance on BC11530E

BASF Hydrozo 100

There were two beams coated with the BASF Hydrozo 100 product, beams BD13525 and BD08506. As can be seen in Figures 49 through 54, both beams have numerous strand ends that are visible with significant rust penetrating the coating.

Figure 49. BD13525 before application of BASF Hydrozo 100

Figure 50. BASF Hydrozo 100 applied to BD13525

Figure 51. BASF Hydrozo 100 field performance on BD13525

Figure 52. BD08506 before application of BASF Hydrozo 100

Figure 53. BD08525 applied to BASF Hydrozo 100

Figure 54. BASF Hydrozo 100 field performance on BD08525

Viking Aqua Guard

All three beams coated with Viking Aqua Guard (BD13522E, BD08505, and BC11528) performed similarly upon field inspection, and the coating on all accounts is holding up adequately (see Figures 55 through 63). The only notable element on all three beam ends was the evidence of some visible rust on a few of the strand ends, although no rust was found to have penetrated the coating to date.

Figure 55. BD13522E before application of Viking Aqua Guard

Figure 56. Viking Aqua Guard applied to BD13522E

Figure 57. Viking Aqua Guard field performance on BD13522E

Figure 58. BD08505 before application of Viking Aqua Guard

Figure 59. Viking Aqua Guard applied to BD08505

Figure 60. Viking Aqua Guard field performance on BD08505

Figure 61. BC11528 before application of Viking Aqua Guard

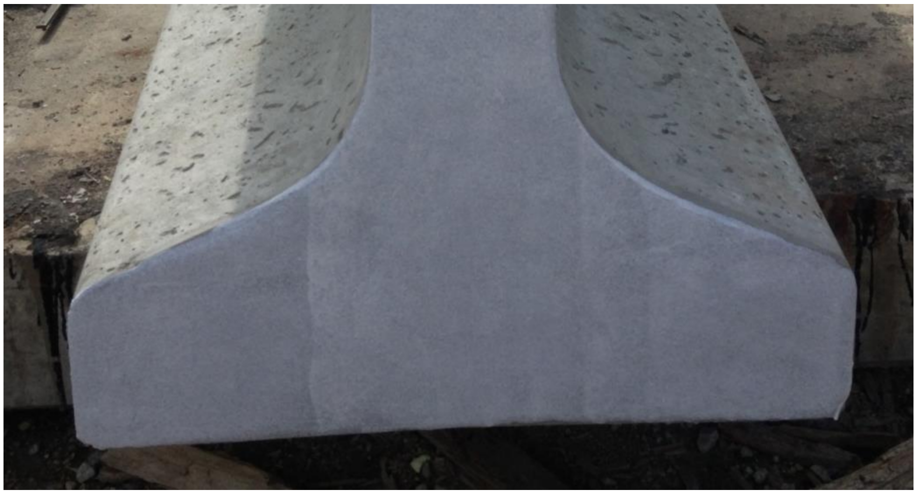

Figure 62. Viking Aqua Guard applied to BC11528

Figure 63. Viking Aqua Guard field performance on BC11528

PAULCO TE-3008-1

During field inspection, this coating alternative showed no signs of deterioration or problematic areas on either of the two beams (BD13523 and BD08504) to which it was applied (see Figures 64 through 69). For both beams, all areas of concrete and the few exposed strand ends appeared to be still well protected, with very little to no rust evident on the strands and no rust penetrating the coating.

Figure 64. BD13523 before application of PAULCO TE-3008-1

Figure 65. PAULCO TE-3008-1 applied to BD13523

Figure 66. PAULCO TE-3008-1 field performance on BD13523

Figure 67. BD08504 before application of PAULCO TE-3008-1

Figure 68. PAULCO TE-3008-1 applied to BD08504

Figure 69. PAULCO TE-3008-1 field performance on BD08504

Sikagard 62

Although no particular bridge beams were coated with Sikagard 62 for this project, there were several beams at the precast plant at the time the research team was installing the other coating alternatives that had been previously coated with Sikagard 62. Figure 70 shows one example.

Figure 70. Beam end coated with Sikagard 62 at precast plant

Note that Figure 70 was taken at the precast plant, not in the field, and the beam was already showing signs of rust penetrating through the coating. In addition, during the field inspection of the other beams detailed above, there were other beams on Bridge BD found to be coated with Sikagard 62. A cursory inspection of several of those beams was also conducted, some showing no signs of distress of the coating, as shown in Figure 71; others were found to have the coating beginning to peel off the strand ends and exposing the rusted strands, as shown in Figure 72.

Figure 71. Good field performance of Sikagard 62 on bridge beams

Figure 72. Poor field performance of Sikagard 62 on bridge beams

ALTERNATIVE BEAM-END DETAIL INVESTIGATION

The current specified preparation technique for prestressed concrete beams fabricated for use on Iowa DOT bridges with expansion joints is to flush cut the strands at the beam ends and subsequently apply the Sikagard 62 to the entire beam-end face, covering the exposed concrete and cut-off strand ends. This procedure is similar to that specified by a few other states, while most others choose to do nothing after flush cutting the strands. The main objective in coating the beam ends is to prevent exposure of the beam ends to the elements. Another option for protection of the prestressed beam ends and exposed strand ends is modification of the beam-end detail during the fabrication process. The main goal of the modification would be to reduce the exposure of the strand ends to the elements as much as possible, more so than with just an epoxy or sealant.

Alternative Selection, Details, and Results

Prior to and during the development of these alternative beam-end details, input was sought from the precaster's perspective so as not to develop a forming alternative that was too complicated or expensive to fabricate and utilize on a repeated basis. Based on input and recommendations from the precasters and the TAC, the following beam-end alternatives were developed for evaluation:

- Single Blockout – The region around the lower cluster of prestressing strands is blocked out, thus creating a large void when the forms/foam are removed, then the blockout is filled with grout or similar material.
- Double Blockout – This detail is similar to the single blockout, except the blockout is split into two smaller blockouts, one encompassing each strand cluster at the base of the beam. The blockouts are filled with grout or similar material.
- Bar Knockout (Burn Back and Patch) – Each strand is individually wrapped with a piece of foam such that when the forms and foam are removed there is a pocket around each strand. The strands within the pocket are cut off and/or burned back, and voids are filled with grout or similar material. Note that this method has been utilized by the prestressing industry in the past.
- Drill Out Strands – The strand ends are flush cut and then 1 to 2 in. of the strands are drilled out into the concrete.

All of these alternatives were only evaluated on the bottom flange of a standard Iowa DOT prestressed concrete T-section to reduce the size of the laboratory specimens and improve handling during testing. Figure 73 illustrates the lab specimen formwork prior to the concrete pour. For the termination of the strand ends on these specimens, most were flush cut with a cut-off wheel on the specimens with the larger blockouts; for the Bar Knockout specimen, the strands were first flush cut with a cut-off wheel and then burned back into the recess using a torch.

Figure 73. Formwork for laboratory beam-end specimens

Single Blockout

This beam-end forming alternative involves creating a blockout in the area surrounding the cluster of prestressing strands such that when the forms and blockout material are removed the area around the strands is recessed from the face of the girder a predetermined distance. This recess allows for the strands to be cut off back from the face of the girder and covered for protection. Three different blockout options were evaluated for the Single Blockout alternative: (1) 1 in. thick foam blockout, (2) 2 in. thick foam blockout, and (3) ¾ in. plywood blockout with chamfered edges. Figures 74 through 76 illustrate the three Single Blockout alternative specimens, both prior to and after concrete placement.

The foam blockout was very simple to fabricate and did not result in any complications when passing the prestressing strands through the ends of the formwork. Two methods were investigated for creating the holes in the foam for passage of the strands: drilling out the foam through the form end with a drill bit and marking the location of each strand on the inside of the foam and simply pushing the strand through the foam and formwork. Both methods worked adequately, although the first option was slightly more construction friendly because the strands slid through much easier with the hole already in place in the foam. On these specimens, the foam was attached to the formwork using a basic spray-on adhesive and presented no issues.

As can be seen in Figures 74 through 76, none of the blockouts created using foam had chamfered edges.

Figure 74. Single Blockout formed with 1 in. foam

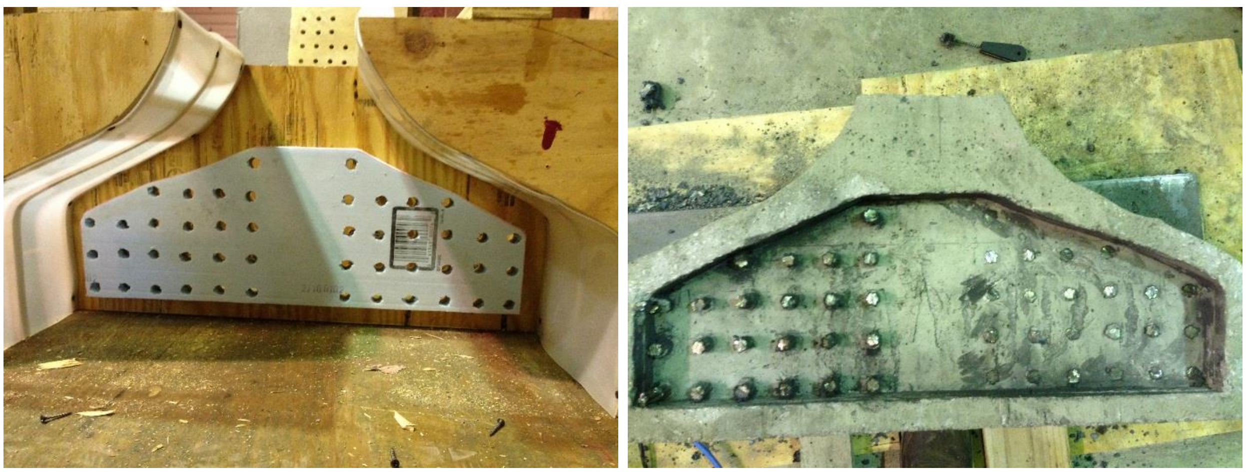

Figure 75. Single Blockout formed with 2 in. foam

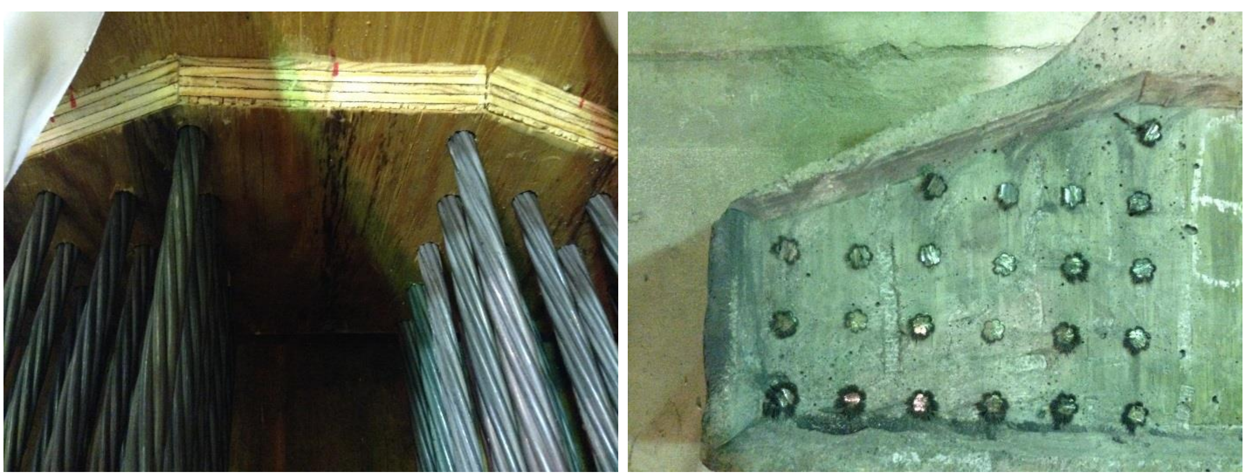

Figure 76. Single Blockout formed with ¾ in. plywood with chamfered edges

When foam is used for this type of blockout, there is no need to chamfer the edges because removal of the end formwork is similar to a standard beam casting. The foam, which typically remains encased in the blockout around the strands, is then simply blasted or picked out quite easily. Note that the strands located in the corners of the blockouts were difficult to remove and cut completely flush with the concrete due to the tight radius of the blockout. In addition, on the 2 in. thick blockout the cluster of strands on the right side was cut flush to the concrete, whereas the strands in the left-hand cluster were cut off at approximately 1 in. to evaluate whether this had an effect on constructability, as well as what effect it may have on the bonding of the grout. Constructability was slightly improved by only cutting off half of the protruding strand length rather than flush cutting the strands in the blockout.

When the blockout was created using plywood or another stiff forming material (i.e., steel), removal of the end formwork became extremely difficult, if not impossible, with some form of damage being done to the formwork, without the chamfers around the edges of the blockout. Even with the chamfer, removal of the formwork was problematic and cumbersome because both the end form and the blockout must be slid over the numerous protruding strands simultaneously. Lastly, it is worth noting that the chamfer in the blockout did facilitate easier cutting/removal of the prestressing strands in the corners of the blockouts. However, further investigation may be necessary to see what long-term effects the chamfer may have on the bond of the grout because any cracking at the interface between the grout and the existing concrete could subsequently funnel moisture (possibly containing chlorides) into the blockout and to the strand ends.

Double Blockout

This blockout alternative is a derivative of the Single Blockout alternative, in that two individual blockouts are created around the main clusters of strands and separated along the vertical centerline of the beam (see Figure 77).

Figure 77. Double Blockout formed with 1 in. foam

This blockout alternative was only evaluated using 1 in. foam for the construction method, and the strands were all flush cut. Much like the Single Blockout alternative, the strands in the four corners of the blockout were extremely problematic to cut given the blockout geometry. Therefore, a slight revision of the blockout geometry may be necessary if used in the future. On the positive side, this alternative has its advantages when applying the grout because there is less of a void to fill, which in vertical applications like this can be an important aspect.

Bar Knockout (Burn Back and Patch)

As noted previously, this method has been used previously by the precaster in limited applications. For this testing, the individual bar knockouts were created using ¾ in. self-sealing tubular foam pipe insulation (see Figure 78).

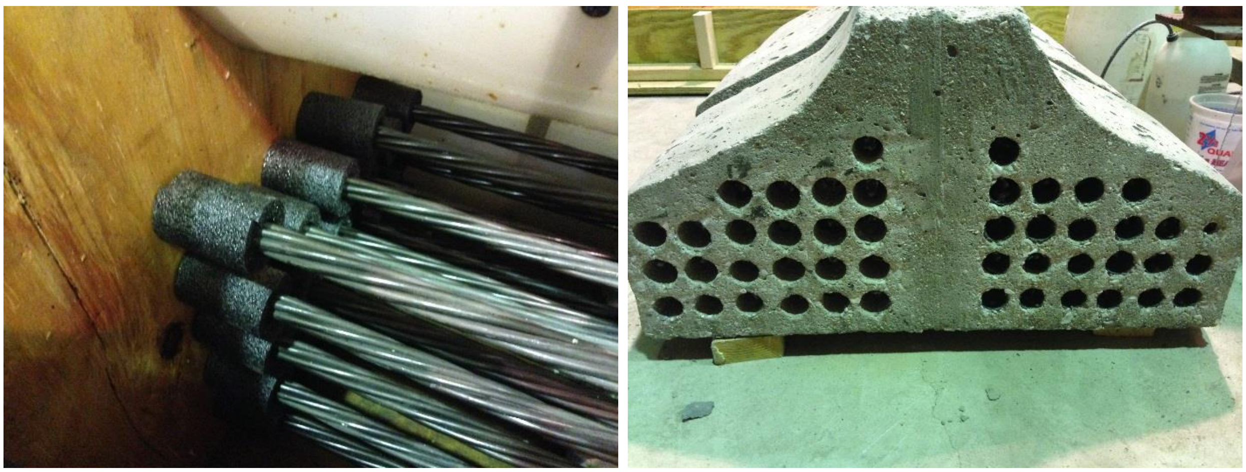

Figure 78. Bar knockout using pipe insulation cut to 2 in. lengths

The tubing was first cut into 2 in. long pieces and then trimmed slightly along its length to create a tight fit around the 0.6 in. diameter prestressing strands. In most cases, the self-sealing adhesive was not sufficient to affix the foam to the strands and was therefore lightly taped closed to keep the foam on the strand during concrete placement. For future applications, an un-slit foam with an inside diameter more closely matching the diameter of the strands would be a more construction friendly alternative. Even so, fabrication of this specimen was very construction friendly and produced great results when the formwork and foam were removed.

Once the concrete was poured and the end formwork was removed, the foam was easily removed from around the strands. The strands were then cut off nearly flush with the beam-end face using a cut-off wheel and then burned back into the pockets using a torch. Burning back of the strands did produce some slag on the insides of the pockets. However, this was easily removed with either a pick or by sandblasting. It is worth noting that sandblasting the slag out created an attractive roughed concrete surface for bonding of the grout material.

Drill Out Strands

The objective of this alternative was to avoid the necessity for any blockouts in the formwork but still allow for the ends of the prestressing strands to be recessed, covered, and protected from exposure to the elements at the ends of the beam. The basic procedure was to flush cut the prestressing strands with the end of the beam and then, utilizing a drill bit, drill out 1–2 in. of the prestressing strand into the concrete. Once the strand was drilled out, the void was filled with grout.

Expectations were high for this method to be a viable beam-end detailing option. However, shortly after the first drill attempt it was clear the simplicity of this method ended in the concept. Numerous attempts were made, varying the procedure from attempting to drill a starter/pilot hole with a smaller bit then switching to a larger bit, to center punching and beginning with the end diameter (~0.5 in.) bit, then varying the drill bit material type, and even varying drill speed and lubrication. Throughout the investigation, the best outcome was a 1/8 in. deep pilot hole using a 1/8 in. bit. On the laboratory specimen, which had untensioned strands, the individual strands that form the woven strand were not tight enough against one another, resulting in a significant amount of vibration during drilling. It is unknown if this issue would be resolved with a tensioned strand. Regardless of this fact, no measurable amount of strand was successfully drilled out using any method or drill bit type. Furthermore, it is believe that with the high cost of the drill bits required for this type of application and the sheer number of them that would be required (many drill bits would likely be required for just one beam-end treatment), this would not be a construction friendly nor cost-effective option.

Beam-End Grouting Investigation

Although the main focus was to develop the beam-end forming alternatives for reducing exposure of the strand ends to the elements, several non-shrink grouts were also evaluated for their ability to fill the voids and encase the strand ends. Given project time limitations, only a short-term evaluation of the performance (ability to apply to vertical surface, bond, etc.) of the grout alternatives in the patch areas was feasible. Selection of the grouts for inclusion in this testing was based on the following two main criteria: the material must be non-shrink and the material must not require formwork and must be able to be applied in overhead or vertical applications. Subsequently, three alternative grout products were selected: Sikacrete 211 SCC Plus, Garon TIGERCRETE SP, and UNIQUE Overhead and Vertical Repair.

Application, Constructability, and Performance

All three grout products were mixed according to manufacturer specifications with a batch size of approximately 0.5 cu ft using a 5-gallon bucket and paddle mixer and hand drill. The three alternatives were evaluated either in the Single Blockout or Double Blockout configuration because these larger voids were believed to be the worst case scenario in terms of constructability in placement and performance of the grout. Both the Sikacrete 211 SCC Plus and Garon TIGERCRETE SP products were evaluated on the Double Blockout configuration, one alternative in each individual blockout on the beam end. For the UNIQUE Overhead and Vertical

Repair, the manufacturer provided four different mixes of the same product in an attempt to best match the grout performance with the application. Therefore, each of the four UNIQUE mixes was evaluated on either a 1 in. or 2 in. thick single blockout.

The beam-end specimens were all sand blasted prior to grouting to create an adequate bonding surface and remove any rust/residue from the strand ends and then conditioned to saturated surface dry (SSD) immediately prior to installing the grouts. Placement of the grout patches, for both the Sikacrete 211 SCC Plus and Garon TIGERCRETE SP as well as the last three mixes from UNIQUE, began with first scrubbing the void area to be filled with a slurry coat of the respective grout mix using a stiff brush. After letting the slurry coat set for approximately one minute, the remainder of the void was filled with the grout using a basic hand trowel. The void was packed and troweled until the entire void was full and relatively flush with the face of the beam end. In total, the grouting process took approximately five to eight minutes from the beginning of the slurry coat to the final troweling of the grout patch.

From a constructability standpoint, all the grout products were easy to mix and were easily placed into the vertical voids using a basic hand trowel, as previously mentioned. Given the relatively short set time of these types of products, it seems unlikely that a batch much bigger than that required for two to three beam ends, which ideally would be seated adjacent to each other in the precast yard, could be managed without several skilled laborers on hand to quickly place the grout. As for short-term performance (i.e., days and weeks), performance of the three grout products was pretty even across the board, with all of them developing some level of cracking within and/or around the patch area (see Figures 79 through 81).

Figure 79. UNIQUE Overhead and Vertical Repair

Figure 80. Sikacrete 211 SCC Plus

Figure 81. Garon TIGERCRETE SP

Typically, the cracks were first visible within a few days of grout placement and after a week or so ceased progression. These cracks are believed to be shrinkage cracks, although the possibility exists that microcracking could have existed in the beam-end specimens and reflected through the grout patches.

In addition to the grout application evaluation, each grout patch alternative was allowed to cure for 28 days and was then evaluated for bond performance by attempting to remove the grout patch with an electric impact chisel. The results are described below.

For the UNIQUE product's bond performance, recall that in the application of the first batch of the UNIQUE Overhead and Vertical Repair the slurry coat step was mistakenly skipped. Removal of this patch was subsequently found to be quite simple because little to no bond between the existing concrete and the grout existed (see Figure 82).

Figure 82. UNIQUE Overhead and Vertical Repair – Batch 1 bond performance

The bond performance of the UNIQUE Overhead and Vertical Repair then began to improve slightly throughout the mix progression. The second batch was found to have a good bond between the slurry coat and the existing concrete but very little bond between the grout and the slurry coat (Figure 83).

Figure 83. UNIQUE Overhead and Vertical Repair – Batch 2 bond performance

The third batch also had a good bond between the slurry coat and existing concrete, as well as a better bond between the slurry and grout than the second batch (Figure 84).

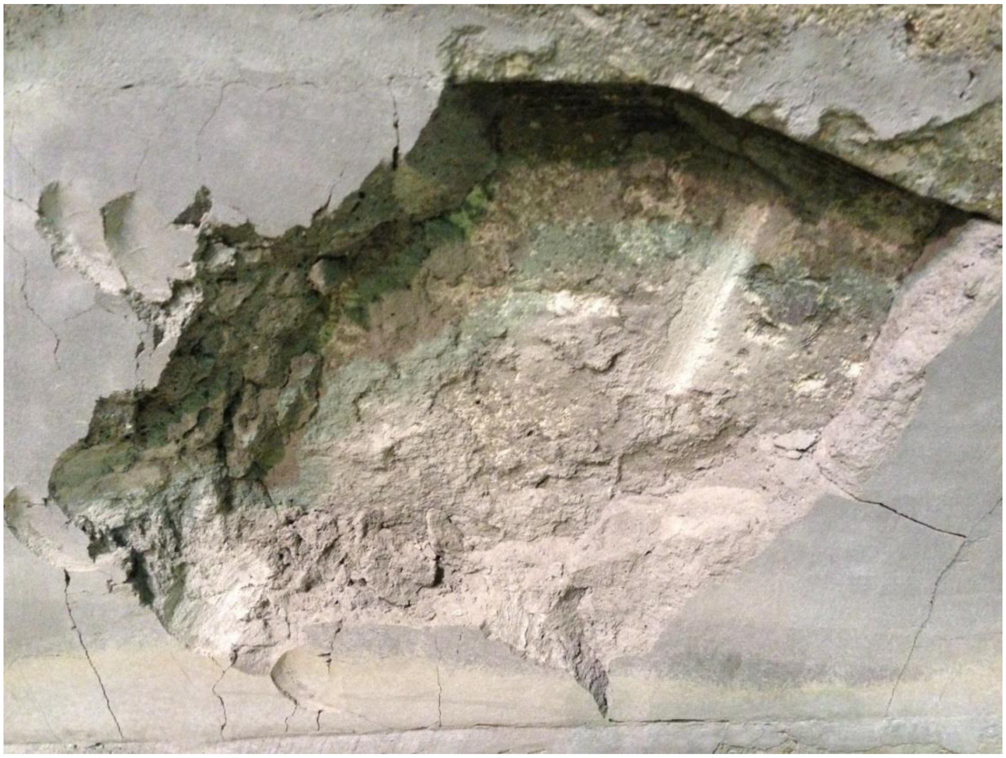

Figure 84. UNIQUE Overhead and Vertical Repair – Batch 3 bond performance

The final batch of the UNIQUE Overhead and Vertical Repair had the best performance in terms of bond, with good bond performance all around (Figure 85).

Figure 85. UNIQUE Overhead and Vertical Repair – Batch 4 bond performance

The bond performance of both the Sikacrete 211 SCC Plus and Garon TIGERCRETE SP products, shown in Figures 86 and 87, respectively, was much like that of the last batch of the UNIQUE Overhead and Vertical Repair. Slurry coats on both applications bonded well to the existing concrete, and the grout exhibited good bond performance to the slurry coats.

Figure 86. Sikacrete SCC 211 Plus bond performance

Figure 87. Garon TIGERCRETE SP bond performance

CONCLUSIONS AND RECOMMENDATIONS

Currently, the Iowa DOT specifies that the ends of precast, prestressed concrete beams used in bridges constructed with expansion joints be finished at the precast plant according to the precaster's specified beam-end finishing procedures, and subsequently have a coating of Sikagard 62 applied to the end of each beam. Although Sikagard 62 has been used by the Iowa DOT as a beam-end coating product for years, no laboratory investigation related to the effectiveness of this detail had been conducted, while anecdotally the performance of in-service bridge beams that have undergone this end treatment process has been found to be highly variable and substandard. Field inspections have found many bridge beams with rusty strand ends exposed, others with spalling and deterioration of the beam ends.

The scope of work for this project incorporated a literature search of the current state of the art and state of the practice, a laboratory evaluation of different concrete coating products utilizing ponded concrete slabs and the AASHTO T259-80 test, and the development of several experimental beam-end detailing alternatives. In addition, beam ends for two Iowa DOT bridges planned for construction near the beginning of the project were also treated with the beam-end coating alternatives evaluated on the ponding slabs and were visually monitored for the duration of the project.

Previous research related to the performance of concrete beam-end treatments found that many state DOTs do not treat the ends of their prestressed concrete beam ends, some do specify beam-end treatment procedures, and a select few specify coating alternatives, although many if not all of the procedures and products that were specified had little to no laboratory or field testing data related to their use in these specific applications. Ultimately, previous research indicated that further laboratory testing was warranted into this subject.

Laboratory ponding tests were conducted on eight different concrete treatment products that were selected based on previous research, current product availability, and TAC recommendations. The eight treatment products selected for evaluation were the following: Sikagard 62, Evercrete DPS, TEX•COTE XL 70 BRIDGE COTE, TEX•COTE RAINSTOPPER 140, BASF Sonoguard, BASF Hydrozo 100, Viking Agua Guard, and PAULCO TE-3008-1. The alternatives were applied to a designated reference square on three separate concrete slabs, each cast at a different precast plant near central Iowa so that the effect of different concrete mixes could also be evaluated. The ponding slabs were evaluated using the AASHTO T259-80 chloride penetration test, and throughout the project all three slabs were subjected to a 90-day ponding cycle, the slabs were then dried, and samples were taken. The process was repeated two more times. In general, over the course of the three ponding cycles there was little to no difference found in the chloride content test results for any of the alternatives; thus, no significant benefit or detriment to the coating's performance was evidenced due to the mix design of the concrete. Comparison of the test data from the sections of the slab with applied coating alternatives to two slab sections left uncovered, i.e., control sections, revealed a marked improvement in the resistance to chloride penetration of the concrete, which was expected; the one exception was the TEX•COTE XL 70 BRIDGE COTE, which the test data indicated did not improve the chloride penetration resistance of the concrete compared to the control sections. The chloride ion penetration performance of all the alternatives were then compared to one another and the coating alternatives ranked in order from best to worst performance based on the ponding data: (1) three-way tie: BASF Sonoguard, BASF Hydrozo 100, Sikagard 62 – two coats, (2) Viking Aqua Guard Concrete Sealer, (3) Sikagard 62 – one coat, (4) TEX•COTE RAINSTOPPER 140, (5) PAULCO TE-3008-1, (6) Evercrete DPS, (7) TEX•COTE XL 70 BRIDGE COTE with Silane. Note that the Iowa DOT currently specifies application of one coat of Sikagard 62, per the manufacturer's recommendations. Addition of another coat of Sikagard 62 did slightly improve the chloride ion penetration performance but likely not enough to warrant the extra time and cost involved in the process.

A total of 19 bridge beam ends were treated with the concrete coating alternatives. Each beam end was prepared according to the precaster's specifications and then the alternative coating applied according to the manufacturers' recommendations. Approximately 18 months after the beam ends had been treated and installed, field inspections were conducted to evaluate their short-term performance. Inspection results from the beam ends treated with the coating alternatives varied not only from product to product, but at times even from one beam to another coated with the same alternative. In general, the performance of all of the alternatives on the concrete surfaces of the beam ends was excellent. There were no signs of peeling or deterioration of the coating *on the concrete surfaces*. All of the problems found during the field inspection appeared to be centered in the areas of the prestressing strand locations. In the rare case where there was a beam end that had all the prestressing strand ends covered as a result of the beam-end preparation process and *then* having the coating applied, the beam end showed no signs of deterioration. However, it was rarely the case that all the strand ends were covered after completion of the preparation process. In most cases, several of the strand ends, and sometimes numerous strand ends, were visible and found to be rusted immediately prior to the coating alternative being applied. Note that all visible rust was removed prior to application of all coating alternatives, although this is believed to be more a superficial fix than a long-term maintenance plan. Further inspection of untrimmed and untreated beam ends at the precast plant found the strands protruding from the ends of the beams to be heavily rusted, and because they are uncovered and exposed to the elements it is highly likely that moisture (and subsequently rust) migrated into the end of the beam end via the strands prior to any beam-end treatment. Possible evidence of this is that there were three beam ends that were treated at the precast plan and less than a week later had to be treated again because the precaster noted that they appeared to be untreated and that there were visible signs of rust on the strand ends under the coatings. Inspection by the research team found that they were treated properly the first time; still, rust had developed and was visible. Subsequently, the strand ends were cleaned of rust and retreated a second time prior to being installed in the field. The moisture and rust that is pre-existing within the beam ends on the strands prior to application of the coating alternative is likely to blame for most of the failures found on the bridge beams treated with the coatings evaluated for this work. Some of the alternatives only had visible signs of rust on the strand ends, with no rust piercing the coating, others had visible rust piercing the coating, and a few others had the coating peeling off and missing completely from the strand ends.

Ultimately, the objective of treating the ends of prestressed concrete beams is to protect the exposed concrete and strands at the end of the beam from exposure to moisture and chlorides, which may penetrate the expansion joint and wreak havoc on the beam ends. In addition to evaluating the coating alternatives, several beam-end forming details were also developed and evaluated for their potential to mitigate this problem. In general, the solutions all centered around creating a void, whether it be an individual void around each strand or a large void around a cluster of strands, such that when the prestressing strands are cut back their ends are behind the vertical face of the beam end. Each of the voids could then be grouted to cover and protect the strand ends and the beam end treated in its traditional manner as a belts and suspenders solution. Creation of the voids must be simple and meet constructability requirements for this type of beam-end detail to ultimately be viable; the process must also not significantly increase the workload during beam fabrication, or a precaster will lose interest or significantly raise costs. In addition, if the detail is too elaborate and requires expensive form modifications, the precaster might resist this option or force the buyer to forgo it due to the increased cost of the end product. Based on these criteria, four alternative beam-end details were evaluated for this work: (1) single beam-end knockout around the entire cluster of strands in the bottom flange of the beam, (2) double beam-end knockout around the two clusters of strands in the bottom flange of the beam, (3) individual strand knockouts around each strand in the bottom flange of the beam, and (4) drilling out the strands.

Drilling out the strands after each is flush cut to the beam face was found to be a nearly impossible process, which, if the process were to be successful, would require lots of labor and expensive drill bits. Therefore, this alternative is not considered a viable option. However, any of the blockout options—single, double, or individual bar—are all excellent options for creating a separation from the face of the beam end and the end of the prestressing strand. Foam was found to be the material of choice for creation of the voids because it allowed for easy installation of both the void blockout and the strands, which could be easily pushed through the foam or through predrilled holes in the foam. Once the forms are removed, the foam is easily removed and the strands may then be cut back to any depth within the exterior face of the beam. Creation of the blockout using plywood, or using metal via modification of a preexisting metal form, would likely require that the outer boundaries of the blockout be chamfered to facilitate easy removal of the forms without damaging the concrete beam end. The final step in the process was to fill the blockouts with a non-shrink grout to protect the ends of the strands. Several grout products were evaluated for this project, including Sikacrete SCC Plus, Garon TIGERCRETE, and UNIQUE Paving Overhead and Vertical Repair. All three products provided an adequate bond to the existing concrete and were easy to mix and apply into the vertical voids regardless of their depth or size. However, even though all products are “non-shrink” grouts, each of the three products developed shrinkage cracks both within the boundaries of the voids and at the perimeter of the voids within a few days of application. Further investigation into potential grout products and/or epoxy products that can adequately fill the voided areas without cracking is warranted.

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