Protecting Piers of Overhead Structures from Degradation Due to Snow and Ice Chemical and Material Usage Phase II

Prepared by:
Richard Miller, PE
Prateek Nepal
Abdullah Haroon
University of Cincinnati

Norbert Delatte, PE
Oklahoma State University

Prepared for:
The Ohio Department of Transportation,
Office of Statewide Planning & Research

Project ID Number: *106177*

April 2021

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2021-13		

4. Title and Subtitle	5. Report Date
Protecting Piers of Overhead Structures from Degradation Due to Snow and Ice Chemical and Material Usage Phase II	**April 2021**
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Richard Miller, PE; Prateek Nepal; Abdullah Haroon **University of Cincinnati; Norbert Delatte, PE** **Oklahoma State University**	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
University of Cincinnati **Cincinnati Ohio 45221-0071**	
	11. Contract or Grant No.
	PID: 106177
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Ohio Department of Transportation **1980 West Broad Street** **Columbus, Ohio 43223**	**Final Report**
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Chloride laden ice and snow thrown from plows can adhere to bridge piers. Eventually the chlorides migrate into the concrete and cause corrosion. This report looks at two methods of protecting bridge piers. One is a polyethylene shield and the other is a polyaspartic coating. The polyethylene shields were easy to install and could be removed for inspection. An attempt was made to use specimens to measure chloride contents and corrosion on protected and unprotected columns. However, mild winters and possible contamination of the specimens provided inconclusive results. The polyaspartics have potential to protect columns better than the epoxy- urethane currently used but require proper surface preparation.

17. Keywords	18. Distribution Statement
Bridges; Chlorides, Column; Concrete; Piers; Polyaspartic; Polyethylene Shields	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**52**	

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

CREDITS AND ACKNOWLEDGMENTS

Prepared in cooperation with the Ohio Department of Transportation
and the U.S. Department of Transportation, Federal Highway Administration

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

The research team wishes to thank:

Dan Wise, P. E., Construction Area Engineer, ODOT District 6

Matt Blythe, P.E., Bridge Design Engineer, ODOT District 7

Sam Morrison, Roadway Services Manager, ODOT District 6

DISCLAIMER

Products noted in this report were used for research purposes. The inclusion of a product name does not constitute an endorsement of or approval by the Ohio Department of Transportation, the University of Cincinnati or Oklahoma State University.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 PROBLEM STATEMENT

Ohio Department of Transportation (ODOT) and the various Ohio local governments use over one million tons of road salt each year. One of the consequences of this salt usage is the deterioration of concrete structures due to the corrosive effects. Piers are particularly vulnerable as they are often subjected to both salt laden water dripping from superstructures above and salt water spray from vehicles below. When plow trucks pass, the salt laden snow is thrown onto or stacked against the piers of overhead bridges. This provides more contact with the salt than occurs on other parts of the structure, where the salt can simply wash or drain off. In addition, the snow will contain salt and road grit scooped up by the plows. When this is thrown against the piers, it can have an abrasive effect and may be responsible for further deterioration of applied epoxy-urethane coatings over time.

To combat the effects of chemical deterioration, ODOT has used protective coatings on some piers. This coating is typically an epoxy-urethane. Over time, the epoxy-urethane often either wears off, probably due to chemical, environmental or abrasive actions, or peels off due to inadequate surface preparation prior to application of the sealant. This leaves the piers vulnerable to the corrosive effects of salt and other chemicals. There are strategies that can be implemented in the construction phase to prevent deterioration of bridge piers. However, there remains the problem of existing piers that are vulnerable to deterioration. Thus methods of preventing or, at least, slowing down the deterioration of these piers need to be explored.

Phase I of this project identified several methodologies which can be used to protect the piers. Some were suitable for new construction and others for maintenance of existing piers. After consultation with ODOT, two viable technologies were identified as worthy of further consideration.

1) Polyethylene Shields: Polyethylene shields, marketed under the trade name Poly Salt Armor, is a high density polyethylene (HDPE) shield placed over pier columns. In theory, this shield will protect columns from the direct impact of snow, ice and grit thrown from plows. It will also protect the columns from direct saltwater splash from passing vehicles.
2) Polyaspartic Polyureas: Polyaspartics are a form of polyurea coatings. Polyureas are a polymer coating that has been shown to act as a protective, surface reinforcement for structural systems. Pure polyureas must be sprayed on with a specialized sprayer and require protective equipment. Unlike pure polyureas, polyaspartics have a longer pot life and can be easily sprayed or rolled on. Common uses of polyaspartics include garage floor coatings and truck bed liners. It is thought that polyaspartic coatings will provide better protection and a longer service life than the epoxy- urethane coatings currently in use, thus justifying the higher cost of the polyaspartic material.

2 RESEARCH BACKGROUND

2.1 Goals and Objectives

The technical objectives of the research are:

1) Determine if polyethylene shields provide a cost-effective method of protection for bridge columns. Determine if they prevent or lessen the amount of salt laden water that comes in contact with the column and if they will prevent grit from abrading and eroding the concrete.
2) Compare the life cycle cost of polyethylene shields to epoxy-urethane, include the cost of removing existing coating.
3) Determine if polyaspartic coatings are a cost-effective method of protection for bridge piers. Determine if polyaspartic materials can be easily applied, with a sufficient thickness, by ODOT maintenance crews in a timely and cost-effective manner, and if training requirements and safety precautions are reasonable for ODOT crews. Determine if these materials are capable of sealing the surface to prevent chloride intrusion, and if they are capable of bridging small cracks that may form after application of the material, especially in areas that have been patched.
4) Compare the cost of applying polyaspartic after removal of deteriorated concrete without patching to the cost of patching only.

2.2 Summary of Phase I

This project was done in two phases. Phase I explored methodologies to protect piers from degradation due to deicing chemicals and Phase II (this report) is the results of testing two of those methodologies. A comprehensive literature search was done in Phase I and is contained in the final report for Phase I (Miller et al., 2017). The reader is referred to that document for the complete literature search.

The literature search examined sealers, patches, repair of corroded rebar and fiber reinforce polymer shells. The important points were:

1) Sealers
    a. There are no accepted criteria for determining effectiveness of a sealer;
    b. There are no long-term studies on sealers;
    c. Data on sealers is conflicting. One study will rate a sealer as effective and another will rate it as ineffective. There does not appear to be any correlation between laboratory studies and field studies of similar materials.
2) Patches/Patching Materials
    a. If the patch is placed over concrete with some other problem (freeze/thaw deterioration or alkali/aggregate deterioration), the underlying concrete will continue to deteriorate, and the patch will debond.
    b. In cases where corrosion is the problem, the repaired area might actually create a corrosion cell. This is caused by the rebar acting as a conductor that connects two materials (the patch and the original concrete) with different electrical potentials.
    c. The patches may not seal properly around the edges, allowing water and chlorides to penetrate at the edges. Thus, it may be necessary to seal over the patching material.
    d. Ideal patching materials have low shrinkage, low permeability, low heat of hydration and excellent bond. Few materials meet all these requirements.
    e. The patch may fail due to improper surface preparation and/or application.
3) Areas with Corroded Reinforcing
    a. Corroded reinforcing can be cleaned before a patch is applied, but the corrosion will likely continue.
    b. Corroded reinforcing can be cleaned and coated before a patch is applied, but the coatings may be difficult to apply and/or not be effective.

c. After repair, a surface applied corrosion inhibitor can be applied. This delays but does not prevent future corrosion.

4) Fiber Reinforced Polymer Jackets
   a. Degradation of polymer jackets can be caused by ultraviolet light exposure, freeze/thaw cycling and exposure to aggressive elements such as chlorides, acids and alkalis. There may be degradation of the mechanical properties of the shell due to environmental condition but this may not be problematic if the shell is used only for protection and not reinforcement.
   b. Polymer jackets do not prevent corrosion that is already occurring in the structure. In fact, the jacket may simply hide the deterioration.
5) Polyethylene shields
   a. These are a proprietary product consisting of a high density polyethylene shell for protecting pier columns. The shell is placed around the column to protect it from salt and snow splash. Internal spacers offset the shell from the column face to provide an air gap which allows the surface of the pier to dry should any water get inside. The system bolts to itself and is not permanently attached to the column; thus it is not necessary to drill into the column to install the system.
   b. Polyethylene shields provide a barrier without the need to bond to the concrete. Thus, the effectiveness of the system does not appear to be affected by concrete surface condition (e.g. wet/dry, damaged/undamaged, coated/not coated, dense/not dense). The shells are easily removable for inspection of the column or for replacement should one of the shells become damaged.
   c. Installation can be done by ODOT maintenance crews.
   d. This is a new system and there is no data on performance but the manufacturer estimates the life at 20 years.
6) Polyaspartics
   a. Polysapartics are a form of polyurea that can be applied without special equipment.
   b. Polyaspartics form a tough, rubber like surface that protects concrete. They are often used for industrial floors.

Phase I recommended testing two possible systems: Polyethylene shields (marketed under the brand name of PolySalt Armor™) and polyaspartic polyureas. As discussed in the summary above, the polyethylene shields are simple, wrap around protectors for the pier columns. They may offer a simple and cost effective solution to column protection.

Polyureas are a 2-component material that develops into a polymer compound by mixing a resin with a catalyst. There different types of polyureas, but there is a variation known as a polyaspartic. The main difference is that other forms need to be sprayed on using a special mixing nozzle and application requires a skilled worker and full body protective equipment. Polyaspartics are formulated to have a longer pot life allowing them to be sprayed, rolled or brushed onto a surface.

As stated above, once applied, polyureas form a plastic or rubber like coating on the surface and are often used for protection of industrial concrete floors. Polyureas seem to bond to most bridge surfaces and form a very resilient coating.

3 RESEARCH APPROACH

3.1 Polyethylene Shields

The deterioration of bridge piers is caused by two factors: chloride laden snow thrown onto the pier columns by snowplows (Figure 1) and improperly placed reinforcing bars. The reinforcing bars are supposed to have 3 inches of cover, but construction errors sometimes result in bars that are too close to the surface. The chloride laden snow adheres to the pier columns for some time, allowing the chlorides to leach into the concrete and cause corrosion in the reinforcing bar. The ODOT standard is to use an epoxy- urethane sealer but these do not seem to be effective. In particular, the epoxy-urethane either deteriorates in a few years leaving the pier column unprotected or the concrete below the epoxy- urethane fails.

Figure 1 – Pier column with snow thrown from a plow. (Courtesy D. Wise, ODOT)

Polyethylene shields (marketed under the brand name of PolySalt Armor™) are intended to form a barrier between the column and the snow. The snow is thrown onto the shield and is kept away from the concrete. Since the chloride laden snow does not reach the concrete, the chlorides do not come in contact with column. The shield should also protect against salt laden spray from passing vehicles and the abrasion from salt and grit being thrown against the columns.

The shields are currently only made for 36 inch diameter columns. The shield consists of 3 individual panels bolted together to form a ring. Rings are then stacked one on top of the other to shield the column (Figure 2). The shields feature a 2 inch air gap that is maintained by the indentations which are seen in the panels in Figure 2. This air gap is to allow air flow to dry the column surface should moisture or condensation get behind the shield.

The main question is whether the shield prevents chloride from reaching the column surface, or significantly reduces the amount of chloride on the surface. A secondary question was to determine how easy the shields were to install. The approach was to choose a number of bridges in ODOT Districts 6 and 7. The bridges in District 6 were north of Columbus on I-71 and the bridges in District 7 were on I-75 north of Dayton. Some of the bridges had the shields installed and other bridges did not. Appendix A lists the bridges and whether or not they had shields.

To determine how easy the shields were to assemble, the research team worked with maintenance crews in Districts 6 and 7 to install the shields. During the installation, the research team documented and timed the procedure. Details are found in Appendix B.

Figure 2 – Shielded column

The process of corrosion initiation usually takes many years, beginning with chloride at the surface of the concrete. The chloride penetrates the concrete over time until it reaches the reinforcing bars and initiates bar corrosion. The time for the chloride to penetrate to the bars depends on the thickness and quality of the cover concrete but is greatly shortened if the concrete is cracked. Once the bar begins to corrode, the reaction is expansive and can break apart the concrete, greatly speeding up the process.

However, to make the comparison for corrosion initiation between protected and unprotected columns would take many years, and would also require drilling to remove concrete from the column for chloride sampling. Neither of those would be acceptable to ODOT. It was therefore necessary to come up with accelerated methods to attempt to quantify the effectiveness of the protection.

To test the effectiveness of the shields, small mortar and reinforcing bar specimens were placed under the shields at height of approximately 5 feet from the ground (Figure 3). The intent was to remove some of these specimens after one year and then the rest after two years. The mortar specimens were to be tested for chloride content and the reinforcing bars for corrosion. The specimens were attached to PVC pipes which were then engraved with specimen number for later identification. Specimen numbers were also marked on specimens themselves and on the PVC with permanent markers as backup identification. A total of 4 mortar and 4 reinforcing bar specimens were installed on some columns. In general, the first and third column (in the direction of traffic) on each shoulder received specimens. In District 6, one of the median columns also has specimens. Appendix C outlines specimen placement.


Figure 3 – Mortar and rebar specimens

After one year, two of each specimen were removed from the bridge. The remaining two specimens were removed after two years.

The mortar specimens were then checked for chloride intrusion. The rebar specimens were cleaned of corrosion and weight loss was measured.

3.2 Polyaspartic Coatings

The use of polyaspartic coatings was examined in this project and another ODOT project which assessed the protection of parapet walls; Evaluation of Maintenance Procedures for Bridge Spalling on Parapet Walls (Miller et al., 2020). The parapet project contained laboratory testing as well as field testing. In the project on parapet wall, five different polyaspartic coatings were tested. For this project, two were selected: Creative Materials and Citadel.

The Creative Materials products were DYNA-PRIME N-23 and DYNA-PUR 7416-BL. DYNA-PRIME N-23 is the primer and DYNA-PUR 7416-BL is the top coat. The DYNA-PRIME N-23 had an interesting property. In most cases, Polyaspartic coatings need to be applied to dry surfaces. However the DYNA-PRIME N-23 uses a “water chasing” technology and the concrete surfaces must be wet when the coating is applied. This can be advantageous when coating concrete. Even apparently dry concrete can still contain water below the surface. In the previous project on parapets, the research team noted that if the parapets were coated with polyaspartic after a rain, water would bubble up under the coating even if the parapets appeared dry and had been dried using propane flames. The DYNA-PRME N-23 is applied to wet concrete so the subsurface moisture is not an issue. It is much easier to achieve a wet surface than a dry surface in the field under most environmental conditions.

The Citadel products were the Polyurea 350 primer and the RG 80 X top coat. The products were applied in late fall (October 2018). The Research Team had ordered the “arctic” blend of the Polyurea 350 but the “summer” blend was shipped. The manufacturer stated the product would still work but the setting time would be increased. Rather than wait for arctic blend to be shipped, the summer blend was used.

In District 6, the polyaspartic materials were applied to three bridges. The bridge over I-71 at Lewis Center Road (DEL 71-498) was coated with the Creative Materials product on October 24/25, 2018. The bridge over I-71 at Berkshire Road (DEL 71-1093) was coated with Citadel product on November 7, 2018. Both bridges had columns which had never been coated. The bridge at Gantz Road over I-270 (FRA 270-960) had a patch on the center column of the Eastbound shoulder pier coated with the Creative Materials product on October 24/25, 2018 and a patch on the west column of the same pier was coated with the Citadel product on November 7, 2018. A third patch on the east column was not coated. There were seams where the patch met the original concrete and some shrinkage cracking in the patches. Of interest was whether the polyaspartic would seal the cracks.

In District 6, the columns were prepared for the application of the material by power washing the surfaces prior to application. The Creative Materials product uses a "water chasing" primer so the columns were washed just before application. The columns for the Citadel product were washed the day before. The material was applied with rollers and paint brushes. Appendix C details the process.

In District 7, only the Citadel material was used. Here, the intent was to see if the material could simply be used as a patch with little or no surface preparation; a severe condition for application and not in conformance with manufacturer's recommendations. The material was applied on November 20 2018. The temperature was 32º F in morning rising to 40º F in afternoon.

The material was applied to three bridges. A small spall on the center column of the median pier was coated on MIA 75 – 1995; a large spall on the front column of the north bound shoulder pier was coated for SHE 75- 0102 and two large spalls on 2nd and 3rd columns on the south bound shoulder pier were coated on SHE 75 1954. Complete information is found in Appendix C.

The coating was inspected after 2 years using the Standard Test for Evaluating Adhesion by Knife from ASTM D6677-07 (2018). This is also called the "V notch test." It consists of using a razor knife to cut the coating and see if there is adhesion. Details are found in Appendix C.

4 RESEARCH FINDINGS AND CONCLUSIONS

4.1 Polyethylene Shields

The complete analysis of the polyethylene shields is found in Appendix B. Unfortunately, there were problems with determining the chloride content of the samples placed. As detailed in Appendix B, the usual method of finding chlorides is titration (ASTM C1152, 2020), but the RT could not get satisfactory results from this method. The RT substituted Inductively Coupled Plasma Mass Spectrometry (ICPMS). Bonta et al., (2016) suggested that ICPMS was better than titration. As noted in Appendix B, the RT sent "doped" samples to the lab to determine if the process was viable. The lab results seemed reasonable. Finally, the RT purchased a standard which is to be used for calibrating the technique.

Due to a lack of prior information about the effectiveness and accuracy of the technique, only half the first year samples were sent for analysis. The results seemed reasonable. All of the second year samples were sent for analysis and the results did not make sense. The results seemed to show lower chloride levels after two years and no difference between shielded and non-shielded columns. After numerous meetings with the chemist who did the analysis, it was concluded that the odd results are likely due to very low chloride levels (like due to mild winters) and some contamination of the specimens from the field. The chemist noted that there was a difference in the analysis of the field specimens versus lab specimens (doped specimens, specimens never put in the field to create a baseline and specimens soaked in salt solution in the lab). The contamination may have come from 3 sources. As noted, the shields are not sealed against the atmosphere so some contamination from the air or condensation inside the shield may have occurred. The RT also found where mice had built nests on some samples (which were discarded). However it is possible that small animals get under the shields and that may have also led to contamination. Finally, the RT did find where, in some cases, grit had gotten under the shields and had settled on the specimens. This may have also led to contamination.

The chemist reran the specimens using a second method. Here, each sample was individually calibrated (see Appendix B). The values of chloride content changed slightly, but the overall conclusion did not change; the data is not conclusive. The data does show a slight difference between the shielded and unshielded columns but the standard deviation of the data is large enough to prevent any conclusion from being reached.

The data from the reinforcing bars shows no statistically significant difference in corrosion between bars on the control columns or under the shields. This is not unexpected. The shields do not seal the column from atmosphere. Rebar left lying outside will corrode. The testing showed that rainwater actually caused the worst corrosion (Appendix B). However, the corrosion meters placed on the structure showed much higher levels of metal loss for the unprotected bridges than for the shielded bridges.

Had the corrosion under the shields been less than the unshielded bars, this would have demonstrated the effectiveness of the shields. Had the corrosion been worse, it would suggest the shield retain moisture and corrode the bars. The probes show less corrosion under the shields than for unprotected bridges and the rebar specimens show no difference. Since the shields do not keep out atmosphere, any exposed bar is going to corrode; the shields may help but do not appear to hurt. Without years of exposure and the ability to extract samples from the column cover concrete, it was not possible to document the potential benefits of shields.

The main conclusions for the polyethylene shields are:

1) They are very easy to install and require very little skill or training. A single column can be shielded in about 30-40 minutes; approximately 12-15 minutes to assemble the individual panels into a ring and approximately 15-20 minutes to install.

2) The cost for the shields was $1065/pier. This provided 3 “rings” which protect the bottom 12 feet of the pier. For a 3 foot diameter pier the cost is approximately $11/square foot including ODOT labor. For a crew of 3, it takes 30-40 minutes to assemble and install one shield. The standard epoxy-urethane coating was found in Phase I of this research to cost about $20/sq foot including labor when installed by a contractor. The epoxy- urethane coatings tend to last about 5-10 years. The shields are estimated to have a life of 20 years by the manufacturer.
3) The chloride specimens installed under the shields provided inconclusive results. The chloride levels were low, and the standard deviations were high. There is a possibility the specimens may have been contaminated by atmosphere, grit or animals. Future research should explore whether some type of top gasket or extending the shields to the top of column would help.
4) The corrosion specimens provided mixed results. Corrosion probes showed less corrosion for the shielded piers. Reinforcing bar specimens showed no difference between the shielded and unshielded piers. Since the shields are not sealed to atmosphere, some corrosion is going to occur in the bars, since the bars were not protected by concrete cover. The bar specimen loss was measured by sandblasting the specimens and measuring weight loss. This method requires some judgement. The probe data is based on metal loss as measured by the manufacture’s calibrated system. Given the short duration of the study, the probe data may be more reliable. The results show that shield might help, but do not hurt the corrosion.
5) There were no signs of water penetration through the joints. There were signs of condensation inside the shields.
6) The shields were easy to remove to allow for inspection. However, it is noted that usually an inspector can just look at the column. Removal and reinstallation does take some time but they can be removed for inspection.
7) The shields are extremely easy to repair. In a few cases, shields had been partially removed, assumed to have been hit by mowers. In most cases, the shield could simply be reinstalled. In the odd case of damage, a new panel is easily installed.

4.2 Polyaspartic Coating

Polyaspartic coatings were applied in three circumstances:

1) Two bridge piers where the concrete columns had a combination of sound and spalled concrete. The columns had no previous coatings. They were power-washed before any application of the material.
2) Over patches on two bridge columns. The area was again cleaned prior to application.
3) Over spalled areas on columns. These were not cleaned and represented an attempt to see if the material would work under extreme conditions.

The coatings were applied and left for two years. The coating was then tested using Standard Test for Evaluating Adhesion by Knife from ASTM D6677-07 (ASTM D6677, 2018) (V notch test).

The conclusions were:

1) The coatings were not difficult to apply and could be applied with rollers and foam paint brushes. The Creative material product has a primer that can be applied to wet surfaces which meant the material could be applied after power washing. The Citadel material required a dry surface. The only difficulties were:
    a. In cold temperatures, it takes 3-4 hours for the primers to set before the top coat can be applied. This would be reduced in hot weather.
    b. The Creative Material primer tended to soak into the concrete (which is an advantage) but it also required a second coat of primer.
    c. The materials have a pot life of about 1 hour so only enough material was mixed to allow application within this time period.
2) When applied to a clean, properly prepared surface, the coatings performed well.

3) When applied over rusted reinforcement, the rust did come through the coating. In some cases there appeared to be proper adherence and in other cases the coating could be peeled off. It is suggested that the steel be sandblasted to remove corrosion prior to the application of the material.
4) When applied over the patches, the material looked sound. There was no peeling and the material appeared to seal the crack. However, the V notch test showed the material would peel off the patch. The patching material was very smooth and dense and that seemed to affect the adherence. Roughening any surface is recommended to assure proper adhesion.
5) When applied with no surface preparation and in cold weather, the material did not perform well. However, this was an extreme test outside of the manufacturer's suggested application method. It was done to see what the limit of the material would be. Thus, the material should be applied with proper surface preparation and according to the manufacturer's recommendations.
6) In cases where there was an existing epoxy- urethane coating, there were failures of that coating under the polyaspartic. Again, this points to the need for proper surface preparation, including removing the existing epoxy- urethane coating and exposing sound concrete.
7) The material costs were $3600-$4000 for enough material to coat 12, 3 foot diameter columns. Six columns were 9 feet high and 6 were 13 feet high. This is approximately $7/sq foot for the material. A worker could coat a column in about 2 hours (one hour per coat including mixing). This adds about $1/sq ft for labor bringing the total to about $8/sq ft.

Table 1 – Cost Comparison

Method	Approximate Cost/Sq ft (including Labor)	Installed by
Polyethylene Shield	$11	ODOT
Polyaspartic	$8	ODOT
Epoxy Urethane	$20	Contractor

5 RECOMMENDATIONS FOR IMPLEMENTATION

1) The polyethelyne shields were easy to install, remove for inspection and repair. Unfortunately, due to mild winters and possible contamination of the samples, the results of this study are inconclusive. However, it is recommended that further studies be done and that the optional top gasket be installed.
2) The polyaspartic coatings work well if the surface is properly prepared and the coating is applied according to manufactures' recommendation. This requires at the very least removal of any existing coating and cleaning the surface. Corroded rebar should be cleaned. Roughening the surfaces is highly recommended.

6 REFERENCES

ASTM C1152/C1152M - 20 (2020) "Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete", ASTM Inc.

ASTM D6677 - 18 (2018), "Standard Test Method for Evaluating Adhesion by Knife" ASTM Inc.

Bonta, Maximilian; Armin Eitzenberger, Stefan Burtscher, Andreas Limbeck (2016) "Quantification of chloride in concrete samples using LA-ICP-MS," Cement and Concrete Research 86 (2016) 78–84

Miller, Richard; Delatte, N., Sarah Mullins (2017), "Protecting Piers of Overhead Structures from Degradation Due to Snow and Ice Chemical and Material Usage," State Job Number 135323, Ohio Department of Transportation, May 2017. Posted on the web at http://cdm16007.contentdm.oclc.org/cdm/ref/collection/p267401ccp2/id/14960

Miller, Richard; Delatte, Norbert; Deshpande, Abhijeet; Hartell, Julie Ann; Mullins, Sarah; Karunaratne, Evan (2020), "Evaluation of Maintenance Procedures for Bridge Spalling on Parapet Walls: Phase II - Final report," State Job Number 135593, Ohio Department of Transportation, February 2020. Posted on the web at https://ohiomemory.org/digital/collection/p267401ccp2/id/18816

Appendix A - INSTALLATION OF THE POLYETHYLENE SHIELDS

A1 Shield Installation Procedure

The polyethylene shield arrives as individual panels stacked on pallets. It takes three individual panel units to encircle a 36 inch diameter column. Panels are 4 foot long. They are shipped nested in a vertical orientation and must be assembled (Figure A1)

Figure A 1 – Shields as shipped

A typical panel is shown in Figure A2. When assembled, a complete section is approximately 40 inches in diameter. Each panel has a number of 2 inch standoffs which create a 2 inch air gap. This allows air flow to allow any moisture that may get under the panels to evaporate.

Installation begins by placing 2 panels side by side. There are 5 attachment tabs on each panel that are fitted with stainless steel bolts and wing nuts and tightened to hand tight. The five attachment points are seen in Figure A2. The third panel is added in the same way. The bolts are secured on only two seams, and the last seam is left open as shown in Figure A3. Leaving the bolts hand tight allows the assembly to flex, making assembly easier and preventing damage.

Figure A 2 – Shield Ring

Figure A 3 - Assembled ring with seam open

On the first day of installation, the pieces were assembled in the field, but this was difficult and time consuming. Some bridges did not have enough room under the bridge for assembly so the panels had to be assembled in another area and carried to the piers. The surfaces under or near the bridge were uneven, making assembly difficult, and any nuts or bolts that were dropped were lost in the grass. It also extended the time spent along the roadside under the bridge, which is a safety concern.

On subsequent days, the panels were pre-assembled into groups of three at the District office prior to going to the field. It was found that a worker could retrieve three panels from the pallets, assemble the unit and place the assembled unit on a truck in about 15 minutes.

The panel assemblies can be transported flat on a trailer as seen in Figure A4 or nested as in Figure A5. When transporting flat (Figure A4), the bolts should be loose enough to prevent any damage to the panels when they are flattened out. The widest possible strap should be used to prevent damage and it should be tightened just enough to prevent the load from falling or shifting.

Figure A 4 – Assembled shields stacked on trailer.

Figure A 5 - Assembled shield nested on trailer

At the bridge site, the height of column or the maximum desirable height for the shields is measured. This is done to determine if the shield has to be cut to fit. If the height of the column is not exactly divisible by the height of the panels (4 feet), then the bottom panels may require trimming unless it is determined by the maintenance engineer that the shields do not need to extend to the top of the column. Normally a stack of 3 shields, which is about 12 feet in height, is sufficient to cover the splash zone. If the panels need to be trimmed, a chop saw can be used cutting off the bottom part with the tabs. However, since the tabs keep the bottom of the panels off the ground to allow air flow, cut panels must be kept off the ground either by the unevenness of the ground under the column or using blocks (Figure A6).

Figure A 6 – Partial ring for column shorter than 12 feet.

Figure A 7 – Using a bar clamp to pull the seam together.

Figure A 9 – Wrapping the shields

The assembly process begins with wrapping one set of three panels around the bottom of the column (Figure A7). The side attachment tabs are aligned and bolted together. Due to the uneven surfaces under the bridge, the tabs frequently do not align. ODOT maintenance workers determined that a bar clamp and the indentations in the panels for the standoffs could be used to pull the panels together and align the tabs (Figure A8). For this first shield, all the bolts are then tightened.

Once the first shield is complete, the assembly can be easily slid up the column and then held in place with a board (Figure A9). The next set of panels are then assembled, however the bolt are only tightened hand tight. The lower shield is rotated so that the slots in the top of the lower shield align with the tabs on the upper shield. The upper shield is then dropped into the lower shield and the bolts of the lower shield are then tightened. The process is repeated until all the shields are in place. A completed bridge is shown in Figure A10. If the panels are preassembled before going to the field, it takes approximately 15-20 minutes to shield a column.

Figure A 10 Assembling a stack of rings.

Figure A 11 – Completed assembly

The optimum assembly crew was 3-4 workers. Fewer than 3 made it difficult to lift and hold the shields in place in the column and if there were more than 4 workers they tended to get in each other's way.

A2 Observations on Shield Assembly and Performance

The shields were very easy to assemble and install. No special skill was involved and only common hand tools were needed. Assembly time was reasonably short. The average bridge in this study had three piers with three columns each and each column requiring 3 shields; or 27 total shields. A crew of 4 workers could assemble enough panels into units for 5 bridges in a single day, 8 hour day. Once in the field, the shields could be installed on an entire bridge (9 columns) in about 2.5 hours.

During subsequent inspections of the bridges, the shield appeared in excellent shape after 2 years. In a few cases, shields had been damaged by traffic or ODOT lawnmowers. In each case, the damaged shields were easily replaced.

The only drawback to the shields is that they need to be removed to inspect the columns. This would require a crew to accompany the inspector to remove and reinstall the shields.
Once the first shield section was assembled, it is lifted and supported with a wooden board or some other means of holding the shield in place. Care was taken to wedge the board securely under the shield section to prevent the section from falling.

Keeping the top shield in place with the help of board, the samples were installed at eye level; a typical height where it has been observed that snow from plows hits the bridge pier.

At this point, the four reinforcing bar specimen sensors and four concrete sensors were tied to the column with a nylon cable tie. A Cosasco 20hd corrosion probe was also installed on selected columns. The second shield is wrapped around the column at the bottom. The clamp is again used to keep the seam together, and the bolts and wing nuts are installed. However, the bolts should not be tightened at this time. The tabs on the bottom of the first shield section are aligned with the slots on the top of the second shield. The board is removed, and the first shield section is dropped down onto the section interlocking the tabs. After fitting the two sections together, the bolts in the second section are tightened. Subsequent sections of the shield are installed in the same way. If a cut section is used, it should be on the bottom, and care must be taken to ensure there is a gap to allow for airflow under the section.

On average, it takes 12 minutes to assemble a set of 3 panels prior to going to the bridge site. At the bridge site, it takes approximately 15 minutes to install three layers of shield on a single column. Thus, assembly of a single, 3 part stack took approximately 50 minutes.

APPENDIX B – POLYSHIELD MEASUREMENT SAMPLES

B1 Measurement Samples Background

The deterioration of bridge pier columns usually begins with chloride laden water penetrating through the concrete to steel. This happens more quickly with insufficient cover concrete thickness or quality. The steel begins to corrode and expand. This eventually causes the concrete over the steel to spall off, exposing the reinforcing bar which then corrodes further, especially with the application of more chlorides. To test the effectiveness of the polyethylene shields, it was decided to use mortar specimens to test for chloride penetration and reinforcing bar samples and corrosion probes to test for rates of corrosion.

B1.1Mortar Samples

The mortar samples needed to fit under the shield, so a sample of 2 inch by 2 inch by 1/2-inch specimen was chosen to fit in the 2-inch air gap within the shields. The mortar is the mortar phase of a typical ODOT mix design. The intent was that the rate of chloride penetration into the mortar should be similar to the penetration into typical ODOT bridge column concrete. ODOT specifies an air content of 4-8% in the concrete, and this is adjusted to account for the lack of aggregate in the specimen.

Five molds were used to cast concrete 450 pieces of 2x2 concrete block of 0.5-inch thickness. A total of 480 cubes were to be made with the required volume of 0.55 cubic ft. of mortar. The mix consisted of 80 pounds of sand, 26.4 pounds of cement, and 13.2 pounds of water. Air entrainment was 8% air content by volume.

After the mixture was prepared, the mortar was cast into the molds. A standard modulus of rupture mold was used. In order to get the desired shape, sheet metal, metal plate, and wooden dowels were used. The sheet metal was cut into 2x2 in with a hole punched into its center.
The sheet metal forms were then placed on a wooden dowel with a nylon spacer, as shown in Figure 3-3. Steel plates separated individual rows of specimens. A total of 10 useable concrete blocks were molded from one column and a total of 90 blocks from a mold set. Figure B1 shows the molds

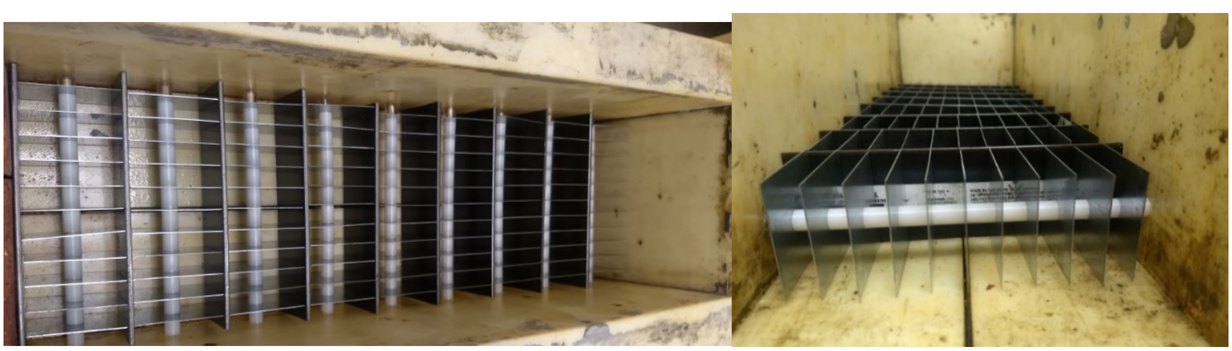

Figure B 1 - Molds

After 24 hours, the concrete pieces were demolded and separated. Each block was carefully weighed on a scale to the nearest 0.01 gram. The sample number of the block was assigned for the identification and was written above the hole and the weight was written below the hole (Figure B2).

To attach the blocks to the columns, the mortar blocks were mounted on pieces of PVC pipe which could be strapped to the columns. Figure B2 shows a typical sample. The sample number and weight of the individual sample were written on top of the PVC pipe with a permanent marker and then engraved with the Dremel tool for easy identification in the future (Figure B2). This triple marking system was to ensure that the sample number would still be visible even after the 2 years. Nylon fasteners were used to prevent contamination or corrosion.

Figure B 2 – Mortar specimens

B1.2 Reinforcing Bar Samples

The reinforcing bar specimen used was selected to fit in the 2-inch gap within the shields. The reinforcing bar sample was a 1/8 in thick slice of an A 615 #8 bar (nominal diameter 1 inch). It was decided that a 1-inch diameter (#8 bar) specimen would be used as this is a fairly common bar size used in bridges. Specimens were cut using a band saw, and a thickness of 0.25 inches was used as it was difficult to achieve a thinner specimen with the band saw.

As with the concrete, the disks were carefully weighed to the nearest 0.01 gram. The sample number of the disc was assigned for identification and was written above the drilled hole, and weight was written below the hole using a marker. This was for temporary identification as this marking will disappear as the steel corrodes.

As with the concrete blocks, the steel disks were attached to a PVC pipe which was then attached to the columns. As with the concrete, nylon fasteners were used since they do not corrode, cause dissimilar metal corrosion or otherwise contaminate the specimen. To allow for corrosion on the entire sample, an additional hex nut and washer were placed between the PVC pipe and sample so the entire sample was exposed. The sample number and weight of the individual disc were written on top of the PVC pipe with a permanent marker and then engraved with the Dremel tool for easy identification in the future (Figure B3).

Figure B 3 – Reinforcing bar specimens

B1.3 Corrosion Probes

As an additional measurement of corrosion, a Cosasco 620 hd commercial corrosion meter was placed on some columns (Figure B4). It provides another measurement of the rate of corrosion. These probes were placed on both shielded and non-shielded columns, but due to cost, only 20 probes were used on project.

Figure B 4 - Corrosion probe and reader

B2 Installation of Specimens

Table B1 shows the bridges where polyethylene shields were installed and piers that were unshielded and used as control specimens. A typical bridge had at least 3 columns for each pier, but a few had more. The shoulder piers had mortar and reinforcing bar specimens placed on the first and third columns in the direction of traffic as shown in Figure B5. In District 6, mortar and reinforcing bar specimens were installed on one column on the center pier. The column was always the first column one side of the bridge; some were first column northbound and some were first column southbound.

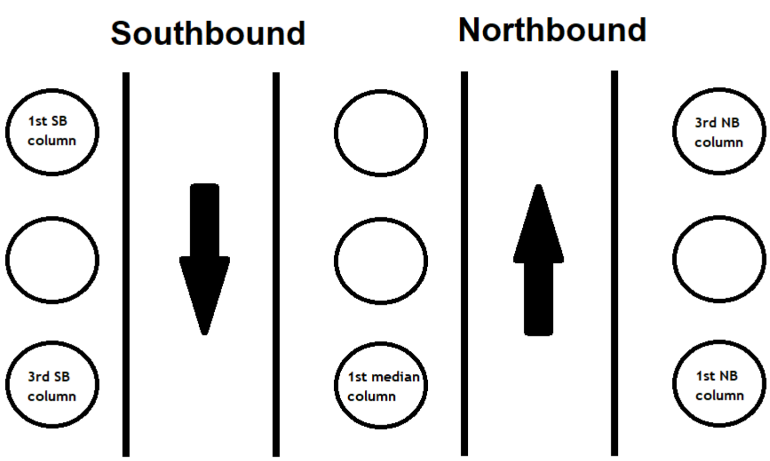

Figure B 5 - Labeling of columns

Table B 1 – List of Bridges with Polyethylene Shields

County	Route	Intersection	Total No. of Columns	Installation	District	Mile marker
Morrow	71	CR15	12	Control –	6	MRW-71-0040
Morrow	71	SR61	21	Control – 42" columns	6	MRW-70-0139
Morrow	71	TR21	9	poly shield all columns	6	MRW-71-0464
Morrow	71	CR170	12	poly shield all columns	6	MRW-71-0825
Morrow	71	CR20	12	poly shield all columns	6	MRW-71-0994
Morrow	71	SR95	21	poly shield all columns	6	MRW-71-1289
Morrow	71	CR14	9	poly shield all columns	6	MRW-71-1528
Morrow	71	TR1	9	poly shield all columns	6	MRW-71-1992
Delaware	71	SR521	12	poly shield all columns	6	DEL-71-1429
Delaware	71	CR34	12	poly shield all columns	6	DEL-71-1307
Delaware	71	CR65	15	Control	6	DEL-71-1563
Morrow	71	SR229	9	poly shield all columns	6	MRW-229-0505
Morrow	71	CR25	12	Control	6	MRW-71-0911
Morrow	71	CR121	9	Control	6	MRW-71 -1374

Miami	75	Shoop	4	poly shield shoulder columns	7	MIA-75-0101
Miami	75	Evanston	6	poly shield shoulder columns	7	MIA-75-0151
Miami	75	Miami/ Shelby	6	poly shield shoulder columns	7	MIA-75-19.95
Shelby	75	Ft Loramie/ Port Jeff	6	poly shield shoulder columns	7	SHE-75-1108
Shelby	75	Meranda	6	poly shield shoulder columns	7	SHE-75-1347
Shelby	75	Amsterdam	6	poly shield shoulder columns	7	SHE-75-1654
Shelby	274	SR-274	6	poly shield shoulder columns	7	SR-274

If a column was to have specimens, a total of four (4) mortar specimens and four (4) reinforcing bar specimens were placed on the column. Some also received corrosion probes (Table B2) Figure B6 shows a typical installation.

Figure B 6 – Installation of specimens and probes

The shields and specimens on north bound and south bound shoulder columns in District 6 were installed in third week of July 2018. The specimens and shields on the median columns were installed the second week of September 2018. The specimens and shields in District 7 were installed in fourth week of September 2018.

After one year, two mortar and two reinforcing bar specimens were collected from each column. This occurred in October 30, 2019 for District 6 and November 18, 2019 for District 7. The corrosion probes were read. After two years (October 13, 2020 for District 6 and October 23, 2020 for District 7) the remaining specimens and the corrosion probes were removed.

For the most part, the specimens seemed in good condition except for the expected corrosion on the reinforcing bar specimens (Figure B7). However, the RT did notice two problems. On a few specimens, rodent nests were found (Figure B9) and these were discarded. On other specimens there was an accumulation of grit on the samples (Figure B8. This occurred because the samples formed a shelf under the shields which could accumulate grit; had they samples not been there grit would have likely fallen out the open bottom of the shield.

Figure B 7 – Specimens and probe under shields after one year of exposure

Figure B 8 – Specimens with grit

Figure B 9 – Specimens with a mouse nest (discarded)

B3 Analysis of the Mortar Samples

The mortar specimens were placed in plastic bags after being taken off the bridge. They were removed from the plastic tube supports, weighed, and then returned to the plastic bags.
The usual method of testing for chlorides is ASTM C1152 Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete (ASTM C1152, 2020). However, the RT had trouble getting this method to work properly. It was suggested to the RT that mass spectrometry might be a better and faster method. The RT contacted the Department of Chemistry at the University and a found a professor who could perform the analysis (Dr. Julio Landero-Figueroa) by Inductively Coupled Plasma Mass Spectrometry (ICPMS). The RT located a recent paper (Bonta et al. 2016) which used this method specifically for finding chlorides in concrete samples.

The procedure, provided by Dr. Landero-Figueroa is provided below:
Approximately ½ the sample was finely crushed and mixed to provide a representative sample. The pulverized samples (0.5g) were placed in a 10 ml high purity borosilicate digestion vial and 1.5 ml of concentrated nitric acid was added. The sample was heated at 130C for 3 h. Then an additional 0.5 ml of concentrated nitric acid and 100 ul of the internal standard mixture was added. The sample was heated at 130C for 3 h. After cooling down the samples, the supernatant was further diluted for analysis. The dilution range was 200x to 1000x depending on the sample results. Certified reference material was prepared in duplicate with the samples.

The analysis was performed on an Agilent 7500ce ICP-MS instrument operated in helium collision mode. The system was configured with a Cetac ASX-500 auto sampler, a quartz micro-concentric nebulizer, a cooled Scott type double pass spray chamber and standard torch and nickel cones. A calibration was run from 0.2 to 25 ppm based on Cl in 1% nitric acid. The 35Cl isotope was monitored for 100 ms with 193Ir as internal standard.

The sequence included the calibration curve, the CRM, a digestion blank, and batches of 15 samples with a calibration point and a blank to verify for memory effects or sensitivity alterations produced by the heavy matrix of the samples. When the CRM, calibration point, or black did not produce results within 5% of the expected value, the previous samples were diluted further."
Prior to providing actual specimens, the RT created specimens with known chloride contents. The mortar used for the specimens was recreated with distilled water. Known amounts of sodium chloride were added to the water. The specimens were sent for analysis and the results are shown in Table B2. Since the RT was expecting higher chloride contents, these results seemed reasonable. The RT also purchased a cement "standard" which could be used to calibrate the apparatus.

Table B 2 - Chloride content of lab samples

Chloride content in sample	Measure chloride content
0.0	0.037
0.3	0.236
0.5	0.385
1.0	0.965

The first year samples were sent for analysis. Since the RT did not as yet have full confidence in the method and since there would be samples in the second year, only one mortar sample from each bridge was used. The remaining samples were retained. For the second year, all the samples were sent for analysis.

The results are shown in Table B3 for District 6 which had the largest number of bridges. The first year results seemed reasonable and correct; although the chloride contents were lower than expected probably due to a relatively mild winter. The standard deviations were large but only a few samples had been tested. The second year data also showed low chloride contents and showed essentially no difference between shielded and unshielded bridges. The standard deviations were large, on the order of 50% of the measured mean. District 7 had far fewer samples but the results are similar (Table B4)

As a comparison, the RT submitted 4 samples which had never been in the field. As shown in Table B5, the chloride contents are very similar to the 0% chloride sample in Table B2. The RT also provided 4 samples that had been soaked in a 3% chloride solution for 2 years and the results, as expected, show high chloride contents. However the standard deviations are well within a reasonable range.

The RT had other concerns about the data. In the second year, two specimens were removed from each bridge tested. In theory, the chloride content for both specimens should be close to the same. For the most part it was but there were several specimens where the two on the same bridge did vary. When discussing this with chemist who performed the analysis, he noted that it appeared that the field specimens might have been contaminated. He stated that the lab specimens seemed to run without difficulty, but he had to continually stop and clean the apparatus when running the field samples. He also noted that to run the samples he first had to dilute the samples. For the first year specimens, he used different dilutions but found that might make the different results not comparable. The second year specimens all have the same dilution.

In an attempt to improve the data, the chemist reran the second year specimens. In this run, each sample was individually calibrated. The sample was run and the chloride content was measured. Next the sample was doped with a known amount of chloride and the then the chloride content was measured again. Ideally, the chloride content should change by the added amount of chloride. If not, the measured change can be used to recalibrate the original measurement. For completeness, all of the measured values are shown in Tables B3 – B5.

The tables show a very low chloride content, probably due to mild winters. The standard deviations are also relatively high. Given that, the RT finds the results inconclusive.

Table B 3 - District 6 Data

		Year 1			Year 2			Year 2 rerun		
Sample Type	Column	No. of Samples	Mean Chloride %	SD	No. of Sampl es	Mean Chloride %	SD	No. of Samples	Mean Chloride %	SD
Contr.	All	26	0.1792	0.09	49	0.2240	0.11	49	0.1770	0.09
	Right first	5	0.1675	0.1	9	0.1967	0.12	9	0.1220	0.06
	Right third	5	0.1721	0.11	10	0.1935	0.09	10	0.1383	0.06
	Left First	5	0.2362	0.19	10	0.1551	0.01	10	0.1445	0.04
	Left third	6	0.1885	0.15	10	0.2607	0.13	10	0.2928	0.12
	Center	5	0.1301	0.06	10	0.3111	0.06	10	0.1807	0.01
Poly shield	All	44	0.1324	0.12	82	0.2295	0.11	82	0.1689	0.06
	Right first	9	0.1747	0.16	16	0.2166	0.12	16	0.1684	0.06
	Right third	9	0.1346	0.09	16	0.1988	0.12	16	0.1705	0.05
	Left First	9	0.1415	0.07	16	0.1912	0.08	16	0.1627	0.08
	Left third	8	0.1148	0.05	16	0.2339	0.11	16	0.1881	0.07
	Center	9	0.0947	0.02	18	0.2981	0.09	18	0.1564	0.04

Note SD = Standard Deviation

Table B 4 - District 7 Data

		Year 1			Year 2			Year 2 Rerun		
Sample Type	Column	No. of Samples	Mean Chloride %	SD	No. of Samples	Mean Chloride %	SD	No. of Samples	Mean Chloride %	SD
Contr.	All	2	0.3218	0.05	2	0.2278	0.12	2	0.2518	0.01
	Left first	2	0.3218	0.05	2	0.2278	0.12	2	0.2528	0.01
Poly shield	All	14	0.1812	0.07	20	0.2478	0.06	20	0.2337	0.02
	Right first	6	0.1979	0.09	9	0.2723	0.06	9	0.2310	0.02
	Right third	0	NA	NA	2	0.2928	0.005	2	0.2242	0.01
	Left First	6	0.1592	0.07	7	0.2279	0.16	7	0.2323	0.02
	Left third	1	0.2356	NA	2	0.0566	0.02	2	0.2425	0.002

Table B 5 - Lab Samples

Never Exposed		
Sample	% Chloride Original	% Chloride rerun
1	0.0343	0.0468
2	0.0542	0.0507
3	0.0477	0.0366
4	0.0447	0.0430
Average	0.0452	0.0443
SD	0.008	0.0060
3% Salt Solution		
Sample	% Chloride Original	% Chloride rerun
1	3.2010	2.6851
2	3.4437	2.5913
3	3.8261	2.5612
4	3.7704	Not run
Average	3.5603	2.615
SD	0.29	0.06

B4 Reinforcing Bar Samples

The reinforcing bar specimen samples from Districts 6 and 7 were sandblasted and weighed. This weight was compared with the initial weight of the reinforcing bar specimen before exposure. For every column, the average of 2 samples has been taken.

The rebar samples were categorized into following categories to facilitate their comparison:

1. The control samples vs the polyshield protected samples to assess effectiveness of the shielding.
2. Samples on the north bound lane vs the samples on the south bound lane to see if the direction of traffic plays any role.
3. Samples on the first columns, the center columns, and the third columns in the direction of traffic to see if the position of the column affects the result.

Figure B10 shows the average weight loss in the control vs shielded samples for the two years. For both the years the average weight loss is slightly higher in the shielded samples than the control samples, but the difference is not statistically significant.

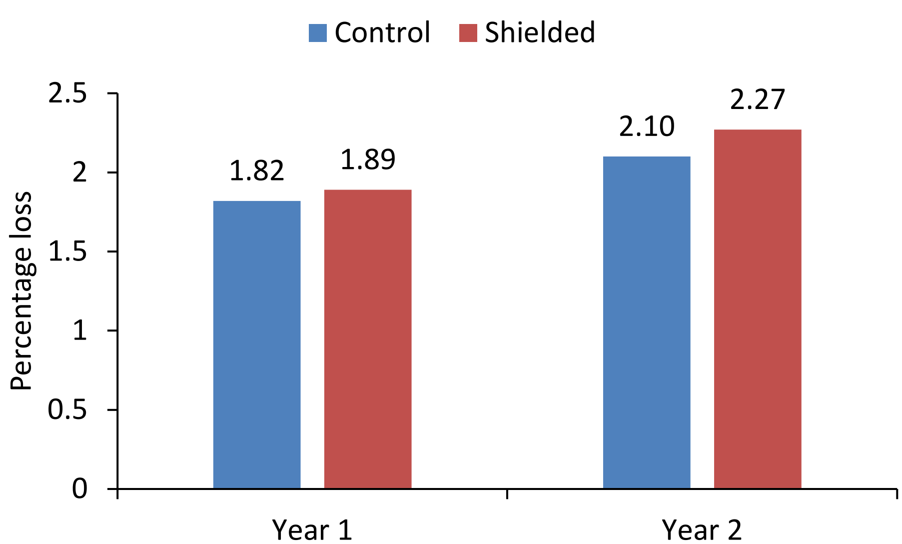

Figure B 10 - Average percentage weight loss for shielded vs control samples.

Figure B11 shows the average weight loss for samples in the north bound traffic vs the samples in the south bound traffic. During year 1 the average weight loss is slightly higher in the north bound traffic for both shielded and control specimen. During year 2 the weight loss is almost equal for the shielded samples and slightly higher in the north bound traffic for the control samples. There is no conclusive evidence to suggest that the direction of traffic influences the weight loss in the samples.

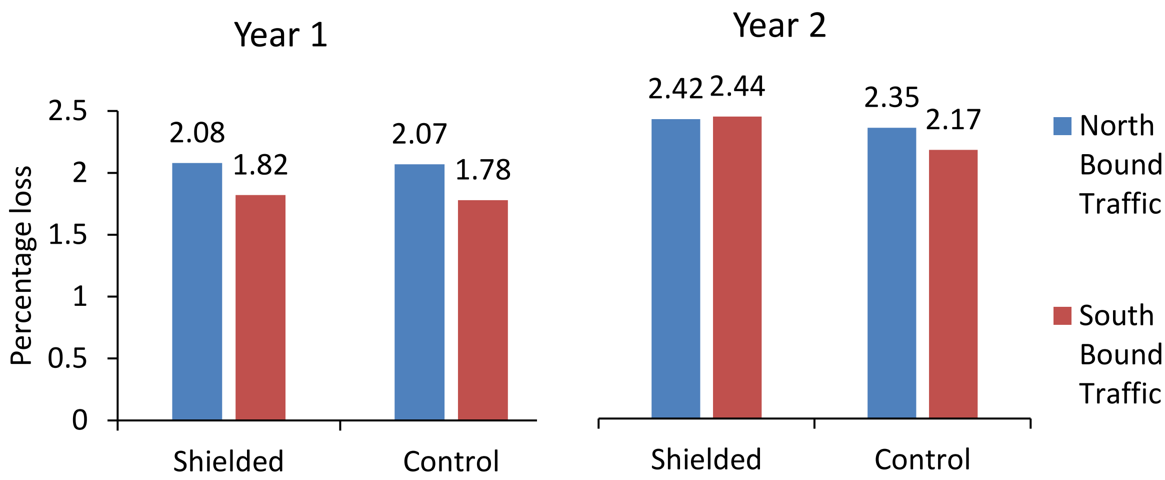

Figure B 11- Average weight loss in the north bound vs the south bound samples

Figure B12 represents the average weight loss in the samples placed on the first column, the third column, and the center column for both the years. There is no consistent pattern in the weight loss of the first column and the third column, however, the center column has the lowest average weight loss in both shielded and control samples.

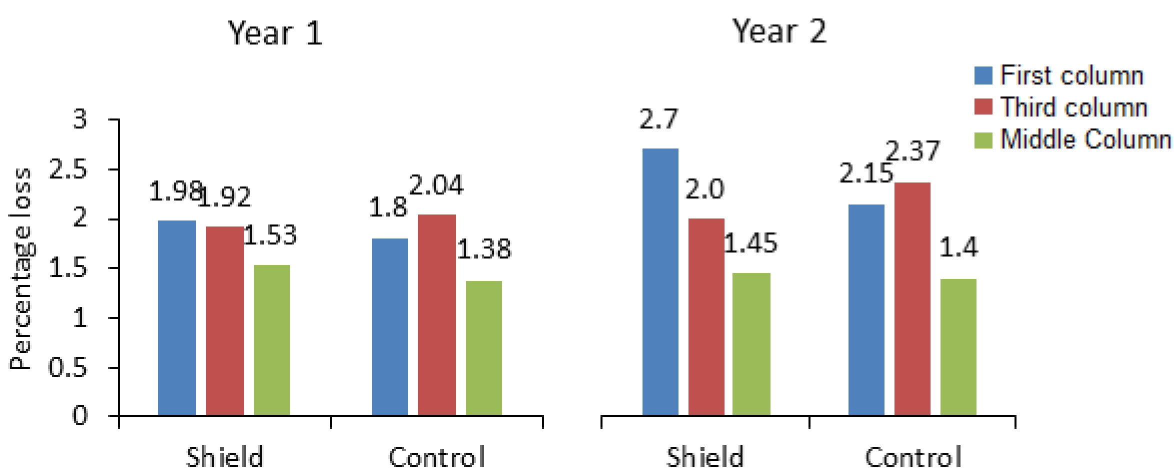

Figure B 12 Average weight loss for different column positions

The data does not show a difference in corrosion of reinforcing bar between shielded and unshielded samples. This is not surprising. A reinforcing bar will corrode if it left outside even if there are no chlorides present.

Figure B13 shows the results of corrosion for reinforcing bar samples placed in a 3.5% chloride solution, a 23% chloride solution and rainwater collected at the University. The 3.5% chloride solution is chosen as literature shows the is the chloride content that maximizes corrosion. ODOT uses a 23% chloride brine to pre-treat roads in the winter. The data, although scattered, shows the worst corrosion occurs under rainwater, then the 3.5% chloride and finally the 23% chloride. As noted, the tops of the shields are not sealed and spray from the road could have gotten under the shield, or the corrosion could have happened from the presence of moisture in the atmosphere.

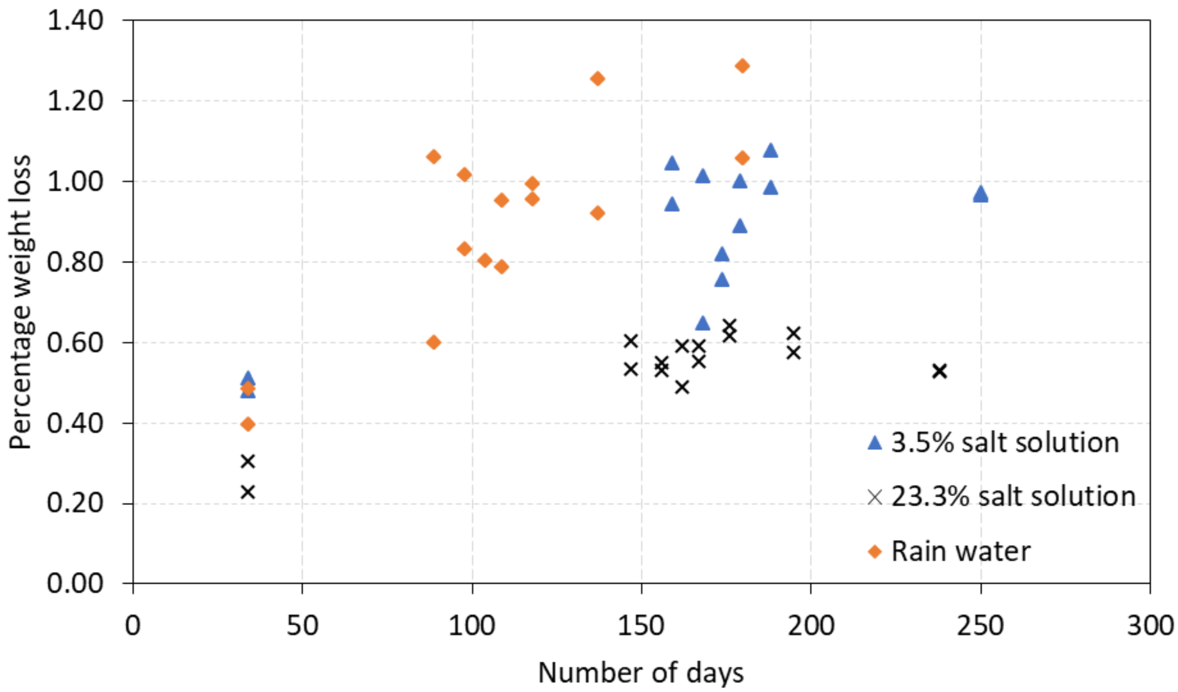

Figure B 13 - Weight loss for lab specimens

The data for reinforcing bar corrosion was not unexpected. As stated, a reinforcing bar will corrode in the atmosphere even if no chlorides are present. The shields are not sealed against the atmosphere, so corrosion was expected. Had the corrosion under the shields been less, that would have demonstrated the effectiveness the shields. The fact that corrosion under the shields is about the same as for unshielded columns means the shields do not do any harm, either.

B5 Corrosion Probes

Table B6 shows the results of metal loss from the corrosion probes. The shielded specimens show less metal loss than the unshielded specimens. The standard deviation is large and there were far fewer probes installed due to cost, but the results are still significant. The probes are made of different steel than the reinforcing bar so they would corrode differently. Here the results show a plus for the shields. The bar specimens were checked by sandblasting the specimens and measuring weight loss. This method requires some judgement. The probe metal loss is measured by the manufacturer's calibrated system. Given the short duration of the study, this may be more accurate.

Table B 6 – Corrosion Probe Data

		Year one metal loss	Year two metal loss
Bridge	Type	Mm	mm
DEL-71-1307	Shielded	0.0219	0.0423
DEL-71-1307	Shielded	0.0259	0.0440
DEL-71-1307	Control	0.0202	0.0362
MRW-71-1374	Control	0.1421	0.2248
MRW-71-1374	Control	0.1254	0.1917
MRW-71-1374	Control	0.0502	0.1131
MRW-71-1992	Shielded	0.0529	0.1046
MRW-71-1992	Shielded	0.0378	0.1017
MRW-71-1992	Shielded	0.0151	0.0252
MIA-75-19.95	Shielded	0.0041	0.0223
MIA-75-0101	Shielded	0.0281	0.0432
MIA-75-0101	Shielded	0.0172	0.0307
SHE-75-1654	Shielded	0.0033	0.0159
SR-274	Control	0.0497	0.1283
SR-274	Shielded	0.0269	0.0542
SR-274	Control	0.1107	0.1802
SR-274	Shielded	0.0142	0.0264
Average Shielded		0.0225	0.0464
STDEV		0.0144	0.0302
Average Control		0.0830	0.1457
STDEV		0.0494	0.0677

APPENDIX C - POLYASPARTIC COATINGS

C1 Background

The use of polyaspartic coatings was examined in this project and another ODOT project which examined the protection of parapet walls; Evaluation of Maintenance Procedures for Bridge Spalling on Parapet Walls (Miller et al., 2020). The parapet project contained laboratory testing as well as field testing. In the project on parapet walls, five different polyaspartic coatings were tested. For this project, two were selected: Creative Materials and Citadel.

The Creative Materials products were DYNA-PRIME N-23 and DYNA-PUR 7416-BL. DYNA-PRIME N-23 is the primer and DYNA-PUR 7416-BL is the top coat. The DYNA-PRIME N-23 had an interesting property. In most cases, Polyaspartic coatings need to be applied to dry surfaces. However the DYNA-PRIME N-23 uses a "water chasing" technology and the concrete surfaces must be wet when the coating is applied. This can be advantageous when coating concrete. Even apparently dry concrete can still contain water below the surface. In the previous project on parapets, the research team noted that if the parapets were coated with polyaspartic after a rain, water would bubble up under the coating even if the parapets appeared dry and had been dried using propane flames. The DYNA-PRME N-23 is applied to wet concrete so the subsurface moisture is not an issue. It is much easier to achieve a wet condition I the field than a dry condition.

The Citadel products were the Polyurea 350 primer and the RG 80 X top coat. The products were applied in late fall (October 2018). The Research Team had ordered the "arctic" blend of the Polyurea 350 but the "summer" blend was shipped. The manufacturer stated the product would still work but the setting time would be increased. Rather than wait for arctic blend to be shipped, the summer blend was used.

The bridge where the polyaspartic coating were used are shown in Table C1.

Table C 1 – List of Bridges for Polyaspartic Coatings

Bridge	District	Product	Element
DEL 71 -498	6	Creative Materials	NB shoulder columns
DEL 71 -498	6	Creative Materials	SB shoulder columns
DEL 71-1093	6	Citadel	NB shoulder columns
DEL 71-1093	6	Citadel	SB shoulder columns
FRA 270-960	6	Creative Materials	Patch on center column; EB shoulder
FRA 270-960	6	Citadel	Patch on west column; EB shoulder
SHE 75-1954	7	Citadel	Deteriorated areas on center column and north column; NB shoulder
MIA 75-1995	7	Citadel	Small spall, center column, median.
SHE 75-0102	7	Citadel	Large spall on first column, NB shoulder

C2 Note on Polyaspartic Coatings

The manufacturers of the coating recommend that the surfaces be cleaned and sandblasted prior to application. However, the intent of the project was to explore the use of the coating for maintenance purposes. Sandblasting requires equipment, protective clothing, means of retaining the sand and environmentally safe disposal of the used sand. Thus, sandblasting is not something a maintenance crew would normally do.

This project explored the use of these products under a maintenance situation where crews would apply the coating with minimal or no preparation. This was clearly an unfavorable set of circumstances for the material. Thus, the results should be interpreted within that context. The failure of the material in some circumstances may not be a flaw in the material, but the desire to test the material under circumstance that are not within the usual use of material.

C3 District 6

C3.1 Application

In District 6, the polyaspartic materials were applied to three bridges. The bridge over I-71 at Lewis Center Road (DEL 71-498) was coated with the Creative Materials product on October 24/25, 2018. The bridge over I-71 at Berkshire Road (DEL 71-1093) was coated with Citadel product on November 7, 2018. Both bridges had columns which had never been coated. The bridge at Gantz Road over I-270 (FRA 270-960) had a patch on the center column of the Eastbound shoulder pier coated with the Creative Materials product on October 24/25, 2018 and a patch on the west column of the same pier was coated with the Citadel product on November 7, 2018. A third patch on the east column was not coated. In specific, there were seams where the patch met the original concrete and some shrinkage cracking in the patches. Of interest was whether the polyaspartic would seal the cracks.

Figure C1 shows the DEL 71-498 bridge just prior to application of the coating. The southbound pier had a large spall on the center column where the reinforcing bar was exposed (Figure C2). Other than power washing the columns prior to application, no other surface preparation was used. The columns were washed just before application because the Creative Material primer is applied to wet surfaces. The product comes in two parts and was mixed according to manufactures' instruction. It was applied with paint rollers. In the spalled area, foam paint brushes where used to apply the material. The temperature varied between 40-50^{o}F. The material has a pot life of about 1 hour.

The primer was applied to the both the southbound and northbound pier columns on DEL 71-498. It took 1.5-2 hours for the primer to dry enough that the top coat could be applied. After the first application of the primer to the DEL 71-498 bridge, the research team noted a "mottled" appearance (Figure C3) in the primer. The manufacturer advised that this was probably due to differences in porosity in different areas of the concrete. A second coat was applied. Since this coat would not dry within before the ODOT work crews had to leave for the day, the top coating was delayed until 10/25/2018. The manufacturer said this was allowable as long as the top coat was applied within 24 hours.

Figure C 1 -DEL 71 498 before coating

Figure C 2 - Column with first coat of primer applied.

Figure C 3 - - Spalled area on center SB column

On 10/25/2018 there were still some bare spots on the DEL-71-498 columns. These were patched an allowed to dry. The top coat was then applied. Weather conditions were similar to the previous day. The only difficulty was that in one small batch, the components were not mixed properly; approximately ¼ of the ISO portion of the material was omitted. This was not noticed until the material had been applied in areas bottom six feet of the center column of the southbound shoulder pier. The manufacturer was contacted and this was not found to be a significant error, the material simply set faster.

The Creative Materials product was used to coat a patch on the center column of the eastbound should pier of the Gantz Road bridge over I-270 (FRA 270-960). The primer was applied on 10/25 and the top coat was applied on 10/26. Figure C4 shows the patch.

Figure C 4 Creative Material product applied on patch FRA 270 960

The Citadel material was applied to the northbound shoulder and southbound shoulder pier columns of the bridge over I-71 at Berkshire Road (DEL 71-1093) and the patch on the west column of the eastbound shoulder pier of the Gantz Road bridge (FRA 270 960) on November 7, 2018. Because this material must be applied to a dry surface, ODOT crews power washed the areas the day before application. The temperature was not recorded but the weather conditions were similar to those on October 25/26. Figures C5 shows the DEL 71-1093 bridge after coating. DEL 71-1093 also had a large spall on the center column of the southbound shoulder pier (Figure C6) Except for the previously cited problem that the summer rather winter material was supplied, there were no issues with application of this product. Figure C7 shows the coated patch on FRA 270-960.

Figure C 6 - - DEL 71-1093 with coating

Figure C 5 - Spall on center SB column DEL 71-1093

Figure C 7- Patch on FRA 270 960 coated with Citadel product

C3.2 Performance of the Material in District 6

The polyasparic coatings were evaluated on December 14, 2020. The coatings were inspected visually and using the "V" notch test. The V-notch bond test (known as "The Standard Test for Evaluating Adhesion by Knife") from ASTM D6677-07 (2018), consisted of using a box cutter with a sharp blade to cut an upside down "V" shape into the coating. The angle between to the two lines of the "V" ranged from 30-45 degrees. The edge of the blade was used to try and pry up the coating from the corner of the V-shape. A well-bonded coating will not pry up or it will pull the concrete off along with the pried polyaspartic material. Meanwhile, a coating that has not bonded to the concrete parapet wall will separate.

The patches on the FRA 270 960 (Gantz Road) bridge were evaluated. Visual inspection showed that the coatings appeared intact and looked the same as when they were installed. However, when the "V" notch test was applied, both materials easily peeled off the patch. It was noted that patching material was very dense and smooth. It seemed that the lack of adhesion was due to the smoothness of the surface. Recall that the manufacturers recommend roughening the surface by sandblasting or some other method. That may have helped adhesion in this case. However, there was no sign of deterioration in the patch and the lack of adhesion was only apparent when an overt attempt was made to remove the material. Figures C8-11 show the results.

Figure C 8 Citadel patch FRA 270-960 west column after 2 years.

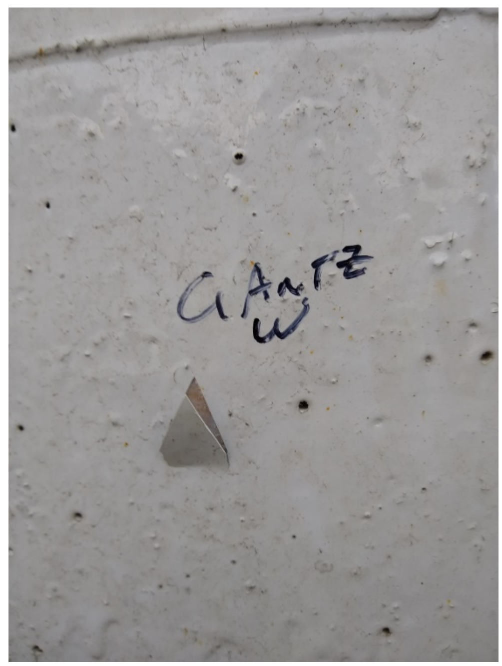

Figure C 9 - V notch test Citadel FRA 270-960 west column

Figure C 10 - Creative Materials patch FRA 270 960 center column after 2 years.

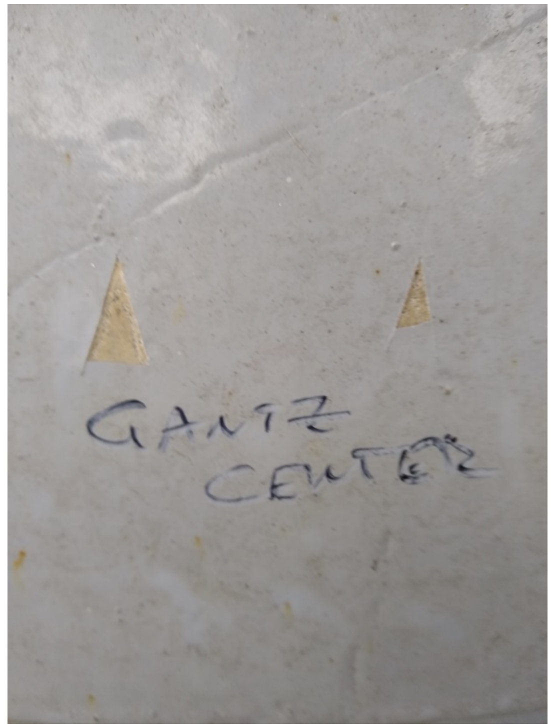

Figure C 11 - - V notch test FRA 960 center column

The Creative Materials product performed well on the NB shoulder of the Lewis Center Road bridge (DEL-71-498). Initial visual inspection showed the coating to be intact except for some damage to the coating on the first pier (Figure C12). The material seemed to adhere but could be chipped off if the blade of a knife was used. The V notch test showed good adhesion (Figure C13). Recall that these columns had a somewhat porous concrete and there was an initial problem with the primer soaking in too much but this may have helped the final adhesion.

On the SB should, there were signs of the rust from the reinforcing bar coming through the coating (Figure C14); but the coating seemed to otherwise be intact. The V notch test showed adhesion to the concrete (Figure C15). On the bar, some tests showed adhesion some did not. This indicates a need to clean the bar before applying the product.

The results for the Citadel product on the Berkshire Road bridge (DEL 71-1093) were similar as shown in Figures C16-C18.

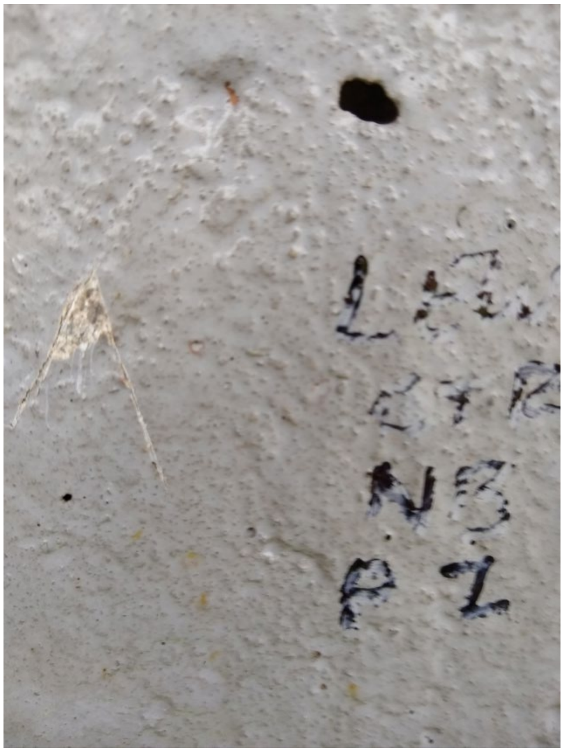

Figure C 12 - - V notch test. Material had to be chipped off; failure in substrate. DEL 71 498

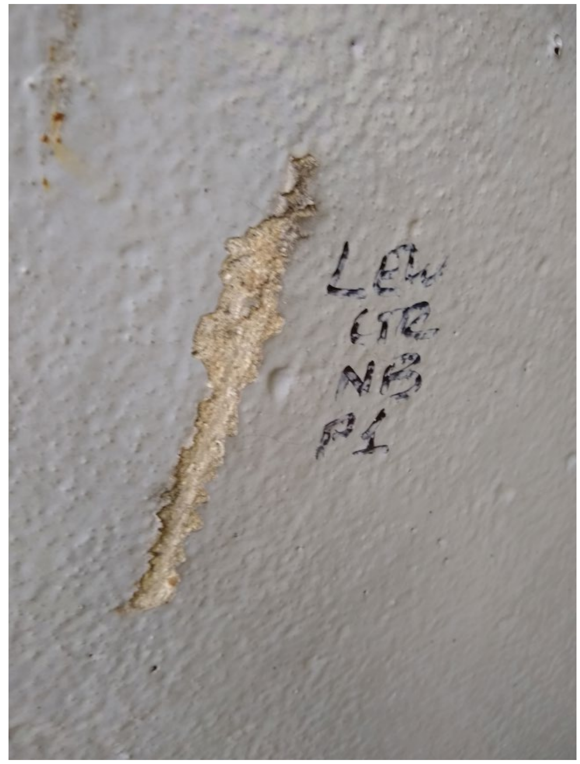

Figure C 13 – Damage to coating NB shoulder first pier; Del 71 498

Figure C 14 - DEL 71 498 center column SB over spall

Figure C 15 - DEL 71 498 V notch center column SB at spall.

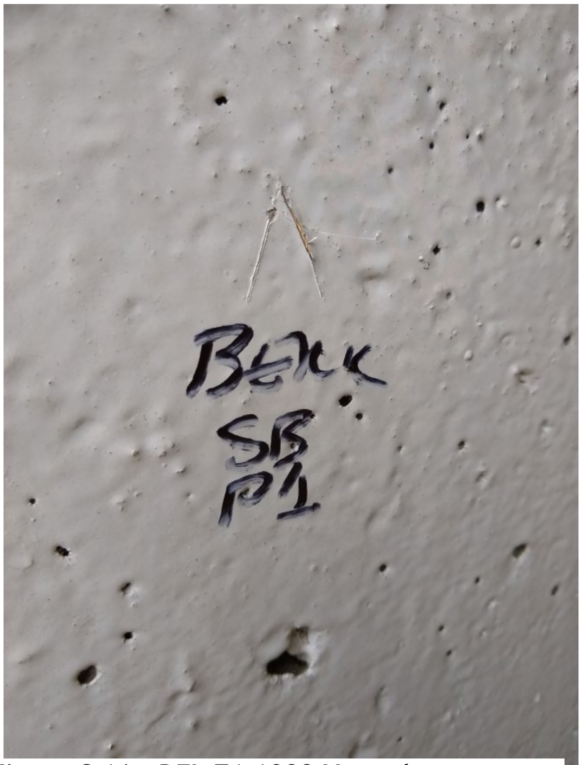

Figure C 16 – DEL 71 1093 V notch test

Figure C 17 - - DEL 71-1093 center column SB over spall

Figure C 18 - DEL 71-1093 V notch over spall on center SB column.

C4 Performance of the Material in District 7

In District 7, only the Citadel material was used. Here, the intent was to see if the material could simply be used as a patch with little or no surface preparation; a severe condition for application and not in conformance with manufacturer's recommendations. The material was applied on November 20 2018. The temperature was 32° F in morning rising to 40° F in afternoon.

The material was applied to three bridges. A small spall on the center column of the median pier was coated on MIA 75 – 1995; a large spall on the front column of the north bound shoulder pier was coated for SHE 75- 0102 and two large spalls on 2nd and 3rd columns on the south bound shoulder pier were coated on SHE 75 1954 (Figures C19-C21).

Figure C 19 – Spall on MIA 75 1995

Figure C 20 - Spall on SHE 75-0102

Figure C 21 - Spalls on SHE 75 1954

The material was inspected after two years on October 23, 2020. In general, the material did not perform well, again because no surface preparation was used. As with the spalls on the bridges in District 6, there were signs of rust bleeding through the material. Unlike District 6, the bond did not appear to be good. The columns in District 7 had originally been coated with epoxy- urethane. The polyaspartic material did not seem to bond to the epoxy- urethane and in other cases the epoxy-urethane below the polyaspartic failed.

For bridge MIA 75-1995, the coating appeared in good shape visually (Figure C22). The V notch test showed that material bonded in some places and did not bond well in other (Figure C23).

Figure C 22 – MIA 75 1995 after two years

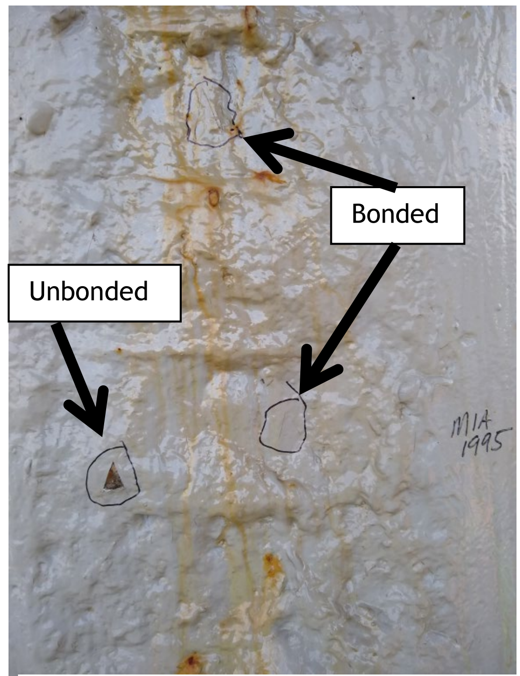

Figure C 23 - - Bonded and unbonded areas MIA 75 1995.

A similar situation was seen for SHE 75-1954. The coatings appeared intact except for some rust bleed through. However, there was little adhesion as shown by the V notch test. (Figures C27-C29).

For bridge SHE 75-0102, there was a complete failure of the coating. In some cases caused by the failure of the substrate and in other cases, it was a failure of the coating. The primer appeared spongy, as if it did not set correctly.

C5 Conclusions for Polyaspartic Coatings

The conclusion is that the polyaspartic material needs to be applied to a surface prepared according to the manufacturer's specification. This may be a barrier to using them for maintenance purposes. At the very least, the surfaces should be power washed which is doable for a maintenance crew, but sandblasting the surfaces, as is recommended, may be unrealistic for maintenance crews due to the need for protective equipment and the problem of disposing of the spent sand.

The material costs were $3600-$4000 for enough material to coat 12, 3 foot diameter columns with some left over to coat the patches in Districts 6 and 7. Six columns were 9 feet high and 6 were 13 feet high. This is approximately $7/sq foot + labor for the material.

Figure C 24 - SHE 75-1954 middle column after two years.

Figure C 25 - SHE 75-1954 south column after two years

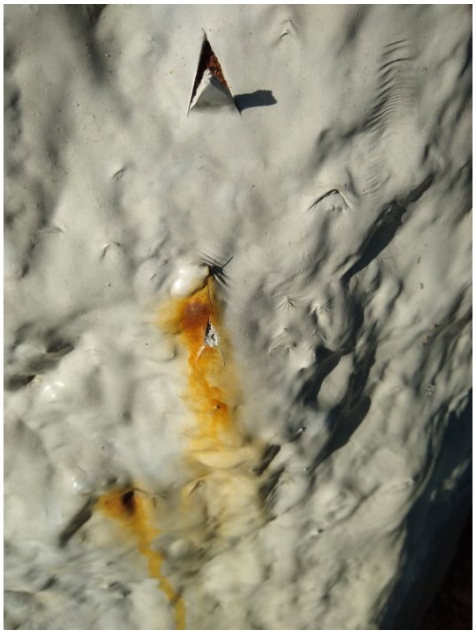

Figure C 26 - SHE 75-1954 south column V notch test

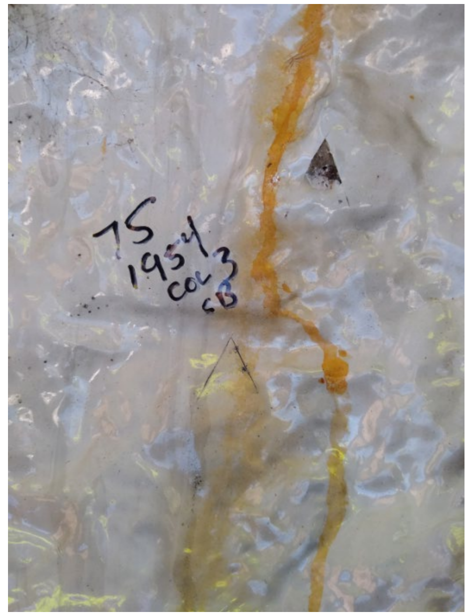

Figure C 27 - SHE 75 1954 middle column V notch test.

Figure C 28 - - SHE 75-0102 coating failure

Figure C 29 – SHE 75 0101 south column after two years