Investigation and Evaluation of Iowa Department of Transportation Bridge Deck Epoxy Injection Process

Final Report
February 2019

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

Since the 1970s, the Iowa Department of Transportation (DOT) has used concrete overlays as a means of restoring its bridge decks and, as a result, the service life of the deck is commonly extended many years. This procedure has proven to be both effective and economically attractive.

Despite that, concrete overlays cannot be considered a permanent repair as they are subjected to harsh conditions, similar to the original bridge decks. As time passes, the overlays often become delaminated from the original deck at or near the bond interface, leading to cracking and the intrusion of water and chloride ions, which accelerate the deterioration. A preservation solution involving the injection of epoxy resin into the cracks and voids has been developed and this solution has been implemented with success across Iowa. Even so, the length of additional service life and the most effective methods and materials of injection remain unknown.

The problem is two-fold. First, a better prediction of typical expected service life must be determined to best plan for additional repair or replacement. This requires a study of both previously and newly injected bridges to identify the effectiveness and durability of epoxy injection of delaminated bridge decks. Second, the seasonal constraints imposed on the injection process, coupled with the work load of Iowa DOT maintenance personnel, create a logistical problem; quite simply, there is more work to be completed than can be effectively accomplished in the available time.

A specification detailing the proper materials, equipment, and procedures was developed to enable others to perform the work. Both a field investigation and a thorough review of industry advances and practices were used to develop the specification.

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CHAPTER 1. INTRODUCTION

Background

The Iowa Department of Transportation (DOT) has been using concrete overlays on bridge decks since the 1970s to restore the concrete deck surface and lengthen the service life of the bridge deck. The overlays inhibit chloride and water intrusion into the bridge deck and have proven effective as a maintenance treatment on Iowa bridges. Bridge deck overlays typically last 15 to 20 years before delamination at the bond interface requires repairs to or replacement of the overlay. The delamination of the overlay is often repaired by Iowa DOT maintenance staff who inject the deck overlay cracks and voids with epoxy.

Anecdotal observations by Iowa DOT field staff suggest that the epoxy injection process can delay repair of the overlays by another 5 to 10 years but currently there is no documentation to substantiate this. The process for injecting epoxy into bridge deck cracks and delaminations has not been formally documented, resulting in variations in materials, equipment, and procedures used in the various districts.

Annually, there is a need to perform this treatment on 120 to 180 Iowa DOT structures. Currently, this work is only performed by Iowa DOT bridge crews since there are not adequate specifications for contract treatment. Due to seasonal limitations and the work load of the Iowa DOT bridge crews, it would be beneficial to have the ability to contract for bridge deck epoxy injection when necessary.

Objectives

The objectives of this project cover three focus areas:

- Determine the effectiveness, durability, and typical service life of epoxy-injected delaminated bridge decks
- Evaluate the current state-of-the-practice in the epoxy injection industry
- Develop procedures and specifications for epoxy injection

CHAPTER 2. LITERATURE REVIEW

Early History

Epoxies have been used in the construction industry for only a relatively short period of time. It wasn't until the 1930s, when the first known patent on epoxy was issued, that several basic epoxy systems were explored and developed (ACI Committee 503 1993). Today, many epoxy systems are used as adhesives and coatings.

Several field tests were completed in the late 1940s and early 1950s, including the use of epoxy as an adhesive to bond two pieces of hardened concrete, as a bonding agent for raised traffic line markers on concrete highways, and as surfacing materials on highways (ACI Committee 503 1993). Favorable results provided the incentive to pursue the use of epoxies in other applications.

Since then, many formulations have been developed that are specific to the end-use requirements. The characteristics of epoxies are unique and have enabled their use in many applications. Epoxies adhere well to numerous surface types, have very good strength characteristics in comparison to concrete, are affected little by temperature variations, and are generally resistant to chemical attack. Additionally, epoxies are resilient to abrasion and can undergo deformation and return to their original shape without ill effect, provided the elastic limit has not been exceeded (ACI Committee 503 1993).

Quality Control

Generally, careful attention should be paid to the surface preparation of injected elements. Given the nature of concrete overlays and the inability to easily access the bond surface, the likelihood of preparing the surface to ideal conditions is slim. Nonetheless, ACI has prescribed preferred conditions that can be achievable in overlay injections. First, delaminated portions should be sound, as adhering a weak surface is nothing more than an exercise in futility. Second, the surfaces should be dry and clean. With epoxy injection of bridge decks this is a bit more difficult to control, but properly using a vacuum bit while drilling injection ports can at least minimize any additional contamination to the delaminated plane. Third, the surface must be at the manufacturer's prescribed temperature to maximize the curing process. The properties of epoxy can significantly change if not cured as instructed (ACI Committee 503 1993).

John Trout, the founder of the Lily Corporation, a manufacturer and supplier of products used in injecting and dispensing two-component construction epoxies, has written several articles and books detailing the practice of epoxy injection. The need for quality control is one significant point emphasized in many of his writings. He states there are two ways of ensuring good quality; procedural specifications and performance specifications. With procedural specifications an injector can follow the best practices of epoxy injection, yet may not achieve good quality. So much is left unknown when the final product is not visible. Even more important, significant resources are required to make certain the means and methods were closely followed by the injector. Performance specifications, on the other hand, enable a contractor to use what has been found to be the best method and then use core samples to verify the quality of the final product. Not only is the owner assured that the product was provided as agreed upon, but the contractor is able to evaluate the performance methods. Trout stresses the importance of core sampling for this very reason (Trout n.d.).

Case Studies

Even though the use of epoxy has become more popular in the construction industry, epoxy injection of bridge decks has not been a common practice in many states. Only a handful of states have ever performed bridge deck injection and even fewer have documented the successes or failures of the practice. A couple of studies have been conducted that shed some light on the subject, however.

In a study conducted in Kansas (Smith 1992), multiple bridges were injected with epoxy and compared to non-injected bridges near the same location. The study successfully demonstrated that the injection of a bridge deck was a robust method of repair and that a deck remained intact especially when reinjected after four years. Continued observation was conducted for seven years after the final injection of the decks and it was determined that a deck remained serviceable and could be effectively repaired up to approximately four years after final injection. Additional injections or other repairs can be planned at that time. It was concluded that epoxy injection provides an effective method of prolonging the life of the original deck.

The Federal Highway Administration Demonstration Project Team conducted a study in the state of Iowa (Whiting 1989) that looked to extend the service life of bridge decks by rebonding delaminations with injected epoxy. In this case, a deck with a delaminated concrete overlay was injected so that the effectiveness of the repair could be determined. Several conclusions were reached after observing the performance of the repairs for many years. Most notably, the repaired delaminations remained intact through five years. The portions of delaminated deck and injected areas remained nearly the same over that period of time. In comparison to other forms of deck rehabilitation or reconstruction, epoxy injection appeared to be a cost effective method if conducted at the proper time. Injection performed too early or too late could negate any cost savings.

CHAPTER 3. PRELIMINARY PERFORMANCE EVALUATION

Field Investigation

One of the original intentions of this study was to identify and conduct a performance evaluation of 30 bridge decks that were epoxy injected in 2003. This year was selected due in part to the observable degradation of previously injected decks at or about seven years post injection.

However, fewer than 30 bridges were injected in the year 2003, which meant that bridges injected in additional years needed to be included in the performance evaluation. Once the researchers removed the bridges that were re-injected, reconstructed, or re-overlaid from consideration, the final sample was taken from bridges injected in the years 2003 through 2006. Figure 3.1 presents the number of epoxy injected bridge decks in Iowa each year since 1985.

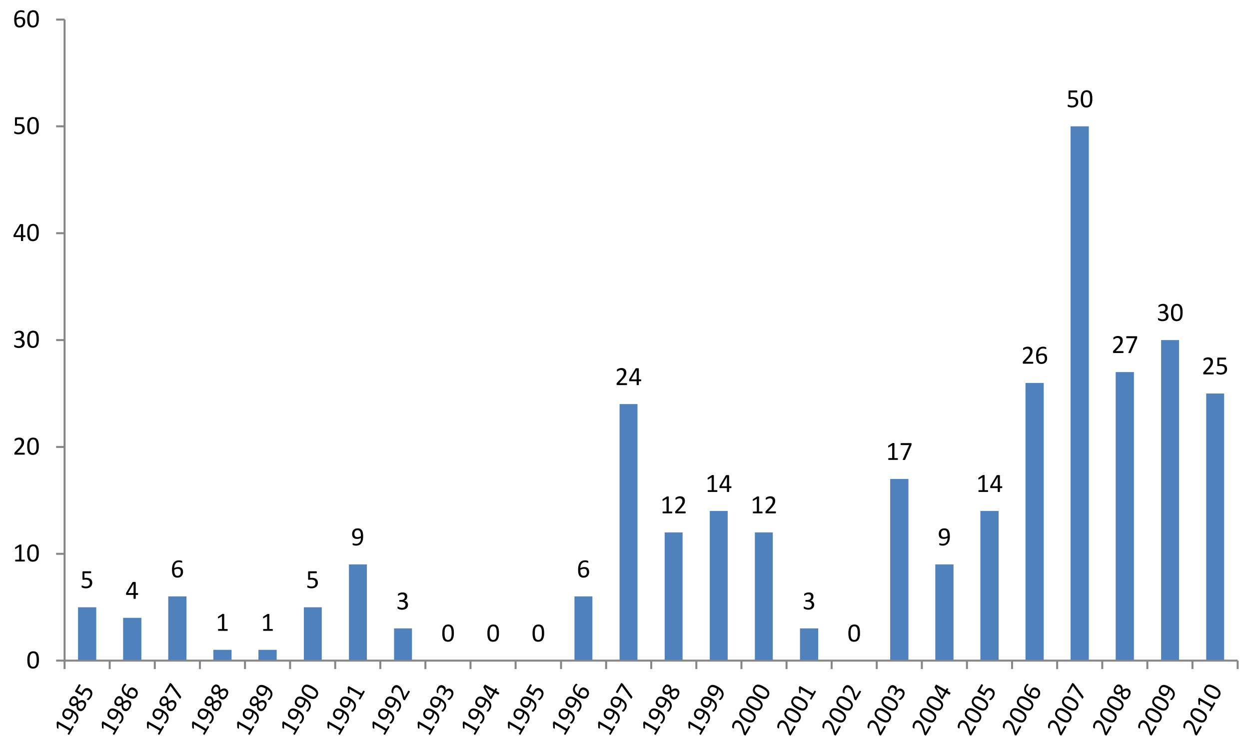


Figure 3.1. Total number of epoxy injected bridge decks in Iowa since 1985

During the fall of 2010, 26 bridges identified as being injected between 2003 and 2006 were visited and a performance evaluation of each was conducted. In addition to visual inspection of the deck surface, sounding of the concrete overlay was completed. Sounding of the deck was performed by dragging chains and hammer tapping, processes in which delaminated portions of the overlay are revealed by tonal fluctuations. Though this process cannot be considered highly scientific, it has been widely accepted as a standard practice for locating delaminated sections. Figure 3.2 shows the tools used for sounding the overlays, including a chain drag, chain whip, five-pound maul, and masonry hammer.

Figure 3.2. Delamination detection tools

A map locating the delaminated portions of the overlay was generated upon completion of sounding. This was achieved by creating a grid of the entire bridge deck surface and transferring the located delaminations to the corresponding sectors of the map. The map shows the locations and sizes of delaminated portions of the overlay, and offers a snapshot of the overall health of the surface. From these maps, data were collected and used to analyze the group of bridges. An example of a delamination map is provided in Figure 3.3.

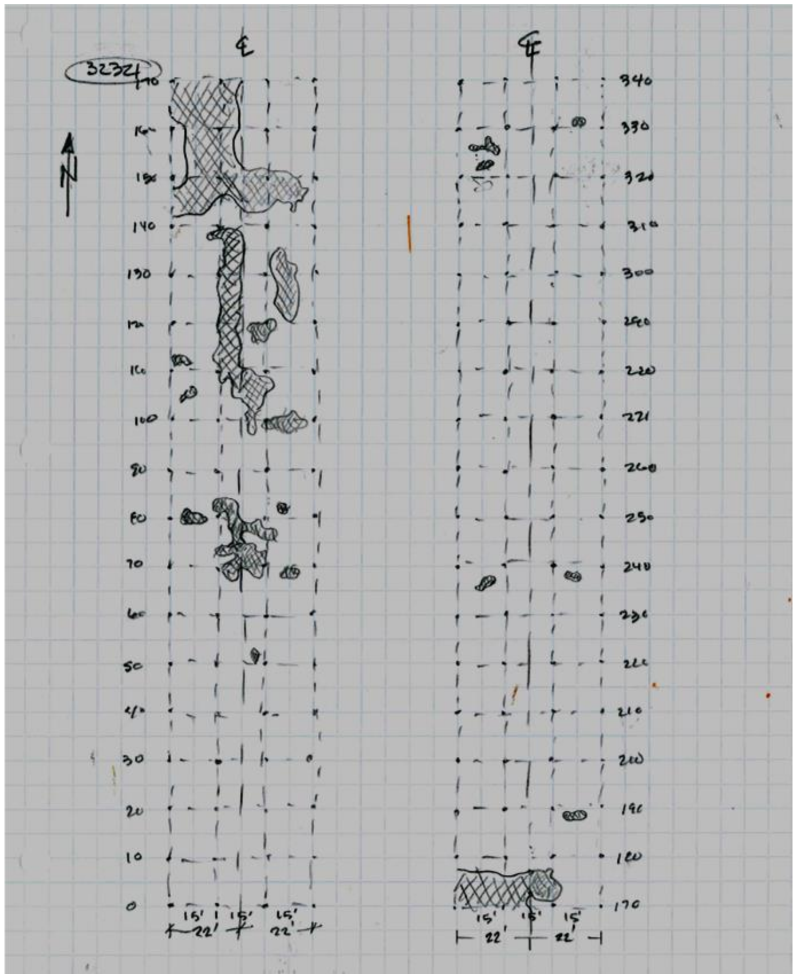


Figure 3.3. Typical delamination map

In addition to sounding the deck, photographs were taken to visually document the surface condition. Figure 3.4 shows an example of conditions seen at many of the bridges.

Figure 3.4. Photographic documentation of delamination

It was common to find delaminated portions of the overlay at or very near locations where both longitudinal and transverse surface cracking were present. It appeared that cracking often resulted in delamination and vice versa, as intuition would suggest. Additionally, delaminated portions of the deck often appeared to originate where cold joints were present, such as at the centerline of bridge. This agreed with the cases of cracking as cold joints are another port of entry for water and chloride ions. Additionally, the condition of the overlay was commonly the poorest where the bridge approach slab met the overlay. This may be due to several factors including: water entry at approach slab-overlay interface, snow plow impact, or magnified localized stresses attributable to thermal behavior (especially at acute angle portions of skewed decks).

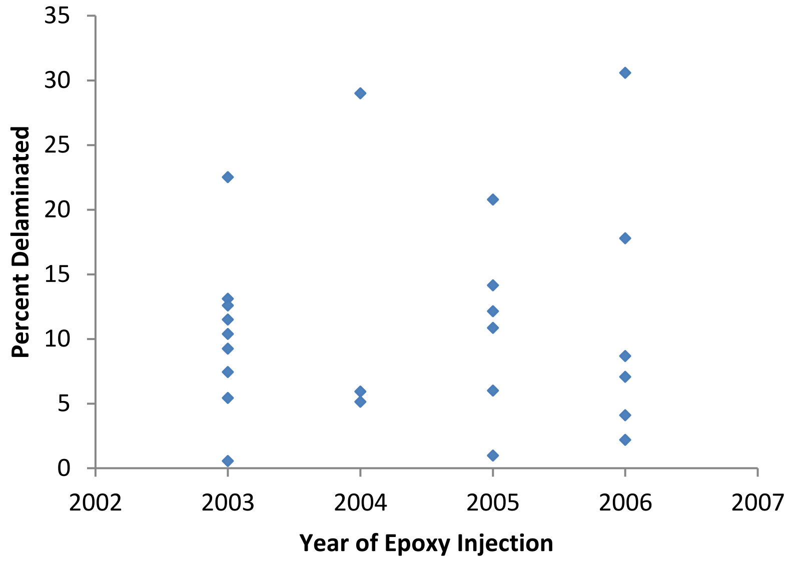
Information Synthesis

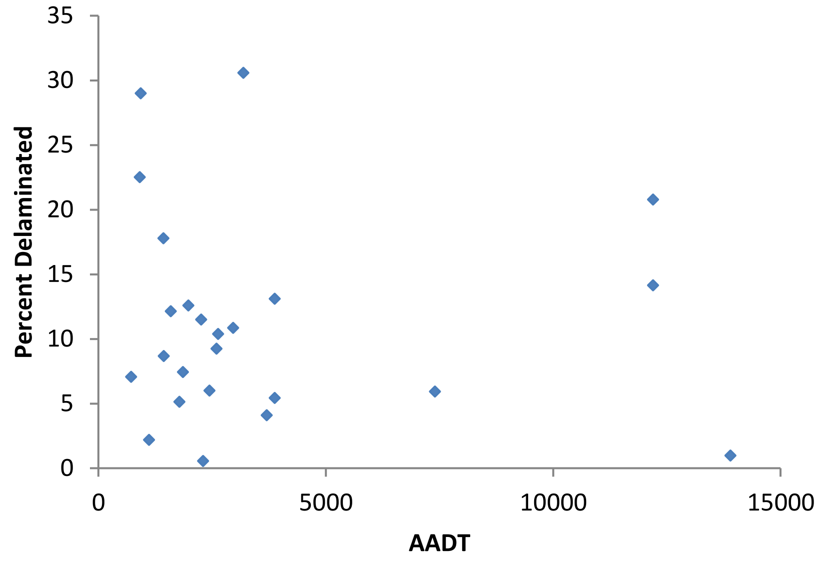
Once the bridge visits were completed, the cumulative information was studied for any observable performance trends with anticipation that a dependent variable would be identified. Table 3.1 presents the variables that were evaluated.

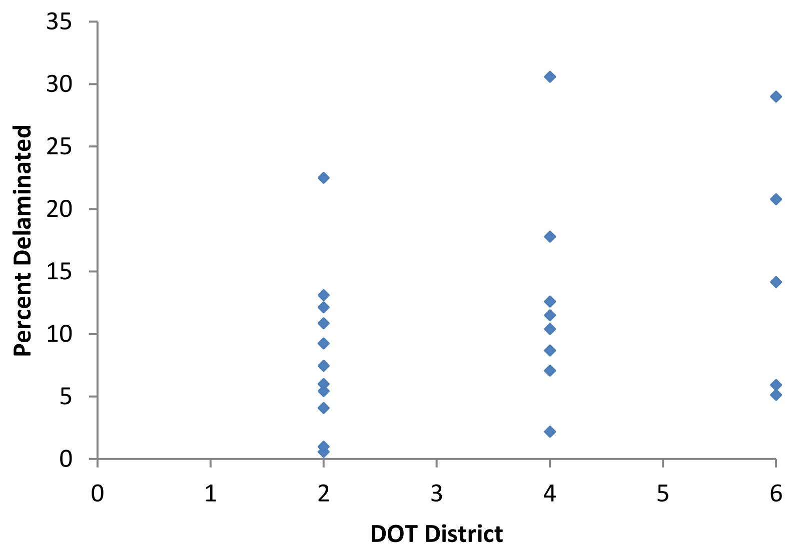
Table 3.1. Field evaluation information studied for observable trends

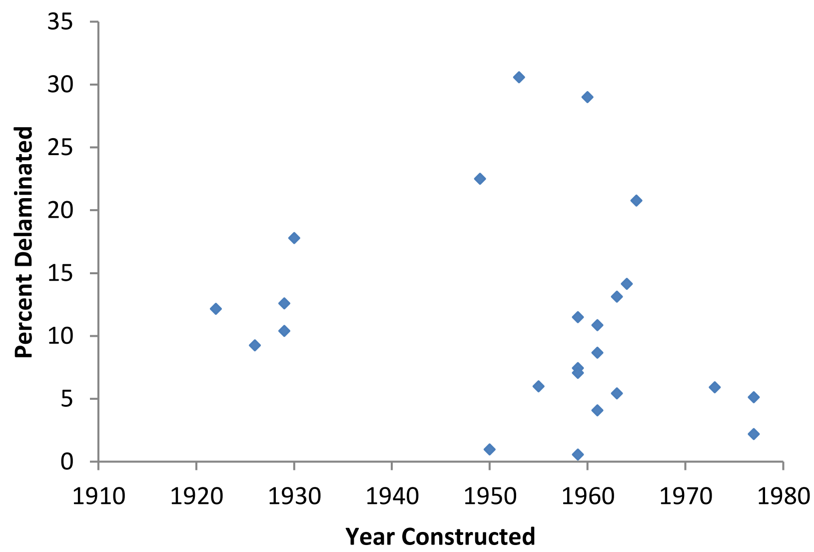
Independent variable	Dependent variable
Year of epoxy injection	Percentage of delaminated portion of deck overlay Total number of individual delaminations Total number of individual delaminations per ft^2
Annual average daily traffic	Percentage of delaminated portion of deck overlay Total number of individual delaminations Total number of individual delaminations per ft^2
DOT district number	Percentage of delaminated portion of deck overlay Total number of individual delaminations Total number of individual delaminations per ft^2
Year of bridge construction	Percentage of delaminated portion of deck overlay Total number of individual delaminations Total number of individual delaminations per ft^2

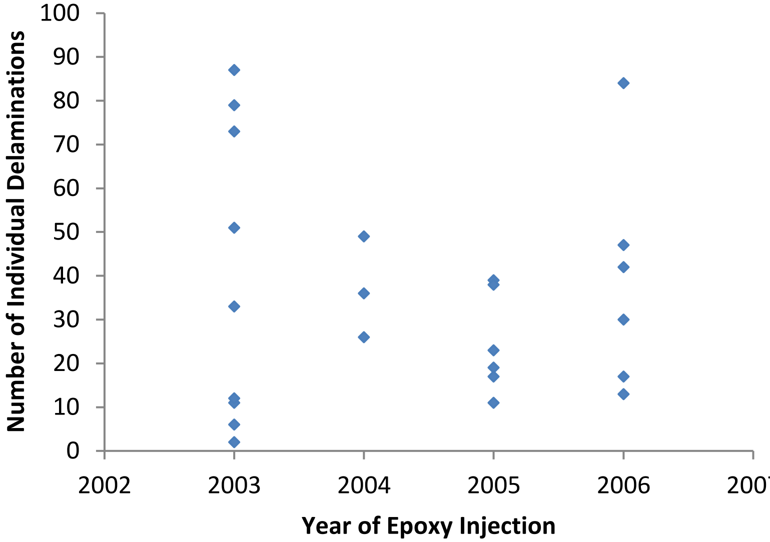
Plots were created for each case to see what, if any, variables predicted the performance of the overlay (see Figure 3.5). Unfortunately, no appreciable trends were discovered.

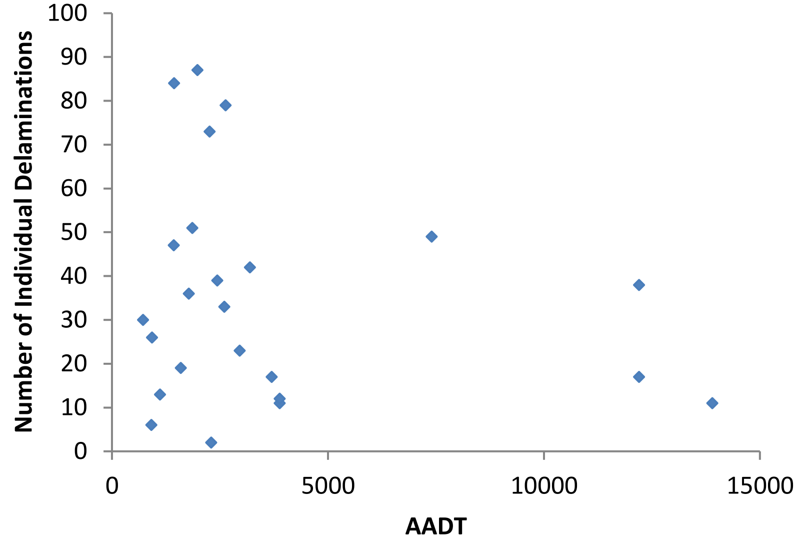

Percent Delaminated
Year of Epoxy Injection

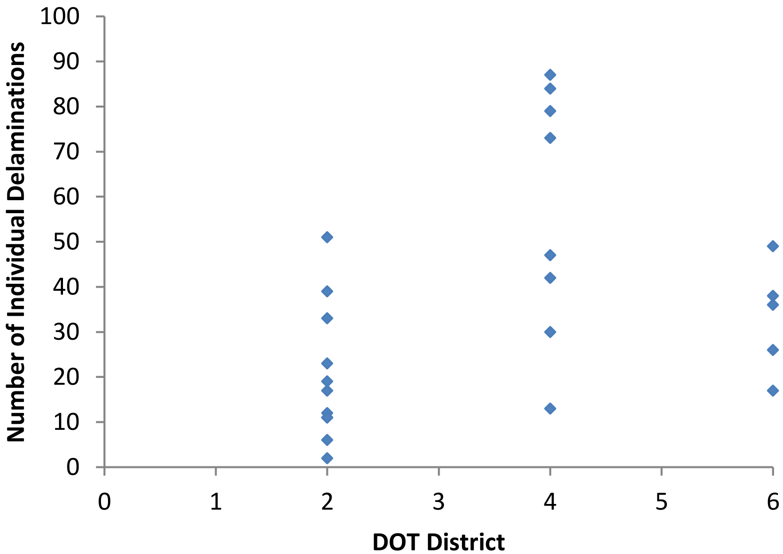

Percent Delaminated
AADT

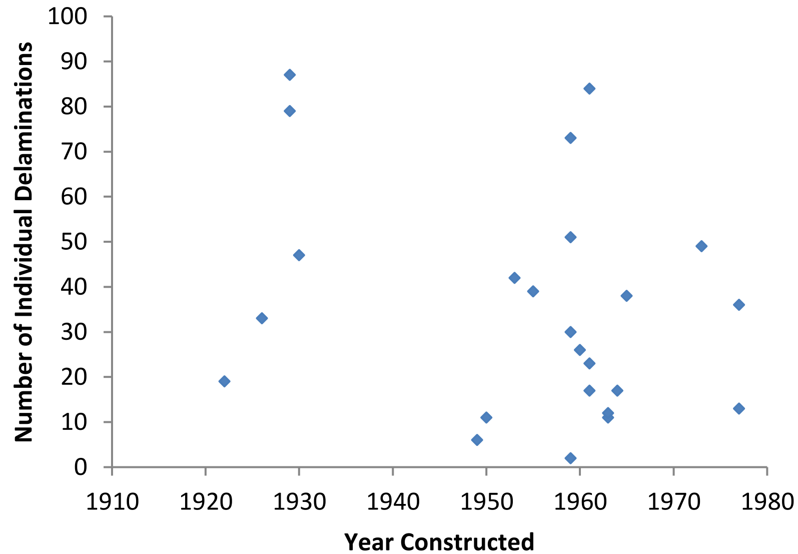

Percent Delaminated
DOT District


Percent Delaminated
Year Constructed


Number of Individual Delaminations
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
Year of Epoxy Injection


Number of Individual Delaminations
100
90
80
70
60
50
40
30
20
10
0
0
5000
10000
15000
AADT


Number of Individual Delaminations
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
DOT District


Number of Individual Delaminations
100
90
80
70
60
50
40
30
20
10
0
1910
1920
1930
1940
1950
1960
1970
1980
Year Constructed

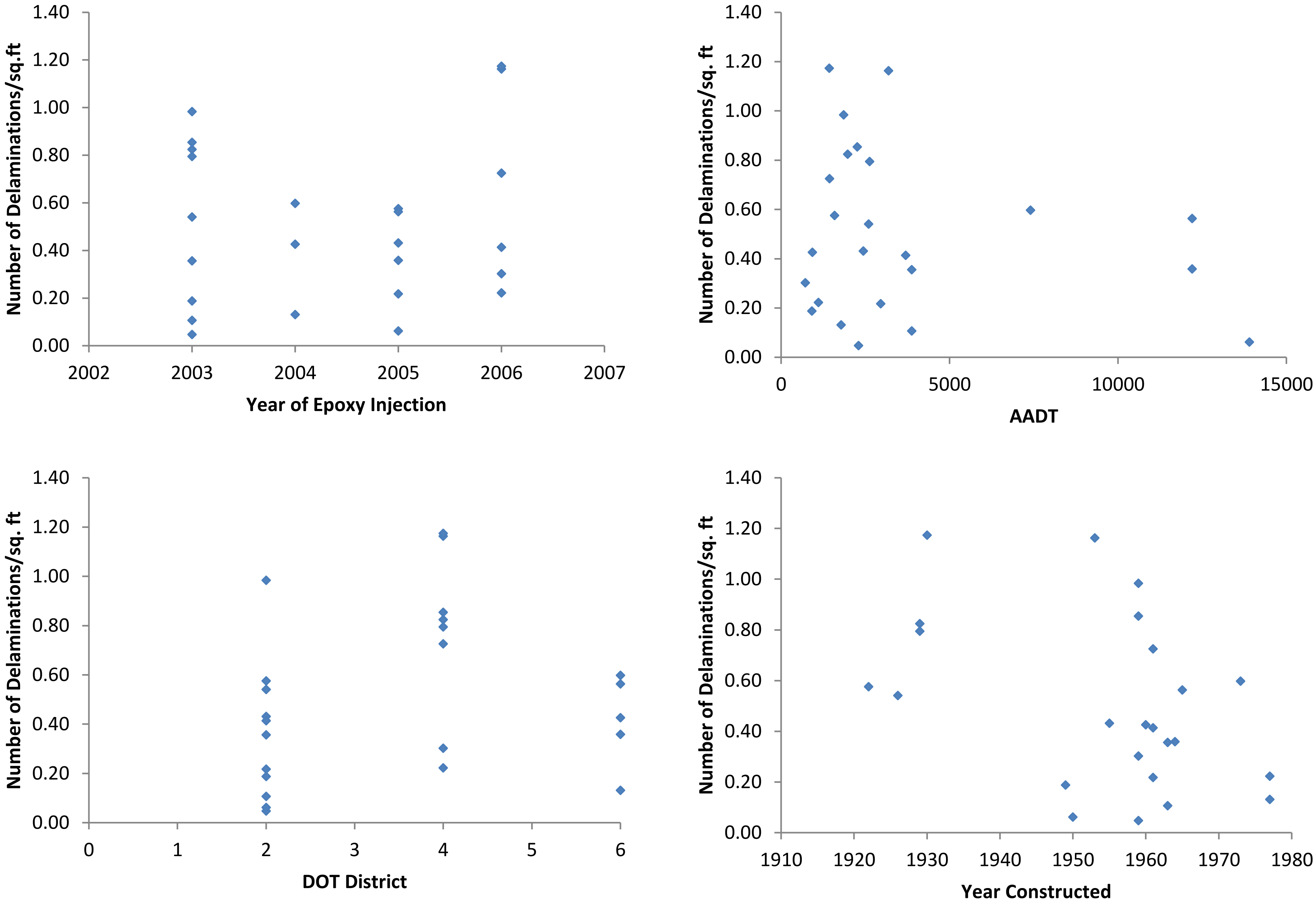


Figure 3.5. Plots created from performance evaluation data

Note that valuable information was gleaned from the field evaluations even though specific trends were not discovered. The general condition of epoxy-injected overlays was revealed through some key metrics that are presented in Table 3.2.

Table 3.2. Notable information from field evaluations

Key metrics	Results
Maximum percentage of delaminated overlay	30.6%
Average percentage of delaminated overlay	11.2%
Maximum number of individual delaminations per ft^2	1.17
Average number of individual delaminations per ft^2	0.50

Knowing that on average only 11 percent of the total deck surface is delaminated may offer evidence for the effectiveness of the epoxy injection procedure. This is especially apparent knowing that each of the bridges evaluated in this study had been injected between five and eight years ago. Overall, the injections collectively appear to be performing well through eight years of service. This observation agrees with those of the DOT bridge crews. As was previously stated, the bridge crews have suggested the epoxy injection can delay repair of the overlays by 5 to 10 years.

CHAPTER 4. STATE SURVEY AND INTERVIEWS

Procedure

To document the state-of-the-practice in Iowa, the bridge crew leaders from each district were interviewed to learn about their respective procedures, materials, and equipment. Prior to the interviews, and similar to the national survey discussed in the next chapter, an online survey request was sent to each of the six bridge crew leaders. Table 4.1 lists the state survey questions.

Table 4.1. Iowa bridge crew survey and interview questions

Question #	Question
Question 1	Identify the epoxy typically used for the injection process.
Question 2	Identify the primary equipment typically involved in the epoxy injection process.
Question 3	At what pressure is the epoxy injected into the delaminated portions of the deck?
Question 4	Is the epoxy injection process inhibited by weather, temperature, or other conditions independent of the actual injection process?
Question 5	How soon is traffic allowed back on to the injected deck?
Question 6	Who typically completes the injection process, and are formal written instructions given to follow?
Question 7	Describe the method of injection used in your district.
Question 8	Rate the effectiveness of the epoxy injection as a maintenance method and how long the typical service life is estimated to be. ❑ 0 to 5 Years ❑ Not Effective ❑ 5 to 10 Years ❑ Slightly Effective ❑ 10 to 15 Years ❑ Moderately Effective ❑ 15 to 20 Years ❑ Very Effective ❑ More than 20 Years
Question 9	Provide any additional information that you feel may be pertinent to this review.

Four responses were received from the crew leaders. These responses were used to gain insight and set a benchmark used to compare and contrast the practices within each district. Also, they formed the basis for the content of individual follow-up interviews with all six of the district crew leaders.

The state survey and interview responses are summarized in the next section. The full responses on the nine questions are included for all six districts in Appendix A.

Response Summary

Generally, the injection process, materials, and equipment used were similar among districts; even so, there were some notable differences. Table 4.2 summarizes some of the more significant similarities and differences. Additional summary points are provided thereafter.

Table 4.2. Notable differences of injection process between districts

District and respondent	What type of epoxy is used for injection?	At what pressure is the epoxy injected?	At what temperatures will you inject the epoxy?	What equipment is used to inject the epoxy?
District 1 Denny Howe	Symons 303N Epoxy Resin	15–20 psi	Min = 55° Max = No Max	AST PCV 310/210
District 2 Kevin Smith	Symons 303N Epoxy Resin	24–30 psi	Min = 60° Max = 100°	AST PCV 310/210
District 3 Greg Mize	Symons 303N Epoxy Resin	30–35 psi	Min = 50° Max = 95°	Lily CD15 and Tempest Mixer
District 4 Delmar Gettler	Adhesives Technology Corp. CrackBond SLV302	20 psi, Never exceeds 30 psi	Min = 50° Max = 100°	Lily CD15 and Tempest Mixer
District 5 Junior Jones	Adhesives Technology Corp. CrackBond SLV302	18–30 psi, Never exceeds 30 psi	Min = 32° Max = No Max	Lily CD15 and Tempest Mixer
District 6 Mark Carter	Adhesives Technology Corp. CrackBond SLV302	100 psi when free flowing, 30–40 psi when nearing finish	Min = 70° Max = 100°	Lily CD15 and Tempest Mixer

- The injection process was viewed as moderately effective to very effective and the typical service life was estimated to be 10 to 15 years.
- The delaminations were found by various methods of sounding. A "high-tech" method was not used in any of the districts.
- Formal training of the injection process was never completed nor were instructions provided. Only a couple of people within each district completed the injection.
- Generally, warm weather and no rain were required to complete the injection.
- Traffic is allowed back on the bridge almost immediately after injections are completed.

CHAPTER 5. NATIONAL SURVEY

Procedure

A national survey was conducted to document the state-of-the-practice for epoxy injection beyond the state of Iowa. Questions were developed and sent to transportation agencies around the nation using the online survey tool, SurveyMonkey.com. Table 5.1 lists the national survey questions.

Table 5.1. National survey questions

Question #	Question
Question 1	If epoxy injection is a maintenance method used in your state, please list typical applications and for how long each has been used as a maintenance method.
Question 2	Please identify the epoxy typically used for the injection process. ❑ ASTM C881 Type___Grade___Class___ ❑ Other
Question 3	Please list the equipment typically involved in the epoxy injection process.
Question 4	Is the epoxy injection limited by conditions unrelated to the actual process? ❑ Weather ❑ Temperature ❑ Maintaining Traffic Flow ❑ Other (please specify)
Question 5	Who typically completes the epoxy injection process? ❑ DOT Maintenance Staff ❑ Hired Contractor ❑ Other (please specify)
Question 6	Has an instruction manual or specification been developed that outlines the process the injector should use? ❑ Yes, Contact the individual below to obtain copy of manual/specification (optional). ❑ No, A manual/specification has not been developed.
Question 7	Please describe the most common method of epoxy injection used in your area.
Question 8	Please rate the effectiveness of the epoxy injection maintenance method. ❑ Not Effective ❑ Slightly Effective ❑ Moderately Effective ❑ Very Effective
Question 9	How long is the typical service life of the epoxy injection? ❑ 0 to 5 Years ❑ 5 to 10 Years ❑ 10 to 15 Years ❑ 15 to 20 Years ❑ More than 20 Years
Question 10	Please indicate the state for which you are completing this survey and provide any additional information that you feel may be pertinent to this review.

Thirty-two responses (from 29 different states) to the national survey request were received. While several responses indicated epoxy injection was not used as a maintenance procedure, many provided information regarding their other uses of epoxy resin.

Due to the length and limited direct application to this study, the responses received are given in their entirety in Appendix B. Note that pertinent information from ASTM C881 (Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete) as it relates to Question 2 of the survey is included in Appendix C.

Summary

Notably, none of the 32 respondents indicated that epoxy resin injection of overlaid concrete decks was specifically a part of a regular maintenance regimen. Rather, where epoxy resin injection was performed, the procedure was typically administered to elements such as abutment and bent caps, columns, prestressed girders, piles, and deck surfaces. Regardless, the information gleaned with respect to epoxy resin materials can be beneficial. Table 5.2 shows which respondents indicated that epoxy injection was used in some capacity within their state.

Table 5.2. Applications of epoxy injection by state

State	Application	State	Application	State	Application
Arizona	Crack repair in decks, girder fascias, and substructure	**Maryland (1 of 2)**	Not used	**Oregon (1 of 2)**	Crack repair
Arkansas	Not used	**Maryland (2 of 2)**	Substructure units	**Oregon (2 of 2)**	Crack repair of structural members with shear issues
California	Crack repair in concrete girders, abutment walls, and columns	**Michigan**	Crack repair for concrete piers, segmental concrete structures, and prestressed beams	**Pennsylvania**	Not used
Delaware	Not used	**Minnesota**	Not used	**South Dakota**	Crack repair in prestressed girders, columns, caps, and abutments.
District of Columbia	Not used	**Missouri**	Surface crack repair	**Tennessee**	Crack repair in substructures
Florida	Repair of beams, piles, pile caps, barrier walls, and seawalls	**Montana**	Not used	**Texas**	Crack repair
Georgia	Repair of columns and bents	**Nevada**	Crack repair of new and existing concrete elements, including bridge decks	**Utah**	Thin bonded epoxy overlays
Hawaii	Not used	**New Hampshire**	Not used	**Virginia**	Crack repair in substructure units
Idaho	Crack repair for columns, substructures, and girders	**New Mexico (1 of 2)**	Thin bonded epoxy overlays	**West Virginia**	Crack sealing bridge decks and void fill
Illinois	Crack repair in substructure units	**New Mexico (2 of 2)**	Not used	**Wyoming**	Crack sealing for abutment and bent caps and columns
Kansas	Bridge deck delamination repair and crack repair of substructure members	**North Carolina**	Crack repair for pier caps and columns		

CHAPTER 6. FIELD INVESTIGATION OF INJECTIONS

Beginning in summer 2011, numerous bridges around Iowa were scheduled for deck injection. These bridges, when possible, were sounded prior to their deck injection to determine the pre-injection level of detectable delamination. In many cases, the injection procedure was observed and documented. Subsequently, each bridge was re-sounded once a year each summer from 2012 through 2016 to track the condition of the deck, with the objective of identifying a rate of deterioration and/or the development of new deck delaminations. This chapter summarizes the observations and take-aways from the field observation of the epoxy injection locations.

Bridge Deck Epoxy Injection Observations

- All observed injections were completed in 65° or higher temperatures.
- The injection pressure at the pump varied between 20 and 30 psi.
- Several comments were made regarding Adhesives Technology SLV302, and its thinner viscosity and ease of use with respect to Rescon 303N.
- Delaminations were located using sounding rods or chain whips. More precise locations and the locations of injection ports were often located using a hammer.
- The distance between port locations varied from 12 in. to 5 ft. The spacing appeared most dependent on the size and degree of delamination.
- Epoxy injection crews varied in size from one to five people.
- The number and size of delaminations varied from a few small delaminations to many large delaminations.
- The bridge deck surface condition was not always indicative of the number or size of voids.
- Occasionally “blowouts” would occur due to delaminations, which were either close to the deck surface or extended to near the deck bottom.
- Some crews used a vacuum core bit to suck out fines while drilling ports, whereas others would vacuum the ports after drilling.
- Some crews would use compressed air blown into the ports to determine the continuity of the delamination.
- The depth of injection ports varied between delaminations and between bridges. The depth was often determined based on the hammer drill sounds before and after passing through the delamination.
- Some injection pumps were trailer mounted and drew epoxy material directly from 50-gallon drums, while others were portable and required filling reservoirs with epoxy material from 5-gallon buckets.
- District 1 personnel switched to using injection ports rather than cork plug ports mid-season and commented on the ease of use and reduced clean-up requirements.
- It was not uncommon to find delaminations that would not accept epoxy.
- It was not uncommon to find injection ports that would not accept epoxy, but would allow epoxy to pass through them when other ports in the same delamination were used.
- Some crews filled nearby surface cracks with epoxy in addition to the delamination.

In summary, there were no consistent guidelines for the epoxy injection of bridge decks. The injection procedure, as well as its quality, were highly dependent upon the experience of the crew.

Investigation of Delamination Rate

The 24 selected bridges that had been epoxy injected in 2011 were, when possible, sounded before the injection, and re-sounded once a year for five years after completion (last soundings were completed in 2016).

The sounding procedure described in Chapter 3 was utilized for these yearly soundings. The delamination rate could then be computed as the delaminated area over the entire deck area. Table 6.1 summarizes the delamination rate for each bridge during the study period, with the corresponding plots included in Appendix D.

Other various pertinent information for each bridge, such as bridge location, average daily traffic (ADT), year built, structure type, and sufficiency rating are also provided in Appendix D.

Table 6.1. Delamination rate for 2011 injected bridges

Bridge:	1	2	3	4	5	6	7	8	9	10	11	12
Federal ID:	**13010**	**17250**	**25340**	**25350**	**25380**	**26211**	**29010**	**30490**	**30500**	**37573**	**37741**	**37781**
District:	4	3	4	4	4	4	2	1	1	4	4	4
2011	--	8.39%	13.32%	14.36%	6.50%	--	7.91%	36.43%	9.95%	--	5.87%	29.06%
2012	1.77%	1.93%	5.02%	3.22%	3.57%	1.60%	3.51%	2.27%	0.79%	0.99%	1.93%	3.24%
2013	2.32%	3.00%	12.39%	7.67%	6.22%	2.47%	4.69%	2.34%	0.87%	1.28%	5.19%	8.98%
2014	1.59%	2.63%	16.93%	10.97%	8.38%	3.85%	5.36%	3.24%	1.34%	1.50%***	3.85%	5.64%
2015	1.95%	3.24%	28.83%	22.00%	21.68%	4.72%	9.10%	3.66%	2.20%	1.72%	5.04%	10.41%
2016	4.64%	4.13%	37.95%	33.21%	32.14%	14.22%	22.14%	5.39%	4.36%	4.48%	14.81%	37.57%

Bridge:	13	14	15	16	17	18	19	20	21	22	23	24
Federal ID:	**43840**	**45420**	**47860**	**47950**	**51930**	**52350**	**52550**	**52560**	**54000**	**54320**	**54330**	**54470**
District:	4	4	4	4	5	1	2	2	2	2	2	2
2011	--	6.06%	66.88%	25.70%	7.35%	35.53%	12.24%	--	--	--	--	--
2012	3.17%	0.43%	31.93%	2.52%	2.71%	6.78%	2.01%	2.21%	2.65%	1.57%	1.67%	4.82%
2013	3.49%	0.69%	81.35%	4.35%	4.00%***	8.00%	2.59%	2.06%	3.96%	2.12%	2.26%	8.20%
2014	3.58%	2.33%	84.16%	3.32%	4.93%	8.53%	2.69%	1.87%	6.81%	1.70%	2.38%	10.84%
2015	5.76%	3.57%	*	7.89%	5.77%	11.51%	2.01%	3.00%	7.48%	3.56%	1.78%	5.86%
2016	9.04%	8.90%	*	19.00%	**	14.37%	2.60%	2.65%	14.23%	9.74%	6.85%	10.73%

*Deck replaced

**Traffic control is not practical due to wide load transportation. The deck was not sounded in 2016.

***Interpolation between previous and following years

The mean and standard deviation for delamination rates before and after the injection were calculated and summarized in Table 6.2.

Table 6.2. Mean and standard deviation of delamination rate

Year	Mean	Standard deviation
2011 (before injection)	19.04%	17.04%
2012	3.85%	6.15%
2013	7.52%	16.00%
2014	8.29%	16.60%
2015	7.51%	7.25%
2016	14.23%	11.44%

It can be seen that, on average, the delamination rate for each bridge was reduced significantly for the first four years after injection. Even for the fifth year, the mean of delamination rate (i.e., 14.2 percent) was still lower than the delamination rate before the injection (i.e., 19.04 percent); and the standard deviation was also lower than that before injection. However, the hypotheses test results showed that this difference was not statistically significant.

It is also worth highlighting that one of the bridges (FHWA #47860) had a delamination rate of 67 percent before epoxy injection. This delamination rate was reduced to 32 percent one year after injection, and had delamination rates of 81 percent and 84 percent, respectively, for the second and third years. The bridge deck was replaced in the fourth year. This observation may indicate that epoxy injection should not be applied to a bridge deck with a high delamination rate. However, due to the scope of this research, this observation needs to be further validated. When possible, a recommended delamination rate threshold should be established via future research work.

Due to the performance of bridge #47860 and its deviation from the other observed bridge performances, it was taken as an outlier and was removed from subsequent data analysis. In Table 6.3, the mean and standard deviation of the delamination rate were recalculated after excluding this bridge.

Table 6.3. Mean and standard deviation of delamination rate without bridge FHWA #47860

Year	Mean	Standard deviation
2011 (before injection)	15.62%	10.73%
2012	2.62%	1.46%
2013	4.31%	2.99%
2014	4.97%	3.87%
2015	7.51%	7.25%
2016	14.40%	11.44%

It can be seen that bridge decks that had been epoxy injected still had reduced average delamination rates after five years. Once again, the hypothesis tests results showed that the difference was statistically significant for the first four years but not statistically significant for the fifth year. Details of the hypothesis testing are documented in Appendix E.

CHAPTER 7. SPECIFICATION DEVELOPMENT

Based on the results from this research effort, draft specifications for epoxy injection of bridge deck delaminations were developed. These specifications relied on input from the districts, as well as first-hand observations of the injection process. The specifications are included here.

Section 24XX. Rebonding a delaminated PCC overlay by epoxy injection

24XX.01 DESCRIPTION

A. Repair of concrete bridge deck by bonding delaminated concrete overlay to original prepared deck surface using epoxy resin. This work may include the use of pressure-injection pumps.

B. The engineer will indicate the areas to be repaired.

24XX.02 MATERIALS

A. Epoxy-resin bonding systems shall be a two-component, solventless, low viscosity, liquid adhesive epoxy specifically formulated for injection into cracks and shall conform to the requirements of ASTM C 881 Type IV, Grade 1, Class C. Class A or B shall be used when the surface temperature of the hardened concrete is below 60°F.

B. Use a single source of epoxy during injection of single bridge deck.

C. Use an epoxy-resin bonding system meeting the requirements of Materials I.M. 491.19.

24XX.03 EQUIPMENT, INJECTION, AND TRAFFIC CONTROL

Prior to the start of injection, submit the following for approval.

1. Specifications of the injection equipment.
2. Material Safety Data Sheets.
3. A written procedure for the injection process.

D. Equipment

1. Furnish equipment consisting of hand tools, air compressors, injection pump, hoses, and continuous mixing nozzles necessary to properly inject epoxy resin into debonded portions of deck overlay per the recommendations of the material manufacturer.

a) Use equipment that has the capacity to automatically proportion the material components within the mix ratio tolerances set by the epoxy materials manufacturer.

b) Use equipment that has the capacity to automatically mix the epoxy component materials within the pump and injection apparatus. The engineer will not allow batch mixing.

c) Use equipment that has the capacity to inject the epoxy resin under controlled variable pressures, with a pressure gauge to indicate actual working pressure.

2. Wear proper clothing, eyewear, gloves, and other appropriate equipment to ensure protection from epoxy resin and associated materials. It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with epoxy use.

E. Pre-injection Procedure

1. Identify extents of delaminated areas and perform a cursory assessment of the materials required to inject a single area. Do not begin the injection procedure outlined below should the necessary material not be available or the time does not exist to fully complete a delaminated area. Once started, it is vital that a single area be completed before injection ceases and epoxy cures.

2. Ensure proper mixing and set-up of epoxy materials prior to injection into the deck.

F. Injection Procedure

1. Injection port installation: Perform drilling for no less than three injection ports per delamination area with a vacuum-attached swivel drill chuck. Remove apparent remaining concrete fines from the hole and surrounding area by vacuuming upon completion of port drilling. Use approved entry port devices spaced at appropriate intervals to ensure full penetration of the epoxy.

2. Begin injection of epoxy at the port of most significant delamination (to be determined by hammer tapping) capping adjacent ports as epoxy appears. Continue until appearance of epoxy at all adjacent ports or until refusal of epoxy occurs. When refusal occurs, cap the injection port and move the pump to a port where epoxy has not yet appeared, continuing in the same manner until all ports have been occupied and the delamination has been filled.

3. Continually regulate injection pressure to ensure excessive pressure build-up does not occur within the delaminated plane which could result in blow-out (surface ballooning and/or cracking resulting in epoxy loss on bottom or top surface of deck). In the event of a blow-out, injection shall immediately cease at current port and the epoxy should be allowed to cure at the surface crack before resuming injection into delamination plane. Remove any epoxy that exited the delamination plane onto the roadway surface.

4. Re-sound delaminated areas to identify that injection has been fully completed.

5. Monitor the bottom of the deck during the injection process to ensure epoxy resin is not leaking through the deck. Leakage must be abated before injection can continue.

G. Traffic Control

1. Apply Traffic Control according to the traffic control plan.

2. Furnish, erect, maintain, and remove all signs and traffic control devices necessary for the work.

24XX.04 METHOD OF MEASUREMENT

Epoxy injection will not be measured separately for payment but will be considered as a lump sum.

24XX.04.1 COMPLIANCE

Measurements of delaminated areas shall take place immediately after construction ends. The contractor shall be permitted to witness these measurements. The post injection measurement shall determine if construction has been completed to satisfaction.

A complete injection must satisfy

1. No single delaminated area larger than 10 square feet
2. Total delamination area doesn't exceed 1 percent of gross deck area

24XX.04.2 NON-COMPLIANCE

If after injection the total delamination in the deck exceeds 1 percent, the contractor may attempt to inject epoxy until the deck has satisfied completion conditions or a reduction in payment is settled upon.

Remaining Delamination in Percent of Gross Deck Area Surveyed by the Delamtect	Price Reduction Percent
0-1.00	0
1.01-1.25	5
1.26-1.50	10
1.51-1.75	15
1.76-2.00	20

24XX.05 BASIS OF PAYMENT.

H. Payment for Epoxy Injection will be the lump sum contract price.

I. Payment is full compensation for:

- Furnishing all material, labor, and equipment, and
- Performing of all work necessary to inject and re-bond delaminated portions of deck overlay according to the contract documents.

CHAPTER 8. CONCLUSIONS

The objectives of this project were to determine the effectiveness of epoxy injection as a bridge deck maintenance technique, as determined by an evaluation of the current practice, and to standardize its implementation for future installations.

As a preliminary performance evaluation, 26 bridges identified as being injected between the years 2003 and 2006 were visited and a performance evaluation of each was conducted. In addition to visual inspection of the deck surface, sounding of the concrete overlay was completed. Based upon these preliminary performance evaluations of injection sites across Iowa, efforts were also made to determine if there was any factor (such as injection temperature, crew size, equipment, delamination rate before injection, etc.) that significantly affected the delamination development after injection. No such correlation was found, though the experience of the crew was seen to play a significant role in the quality of the injection. In addition, deck delaminations were seen to be most common at cracking areas, cold joints, and the interface between the deck and approach slab. To gain further insight into the procedures and applicability of epoxy deck injections, both state and national surveys were distributed. The results of the survey responses showed that a uniform procedure for the implementation of epoxy deck injections was not present and that the method was not widely implemented on a national scale.

In an effort to better understand the performance of injected bridge decks, a field evaluation of 24 sites in Iowa was performed over a period of 5 years after injection. The data collected indicated that epoxy injection can extend the service life of a bridge deck by at least four years. One bridge that was part of the field investigation exhibited a very high delamination rate prior to injection, and also subsequently had poor long-term performance as bridge deck replacement was necessary after three years. This indicates that epoxy deck injections were not beneficial once a certain threshold of deterioration was present. However, further work is necessary to investigate this finding, as the sample size was not large enough to reach verifiable conclusions.

Based on the survey and the performance evaluation results, draft specifications were compiled in an effort to create uniformity within the state for the implementation of epoxy deck injections. These specifications will allow for other work forces to perform the injections and alleviate demand on DOT maintenance crews.

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APPENDIX A. IOWA SURVEY RESPONSES

1) Identify the epoxy typically used for the deck injection process within your district.

District 1

Symons 303N Epoxy Resin is used. Part A (resin) is mixed with Part B (hardener) in a 2:1 ratio, respectively. This product was chosen primarily because of its low cost in comparison to similar products.

District 2

Symons 303N Epoxy Resin is used. Part A (resin) is mixed with Part B (hardener) in a 2:1 ratio, respectively.

District 3

Symons 303N Epoxy Resin is used. Part A (resin) is mixed with Part B (hardener) in a 2:1 ratio, respectively. This product was selected based on the state approved products list and because other districts are using this product. The achieved results are satisfactory.

District 4

Adhesive Technology CrackBond SLV302 is used. Part A (resin) is mixed with Part B (hardener) in a 2:1 ratio, respectively. This product was chosen primarily because of its low cost in comparison to similar products. Prior to last year, Symons 303N was being used. It was found that the CrackBond was easier to work with (higher viscosity) than the 303N (lower viscosity created pumping problems).

District 5

Adhesives Technology Corp CrackBond SLV302 is used. Part A (resin) is mixed with Part B (hardener) in a 2:1 ratio, respectively. This product was chosen primarily because it’s generally less expensive and somewhat more viscous than similar products. Some independent research has confirmed the product to be satisfactory.

District 6

Adhesive Technology CrackBond SLV302 is used. Part A (resin) is mixed with Part B (hardener) in a 2:1 ratio, respectively. This product was chosen primarily because of its low cost in comparison to similar products. Formerly, Symons 303N was used but other options were pursued when the material cost annually increased. No differences have been noticed between each product.

2) Identify the primary equipment typically involved in the epoxy injection process.

District 1

A generator, air compressor, 1½ in. hammer drill, shop vacuum, and AST epoxy injection machine are used.

District 2

A generator, air compressor, 1½ in. hammer drill, vacuum bit, shop vacuum, and AST epoxy injection machine are used.

District 3

A generator, air compressor, 1½ in. hammer drill, shop vacuum, Lily CD15 epoxy injection machine, and Tempest mixer are used.

District 4

A generator, air compressor, 1½ in. hammer drill, shop vacuum, Tempest mixer, and Lily CD15 injection machine are used.

District 5

A generator, air compressor, 1½ in. hammer drill, shop vacuum, Tempest mixer, and Lily CD15 injection machine are used.

District 6

A generator, air compressor, 1½ in. hammer drill, shop vacuum, Tempest mixer, and Lily CD15 injection machine are used.

3) At what pressure is the epoxy injected into the delaminated portions of the deck?

District 1

15 to 20 psi per the guidelines of the manufacturer is the typical injection pressure.

District 2

The epoxy is typically injected between 24 psi and 30 psi.

District 3

30 to 35 psi is the typical injection pressure. If pumping tends to be easy, the pressure can be backed down to 20 psi.

District 4

20 psi is the typical injection pressure. The pressure should never exceed 30 psi.

District 5

18 to 30 psi is the typical injection pressure. Anything more could pop off the delaminated portion of the overlay.

District 6

The epoxy is injected at a pressure near 100 psi when epoxy is free flowing. When completion of a void is imminent, the pressure is backed down to around 30 to 40 psi.

4) Is the epoxy injection process inhibited by weather, temperature, or other conditions independent of the actual injection process?

District 1

The injection typically is not performed in the rain. Water can infiltrate the port holes and become trapped within the delaminated portions of the deck. Sometimes drilling holes from below is required to drain the excess water. Additionally, the vacuum bit on the hammer drill can easily become clogged if used in the rain. As a general rule, injection occurs above 55 degrees. If injection occurs below 55 degrees, the injection pump struggles to push the epoxy. The epoxy sets up much quicker in hot weather and slower in cold weather.

District 2

The injection typically is not performed in the rain or 24 hours after a significant rain. Water can infiltrate the port holes and become trapped within the delaminated portions of the deck. Additionally, the vacuum bit on the hammer drill can easily become clogged if used in the rain. Injection occurs above 60 degrees and below 100 degrees. The quantity of work does not require injection before or after ideal summer temperatures. The epoxy sets up much quicker in hot weather and is harder for the injection machine to pump in cooler weather.

District 3

Rain will disrupt the injection process primarily because the vacuum bit on the hammer drill can easily become clogged. Injection should occur between 50 and 95 degrees. If injection occurs below 50 degrees, the viscosity of the epoxy is too low and will not pump correctly. If injection occurs above 95 degrees, the epoxy sets too quickly.

District 4

The injection typically is not performed in the rain or even if the surface is wet. The vacuum bit on the hammer drill can easily become clogged if used in the rain. As a general rule, injection should be completed above 50 degrees and below 100 degrees. If injection occurs below 50 degrees, the injection pump struggles to push the epoxy. If injection occurs above 100 degrees the epoxy sets up very quickly making it difficult to work with. The ideal injection temperature is 80 degrees.

District 5

The injection typically is not performed in the rain. The epoxy does not mix well with water. Additionally, the vacuum bit on the hammer drill can easily become clogged if used in the rain. The injection process can occur above freezing temperatures. If injection is completed at low temperatures, a short lead is required out of the mixer. There is no maximum temperature limit. However, it is important to know that epoxy sets much quicker in hot weather and slower in cold weather.

District 6

The injection typically is not performed in the rain or even if the surface is wet. The vacuum bit on the hammer drill can easily become clogged if used in the rain. Formerly, injection would not be conducted if temperature was 40 degrees or cooler. Now, injections are conducted only when temperature is 70 degrees or greater. Ideally, injection would be conducted only between 70 degrees and 90 degrees. Injection becomes very difficult if temperature is 100 degrees or warmer as the epoxy sets up very quickly making it difficult to work with. A 25 ft whip from the tempest mixer to the injection port is used.

5) How soon is traffic allowed back on to the injected deck?

District 1

Traffic is allowed back on the deck almost immediately after final injection and clean-up. It would be interesting to learn how quickly the epoxy sets up.

District 2

Traffic is allowed back on the deck almost immediately after final injection and clean-up.

District 3

Traffic is allowed back on the deck almost immediately after final injection and clean-up.

District 4

Traffic is allowed back on the deck almost immediately after final injection and clean-up.

District 5

Traffic is allowed back on the deck almost immediately after final injection and clean-up.

District 6

Traffic is often allowed back on the deck almost immediately after final injection and clean-up. However, if time allows, holding traffic for a couple of hours especially in colder temperatures would be ideal. It feels like the epoxy may start to pump if traffic is let on the bridge too early. This should be somehow verified.

6) Who typically completes the injection process and are formal written instructions given to follow?

District 1

DOT staff completes the injection. Each shop is "trained" and is able to inject thereafter. Formal written instructions are not provided. All training is hands-on.

District 2

DOT staff completes the injection. (Kevin +1) Formal written instructions are not provided. Initially the process was learned from the District 1 bridge crew.

District 3

DOT staff completes the injection. Usually a two-man crew is needed (Greg +1). Sometimes if a stretch of good weather is forecasted, the injection ports can be pre-drilled a couple of days prior to injection. All training is and has been hands-on. There are no formal instructions for the injectors to use. Information and best practices are shared between DOT districts.

District 4

DOT staff completes the injection. Usually only one person with minimal help from flaggers is required. No formal instruction is given, only hands-on learning.

District 5

DOT staff completes the injection. One of three “trained” employees along with one or two additional employees is required. There is no formal training or instruction manual. All “training” is hands-on.

District 6

DOT staff completes the injection. One “trained” individual along with an additional helper is required. One additional helper can be used on longer bridges. No formal instruction is given, only hands-on learning and independent research. Without “training” or with limited experience performing injections, some common problems are often presented: 1) Lack of attention to pump and mixer sometimes results in system breakdown, 2) Too many or too few injection ports are drilled, 3) Too much pressure is used to inject the epoxy, 4) Delaminations are not injected tightly, and 5) Unable to identify problems with materials or equipment.

7) Describe the method of injection used in your district.

District 1

First, the deck is sounded using chains and hammers to determine the delaminated areas to be repaired. Second, the best place to drill the injection holes is found by using a hammer. Next, ½ in. holes are drilled and checks for air movement between holes using compressed air are completed. The air movement determines the best place to start injection. Then, a ¼ in. rubber tube with a rubber stopper or cork on the end is placed in the injection port and injection is started. Using the injection machine and the air compressor, epoxy is injected at 15 to 20 psi. While injecting, the movement and location of epoxy is determined by sounding the deck with a hammer and by viewing other port holes. Once the epoxy has moved through the delaminated portions, the holes are corked to prevent epoxy from leaking out.

District 2

First, the deck is sounded using a sounding stick to determine the delaminated areas to be repaired. Second, a hammer is used to find what appears to be the center of the void. Next, ½ in. holes are drilled into the void and occasionally compressed air is blown into them to push out any dust that may be in the void. Then, a ¼ in. rubber tube with a rubber stopper or cork on the end is placed in the injection port and injection is started. Using the injection machine and the air compressor, epoxy is injected at 24 to 30 psi. While injecting, the movement and location of epoxy is determined by sounding the deck with a hammer and by viewing other port holes. Once the epoxy has moved through the delaminated portions, the holes are corked to prevent epoxy from leaking out.

District 3

First, the deck is sounded using sounding rods to determine the delaminated areas to be repaired. Next, holes are drilled 18 in. to 24 in. apart in large areas and 8 in. to 9 in. apart in small areas. The holes are to remain 5 in. to 6 in. from the perimeter of the delaminated areas. Compressed air is blown into the ports. Then, a rubber tube is placed over the injection ports and injection is started. Using the injection machine and the air compressor, epoxy is injected at 30 to 35 psi. While injecting, the movement and location of epoxy is determined by sounding the deck with the sounding rod and by viewing other port holes. The dispenser will slow and/or back pressure will be present at the injection port once the epoxy has filled the void. Once the epoxy has moved through the delaminated portions and the excessive back-pressure is released, the injection ports are capped.

District 4

First, the deck is sounded using sounding rods and hammers to determine the delaminated areas to be repaired. Next, holes are drilled with a hammer drill and vacuum bit. The hole locations are determined by the size of void and sounding tone. If a higher tone is found, holes are drilled closer together. If a lower tone is found, holes are drilled farther apart. Once drilled, the holes are blown out with a wand in quick, short bursts so as to not increase severity of the delaminated portions. Then, a rubber tube is placed over the injection ports and injection is started. Using the injection machine, epoxy is injected at 20 psi. While injecting, the movement and location of epoxy is determined by sounding the deck with the sounding rod and by viewing other port holes. Once the epoxy has moved through the delaminated portions, the injection ports are capped.

District 5

First, the deck is sounded using chains to determine the delaminated areas to be repaired. A metal shaft hammer is used to locate the perimeter of the delamination. Next, ½ in. holes are drilled approximately 18 in. apart for large delaminations. For small delaminations only two holes are drilled. No compressed air is blown into the ports because fines can be blown into the cracks thus plugging them from epoxy injection. Then, a rubber tube is placed over the injection ports and injection is started. Using the injection machine, epoxy is injected at between 18 and 30 psi. While injecting, the movement and location of epoxy is determined by sounding the deck with hammers and by viewing other port holes. Also, it is an indication the void has been filled when the dispenser slows and there is backpressure at the port. Once the epoxy has moved through the delaminated portions, the injection ports are capped.

District 6

First, the deck is sounded using a length of rebar to determine the delaminated areas to be repaired. Next, holes are drilled with a hammer drill and vacuum bit. The injection port is located at the center of the delamination and a number of vents are drilled around the perimeter. The holes are then vacuumed and sometimes compressed air is blown into them if needed. After, a rubber tube is placed over the injection ports and injection is started. Using the injection machine, epoxy is injected at 100 psi until the delamination is nearly filled, at which time the pressure is backed down to around 30 or 40 psi. While injecting, the movement and location of epoxy is determined by sounding the deck with the rebar rod and by viewing other port holes. Port holes are capped once the epoxy has reached that hole. The delamination is filled when the injection machine starts to work harder and back pressure is found at the injection port.

8) Rate the effectiveness of the epoxy injection as a maintenance method and how long the typical service life is estimated to be.

District 1

The effectiveness is moderately effective and the typical service life is estimated to be 10 to 15 years. It is rare to re-inject a bridge multiple times.

District 2

The procedure is considered moderately effective and the typical service life is estimated to be 10 to 15 years while some decks could be longer. Some bridges require re-injection between 5 and 10 years.

District 3

The effectiveness is very effective and the typical service life is estimated to be 10 to 15 years as long as the deck is a good candidate for injection.

District 4

The effectiveness is very effective and the typical service life is estimated to be 15 to 20 years. The service life of some bridges is less, though some bridges probably should not be injected originally.

District 5

The effectiveness is very effective and the typical service life is estimated to be 10 to 15 years. It isn’t uncommon to go back to a previously injected bridge three to five years after initial injection to re-sound and inject any new voids.

District 6

The effectiveness is very effective and the typical service life is estimated to be 10 to 15 years. Some minor failures are seen around five years after initial injection. A reinjection is usually needed around 10 years. The process is generally viewed as only a tool for buying time and saving money. It is not a permanent fix.

9) Provide any additional information that you feel may be pertinent to this review.

District 1

Some locations have excess moisture in the delaminations, therefore compromising the injection process. Map cracking is sometimes visible from below the deck prior to injection. After the injection has been completed the map cracking disappears.

District 2

There has never been a prescribed level of deterioration that dictates when a bridge deck is to be injected with epoxy. The deciding factors could be different from district to district.

District 3

As a rule-of-thumb, it has been found for estimating purposes that a deck will accept 1 gallon of epoxy per 10 sq. ft of deck.

District 4

It is important to bring sand along to use for any epoxy that ends up on the deck surface.

District 5

No additional comments.

District 6

An emphasis should be placed on training because a proper injection is the key to success. The maximum rate of injection is 40 gallons per day. Time and resources can be saved if the injection is coupled with deck patching. Traffic control is already onsite.

APPENDIX B. NATIONAL SURVEY RESPONSES

Arizona

- Q1: Epoxy injection is used in deck cracks, girder fascias, and substructure units.
- Q2: ASTM C881 Type I or IV, Grade I or II
- Q3: The equipment used to meter and mix the two injection adhesive components and inject the mixed adhesive shall be portable, positive displacement type pumps with interlock to provide positive ratio control of exact proportions of the two components at the nozzle.
- Q4: Temperature
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain a copy of manual/specification
- David Benton, P.E. Phone: (602) 712-7910 Email: DBenton@azdot.gov
- Q7: Various ports injection
- Q8: Moderately Effective
- Q9: Unknown
- Q10: Arizona

Arkansas

- Q1: Arkansas has not used epoxy injection to repair bridge deck overlays.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: Arkansas Highway and Transportation Department

California

- Q1: California DOT, Caltrans, stopped repairing bridge decks by epoxy injection in 1985. Caltrans uses high molecular weight methacrylate to repair bridge deck cracks.
- Q2: ASTM C881 Type1, Grade 1, Class B or C
- Q3: Contractor selects equipment suitable for application.
- Q4: None
- Q5: Hired Contractor
- Q6: No, A manual/specification has not been developed
- Q7: Repair cracks in concrete girders, abutment walls, and columns.
- Q8: Very Effective
- Q9: More than 20 years

- Q10: California. Caltrans uses high molecular weight methacrylate to repair concrete cracks in bridge decks.

District of Columbia

- Q1: The District of Columbia does not employ epoxy injection as a maintenance method to repair concrete overlays.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: District of Columbia

Florida

- Q1: Repair of beams, piles, pile caps, barrier walls, and seawalls. For at least 10 years.
- Q2: Use epoxies for FDOT Qualified Products List at: http://www.dot.state.fl.us/specificationsoffice/ProductEvaluation/QPL/default.shtm
- Q3: Either hand pump or pneumatic pump depending on job. Equipment may be specified by supplier.
- Q4: Weather, Temperature, Maintaining Traffic Flow, per manufacturer's instructions.
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- FDOT specification 926. Available from FDOT website.
- Q7: Beam and barrier wall impacts. Sealing deck cracks
- Q8: Very Effective, Very effective for impact damage, less effective for sealing cracks resulting from corrosion.
- Q9: 10 to 15 years, Service life depends on location and environment.
- Q10: Florida Department of Transportation

Georgia

- Q1: Georgia DOT uses epoxy injection to repair columns and bents but does not use it for concrete overlays.
- Q2: N/A
- Q3: N/A
- Q4: N/A
- Q5: N/A
- Q6: No, A manual/specification has not been developed.

- Q7: N/A
- Q8: N/A
- Q9: N/A
- Q10: Georgia DOT

Hawaii

- Q1: Hawaii has not used epoxy injection to repair overlays. We also have very few overlays on our decks.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: Hawaii

Idaho

- Q1: Idaho has not used injection in regards to deck overlay bond to substrate. We do use injection for columns and substructures and some superstructure girder repairs.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: Hired Contractor
- Q6: No Response
- Q7: No Response
- Q8: Moderately Effective
- Q9: 5 to 10 years
- Q10: Idaho

Illinois

- Q1: Typically used in concrete substructure repair. Our current specification has been in use since 2007.
- Q2: ASTM C881 Type IV, Grade 1, Class A, B, or C. The class supplied shall be governed by the range of temperature for which the material is to be used.
- Q3: Oil-free compressed air and/or vacuum to remove dust/debris from crack. One-way injection ports installed every 6 to 18 in. Mechanical pressure equipment to inject the epoxy bonding compound into the crack.
- Q4: Nothing currently in our spec.

- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Jayme F. Schiff Acting Engineer of Structural Services IDOT Bureau of Bridges and Structures 2300 S. Dirksen Parkway Springfield, IL 62764 217-782-2125 Jayme.Schiff@illinois.gov
- Q7: Repair cracks in concrete substructures
- Q8: Moderately Effective
- Q9: 10 to 15 years. This is an estimate, since we have only been using our current specification since 2007.
- Q10: State of Illinois

Kansas

- Q1: Paul Virmani – FHWA – 202 493 052. Prior to FHWA, I worked at the Kansas DOT (1973 to 1976). Epoxy injection for delamination repair for bridge decks as well as for crack repair for substructure members. This was one of the repairs developed by Kansas DOT.
- Q2: You can get details from Kansas DOT or I can get for you.
- Q3: Contact Kansas DOT.
- Q4: Temperature
- Q5: DOT Maintenance Staff
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Kansas DOT
- Q7: No Response
- Q8: Moderately Effective
- Q9: 10 to 15 years
- Q10: I am making this survey as one of the researchers working for the Kansas DOT at that time.

Maryland (1 of 2)

- Q1: We have not used injection as a maintenance/rehab method on delaminated bridge deck overlay.
- Q2: N/A
- Q3: N/A
- Q4: N/A
- Q5: No response
- Q6: N/A
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: Robert Healy Deputy Director – Maryland DOT Office of Structures 410-545-8063

Maryland (2 of 2)

- Q1: Maryland does not use epoxy injection for the repair of bridge decks, only cracks in substructure units. Answers below will be related to how we use the epoxy injection for repair of substructure units.
- Q2: ASTM C881 Type I – Different grades are used.
- Q3: Pump
- Q4: Weather, Temperature
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Jeff Robert Maryland SHA. jrobert@sha.state.md.us
- Q7: No Response
- Q8: Moderately Effective
- Q9: 10 to 15 years
- Q10: Maryland State Highway Administration responder: Jeff Robert, Office of Structures jrobert@sha.state.md.us

Michigan

- Q1: Michigan has been utilizing epoxy injection since the mid-1970s or earlier. The maintenance method is typically applied to cracked or damaged structural concrete including piers, segmental concrete structures, and prestressed concrete beams.
- Q2: MDOT maintenance crews typically use Axson AkaBond 818 FG or Dedoes Tru Grip 150. Other tested and approved products are specified in section 914.06 of the Construction & Technology Division Materials Source Guide.
- Q3: Electric inverter or generator. Webac two component electric epoxy pump. Dedoes Tru Grip Superseal or Axson AkaBond 551 epoxy paste adhesive. Lily Injecti-Port nozzles. ND Industries superglue and accelerator.
- Q4: Weather, Temperature, Maintaining Traffic Flow, Common limitations include a required surface temperature of at least 50 degrees Fahrenheit, and a crack size width no exceeding 0.125 in. Larger cracks require a modified epoxy.
- Q5: DOT Maintenance Staff
- Q6: No, A manual/specification has not been developed. As-needed training classes are provided by experienced MDOT staff.
- Q7: Two component structural moisture insensitive resin injection.
- Q8: Very Effective, The materials are effective when installed according to manufacturer's specifications. The two brands previously listed produce certain colors during the mixing process that ensure proper proportioning.
- Q9: More than 20 years
- Q10: Michigan. The epoxy pump mix proportioning may change over time and needs to be checked often. Otherwise inconsistencies may develop.

Minnesota

- Q1: Epoxy injection to bond delaminated low slump concrete overlays has not been used in Minnesota. Delaminations are repaired with conventional concrete patching methods. Most delaminations are corrosion induced, and are not due to bond failures.
- Q2: No response
- Q3: No response
- Q4: No response
- Q5: No response
- Q6: No response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: Minnesota, Submitted by: Paul Kivisto Metro Region Bridge Engineer (651) 366-4563

Missouri

- Q1: Missouri doesn’t typically use epoxy injection.
- Q2: We do not inject, but do allow filling of surface cracks by routing and filling with Type III, Grade 1, Class B or C epoxy
- Q3: N/A
- Q4: N/A
- Q5: No Response
- Q6: No, A manual/specification has not been developed
- Q7: N/A
- Q8: N/A
- Q9: N/A
- Q10: Missouri DOT. Went to a workshop in Iowa over 10 years ago on epoxy injection but have never used it on bridge decks or overlays. MoDOT repairs dry cracks in concrete by routing and filling with Type III epoxy, see #2 above.

Montana

- Q1: Epoxy injection isn’t typically used in Montana for this application.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: Montana.

Nevada

- Q1: Crack repair of new and existing concrete elements, including bridge decks.
- Q2: AASHTO M235 Type IV, Grades 1, 2, or 3, Class A, B, or C
- Q3: Contractor’s means and methods (equipment not specified). Injection pressure of 25 psi is required.
- Q4: Weather, Temperature, Material must be placed in accordance with manufacturer’s requirements.
- Q5: Hired Contractor
- Q6: No, A manual/specification has not been developed
- Q7: No Response
- Q8: Very Effective
- Q9: More than 20 years
- Q10: Nevada Department of Transportation

New Hampshire

- Q1: New Hampshire does not use epoxy injection.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: New Hampshire

New Mexico (1 of 2)

- Q1: Not used.
- Q2: N/A
- Q3: N/A
- Q4: N/A
- Q5: N/A
- Q6: N/A
- Q7: N/A
- Q8: N/A
- Q9: N/A
- Q10: New Mexico DOT. Jimmy Camp. Comments: New Mexico has basically stopped using concrete overlays on bridge decks because of the delamination issues, added dead load, and costs. New Mexico has been using thin bonded epoxy overlays instead for about 10 years and is very satisfied with thin bonded epoxy overlays to extend bridge deck life.

New Mexico (2 of 2)

- Q1: We generally do not epoxy inject any bridge overlays in our state. When we get a section that is spalled out we usually just patch it. Our climate in this state generally has a mild climate.
- Q2: No Response
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: New Mexico Department of Transportation

North Carolina

- Q1: We occasionally have used epoxy injection to fill cracks in pier caps and columns but never to inject under delaminated areas of concrete overlays.
- Q2: No Response
- Q3: No Response
- Q4: Weather, Temperature, How bad the cracking is and whether the injection will be successful.
- Q5: DOT Maintenance Staff
- Q6: No, A manual/specification has not been developed
- Q7: No Response
- Q8: Moderately Effective
- Q9: 5 to 10 years
- Q10: North Carolina, We seem to be using epoxy injection less and less as time goes on. Dan Holderman, State Bridge Management Engineer (dholderman@ncdot.gov)

Oregon (1 of 2)

- Q1: RCDG crack repair – Usually done under contract but occasionally by maintenance
- Q2: ASTM C881 Type __ Grade __ Class ___
- Q3: Pumps, ports, etc. Hand applied equipment as well depending upon size of job.
- Q4: Weather, Temperature, Maintaining Traffic Flow. We use according to manufacture recommendations.
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Scott Nelson, P.E. scott.d.nelson@odot.state.or.us
- Q7: Pump/port
- Q8: Moderately Effective, Some sealed cracks have recracked due to movement. Generally

not a strength issue but a serviceability issue.

- Q9: 10 to 15 years
- Q10: Oregon

Oregon (2 of 2)

- Q1: Typically injection of structural members with shear issues. By filling the cracks the shear capacity should increase in theory.
- Q2: ASTM C881 Type __ Grade __ Class ___ Crack injection epoxy. Several different manufacturers. See ODOT Construction website Qualified Products Listing for names.
- Q3: Mixers and pumps
- Q4: Weather, Temperature
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- See ODOT specification website. The specification SP538.
- Q7: Seal the outside of cracks and install small ports for injection and escapement. Pump from the low elevations until full.
- Q8: Moderately Effective
- Q9: Impossible to gauge
- Q10: Oregon

Pennsylvania

- Q1: Epoxy injection is not used to repair delaminated concrete overlays.
- Q2: N/A
- Q3: No Response
- Q4: No Response
- Q5: No Response
- Q6: No Response
- Q7: No Response
- Q8: No Response
- Q9: No Response
- Q10: Pennsylvania

South Dakota

- Q1: Crack repair in structural concrete elements such as prestressed girders, columns, caps, abutments, etc. Also, have used on cracked timber beams
- Q2: ASTM C881 Type IV, Grade I, Class B or C
- Q3: Low pressure epoxy injection pump.
- Q4: Weather, Temperature, Maintaining Traffic Flow.
- Q5: Hired Contractor
- Q6: No, A manual/specification has not been developed.

- Q7: Low pressure epoxy injection with the use of crack surface sealers and port to port injection.
- Q8: Very Effective
- Q9: More than 20 years
- Q10: South Dakota DOT

Tennessee

- Q1: Typically injecting cracks in substructures, not sure how long it's been used but more than 15 years.
- Q2: To get on QPL C881 or C882. Slant shear hardened to hardened concrete, 2 day 1000 psi, 14 day 1500 psi.
- Q3: Equipment if supplied by subcontractor in a contracted repair. Maintenance forces do not typically do this type of work.
- Q4: Manufacturer's recommendations
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Brian Egli Brian.Egli@tn.gov
- Q7: Not sure, up to the injection subcontractor
- Q8: Moderately Effective
- Q9: 15 to 20 Years
- Q10: Tennessee DOT

Texas

- Q1: Repairs for cracks in structural concrete members. 25+ years for all.
- Q2: Other. See our specs at: ftp://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/6000_series/pdfs/6100.pdf
- Q3: See specs at: ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standards/s780.pdf
- Q4: See: ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standards/s780.pdf
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/standards/s780.pdf
- Brian Merrill 512-416-2232 or Brian.Merrill@txdot.gov
- Q7: Not sure what this means
- Q8: Moderately Effective, depends on if the cause of the cracks is also addressed.
- Q9: 15 to 20 Years
- Q10: Texas

Utah

- Q1: Thin bonded polymer overlay – 10 years (This application bridges the cracks and seals the deck) Low viscosity healer/sealer – 5 years (This application fills the cracks well but quickly wears off the deck riding surface).

- Q2: Meets ASTM C881 and our standard specification (03372) which can be found on the UDOT website, www.udot.utah.gov
- Q3: Type II for low ADT roads that is usually mixed in 50 gallon barrels and applied manually with squeegee brooms. Type I for high ADT facilities that requires a mechanically mixed and metered system to ensure high volume application with reliability.
- Q4: Weather, Temperature, Maintaining Traffic Flow
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Chris Potter, cpotter@utah.gov, 801-964-4463, www.udot.utah.gov (Thin bonded polymer overlay specification 03372)
- Q7: Thin bonded polymer overlay type I which is mechanically mixed and metered
- Q8: Moderately Effective, Effective if the preparation is done properly. In Utah the summers are dry, hot and can be windy so curing compounds are applied to retain the moisture and facilitate the hydration process. These compounds have wax and if the waxes are not completely removed prior to applying the overlay they will prematurely debond (usually within 5 years). It sometimes requires shot blasting twice to remove the compounds completely if the deck is new.
- Q9: 10 to 15 years, If the preparation is done correctly.
- Q10: Utah. Utah does not apply polymer overlays to decks over 5 years old because experience has shown that the corrosion process has already started and the concrete will delaminate through the overlay. The overlay may also be retaining moisture and accelerating the corrosion process.

Virginia

- Q1: The Virginia Department of Transportation has used epoxy injection to repair rigid cracks in concrete substructure units for 30 plus years.
- Q2: Virginia Department of Transportation (VDOT) Epoxy Type EP4-LV. See Section 243 of the 2007 VDOT Specifications. Copy available upon request.
- Q3: Air compressor, injection pump, injection ports, abrasive blasting equipment, torch, standard hand and power tools.
- Q4: Temperature, Typically the air and concrete temperature should be greater than 50 degrees F.
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- J.L. Milton, Bridge Preservation Specialist Structure and Bridge Division, Virginia Department of Transportation. Phone: (434) 856-8278. Cell: (434) 841-1463. Fax: (434) 947-2689. Email: Jeffrey.Milton@VDOT.Virginia.gov
- Q7: The means and methods are described in the VDOT Special Provision for Epoxy Injection Pressure Crack Sealing. Copy available upon request.
- Q8: Epoxy injection of cracks in concrete substructure units (as described in the referenced Special Provision) is effective for dormant cracks.
- Q9: 10 to 15 years

- Q10: Virginia Department of Transportation

West Virginia

- Q1: It has been used for at least 2 decades in applications that range from filling voids to crack sealing in bridge decks.
- Q2: Other, We have utilized various ASTM C881 types, grades, and classes from very viscous to materials with the consistency approaching tree sap.
- Q3: Equipment would include port drilling devices and pumping apparatuses.
- Q4: Weather, Temperature, Maintaining Traffic Flow, All conditions shown would be limiting factors as well as crack type, depth, and width.
- Q5: Other, We have utilized hired contractors as well as our own DOH staff
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Yes, our construction manual, specifications, as well as, Material Division publication reference this process. All our documents and materials are readily available by contacting the Director of Materials Divisions, and many are on our website.
- Q7: Porting and pumping the epoxy material is most common.
- Q8: Moderately Effective, Moderately effective to very effective provided appropriate process was implemented properly.
- Q9: 5 to 10 years. We do not have data readily available; however, I would expect 5 to 10 years.
- Q10: West Virginia contacts: Jim Shook (james.d.shook@wv.gov), Jimmy Wriston (jimmy.d.wriston@wv.gov), Aaron Gillispie (aaron.c.gillispie@wv.gov)

Wyoming

- Q1: Crack sealing for abutment and bent caps and columns.
- Q2: Other. Epoxy Type I, grade 2 bonding compound type V, grade 2
- Q3: Handgun or pot for injection
- Q4: No Response
- Q5: Hired Contractor
- Q6: Yes, Contact the individual below to obtain copy of manual/specification
- Keith Fulton, State Bridge Engineer, 5300 Bishop Blvd, Cheyenne, WY 82009, 307-777-4427. Spec can also be found at: http://www.dot.state.wy.us/wydot/engineering_technical_programs/manuals_publications/2010_Standard_Specifications
- Q7: No Response
- Q8: Moderately Effective
- Q9: 5 to 10 Years
- Q10: Wyoming

APPENDIX C. ASTM C 881

Type

- Type I: For use in non-load bearing applications for bonding hardened concrete to hardened concrete and other materials, and as a binder in epoxy mortars or epoxy concretes.
- Type II: For use in non-load bearing applications for bonding freshly mixed concrete to hardened concrete.
- Type III: For use in bonding skid-resistant materials to hardened concrete, and as a binder in epoxy mortars or epoxy concretes, used on traffic bearing surfaces (or surfaces subject to thermal or mechanical movements).
- Type IV: For use in load bearing applications for bonding hardened concrete to hardened concrete and other materials and as a binder for epoxy mortars and concretes.
- Type V: For use in load bearing applications for bonding freshly mixed concrete to hardened concrete.
- Type VI: For bonding and sealing segmental precast elements with internal tendons and for span-by-span erection when temporary post tensioning is applied.
- Type VII: For use as a non-stress carrying sealer for segmental precast elements when temporary post tensioning is not applied in span-by-span erection.

Grade

- Grade 1: Low viscosity
- Grade 2: Medium viscosity
- Grade 3: Non-sagging consistency

Class

- Class A: Below 40°F to manufacturer defined low
- Class B: 40° to 60°F
- Class C: Above 60°F to manufacturer defined high
- Class D: 40° to 65°F
- Class E: 60° to 80°F
- Class F: 75° to 90°F

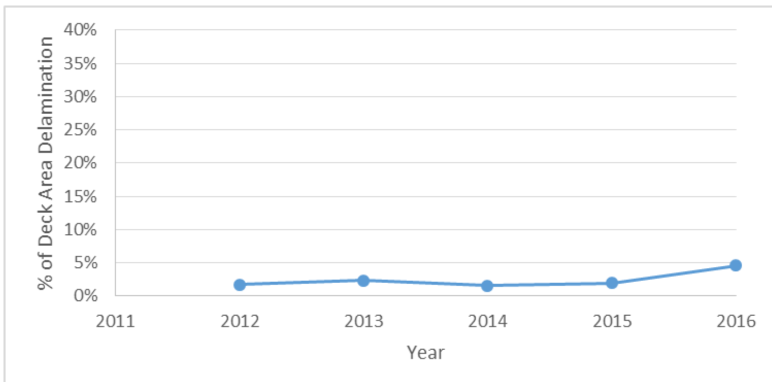
Classes A, B, and C are defined for types I through IV. Classes D, E, and F are defined for Types VI and VII according to the range of temperatures for which they are suitable.

APPENDIX D. DELAMINATION RATE FOR BRIDGES EPOXY INJECTED IN 2011

Federal ID	013010	
State ID	0170.6S092	
County	Adair	
Location	1.6 MI. East of SR N51	
Facility Carried	IA 92	
Feature Crossed	West Fork of Nodaway River	
Iowa District	4	
ADT	1330	
Year Built	1950	
Structural Type	Steel Girder	
Sufficiency Rating	46.8	

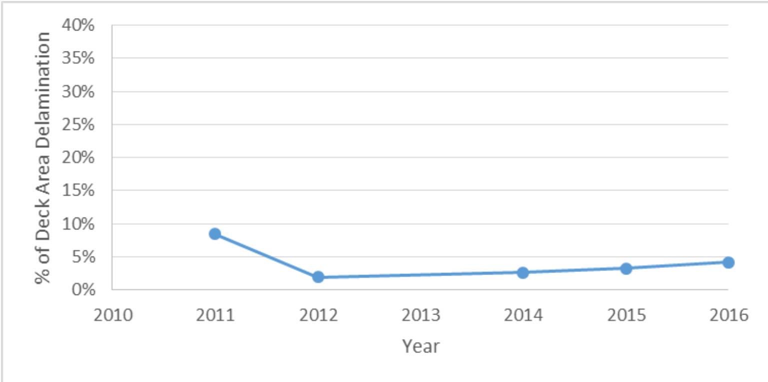
Notes

Before injection data is not available



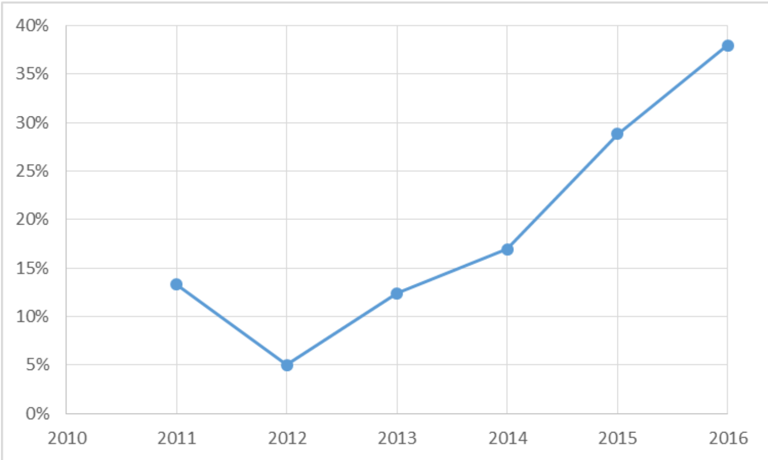
Federal ID	017250
State ID	1477.0S141
County	Carroll
Location	In Manning, IA
Facility Carried	IA 141
Feature Crossed	West Nishnabotna River
Iowa District	4
ADT	2820
Year Built	1962
Structural Type	Concrete Slab
Sufficiency Rating	90.9

Notes

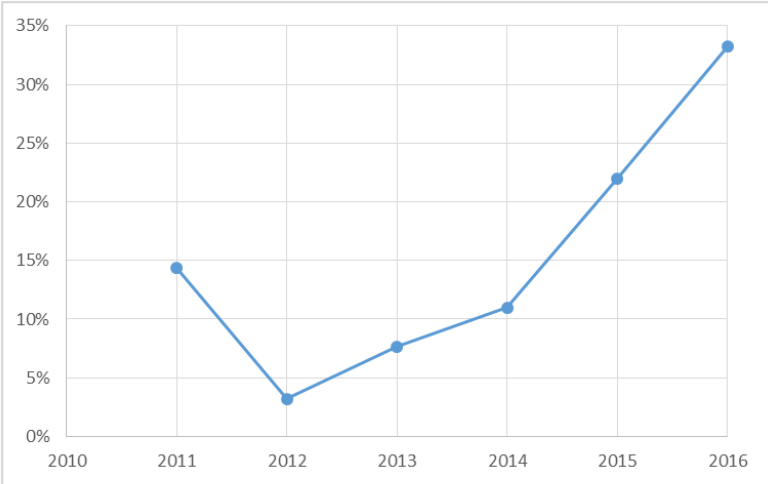


Federal ID	025340
State ID	3606.2S002
County	Fremont
Location	2.4 MI. East of JCT. IA 29
Facility Carried	IA 2
Feature Crossed	Drainage Ditch
Iowa District	4
ADT	1860
Year Built	1953
Structural Type	Concrete Slab
Sufficiency Rating	70.6

<u>Notes</u>



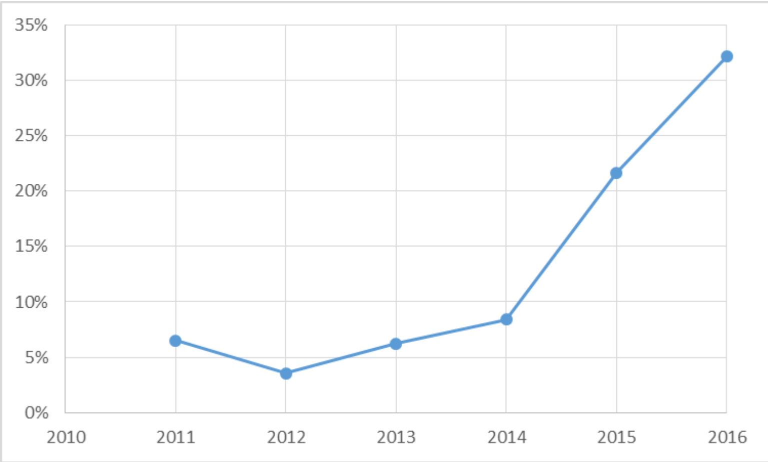
Federal ID	025350
State ID	3606.5S002
County	Fremont
Location	3.1 MI. East of JCT. IA 29
Facility Carried	IA 2
Feature Crossed	Drainage Ditch
Iowa District	4
ADT	1860
Year Built	1953
Structural Type	Concrete Slab
Sufficiency Rating	64.6



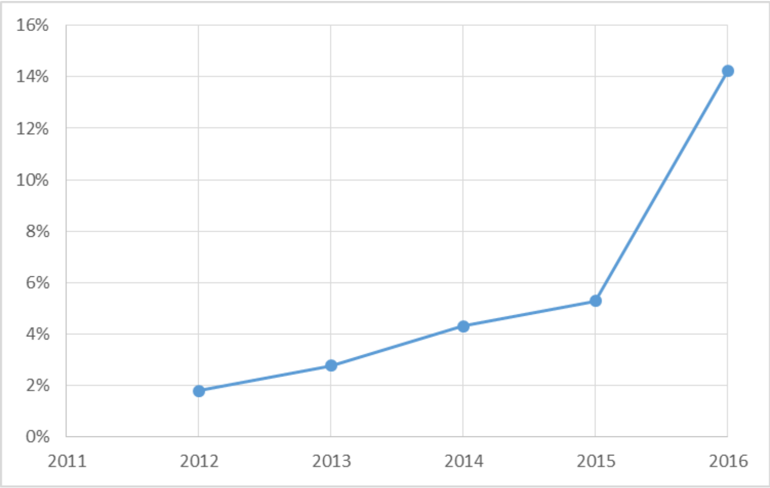
<u>Notes</u>

Federal ID	025380
State ID	3617.5S002
County	Fremont
Location	1.7 MI. East of East JCT. IA 275
Facility Carried	IA 2
Feature Crossed	West Nishnabotna River
Iowa District	4
ADT	2000
Year Built	1954
Structural Type	Steel Girder
Sufficiency Rating	59.2

<u>Notes</u>



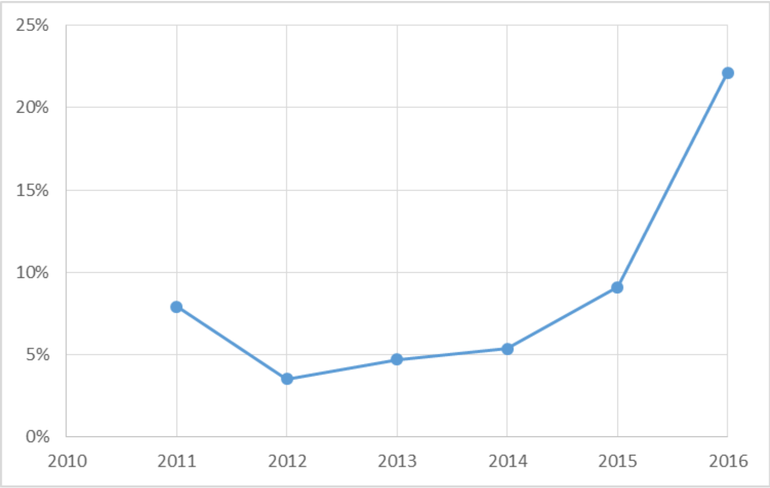
Federal ID	026211
State ID	3973.3S044
County	Guthrie
Location	1.2 MI. West of JCT. IA 4
Facility Carried	IA 44
Feature Crossed	Raccoon River
Iowa District	4
ADT	3480
Year Built	1972
Structural Type	Steel Girder
Sufficiency Rating	92.9



Notes
Before injection data is not available

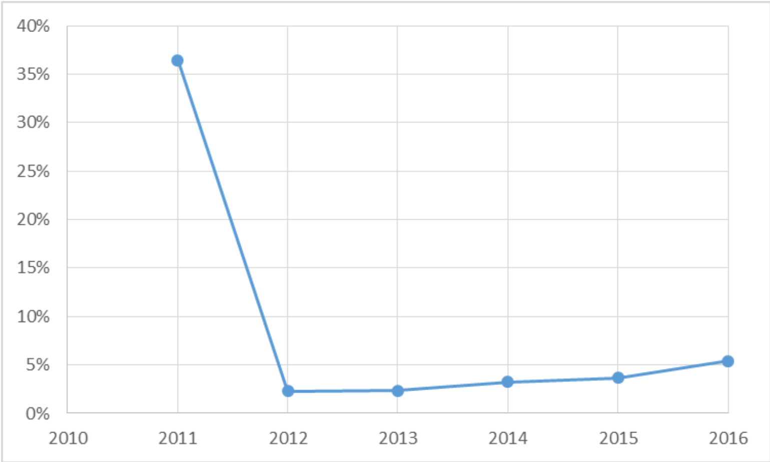
Federal ID	029010
State ID	4631.1S003
County	Guthrie
Location	1.8 MI. East of US 169
Facility Carried	IA 3
Feature Crossed	East Fork of Des Moines River
Iowa District	2
ADT	3350
Year Built	1955
Structural Type	Steel Girder
Sufficiency Rating	58.5

<u>Notes</u>



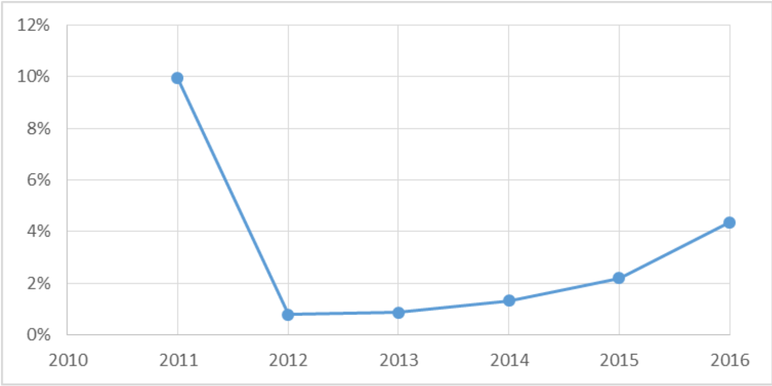
Federal ID	030490
State ID	5077.7S006
County	Jasper
Location	1.3 MI. East of JCT 224
Facility Carried	US 6
Feature Crossed	North Skunk River
Iowa District	1
ADT	2060
Year Built	1924
Structural Type	Steel Girder
Sufficiency Rating	63.7

Notes



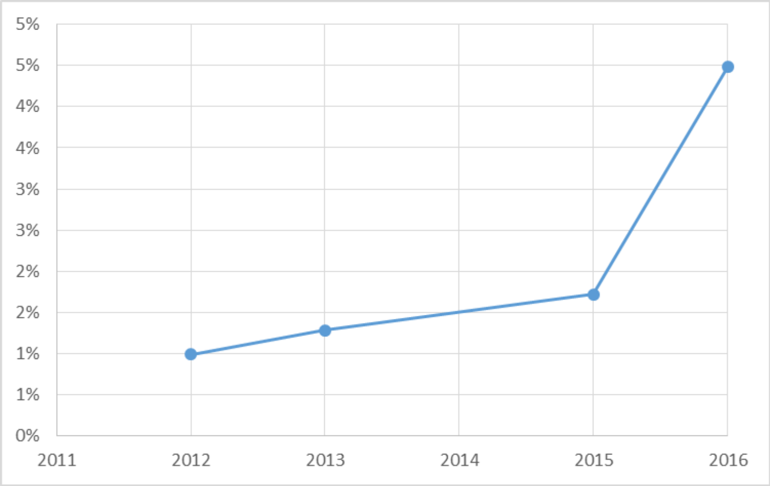
Federal ID	030500
State ID	5077.9S006
County	Jasper
Location	1.5 MI. East of JCT 224
Facility Carried	US 6
Feature Crossed	IAIS RR
Iowa District	1
ADT	1950
Year Built	1952
Structural Type	Steel Girder
Sufficiency Rating	76.1

Notes



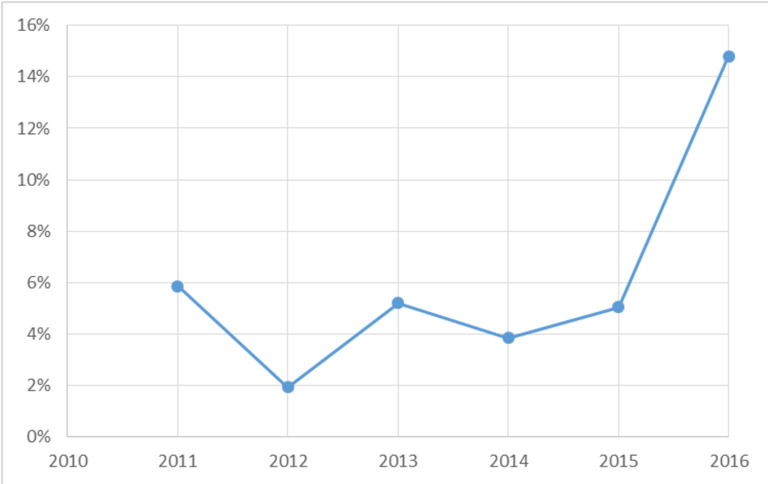
Federal ID	037573
State ID	6948.8L034
County	Montgomery
Location	0.5 MI. West of JCT 71
Facility Carried	WB US 34
Feature Crossed	West Nodaway River
Iowa District	4
ADT	1290
Year Built	1970
Sufficiency Rating	86.0

Notes
Before injection data is not available



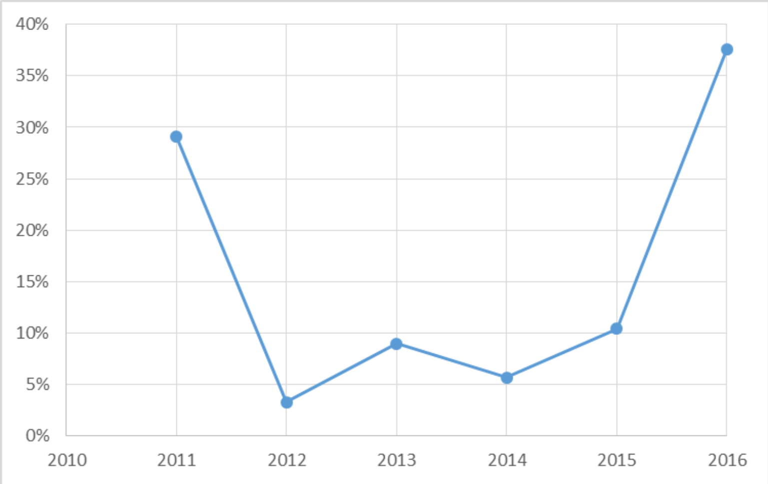
Federal ID	037741
State ID	6925.3S048
County	Montgomery
Location	1.7 MI. North of JCT 34
Facility Carried	IA 48
Feature Crossed	East Nishnabotna River
Iowa District	4
ADT	2410
Year Built	1973
Sufficiency Rating	77.4

<u>Notes</u>



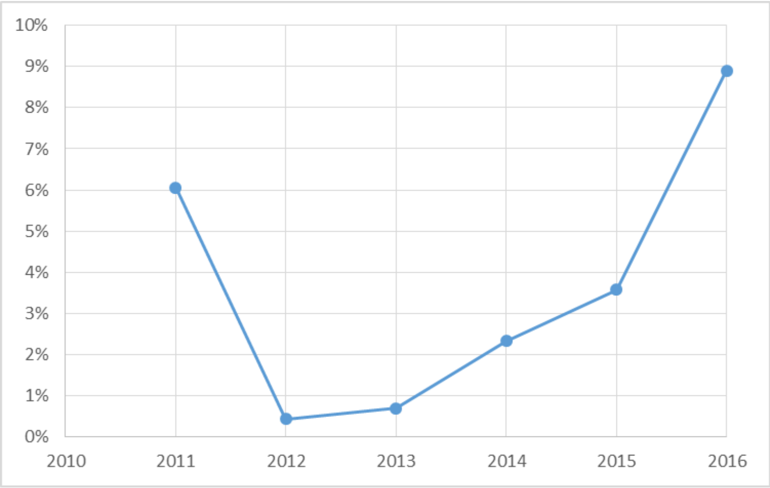
Federal ID	037781
State ID	6934.6S048
County	Montgomery
Location	1.9 MI. South of SR H14
Facility Carried	IA 48
Feature Crossed	East Nishnabotna River
Iowa District	4
ADT	1190
Year Built	1960
Sufficiency Rating	66.2

<u>Notes</u>
Before injection data is not available

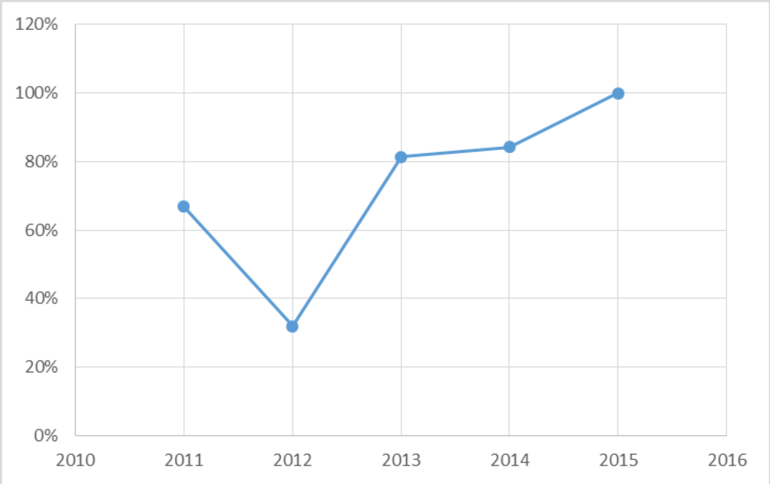


Federal ID	045420
State ID	7829.6O080
County	Pottawattamie
Location	3.5 MI. West of JCT. SR M-16
Facility Carried	FM L-66
Feature Crossed	I-80
Iowa District	4
ADT	540
Year Built	1965
Sufficiency Rating	74.6

<u>Notes</u>



Federal ID	047860
State ID	8334.8S037
County	Shelby
Location	1.4 MI. West of JCT. IA 191
Facility Carried	IA 37
Feature Crossed	Moser Creek
Iowa District	4
ADT	640
Year Built	1961
Sufficiency Rating	85.4

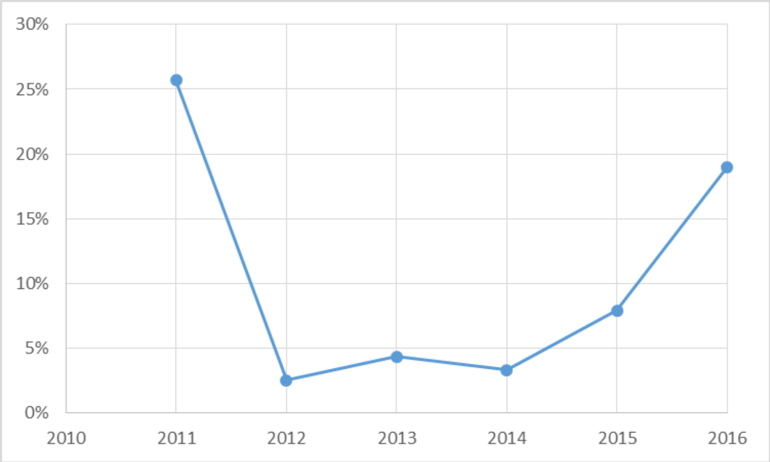


Notes

Deck replaced in 2015

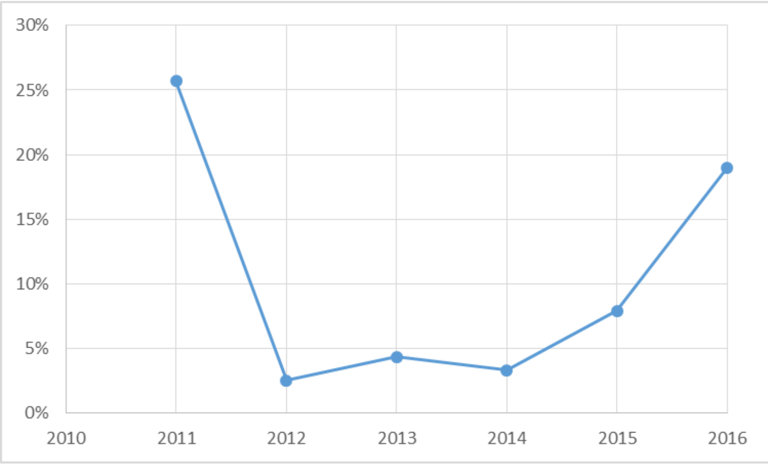
Federal ID	047950
State ID	8311.9S044
County	Shelby
Location	0.3 MI. East of JCT. IA 191
Facility Carried	IA 44
Feature Crossed	Mosquito Creek
Iowa District	4
ADT	1280
Year Built	1959
Sufficiency Rating	80.6

Notes

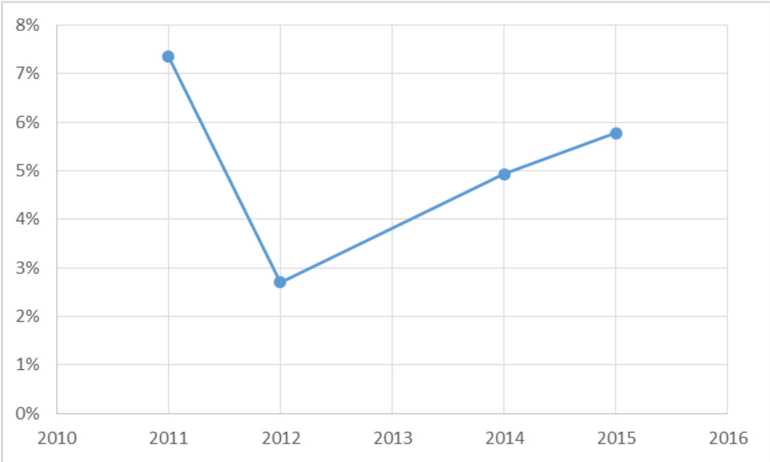


Federal ID	047950
State ID	8311.9S044
County	Shelby
Location	0.3 MI. East of JCT. IA 191
Facility Carried	IA 44
Feature Crossed	Mosquito Creek
Iowa District	4
ADT	1280
Year Built	1959
Sufficiency Rating	80.6

<u>Notes</u>



Federal ID	051930
State ID	9334.5S002
County	Wayne
Location	2.0 MI. East of SR R-69
Facility Carried	IA 2
Feature Crossed	Steele Creek
Iowa District	5
ADT	950
Year Built	1963
Sufficiency Rating	70.8

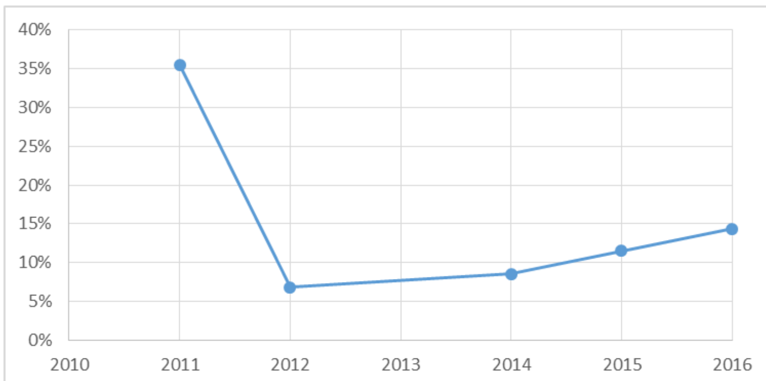


<u>Notes</u>

Data were not collected in 2016 due to interference with wide load transportation

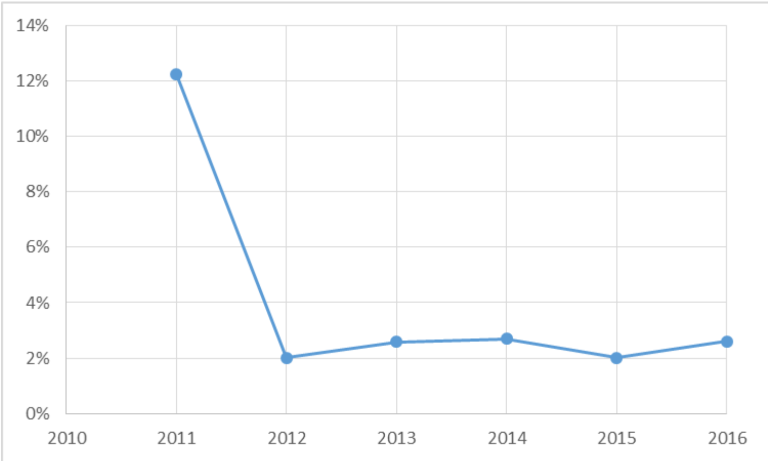
Federal ID	052350
State ID	9413.4S175
County	Webster
Location	1.7 MI. East of SR P-29
Facility Carried	IA 175
Feature Crossed	Drainage Ditch
Iowa District	1
ADT	1100
Year Built	1953
Sufficiency Rating	76.1

Notes



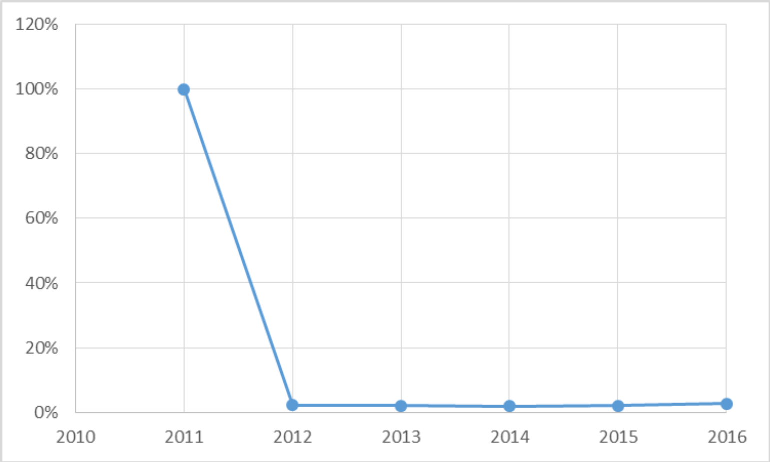
Federal ID	052550
State ID	9650.3S052
County	Winneshiek
Location	0.6 MI. North of JCT. IA 9
Facility Carried	US 52
Feature Crossed	Stream and Twin Springs Rd.
Iowa District	2
ADT	4280
Year Built	1963
Sufficiency Rating	66.6

<u>Notes</u>



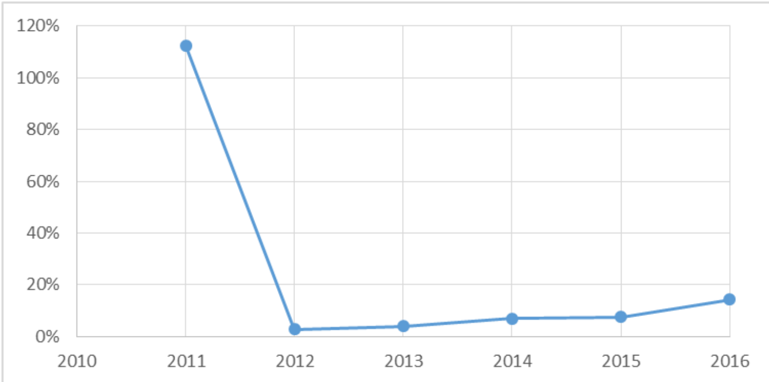
Federal ID	052560
State ID	9651.5S052
County	Winneshiek
Location	1.8 MI. North of JCT. IA 9
Facility Carried	US 52
Feature Crossed	Upper Iowa River
Iowa District	2
ADT	3100
Year Built	1963
Sufficiency Rating	65.0

<u>Notes</u>



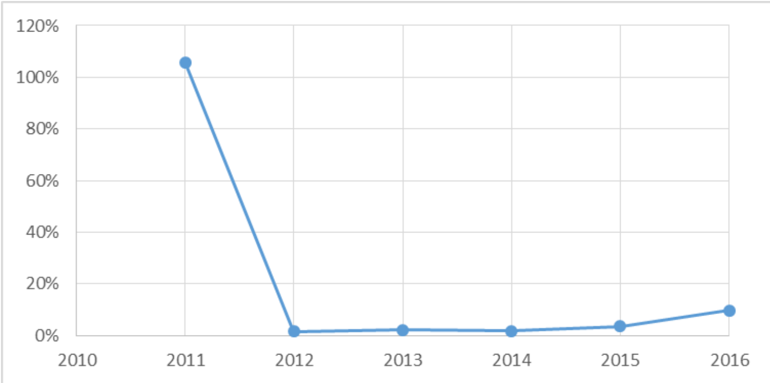
Federal ID	054000
State ID	9866.5S009
County	Worth
Location	0.5 MI. West of West JCT. S18
Facility Carried	IA 9
Feature Crossed	Beaver Creek
Iowa District	2
ADT	2640
Year Built	1947
Sufficiency Rating	68.1

Notes



Federal ID	054320
State ID	9975.3S069
County	Wright
Location	0.2 MI South of JCT. SR C20
Facility Carried	US 69
Feature Crossed	Iowa River
Iowa District	2
ADT	2970
Year Built	1956
Sufficiency Rating	73.0

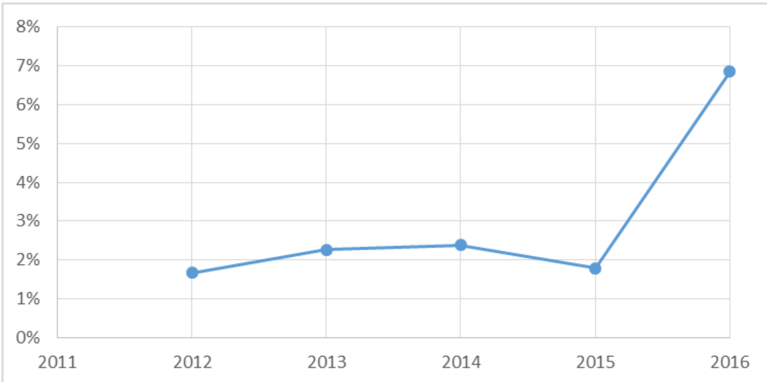
Notes



Federal ID	054330
State ID	9975.6S069
County	Wright
Location	At South JCT. SR C20
Facility Carried	US 69
Feature Crossed	Iowa River
Iowa District	2
ADT	2620
Year Built	1927
Sufficiency Rating	65.5

Notes

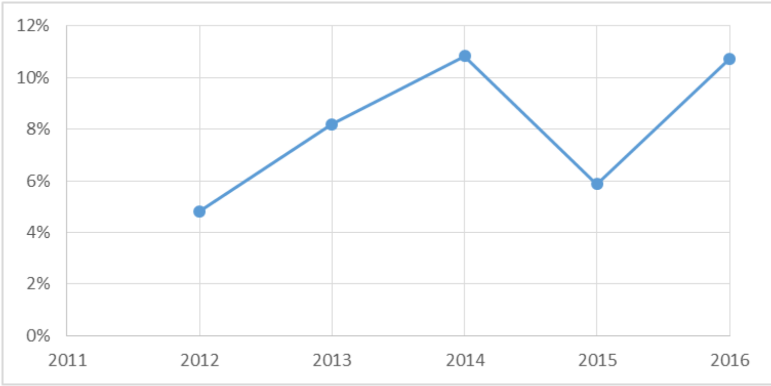
Before injection data is not available



Federal ID	054470
State ID	9985.4S017
County	Wright
Location	0.9 MI. North of JCT. SR C26
Facility Carried	IA 17
Feature Crossed	Prairie Creek
Iowa District	2
ADT	860
Year Built	1949
Sufficiency Rating	69.7

Notes

Before injection data is not available



APPENDIX E. HYPOTHESIS TEST

A two sample t-test was used in this study to determine whether the delamination rate in a specific year was significantly smaller than that before epoxy injection. Although the delamination rate for bridges was not normally distributed, when the sample size is big, t-test is still applicable. T-test is based on the means of two groups. Because of the central limit theorem, the distribution of these converges to a normal distribution in repeated sampling, irrespective of the original distribution of the population.

The delamination rate before epoxy injection was denoted as d_0, and n-year after injection was denoted as d_n. The research question here was: does the collected data suggest that on average the delamination rate of n-year after injection (d_n) is smaller than the delamination rate before injection (d_0)?

Null Hypothesis: $d_0 = d_n$; there is no significant difference between d_0 (delamination rate before injection) and d_n (delamination rate n-year after injection).

Alternative Hypothesis: $d_0 > d_n$; d_0 is significantly larger than d_n (one-side test).

Test Statistic: $T_n = \frac{\bar{X}_1 - \bar{X}_n}{\sqrt{\frac{{s_1}^2}{N_1} + \frac{{s_n}^2}{N_n}}}$

Where: N_1 and N_n are the sample sizes

$\bar{X}_1$ and $\bar{X}_n$ are the sample means

and ${s_1}^2$ and ${s_n}^2$ are the sample variances

Significance Level: α = 0.025

Critical Region: Reject the null hypothesis that the two means are equal if $T > t_{1-\alpha,\nu}$

The dataset used in hypothesis tests is shown in Table E.1.

Table E.1. Delamination rate

d_0	d_1	d_2	d_3	d_4	d_5
0.08	0.02	0.02	0.02	0.02	0.05
0.13	0.02	0.03	0.03	0.03	0.04
0.14	0.05	0.12	0.17	0.29	0.38
0.06	0.03	0.08	0.11	0.22	0.33
0.08	0.04	0.06	0.08	0.22	0.32
0.36	0.02	0.02	0.04	0.05	0.14
0.10	0.04	0.05	0.05	0.09	0.22
0.06	0.02	0.02	0.03	0.04	0.05
0.29	0.01	0.01	0.01	0.02	0.04
0.06	0.01	0.01	0.02	0.02	0.04
0.26	0.02	0.05	0.04	0.05	0.15
0.07	0.03	0.09	0.06	0.10	0.38
0.36	0.03	0.03	0.04	0.06	0.09
0.12	0.00	0.01	0.02	0.04	0.09
	0.03	0.04	0.03	0.08	0.19
	0.03	0.04	0.05	0.06	0.14
	0.07	0.08	0.09	0.12	0.03
	0.02	0.03	0.03	0.02	0.03
	0.02	0.02	0.02	0.03	0.14
	0.03	0.04	0.07	0.07	0.10
	0.02	0.02	0.02	0.04	0.07
	0.02	0.02	0.02	0.02	0.11
	0.05	0.08	0.11	0.06	

Bridge #47860 was taken as an outlier and was not included in the test dataset. The t-test results summarized in Table E.2 show that the null hypothesis should be accepted for the first four years after injection and should be rejected only for the fifth year.

Table E.2. Summary of hypothesis test results

n-year after injection	1 year	2 year	3 year	4 year	5 year
T	4.2283	3.6809	3.3626	2.3476	0.3301
ν	35	44	44	44	43
$t_{1-\alpha,\nu}$	1.95	1.95	1.95	1.95	1.95
Is $T > t_{1-\alpha,\nu}$	yes	yes	yes	yes	no

In other words, with a 97.5 percent confidence level, the delamination rate after the injection was smaller than the delamination rate before injection until the fourth year; and the collected data were not sufficient to show the same case for the fifth year. From the analysis results, it was safe to conclude that epoxy injection could extend the service life of the deck by at least four years. More research is required to determine if epoxy injection could extend the service life for more than four years.

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