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INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Bridge Preservation Treatments and Best Practices

Mark D. Bowman, Luis M. Moran

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16. Abstract

Aging of the bridge infrastructure inventory has caused Department of Transportation agencies to critically focus on bridge preservation and replacement needs, while often faced with constrained or reduced budgets every year. A strategic bridge preventive maintenance program has been shown to be an effective way to preserve and extend bridge service lives. A bridge preventive maintenance program is related to routine practices that are repeated with some particular frequency to obtain the best results. Moreover, it is well known that frequently performing less-costly preventive maintenance activities results in a more efficient alternative than performing fewer expensive repairs/rehabilitation or even replacements of bridge elements. The objective of this research was to review bridge maintenance activities recommended by specialized literature, to examine maintenance activities currently conducted by the various INDOT districts, and also to review maintenance activities performed by several other DOT agencies. Based on the results of this review, a list of ten new and enhanced bridge preventive maintenance activities was identified to improve the effectiveness of bridge maintenance operations in Indiana. The required conditions and frequency to perform each activity was analyzed, and the cost and benefit of such operations was studied to ensure that the proposed activities are economically feasible and sustainable.

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EXECUTIVE SUMMARY

BRIDGE PRESERVATION TREATMENTS AND BEST PRACTICES

Introduction

Highway bridges constitute vital links in any transportation system. At present more than 50% of the bridge national inventory (BNI) has exceeded a 50-year service life, and 25% of the existing bridges are rated as structurally deficient or functionally obsolete. The number of structurally deficient bridges will be likely to continue increasing if measures are not implemented to reduce the rate of the deterioration process. Department of Transportation (DOT) agencies nationally have to deal with consistently increasing bridge preservation and replacement needs, while often faced with constrained or reduced budgets every year. A bridge preventive maintenance program has been shown to be a very efficient way to preserve and extend bridge service life.

A bridge preventive maintenance program is related to a routine practice that is repeated with some particular frequency to obtain the best results. Moreover, it is well known that when it is possible to perform cheaper preventive maintenance activities, with more frequency, this results in a more efficient alternative than performing fewer expensive repairs/rehabilitation or even replacements of bridge elements. To address the continued deterioration of Indiana highway bridges requires the development of a cost-effective strategy to deal with increasing bridge maintenance, rehabilitation, and replacement expenses. Bridge preventive maintenance activities can prolong the life of Indiana bridges by consistently using simple, economical treatments at strategic points in a structure's life cycle.

Findings

The objective of this research was to review bridge maintenance activities recommended by specialized literature and to examine those maintenance activities currently conducted by the various Indiana Department of Transportation (INDOT) districts, as well as maintenance activities performed by several other DOT agencies. Based on the results of this review, a list of ten new and enhanced bridge preventive maintenance activities was identified to improve the effectiveness of bridge maintenance operations in Indiana. The required conditions and frequency to perform each activity was analyzed, and the cost and benefit of such operations was studied to ensure that the proposed activities are economically feasible and sustainable. Based upon the analysis, all ten preventative maintenance activities were found to be cost effective and are recommended as an effective means of bridge preservation.

Implementation

The list of the ten bridge preventive maintenance activities and sub activities proposed to be implemented by INDOT includes the following operations

1. Clean and sweep the bridge deck every year; wash and flush the drainage system from the deck annually; and flush the deck before sealer application.
2. Seal concrete deck cracks using a sealer according to the type of cracks; seal the deck with a penetrating silane-based, hydrophobic sealer and patch small potholes. Repeat this procedure every five years.
3. Clean and flush deck joints annually.
4. Clean and wash elastomeric and steel bearings and seats every two years; lubricate steel bearings every four years; and spot paint steel bearings every ten years.
5. Clean and sweep approach slabs annually; wash and flush the slab approach drainage system annually; seal slab and cracks in conjunction with concrete deck; and clean and flush slab joints annually.
6. Clean and wash steel superstructure every two years.
7. Apply spot painting to all superstructure steel elements every ten years.
8. Provide vegetation control annually.
9. Perform tree and debris removal from piers and abutments annually.
10. Clean and flush pin and hanger connections every two years; clean and flush the expansion joints located over the pin and hanger connections annually; lubricate the contact surfaces in a pin and hanger connection every four years; and spot paint pin and hanger members every ten years.

The performance of many of these bridge maintenance activities will likely require the use of crews and equipment. The sequencing and scheduling of activities is left to the district personnel who will complete the required maintenance in a timely fashion to optimize the use of their personnel and resources.

INDOT should implement the methodology guide presented in Appendix G, where basic information is provided to perform each of the aforementioned maintenance activities. Included for each activity is a description of materials and labor needed to perform the maintenance, basic procedures, and associated safety measures.

Following the best practices from other DOT agencies, INDOT should incorporate a Technical Training Program to provide skills and practices in performing the recommended maintenance activities. Practical training that provides both basic theoretical background together with on-the-job practices will provide maintenance personnel with adequate knowledge and expertise to significantly improve the condition of the bridge inventory.

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1. INTRODUCTION

Highway bridges constitute vital links in any transportation system. According to the U.S. Department of Transportation, as of December 2013, there are 607,751 bridges across the country (FHWA, n.d.). Many of them were constructed after World War II, with significant sustained construction after 1950, as seen in Figure 1.1. At present more than 50% of bridge national inventory (BNI) has exceeded a 50-year service life, and 25% of the existing bridges are rated as structurally deficient or functionally obsolete. The number of structurally deficient bridges will be likely to continue increasing if measures are not implemented to reduce the rate of the deterioration process.

The highway bridge system in Indiana is representative of the national trend. Of the 18,953 bridges in Indiana, 10% of them are rated as structurally deficient and 12% as functionally obsolete (FHWA, n.d.). There are many factors affecting bridge condition, such as an excessive live load regime, an aggressive environment, the type of material used for the superstructure, and bridge maintenance operations. These factors, among others, produce different types of deterioration problems.

Hema, Guthrie, and Fonseca (2004) indicated that a lack of proper maintenance operations is one of the main reasons for bridge deterioration. Deficiencies continue to affect more bridges every year as a result of several negative effects. According to AASHTO (2007) the most common problems affecting bridge structures include: corrosion of the reinforced steel in concrete decks due to the penetration of chloride ions from deicing products, leakage through damaged joints, malfunction of frozen bearings, pronounced bumps at bridge approach slabs, and damaged coating systems.

Department of Transportation (DOT) agencies nationally must consistently deal with increasing bridge preservation and replacement needs, while often faced with constrained or reduced budgets every year. Under these circumstances, a normal practice for DOT's is to be more reactionary when addressing bridge maintenance problems, mainly due to its "initial" low cost. Nevertheless, a scheduled preventive maintenance program has been shown to be a more efficient way to preserve and extend the bridge service lives.

Bridge preservation is a concept with many definitions, but generally means the ability to keep a bridge in good condition (Dunne, 2014a). In particular, a bridge preventive maintenance program is related to a routine practice that is repeated with some particular frequency to obtain the best results. Moreover, it is well known that when it is possible to perform cheaper preventive maintenance activities, with more frequency, this results in a more efficient alternative than performing fewer expensive repairs/rehabilitation or even replacements of bridge elements. Figure 1.2 depicts the application of the two aforementioned alternatives. Shown on the left is a less costly program applying only preventive maintenance activities with more frequency, while on the right a more expensive alternative is shown with fewer major repair/rehabilitation works.

The most common bridge maintenance activities were reviewed for this research. Emphasis was given to those activities that are known to be efficient when performed on a regularly scheduled basis, working under a preventive maintenance program. Each activity was described and an economic analysis performed to assess and support its convenience and effectiveness. A list of the most effective bridge preventive maintenance activities, including the frequency of application, was developed for recommendation to the Indiana Department of Transportation (INDOT). A methodology guide was prepared to assist INDOT personnel on the steps to follow when performing those maintenance activities.

2. PROBLEM STATEMENT

To effectively address the continued deterioration of Indiana highway bridges requires the development of a cost-effective strategy to deal with increasing bridge

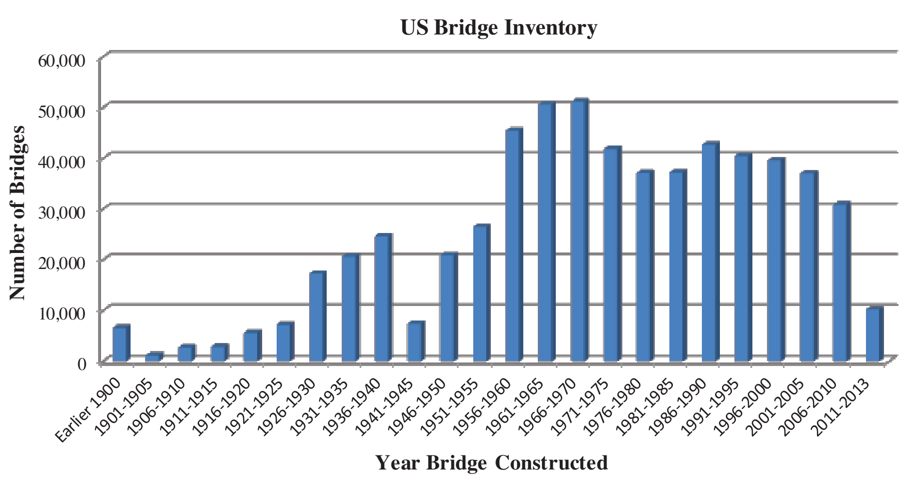

Figure 1.1 U.S. bridge inventory by year of construction (FHWA, n.d.).

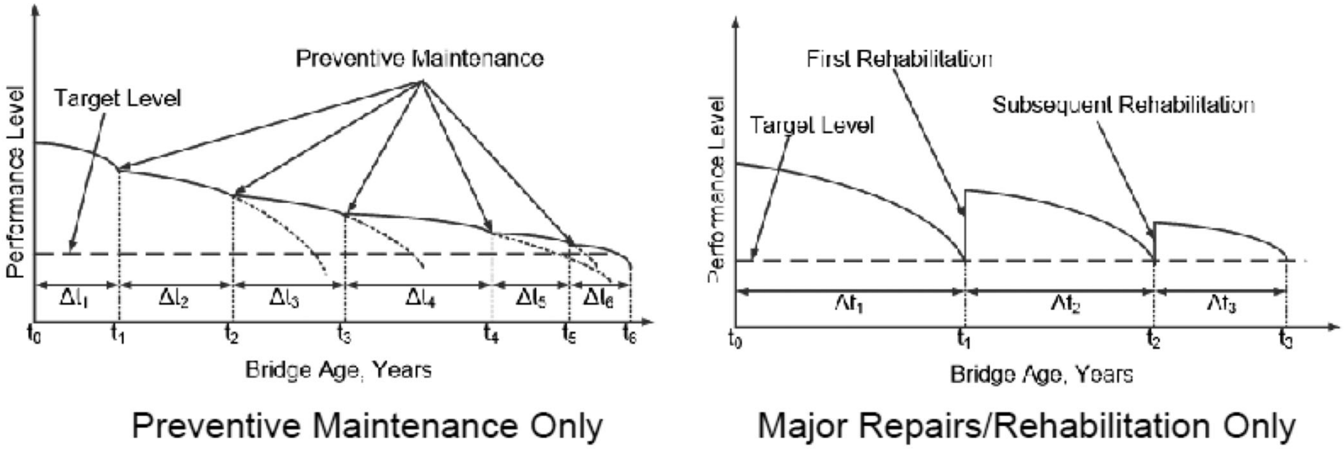

Figure 1.2 Application of two different preservation treatments. Left: only preventive maintenance activities; right: major rehabilitation works (Dunne, 2014b).

maintenance, rehabilitation, and replacement expenses. A reduced budget for bridge preservation requires from INDOT the maximum efficiency in allocating their resources. Each year more bridges reach a longer service life, showing more deterioration aspects and damage that require appropriate attention.

Bridge preventive maintenance activities can prolong the life of Indiana bridges by consistently using simple, economical treatments at strategic points in a structure's life cycle. INDOT is placing an increased focus on bridge preservation, but one area that is lacking is a consistent and coordinated program for in-house maintenance activities.

Currently, INDOT expends only a small fraction of maintenance time on bridges. Clearly, there is a need to both enhance existing maintenance operations and to identify new bridge maintenance activities that will improve the service life of bridges.

3. OBJECTIVE AND SCOPE

The objective of this research was to review bridge maintenance activities recommended by specialized literature, to examine those maintenance activities currently conducted by the various INDOT districts, and also maintenance activities performed by several DOT agencies. Based on the results of this review, a list of new and enhanced bridge preventive maintenance activities was proposed to improve the effectiveness of bridge maintenance operations in Indiana. The required conditions and frequency to perform each activity was analyzed. The cost and benefit of such operations was studied to ensure that the proposed activities are economically feasible and sustainable.

A methodology guide detailing the procedures to follow during the application of each maintenance activity was prepared to ensure that the activities are implemented in an effective and successful manner.

These objectives were accomplished by completing the following tasks in chronological order:

1. An extensive review of specialized literature on bridge maintenance. Previous studies devoted to the maintenance activities for different bridge elements were considered.
2. Review of websites from selected DOT agencies, regarding bridge maintenance activities.
3. The development of an initial list of bridge preventive maintenance activities.
4. Identification of the most common bridge maintenance activities performed by several different DOT agencies.
5. Identification of bridge maintenance activities performed by INDOT District personnel.
6. Compilation and analysis of information for identified preventive maintenance activities.
7. Development of a list of selected preventive maintenance activities to be recommended for implementation by INDOT.
8. Economic evaluation of each maintenance activity to be recommended.
9. Development of a methodology guide for best practices on the recommended preventive maintenance activities.

4. DEVELOPMENT OF MAINTENANCE WORK TASKS

The research considered several phases to achieve the proposed objectives. A methodology procedure was implemented to identify the most common bridge preventive maintenance activities performed currently by INDOT and by different DOT state agencies. An initial extensive list of activities was evaluated and subsequently reduced to a final list of activities. Presented in the next few sections are the different tasks followed to accomplish the research, with a brief explanation of each task. More specific details on each task are presented in Appendices A to G.

4.1 Literature Review

An extensive literature review was devoted to previous research work done by the Federal Highway

Administration (FHWA), American Association of State Highway and Transportation Officials (AASHTO), United Sates Department of Transportation (USDOT), National Cooperative Highway Research Program (NCHRP), State DOTs, and other federal and state organizations as well as private institutions. Several research reports, papers, conference presentations, and dissertations in the field of bridge maintenance were studied. Relevant information from those studies was identified and used to support the proposed list of bridge preventive maintenance activities. It was found that several DOT agencies have their own list of recommended bridge preventive maintenance activities, which are presented in Appendix A.

4.2 Review of Websites for Selected DOTs

The websites from selected DOTs were reviewed and relevant information was cataloged. Specifically, information was gathered regarding the particular department or section responsible for bridge maintenance operations, persons in charge of these duties, documents related to those activities, and any other relevant source or tool related to bridge maintenance. The DOTs selected included all of those states surrounding Indiana (Kentucky, Illinois, Michigan, and Ohio,), as well as a few additional states recommended by the INDOT Study Advisory Committee (Louisiana, Minnesota, and New York).

Each state DOT website has information regarding bridge maintenance activities. Some websites provide very detailed information, such as the Bridge Maintenance Manual presented by New York State DOT (NYSDOT, 2008) or the On-line Bridge Maintenance Manual offered by the Ohio DOT (ODOT, n.d.). Those documents offer substantial information on bridge maintenance activities, the requirements and procedures to apply them, and recommended frequency for application. In contrast, only scattered information related to bridge maintenance activities is offered by the Illinois and Louisiana DOTs website. A more detailed analysis from each DOT website related to bridge maintenance practices is reported in Appendix B.

4.3 Preliminary List of Bridge Preventive Maintenance Activities

A preliminary list was prepared with the most common bridge preventive maintenance activities that were identified from the various DOT websites. The list, which is shown in Table 4.1, was not limited and simply represented a collection of various activities that were reported.

4.4 Bridge Maintenance Activities from Selected DOT Agencies: Survey

A brief survey was sent to selected personnel at each state DOT considered in the research. The survey contained an introductory letter, a series of questions

TABLE 4.1
Preliminary list of bridge preventive maintenance activities.

No.	Maintenance activity
1	Superstructure washing
2	Deck sweeping
3	Deck flushing/washing
4	Substructure washing
5	Vegetation control
6	Bearing lubrication
7	Pin & hanger lubrication
8	Drainage system cleaning / repair
9	Spot painting
10	Joint repair
11	Concrete sealing (deck &/or railing)
12	Minor concrete patching and repair
13	Concrete crack sealing
14	Approach pavement relief joints
15	Clean debris from bridge seats
16	Clean expansion joint seals
17	Clean debris and trees around piers

related to bridge maintenance duties and responsibilities, and the preliminary list of bridge preventive maintenance activities identified in Table 4.1. The aim of this survey was to look for more detailed information on the bridge maintenance activities performed by each DOT. Due to the fact that four out of seven DOT agencies responded to the survey (Illinois, Michigan, Minnesota, and New York) another state was considered. Hence, Missouri DOT was added to the original list, and the contact person was interviewed by telephone.

From the information collected by the survey it was found that Michigan DOT and New York State DOT have had a regular bridge maintenance program for many years, performing several maintenance activities, most of them at a regular frequency or in some cases as needed. Also these two agencies have implemented an on-the-job training program for their own personnel. Minnesota DOT personnel indicated that they have notably increased their resources for bridge inspection and maintenance since the I-35W tragedy in August 2007, performing currently several maintenance activities. Missouri DOT reported that they primarily perform very basic bridge maintenance activities, consisting mostly of bridge deck sweeping, deck washing, and drainage washing each two years, as well as some deck patching each five years. Illinois DOT reported they do not perform routine bridge maintenance activities at all, and only apply rehabilitation activities when they are needed.

Appendix C contains the documents prepared for the survey regarding bridge maintenance procedures, including a summary of the information obtained from each contacted person from the DOTs.

4.5 Bridge Maintenance Activities from INDOT Districts: Interviews

To identify the most common bridge maintenance activities in Indiana DOT, the research team contacted personnel responsible for these activities in each of the six INDOT Districts to collect more detailed information than what is typically obtained from a written response to a survey.

During the interviews with INDOT Districts' personnel, substantial information was obtained regarding bridge maintenance activities. Personnel reported that some activities are done directly by personnel from District Offices, other activities are performed by personnel from sub-Districts, and in some occasions there are activities that are done in conjunction by personnel from District and sub-District Offices. Also, there are some maintenance activities that are done by contractors due to their complexity or extensive nature. One District indicated that contractors are pre-qualified and they usually do most of the work.

From the interviews it was found the INDOT Districts perform bridge deck sweeping and deck washing regularly every year, during May and June. Also, all Districts indicated that they wash the drainage system and clean joints at the same time as deck washing. Other maintenance activities are performed on a reactionary basis to items identified during the bridge inspections, such as repairing the expansion joints, deck patching, or deck crack sealing. Some activities are not performed by Districts due to the lack of adequate equipment, such as cleaning bearings and seats. In summary, INDOT Districts perform very basic routine maintenance activities, with most maintenance activities performed on a reactionary basis.

Details of the meetings held at each District, including a summary of the information provided for the staff Districts in relation to the bridge maintenance activities they perform is presented in Appendix D.

4.6 Economic Evaluation: Life-Cycle Cost Analysis

The effectiveness of each proposed maintenance activity was analyzed, based on an economic evaluation. The cost of keeping a bridge in a safe and good condition is not a one-time expenditure based on the initial cost of construction. The cost of operating a bridge in good condition requires a long-term investment during the entire expected service life (Hema et al., 2004). The bridge's "service life" is considered to be the period of time from when the structure starts operating until its eventual replacement or removal.

To achieve the expected bridge service life, all the structure's elements should receive appropriate maintenance, rehabilitation, and repairs, which can be provided applying different strategies. The strategy selection is based on the transportation agencies' expectations on bridge service life, the costs of possible strategies, and the available resources to be used (Hawk, 2003).

In order to select the best bridge maintenance strategy among all available options, DOT agencies are prone to use a cost-benefit analysis, based on a life-cycle cost analysis (LCCA). LCCA is a decision making tool oriented to show the benefits from different alternatives to achieve the same expected results (Azizinamini et al., 2014). For bridge maintenance, the expected results always aim to keep the structure in a safe condition and appropriate operating level.

When performing this type of analysis, cash flows from past, present or future actions have to be evaluated and compared. A widely accepted method is evaluating the present value (PV), which represents the value of any cash flow expressed as a value corresponding to the present time. A discount rate, r, to relate future and present costs has to be used when applying financial math. A discount rate "r" of 4% was recommended for use by INDOT (2013). Additional details are presented in Appendix E when evaluating the PV for different situations and the procedures for a LCCA.

4.7 Consolidated List of Bridge Preventive Maintenance Activities

A new, refined list of bridge preventive maintenance activities was prepared. The initial list was modified based upon pertinent information collected from several studies analyzed during the research, information provided by specialized personnel from DOT agencies, and staff from INDOT Districts. As a result of this research, ten preventive maintenance activities were prioritized and the appropriate frequency of operation was prescribed. For each maintenance activity a complete report was prepared, focusing on: a brief description of the corresponding bridge element, problems presented during the bridge service life, most common maintenance activities, and most efficient frequency identified through economic analysis. Some activities include more than one sub-activity. Appendix F presents the comprehensive reports for the ten recommended activities.

4.8 Bridge Preventive Maintenance Guidelines

A methodology guide was developed to support INDOT personnel when performing the recommended bridge preventive maintenance activities. For each activity or sub-activity, the following information is provided: a brief description of the activity and sub-activity, required materials and equipment, steps to accomplish the activity, and safety procedures to be considered. The methodology guide is presented in Appendix G.

4.9 Technical Training Program

The implementation of a Technical Training Program is strongly recommended to achieve a high standard in bridge preventive maintenance practices. Based on best practices from other DOT agencies, a curriculum for preventive maintenance activities should be developed and implemented by INDOT. The Technical Training Program could include the procedures from the methodology guide presented in this study and complemented with contents from other recognized training documents. This Program should provide skills and practices to INDOT maintenance crews in performing recommended maintenance activities. Basic theoretical background and on-the-job practices will provide the adequate knowledge and expertise needed.

5. TYPICAL MAINTENANCE ACTIVITY ANALYSIS

As a result of performing the tasks described in section 4, the preliminary list of 17 maintenance activities (Table 4.1) was reduced to 10 activities. The 10 recommended preventive maintenance activities are presented in Table 5.1.

To illustrate the methodology utilized in the study of each of the ten maintenance activities listed in Table 5.1, a brief overview of the evaluation of the second activity on the recommended list, "Deck maintenance," is presented below.

5.1 Concrete Deck Maintenance

By the 1960s, many Snow Belt states introduced the use of deicing products to reduce snow accumulation on the decks during winter seasons (Kepler, Darwin, & Locke, 2000). Some years later, many bridges in Indiana, and in other states, started developing deterioration of the concrete deck surfaces, such as cracking and delamination. The studies concluded that accelerated corrosion of reinforcing steel bars was the main cause, produced by the introduction of chloride ions from deicing products into the deck through the cracks (Frosch, Gutierrez, & Hoffman, 2010; Rahim, Jansen, & Abo-Shadi, 2006; Soriano, 2002).

TABLE 5.1
Recommended bridge preventive maintenance activities.

No.	Bridge preventive maintenance activities	Frequency (years)
1	Deck sweeping/cleaning	
	- deck sweeping/cleaning	1
	- drainage system cleaning/washing	1
2	Concrete deck maintenance	
	- deck sealing	5
	- deck crack sealing	5
	- deck partial patching	5
3	Joints maintenance	
	- joints cleaning/flushing/resealing	1
4	Bearings maintenance	
	- bearings, seats and slope wall cleaning/flushing	2
	- lubricating	4
	- spot painting	10
5	Approach slab maintenance	
	- sweeping and cleaning	1
	- drainage system cleaning/flushing	1
	- seal approach deck/cracks	5
	- joints cleaning/flushing	1
6	Superstructure washing	
	- cleaning/washing	2
7	Spot painting	10
8	Vegetation control	1
9	Remove debris from piers/abutments	1
10	Pin/hanger (or hinge) connection maintenance	
	- clean/flush connection members	2
	- lubricate connection members	4
	- spot paint connection members	10

5.2 Concrete Bridge Deck Maintenance Activities

Concrete bridge deck maintenance activities have the aim to avoid or reduce the penetration of chloride ions and moisture into the concrete, minimizing the level of corrosion in the steel reinforcing bars (FDOT, 2011). There are many actions that can be taken within this approach. Some maintenance activities can be classified as preventive, such as the application of sealants, surface sealers, and coatings, to surfaces without significant damage or chloride contamination, while other activities are classified as reactive such as the application of overlays and patching to significant damaged and contaminated surfaces (Ball & Whitmore, 2003; Hema et al., 2004). Bridge preventive maintenance activities are considered an important investment because the cost of repairing damaged bridge decks can result in much higher costs, often as much as ten times the cost of preventive maintenance actions (Rostam, 1991). As part of a bridge deck maintenance program, three activities should be performed: concrete bridge deck sealing, concrete bridge crack sealing, and concrete bridge deck patching.

1. Concrete Bridge Deck Sealing

Deck sealing is applied to avoid the penetration of chloride ions from deicing products into the deck. There are different types of deck sealers, and they can be classified into two main groups, penetrating sealers and surface coatings (Johnson, Schultz, French, & Reneson, 2009; Sohanghpurwala, 2006). Penetrating sealers are silicon-based products, divided in silicates, siliconates, silanes, and siloxanes. Penetrating sealers have good acceptance because they penetrate deeper into the concrete deck, avoiding wear due to traffic abrasion. These products have a sub-classification based on the way they avoid contamination from chloride ions: hydrophobic sealers (or water-repellents) and pore blockers.

To achieve the best results, penetrating hydrophobic sealers have to be applied as early as possible after deck construction (approx. 3 to 6 months), and before the deck is contaminated by chloride ions. A reapplication program of the sealer is necessary under a periodic basis (every 5 to 7 years) to achieve long term protection (Mamaghani, Moretti, & Dockter, 2007; Sohanghpurwala, 2006; Soriano, 2002; Sprinkel, Sellars, & Weyers, 1993; Tabatabai, Ghorbanpoor, & Pritzl, 2009; Weyers, Prowell, Sprinkel, & Vorster, 1993). Silane products stand out over other deck sealing products due to their depth penetration ability and resistance to chloride ingress (Johnson et al., 2009).

2. Concrete Bridge Deck Crack Sealing

A serious problem arises when a cracked deck is exposed to deicing products, because the crack becomes a direct path for the penetration of chloride ions into the concrete. In that case, it is recommended to seal all cracks with widths wider than 0.007 in., the maximum crack width acceptable for concrete exposed to deicing chemicals (ACI, 2001). The types of products to seal cracks are: epoxies, high molecular weight methacrylates (HMWM), urethanes, and water proofers (Gutierrez, 2010).

HMWM products have good performance on depth penetration because of their low viscosity and they are an alternative for very narrow cracks ($<$ 0.016 in.). HMWM are applied as a flood coat. For wider cracks ($>$ 0.016 in.) an epoxy sealer is recommended, because of its higher bond strength. Epoxy sealer is applied to individual cracks (Frosch et al., 2010; Johnson et al., 2009).

Due to early-age cracking of concrete, it is recommended to seal the cracks right after construction and then a good practice is reapply crack sealers in a cyclic scheme.

3. Concrete Bridge Deck Patching

Concrete deck patching consists of the removal of all contaminated, delaminated, unsound concrete, until reaching the steel bars in the compromised area. Steel bars are exposed and cleaned by sandblasting processes; also, any damaged steel reinforcement must be replaced. Finally the space is filled (patched) with a new high quality concrete or mortar, with low permeability (Liu & Olek, 2001).

There some disadvantages with this type of reparation because generally the corrosion process is not totally stopped but delayed, especially when not all contaminated concrete in the surrounding area is removed. When some contaminated concrete remains in the patch area, adjacent to the new uncontaminated concrete, a chemical reaction is produced. As a consequence, a high differential of potential is created, generating a new corrosion activity in the repaired area, known as “ring anode corrosion” or “halo effect” (Ball & Whitmore, 2003).

Based on a survey carried out by the Research Division of the Indiana Department of Transportation, some “repaired” decks exhibited significant corrosion problems after 7 years of reparation (Liu & Olek, 2001). For this reason, concrete deck patching should be performed as early as possible, to prevent the development of a larger contaminated area of deck. The patching process must be done following the requirements to eliminate all contaminated concrete and reinforcing steel in the damaged area, in order to achieve a durable repair.

5.3 Life-Cycle Cost Analysis

A life-cycle cost analysis (LCCA) of four alternatives was considered to examine the cost-effectiveness of routine maintenance: LCCA for a concrete bridge deck without maintenance until replacement is required (alternative 1), and LCCA for a concrete bridge deck with various different scheduled maintenance activities (alternatives 2 to 4).

Based upon information provided by INDOT, the analysis used the following unit costs: new deck construction = \$22.04/ft^2, deck replacement = \$95.00/ft^2, deck overlay = \$60.00/ft^2, partial deck patching (10% of total deck area) = 27.00*0.10 =\$2.70/ft^2, and penetrating deck sealing application (sealant) = \$1.14/ft^2. Several researchers estimated the service life for penetrating sealers to last from 3 to 11 years. Therefore, an average service life of 5 years was assumed in this analysis.

More details and references for the unit costs and service life of deck sealing used in this analysis are presented in Appendix F2. The LCCA is performed based on a typical bridge with the following parameters: bridge service life of 75 years; discount rate of 4%, and a salvage value of \$0. The present value (PV) for each case is evaluated based on the mathematical expressions presented in Appendix E.

Alternative 1

This alternative is based on the current INDOT policy, which considers no routine deck maintenance activities. After 15 to 20 years of construction, the deck will require complete rehabilitation, receiving an overlay. Then, after an additional 15 to 20 years the deck will need to be replaced. After another 15 to 20 years the replaced deck will require an overlay again. Finally, the entire bridge is expected to be replaced in the next 15 to 20 years. For simplicity, the LCCA is performed considering a fixed time of 18.75 for each stage until the concrete deck reaches the 75 years of expected service life. Figure 5.1 illustrates the corresponding cost and time when the various actions are performed for alternative 1. The surface of each new constructed deck is always sealed as indicated in years 0 and 37.5. The

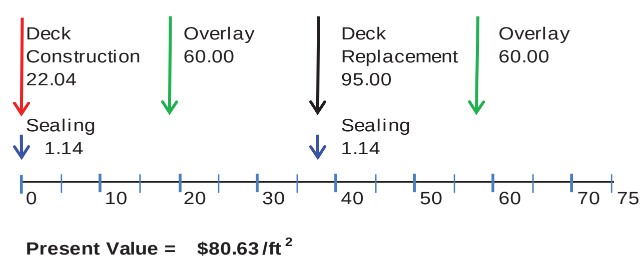

Figure 5.1 Alternative 1—current INDOT policy for a concrete bridge deck.

cost of deck replacement is several times higher than the initial deck cost when the bridge was built, due to higher additional costs related to traffic control, equipment mobilization, deck demolition, debris elimination, etc.

For this alternative a PV = \$80.63/ft^2 is estimated at year zero using the one-time future event several times (Equation 5.1).

$$PV = \frac{FV_n}{(1+r)^n}$$

$$PV = 22.04 + 1.14 + \frac{60.00}{(1.04)^{18.75}} + \frac{95.00}{(1.04)^{37.5}} + \frac{1.14}{(1.04)^{37.5}} + \frac{60.00}{(1.04)^{56.25}} \quad (5.1)$$

$$PV = \$80.63/ft^2$$

Alternative 2

Based on the references presented, a cyclic maintenance program of concrete deck sealing is expected to extend the service life of the deck until 40 years, according to Weyers et al. (1993), and Zemajtis and Weyers (1996). The deck sealing has to be performed early after the construction. For that reason, deck sealing is considered starting in the year 0, preferable from three to six months after construction, and before application of any deicing product over the new deck. Due to its service life, the sealing must be reapplied every 5 years to be effective. Deck rehabilitation consisting of a deck overlay is considered at year 35, which represents a considerable extension in the deck service life by sealing applications. Following the overlay, deck sealing is applied at the same frequency each five years until the bridge reaches the 75 years of expected service life. Figure 5.2 presents the corresponding costs and times for this case, resulting in a PV = \$43.30/ft^2.

Alternative 3

This is similar to alternative 2, with the inclusion of some partial patching each 10 years. The partial patching can be related to some problems on the surface, but not patches that are deeper than the steel and produced by chloride contamination. In this case, 10% of the total deck area is assumed to require patching. The PV for this alternative is \$48.18/ft^2

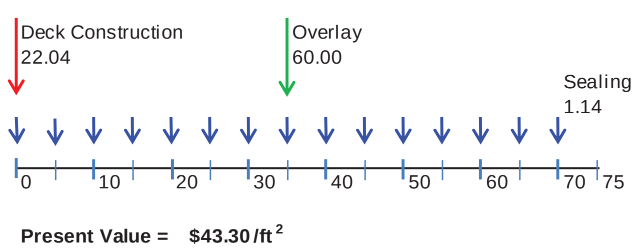

Figure 5.2 Alternative 2—sealing at 5 years/overlay at 35 years.

Alternative 4

In this alternative the deck is sealed early after construction and then the sealing is repeated in a 5-year cycle during the entire deck life. Additionally, an overlay is applied at year 30, and at year 50 the deck is replaced. The PV for this alternative is \$59.96/ft^2.

The present values resulting from the four alternatives are summarized in Table 5.2, and the detailed operations are presented in Appendix F2.1.

The different LCCA analyzed in this section show that a scheduled sealing deck program is the most cost-effective strategy to extend the service life of the deck. Alternative 2: concrete deck sealing every five years and deck overlay at year 35 is the most cost-effective alternative, with the lower present value (\$43.30/ft^2). However, this alternative is by far the most optimistic and assumes that sealing of the overlay will extend the normal service life. It should be noted that the effectiveness of the sealants was for studies on the original decks, and not for overlays.

Alternative 1, which represents the current INDOT policy (with no routine deck sealing maintenance of the concrete decks), is the least effective alternative with the highest present value (\$80.63/ft^2).

A scheduled sealing program can be combined with additional deck rehabilitations activities, such as partial patching, overlay application, or even deck replacement, and it always results in a more cost-effective alternative than the no maintenance option. Based on the results obtained in this study, it appears that Indiana DOT should incorporate a concrete deck sealing program in order to prolong the service life of the concrete decks in the state. For the greatest effectiveness, the deck sealing treatment (penetrating, solvent-base silane) should be applied approximately three to six months after construction of the deck. Reapplication should then be performed cyclically at intervals of five years. More details for the analysis of this maintenance activity are presented in Appendix F2.

TABLE 5.2
Present value for different alternatives of concrete bridge deck maintenance.

Case	Description	PV [\$/ft^2]
1	No maintenance: current INDOT policy	80.63
2	Sealing @ 5 years / Overlay at year 35	43.30
3	Sealing @ 5 years / Patching @ 10 years / Overlay at year 35	48.18
4	Sealing @ 5 years / Overlay at year 30 / Replace deck at year 50	59.96

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The aim of this study was to identify the most common and cost-effective bridge preventive maintenance activities for implementation in a bridge preventive maintenance plan by INDOT. All the preventive maintenance activities presented in this study were based upon results and procedures either implemented by other DOTs or developed through previous research, technical literature, and official documents. All recommended bridge preventive maintenance activities were analyzed individually in this study, but actually they should be applied in conjunction as a comprehensive bridge maintenance program at their corresponding recommended frequency. Bridge preventive maintenance activities are most effective when performed on bridge elements still in good condition.

6.2 Recommendations

INDOT should incorporate a bridge preventive maintenance program based on the preventive maintenance activities identified in this study and presented in Table 5.1. The preventive maintenance activities and the frequency of the maintenance operations are recommended as follows:

1. Bridge deck cleaning/washing

a. Clean and sweep the bridge deck every year.
b. Wash the deck before sealer application only. Otherwise it is not necessary.
c. Wash and flush the drainage system every year.

2. Bridge concrete deck maintenance

a. Seal concrete deck cracks using a high molecular weight methacrylate (HMWM) or epoxy crack sealer based on the characteristics of the cracks.
b. Apply partial patching to small, superficial potholes. Patching should be performed as early as possible, ensuring the elimination of all contaminated concrete and damaged steel reinforcement.
c. Seal the concrete deck with a penetrating, silane-based, hydrophobic, sealer. Seal the deck after all deck cracks and partial patching have been performed.
d. Seal the deck approximately three to six months after deck construction.
e. Repeat the deck patching, deck crack sealing and deck sealing cyclically at intervals of five years.

3. Bridge joints

a. Clean and flush deck joints every year.
b. Reseal minor problems on joint seals every year.
c. Replace joints every ten years or when needed.

4. Bridge bearings

a. Clean and wash elastomeric, steel bearings, seats, and slope walls each two years.
b. Lubricate steel bearings each four years.
c. Spot paint steel bearings each ten years.

5. Bridge approach slab

a. Clean and sweep the approach slab every year.
b. Wash and flush the drainage system every year.
c. Seal approach slab cracks using a high molecular weight methacrylate or epoxy crack sealer based on the characteristics of the cracks.
d. Apply partial patching to small, superficial potholes. Larger and deeper potholes may be patched under this maintenance plan, but they may manifest a more serious problem and probably indicate the need of slab replacement in the near future.
e. Seal the concrete slab with a penetrating, silane-based, hydrophobic, sealer. Seal the slab after all cracks and partial patching have been performed.
f. Seal the approach slab approximately three to six months after construction.
g. Repeat the slab patching, slab crack sealing and slab sealing cyclically at intervals of five years.
h. Clean and flush slab joints every year.
i. Seal minor problems on seals every year.
j. Replace joint seals every ten years.

6. Superstructure cleaning/washing

a. Clean and wash steel superstructure each two years.
b. Verify there is low contaminant when discharging to stream under the bridge.

7. Spot painting

a. Apply spot painting to all superstructure steel elements each ten years.
b. Verify there is not lead paint. If lead paint is present then do not spot paint, but consider abatement.
c. Apply spot painting when no more than the 10% of superstructure's area is problematic.
d. When the surface does not match the indicated requirements for application, spot painting will not be a reliable alternative. In such a case a more complex maintenance procedure will be required, as zone painting or over-coating.

8. Vegetation control

a. Provide vegetation control every year.
b. Eliminate all brush, tree branches, and tree limbs that can obstruct driver visibility, obstruct traffic signals, damage any bridge sub/superstructure elements, obstruct or damage the drainage system, or became a traffic hazard.

9. Removing Debris from Piers/Abutments

a. Perform debris removal for all the bridges every year.
b. Implement routine inspections on the most important bridges after each flooding.

10. Pin and hanger (or hinge) connection

a. Clean and flush the pin and hanger (or hinge) members every two years.
b. Clean and flush the expansion joints located over the pin and hanger (or hinge) connections every year.
c. Lubricate the contact surfaces between members in the pin and hanger (or hinge) connection every four years.

d. Spot paint the pin and hanger (or hinge) members each ten years.

The recommended preventive maintenance activities are considered to be most effective when performed on an element in good condition. Nevertheless, it is recommended that INDOT perform the bridge preventive maintenance activities for all bridges, but is especially important for new bridges or when a bridge element is replaced by a new one.

Performing some activities from the recommended list, and avoiding some others, may not achieve the expected results for the performed activities. Because the damage in one element of the bridge can produce negative effects in other elements, all the recommended activities should be performed by INDOT as a whole, according to the suggested frequencies, as summarized in Table 5.1.

INDOT should implement the methodology guide presented in Appendix G, where basic information is provided to perform each maintenance activity, including a summary of the necessary tools and supplies, basic procedures, and safety measures.

Following the best practices from other DOT agencies, INDOT should incorporate a Technical Training Program to provide skills and practices in performing the recommended maintenance activities. The training should present both basic theoretical background on maintenance activities, supplemented with field practices that will provide adequate knowledge and expertise.

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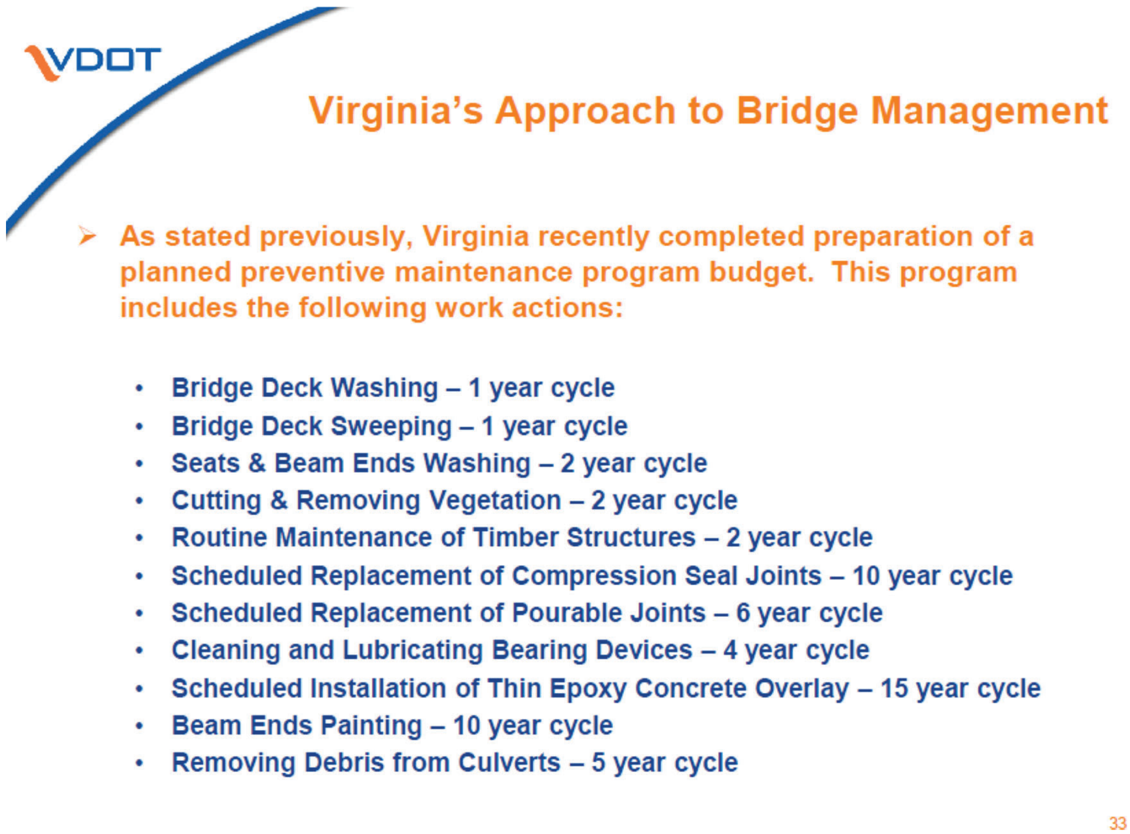
APPENDICES

APPENDIX A: LIST OF RECOMMENDED BRIDGE MAINTENANCE ACTIVITIES GIVEN BY OTHER ORGANIZATIONS

From the literature review performed for this study, several lists of recommended bridge maintenance activities from DOT agencies and governmental institutions were identified. Some organizations recommend a specific frequency for each activity, while others do not.

A.1. VIRGINIA DOT (MILTON, 2011)



A.2. MICHIGAN DOT (MDOT, 2011)

Capital Scheduled Maintenance Manual

Scheduled Maintenance		
Superstructure Washing	When salt contaminated dirt and debris collected on superstructure is causing corrosion or deterioration by trapping moisture, or in response to Inspector's work recommendation.	2 yrs
Vegetation Control	When vegetation traps moisture on structural elements or is growing from joints or cracks, or in response to Inspector's work recommendation for brush cut.	1 yr
Debris Removal	When vegetation, debris, or sediment accumulates on the structure or in the channel or in response to inspector's work recommendation.	1 yr
Drainage System Clean-Out/ Repair	When drainage system is clogged with debris, or drainage elements are broken, deteriorated, or damaged.	2 yrs
Spot Painting	For zinc based paint systems only, in response to Inspector's work recommendation.	5 yrs
Seal Concrete Cracks / Joints	Concrete is in good or fair condition, and cracks extend to the depth of the reinforcement, or in response to Inspector's work recommendation	5 yrs

Typical CSM work activities include:

- ✓ Superstructure Washing
- ✓ Vegetation Control
- ✓ Drainage System Cleaning / Repair
- ✓ Spot Painting
- ✓ Joint Repair
- ✓ Concrete Coating / Sealing
- ✓ Minor Concrete Patching and Repair
- ✓ Concrete Crack Sealing & Healer/Sealer
- ✓ Approach Pavement Relief Joints
- ✓ Slope Paving Repair

A.3. OREGON DOT (HARTMAN, 2012)

Cyclical PM Activity Examples	Commonly Used Frequencies (Years)[4]
Wash/clean bridge decks or entire bridge	1 to 2
Install deck overlay on concrete decks such as: - Thin bonded polymer system overlays - Asphalt overlays with waterproof membrane - Rigid overlays such as silica fume and latex modified	 10 to 15 10 to 15 20 to 25
Seal concrete decks with waterproofing penetrating sealant	3 to 5
Zone coat steel beam/girder ends	10 to 15
Lubricate bearing devices	2 to 4

A.4. IDAHO DOT (USDOT, 2009)

Table 8 ITD Work Programs & Activities

Program	Activities
Operations Maintenance	Clean structure, Clear drains Painting[13], Coating and sealant applications[13] Minor deck patching Railing repairs Debris removal, Stabilizing banks[13], Correcting erosion problems
Preservation	Structure improvements, Rehabilitation[13] Rail modification Deck protection systems, Crack Sealing, Seal Coating, Repairs[13], Overlays[13], Replacements Joint repairs[13] and replacements[13] Painting[13] Incidental repairs[13]
Restoration	Structure rehabilitation, Replacement Deck replacement Incidental repairs
Local bridge	Structure rehabilitation, Replacement Deck replacement Painting

A.5. NEW YORK STATE DOT (NYSDOT, 2008)

PREVENTIVE MAINTENANCE ACTIVITIES

TASK DESCRIPTION	FREQUENCY
REMOVE BRUSH - SPOT LOC.	as needed
MAINTAIN STREAM CHANNELS	as needed
MAINTAIN BANK PROTECTION & WALLS	as needed
CLEAN SUBSTRUCTURE	2 years
SEAL SUBSTRUCTURE	6 years
LUBRICATE BEARINGS	4 years
REPAIR BEARINGS	as needed
CLEAN SUPER & DECK	2 years
REPAIR JOINTS	as needed
REMOVE WEARING SURFACE	12 years
PLACE WEARING SURFACE	12 years
PLACE MEMBRANE	12 years
SEAL DECK	4 years
SEAL CURB, SDWK, FASCIA	5 years
FILL CRACKS & JOINTS	4 years
CLEAN DRAINAGE SYSTEM	2 years
SPOT PAINTING	as needed
PAINT BRIDGES	12 years
MAINTAIN ELEC. & MECH. EQUIP.	as needed

Figure 4. NYSDOT Preventive Maintenance Activities

A.6. FLORIDA DOT (WEYKAMP ET AL., 2009)

- Steel bridge painting
- Concrete deck replacement and/or sealing
- Channel restoration
- Concrete culvert rehabilitation
- Beam bearing rehabilitation
- Bridge vertical clearance upgrade
- Bridge joint rehabilitation

A.7. DELAWARE DOT (WEYKAMP ET AL., 2009)

- Concrete spall repair
- Painting of steel
- Deck overlay w/concrete
- Deck overlay w/epoxy
- Replace AC overlay and add waterproofing
- Joint replacement/repair
- Repair/replace joint trough and piping
- Concrete crack sealing
- Pile jackets (nonstrengthening)
- Re-point masonry
- Clean and restore paint/coating (cables)
- Clean, paint, and grease bearings
- Replace bearings
- Waterproofing membrane (concrete and timber decks/slabs)
- Concrete sealing
- Power wash – steel
- Power wash – concrete decks
- Power wash – bearing and bearing seats
- Lubricate bearings
- Drill weep holes in PS box beams/slabs
- Scour countermeasures
- Seismic retrofit
- Safety enhancements

- Removal of vegetation and debris when affecting the bridge
- Repair of erosion and placement of erosion control measures when the bridge is affected (Condition State 2 or worse) (Element #364)
- Repair of deck, slab, and approach slab spalls (Condition State 2 and top surfaces only)
- Repair of asphaltic concrete (AC) overlay (Condition State 2 only) (Element #11) or repair of hot mix (any condition state) over culvert, slab under fill, filled arch or approach slab, or hot mix wedge placement to account for settlement at the ends of bridges
- Cleaning out of scuppers and/or drains
- Cleaning/clearing of weep holes in prestressed (PS) concrete box beams
- Cleaning/flushing of bearings/bearing seat (use when debris may cause deterioration of bearing or bearing seat)
- Application of protective coating – deck (when element #358 is Condition State 2 or worse), parapets, sidewalk, or approach slab (used to seal minor cracks; specify coating material to be used)
- Sealing of joints in concrete slope paving and/or between the slope paving and the abutment or wing wall

A.8. WASHINGTON DOT (WEYKAMP ET AL., 2009)

4A3 Bridge Cleaning	Includes all work necessary to clean bridge surfaces, sidewalks, and drains to remove sand and debris build-up, provide proper drainage, and an aesthetically clean appearance. Work includes sweeping and washing decks and sidewalks, power-washing or sand-blasting rust, moss, bird guano, or dirt from surfaces, and cleaning plugged drains and grates so water flows through them freely. This activity also includes painting steel structures to prevent rusting and present an aesthetically pleasant appearance.
4B1 Movable and Floating Bridge Operation	Includes maintenance of all mechanical and electrical working parts so the bridges can be opened and closed when needed. The activity includes the work operation of opening and closing the bridge span. Also includes work to operate floating bridges, including pumping water out of pontoons and adjusting anchor cable tension.
4B3 Urban Tunnel Systems	Includes all work necessary to ensure that all the mechanical, electrical, and electronic equipment, such as exhaust fans, fire protection systems, carbon dioxide monitoring equipment, lighting, radio systems, and all other equipment, including the computer control system, is operational at all times.

A.9. OHIO DOT (WEYKAMP ET AL., 2009)

Maintenance Category	Maintenance Actions (examples)
Cyclic maintenance	Bridge cleaning
Preventive maintenance	Cleaning, minor repairs, major repairs, component treatments, component replacements, and sealing concrete surfaces
Scheduled maintenance	Expansion joint replacement, deck replacements and overlays , painting structural steel, paving flowlines, and replacing headwalls on culverts
Reactive maintenance	Deck patching and corrective repair from accidents, weather, etc.
Minor maintenance	Work that has no effect on general appraisal or load rating of structure
Major maintenance	Work that has an effect on general appraisal or load rating of structure

Table 10.3 *Ohio maintenance categories*

A.10. MINNESOTA DOT (MNDOT, 2006)

Bridge Preservation Activities

Figure 4.3: Preventive Maintenance Activities for Bridges

crack seal on concrete decks--Crack sealing of bridge decks prevents water and corrosive materials from reaching the reinforcing steel in the deck.

lubricate expansion bearings--Expansion bearings are lubricated to maintain their ability to move. Bearings that cannot move in response to expansion of bridge components may cause stress on other components of the bridge.

flush winter residue--Salt, sand, debris, and corrosive materials are flushed from bridge decks and other surfaces (such as bridge seats) to prevent the concrete from cracking and scaling and steel components from corroding.

reinstall strip neoprene glands--A strip neoprene gland is a flexible material placed in expansion joints to prevent water and debris from reaching components below the bridge deck. The glands can pull out of the joints or tear.

clean and reseal joints--Joints that are not sealed with neoprene glands are filled with some other material, such as cork or felt, that is covered with a sealer. These joints are hard to maintain, and the seal does not last long. The joints need to be cleaned and resealed to prevent corrosive materials from leaking onto components below the deck.

spot paint--A protective coat of paint prevents corrosion of steel elements. Spot painting may extend the life of the paint coat.

install relief joints in concrete approaches--Relief joints in concrete approaches to bridges relieve the pressure on bridge components caused by expanding concrete. The pressure may cause damage to bridge components.

correct approach panel settlement[1]--Correcting approach panel settlement improves the smoothness of the ride and safety and reduces the impact of traffic on the bridge.

place drain extensions on floor drains--Drain extensions carry water away from the supporting structures below the bridge deck.

Note: These activities were taken from the list of preventive maintenance activities in Mn/ DOT's Bridge Maintenance Manual. The manual includes activities not included above.

[1]Approach panel settlement occurs when the approach panel to the bridge settles so that it is o n a lower level than the bridge.

The following activities are considered cost-effective bridge preservation activities that extend the useful life of a bridge:

1. Sealing or replacement of leaking joints or elimination of deck joints (to minimize the deterioration of superstructure and substructure elements beneath the joints);
2. Deck overlays consisting of proven effective systems, which significantly increase the service life of the deck by sealing the deck surface from aggressive solutions and reducing the impact of aging and weathering;
3. Spot and zone painting of structural steel (if unsound condition $< 20\%$);
4. Painting of structural steel;
5. Cathodic Protection (CP) Systems;
6. Electrochemical Chloride Extraction (ECE) Treatment;
7. Installations of scour countermeasures;
8. Removal of large debris from channels;
9. Retrofit of fracture-critical details;
10. Retrofit of fatigue-prone details;
11. Concrete deck repairs including those used in conjunction with the installation of deck overlays, CP systems, or ECE treatment;
12. Substructure concrete repairs including those used in conjunction with installation of CP systems or ECE treatment;
13. Other concrete repairs that are necessary to improve element condition and are followed by the application of concrete sealants, coatings, and membranes for surface protection of the concrete, or are efficiently done when packaged with other preventative bridge maintenance activities;
14. Heat straightening of damaged load-carrying bridge members; and
15. Repairs to railings that extend element life and meet the railing policy presented in Appendix E.

A.11. CALIFORNIA DOT (WEYKAMP ET AL., 2009)

Imms action code	Bms action code	Description	Typical esecution	Typical unit cost range	Units	Typ. struct. target
H30020	01	Deck-patch spalls	Bridge crew	$1,300–$2,600	Square feet	2 years
H30030	02	Deck-repair potholes	Bridge crew	$1,300–$2,600	Square feet	2 years
H30012	03	Deck-rehab	Contract	$20.90–$74.32	Square feet	4 years
H30013	04	Deck-resurface	Contract	$2.32–$16.16	Square feet	3 years
H30060	05	Deck-place overlay	Contract	$1.67–$15.51	Square feet	3 years
H30050	06	Deck-methacrylate	Contract	$1.30	Square feet	2 years
H30011	07	Deck-replace	Contract	$55.74–$92.90	Square feet	5 years

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Imms action code	Bms action code	Description	Typical esecution	Typical unit cost range	Units	Typ. struct. target
H30090	09	Deck-misc.	Bridge crew or contract	Varies	Square feet	3 years
H20010	10	Super-patch spalls	Bridge crew	$1,300–$2,600	Square feet	2 years
H20012	11	Super-rehab	Bridge crew or contract	Consult maint design	Square feet	4 years
H20011	12	Super-replace	Contract	$92.90–$167.22	Square feet	5 years
H20013	13	Super-epoxy inject	Contract	$152.40	Linear feet	3 years
NA	14	Super- strengthen	Contract	$900,000	Each	6 years
H20090	19	Super-misc.	Bridge crew or contract	Varies	Each item	4 years
H10010	20	Sub-patch spalls	Bridge crew	$1,300–$2,600	Square feet	2 years
H10013	21	Sub-epoxy inject	Contract	$76.20	Linear foot	3 years
H10012	23	Sub-rehab	Bridge crew or contract	Consult maint design	Each	5 years
H10011	24	Sub-replace	Contract	Varies	Linear foot6/ea	5 years
NA	25	Sub-scour mitigate	Bridge crew or contract	Consult hydraulics	Each	2 years
H10040	26	Sub-nav. Protect	Contract	Varies	Each location	3 years
H10090	29	Sub-misc.	Bridge crew or contract	Varies	Each item	4 years
H40010	30	Joint seals-repair/clean	Bridge crew	$47.55–$82.30	Feet	2 years
H40012	31	Joint seals-rehab	Contract	$473–$915	Feet	3 years
H40011	32	Joint seals-replace	Bridge crew or contract	$47.55–$82.30	Feet	3 years
		Joint-asphaltic plug	Contract	$260	Feet	
		Expansion dam	Contract	$153	Feet	
H41050	40	Bearings-clean	Bridge crew	$300	Each	2 years

H41013	41	Bearings-reset	Bridge crew or contract	$2,500-$5,000	Each	2 years
H41012	42	Bearings-rehab	Bridge crew or contract	Consult maint design	Each	2 years
H41011	43	Bearings-replace	Contract	Varies	Each	3 years
H31080	50	Appr. slab-mudjack	District	$360	Each slab/lane	2 years
NA	51	Appr. slab-repair	District	$840	Each slab/lane	2 years
H31060	52	Appr. slab-overlay	District	$1.67-$15.51	Square feet	3 years
H31011	53	Appr. slab-replace	District	$17,000	Each slab/lane	4 years
H50010	60	Railing-repair	Bridge crew	$1,300-$2,600	Feet	2 years
H50012	61	Railing-rehab	Contract	$46-$610	Feet	2 years
H50011	62	Railing-replace	Contract	$78-$101	Feet	5 years
NA	69	Railing-misc.	Bridge crew or contract	Varies	Each item	2 years

H91040	70	Seismic-retrofit	Contract	Varies	Each site	4 years
H91010	71	Seismic-maintenance	Bridge crew or contract	$2,500-$5,000	Each location	2 years
NA	79	Seismic-misc. repair	Bridge crew	Varies	Each item	2 years
H90011	80	Bridge-replace	Contract	$177-$214	Square feet	7 years
NA	81	Bridge-rehab	Contract	$93	Square feet	5 years
NA	82	Bridge-collision damage	Bridge crew or contract	$15,000-$200,000	Each	1 year
NA	83	Bridge-paint ID	Bridge crew	$500	Each location	2 years
NA	84	Bridge-widen	Contract	$186	Square feet	5 years
NA	89	Bridge-misc.	Bridge crew or contract	Varies	Each item	2 years

H70060	90	Paint-rigging/contain	Paint crew	Varies	Each set-up	3 years
H70061	91	Paint-spot prep/spot paint	Paint crew	$5-$6	Square feet	3 years
H70062	92	Paint-spot prep/ full paint	Paint crew or contract	$7-$10	Square feet	4 years
H70063	93	Paint-full prep/full paint	Paint crew or contract	$31-$35	Square feet	5 years
H70069	99	Paint-misc activities	Paint crew	Varies	Each occurrence	2 years
NA	MA	Mech/elect-clean	M&E crews	Varies	Each location	
H80010	MB	Mech/elect-repair/adj.	M&E crews	Varies	Each set-up	
H80012	MC	Mech/elect-rehab/ upgrade	M&E crews	Varies	Each set-up	
H80011	MD	Mech/elect-replace	M&E crews	Varies	Each set-up	
NA	ME	Mech/elect-monitor/ test	M&E crews	Varies	Each set-up	
H80090	MZ	Mech/elect-misc.	M&E crews	Varies	Each item	

A.12. ERIE-NIAGARA DOT (GBNRTC, 2007)

Cyclical Activity	Selection Criteria	Cycle
Bridge Washing (including substructure concrete, deck & crack sealing)	All functional structures regardless of CR, priority to structures over highways.	2 years
Deck Sealing (including crack & substructure concrete, sealing)	Concrete wearing surfaces (present wearing surface codes 02, 03, 06, 12, 22, 32, 42, 45, 52 in RC 15 of BDMS) rated ≥ 5.0 on structures rated 4.5 to 7. • 02 - Portland Cement concrete overlay • 03 - Precast Portland Cement Concrete Plank • 06 - Integral or Monolithic Portland Cement Concrete • 12 - Bonded Concrete • 22 - Concrete with membrane • 32 - High Density Concrete • 42 - Latex Modified Concrete • 45 - Micro-Silica Overlay • 52 - Class "HP" Concrete	6 years
Bridge Painting	Painted structures (coating types 1, 2 or 3 in RC 15 of BDMS) on structures rated 4.5 to 7. • 1 - Painted, Lead-Based • 2 - Painted, Not Lead-Based • 3 - Painted, Unknown	12 years
Deck Overlay	Wearing surfaces (present wearing surface codes 04, 14, 24, 34, 44, 54, 64 in RC 15 of BDMS) on structures rated 4.5 to 7. • 04 - Asphalt Concrete • 14 - Asphalt Concrete without Membrane • 24 - Asphalt Concrete with Membrane • 34 - Asphalt Concrete with Preformed Sheet Membrane • 44 - Asphalt Concrete with Coal Tar Epoxy Membrane • 54 - Asphalt Concrete with Membrane other than Coal Tar • 64 - Asphalt Concrete with Mastic Membrane	12 years

A.13. FEDERAL HIGHWAY ADMINISTRATION (FHWA, 2011)

Examples of PM Activities That May Extend the Life of Bridges

Decks

1. **Seal or replace leaking joints or eliminate deck joints -** minimizes the deterioration of superstructure and substructure elements beneath the joints.
2. **Deck overlays -** significantly increase the life of the deck by sealing of aging and weathering. Overlay systems include waterproofing membrane with asphaltic concrete overlay, low permeability or high performance concrete overlays, and methyl methacrylate and polymer-system overlays.
3. **Cathodic Protection (CP) systems for bridge decks -** proven technology for stopping the corrosion of reinforcing steel.
4. **Electrochemical Chloride Extraction (ECE) treatment -** removes the chloride ions from the vicinity of the reinforcing steel and thus eliminates the source of corrosion.
5. **Concrete deck repairs in conjunction with installation of deck overlays, CP systems, or ECE treatment -** proven technology for stopping the corrosion of reinforcing steel.

Superstructure

6. **CP systems for superstructure elements other than decks -** proven technology for stopping the corrosion of reinforcing steel.
7. **Spot and zone painting/coating -** protects against corrosion. Target areas where the paint deteriorates the fastest to slow the deterioration process and thus extend the life of the paint system and the painted element.
8. **Painting/coating or overcoating of structural steel -** protects against corrosion. Reduces the deterioration of the structural steel.
9. **Retrofit of fracture critical members** methods to add redundancy to the structure such as installing a redundant catch system for pin and link assemblies.
10. **Retrofit of fatigue prone details -** methods to increase the life of fatigue prone details, such as using ultrasonic impact treatment on welds at ends of cover plates or connection plate welds not positively connected to flanges or other conventional fatigue retrofit methods.
11. **CP systems for substructure elements -** proven technology for stopping the corrosion of reinforcing steel.
12. **ECE treatment for substructure elements -** removes the chloride ions from the vicinity of the reinforcing steel and thus eliminates the source of corrosion. Can be very effective when the source of chlorides is eliminated.
13. **Installation of scour countermeasures -** protects the substructure elements from undermining and failure due to scour.
14. **Removing large debris from channels -** prevents channel bed material from scouring.
15. **Substructure concrete repairs in conjunction with installation of CP systems or ECE treatment -** proven technology for stopping the corrosion of reinforcing steel.
16. **Installation of jackets with CP systems around concrete piles -** protects against corrosion and deterioration.

Deck, Superstructure and Substructure

17. **Bridge cleaning and/or washing services -** cleaning of decks, joints, drains, superstructure, and substructure horizontal elements. Slows the deterioration of concrete and steel elements since debris, bird droppings, and contaminants in conjunction with water will accelerate the deterioration of concrete and steel elements. Histoplasmosis from bird droppings is a known health hazard to inspectors and maintenance personnel.
18. **Application of concrete sealants, coatings, and membranes for surface protection of the concrete -** protect the rein forcing steel from corrosion by stopping or minimizing the intrusion of water and chloride through the concrete.

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APPENDIX B: COLLECTED INFORMATION FROM STATE DOT WEBSITES

For each selected DOT their websites were visited, and relevant information to bridge maintenance activities was registered. Appropriate information related to bridge maintenance activities included the following: department, section or office responsible for bridge maintenance operations; personnel in charge of these duties; and, lastly, manuals, specifications, reports, research and procedure guides oriented to bridge maintenance. The electronic sites visited were:

Illinois (IL): http://www.idot.illinois.gov/index

Kentucky (KY): http://transportation.ky.gov/pages/default.aspx

Louisiana (LA): http://www.dotd.la.gov/

Michigan (MI): http://www.michigan.gov/mdot/

Minnesota (MN): http://www.dot.state.mn.us/

New York (NY): http://www.dot.ny.gov/index

Ohio (OH): http://www.dot.state.oh.us/pages/home.aspx

B.1. ILLINOIS DOT

The Bridge Investigations and Repair Plans Unit in the Illinois DOT has the responsibility for all activities related to bridge maintenance and reparations. The document "Guide Bridge Special Provisions (GBSP)" is available at http://www.idot.illinois.gov/doing-business/procurements/engineering-architectural-professional-services/consultants-resources/guide-bridge-special-provisions, and it has been developed with the aim to simplify the work involved with the design and construction of structures as bridges. Some information can be found in this document related to a few bridge maintenance activities such as: bridge painting, cleaning and painting contact surface, and cleaning and painting existing steel structures.

B.2. KENTUCKY DOT

The Bridge Maintenance Branch in the Kentucky DOT is responsible for coordinating bridge inspection activities, preparing bridge repair contracts, and determining bridge weight restrictions.

A document oriented to maintenance activities is available online from KYDOT (KYTC, 2009).

The document provides information and guidance to personnel of the Kentucky Transportation Cabinet. The aim of the document is to establish uniform criteria for interpretation of laws, regulations, policies, and procedures applicable to the operations of the Division of Maintenance. Some of the maintenance activities indicated in the document included: patch and replace concrete floors; spot paint structural steel and paint small steel structures and bearings; clean lower chords and bearing seats of bridges of all dirt, drift, and debris.

B.3. LOUISIANA DOT

The Bridge Maintenance Division in the Louisiana DOT is presented at the website as the branch in charge of bridge maintenance activities. The website also makes reference to a Maintenance Management System, but no information is provided. Documents or any other source of information related to bridge maintenance activities for this Department could not be located.

B.4. MICHIGAN DOT

The Bridge Operations Section in the Michigan DOT is in charge of the operational aspects of the Department's annual bridge program. The Section provides support and liaison to the Department's seven Regions and Lansing Support Areas for all bridge operational issues. The Michigan DOT has developed the Capital Scheduled Maintenance program (CSM; MDOT, 2010) and the Capital Preventive Maintenance program (CPM; MDOT, 2003), two strategies to give guidance for efficient use of resources for bridge maintenance activities. The documents are available online.

The purpose of the Capital Scheduled Maintenance program (CSM) is to sustain an element's current condition longer. The program includes the following activities: superstructure washing, vegetation control, drainage system cleaning/repair, spot painting, joint repair, concrete coating/sealing, minor concrete patching and repair, concrete crack sealing & healer/sealer, approach pavement relief joints, and slope paving repair.

The purpose of the Capital Preventive Maintenance program (CPM) is to address the needs of the elements which can lead to significant deterioration if a condition rating below "fair" is reached. The program includes these activities: pin & hanger replacement, complete painting, zone painting, joint replacement, epoxy overlay, deck patching, scour countermeasures, HMA overlay with waterproofing membrane, HMA cap (no membrane) and minor substructure repair.

B.5. MINNESOTA DOT

The Bridges and Structures section in the Minnesota DOT provides structural and hydraulic leadership for Minnesota DOT Districts, with services for the design, construction and maintenance of bridges and structures. The *Bridge Preservation, Improvement and Replacement Guidelines* report is available online (MnDOT, 2006).

The document is an aid to District and Bridge Office personnel when selecting candidate projects and identifying the specific preservation, improvement, rehabilitation or replacement recommendations for an existing bridge.

The Minnesota DOT defines "routine bridge maintenance" as maintenance activities that the District Bridge Maintenance Staff performs and is considered to be good practice but may be reactive, may have only a short-term impact by itself, or may need to be done frequently or repeatedly to appreciably extend bridge service life. Routine maintenance activities include bridge flushing, sweeping, debris removal, graffiti removal, and small quantities of spot painting or concrete and steel repairs.

B.6. NEW YORK STATE DOT

The Office of Transportation Maintenance in the New York State DOT is responsible to preserve, repair and safely operate the State's highway and bridge infrastructure. Duties for this Office include preventive and corrective maintenance and general repairs to the State's highways, bridges, appurtenances, roadsides and rest areas performed by State Forces and contractors.

A document titled "Fundamentals of Bridge Maintenance and Inspection" is provided online by the New York State DOT (NYSDOT, 2008).

The document emphasizes the concept that preventive maintenance is a cost-effective investment and that deferring it only adds to bridge life-cycle cost. Preventive maintenance activities are indicated as "activities that will preserve bridge components in their present (or intended) condition, forestalling development of a structural deficiency." Preventive maintenance activities are classified into two groups: scheduled and response.

From the NYSDOT document, scheduled (cyclical) activities are programmed according to a routine. The most relevant activities include: cleaning decks, seats, caps, and salt splash zones; cleaning bridge drainage systems; cleaning and lubricating expansion-bearing assemblies; and sealing concrete decks or substructure elements. Response activities are corrective or minor repairs, and they are done when needed based on inspection reports. Typical activities under this classification include: resealing expansion joints; painting structural steel members; removing debris from waterway channels; replacing wearing surfaces; and extending or enlarging deck drains.

A graphical interpretation of preventive maintenance work is presented in the NYSDOT document (2008; see Figure B.1),

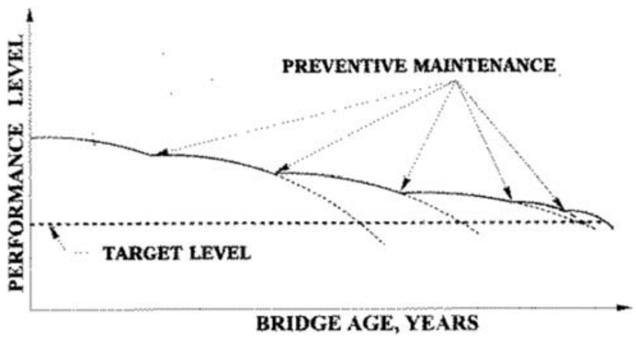

Figure B.1 Life extension by subsequent maintenance actions (NYSDOT, 2008).

showing the effectiveness of maintenance activities in the life extension of bridges. From Figure B.1, it can be concluded that the bridge life cycle is extended when performing preventive maintenance activities. These activities reduce the rate of bridge performance deterioration, while prolonging the life cycle of the structure.

B.7. OHIO DOT

The Structural Engineering Section in the Ohio DOT is responsible for Bridge Operations and Maintenance duties. That section is responsible for maintenance needs assessment to assure compliance with the department's preventive maintenance policy, providing technical support to assess structural damage in accordance with the department's standard operating procedure.

The Ohio DOT (ODOT, n.d.) offers an on-line tool that offers the most common bridge maintenance and repair activities. The on-line manual provides: definition for each activity, recommendations for preventive maintenance and minor reparations, estimated unit costs, estimated expected structure's life after maintenance and repair activities, and examples of some activities. The on-line manual emphasizes that "a structure starts to deteriorate the day its construction is completed, and it is the duty of the person in charge to slow the deterioration as much as practical using methods and materials that are considered best practices."

This Manual presents the best practices that can be applied in Ohio's environment based on results from previous maintenance activities and operations, applying the type of construction and materials most commonly found in this state. At the same time, the manual indicates that, "It is always more cost-effective in the long run to perform preventive maintenance activities than to allow a known condition get progressively worse until the entire member or structure has to be replaced." Some of the topics considered in the manual are related to maintenance of abutments, slab, bearings, culverts, railings, drain pipes, expansion joints, piers, steel beams and concrete beams.

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APPENDIX C: SURVEY MATERIAL AND SURVEY INFORMATION COLLECTED FROM STATE DOTS

A survey was sent to personnel responsible for bridge maintenance activities at each DOT in the selected states. The aim of this survey was to look for more precise and direct information on the bridge maintenance activities operated at each DOT. The contact persons that were approached to respond the survey were identified from the information in the same websites of each DOT, or in some cases from references provided by INDOT staff. The personnel of the DOT from Michigan, New York and Illinois responded the required survey by e-mail, while Minnesota DOT was approached by telephone. Due to the fact that four out of seven DOTs responded the survey, another state was considered. Hence, Missouri DOT was incorporated to the original list, and the contact person responded the survey by telephone.

C.1. SURVEY MATERIAL

Figure C.1 presents the survey material remitted to each selected DOT agency consistently in an introductory letter, a series of questions related to bridge maintenance duties and responsibilities, and the preliminary list of bridge preventive maintenance activities identified in Table 4.1.

C.2. SURVEY INFORMATION COLLECTED FROM STATE DOTS

A summary of the information obtained from each contacted person during the survey is presented in this section.

C.2.1 Illinois DOT (IDOT)

The survey was submitted by Carl Puzey, Bureau Chief, Bureau of Bridges and Structures, phone: (217) 782-2124. Mr. Puzey reported that IDOT does not practice regular preventive maintenance activities, but only deck sealing for decks in good condition. This unique preventive maintenance activity started two years ago and it has been scheduled for execution each four years. This maintenance activity is done by contractors following a special provision from the IDOT. Other bridge maintenance activities are performed just on reactionary basis, after inspector reports. IDOT does not have any specific maintenance training program for its personnel and does not have a written document oriented to bridge maintenance activities.

C.2.2 Michigan DOT (MDOT)

The survey was answered by Mr. Eric Burns, Structure Management Section Engineer, Bridge Field Services, MDOT, burnse@michigan.gov and phone: (517) 322-3326. Mr. Burns reported that Michigan DOT conducts a variety of bridge maintenance activities according to their needs. These activities are performed both by in-house personnel and by contractors. The MDOT has a written maintenance procedure titled “Capital Scheduled Maintenance” (MDOT, 2011), a manual approved in 1997 as part of the development of MDOT’s Strategic Investment Plan for Trunkline Bridges. The aim of the Capital Scheduled Maintenance (CSM) procedure is to establish resources for preserving bridges in their current condition state for a longer period of time. MDOT provides training for the personnel in topics like: pavement relief joints; thin epoxy overlays; and expansion joint replacement.

The basic bridge maintenance activities performed by MDOT, the frequency they are performed and some comments related to the activities are shown in Table C.1.

Another document referenced by MDOT is *Bridge Management—Practices in Idaho, Michigan and Virginia*, a Transport Asset Management Case Studies published by the U.S. Department of Transportation and the Federal Highway Administration (USDOT, 2009). The document provides technical assistance to the bridge community, sharing information on best practices for bridge maintenance.

C.2.3 Minnesota DOT (MnDOT)

A telephone interview was conducted involving Mr. Tom Styrbicki, Bridge Construction & Maintenance Engineer, MnDOT, tom.styrbicki@state.mn.us phone: (651) 366-4507, and Sarah Sondag, Bridge Operations Support. Mr. Styrbicki and Mrs. Sondag indicated that specific frequencies are recommended for a number of bridge maintenance activities. Also, they indicated that MnDOT personnel use element condition to determine when to perform an activity. In some cases, a maintenance activity might be performed earlier or later than the prescribed frequency.

According to the interviewees, MnDOT is divided into 8 Districts and each District has a District Bridge Engineer who is responsible for all aspects of bridge management (inspection, maintenance, planning/programming). Larger Districts are divided into two maintenance subareas. The Minneapolis/St. Paul Metro District is divided into six maintenance subareas. Each subarea has at least one crew dedicated primarily to bridge inspection and maintenance. In total, there are 20 bridge maintenance crews around the state. Each crew generally has 4 to 8 permanent members depending on the District needs. There has been a significant and increased commitment to bridge maintenance and inspection, with 55 new crew members added since August 2007. MnDOT has an annual budget of $ 10M to maintain 5000 bridges.

The Districts essentially perform the same maintenance activities, but the type and extent of the maintenance depends on the needs of the District, and the frequency of certain maintenance activities may differ between Districts. Traffic demands and bridge safety issues are often prioritized above bridge maintenance needs in the Metro District (Twin Cities area).

MnDOT’s bridge maintenance program is divided into Preventive and Reactive Maintenance Activities. Preventive Maintenance includes routine maintenance activities performed according to an assigned frequency and other repairs when certain bridge elements deteriorate to the point where they need to be addressed. Reactive Maintenance includes those activities that are scheduled in response to an identified condition that may compromise public safety or bridge structural function.

MnDOT has a bridge maintenance manual that is currently being updated. Following the update, a copy will be available on the MnDOT website. MnDOT has started to develop a Bridge Maintenance Academy Training Program with three distinct stages. Bridge Maintenance Academy 1 focuses on bridge maintenance workers that have less than 5 years of experience and includes information on bridge components, elements, design concepts, plan reading, concrete, safety, traffic control and an introduction to bridge maintenance. Bridge Maintenance Academy 2 includes hands on training for formwork, pouring concrete, identifying delamination, concrete repair, shotcrete repair and steel repair. Bridge Maintenance Academy 3 (which has not been developed yet) will most likely cover hands-on training for joints, bearings and jacking.

An additional dimension to the bridge maintenance effort in Minnesota is the teamwork approach. This is facilitated through regular meetings and open communication. They reported that there is a one and one-half day meeting held twice each year between the Bridge Maintenance organizers and the supervisor and lead workers for each of the Districts. Moreover, once every two years a Bridge Worker Conference is held with all of the personnel involved in bridge maintenance. This is a two and one-half day meeting and involves training on bridge maintenance, safety training, and a presentation of a top project from each of the Districts. The organizers believe that the project presentations are critically important because it builds pride and teamwork among the District personnel. Table C.2 presents the list of bridge

SURVEY ON BRIDGE MAINTENANCE

Professor Mark D. Bowman and Luis Moran, Purdue University
Conducted in cooperation with the Indiana Department of Transportation
and the Joint Transportation Research Program

Below is a very brief survey that examines highway bridge maintenance conducted by or for your state department of transportation. We are asking you to complete the survey and return it to Professor Bowman. Your responses will be combined with those from other state DOTs to examine maintenance activities performed elsewhere in the US. The ultimate goal of this research study is to propose improved maintenance procedures for Indiana. We know that completing such a survey takes valuable time, and we have tried to keep it as brief as possible. We thank you in advance for the time that you have taken to respond to this survey. Feel free to contact Professor Mark Bowman at (765) 494-2220 if you have any questions whatsoever. You may return the completed survey either electronically or by surface mail. Please return the survey to us using one of the following addresses:

E-mail: bowmanmd@purdue.edu

Surface mail: Professor Mark D. Bowman
Lyles School of Civil Engineering
Purdue University
550 Stadium Mall Drive
West Lafayette, IN 47907-2051

Bridge Preservation Treatments and Best Practices

LIST OF QUESTIONS FOR DOTs

1. Do you conduct regular scheduled maintenance activities to bridges under your responsibility? Identify them from the list on the attached page, and please add any activities that are done on a regular basis that are not listed.

2. Is maintenance done by in-house personnel in a centrally located office or through District Offices? Or is the maintenance done by consultants or contractors hired to perform the work?

3. If maintenance is done through District Offices, do the scheduled maintenance activities vary among the Districts (i.e., do some Districts do more than others, or are all of the Districts performing essentially the same maintenance activities)?

4. How often is maintenance done? On a regular scheduled basis, or is the bridge condition considered when deciding the maintenance frequency?

5. Is there a written maintenance procedure followed when it is done? If yes, can we please obtain a copy of the procedures?

6. Is there training for personnel who do the maintenance? If so, would you please elaborate (i.e., is it a web-based or online training course, a manual, or video)?

Figure C.1 Survey material. (Continued on next page.)

BASIC MAINTENANCE ACTIVITIES

DOT: ______________________________

No.	Maintenance Activity	Yes	Frequency	Additional Comments
01	Superstructure washing			
02	Deck sweeping			
03	Deck flushing/washing			
04	Substructure washing			
05	Vegetation control			
06	Bearing lubrication			
07	Pin & hanger lubrication			
08	Drainage system cleaning/ repair			
09	Spot painting			
10	Joint repair			
11	Concrete sealing (deck &/or railing)			
12	Minor concrete patching & repair			
13	Concrete crack sealing			
14	Approach pavement relief joints			
15	Clean debris from bridge seats			
16	Clean expansion joint seals			
17	Clean debris and trees around piers			

Notes: In the third column check "Yes" if this is part of the regular routine maintenance conducted by your state DOT. If the third column is checked, then indicated how often or frequently the maintenance is conducted: if every year then write either "annual" or "1 yr"; if every two years then write "2 yrs"; etc. The last column is provided for any additional comments that you wish to make.

Optional: Your Name: ______________________
Your Phone: ______________________
Check if you want a copy of survey results: ________

Figure C.1 Continued.

maintenance activities reported to be performed by MnDOT, indicating frequency of maintenance operations and some comments regarding the activity.

C.2.4 Missouri DOT (MoDOT)

A telephone interview was held with Mr. Jerry Goodman, Bridge Maintenance Superintendent of the Missouri DOT. The interviewed indicated that MoDOT has a Central Office and seven district offices. Each district has a Bridge Engineer who is responsible for bridge inspections. At the same time each district has a crew for maintenance activities in general, while some districts have specific crews for bridge maintenance activities. In the last few years MoDOT has experienced a significant reduction in their personnel, both at the office level as well as at the field level. Therefore, the remaining personnel are now responsible for more duties overall. Moreover, it was noted that the personnel reduction transformed the crew organization from a central office system to a district system. The compositions of crews are different in each District, depending on the number of bridges inside the districts.

MoDOT has prepared the Engineering Policy Guide, which was written by MoDOT personnel and is available online (MoDOT, n.d.).

Lastly, other than training regarding basic safety procedures, MoDOT has not developed a personnel training program for bridge maintenance. Table C.3 is the list of bridge maintenance activities performed by MoDOT, indicating frequency of operations for some of those activities, and comments.

C.2.5 New York State DOT (NYSDOT)

The survey was submitted by Peter Weykamp, Bridge Maintenance Program Engineer, NYSDOT, pweykamp@dot.state.ny.us and phone: (518) 457-8485. Mr. Weykamp responded through the survey documents that NYSDOT conducts regular scheduled maintenance activities to bridges under their responsibility. The procedures utilized are presented in the document "Fundamentals of Bridge Maintenance and Inspection" a publication of the NYSDOT (2008). Different scheduled preventive maintenance as well as corrective maintenance activities are presented in this document. Some activities are scheduled after a number of years, while others are as needed. In Table C.4 are presented the activities reported by NYSDOT, indicating the recommended frequency.

The management and direction of work activities is done by in-house forces at the District level, known as Regions in New York

TABLE C.1
Michigan DOT maintenance activities.

No.	Maintenance activity	Frequency	Comments
1	Superstructure washing	Twice per year	Movable bridges
2	Deck sweeping	—	
3	Deck flushing/washing	Twice per year	Movable bridges
4	Substructure washing	—	
5	Vegetation control	As needed	
6	Bearing lubrication	Monthly	Movable bridges
7	Pin & hanger lubrication	—	
8	Drainage system cleaning / repair	As needed	
9	Spot painting	As needed	Emergency repair
10	Joint repair	As needed	
11	Concrete sealing (deck &/or railing)	As needed	Thin epoxy overlays
12	Minor concrete patching and repair	As needed	
13	Concrete crack sealing	As needed	
14	Approach pavement relief joints	As needed	
15	Clean debris from bridge seats	—	
16	Clean expansion joint seals	—	
17	Clean debris and trees around piers	As needed	

State DOT. Maintenance work activities are also contracted to consultants and contractors.

Regarding regularly scheduled maintenance activities, all Regions must give priority consideration to the bridge washing activity, and also whenever possible to the deck sealing. Regions will vary their priorities on execution of other scheduled activities, based on their resources. Also, the activities done by State DOT personnel or contractors may

TABLE C.2
Minnesota DOT maintenance activities.

No.	Maintenance activity	Yes	Frequency	Additional comments
1	Superstructure washing	X	Annually	Truss joints and steel beam ends are generally washed with annual deck flushing.
2	Deck sweeping	X	Annually	May sweep prior to performing another activity, such as crack sealing, but it is not part of annual flushing.
3	Deck flushing/washing	X	Annually	
4	Substructure washing	X	Annually	Bridge seats are generally washed with annual deck flushing.
5	Vegetation control	X	As needed	
6	Bearing lubrication	X	As needed	Recommended for a 4 year cycle, but typically it is just performed as needed.
7	Pin & hanger lubrication	X	As needed	
8	Drainage system cleaning/ repair	X	As needed	Drains are generally cleaned with the annual deck flushing. Repair is as needed.
9	Spot painting	X	5 years	
10	Joint repair	X	8 years (Joint seal); repair as needed	Poured joints are recommended to be resealed on an 8 year cycle, unless it is needed sooner. Strip seal gland replacement is recommended at 25 years, but repair is as needed.
11	Concrete sealing (deck &/or railing)	X	7 years	Flood seal (deck)
12	Minor concrete patching & repair	X	As needed	
13	Concrete crack sealing	X	5 years	Epoxy crack seal
14	Approach pavement relief joints	X	As needed	
15	Clean debris from bridge seats	X	Annually	This is done with the annual deck flushing.
16	Clean expansion joint seals	X	Annually	This is done with the annual deck flushing.
17	Clean debris and trees around piers	X	As needed	Each district has a list of bridges that are scour susceptible and prone to debris build up. Every spring these bridges are checked and a debris removal task is assigned if needed.
	See MnDOT Bridge Maintenance Activities. PDF for additional activities commonly performed by MnDOT.			

TABLE C.3
Missouri DOT maintenance activities.

No.	Maintenance activity	Yes	Frequency	Additional comments
1	Superstructure washing			Not on regular schedule. Depends on reports from inspector from each district.
2	Deck sweeping	X	2 years	Done by general maintenance crew. Use of truck + tank for washing. One for each county.
3	Deck flushing/washing	X	2 years	Done by general maintenance crew. Use of truck + tank for washing. One for each county.
4	Substructure washing			Not on regular schedule. Depends on reports from inspector from each district.
5	Vegetation control			Herbicide treatment done by the general maintenance crew. Done around abutments. Some district doing better than others.
6	Bearing lubrication			No
7	Pin & hanger lubrication			Years ago they use to do but not now. There only few bridges with this element, so after inspection report they repair/ replace as needed.
8	Drainage system cleaning/repair			When cleaning deck. Clean debris of bridges over Missouri and Mississippi rivers.
9	Spot painting			Not done typically. Done when the structure is repaired only.
10	Joint repair			Done by routine maintenance crew along with specialized group. For complicated or significant bridges the joint repairs are done by contracts.
11	Concrete sealing (deck &/or railing)	X	5 years	Yes, depending on condition of deck.
12	Minor concrete patching & repair	X	5 years	Yes, most districts do this with specialized groups.
13	Concrete crack sealing			No, done only when there are huge cracks.
14	Approach pavement relief joints			Some areas do this work, but most districts contract the work out.
15	Clean debris from bridge seats			No.
16	Clean expansion joint seals			Only when deck joints are repaired
17	Clean debris and trees around piers			Based on the indication of the inspectors.

TABLE C.4
New York State DOT preventive maintenance activities (NYSDOT, 2008).

Task description	Frequency
Remove brush-spot loc.	As needed
Maintain stream channels	As needed
Maintain bank protection & walls	As needed
Clean substructure	2 years
Seal substructure	6 years
Lubricate bearings	4 years
Repair bearings	As needed
Clean super & deck	2 years
Repair joints	As needed
Remove wearing surface	12 years
Place wearing surface	12 years
Place membrane	12 years
Seal deck	4 years
Seal curb, sdwk, fascia	5 years
Fill cracks & joints	4 years
Clean drainage system	2 years
Spot painting	As needed
Paint bridges	12 years
Maintain elec. & mech. equip.	As needed

vary between Regions. A special consideration is the fact that demand works (non-scheduled repairs) take precedent over regularly scheduled maintenance actions. Non-scheduled repairs are identified and scheduled at the Region level, by the Regional Structures Management Team and the decision is based on the condition of the bridge.

NYSDOT personnel are commonly trained on-the-job. NYSDOT developed the "Bridge Skills Training program" comprised of different training modules. Some of the training modules can be downloaded from the NYSDOT website and include: Environmental awareness, Concrete mixing, Concrete placement and finishing, and Form building installation and removal.

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APPENDIX D: INFORMATION COLLECTED FROM INDOT DISTRICTS

During the interviews with INDOT District personnel substantial information was obtained regarding bridge maintenance activities. The personnel from District and sub-District Offices have the responsibility to execute the different bridge maintenance activities according to their organization and resources. Some activities are done directly by personnel from District Offices, other activities are executed by personnel from sub-Districts, and in some occasions there are activities that are done in conjunction by personnel from District and sub-District Offices. Also, there are some maintenance activities that are done by contractors due to their complexity or extension. One District indicated that contractors are pre-qualified and they usually do the work.

The information reported by Districts is presented in a general form without any individualization.

D.1. TRAINING ACTIVITIES AT INDOT DISTRICTS

All the Districts indicated that training activities for new crew members are done on site during actual maintenance activities. The training is conducted by skilled staff from the bridge maintenance crews or by the bridge maintenance supervisor. Also they mentioned that the official document for written maintenance procedures to be followed is the INDOT Manual entitled “INDOT Work Performance Standards” (INDOT, 2017). They mentioned that INDOT Central Office also requires from all personnel a number of hours in safety training. During the safety sessions some training in maintenance activities are accomplished, but not specifically in bridge issues.

Training videos were mentioned, but these appear to be somewhat dated and are perhaps not used frequently. Hence, training has not been consistent. Another training tool is the HT (Highway Technician) training. Particular levels –such as HT Level 1, 2, or 3- can be achieved through a combination of classes that can be taken as well as experience in particular roles. There is a financial incentive to advance through the HT levels.

D.2. DETAILS OF MEETING ON EACH DISTRICT

Details of the meetings with personnel in charge of bridge maintenance activities at each INDOT District are presented in the following:

D.2.1 Greenfield

- **Interviewed:** Doug Briar, District Maintenance Supervisor
- **Date:** August 16, 2012
- **Time:** 10:00 am to 12:00m
- **Location interview:** Traffic Division Office, Greenfield
- **Team participants:** Mark Bowman, Luis Moran, Victor Hong, Drew Storey

D.2.2 Seymour

- **Interviewed:** Jim Matern, District Maintenance Supervisor; and Gary Vandegriff, Highway Maintenance Director
- **Date:** September 4, 2012
- **Time:** 11:00 am to 12:30 pm
- **Location interview:** Bloomington Sub district Offices
- **Team participants:** Mark Bowman, Luis Moran, Victor Hong, Drew Storey

D.2.3 Vincennes

- **Interviewed:** Dave Lane, District Maintenance Supervisor; Steve Rininger, Vincennes Maintenance Liaison; Dennis Barton, Vincennes Bridge Forman
- **Date:** September 4, 2012
- **Time:** 12:35 pm to 1:50 pm
- **Location interview:** Bloomington Sub district Offices
- **Team participants:** Mark Bowman, Luis Moran, Victor Hong, Drew Storey

D.2.4 Crawfordsville

- **Interviewed:** Vern Van Allen, Bridge Maintenance Supervisor
- **Date:** September 25, 2012
- **Time:** 9:00 am to 12:15 pm
- **Location interview:** Bowen Laboratory - Purdue University
- **Team participants:** Mark Bowman, Luis Moran, Drew Storey

D.2.5 La Porte

- **Interviewed:** Imre Falatovics, Bridge Maintenance Supervisor
- **Date:** September 25, 2012
- **Time:** 9:00 am to 12:15 pm
- **Location interview:** Bowen Laboratory - Purdue University
- **Team participants:** Mark Bowman, Luis Moran, Drew Storey

D.2.6 Fort Wayne

- **Interviewed:** Todd Johnson, District Deputy Commissioner; and Chuck Neuenschwander, Highway Maintenance Director
- **Date:** October 18, 2012
- **Time:** 9:30 am to 10:10 am
- **Location interview:** Phone interview from Bowen Laboratory - Purdue University
- **Team participant:** Mark Bowman

D.3. COLLECTED INFORMATION FROM INDOT DISTRICTS

In this section is presented the information collected during the interviews of personnel from all of the INDOT Districts, regarding the 17 identified activities. A composite summary of their reports and comments for each activity are presented, without individualizing each answer.

1. Superstructure washing

None of the Districts regularly execute this activity. One of the Districts reported that they used to wash the structure years ago, but not now. A few Districts reported some limited washing of truss elements prior to bridge inspection.

2. Deck sweeping

All of the Districts execute this activity every year with their own personnel, and typically during the months of April and May.

3. Deck flushing/washing

All of the Districts execute this activity every year as a scheduled activity during the months of April and May, with their own personnel. Normally it is executed shortly after deck sweeping. Some of the Districts have better equipment for this activity, consisting on an adapted truck, including pipes, tank and pump.

4. Substructure washing

This activity is typically not executed because the difficulty to reach places below the deck. One District reported that they occasionally do flush some of the abutment seats.

5. Vegetation control

This activity is executed in different ways in the Districts. All Districts perform some type of vegetation control, but not as a regular activity. Some Districts have herbicide crews while others do not. One of the Districts reported that they do this activity almost each four years.

6. Bearing lubrication

None of the Districts regularly execute this activity. Some Districts reported that they clean and lubricate a bearing only if it needs to be reset or re-aligned.

7. Pin & hanger lubrication

None of the Districts regularly execute this activity. Bridges with these structural elements are being replaced in Indiana.

8. Drainage system cleaning/repair

Almost all Districts indicated that they execute this activity every year at the same time as deck flushing. Some of them also consider PVC repairs. Only one District indicated that they do it occasionally in response to inspector reports.

9. Spot painting

This activity was reported in different ways by the Districts. Two Districts indicated that they do this only to remove graffiti, while others indicated that they do not do it at all.

10. Joint repair

All the Districts indicated that they execute this activity as a reactionary action when needed. Some Districts perform the repair with their own crew when the damage is not too severe. Other Districts use contractors to perform the repairs.

11. Concrete sealing (deck &/or railing)

Some Districts reported that they perform concrete deck sealing after deck patching has been done. This work is typically done by an external contractor.

12. Minor concrete patching & repair

All the Districts reported they do minor concrete patching and repair work with their own crew when the damage is not too extensive. In many Districts the work is done by District maintenance crew personnel rather than sub-District personnel. The work is usually reactionary, based on input from the bridge inspector. For repair work that is more significant, or in cases where the work is done in large urban areas, the work is primarily done by contract.

13. Concrete crack sealing

Sealing of concrete deck cracks is typically done by Districts with their own personnel. In a couple of cases it is done by contract. In both cases the work is reactionary and it is initiated only after the reports from bridge inspectors indicate the need for a repair.

14. Approach pavement relief joints

Two Districts reported that they rarely do any work on pavement relief joints, three Districts indicated that the work is done by sub-District personnel, while only one District indicated they do the job by contract when needed.

15. Clean debris from bridge seats

Some Districts clean debris from bridge seats whenever it is possible. However, accessibility is often a serious problem, because it is difficult to reach the deposit of debris under the deck without adequate equipment. Two of the Districts indicated that they do this activity as part of deck cleaning/flushing in the spring. They often use a wand extension and high-pressure flushing to clean the seats.

16. Clean expansion joint seals

Most of the Districts indicated that the expansion joint seals are cleaned by their crews annually during the deck cleaning activity.

17. Clean debris and trees around piers

All the Districts indicated that they routinely clean debris and trees from the bridge piers. Most Districts use their bridge maintenance crews to do the work. Depending on the number and size of debris accumulations, however, the Districts may group several bridges in one contract. All the Districts indicated that this is typically a reactionary activity.

REFERENCE

INDOT. (2017). *INDOT work performance standards*. Indianapolis, IN: Indiana Department of Transportation https://www.in.gov/indot/files/INDOT-Work-Performance-Standards.pdf.

APPENDIX E: LIFE-CYCLE COST ANALYSIS

Life-cycle cost analysis (LCCA) is a decision making tool oriented to show the benefits from different alternatives to achieve the same expected results (Azizinamini et al., 2014). When performing a LCCA, cash flows from past, present or future interventions have to be evaluated and compared. A widely accepted method is evaluating the present value (PV), which represents the value of any cash flow expressed as a value corresponding to the present time. A discount rate, r, to relate future and present costs has to be used when applying financial math. A discount rate "r" of 4% was recommended to be used by INDOT (2013).

Some basic financial expressions to evaluate the PV are provided in the following (Hawk, 2003):

- One-time future event:

$$PV = \frac{FV_n}{(1+r)^n} \quad \text{(E.1)}$$

Where: PV = present value of the expenditure

FV_n = future value of an expenditure made at time n

n = # of periods (generally years) between the present and future times

- Equal annual events:

$$PV = \frac{C[1-(1+r)^{-n}]}{r} \quad \text{(E.2)}$$

Where: C = value of uniform periodic resource flows

A LCCA is performed following the next steps:

- Identify alternatives
- Define time for analysis, normally the bridge service life
- Define costs components for each alternative
- Evaluate PV for each alternative
- Compare PV from different alternatives and take decision

Therefore, the benefit of consider certain maintenance activities can be determined by comparing the PV of all the costs for the proposed maintenance activities with the PV of the alternative that considers not performing the maintenance. Whether the PV of all the costs of the maintenance activities exceeds the PV of the alternative of do not perform any maintenance, then, performing those maintenance activities may not be worth pursuing, and should be rejected. However, when the PV of the maintenance activities is less, and sometimes far less than the PV of the alternative of not performing maintenance, then the maintenance activities will be worth pursuing.

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APPENDIX F: REPORTS OF RECOMMENDED BRIDGE PREVENTIVE MAINTENANCE ACTIVITIES

F1. DECK SWEEPING/CLEANING
F2. CONCRETE DECK MAINTENANCE
F3. JOINTS MAINTENANCE
F4. BEARINGS MAINTENANCE
F5. APPROACH SLAB MAINTENANCE
F6. SUPERSTRUCTURE WASHING
F7. SPOT PAINTING
F8. VEGETATION CONTROL
F9. REMOVING DEBRIS FROM PIERS/ABUTMENTS
F10. PIN AND HANGER CONNECTION

APPENDIX F1: DECK SWEEPING/CLEANING

F1.1. INTRODUCTION

From the many causes of problems a bridge deck can experience, chloride attack from deicing components is the most relevant (Hu, Burgueño, Haider, & Sun, 2012). In regions with moderately cold weather, such as Indiana, snow and ice accumulates on top of bridge decks during the winter season. Sodium chloride and other de-icing agents are often applied to remove the snow and ice (Hema, Guthrie, & Fonseca, 2004). Due to the porosity of concrete, salt compounds are able to travel through the depth of the deck. Upon reaching the reinforcing bars, they produce a chemical reaction, breaking down the passive layer around the bars and initiating their corrosion. Cleaning-washing the bridge deck is expected to be a very simple and cheap alternative to avoid or reduce this problem when performed at an adequate frequency (Soltesz, 2005). Deck cleaning should also include cleaning and washing the deck drainage system. This is also an important action to allow the elimination of contaminants from the deck surface (NYSDOT, 2008).

F1.2. BRIDGE DECK DETERIORATION

Deck contamination by chloride compounds has two negative effects in a concrete deck. Firstly, a corroded steel bar suffers from loss of material, consequently it reduces its structural capacity due to a reduction in cross sectional area. Secondly, the rust of material formed around the corroded bar increases its volume exponentially, ending in splitting failures and spalling portions of concrete. As a result, the serviceability and durability of the structure is compromised (Gopalaratnam, Meyer, De Young, Belarbi, & Wang, 2006).

Deck cleaning-washing regularly is expected to reduce the chloride concentration on the surface deck, and this in turn is expected to reduce the corrosion of reinforcing bars, and consequently to reduce the damage of concrete.

A drainage system in good conditions is required to remove water and runoff from the deck. Hence, keeping properly clean and unblocked gutters, scuppers, inlet boxes, pipes, downspouts, and any other component is a good policy to protect the bridge deck from deterioration. Moreover, another benefit from an adequate drainage system is the effectiveness to remove water accumulated on the deck, and therefore, reducing the risk of hydroplaning (FHWA, 1993).

F1.2.1 Chloride Contamination Model

Concrete has a high level of pH (>13.5; Coggins & French, 1990), which allows the formation of a protective film on the reinforcing steel, preventing corrosion. When a critical chloride concentration is reached at the level of the steel bars, the protective film is reduced or destroyed, initiating the corrosion. The concentration of chloride ions required to start corrosion on steel bars, known as chloride-threshold level, was estimated by Cady and Weyers (1983) to be 1.2 lb/yd3 of concrete. The presence of oxygen and moisture at the depth of the steel is also required to maintain the corrosion process.

A model describing the behavior of reinforced concrete structures under chloride contamination is based on Flick's law of diffusion (Lounis, 2005). The model is composed of a two-stage process: a corrosion initiation stage and a propagation stage. The rate of chloride penetration into concrete can be expressed as a function of the distance from the concrete surface to a certain depth (x), and the elapsed time (t). Fick's law of diffusion is applied and the solution of the differential equation results in the following expression:

$$C(x,t) = C_0 \cdot \left(1 - \mathrm{erf}\left(\frac{x}{2\cdot\sqrt{D_c \cdot t}}\right)\right) \qquad \text{(F1.1)}$$

In Equation F1.1 C_0 is the surface chloride concentration, erf( ) is the error function, D_c is the chloride diffusion coefficient, and C(x,t) is the function of the chloride concentration at any depth 'x' and time 't'. A study conducted by Weyers et al. (1994), considered a database of 2,700 powdered samples from concrete decks, corresponding to 321 bridges located in 16 US states. From that study, typical range of values for surface chloride concentration C_o and chloride diffusion coefficient D_c were determined. For concrete bridge decks in the state of Indiana the proposed values were: C_0=9.0 lb/yd^3 and D_c=0.09 in^2/year.

F1.2.2 End of Functional Service Life of Concrete Deck

The end of functional service life (EFSL) is defined as the condition for a bridge component, when the component condition has reached a severe deterioration, that rehabilitation/replacement is required to continue operating (Weyers at al., 1994). For a bridge concrete deck, the EFSL is the result of two stages, the corrosion initiation and the corrosion propagation. The sum up of the corresponding times for those two stages gives the time to reach the EFSL of the deck.

The chloride contamination in time for a typical concrete bridge deck in the state of Indiana is analyzed in this section. The deck deterioration is analyzed under the attack of chloride components from deicing products. The concrete deck does not receive maintenance during its service life, which means no cleaning/washing activities are provided to the deck surface.

1. Time of corrosion initiation stage The deterioration model presented in Section F1.2.1 is considered and typical values for Indiana bridges were used to evaluate their service life. From Equation F1.1 and equating the chloride concentration to the chloride-threshold level, with depth equal to the concrete cover, x=2.5 in, results in a corrosion initiation time of $t = T_i = 15.4$ years. This is the time to corrosion initiation for the top layer of steel reinforcement for a new concrete deck.

2. Time of corrosion propagation stage This is the period of time when the concrete around the corroded steel bars manifest cracks, spalling, and delamination (CRSI, 2005). Weyers, Sprinkel, and Brown (2006) presented a method that relates the corrosion propagation time, T_p, with a critical depth of corrosion penetration to cause cracking, X_{crit}, and the rate of corrosion, CR, as expressed in Equation F1.2.

$$T_p = \frac{X_{crit}}{CR} \qquad \text{(F1.2)}$$

This time is typically assumed to be from 3 to 6 years for uncoated reinforcing bars (CRSI, 2005). For bridge decks built with two mats of epoxy-coated reinforcing (ECR) bars, as required by INDOT, the corrosion rate will be lower, and consequently, the propagation time will be larger than the case of uncoated bars. Weyers et al. (2006) determined the propagation time for ECR as T_p = 7.6 years. This is the time for accumulation of enough corrosion products to produce cracking and spalling of concrete around the corroded steel bars of a new concrete deck.

3. Time for the end of functional service life Consequently, the time for a new concrete deck to reach its end of functional service life (EFSL) can be considered as the time (T) resulting by the sum up of the initiation time T_i and the propagation time T_p to failure. This time T resulted to be 23 years in this case. This is the time when a new concrete deck with ECR reinforcement, that has been receiving deicing products yearly without cleaning/washing treatments, will require rehabilitation.

F1.3. SCHEDULED DECK CLEANING/ WASHING ACTIVITIES

F1.3.1 Deck Cleaning/Washing

Bridge deck cleaning and washing is done to remove dirt and debris which contain moisture and chloride compounds from the deck surface. If those chloride compounds are not removed, in time they will produce corrosion problems to the reinforced bars. Bridge deck cleaning could be considered an alternative to mitigate chloride induced corrosion. If chloride concentration can be eliminated or substantially reduced from the deck surface by cleaning-washing, then chloride contamination through the deck depth is expected to be eliminated or reduced.

Soltesz (2005) determined the percentage of reduction of chloride contents in deck samples, with ponded chloride solutions, based on different frequencies of washing, as presented in Table F1.1. From the obtained data, Soltesz (2005) concluded that deck washing does not stop the ingress of chloride into the deck and only very frequent deck washing can reduce significantly the ingress of chloride compounds.

TABLE F1.1
Chloride ion content and percentage of reduction (in parentheses), after 25 and 49 months of continued deck washing at indicated frequency (Soltesz, 2005).

Wash Frequency	25 Months	49 Months
No washing	15.9 (0%)	27.5 (0%)
1/month	12.5 (21%)	25.9 (5%)
1/week	11.7 (26%)	17.4 (36%)
1/day	1.69 (89%)	3.90 (86%)

F1.3.2 Drainage System Cleaning/Washing

A bridge drainage system is composed by several elements, all designed and constructed for the purpose of intercepting and evacuate runoff from the deck. There are three types of drainage system: open systems, closed systems, and a combination of both systems. All types of drainage system are affected when one or more components become clogged due to the accumulation or trapping of debris and any other kind of materials. A clogged drainage system could redirect runoff and deicing compounds towards joints and the structural elements under the deck, such as seats, bearings, connections, initiating corrosion on those elements.

Gutters, inlet chambers, grate openings, pipes, and curb openings are designed to avoid problems with trapped debris and waste materials. Because this is impossible to accomplish during all the system service life, periodic maintenance procedures are required to ensure an adequate function of the whole system. Therefore, it is a primary requirement to clean and wash all the elements from the drainage system to keep it in adequate working conditions.

F1.4. FREQUENCY OF MAINTENANCE ACTIVITIES

F1.4.1 Deck Cleaning/Washing

Several DOTs agencies consider deck cleaning/washing as an effective preventive maintenance activity that has to be performed regularly in order to keep the deck surface free of chloride compounds. In Table F1.2 is presented a list of DOTs agencies that recommend deck cleaning/washing as a preventive maintenance activity. Some of those agencies indicate a specific frequency to perform the maintenance.

TABLE F1.2
DOT agencies recommending deck cleaning/washing.

State DOT	Frequency (years)	Reference
Delaware	NI	Weykamp et al., 2009
Erie-Niagara	2	GBNRTC, 2007
Georgia	NI	GDOT, 2012
Iowa	1	IowaDOT, 2014
Michigan	2	MDOT, 2011
Minnesota	NI	MnDOT, 2006
New York	2	NYSDOT, 2008
Ohio, Washington	NI	USDOT, 2009
Oregon	1 - 2	Hartman, 2012
Virginia	1	Milton, 2013

NI: Not indicated.

F1.4.2 Bridge Drainage System Cleaning/Washing

In Table F1.3 is presented a list of DOTs agencies that recommend cleaning/washing to bridge drainage systems. Some of those agencies indicate a specific frequency to perform the maintenance activity.

TABLE F1.3
DOT agencies recommending cleaning/washing drainage system.

State DOT	Frequency (years)	Reference
Delaware	NI	Weykamp et al., 2009
Erie-Niagara	2	GBNRTC, 2007
Georgia	NI	GDOT, 2012
Iowa	1	IowaDOT, 2014
Michigan	2	MDOT, 2011
New York	2	NYSDOT, 2008
Ohio, Idaho, Washington	NI	USDOT, 2009
Virginia	1	Milton, 2011

NI: Not indicated.

F1.5. COST OF DECK CLEANING/WASHING

A study by Yanev and Richards (2011) reported the unit cost for several bridge maintenance activities. Some of those unit costs are presented in Table F1.4. The cost were presented in $\$/m^2$, and then transformed to $\$/ft^2$. The costs are referred to year 1999, and

TABLE F1.4
Unit costs for bridge maintenance activities (Yanev & Richards, 2011).

Activity	US$/m² (1999)	US$/ft² (2013)
Debris removal	0.13	0.02
Sweeping	0.02	0.01
Wash deck	1.01	0.13
Clean drain	0.33	0.04
Total	1.49	0.20

actualized at year 2013 using the Consumer Price Index (CPI) factor of 1.40 (BLS, n.d.). The total cost for deck cleaning/washing resulted to be US$1.49/m^2 at year 1999 or $0.20/ft^2 at year 2013.

A unit cost of $95/ft^2 for bridge deck replacement at year 2013 was provided by Mr. George Snyder from INDOT. This cost includes the construction of the new deck, equipment movement, demolition of the old deck, and incidental costs related to traffic control.

F1.6. LIFE-CYCLE COST ANALYSIS

An economic analysis is performed using the life-cycle cost analysis (LCCA), to study the convenience between two alternatives: (a) no deck cleaning/washing until the EFSL is reached, and (b) perform deck cleaning/washing with a specific frequency to delay the EFSL. The costs of the two options are evaluated using the method of present value. A bridge span life of 75 years and a discount rate of 4% (INDOT, 2013) were considered.

Alternative 1: No Deck Cleaning/Washing

This alternative implies do not perform deck cleaning/washing as a maintenance activity. Therefore, no annual costs are considered until the EFSL is reached, which was found to be after 23 years of service. At that moment it is assumed the deck will need to be replaced. The cost of $95/ft^2 for deck replacement will have to be assumed twice, first at year 23 when the EFSL is reached, and then at year 46 of service life when a second replacement will be required. Applying a one-time future event at years 23 and 46 and using twice Equation E.1, a total PV of $54.18/ft^2 is obtained. Figure F1.1 represents the analysis for this alternative considering the two replacements.

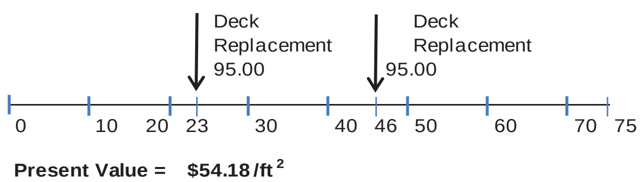

Figure F1.1 Present value for alternative with no maintenance.

Alternative 2: Deck Cleaning/Washing Frequently

This alternative considers performing deck cleaning/washing frequently. The larger frequency analyzed in the study by Soltesz (2005) was monthly according to Table F1.1. Assuming this value can be applicable for a yearly frequency, the reduction in chloride concentration into the deck could be assumed to be of 5%. From Equation F1.1, considering the 5% of reduction in surface chloride concentration, the initiation time is extended to $T_i = 16.5$ years. Considering that the time between corrosion initiation and spalling remains constant, as indicated in section F.1.2.2, then $T_p = 7.6$ years. Therefore, the total time to reach the EFSL of the deck will be 16.5 + 7.6 = 24.1 years. Consequently, the bridge deck will need to be replaced the first time at year 24 and then again after other 24 years of service life. Considering deck replacement at years 24 and 48, the PV results to be $51.52/ft^2.

Additionally, the cost of yearly deck cleaning/washing can be assumed as $0.20/ft^2 to constant dollars of 2013. Therefore, using Equation E.2 the PV for this maintenance activity during 75 years will be $4.74/ft^2. Hence, the total PV will result to be $56.26/ft^2, when deck cleaning/washing is applied annually to the bridge deck, and replacement at years 24 and 48 are considered. Figure F1.2 shows graphically this alternative.

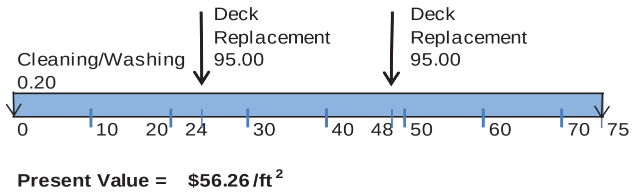

Figure F1.2 Present value for alternative with deck cleaning/washing each year.

From the PV obtained for the two alternatives considered can be concluded that cleaning/washing the bridge deck each year is not a cost-effective option, since the PV for alternative 2 (considering cleaning/washing) is higher than PV for alternative 1 (considering no maintenance).

F1.7. CONCLUSIONS AND RECOMMENDATIONS

F1.7.1 Conclusions

Bridge deck washing is not a cost-efficient alternative to reduce the chloride concentration into the deck. The chloride concentration is reduced in considerable amount only when washing is performed every day, which is an impractical alternative. When deck washing is performed at a frequency longer than each month, it is negligible the reduction of chloride concentration inside the deck.

Deck cleaning should be performed every year, preferable after the end of the winter season. Clean/washing the drainage system should be performed every year, because as indicated previously, when the system does not work properly can produce the damage to other important structural elements, such as joints, bearings, and connections.

F1.7.2 Recommendations

Based on the results obtained in this study it appears that INDOT should perform deck sweeping every year, preferably after the end of the winter season. It is recommended that INDOT perform cleaning/washing the bridge drainage system every year. These activities should be performed on a new or replaced deck, preferable after the end of the winter season, and then repeated at the indicated frequency. Avoid eliminating contaminant products to stream below the bridge as a result of these activities, in such a case, appropriate measures should be taken.

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APPENDIX F2: CONCRETE DECK MAINTENANCE

F2.1. INTRODUCTION

The bridge deck is the part of bridge structure that provides the riding surface for vehicles passing through. Also the bridge deck is responsible for giving support to live loads and transferring them to the beams, girders, piers and/or abutments. Also, this bridge element provides a certain sort of cover to the underneath elements from external factors such as rain drops, dust and debris, deicing products, etc.

By the 1960s, many Snow Belt states introduced the use of deicing products to reduce snow accumulation on the decks during winter seasons (Kepler, Darwin, & Locke, 2000). Some years later, many bridges in Indiana and other states started developing deterioration of the concrete deck surfaces, such as cracking and delamination. The studies concluded that accelerated corrosion of reinforcing steel bars was the main cause, produced by the introduction of chloride ions from deicing products into the deck through the cracks (Frosch, Gutierrez, & Hoffman, 2010).

Consequently, some actions have to be taken to reduce corrosion of reinforcing steel bars due to chloride ions from deicing products. It is considered that concrete bridge deck maintenance activities can be effective methods to deal with this problem.

F2.2. CONCRETE BRIDGE DECK DETERIORATION

When the stresses on concrete bridge deck exceed the tensile resistance, the concrete will present cracks in the surface deck or inside the deck. These stresses can be caused by different factors, such as shrinkage, thermal changes, applied loads, and corrosion. Chemical reactions of chloride ions with reinforcing steel bars are the cause of the corrosion process. This chemical reaction produces the formation of rust around the steel bars. The volume of the produced material (rust, iron hydroxide) is much larger than the volume of steel transformed during the corrosion process. As a consequence, the additional volume created during corrosion

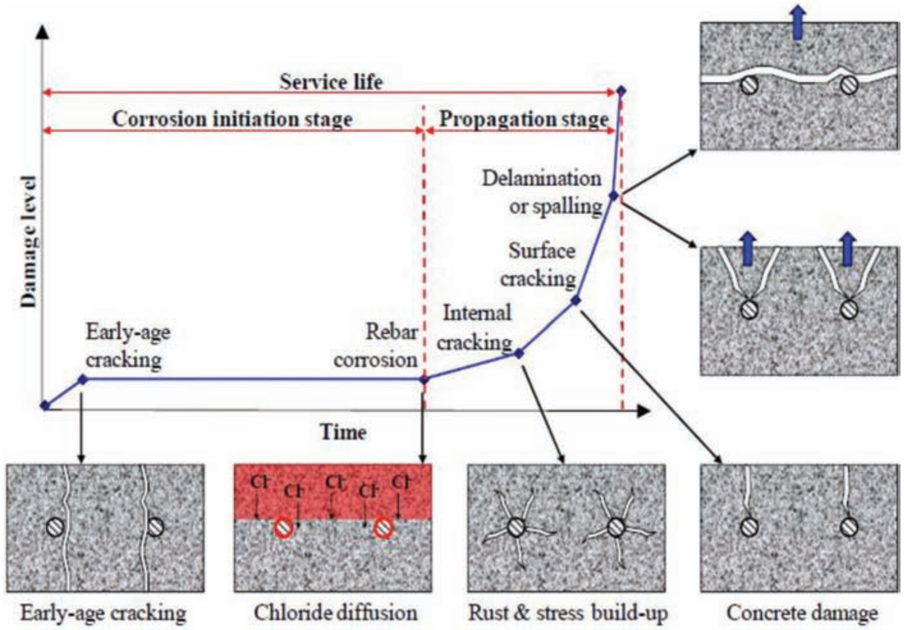

Figure F2.1 Schematic description of bridge deck deterioration (Cusson, Lounis, & Daigle, 2011).

exerts radial stresses in the concrete surrounding the steel bars (Grace & Jensen, 2012). The corrosion is a continuous process, and therefore the increment of volume produces the increment of stresses on time. Cracks arise in the concrete when the stresses exceed the concrete tensile limit. The formation of these new cracks allows for the introduction of more moisture and chloride ions inside the concrete, generating an accelerated corrosion process. Figure F2.1 presents a schematic description of the process of bridge deck deterioration. This process reduces the service life of the deck and sometimes leads to an eventual structural deficiency of the bridge structure (Rahim, Jansen, & Abo-Shadi, 2006).

Deterioration in a concrete bridge deck can be evidenced in different ways, as follows (Al-Ostaz, 2004):

- *Cracking:* The break of concrete mass, producing the separation of the concrete in blocks. These separations can be very thin in some cases or thicker in others.
- *Scaling:* The gradual loss of surface material (mortar and aggregate) in a specific area of the deck.
- *Delamination:* The separation of layers of concrete from the top surface to the upper reinforcing map.
- *Spalling:* The result of delaminated areas completely separated from the deck surface. The formed depression in the deck surface is called "spall."

F2.3. CONCRETE BRIDGE DECK MAINTENANCE ACTIVITIES

Concrete bridge deck maintenance activities have the aim to avoid or reduce the penetration of chloride ions and moisture into the concrete, minimizing the level of corrosion in the steel reinforcing bars (FDOT, 2011). There are many activities that can be applied within this approach. Some maintenance activities can be classified as preventive while others will be considered as reactive. Preventive maintenance activities can be considered the application of sealants, surface sealers, and coatings, to surfaces without significant damage or chloride contamination. Reactive maintenance activities are considered the application of overlays and patching to surfaces with significant damage and chloride contamination (Ball & Whitmore, 2003; Hema, Guthrie, & Fonseca, 2004). Bridge maintenance activities are considered an important investment because the cost of repairing damaged bridge decks can result in much higher costs, often as much as ten times the costs of preventive maintenance actions (Rostam, 1991).

F2.3.1 Concrete Bridge Deck Sealing

Deck sealing is applied to avoid the penetration of chloride ions from deicing products into the deck. There are different types of

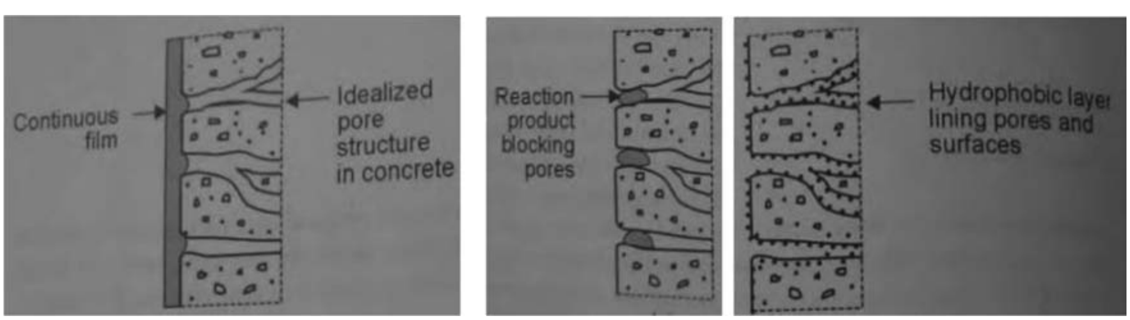

Figure F2.2 Graphic description of different types of concrete sealers. Left: surface coating; middle: pore blocker; right: hydrophobic sealer (Liang, Zhang, & Xi, 2010).

deck sealers as shown in Figure F2.2, and they can be classified into two main groups, penetrating sealers and surface coatings (Johnson, Schultz, French, & Reneson, 2009; Sohanghpurwala, 2006).

1. Penetrating sealers: Silicon-based products, divided in silicates, siliconates, silanes, and siloxanes. Penetrating sealers have good acceptance because they penetrate deeper into the concrete deck, avoiding wear due to traffic abrasion. These products have a subclassification based on the way they avoid contamination from chloride ions: hydrophobic sealers (or water-repellents) and pore blockers.

- Hydrophobic sealers: React with the interior walls of the pore structure, lowering the surface tension, which allow to repel the ingress of water inside the pores. A hydrophobic sealer also allows the transmission of water vapor produced during temperature changes. They are formed by siliconates, silanes, and siloxanes.
- Pore blockers: Penetrate and fill the pore structure, blocking the ingress of moisture and chlorides. In this case, blocking the pores eliminates vapor transmission from the concrete to the exterior, generating interior stresses that can result in durability problems to the concrete deck.

To achieve the best results, penetrating sealers have to be applied as early as possible after deck construction (approx. three to six months), and before the deck is contaminated by chloride ions. A reapplication program of the sealer is necessary under a periodic basis (every five to seven years) to achieve long term protection (Mamaghani, Moretti, & Dockter, 2007; Sohanghpurwala, 2006; Soriano, 2002; Sprinkel, Sellars, & Weyers, 1993; Tabatabai, Ghorbanpoor, & Pritzl, 2009; Weyers, Prowell, Sprinkel, & Vorster, 1993). Silane products stand out over other deck sealing products due to their depth penetration ability and resistance to chloride ingress (Johnson et al., 2009).

2. Surface coatings: Also known as film formers, they work forming an impermeable barrier over the deck surface, preventing the ingress of moisture and chloride ions into the concrete. These coatings suffer from traffic wear, and avoid vapor transmission as the pore blockers, therefore they are not considered as a good prevention system. These products consist of linseed oil, epoxies, methacrylates, and urethanes (Johnson et al., 2009; Sohanghpurwala, 2006).

F2.3.2 Concrete Bridge Deck Crack Sealing

Cracks can be produced due to different effects, shrinkage, thermal changes, applied loads, and corrosion. Concrete cracking is something difficult to avoid, but the number and thickness of cracks can be controlled with a proper design. The most common methods used to repair cracks are noted as follows: epoxy injection, routing and sealing, gravity filling, and overlay. The types of products to repair cracks are: epoxies, high molecular weight methacrylates (HMWM), urethanes, and water proofers (Gutierrez, 2010).

A serious problem arises when a cracked deck is exposed to deicing products, because the crack becomes a direct path for the penetration of chloride ions into the concrete. In that case, it is recommended to seal all cracks with widths wider than 0.007 in., the maximum crack width acceptable for concrete exposed to deicing chemicals (ACI, 2001). For some cracks the solution could be epoxy injection, or topically filling each crack. In case of extended cracks along a large surface area, the application of penetrating sealers in the affected area is the most effective treatment (Krauss, Lawler, & Steiner, 2009).

HMWM products have good performance on depth penetration because of their low viscosity, which is why they are recommended for very narrow cracks ($<$ 0.016 in.). HMWM products are typically applied as a flood coat. For wider cracks ($>$ 0.016 in.) an epoxy sealer is recommended because of their high bond strength. Epoxy sealers are applied to individual cracks (Frosch et al., 2010; Johnson et al., 2009).

Due to early age cracking of concrete, it is recommended to seal the cracks right after construction and then a good practice is reapply crack sealers in a cyclic scheme. The State of Wisconsin reseals cracks every 4 years, while Montana reseals every 15 years (Johnson et al., 2009).

F2.3.3 Concrete Bridge Deck Patching

Concrete deck patching is performed on existing bridges. It consists in the removal of all contaminated, delaminated, unsound concrete, until the patch depth reaches the level of the steel bars in the compromised area. Steel bars are exposed and cleaned by sandblasting processes, including the replacement of any damaged steel portion. Finally the whole area is filled (patched) with a new high quality concrete or mortar with low permeability (Liu & Olek, 2001).

There are some disadvantages with this type of reparation because occasionally the corrosion process is not totally stopped but delayed, especially when not all surrounded contaminated concrete is removed. When some contaminated concrete remains in the patched area, adjacent to the new uncontaminated concrete, a chemical reaction is produced. As a consequence, a high differential of potential is created, generating a new corrosion activity in the repaired area, known as "ring anode corrosion" or "halo effect" (Ball & Whitmore, 2003).

Based on a survey carried out by the Research Division of the Indiana Department of Transportation, some "repaired" decks presented important corrosion problems after 7 years of reparation (Liu & Olek, 2001). For this reason, concrete deck patching should be performed as early as possible, to prevent a larger contaminated area of the deck. The patching process must eliminate all contaminated concrete and corroded reinforcing steel in the damaged area in order to achieve a durable repair.

F2.4. SERVICE LIFE OF SEALANTS

Several researchers have studied the benefits of concrete deck sealing as a protection method to avoid chloride contamination from deicing products defusing into the concrete. Reducing the ingress of chloride ions will extend the deck service life. The studies found that the service life of penetrating sealers is affected for different factors, such as exposure to ultraviolet light, moisture, and surface wear (Weyers et al., 1993). Following is a compilation of some of those studies:

- Weyers et al. (1993), in a study for the Strategic Highway Research Program, concluded that the service life of penetrating sealers (silanes and siloxanes) ranges from 5 to 7 years. The sealers should be reapplied every 6 years and will provide deck protection for 40 years.
- Zemajtis and Weyers (1996) indicated that the maximum service life of a hydrophobic sealant as silane is about 7 years, and they can extend the service life of a bridge deck to almost 40 years.
- NYSDOT (2008) indicated that New York State DOT should seal concrete decks every four years, giving priority to seal new decks and those with thin cracks. The manual proposed the use of silanes, siloxanes, silicone, and polymers.
- Meggers (1998), in a study for Kansas DOT, estimated the service life of HMWM sealers from 8 to 11 years.
- Soriano (2002) performed a study for South Dakota DOT where it was concluded that penetrating sealers (i.e., silanes, siloxanes, and siliconates) should be applied within 3 to 6 months after deck construction and repeated every 5 years.
- Sohanghpurwala (2006) in NCHRP Report 558 indicated that penetrating sealers, such as silanes and siloxanes, create a hydrophobic surface reducing the ingress of chloride ions into the deck. The service life of these products ranges from 5 to 7 years, and have to be reapplied every 6 years.
- Mamaghani et al. (2007) in the study sponsored by North Dakota DOT, found penetrating sealers (silanes and siloxanes) as a means to protect concrete bridge decks from chloride contamination. The sealers should be applied approximately 3 to 6 months after deck construction, with reapplication every 5 years.

- Wenzlick (2007) from Missouri DOT identified silane application as an adequate protective concrete deck sealant. The expected service life of silane products was determined between 3 to 10 years.
- Filice and Wong (2008), in the Practice Guidelines for Alberta DOT, indicated that penetrating sealers are applied to reduce the rate of chloride contamination on concrete decks. The document states Alberta DOT seals concrete decks with penetrating silane sealers on a 4-year cycle, to extend their service life.
- Johnson et al. (2009) in the study for Minnesota DOT, concluded that solvent-based silane deck sealers with high contents of solids perform as the best products for deck sealing.
- Krauss et al. (2009), in the study requested by NCHRP (Project 20-07) and based on a survey sent to all US and Canadian DOTs, found that the service life for sealers (epoxy, methacrylate, and silane) ranges from 5 to 10 years.
- Morse (2009) from Illinois DOT recommended the use of silane/siloxane products in a 4 to 5 years scheduled cycle for all new bridge deck construction, new overlays and existing bridge decks.

F2.5. LIFE-CYCLE COST ANALYSIS

A life-cycle cost analysis (LCCA) of four alternatives were considered to examine the cost-effectiveness of routine maintenance: LCCA for a concrete bridge deck without maintenance until replacement is required (alternative 1), and LCCA for a concrete bridge deck with various different scheduled maintenance activities (alternatives 2 to 4). The cost of each alternative is represented by its corresponding present value (PV), a representation of initial and future costs by a single value at the present time.

The analysis will consider the following costs: deck construction, deck replacement, deck overlay, partial deck patching, and penetrating deck sealing application (sealant). All the costs were actualized to the year 2013. A brief explanation is described in the following:

- New deck construction cost considers expenditures in design, construction and supervision during a new bridge construction. A cost of $\$22.04/ft^2$ is considered as average from different sources. The average value from several references is presented in Table F2.1.

TABLE F2.1
Average unit cost for new deck construction.

Reference	Year reference	Cost [$\$/ft^2$]	CPI [factor]	Cost 2013 [$\$/ft^2$]
Pyc (1998)	1997	11.54	1.45	16.73
Kepler et al. (2000)	1999	13.33	1.40	18.66
Sinha et al. (2005)	2002	24.44	1.29	31.53
Hearn and Xi (2007)	2003	12.30	1.27	15.62
Fu et al. (2007)	2007	24.86	1.12	27.84
O'Reilly et al. (2011)	2011	21.01	1.04	21.85
		Average cost =		**22.04**

- Deck replacement cost considers the same cost of a new deck construction, but at some moment during the bridge operation, including workplace conditioning, equipment movement, hydrodemolition of old deck, debris elimination, and incidental costs related to traffic control. A cost of $\$95/ft^2$ is considered based on data provided by Indiana DOT staff (Mr. George Snyder).
- Deck overlay cost represents the cost related to a polymer modified overlay, including scarification, and incidental costs related to traffic delays. A value of $\$60/ft^2$ is considered based on data provided by INDOT staff (Mr. George Snyder).
- In some cases, partial deck patching is considered as a complement during deck maintenance. An average cost of $\$27.03/ft^2$ is obtained from different sources as presented in Table F2.2. The analysis is performed assuming the area to be patched as the 10% of the total deck area, which results in a unit cost of 0.10x\$27.03 = $\$2.70/ft^2$.
- Penetrating sealer cost includes the costs of surface preparation and all labor, equipment, and materials. A cost of $\$1.14/ft^2$ is considered as average from different sources as presented in Table F2.3.

TABLE F2.2
Average unit cost for partial deck patching.

Reference	Year reference	Cost [$\$/ft^2$]	CPI [factor]	Cost 2013 [$\$/ft^2$]
Huang et al. (2004)	2004	14.90	1.23	18.33
Weyers et al. (1993)	1991	15.74	1.71	26.92
Kepler et al. (2000)	1999	17.59	1.40	24.63
Tabatabai et al. (2009)	1998	36.57	1.43	52.30
Morcous (2013)	2013	13.00	1.00	13.00
		Average cost =		**27.03**

TABLE F2.3
Average unit cost for penetrating sealer (sealant).

Reference	Year reference	Cost [$\$/ft^2$]	CPI [factor]	Cost 2013 [$\$/ft^2$]
Weyers et al. (1993)	1991	1.00	1.71	1.71
Kepler et al. (2000)	1999	0.39	1.40	0.55
Soriano (2002)	2002	0.28	1.29	0.36
Hearn et al. (2007)	2003	0.52	1.27	0.66
Wenzlic (2007)	2007	0.18	1.12	0.20
Morse (2009)	2008	0.25	1.08	0.27
Krauss et al. (2009)	2009	4.00	1.09	4.36
Morcous (2013)	2013	1.00	1.00	1.00
		Average cost =		**1.14**

The LCCA is performed considering a typical bridge with the following parameters:

- Bridge service life 75 years
- Discount rate 4%
- Salvage value \$0

Alternative 1

This alternative is based on the current INDOT policy, which considers no routine deck maintenance activities. After 15 to 20 years of construction, the deck will require complete rehabilitation, receiving an overlay. Then, after an additional 15 to 20 years the deck will need to be replaced. After another 15 to 20 years the replaced deck will require an overlay again. Finally, the entire bridge is expected to be replaced in the next 15 to 20 years. For simplicity, the LCCA is performed considering a fixed time of 18.75 for each stage until the concrete deck reaches the 75 years of expected service life. Figure F2.3 illustrates the corresponding cost and time when the various actions are performed for alternative 1. The surface of each new constructed deck is always sealed as indicated in years 0 and 37.5. The cost of deck replacement is several times higher than the initial deck cost when the bridge was built, due to higher additional costs related to traffic control, equipment mobilization, deck demolition, debris elimination, etc.

For this alternative a PV = \$80.63/ft^2 is estimated at year zero using the one-time future event several times (Equation F2.1).

$$PV = \frac{FV_n}{(1+r)^n}$$

$$PV = 22.04 + 1.14 + \frac{60.00}{(1.04)^{18.75}} + \frac{95.00}{(1.04)^{37.5}} + \frac{1.14}{(1.04)^{37.5}} + \frac{60.00}{(1.04)^{56.25}} \quad \text{(F2.1)}$$

$$PV = \$80.63/ft^2$$

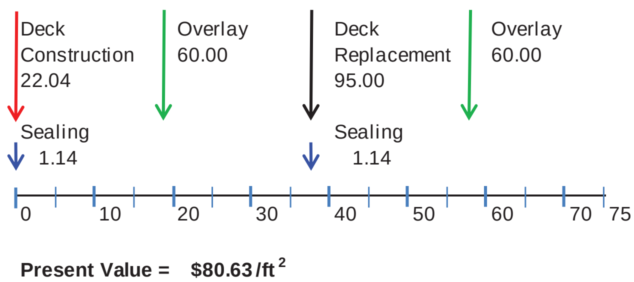

Figure F2.3 Alternative 1—current INDOT policy for a concrete bridge deck.

Alternative 2

Based on the references presented, a cyclic maintenance program of concrete deck sealing is expected to extend the service life of the deck until 40 years, according to Weyers et al. (1993), and Zemajtis and Weyers (1996). The deck sealing has to be performed early after the construction. For that reason, deck sealing is considered starting in the year 0, preferable from three to six months after construction, and before application of any deicing product over the new deck. Due to its service life, the sealing must be reapplied every 5 years to be effective. Deck rehabilitation consisting in a deck overlay is considered at year 35, which represents a considerable extension in the deck service life by sealing applications. After applied the overlay, deck sealing is applied at the same frequency each five years until the bridge reaches the 75 years of expected service life. Figure F2.4 presents the corresponding costs and times for this case, resulting in a PV = \$43.30/ft^2.

Alternative 3

This is similar to alternative 2, with the inclusion of some partial patching each 10 years. The partial patching can be related to some mechanical problems on the surface, but not patches that

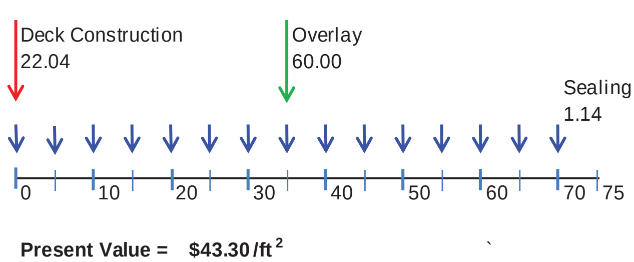

Figure F2.4 Alternative 2—sealing at 5 years/overlay at 35 years.

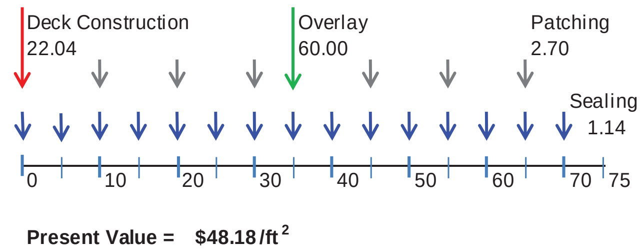

Figure F2.5 Alternative 3—sealing at 5 years/patching at 10 years/overlay at 35 years.

are deeper and produced by chloride contamination. In this case, 10% of the total deck area is assumed to require patching. Figure F2.5 presents the corresponding costs and times for this case, resulting in a PV = \$48.18/ft^2.

Alternative 4

In this alternative the deck is sealed early after construction and then the sealing is repeated in a 5-year cycle during the entire bridge life. Additionally, an overlay is applied at year 30, and at year 50 the deck is replaced. Figure F2.6 presents the corresponding costs and times for this case, resulting in a PV = \$59.96/ft^2.

The present values resulting from the four cases are summarized in Table F2.4, and the detailed operations are presented in Appendix F2.1.

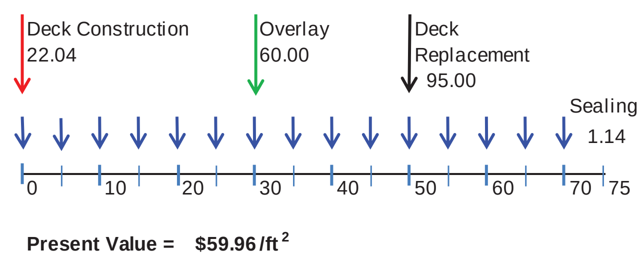

Figure F2.6 Alternative 4—sealing at 5 years/overlay at 30 years/replacement at 50 years.

TABLE F2.4
Present value for different alternatives of concrete bridge deck maintenance.

CASE	DESCRIPTION	PV [\$/ft^2]
1	No Maintenance: Current INDOT Policy	80.63
2	Sealing @ 5 years / Overlay at year 35	43.30
3	Sealing @ 5 years / Patching @ 10 years / Overlay at year 35	48.18
4	Sealing @ 5 years / Overlay at year 30 / Replace deck at year 50	59.96

F2.6. CONCLUSIONS AND RECOMMENDATIONS

F2.6.1 Conclusions

A scheduled maintenance program for a concrete bridge deck can significantly extend the service life of the deck and the bridge structure itself. Concrete deck sealing, using a penetrating sealant in a cyclic schedule, result in the best way to reduce the ingress of chloride ions into the concrete deck. From a vast source of references, it seems that the most efficient scheme is to seal the concrete deck after three to six months of construction, and then repeat the sealing application every five years. Sealing an older deck is not an alternative to eliminate or reduce the amount of chloride ions inside the concrete. It has been demonstrated that previously contaminated decks will continue a deteriorating process. Consequently, to seal a concrete deck some years after construction is less cost-effective than sealing a new concrete deck.

Silane products show better results than other sealants alternatives (i.e. siloxanes), which is explained due to the small size of their particles, and the ability of deeper penetration trough the concrete pore structure. Solvent-base sealants have better performance than water-based, mainly because water-based sealants are not adequate for reapplication. The already sealed deck will repel the ingress of new water-based compounds.

Different LCCA presented in this study show that a scheduled sealing deck program is the most cost-effective strategy to extend the service life of the deck. Alternative 2: Concrete deck sealing every 5 and overlay at year 35 is the most cost-effective alternative, with the lower present value ($43.30/ft^2). Alternative 1: Current INDOT policy to concrete decks is the less effective alternative, with the highest present value ($80.63 ft^2). However, alternative 1 is by far the most optimistic and assumes that sealing of the overlay will extend the normal service life. It should be noted that the effectiveness of the sealants was for studies on the original decks, and not for overlays.

A scheduled sealing program can be combined with additional deck rehabilitations activities, such as partial patching, overlay application, or even deck replacement and it always result in a more convenient alternative to the no maintenance option. These additional activities increment the present value but they are always bellow the present value corresponding to the no maintenance alternative (current INDOT policy to concrete decks).

Concrete deck crack sealing can be performed in conjunction with deck sealing. Based on the thickness of the crack, different types of sealant can be selected. For narrow, wide spread cracks, the recommended option is high molecular weight methacrylates (HMWM) due to their deep penetration. In the case of thick cracks, an epoxy crack sealer is the best option, based on their outstanding bond strength. Concrete deck patching should be performed as early as possible, to prevent the development of a larger contaminated area of deck. The patching process must be done following the requirements to eliminate all contaminated concrete and corroded reinforcing steel in the damaged area in order to achieve a durable repair.

Some deck sealant products have been found to produce unfavorable chemical reactions with deck crack sealers (Frosch, Kreger, & Strandsquit, 2013). Therefore, care should be taken to ensure that the products used to seal the deck and the cracks are compatible.

F2.6.2 Recommendations

Based on the vast references presented and the different life-cycle cost analysis (LCCA) carried out in this report, Indiana DOT should incorporate a concrete deck sealing program in order to prolong the service life of the concrete decks in the state. The deck sealing treatment should start early after the construction of the deck, approximately after three to six months. Reapplication should be performed cyclically at intervals of five years. It is recommended the use of penetrating sealers. Solvent-base silane products have better performance over other types of sealers.

When concrete deck crack sealing is required, the use of high molecular weight methacrylate (HMWM) or epoxy crack sealer is recommended, and the selection has to be made based on the characteristics of the cracks. After deck cracks are sealed, deck sealing can be applied.

For efficiency and to obtain the best results, it is logical to combine concrete bridge deck sealing with other maintenance activities such as concrete bridge deck crack sealing and concrete bridge deck patching. Be careful to avoid unfavorable chemical reactions between the concrete deck sealer and the concrete crack sealer products.

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CONCRETE BRIDGE DECK MAINTENANCE

Life Cycle Cost Analysis

Discount Rate =	4.00%
Bridge Service Life =	75 years
Penetrating Sealant =	Silane

Activity	Cost	Unit	Comments	Reference
Deck Construction =	22.04	$/ft2	As part of initial superstructure	Table F2.1
Deck Replacement =	95.00	$/ft2	includes hydrodemolition, incidental costs, etc.	George Snyder - INDOT
Overlay =	60.00	$/ft2	includes scarification, incidental costs	George Snyder - INDOT
Partial Depth Patching =	2.70	$/ft2	Considers repair 10% of deck area	Table F2.2
Sealing =	1.14	$/ft2	Penetrating sealer	Table F2.3
Salvage Value =	0.00	$		

ALTERNATIVE 1:

No Maintenance: Current INDOT Policy

Activity	Year	Cost	Present Value
Deck Construction + Sealing	0.00	23.18	23.18
Overlay	18.75	60.00	28.76
Deck Replacement + Sealing	37.50	96.14	22.09
Overlay	56.25	60.00	6.61
			80.63 $/ft^2

ALTERNATIVE 2:

Maintenance: Sealing @ 5 years / Overlay at year 35

Activity	Year	Cost	Present Value
Deck Construction + Sealing	0	23.18	23.18
Sealing	5	1.14	0.94
Sealing	10	1.14	0.77
Sealing	15	1.14	0.63
Sealing	20	1.14	0.52
Sealing	25	1.14	0.43
Sealing	30	1.14	0.35
Overlay + Sealing	35	61.14	15.49
Sealing	40	1.14	0.24
Sealing	45	1.14	0.19
Sealing	50	1.14	0.16
Sealing	55	1.14	0.13
Sealing	60	1.14	0.11
Sealing	65	1.14	0.09
Sealing	70	1.14	0.07
			43.30 $/ft^2

ALTERNATIVE 3:

Maintenance: Sealing @ 5 years / Patching @ 10 years / Overlay at year 35

Activity	Year	Cost	Present Value
Deck Construction + Sealing	0	23.18	23.18
Sealing	5	1.14	0.94
Patching + Sealing	10	3.84	2.60
Sealing	15	1.14	0.63
Patching + Sealing	20	3.84	1.75
Sealing	25	1.14	0.43
Patching + Sealing	30	3.84	1.18
Overlay + Sealing	35	61.14	15.49
Sealing	40	1.14	0.24
Patching + Sealing	45	3.84	0.66
Sealing	50	1.14	0.16
Patching + Sealing	55	3.84	0.44
Sealing	60	1.14	0.11
Patching + Sealing	65	3.84	0.30
Sealing	70	1.14	0.07
			48.18 $\$/ft^2$

ALTERNATIVE 4:

Maintenance: Sealing @ 5 years / Overlay at year 30 / Replacement at year 50

Activity	Year	Cost	Present Value
Deck Construction + Sealing	0	23.18	23.18
Sealing	5	1.14	0.94
Sealing	10	1.14	0.77
Sealing	15	1.14	0.63
Sealing	20	1.14	0.52
Sealing	25	1.14	0.43
Overlay + Sealing	30	61.14	18.85
Sealing	35	1.14	0.29
Sealing	40	1.14	0.24
Sealing	45	1.14	0.19
Replacement + Sealing	50	96.14	13.53
Sealing	55	1.14	0.13
Sealing	60	1.14	0.11
Sealing	65	1.14	0.09
Sealing	70	1.14	0.07
			59.96 $\$/ft^2$

APPENDIX F3: JOINTS MAINTENANCE

F3.1. INTRODUCTION

Bridge deck joints, also known as expansion joints, are elements located between consecutive decks above the piers or at the transition between the bridge deck and an approach slab above the abutments. Their primary function is to accommodate different deck movements produced by temperature changes, vertical and horizontal forces due to live load actions, concrete creep and shrinkage, and wind and earthquake vibrations (Baker Engineering and Energy, 2006; Malla, Shaw, Swanson, & Gionet, 2003). While allowing all of those indicated movements, the joint system should provide a barrier against dirt, debris, and leakage of water and deicing compounds, protecting underneath structural elements, such as girders, bearings, piers, and abutments. All of these targets must be achieved with a smooth and noiseless riding surface (Azizinamini, Powers, Myers, & Ozyildirim, 2013).

F3.2. TYPES OF JOINTS

A bridge joint can be classified by two different characteristics: the manner in which it is constructed or by the length of allowable expansion it provides. Based on the manner in which a bridge joint is constructed, there are two basic joint types (INDOT, 2008):

1. An opening in the concrete which may be left open, or filled with rubber or fiber.
2. A steel joint that is set in place, has concrete placed around the joint, and then has some type of rubber filler inserted.

Based on the allowable longitudinal movement, joints can be classified differently as follows (Azizinamini et al., 2013; Chang & Lee, 2001; Malla, Shaw, Swanson, & Gionet, 2011):

1. Expansion joints for small movements (less than 3 in.), which include several types:

- Compression seal
- Asphaltic plug joint
- Sheet seal
- Open joint
- Poured sealants
- Polymer modified asphalt
- Sliding plate joint

2. Expansion joints for medium movements (in between 3 to 5 in.):

- Strip seal

3. Expansion joints for large movements (bigger than 5 in.), which include:

- Modular expansion joint
- Finger plate joint

The most common types of expansion joints used by the Indiana Department of Transportation (INDOT) according to Chang and Lee (2001) are the following: compression seal, strip seal, poured silicone, and polymer modified asphalt. INDOT also considers an integral abutment as a type of joint, where the joint actually disappears because the deck is incorporated with the abutment.

F3.3. PROBLEMS OF JOINTS

Many factors have negative effects on the performance of expansion joints. Those effects are related to external and internal factors such as: weather, traffic loads, passing of snow plows, appropriate design, materials quality, construction procedures, aging, and lack of maintenance. Throughout the service life of the bridge deck joint these factors can produce serious problems and, if not properly attended, it could result in significant joint damage and lead to notable deterioration of the deck, girders, and substructure elements below the deck (Malla et al., 2011).

The study conducted by Chang and Lee (2001) identified a number of the most common problems for different types of expansion joints used in Indiana bridges:

- *Compression seal joint:* Spalling of the adjacent concrete; hardening of the joint due to debris; and loosening of the seals.
- *Strip seal joint:* Breaking of steel angles by snowplows; pop out of rubber from the holding glands due to accumulation of debris and deicing products.
- *Poured silicone:* Cracks between the seal and adjacent material due to poor installation of silicone strip or bad position (too low or too high).
- *Polymer modified asphalt:* Missing polymer modified asphalt; steel plates rusted and cracked.

Most expansion joints problems are related to the seal and/or the concrete adjacent to the joint. The concrete surrounding the joints normally presents cracks and spalling issues. The seal problems often involve holes, tears, breakings, and loose of material. These problems not only produce inconvenient conditions for the passing traffic, but aggravates the situation when deicing products leak through the joints and reach the under deck elements such as bearings, beam ends, abutment walls, and caps. In that situation the problems can compromise the integrity of the whole structure (Azizinamini et al., 2014; Hopwood & Courtney, 1989). The transference of wheel loads to strip seals through the debris trapped into the expansion joint gap is one of the primary factors to produce premature fails on joint bridges (Bolluyt, Kau, & Greimann, 2001).

F3.4. PREVENTIVE MAINTENANCE ACTIVITIES OF JOINTS

Bridge joints are exposed to severe working conditions, requiring adequate maintenance programs, including regular resealing of minor joint problems and programmed replacements during their service life. Bridge maintenance activities can be approached from two different ways, proactive and reactive. When considering the maintenance of bridge joints, the proactive approach is the most recommended manner to keep these elements in good conditions (Spuler, Loehrer, & O'Suilleabhain, 2012). Proactive policy considers regular inspection and preventive maintenance. The study from the National Cooperative Highway Research Program Synthesis 319 (Purvis, 2003) indicated that, "All currently available joints require preventive maintenance to keep joints functioning and avoid costly structural damage … it is important to minimize the leakage to avoid serious damage to the bridge structural support system." The study concluded that a proactive maintenance policy will improve the service life of bridge expansion joints.

Moreover, regarding joint failures, in the Report 467 from the National Cooperative Highway Research Program (Dexter, Mutziger, & Osberg, 2002) it was concluded that "failures are often a chain reaction (i.e., the failure of one component leads to the destruction of other components). Eventually, this chain reaction leads to a failure or loss of serviceability or functioning." A joint failure leads to water and deicing compounds passing through the joint, generating damage to other critical components from the superstructure and substructure, aside or under the joint (Purvis, 2003).

Bridge expansion joints are not regularly retrofitted, therefore they normally have to be replaced when a particular level of deterioration is reached (Azizinamini et al., 2014). Due to the complexity and expense of joint replacement, basic and economical maintenance actions are recommended in order to prolong the service life of the joint. Consequently, preventive maintenance of bridge deck expansion joints is strategic, vital, and cost effective. The most basic preventive maintenance activities for bridge joints are to clean debris which is build up and below the deck joints, and to clean steel parts of joints.

It is important to clean debris from joints with certain frequency because undeformable small bodies can be trapped, restricting the movement capacity of the joint. Also, debris form a recipient body for the accumulation of moisture and salt compounds, which in time will produce corrosion of steel elements (Berman, Roeder, & Burgdorfer, 2013). Figure F3.1 shows a typical case of a joint with accumulated debris.

Following are some other practices for joint maintenance that should be considered (Guthrie, Nelson, & Ross, 2005):

- When a joint has failed the best practice is to replace the entire joint, since it is difficult to achieve a complete bond at the interface between the old and new portions of a partial joint replacement.
- Deteriorated areas in the approach slab and deck, adjacent to the joints should be repaired with high priority, to reduce impact loads that could damage the joint.
- Cleaning and flushing troughs under the joints to avoid the accumulation of debris.

Figure F3.1 Accumulation of debris in a bridge expansion joint (Kaczinski, 2010).

F3.5. FREQUENCY OF MAINTENANCE ACTIVITIES

Several states DOTs consider preventive maintenance of bridge deck joints as a strategy practice to extend the joint service life, as well as the service life of other structural elements in the superstructure and substructure. On the other hand, some state DOTs do not consider preventive bridge deck joints in their maintenance programs, but respond to joint problems only when a safety hazard is presented or when the deck is rehabilitated or replaced (Spuler et al., 2012).

The study conducted by Berman et al. (2013) presented the results from a national survey to state DOT agencies, with information regarding preventive maintenance practices for bridge deck joints and the frequency of cleaning. Table F3.1 presents a summary of the findings from the mentioned study.

The Pennsylvania Department of Transportation (PennDOT) indicates that they can significantly extend the service life of their bridges with a regular maintenance program consisting of cleaning and resealing bridge joints expansions (PennDOT, 2008).

The Virginia Department of Transportation (VDOT) indicates that both Preventive Maintenance and Restorative Maintenance are the components of Virginia's Bridge Preservation Program (Milton, 2011). Preventive maintenance can be condition based or non-condition based. Non-condition based preventive maintenance is typically referred to as Planned Preventive Maintenance. Planned Preventive Maintenance includes Scheduled Replacement of Compression Seal Joints in good condition (10 year cycle) and Schedule replacement of Pourable Joints in good condition (6 year cycle).

During this study, personnel in charge of maintenance from the six Indiana DOT Districts and from the Central Office were interviewed to collect direct information regarding INDOT maintenance practices. The information indicated that INDOT Districts do not perform preventive maintenance activities to bridge deck joints. This information is in opposite to what was reported in the study by Berman et al. (2013).

TABLE F3.1
Relation of state DOTs performing washing programs for expansion joints and corresponding frequency (Berman et al., 2013).

State DOT	Frequency (years)
Colorado, Delaware, Florida, Hawaii, Illinois, Maryland, Michigan, Nevada, Tennessee, Washington	Not performed
California, Indiana, Maine, Minnesota, North Carolina, North Dakota, Oregon, Pennsylvania, South Dakota, Utah, Virginia, Wyoming	1
New Hampshire, New York, Vermont, West Virginia	2
Arizona, Georgia, Missouri, Oklahoma	3–5
Alabama, Iowa, Kentucky, Texas	>5

F3.6. SERVICE LIFE OF JOINTS

Chang and Lee (2001) performed a study sponsored by Indiana Department of Transportation (INDOT) to examine the performance of bridge expansion joints in Indiana and the reason behind the short service lives of these devices. From that study were identified compression seal joints and strip seal joints as the most common extension joints used in Indiana bridges. Two surveys were implemented as part of the study. One survey was oriented to bridge inspectors and engineers from INDOT Districts and Central Office. The second survey was responded by bridge inspector engineers from DOT agencies from Michigan, Ohio, Illinois, and Kentucky. Table F3.2 presents the results of both surveys presenting the estimated service life of the most common used joints.

In the study prepared by Bolluyt et al. (2001) for the Iowa Department of Transportation, a manufacturer's representative indicated that the service life of a strip seal is expected to be fifteen to twenty years. However, the experience with Iowa bridges is that a considerable number of those joints have failed in less than five years.

Chandler (2004) performed a life-cycle cost analysis to compare between two alternatives: the use of conventional bridge expansion joints, and the use of Engineered Cementitious Composites (ECC) as an alternative to eliminate the use of expansion joints. From the data used by the study, Chandler estimated to be 15 years the frequency to replace bridge expansion joints.

A research sponsored by the Utah Department of Transportation (Guthrie et al., 2005) investigated the performance of concrete bridge joints, their primary functions and movement ranges. Bridge engineers from twenty state DOT agencies were surveyed to collect relevant information concerning the types of bridge deck joints they were using, and their maintenance and replacement practices. From the survey data, the average service life was determined for different types of deck expansion joints, as presented in Table F3.3.

Baker Engineering and Energy (2006) in cooperation with the U.S. Department of Transportation (USDOT) and the Federal Highway Administration (FHWA) conducted a research for the Arizona Department of Transportation (ADOT) to evaluate and determine the quality of expansion joints in Arizona bridges.

TABLE F3.2
Estimated joint service life (years) (Chang & Lee, 2001).

Joint type	Compression seal joint	Strip seal joint
1st survey	11.7	11.9
2nd survey	10.3	10.9

TABLE F3.3
Expected joint service life (years) (Guthrie et al., 2005).

Compression seal joint	Strip seal joint	Reinforced elastomeric joint	Modular elastomeric joint
16.5	18.8	17.5	20.5

TABLE F3.4
Estimated joint service life (years) (Baker Engineering and Energy, 2006).

Pourable seals	Compression seals	Strip seals	Finger or slide plate joints	Modular joints	Integral abutments
11.5	12.7	18.0	28.1	19.2	50.9

TABLE F3.5
Expected joint service life (years) (Azizinamini et al., 2014).

Field molded or equivalent joints	Strip seal joint	Compression seal joint	Finger plate joint	Modular expansion joint
1 to 3	3 to 30	3 to 30	10 to 50	10 to 50

Table F3.4 shows the estimated service lives for different types of bridge deck joints considered in the study.

The study by Azizinamini et al. (2014), sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials, developed a systematic and general approach to design oriented for service life. According to Azizinamini et al. (2014) "almost all expansion joints leak, and most, even with proper maintenance, have a service life of less than 10 years." The study presented a list of the most expansion joints used in practice, indicating their expected service life, as seen in Table F3.5.

The gathered data from different studies show a high variation in the estimated service life of extension joints. The variation could be related to different factors such as initial design, assigned budget, construction quality, traffic conditions, maintenance policy, etc.

F3.7. COST OF JOINTS MAINTENANCE AND REPLACEMENT

The initial cost of supply and install a joint expansion during the construction of a new bridge represents a small percentage of the total cost of construction. But, the cost of joint replacement can result very significant, due to the costs of site mobilization, traffic disruption and control, removal of damaged joint, and supply and installation of a new joint. The direct cost of joint replacement could be about three to six times the initial cost of installation (Spuler et al., 2012). When user costs are considered additionally to the direct cost, the cost of joint replacement can be increased ostensibly. Consequently, a properly selected, designed, constructed and maintained bridge joint should provide an adequate service life, avoiding recurrent and expensive work replacements.

The study done by Baker Engineering and Energy (2006) performed an economic analysis of typical bridge deck joints. From that study different costs for construction, replacement and maintenance are provided for a typical seal joint. Table F3.6 shows the unit costs ($/ft.) for those activities and more detailed information is presented in Appendix F3.1.

TABLE F3.6
Unit costs for typical joint (Baker Engineering and Energy, 2006).

Activity	Cost ($/ft.)
Construction	172
Replacement	466
Maintenance	15

F3.8. LIFE-CYCLE COST ANALYSIS

In this report is presented an economic analysis for bridge joints considering different alternatives: (i) The cost associated with bridge joints with no maintenance until replacement is required (alternative 1), and (ii) The cost associated with scheduled maintenance activities (alternatives 2 and 3). Two different frequencies of maintenance are considered. The cost of each alternative is represented by its corresponding present value (PV), a representation of initial and future costs by a single value at present time.

The LCCA is conducted for a typical bridge with the following parameters:

Bridge service life 75 years
Deck width/Joint length 60 ft.
Salvage value $0
Discount rate 4%

A bridge joint with no maintenance has a service life of 5 to 10 years, then, it is assumed a limit value of 5 years. According to the data presented, a bridge joint with appropriate maintenance could reach a service life between 10 to 20 years, therefore, a limit value for service life of 15 and 10 years could be assumed for the analysis.

Alternative 1

No maintenance activity and joint replacement each 5 years (see Figure F3.2).

Alternative 2

Considering joint maintenance every year and joint replacement each 15 years (see Figure F3.3).

Alternative 3

Considering joint maintenance every year and joint replacement each 10 years (see Figure F3.4).

The PVs for the three alternatives are shown in Table F3.7, and the detailed operations are presented in Appendix F3.1.

Based on data collected from several studies, average values for cost of construction, maintenance and replacement were used to estimate the joint service life. Under the assumed parameters, the results from the LCCA show that a schedule preventive bridge joint maintenance plan is an effective alternative to extend the joint service life. Also, a bridge join replacement plan serves to extend the deck and bridge service life.

F3.9. CONCLUSIONS AND RECOMMENDATIONS

F.3.9.1 Conclusions

Expansion joints are critical elements exposed to severe working conditions, with a service life shorter than the bridge structure. Most joint problems are related to loss of seal and damage in the concrete adjacent to the joint, allowing the pass of water, deicing compounds, and debris, damaging structural elements under the deck. The cost of bridge joint replacement could be as several times the cost of initial installation. The lack of maintenance reduces ostensible the service life of bridge joints. A scheduled maintenance program for bridge joints can significantly extend the service life of the joint, the concrete deck and the structure itself.

F3.9.2 Recommendations

INDOT should incorporate cleaning/flushing maintenance actives for bridge deck joints as a regular activity every year,

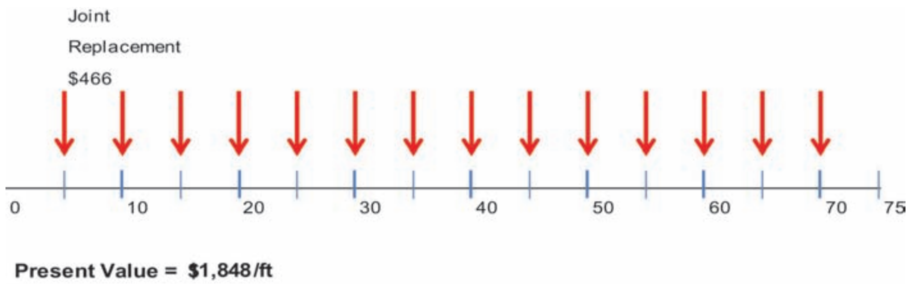

Figure F3.2 LCCA representation for alternative 1.

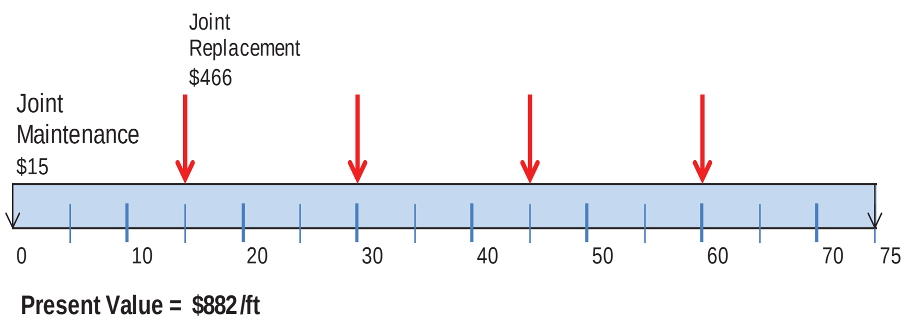

Figure F3.3 LCCA representation for alternative 2.

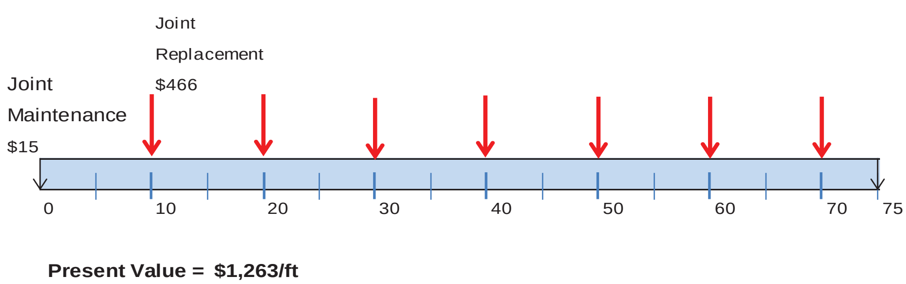

Figure F3.4 LCCA representation for alternative 3.

TABLE F3.7
Present value for different alternatives of bridge joint maintenance.

Alternative	Description	PV ($/ft)
1	No maintenance / Replace joint @ 5 years	1,848
2	Maintenance each year / Replace joint @ 15 years	882
3	Maintenance each year / Replace joint @ 10 years	1,263

preferably after the winter season. Reseal minor problems on seals every year during cleaning/flushing activities. Moreover, it is recommended that deck joints be replaced each 10 years, or when needed, before they reach a significant damage level that may lead to greater deck or substructure deterioration.

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LIFE-CYCLE COST ANALYSIS

Bridge Width =	60 ft
Discount rate =	4%
Bridge S.L.	75 y

Joint Construction

ITEM	UNIT	QUANT	MIN ($)	MAX ($)	UNIT COST ($/ft.)
Materials	ft	60.00	55.00	140.00	98
Concrete	yd3	4.60	200.00	300.00	19
Foreman	hr	9.20	60.00	70.00	10
Co. Finish	hr	18.50	45.00	55.00	15
Welder	hr	15.00	55.00	65.00	15
Laborer	hr	30.00	25.00	35.00	15
TOTAL					**172**

Joint Maintenance

ITEM	UNIT	QUANT	MIN ($)	MAX ($)	UNIT COST ($/ft.)
Maintenance	ft	60.00	10.00	20.00	15
TOTAL					**15**

Joint Replacement

ITEM	UNIT	QUANT	MIN ($)	MAX ($)	UNIT COST ($/ft.)
Mob/Desm	LS	1	3,280.00	17,000.00	169
Traffic Disruption	hr	5.00	1,000.00	2,000.00	125
Construction					172
					466

ALTERNATIVE 1

No Maintenance / Replace Joint @ 5 years

r = 0.04

Activity	Year	Cost ($/ft)	PV ($/ft)
Joint Replacement	5	466.05	383
Joint Replacement	10	466.05	315
Joint Replacement	15	466.05	259
Joint Replacement	20	466.05	213
Joint Replacement	25	466.05	175
Joint Replacement	30	466.05	144
Joint Replacement	35	466.05	118
Joint Replacement	40	466.05	97
Joint Replacement	45	466.05	80
Joint Replacement	50	466.05	66
Joint Replacement	55	466.05	54
Joint Replacement	60	466.05	44
Joint Replacement	65	466.05	36
Joint Replacement	70	466.05	30
		TOTAL =	1,848

ALTERNATIVE 2

Maintenance each year / Replace Joint @ 15 years

r = 0.04

Activity	Year	Cost ($/ft)	PV ($/ft)
Joint Replacement	15	466.05	259
Joint Replacement	30	466.05	144
Joint Replacement	45	466.05	80
Joint Replacement	60	466.05	44
Maintenance each year	1 to 75	15.00	355
		TOTAL =	882

ALTERNATIVE 3

Maintenance each year / Replace Joint @ 10 years

r = 0.04

Activity	Year	Cost ($/ft)	PV ($/ft)
Joint Replacement	10	466.05	315
Joint Replacement	20	466.05	213
Joint Replacement	30	466.05	144
Joint Replacement	40	466.05	97
Joint Replacement	50	466.05	66
Joint Replacement	60	466.05	44
Joint Replacement	70	466.05	30
Maintenance each year	1 to 75	15.00	355
		TOTAL =	1,263

APPENDIX F4: BEARINGS MAINTENANCE

F4.1. INTRODUCTION

Bridge bearings are devices that connect the structural members of the superstructure (beams and girders) to the supporting units of the substructure (bents, abutments and piers). The bearings support the superstructure at a particular elevation and transmit forces (dead, live, dynamics, etc.) from the superstructure to the substructure in a smooth and controlled way. Moreover, they allow superstructure motions (linear displacements and rotations) and provide necessary restraint to the structure. Also, bearings support thermal expansion and contraction, long term movements caused by concrete shrinkage, and prestressing creep.

These devices are subjected to severe service conditions, which may lead to service lives that are shorter than for other bridge components. Bearing selection is influenced by many different factors: loads, geometry, maintenance, available clearance, displacement, rotation, deflection, availability, policy, designer preference, construction tolerances, cost, etc.

F4.2. TYPES OF BEARINGS

The most common types of bearings currently in use are (Azizinamini, Power, Myers, & Ozyildirim, 2013):

- “Elastomeric bearings, which include steel-reinforced pads and plain elastomeric pads;
- Cotton duck pads (CDP);
- Sliding bearings, using Polytetrafluorethylene (PTFE) pads;
- Manufactured high-load multi-rotational (HLMR) bearings, which include pot bearings, disc bearings and spherical bearings; and
- Mechanical, fabricated steel bearings, for fixed application and for expansion application using rollers or rockers.”

Indiana DOT typically requires for its bridges one of two types of bearing devices. The use of elastomeric bearings is prescribed for concrete structural members. For steel beam or girder members, either elastomeric bearings or steel bearings are used (INDOT, 2008). This report is focused in both, steel and elastomeric bridge bearings.

F4.2.1 Steel Bearings

Steel bearings are the oldest types of bearing. According to Oladimeji (2012), bearings are classified as:

- “Pin bearing - permits rotational movement by means of a circular steel pin, connected to circular recessed surfaces, while at the same time preventing longitudinal movement.
- Rocker bearing - are pedestals with a circular bottom that are supported by a pin.
- Roller bearing - rolling devices provide expansion movement by using some form of roller to accommodate the relative movement of the superstructure.
- Sliding plate bearing - Sliding occurs between a stainless steel insert and a PTFE plate”

F4.2.2 Elastomeric Bearings

Elastomeric bearings permit movements in all directions by elastic deformation and rotation around all directions, transferring forces from the superstructure to the substructure. Elastomeric bearings incorporate an elastic material—natural rubber (polyisoprene) or neoprene (polychloroprene) a synthetic rubber—in the form of single or multiple pads, with or without steel plates embedded into the laminations, accommodating both type of movements, displacements and rotations (Heymsfield, McDonald, & Avent, 2001). Elastomers are strong in compression and weak in shear, regaining its initial shape and dimensions when subjected to loads within their elastic range. When an elastomeric bearing supports high vertical loads, it will experience compression deformations, which may result in bulging of the rubber (Oladimeji, 2012). There are two types of elastomeric bearings:

1. Plain elastomeric pads.
2. Laminated elastomeric bearings with steel sheet reinforcement.

Bridge bearings have the following functions according to Oladimeji (2012):

- "Connects the bridge superstructure to the substructure.
- Accommodates and transfers dynamic forces and vibrations without causing wear or destruction to the substructure.
- Enables movement (translational, vertical or rotational) of the bridge structure in reactions to loads.
- Controls the movement in bridge structure; direction and degree wise.
- Ensures that deformations, which occur in the superstructure of the bridge, do not lead to large forces and moments in the substructure.
- Can be used to adjust the dynamic properties of the bridge.
- Bearings reduce shear on the head of the piers, viaducts or abutments.
- Recent bridge bearings are designed to act as seismic protectors that arrest and dissipate energy during earthquakes and other seismic activities."

F4.3 BEARING PROBLEMS

Bearing failure, or improper behavior, can produce changes in the general behavior of the structure, affecting negatively the superstructure/substructure interaction. Some cases of rocker bearing rollover have nearly lead to catastrophic span collapses (Azizinamini et al., 2013). One of the most common causes of steel bearing deterioration is deck drainage through deck joints, which produce the corrosion and freezing (restricted lateral or rotational movement) of the bearing. Figure F4.1 shows a typical damaged bearing due to corrosion problems.

The corrosion process can be accelerated due to the use of deicing solvents or when the bridge location is near to the coast. The examination of some cases have shown that the corrosion is more severe for bearings located on the abutments where closed spaces facilitate the accumulation of debris, in contrast to less corroded bearings located at intermediate piers where open places allow less accumulation of debris and water leakage.

Another serious problem affecting steel bearings is the accumulation of debris, and corrosion material, as represented in Figure F4.2. This may cause variations in the mechanical behavior of steel bearings, reducing their intended function, such as allowing movements and transferring loads.

F4.4. PREVENTIVE MAINTENANCE ACTIVITIES OF BEARINGS

Maintenance of bridge bearings is a significant part of overall bridge maintenance. As indicated, the most important problems of bearings are related to the accumulation of debris or leakage of water. A malfunctioning or faulty bearing that is not rectified would resist movements, which could create undesirable forces and moments in the bridge, resulting in unexpected stresses at different locations of the bridge elements. The lack of attention to these problems could lead to damage not only the bearings but the steel girders supported by the bearings.

Generally, maintenance of bearings can be classified as either corrective or preventive. Corrective maintenance activities are performed to retrofit a damaged device. Preventive maintenance is carried out to prevent deterioration of the bearing. Preventive maintenance activities commonly include cleaning, lubricating, painting, and sealing deck joints (INDOT, 2014; Nobles, 1997; Rossow, 2009; Tonias & Zhao, 2007). Also, a good practice in conjunction with bearing maintenance is to wash off concrete slope walls close to bearings to facilitate access for further maintenance or inspection.

Figure F4.1 Steel bearing corroded, which has reduced its ability for displacement and rotations (Balassone, 2010).

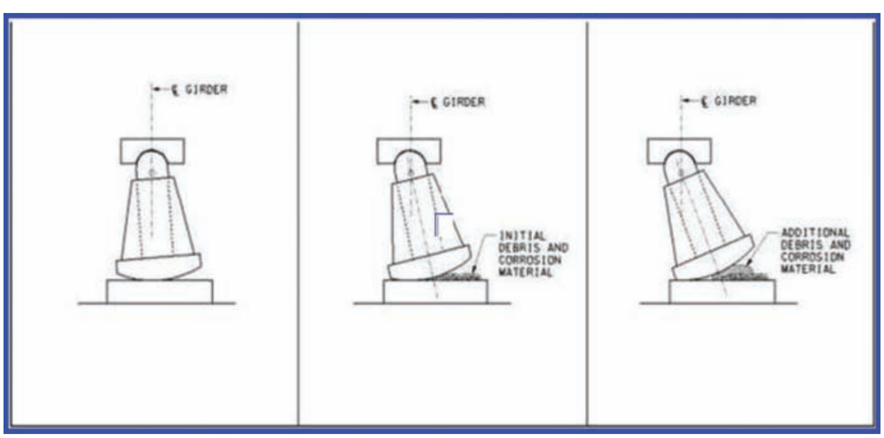

Figure F4.2 Accumulation of debris and corrosion material on rocker bearing produces a racketing effect (Balassone, 2010).

Figure F4.3 Before (left) and after (right) cleaning/washing bridge bearing (Hartman, 2012).

F4.4.1 Cleaning

Cleaning is undertaken for both elastomeric bearings and steel bearings. Washing and flushing is common for elastomeric bearings. For steel bearings common cleaning is done to remove rust, dirt, mill scale, surface impurities etc. Cleaning steel bearings also prepares the surface of the steel for corrosion protection treatments. Figure F4.3 shows a typical bearing before and after cleaning/washing maintenance. Common cleaning methods for steel bearings are (Oladimeji, 2012):

- "Water jetting
- Solvent cleaning by mineral spirits or turpentine
- Wire brushing
- Pickling with sulphuric acid, phosphoric acid or iron phosphate
- Flame cleaning with oxyacetylene flame
- Sand blasting or steel grit blasting"

F4.4.2 Lubricating

Lubricants are introduced to reduce the friction between the contact surfaces of steel elements of steel bearings. Lubrication of steel bearings many times requires extra work to jack the girders to access the surfaces to be maintained.

F4.4.3 Painting

Special paints are applied on steel bearing parts to protect them from rust and corrosion. Common paints used are (Oladimeji, 2012):

- "High performance paint coatings such as alkyd, vinyl, phenolic, iron ore paints etc.
- Zinc metal paint applied by thermal spray galvanizing or hot dip galvanizing (involves moving parts to the shop)"

F4.4.4 Maintaining Deck Joints

Providing adequate maintenance to deck joints will prevent the passage of dirt, corrosion products, and deicer compounds from the upper face of the deck to the lower face, where the girders and bearings are located, reducing the possibility of corrosion to the bearings. Sealing the deck joints also will prevent the passage of dirt. Sealing the deck joint may involve the installation of a different type of joint, or the removal of the deck joint. This activity can be considered a rehabilitation activity instead of a maintenance activity.

F4.5. FREQUENCY OF MAINTENANCE OPERATION

Lubricating and cleaning the bearings are preventive maintenance activities that should be performed at a certain frequency that depends upon the type of bridge, bridge location, bridge loading, stakeholders, available funds, etc. This will help to prolong the life cycle of the bearings and reduce the need for frequent major maintenance (Oladimeji, 2012).

Few researchers have focused on characterizing the behavior of steel bearings. Mazroi, Wang, and Murray (1983) and Mander, Kim, Chen, and Premus (1996) performed studies focused on the effect of corrosion on steel bearings. However, no specific information was provided regarding the corrosion progress on steel bearings and the necessary time for maintenance activities such as cleaning or lubricating.

Some State DOTs consider bridge bearing maintenance activities as preventive activities. Some of them indicate the activity must be performed at a specific cyclic time, while others do not indicate the period of time but only its regular application. All of the proposed cyclic times for bearing maintenance activities are defined solely based upon empirical experience provided by field inspectors. Listed in the following is a review of some State DOTs that recommend the application of bridge bearing maintenance activities (some State DOTs give the frequency of application, while other State DOTs do not define a time frame).

- California DOT (Weykamp et al., 2009) considers as a part of its Bridge Maintenance Program the activity of cleaning the bearings each 2 years.
- Delaware DOT (DelDOT, 2012) recommends that bridge bearing surfaces should be flushed annually after the threat of snow and ice has diminished or passed.
- Florida DOT (Weykamp et al., 2009) indicates that one of its bridge work areas is bridge bearing maintenance and repair, which involves activities such as cleaning corrosion from beam bearings, and painting or replacing bearing pads.
- Indiana DOT (INDOT, 2014) proposes cleaning/lubricating bearings each year as a preventive maintenance activity. Indiana DOT personnel reported for this study that they do not actually perform this activity.
- New York State DOT (NYSDOT, 2008) requires the following times for preventive maintenance activities: clean substructure (including bearings) each 2 years, and lubricate bearings each 4 years.
- Virginia DOT (VDOT, 2012) indicates that as part of its Bridge Preservation Program, a preventive maintenance activity is cleaning and lubricating bearings and should be performed each 4 years.
- Georgia DOT (GDOT, 2013) has implemented a Bridge Structures Maintenance Plan that requires lubricating bearings as a preventive maintenance activity.
- Kentucky Transportation Center (Wilhoite, 2010) requires cleaning bearing devices and lubrication as a preventive maintenance activity for steel bridges.
- South Carolina DOT (Floyd, 2011) indicates bearing support maintenance as a preservation activity in its Bridge Management Policy.
- Oregon DOT (Weykamp et al., 2009) requires cleaning or painting of bearings and seats as part of its Bridge Maintenance Program.
- The US Department of Transportation and the Federal Highway Administration have published the Bridge Preservation Guide (FHWA, 2011). In this document bearing lubrication is recommended as one of the bridge preventive maintenance activities.

Oladimeji (2012) performed an international survey on bearing maintenance, gathering information from a total of 76 respondents from 44 different countries. Most of the knowledge and experience was collected from Sweden, UK and the USA. According to this study only 25% choose cleaning as an activity to prevent deterioration, and 27% of the respondents carried out painting/repainting with anticorrosive paints to prevent corrosion. In relation to the frequency of maintenance activities, 22% of the respondents indicated that they perform maintenance operations on bearings yearly and 11% every second year.

F4.6. SERVICE LIFE OF BEARINGS

The oldest known example of bearing pads used in a bridge were 1/2 inch natural rubber pads installed in 1889 under a railway bridge in Melbourne, Australia (Burpulis, Seay, & Graff, 1990). These pads, designed to allow rotation and absorb impact in bridges and other structures, have lasted for over 100 years. Made from a natural rubber compound that included no antidegradants, they were found to have experienced only minor degradation when inspected in the mid 1980's (Chen, 1995; Chirgwin, 1998).

Neoprene's resistance to shear, weather, aging, and compression set ensures a long service life, with no important maintenance needed in bridge-bearing applications. This conclusion is supported by bearing performance in acceptance tests after 22 years in service (Doody & Noonan, 1992).

Neoprene bearings have exhibited satisfactory performance in the past, as documented for different sites (Burpulis et al., 1990):

- New York State: 29 years performance
- Idaho: 31 years performance
- Illinois: 29 years performance
- Texas: 32 years performance
- Japan: 28 years performance

Based on a study from Lee (1994), when the bridge bearings are properly designed, fabricated, and maintained, they should last the lifetime of the bridge. The elastomeric bearings should require only basic maintenance activities at normal working conditions, but when they are exposed to extreme weather, more frequent maintenance actions will be required to keep their expected service life. The same author indicated that steel bearings always need inspection and appropriate maintenance, particularly because of corrosion problems.

Oladimeji (2012) examined bridge bearing service lives. The study found that 56% of the survey respondents considered the service life of bridge bearings to be less than 30 years, 32% considered it to be from 30 to 50 years, while only 12% of respondents considered the service life of bearing to last from 50 to 70 years.

Azizinamini et al. (2013) stated that steel reinforced elastomeric (SRE) bearings, when adequately designed, manufactured, and installed, and maintained may reach a service life of 100 years or more, with almost no long-term maintenance requirements. The large number of bearings with more than 50 years of service in the United States, and many more years in other countries appears to support this conclusion. Based on a survey among 19 state DOTs, Azizinamini et al. (2013) constructed a range of expected and experienced service lives for different types of bearings.

The results are shown in Table F4.1 and indicate that many of the different bearing types are able to achieve their expected service life.

F4.7. COST OF BEARINGS

A document prepared by the Nebraska Department of Roads (NDOR, 2013) reports the unit costs for various bridge bearing maintenance activities as indicated in Table F4.2.

TABLE F4.2
Unit costs for bridge bearing maintenance activities (NDOR, 2013).

Name	Work description	Unit cost ($)	Unit
Bearing device	Replacement	2,858.00	ea.
Expansion bearing TFE	Replacement	923.00	ea.
Bearing bracket	Extend and repair seat	2,500.00	ea.
Clean bearings	Clean bearings	200.00	ea.
Clean and paint bearings	Clean and paint bearings	300.00	ea.
Clean and reset bearings	Clean and reset bearings	2,000.00	ea.

F4.8. LIFE-CYCLE COST ANALYSIS

F4.8.1 Steel Bearing

A life-cycle cost analysis (LCCA) is performed for two different alternatives for steel bearings from a typical bridge. The first alternative is when no maintenance activities are applied to the bridge bearings. The second alternative is when maintenance activities are performed; in this case, cleaning, lubricating, and painting are the proposed maintenance activities. A discount rate of 4% is considered in the analysis for both alternatives.

Alternative 1A

Considering no steel bridge bearing maintenance activities.

Considerable damage on steel bearings due to corrosion effects can be expected after 20 years if no maintenance is performed. In this situation a replacement of the unit will be necessary, at a cost of $3,000. This task requires jacking the girders, and therefore, traffic control procedures are also required, at a cost of $5,000 summing up a total cost of $8,000 which will have to be assumed each 20 years (NDOR, 2013). The present value (PV) for this alternative is $6,078 as depicted in Figure F4.4.

TABLE F4.1
Ranges of Service Life Reported for Different Bearing Types (Azizinamini et al., 2013).

Bearing Types	Expected Service Life	Experienced Service Life	Comments
Elastomeric	50–75, closer to 75	15–50	Experienced service life limited by current years in service
Cotton Duck	75	35–50	Only two DOTs reported
PTFE	30–75	30–50	
HLMR	30–75, mostly 50	10+ Pots 15–40 others	Early pots had problems. Lower service life often limited by current years in service
Fabricated Steel	50–75	15–100	Oldest type of bearing in service

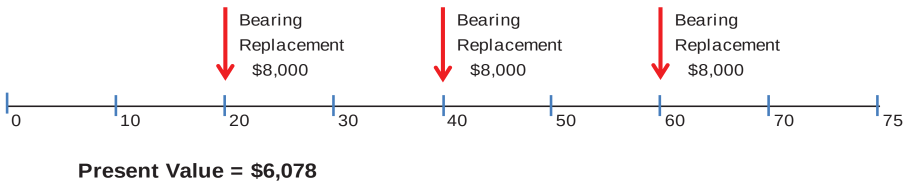

Figure F4.4 LCCA for alternative 1A—no maintenance on steel bearing.

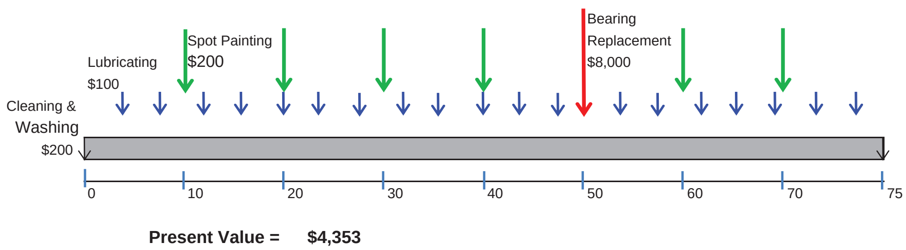

Figure F4.5 LCCA for alternative 1B—performing maintenance on steel bearing.

Alternative 1B

Considering steel bridge bearing maintenance activities.

This alternative considers cleaning the bridge bearing each two years at a cost of $200, and lubricating and painting the bridge bearing every four years at a cost of $200 (additional to cleaning). Under this maintenance plan it is expected the bearing will last for 50 years, when it will need to be replaced. For this alternative, the present value of all costs will be $4,541 as shown in Figure F4.5.

F4.8.2 Elastomeric Bearing

A similar analysis can be done to analyze the behavior of an elastomeric bearing. Considering the same 4% discount rate, the LCCA is presented.

Alternative 2A

Considering no elastomeric bearing maintenance activities.

Consider the elastomeric bearing requires to be replaced after 20 years if no maintenance is performed. The unit cost of an elastomeric bearing can be assumed as $500 (INDOT, 2012). This task requires jacking and traffic control procedures, at a total cost of $5,000 as considered previously. Then, a total cost of $5,500 has to be assumed each 20 years. The present value (PV) for this alternative is $4,179 as depicted in Figure F4.6.

Alternative 2B

Considering elastomeric bearing maintenance activities.

This type of bearing only requires to cleaning it each two years, at a cost of $200. Under this maintenance plan it is expected the bearing will last for 50 years, when it will need to be replaced. For this alternative, the present value of all costs will be $3,090 as shown in Figure F4.7.

The LCCA studied for both types of bridge bearings, steel and elastomeric, show that providing a bridge bearings maintenance program is more cost effective than the no maintenance alternative. The steel bearings maintenance includes cleaning and washing each two years, lubricating each four years, and spot painting each ten years. The elastomeric maintenance plan requires cleaning and washing each two years. The detailed operations to evaluate the PV for each alternative are presented in Appendix F4.1.

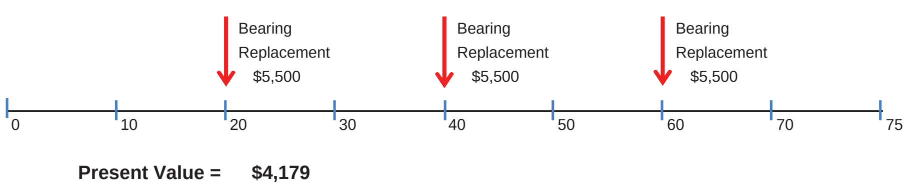

Figure F4.6 LCCA for alternative 2A—no maintenance on elastomeric bearing.

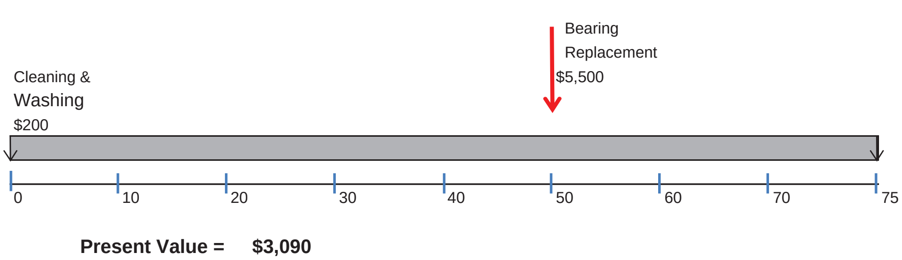

Figure F4.7 LCCA for alternative 2B—performing maintenance on elastomeric bearing.

F4.9. CONCLUSIONS AND RECOMMENDATIONS

F4.9.1 Conclusions

There is a lack of detailed studies on the behavior and performance of bridge bearings. Indiana bridges commonly use both steel and elastomeric bearings. Common problems for bridge bearings are the accumulation of debris around the device and slope walls, and corrosion due to leakage of water through expansion joints. A greater accumulation of debris is expected at abutments. Cleaning, washing, painting, and lubricating are the most effective preventive maintenance activities for steel bridge bearings. Elastomeric bearings also need to be cleaned regularly. The frequency of preventive maintenance activities for bridge bearings is established primarily on empirical knowledge provided by bridge inspectors and field crews. Providing adequate maintenance to deck joints also helps to keep the bridge bearings in good conditions. When properly designed, fabricated, installed, and maintained, the service life of bridge bearing is expected to last from 50 to 75 years.

F4.9.2 Recommendations

INDOT should incorporate a plan of bridge bearing maintenance actives, consisting of:

- Clean and wash elastomeric bearings, steel bearings, and slope walls each two years.
- Lubricate and paint steel bridge bearings each four years.
- Spot painting steel bearings each ten years.

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APPENDIX F4.1

LIFE-CYCLE COST ANALYSIS

Discount Rate = 4%

Bridge Service Life = 75 years

UNIT COST OF BEARING MAINTENANCE

ACTIVITY	COST ($)
Cleaning/Washing	200.00
Lubricating	100.00
Spot Painting	200.00
Steel Bearing	3,000.00
Elastomeric Bearing	500.00
Jacketing/Traffic control	5,000.00

PRESENT VALUE

ALTERNATIVE 1A: No steel bridge bearing maintenance activities

Cost of Steel Bearing Replacement	
Cost of Steel Bearing	3,000.00
Cost of Jacking/Traffic Control	5,000.00
Total Cost	8,000.00

Activity	Year	Cost ($)	PV ($)
Steel Bearing Replacement	20	8,000.00	3,651.10
Steel Bearing Replacement	40	8,000.00	1,666.31
Steel Bearing Replacement	60	8,000.00	760.48
			$6,078

ALTERNATIVE 1B: Steel bridge bearing maintenance activities

Activity	Year	Cost ($)	PV ($)
Cleaning/Washing @ 2 years	2 to 74	200.00	2,316.43
Lubricating @ 4 years	4 to 72	100.00	549.65
Spot Painting @ 10 years	10 to 70	200.00	361.57
Steel Bearing Replacement	50	8,000.00	1,125.70
			$4,353

ALTERNATIVE 2A: No elastomeric bridge bearing maintenance activities

Cost of Elastomeric Bearing Replacement	
Cost of Elastomeric Bearing	500.00
Cost of Jacking/Traffic Control	5,000.00
Total Cost	5,500.00

Activity	Year	Cost ($)	PV ($)
Elastomeric Bearing Replacement	20	5,500.00	2,510.13
Elastomeric Bearing Replacement	40	5,500.00	1,145.59
Elastomeric Bearing Replacement	60	5,500.00	522.83
			$4,179

ALTERNATIVE 2B: Elastomeric bridge bearing maintenance activities

Activity	Year	Cost ($)	PV ($)
Cleaning/Washing @ 2 years	2 to 74	200.00	2,316.43
Steel Bearing Replacement	50	5,500.00	773.92
			$3,090

APPENDIX F5: APPROACH SLAB MAINTENANCE

F5.1. INTRODUCTION

Bridge approach pavement settlement is a common problem that often produces a “bump,” a notable difference at the encounter of pavement and bridge abutments. The “bump” problem is caused by uneven settlement due to the different characteristics of the pavement and bridge foundations. The bridge abutments are typically founded on a rigid and stable deep foundation, such as bedrock, producing minimal settlements. On the other hand, the approach pavement is supported by an embankment of compacted backfill soil, which is more flexible and prone to more pronounced settlements (Helwany, Koutnik, & Ghorbanpoor, 2007; Hopkins, 1985; Islam, 2010). According to Mishra et al. (2010) 25% of U.S. bridges suffer from this problem, and 44% of the state DOTs consider it a “major” problem (Hoppe, 1999). When unattended, bumps at bridge approaches affect negatively the road and bridge service life.

The use of a reinforced concrete approach slab is an alternative to eliminate or reduce the approach pavement settlement problem, acting as a connection between the bridge abutment and the pavement (Dupont & Allen, 2002). Typically, the approach slab is supported at one end by the bridge abutment and at the other end by a concrete sleeper slab. Figure F5.1 presents the elements in a typical bridge approach system. The concrete approach slab provides a smooth transition between the bridge and roadway, keeping the differential settlement under a lower limit (Hoppe, 1999; Puppala, Archeewa, Saride, Nazaria, & Hoyos, 2012).

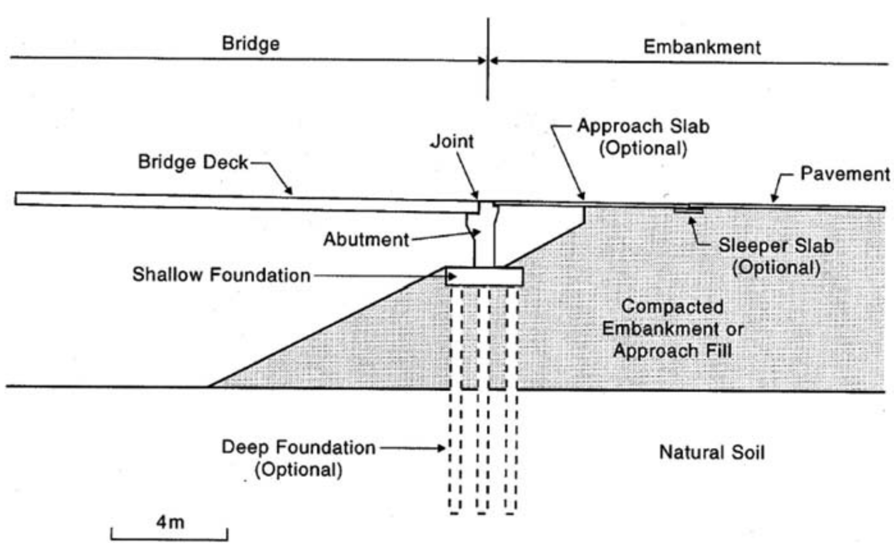

Figure F5.1 Elements in a typical bridge approach system (Briaud, James, & Hoffman, 1997).

F5.2. PROBLEMS ON BRIDGE APPROACH SLAB

The problems of bridge approach slabs are related to the loss of support material under the slab. The development of voids beneath the slab have many causes with the same result, the formation of cracks and settlements, which eventually lead to the failure of the slab approach. These problems are originated by one or more than one of the following causes (Dupont & Allen, 2002; Puppala et al., 2012; Wahls, 1990):

- Foundation compression
- Embankment compression
- Poor compaction near the abutment
- Erosion of embankment at abutment face
- Improper drainage on embankment and abutment fill
- Poor expansion joints condition
- Approach slab design
- Abutment and foundation type
- Construction and supervision

Figure F5.2 shows the different problems that can lead to the formation of a bump at the bridge approach, and the approach slab deterioration.

Problems related to material properties and design/construction issues can only be solved throughout rehabilitation or reconstruction of the corresponding structures. The other remaining approach slab problems are related to water intrusion into the embankment and backfill, and can be classified based on the following three different causes.

F5.2.1 Damaged Expansion Joints

Damaged expansion joints allow infiltration of water below the approach slab, generating saturation of the base/subgrade, erosion of the fill material, and causing settlements and deterioration of the slab (Abu-Hejleh, Hanneman, White, Wang, & Ksouri, 2006; Jayawickrama, Nash, Leaverton, & Mishra, 2005; Mishra, Jayawickrama, & Nash, 2010).

F5.2.2 Development of Cracks/Potholes in the Approach Slab Surface

Moisture reaching the slab subsurface through slab surface cracks and potholes can erode the base and sub-grade material underneath. As a consequence, the slab experiences pronounced settlements, and formation of more cracks and potholes, accentuating the deterioration process (Jayawickrama et al., 2005).

F5.2.3 Poor Bridge Approach Slab Drainage System

Settlement of the bridge approach slab is caused by a poor drainage system below the slab and behind the abutments. A poor drainage system allows water accumulation in the embankment and abutment fill, which leads to soil erosion, softening of soil zones, slope stability failures, increment of hydrostatic pressures, and pumping of fines (Abu-Hejleh et al., 2006; Helwany et al., 2007; Mishra et al., 2010).

F5.3. PREVENTIVE MAINTENANCE ACTIVITIES FOR APPROACH SLAB

Keeping the expansion joints in good condition, the slab surface without deterioration, and the bridge approach slab drainage system operating suitably are three conditions that will ensure adequate performance of the bridge approach slab. Preventive maintenance activities can be performed to preserve the three aforementioned conditions, allowing the approach slab to achieve its expected service life. The required preventive maintenance activities are described as follow.

F5.3.1 Maintenance of Approach Slab Expansion Joints

Surface water from the bridge deck and approach slab can flow into the material beneath the approach slab through damaged seals at the expansion joints located between the bridge approach slab and abutments. Also, malfunction of joints produces crushing and cracking of surrounding concrete, allowing water infiltration. The infiltrated water can erode the fill material producing voids under the slab which subsequently will experience settlements, more cracks, and possible failure (Abu-Hejleh et al., 2006; Puppala et al., 2012). A deteriorated deck-slab approach joint is presented in Figure F5.3.

Preventive maintenance of expansion joints is significant and should be carried out regularly. Based on the study for bridge deck joints, approach slab joints should be cleaned and flushed every year and replaced every 15 years.

F5.3.2 Maintenance of Approach Slab Surface

Surface water can leak into the base and sub-base material through approach slab cracks, producing erosion and voids in the

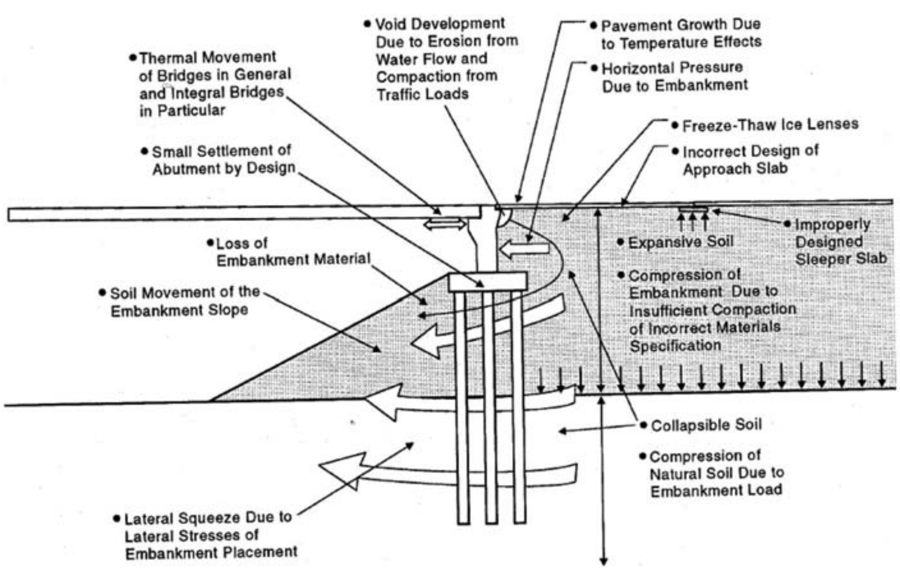

Figure F5.2 Problems leading to the existence of a bump (Briaud et al., 1997).

Figure F5.3 Poorly maintained wide joint between bridge deck and approach slab (Jayawickrama et al., 2005).

Figure F5.4 Damaged approach slab showing surface cracks (Abu-Hejleh et al., 2006).

soil material under the approach slab (Figure F5.2). As a consequence, considerable settlements and more cracks can be developed, leading to slab failure (Abu-Hejleh et al., 2006; Mishra et al., 2010). In Figure F5.4 is presented a slab approach showing severe damage.

Preventive maintenance activities should be performed on the approach slab surface to avoid or delay the formation of cracks. Based on the study of concrete deck maintenance, the following maintenance activities should be applied:

- Seal approach slab with a penetrating sealant after 3 to 6 months of slab construction
- Seal all slab cracks with epoxy and/or sealant.
- Repeat the indicated maintenance activities every 5 years

F5.3.3 Maintenance of the Bridge Approach Slab Drainage System

Adequate surface and subsurface drainage is essential to maintain good condition of approach slab. A bridge approach drainage system collects drainage immediately upslope and downslope of the bridge, and can be divided into two categories: surface drainage and subsurface drainage (Jayawickrama et al., 2005; Wahls, 1990).

The surface drainage system collects the water from the surface of the approach slab and its surrounding, avoiding ponding or infiltration into the base/sub-base material. The surface drainage system employs shoulders, swales, gutters, ditches, channels, inlets, etc. Because some water always infiltrates into the base/sub-base material, a subsurface drainage system is required to intercept, collect and eliminate the water that reaches the interior of the fill and embankment below the approach slab. The subsurface drainage employs edge drains, drainage pipes, and permeable bases.

Regular preventive maintenance activities include cleanout and flushing of all drains, inlets, and outlets, eliminating all debris accumulated in the system. Based on the study of cleaning and flushing the bridge deck, the approach slab drainage systems, both surface and subsurface, should be cleaned and flushed every year. Figure F5.5 presents a gutter without appropriate maintenance.

Figure F5.5 Drainage system obstructed by accumulation of weeds and debris (Jayawickrama et al., 2005).

F5.4. CONCLUSIONS AND RECOMMENDATIONS

F5.4.1 Conclusions

There are some problems on approach slabs related to quality of materials and design/construction issues than can only be solved by rehabilitation or reconstruction. Water intrusion in the fill and embankment is one of the major negative factors that affect an approach slab performance. Preventive maintenance activities applied to expansion joints, slab surface, and the drainage system, can avoid the intrusion of water into the fill and embankment or facilitate its elimination, preserving the integrity of the approach slab. Maintenance of a bridge approach slab can be studied in the same manner than a bridge concrete deck.

F5.4.2 Recommendations

It is recommended that INDOT should incorporate a preventive maintenance plan for bridge approach slabs, considering the following activities:

- Seal the approach slab with a penetrating sealant after three to six months of slab construction.
- Seal all slab cracks whit epoxy and/or sealant.
- Repeat the slab and cracks sealing every five years.
- Clean and flush the approach slab joints every year and replace them every ten years.
- Clean and flush the approach slab drainage systems every year.

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APPENDIX F6: SUPERSTRUCTURE WASHING

F6.1. INTRODUCTION

Modern steel bridges require an adequate protective system to resist general corrosion attack and stand for their expected service life. The most widely used protective systems have been the use of either coating systems or the use of weathering steel (AISI, 1995; Corus, 2012). Exposure of steel bridge structures to polluted environments, continuous wet and dry cycles, leaking of deicing solutions from the deck, accumulation of dirt and debris, and spray of water and salts by tires of moving vehicles are the common sources to initiate the process of corrosion on steel elements. Figure F6.1 shows a steel girder damaged due to advanced corrosion process.

The application of a regular bridge superstructure washing program is believed to remove chloride ions from steel surfaces, thereby reducing the corrosion process. However, there is not total agreement in the effectiveness of bridge washing in extending the service life of steel coatings and weathering steel. The specialized literature shows few studies analyzing the benefits of bridge washing to reduce the corrosion or extend the service life of steel coatings (Berman, Roeder, & Burgdorfer, 2013).

F6.2. BRIDGE WASHING PROGRAMS AT DOTS

Many State Department of Transportation (DOT's) consider that regular bridge washing is an effective way to slow corrosion on weathering steel and extend the service life of steel coatings life (Berman et al., 2013; Crampton, Holloway, & Fraczek, 2013). The Berman et al. (2013) study performed a national survey on steel bridge superstructure washing programs. The survey requested the following from those DOT's that perform a bridge washing program: more details in relation to the time when the program started, the method used to wash the bridge superstructure, the frequency of the washing and whether the decision of implementing the program was based on factual demonstration of the benefits of steel bridge superstructure washing. The pertinent information from the survey is presented in the Table F6.1.

Data from Table F6.1 reported that some states practice routine bridge washing programs. The methods of washing have a common pattern, with a first stage of dry cleaning, when all type of debris and materials are collected by brushes and shovels, then a spray washing with normal water hose pressures is applied to steel elements, as

Figure F6.1 Loss of section on steel girder due to corrosion (Zaffetti, 2010).

TABLE F6.1
Information from DOT's national survey on bridge washing programs (Berman et al., 2013).

Agency	Washing program characteristics	Washing method	Frequency of washing	Correlation
Alaska Department of Transportation and Public Facilities (ADOT&PF)	Started a bridge inspection program in 2004 labeled the Fracture Critical Inspection Program (FCIP). There is rarely an issue with regulations as salt is rarely used.	Bridges at the interior of the state have debris cleared off with compressed air. Bridges located in the coastal regions are washed with low pressure hoses, without any dry debris collected beforehand, and then a spray washing is applied.	Every bridge under FCIP is cleaned and inspected every 2 years.	The Alaska DOT has not studied any correlation between bridge washing and paint life or corrosion.
Kentucky Transportation Cabinet (KYTC)	Started a bridge washing program beginning in 2010. Only bridges in moderately good condition are chosen to be cleaned. Focused on washing the lower chords, abutments, joints, and any other problem/splash areas	The KYTC collects the majority of solid waste with brooms and shovels before spray washing.	Paint and corrosion do not specifically determine when a bridge is scheduled to be washed.	The KYTC have drawn no correlation between paint life/corrosion and bridge washing.
New York State Bridge Authority (NYSBA)	The NYSBA initiated their bridge washing program in the 1960's. Salt is not used on bridge decks as a deicer, but instead they use sand.	There is a dry-cleaning process in which the sand and other debris is swept and shoveled up and disposed of before spraying. The bridge is then sprayed at garden hose pressure with water.	All bridge sections are washed annually. Paint condition and corrosion are assessed visually on an annual basis.	The NYSBA has no documented correlation between bridge washing and paint life but remarked that they have only needed about 25,000 pounds of steel replacement in the past 80 years.
New Hampshire Department of Transportation (NHDOT)	NHDOT has had a bridge washing program since the 1970's.	There is a dry-cleaning process that involves sweeping, shoveling, and collecting debris before spraying. Dry cleaning and spray washing focus mainly on splash areas (spray from tires) and only occasionally move to the underside of the bridge deck.	According to the program, every bridge is ideally washed every other year. Paint condition and corrosion are assessed visually during inspection.	The NHDOT has completed no studies on the correlation between bridge washing and paint life.
Missouri Department of Transportation (MoDOT)	MoDOT has had a bridge washing program in effect since 2002.	There is a dry-cleaning process that involves sweeping, shoveling, and removal of debris before spraying but this is not performed during every washing.	Every bridge is washed twice per year; once in the spring and once in the fall. Paint condition and corrosion are assessed visually during inspection and given a rating. These two attributes do not determine if a bridge is slated to be washed.	The MoDOT has no documented correlation between bridge washing and paint life.

shown in Figure F6.2. Only a few states, under special conditions, collect the effluents resulting from the flushing process.

The information reported is conclusive that no state has a study supporting a correlation between the steel bridge washing programs and the improvement of coating systems and reduction of the corrosion process on girders. A particular case is the state of New York, which has a long history of using bridge washing. The New York State Bridge Authority (NYSBA) reported that in 80 years they needed to replace only 13 tons of steel from their bridges, which can be considered as a direct consequence of its washing program, but in conjunction with all of the other maintenance activities they apply to their steel bridges.

According to a study for the Iowa Department of Transportation (Crampton et al., 2013), there does not exist a reliable method to measure the level of chloride contamination in the patina layer developed on the surface of weathering steel, and consequently, it cannot be possible to define what level of chloride contamination is detrimental for the patina performance.

Figure F6.2 Steel bridge superstructure washing (Crampton et al., 2013).

F6.3. RESEARCH ON BRIDGE SUPERSTRUCTURE WASHING

There is not conclusive information on the effectiveness of bridge washing activities to increase the service life of steel coatings or to reduce the effects of the corrosion process. The references on bridge washing effectiveness are mostly based on assumptions or beliefs, rather than formal and documented studies showing conclusive results. In the following, some studies on benefits of steel bridge washing are presented and analyzed.

FHWA Technical Advisory (1989)

In 1988 the Federal Highway Administration sponsored a Weathering Steel Forum, with specialists from throughout the US. The speakers presented histories and data from studies on the use of weathering steel in highway structures. As a result of the event, suggested guidelines were presented as recommendations to achieve the greatest potential of the product (FHWA, 1989).

One of the recommendations from the guidelines was focused on maintenance actions, indicating that "effective inspection and maintenance programs are essential to ensure that all bridges reach their intended service life. This is especially true in the case of uncoated weathering steel bridges" (FHWA, 1989). Some specific maintenance activities recommended by the document were: "Remove dirt, debris and other deposits that hold moisture and maintain a wet surface condition on the steel. In some situations, hosing down a bridge to remove debris and contaminants may be practical and effective. Some agencies have a regularly scheduled program to hose down their bridges."

Hara et al. (2005)

The Shikoku Regional Bureau of Japan Highway Public Co. (JH) conducted a pilot study from 2001 to 2004 based on the behavior of two weathering steel bridges under an experimental bridge washing program. The focus of the study was to analyze the effect of bridge superstructure washing as a mean to eliminate corrosive products derived from deicers applied on bridge decks.

During the study fixed points on the bridge girders were observed and documented once a year, before and after the application of deicers products. For those points in the steel surface the loss of mass and rust characteristics were analyzed. The researchers concluded that washing the steel surface had the effect of suppressing the increase of rust particles size, and this was a way to reduce the corrosion due to deicer products (Hara, Miura, Uchiumi, Fujiwara, & Yamamoto, 2005).

Crampton et al. (2013)

The Iowa Department of Transportation (Iowa DOT) together with Wiss, Janney, Elsner Associates, Inc. (WJE), studied the behavior of steel weathering bridge structures. The research considered methods to assess the quality of the weathering steel patina layer and chloride contamination, and the possible benefits from regular bridge washing.

The study concluded that high-pressure washing (3,500 psi) is an adequate procedure to reduce chloride ion concentrations on weathering steel patinas; however, not all chlorides could be completely eliminated. This could indicate that bridge superstructure washing mainly removes chlorides from the patina surface, while some amount of chlorides remains under the patina surface, inside the pores and voids of the patina. WJE found that when performed immediately after the winter deicing season, bridge washing will be able to remove the majority of chloride products, before they migrate under the patina layer, as predicted by Fick's Law (Crampton et al., 2013). Therefore, the study concluded that repeating bridge washing on a regular basis will reduce the corrosion process on the steel girders, but qualified this conclusion and indicated that further study needs to be conducted on this topic.

Berman et al. (2013)

This study sponsored by the Washington State Department of Transportation (WSDOT) and the Federal Highway Administration (FHWA) analyzed the costs and benefits of regular washing of steel bridges. The study was implemented in 2011, consisting in washing some bridges annually while some other would not be washed (Berman et al., 2013). WSDOT inspectors will annually inspect each bridge from the project and will record steel coating condition and corrosion level, for both, washed and unwashed bridges. Processing the data obtained annually will indicate the cost effectiveness of bridge washing for extending steel coating life and retarding the corrosion process. The project is at present under development.

Purdue University (Moran Yanez, 2016)

A research study on the benefits of regular bridge washing was recently conducted at Purdue University (Moran Yanez, 2016). Plain carbon steel as well as weathering steel plates, coated and uncoated, have been tested under an accelerated corrosion process. The plates were grouped in sets and washed regularly following different frequencies (weekly, every other week, etc.). One set of plates was never washed to work as a control group. Preliminary results from the study indicate no conclusive correlation between the frequency of washing activities and the reduction of the steel corrosion process for the uncoated set of plates. The coated sets of plates do not show any signs of corrosion on the coated surface, concluding that the accelerated corrosion process was not long enough to produce damage on the coating system.

Other sets of coated plates were analyzed when a scratch was made on the coated surface and then a rust-inhibiting spray paint was applied to the scratch. Preliminary results show the benefits of spot painting under an accelerated corrosion process.

F6.4. BRIDGE WASHING BENEFITS

According to a Rhode Island Department of Transportation study (RIDOT, 2002), washing steel bridges could offer several benefits, both in the short term to optimize bridge inspections and in the long term by reducing the steel corrosion process and extending the service life of the steel coatings.

1. Bridge Inspection Quality

It is a common situation for steel girders, concrete beams, seat bearings, and all type of horizontal surfaces below the bridge deck, to be covered by sand, mud, salt, bird droppings, bird nests and other foreign materials. Figure F6.3 shows the interior of some truss element presenting bird droppings and rubbish. Bridge inspection is based principally on visual observation; therefore, an unobstructed view of the steel element surface is needed. Without an appropriate cleaning and washing of those foreign materials, the inspection performance will not be as accurate as it should be (Crampton et al., 2013).

2. Bridge Inspector Safety

The presence of organic materials (bird droppings, waste of nests, etc.) covering the superstructure could be a serious health hazard for bridge inspectors. This problem is clearly presented in Figure F6.3. Performing bridge washing just before the bridge inspection will help to reduce those health hazards to inspectors (RIDOT, 2002).

3. Structural Benefits

As referenced by previous studies, bridge washing is believed to be beneficial for bridge integrity, extending the life of steel coatings and slowing the steel corrosion process. Although, still more research needs to be done to determine the cost-benefit of a regular washing program.

F6.5. ECONOMIC ANALYSIS

The Rhode Island Department of Transportation study (RIDOT, 2002) performed an economic analysis of washing Interstate highway bridges. The analysis was done applying the FHWA PONTIS program to a random sample of 96 steel bridges from the state inventory. PONTIS utilizes mathematical formulas and probability estimates to predict future bridge conditions, based on current condition and the application of hypothetical actions on the structure. In this case, an eight years period (arbitrary) was considered as a framework for two alternatives. One alternative was the Do Nothing (DN) alternative during the eight years period, while the other alternative was the implementation of a regular bridge cleaning and washing program, performed each two years during the eight years.

The PONTIS element No. 107 "Painted steel open girder" was utilized for the analysis. The PONTIS program classifies the condition of a "Painted steel open girder" in a five levels scale (1 to 5) as shown in Appendix F6.1. The classification of the 96 bridges according to the initial condition state classification is shown in Table F6.2.

Figure F6.3 Interior of lower chord from truss. Before (left) and after (right) cleaning and washing (Berman et al., 2013).

According to the feasible maintenance options that can be done to the PONTIS element No. 107 "Painted steel open girder," only bridges in condition 1 and 2 are recommended for clean and wash action. Therefore, only 45 bridges (13 bridges in condition state 1 and 32 bridges in condition state 2) are recommended to be cleaned and washed. The remaining 51 bridges from the initial sample in state conditions 3, 4 and 5 are not considered for the analysis, since cleaning and washing is not prescribed to those condition states. On the other hand, the No Maintenance alternative can always be considered for all 5 condition states.

Based on transitional probabilities, the study assumed the percentages of probability that one element remains on its current state or decreases one level when nothing is done to protect it. On the other hand, there is a 100% (certainty) that an element in conditions 1 or 2 will remain in its current condition when using a regular washing program.

After applying the transitional probabilities to the selected 45 bridges, each two years for a period of eight years, the predicted conditions of the bridges are obtained for both alternatives. Table F6.3 presents the predicted condition state for the 45 bridges for the Do Nothing alternative.

The predicted conditions of bridges for the second alternative, performing bridge cleaning and washing each two years during eight years, are presented in Table F6.4. Details of the probability analysis are presented in Appendix F6.2, detailing the changes in state conditions for the 45 selected bridges.

The economic analysis used the unit costs presented in Table F6.5, which are based on the element condition and the corresponding maintenance activities.

Using the predicted element condition and the provided costs of maintenances, the total cost of maintenances for the 45 selected bridges can be evaluated after the eight years cycle considered. For the Do Nothing alternative, the total cost is the result of applying the corresponding maintenance activity to each bridge at the end of the eight years, as presented in Table F6.6.

TABLE F6.2
Sample of 96 bridges classified by their initial condition state.

	Condition state					
	1	**2**	**3**	**4**	**5**	**Total**
# Bridges	13	32	22	25	4	96

TABLE F6.3
Predicted condition of selected 45 bridges after 8 years for the Do Nothing alternative.

	Condition state					
	1	2	3	4	5	Total
# Bridges	5	16	16	6	2	45

TABLE F6.4
Predicted condition of selected 45 bridges after 8 years for the clean and wash alternative.

	Condition state					
	1	**2**	**3**	**4**	**5**	**Total**
# Bridges	13	32	0	0	0	45

TABLE F6.5
Unit costs for different maintenance activities on painted steel girder (RIDOT, 2002).

Condition state	Action	Cost
	Do Nothing	No cost
C1, C2	Wash and clean steel	$0.10 per SF: say $2,000 per bridge
C3	Spot blast, clean & paint	$2.00 per SF: say $40,000 per bridge
C4	Spot blast, clean & paint	$3.00 per SF: say $60,000 per bridge
C5	Major rehab. unit	$5.00 per SF: say $100,000 per bridge

TABLE F6.6
Total cost of maintenance for 45 bridges under the Do Nothing alternative (RIDOT, 2002).

Condition	Cost of maintenance ($)	No. of bridges	Cost ($)
1	2,000.00	5	10,000.00
2	2,000.00	16	32,000.00
3	40,000.00	16	640,000.00
4	60,000.00	6	360,000.00
5	100,000.00	2	200,000.00
	Total	45	1,242,000.00

For the second alternative, cleaning and washing 45 bridges each two years, for eight years, results in a total cost of

45 bridges x $2,000 x 4 times = **$ 360,000**

The total costs for both alternatives show that providing a regular maintenance program to a painted steel open girder, consisting of cleaning and washing, would be more effective than the Do Nothing alternative.

F6.6. CONCLUSIONS AND RECOMMENDATIONS

F6.6.1 Conclusions

There is a lack of conclusive studies proven the benefits of bridge washing as an effective maintenance activity to reduce the corrosion process in the long term. There is a common agreement in the benefits of regular cleaning and washing steel bridges, which is based on opinions, beliefs, and few factual steel bridge performances. Bridge washing is an important maintenance activity in the short time, since it allows better inspection procedures and provides less hazard conditions for bridge inspectors.

F6.6.2 Recommendations

Steel bridge washing should be part of a comprehensive bridge maintenance program, incorporating cleaning the deck surface and cleaning and washing drains, joints, bearings, and all other important bridge elements.

Based on all the literature reviewed, the research presented in this report, and the positive experiences reported by some transportation agencies, it is advisable that INDOT should implement a regular steel bridge washing program, on a frequency of each two years, after the end of winter season and before inspection procedures are conducted. Preferable perform this activity after the end of the winter season. Verify there is low contaminant when discharging to a stream under the bridge.

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APPENDIX F6.1: PONTIS ELEMENT 107—PAINTED STEEL OPEN GIRDER

CONDITION STATES DESCRIPTIONS

This element defines only those steel open girder units that are painted. This element includes two girder systems as well as rolled beams on multiple beam spans.

Condition State 1

There is no evidence of active corrosion and the paint system is sound and functioning as intended to protect the metal surface.

Feasible actions

- Do nothing
- Surface clean

Condition State 2

There is little or no active corrosion. Surface or freckled rust has formed or is forming. The paint system may be chalking, peeling, curling or showing other early evidence of paint system distress but there is no exposure of metal.

Feasible actions

- Do nothing
- Surface clean
- Clean and paint

Condition State 3

Surface or freckled rust is prevalent. There may be exposed metal but there is no active corrosion which is causing loss of section.

Feasible actions

- Do nothing
- Spot blast, clean and paint

Condition State 4

Corrosion may be present but any section loss due to active corrosion does not yet warrant structural analysis of either the element or the bridge.

Feasible actions

- Do nothing
- Spot blast, clean and paint
- Replace paint system

Condition State 5

Corrosion has caused section loss and is sufficient to warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge.

Feasible actions

- Do nothing
- Rehab unit
- Replace unit

APPENDIX F6.2

A. FIRST SCENARIO (DO NOTHING)

A.1 Analyzing 13 Bridges Initially in Condition 1 (4 cycles of 2 years each)

- End of first 2-year period: C1 = 13 x 0.76* = 10 bridges

$C2 = 13x0.24^* = 3$ bridges

- End of second 2-year period: C1 = 10 x 0.76* = 8 bridges

$\left.\begin{array}{l} C2 = 10x0.24^* = 2 \text{ bridges} \\ C2 = 3x0.76^* = 2 \text{ bridges} \\ C3 = 3x0.24^* = 1 \text{ bridges} \end{array}\right\} 4 \text{ bridges}$

- End of third 2-year period: C1 = 8 x 0.76* = 6 bridges

$\left.\begin{array}{l} C2 = 8x0.24^* = 2 \text{ bridges} \\ C2 = 4x0.76^* = 3 \text{ bridges} \end{array}\right\} 5 \text{ bridges}$

$\left.\begin{array}{l} C3 = 4x0.24^* = 1 \text{ bridges} \\ C2 = 1x0.76^* = 1 \text{ bridges} \end{array}\right\} 2 \text{ bridges}$

$C4 = 1x0.24^* = 1$ bridges

- End of fourth 2 year period: C1 = 6 x 0.76* = 5 bridges

$\left.\begin{array}{l} C2 = 6x0.24^* = 1 \text{ bridges} \\ C2 = 5x0.76^* = 4 \text{ bridges} \end{array}\right\} 5 \text{ bridges}$

$\left.\begin{array}{l} C3 = 5x0.24^* = 1 \text{ bridges} \\ C3 = 2x0.76^* = 2 \text{ bridges} \end{array}\right\} 3 \text{ bridges}$

$C4 = 2x0.24^* = 0$ bridges

* Transitional probability from expert elicitation.

Therefore at the end of four 2-year periods, or 8 years, the deterioration as a result of Do Nothing (DN) will end with the 13 bridges, originally all in condition state one (1), in the following condition states.

	Condition State					
	1	2	3	4	5	Total
# Bridges	5	5	3	0	0	13

A.2 Analyzing 32 Bridges Initially in Condition 2 (4 cycles of 2 years each)

- End of first 2-year period: C2 = 32 x 0.76* = 24 bridges

C3 = 32 x 0.24* = 8 bridges

- End of second 2-year period: C2 = 24 x 0.76* = 18 bridges

$\left.\begin{array}{l} C3 = 24x0.24^* = 6 \text{ bridges} \\ C3 = 8x0.76^* = 6 \text{ bridges} \\ C4 = 8x0.24^* = 2 \text{ bridges} \end{array}\right\} 12 \text{ bridges}$

- End of third 2-year period: C2 = 18 x 0.76* = 14 bridges

$\left.\begin{array}{l} C3 = 18x0.24^* = 4 \text{ bridges} \\ C3 = 12x0.76^* = 9 \text{ bridges} \end{array}\right\} 13 \text{ bridges}$

$\left.\begin{array}{l} C4 = 12x0.24^* = 3 \text{ bridges} \\ C4 = 2x0.76^* = 2 \text{ bridges} \end{array}\right\} 5 \text{ bridges}$

$C5 = 2 \times 0.24^* = 0$ bridges

- End of fourth 2-year period:
  C2 = 14 x 0.76* = 11 bridges

$\left.\begin{array}{l} C3 = 14x0.24^* = 3 \text{ bridges} \\ C3 = 13x0.76^* = 10 \text{ bridges} \end{array}\right\} 13 \text{ bridges}$

$\left.\begin{array}{l} C4 = 13x0.24^* = 3 \text{ bridges} \\ C4 = 5x0.63^* = 3 \text{ bridges} \end{array}\right\} 6 \text{ bridges}$

C5 = 5 x 0.37* = 2 bridges

* Transitional probability from expert elicitation.

Therefore, at end of four 2-year periods, or 8 years, the deterioration as a result of Do Nothing (DN) will end with the 32 bridges, originally all in condition state two (2), in the following condition states.

	Condition State					
	1	2	3	4	5	Total
# **Bridges**	0	11	13	6	2	32

Finally, **for the first scenario, Do Nothing,** the total amount of bridges, in the predicted conditions results in:

Condition 1: 5 + 0 = 5 bridges
Condition 2: 5 + 11 = 16 bridges
Condition 3: 3 + 13 = 16 bridges
Condition 4: 0 + 6 = 6 bridges
Condition 5: 0 + 2 = 2 bridges
TOTAL: 45 bridges

B. SECOND SCENARIO (CLEAN AND WASH)

B.1 Analyzing 13 Bridges Initially in Condition 1 (4 cycles of 2 years each)

- End of 1st 2 year period: C1 = 13 x 1.0 = 13 bridges

(Immediately after action) C2 = 13 x 0.0 = 0 bridges

- End of 2nd 2 year period: C1 = 13 x 1.0 = 13 bridges

(Immediately after action) C2 = 13 x 0.0 = 0 bridges

- End of 3rd and 4th 2 year periods, theoretically all original 13 bridges will remain in condition 1, if cleaned and washed.

B.2 Analyzing 32 Bridges Initially in Condition 2 (4 cycles of 2 years each)

- At end of 8 years, theoretically all original 32 bridges will remain in condition 2, if cleaned and washed.

Finally, **for the second scenario, Cleaning and Washing Surface,** the total amount of bridges, in the predicted conditions results in:

Condition 1: 13 bridges
Condition 2: 32 bridges
Condition 3: 0 bridges
Condition 4: 0 bridges
Condition 5: 0 bridges
TOTAL: 45 bridges

APPENDIX F7: SPOT PAINTING

F7.1. INTRODUCTION

The development of the U.S. interstate highway system took place between the 1950's through the 1970's, at the same time when the majority of steel bridges were built. At present those bridges are experiencing significant need for maintenance and rehabilitation. Figure F7.1 shows a bridge with typical steel girders showing extended damage in its coating. Most of the bridges were built using carbon steel. To protect the bridges from corrosion due to atmospheric conditions, all steel pieces were coated with lead-based paint systems, without any type of surface treatment (Farschon, Kogler, & Ault, 1997; Yunovich, Thompson, Balvanyos, & Lave, 2014). In recent years more steel protection systems have been implemented, including hot and cold galvanizing, thermal coatings, and the use of weathering steel (Yuan, 2005). From all available methods, paint systems have been chosen as the most preferable alternative to protect carbon steel bridges, based on its relative low cost and simplicity of application.

Figure F7.1 Steel girder coating showing damages (Meade, 2013).

Since the end of 1980's abrasive blasting of old lead-based paints and the removal of various pollutants on the steel surface have been reduced due to environmental concerns from government authorities (Bernecki et al., 1997). Consequently, more stringent environmental requirements and safety conditions for workers have been mandated by legislation requirements, making procedures for abrasive blasting, residuals elimination, and repainting operations more regulated and expensive (Bernecki et al., 1997; Hopwood & Oberst, 1996; Zayed, Chang, & Fricker, 2001b). By 1995, because of the ostensible cost increment, several highway agencies had ceased or reduced their bridge repainting operations. Painting maintenance activities are considered an economical option to extend the coating service life of steel bridges. In particular, spot painting, when applied appropriately, is a low cost alternative to more advanced and expensive methods, due to the reduced working area and required resources.

F7.2. MAINTENANCE FOR STEEL BRIDGE COATING

Maintenance painting practices on steel bridges have changed dramatically in the last decades in the United States. Before the adoption of current regulations regarding steel bridge coating, maintenance practices consisted in performing a simple hand tool cleaning of surfaces or a power blasting of original substrates, and the application of new fresh paint layers, without special protection to the workers and concerns with the environment. (Hopwood & Oberst, 1996). Due to current higher costs of total repainting including protection measures, maintenance activities are sought as more efficient alternatives to extend the service life of the structure. Coating maintenance activities are listed in the following (Kline, 2012; Richards & Grisso, 2013):

- Spot painting: Cleaning, treatment and coating of very small damaged area on original coating. Figure F7.2 shows a candidate girder for spot painting.
- Zone painting: Cleaning, treatment and coating of a defined damaged area on original coating.
- Overcoating: Application of a full coating over an existing coating, after appropriate cleaning.

Figure F7.2 Steel girder candidate for spot painting (MoDOT, 2010).

- Repaint: Full removal of the existing coating system and application of a new enhanced coating system.

In some cases, a combination of spot and zone painting can result in a convenient and effective solution.

F7.3. SPOT PAINTING MAINTENANCE

Spot painting maintenance is the treatment of only a small area showing damaged paint or the initiation of corrosion. Localized damage during girder erection is a good candidate for spot painting. The activity involves: (1) surface cleaning of the damaged paint or corroded material using hand/power tools, and (2) application of a paint system (brush or roller) compatible with the original coating, including a primer coat, an intermediate, and a finish coat. The application of spot painting as soon as possible provides adequate benefits, since the progress of the problem is stopped at an early age, avoiding the progress to a more significant area, which will require more complex and expensive painting treatment (Lanterman, 2009; Rossow, 2009). Spot painting is cost effective only when less than the 1% of the total surface area is damaged or it has a corrosion grade of 7 or above according to the scale described in ASTM D610 (ASTM, 2012; Chan, 2003).

Some advantages offered by spot painting can be the reduced surface to be treated, minimal application of a paint system, and less expense than other alternatives. On the other hand, some disadvantages that can be observed are the lowering of aesthetics due to a lack of uniformity in the finishing color, requirement of more frequent treatment, and a more expensive unit cost activity (Rea, 2014; Richards & Grisso, 2013). Spot painting is applied for many states in the U.S. such as New York, New Jersey, Virginia, Pennsylvania, Washington, Oregon, New Hampshire, Maine, and Minnesota.

F7.4. COST OF SPOT PAINTING

The unit cost ($/ft^2) of spot painting is the sum of costs of surface preparation, materials, and application procedures. Costs of surface preparation and application procedures are strongly influenced by the work conditions (accessibility, height above the ground, environment, etc.). Table F7.1 presents a relation of averaged unit cost for spot painting from different sources.

F7.5. SERVICE LIFE OF SPOT PAINTING

The service life of a coating system is affected by many factors, such as climate, age and traffic conditions (Fricker, Zayed, & Chang, 1999). Aggressive weather will undoubtedly reduce the service life of the coating system. The most important requirement to achieve a long service life for any coating is a good application, and more specifically, an outstanding surface preparation. The service life of a spot painting application will vary considerably, depending on those affecting factors. Table F7.2 shows a list of expected service life for spot painting from different researchers.

TABLE F7.1
Cost of spot painting.

Researcher/DOT	Cost ($/ft^2)[1]
Chan, 2003	3–6
IDOT, 1998[2]	5
INDOT, 1998[2]	2.8
Kaito et al., 2001	6
Kline, 2012	2
MDOT, 1998[2]	9.3
ODOT, 1998[2]	4–6
Richards & Grisso, 2013	2–3
Sharp et al., 2013	6.5
Yuan, 2005	3–6

[1]Ft^2 of total surface area.
[2]Compiled and reported by Zayed et al. (2001b).

TABLE F7.2
Service life of spot painting.

Researcher/DOT	Service life (yr)
Chan, 2003	10–15
Fricker et al., 1999	15
Helsel et al., 2008	4–5
MDOT, 2011	5
Petcherdchoo et al., 2008	10–15
Yuan, 2005	10–15
Yunovich et al., 2014	4
Zayed et al., 2001a	15

F7.6. LIFE-CYCLE COST ANALYSIS

An economic analysis based on the present value (PV) is an acceptable option to analyze different scenarios on bridge painting. With this tool, the cost of different maintenance strategies can be compared. For comparison purposes, one of the alternatives is the "do nothing" option, which allows no maintenance at all to be compared against the different maintenance strategies. Several studies have performed a life-cycle cost analysis for steel bridge coating maintenance systems. Economic analyses from these studies are summarized in the following.

Tam and Steimer (1996)

The research by Tam and Steimer (1996) performed a life-cycle cost analysis using the method of the equivalent annual costs to compare the effectiveness of the three coating maintenance strategies for steel bridges: spot painting, overcoat, and full recoat. The model uses a methodology to define the level of failure of steel coating, based on the extension of corrosion damage according to ASTM D610 Standard (ASTM, 2012) and the adhesion characteristics of the surface to be treated according to ASTM D3359 Standard (ASTM, 2009). The study concluded that spot repair is the most cost effective alternative to extend the service life of coating steel bridges. The effectiveness of spot painting is due to its reduced cost, because of the small worked area, reduced consumption of materials, and minimal disposal and containment requirements. But, spot painting is not an effective alternative when the surface presents severe damage, equivalent to a rating less than 6 in the ASTM D610 (ASTM, 2012) and adherence rating lower than 3B according to the ASTM D3359 (ASTM, 2009).

Fricker et al. (1999)

The study performed an economic analysis for the Indiana Department of Transportation (INDOT) on steel bridge paint maintenance problems. The analyses were performed for the 3-coat paint system with three alternatives for rehabilitation. Maintenance activities were initiated when the coating exhibited some level of deterioration based on the condition rating proposed by the National Bridge Inventory (NBI). A discount rate of 7% and an inflation rate of 3.5% were used. The unit costs considered: full repainting = \$4.0/ft^2, spot painting at rating level 7 = \$1.5/ft^2, spot painting at rating level 6 = \$2.5/ft^2. Bridge life span was assumed to be 60 years. Three alternatives were analyzed as noted below.

Alternative 1

Perform no maintenance prior to complete repainting when rating level 5 is reached (approximately 25 years). See Figure F7.3.

Alternative 2

Spot painting is made at rating level 7, and occurs every 15 years until the end of the bridge service life. See Figure F7.4.

Alternative 3

Spot painting is made at rating level 6, and occurs every 20 years until the end of the bridge service life. See Figure F7.5.

Alternative 2, spot painting at rating level 7 each 15 years, was the best option of the three considered for maintenance of steel bridge painting.

Zayed et al. (2001a)

The study analyzed data from Indiana DOT and Michigan DOT, considering different scenarios for steel bridge paint maintenance activities. A life-cycle cost analysis was performed to identify the most cost-effective maintenance alternative from spot painting, overcoat, and total recoat. The “do nothing” scenario was also considered. Five condition states (1 to 5) were defined, with state 1 corresponding to the best condition and state 5 to the worst one. Bridge life span was assumed to be 60 years.

For data corresponding to INDOT, the following alternatives were analyzed:

1. Perform no maintenance prior to complete repainting after reaching state 5 (approximately 30 years);
2. Perform spot repairs at state 2, and repeat it approximately every 10 years until the end of the bridge life;
3. Perform spot repairs at state 3, and repeat it every 18 years until the end of the bridge life;
4. Overcoat the bridge at state 3, and repeat every 18 years until the end of the bridge life; and
5. Overcoat the bridge at state 4 after the first 24 years and do spot repairs after 18 years, that is, at the 42nd year, until the end of the bridge life.

The economic analysis indicated that alternative 2, perform spot painting each 10 years, until the end of the bridge service life, resulted as the most cost effective method to protect steel bridge coating and extend the bridge service life.

For data corresponding to MDOT, the following alternatives were analyzed:

1. Perform no maintenance prior to complete repainting after reaching state 5 (approximately 25 years), until the end of the bridge service life.
2. Perform spot repairs at state 3 and then approximately every 15 years until the end of the bridge life.
3. Perform spot repairs at state 4, and repeat every 20 years until the end of the bridge life.

In this case, alternative 2, to perform spot painting each 15 years, resulted as the most cost effective corrosion protection method for steel bridge painting.

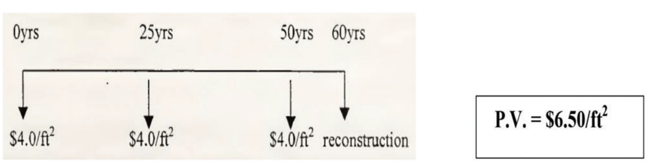

Figure F7.3 Alternative 1.

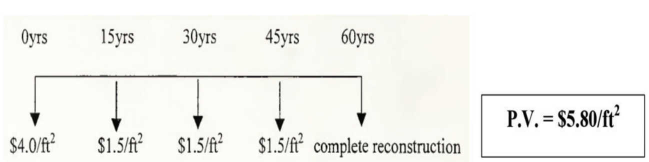

Figure F7.4 Alternative 2.

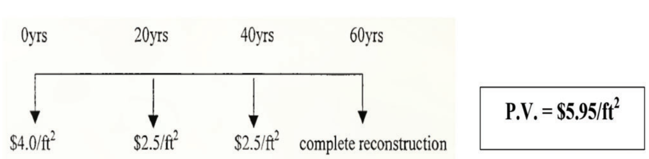

Figure F7.5 Alternative 3.

Chan (2003)

The study analyzed the coating maintenance practices performed by the Ministry of Transportation of British Columbia (MoT) on their inventory of steel bridges. A steel bridge coating maintenance evaluation model was developed implemented. The model used a condition rating to define which maintenance activities best protect the steel bridge coating system. The rating is based on the ASTM D610 Standard (ASTM, 2012). The coating protection activities considered by the model, service life, and costs are given in Table F7.3.

The model considered five variations to be analyzed: (1) Overall bridge condition rating, using deterministic inputs, (2) Bridge component condition rating, using deterministic inputs, (3) Overall bridge condition rating, using probabilistic inputs, (4) Bridge component condition rating, using probabilistic inputs, and (5) Bridge inventory, using overall bridge condition rating and deterministic inputs.

For all the five considered models, touch-up painting (spot painting) always resulted as the most effective corrosion protection coating maintenance strategy for main structural components from steel bridges. Spot painting is an effective strategy for a structure when the corrosion rating per ASTM D610 (ASTM, 2012) is 8 or above and shows adequate adhesion.

TABLE F7.3
Service life and costs of maintenance activities (Chan, 2003).

Activity	Service life (years)	Cost (\$/ft^2)
Touch-up painting	10–15	3–6
overcoat	15–25	1–1.6
recoat	20–30	1.5–2

Yuan (2005)

A decision making model was developed in this study to be applied when alternatives for bridge rehabilitation have to be taken. A life-cycle cost analysis is performed to determine the best alternative for steel bridge corrosion protection maintenance. The model considered three maintenance activities: spot painting, overcoating, and recoating. The no maintenance option is also considered. From all scenarios, the study concluded that the best steel bridge coating maintenance alternative is the application of spot painting when the surface to be coated present both conditions: a rating of 8 or higher according to the ASTM D610 (ASTM, 2012) and appropriate surface adherence.

In summary, from the several studies presented, spot painting resulted always as the most cost-efficient maintenance alternative to protect a coating system on steel bridges. The economic analysis performed in the different researches showed the cost effectiveness of spot painting, provided adequate conditions existed for its application. Those studies considered different inputs, such as life span of bridge, unit costs, service life of each maintenance activity, criteria for failure definition, maintenance strategies, etc., but always spot painting resulted as the best option. Consequently, spot painting should be considered an adequate alternative as a preventive maintenance activity in a bridge preservation plan.

F7.7. CONCLUSIONS AND RECOMMENDATIONS

F7.7.1 Conclusions

From different available sources it is concluded that the most reliable coating system for steel bridges is the 3-coat system, consisting of an inorganic/organic zinc primer, intermediate epoxy, and finishing urethane topcoat. Spot painting can be performed based on a 3-coat system or a system including a primer coat and a top coat. In both cases, the selected system should comply with the characteristics of the original coat system. Coating service lives vary under the effect of several factors that affect the integrity of the coating. From the different references presented in this report, there is not a general accepted value for the service life for spot painting coats. The best maintenance alternative for this coating system is spot painting each 10 to 15 years and/or when the bridge coating reaches a rating level of 8 to 7 from the ASTM D610 Standard (ASTM, 2012). Analyze the content of lead before any work is planned to perform, in such a case, spot painting may not be an appropriate alternative.

F7.7.2 Recommendations

It is recommended that INDOT should incorporate spot painting as a preventive maintenance activity. Spot painting can be performed applying a 2-coat system, conformed by a primer coat and a top coat. INDOT should apply spot painting each 10 years on those steel elements that present small damages in their coats, in order to protect the coating system and extend the structure service life in a cost effective manner. Consider spot painting when no lead contents are found in the original coat and no more than 10% of the total area of the element needs to be treated. When the surface does not exhibit the indicated requirements for application, spot painting will not be a reliable alternative. In such a case a more complex maintenance procedure will be required, as zone painting or overcoating.

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APPENDIX F8: VEGETATION CONTROL

F8.1. INTRODUCTION

The primary purpose of bridge vegetation control is to ensure safe conditions by maintaining adequate sight distance (Wahkiakum County, 2014). Bridge vegetation control is required to maintain access to the bridge structure for inspections, maintenance, and fire safety, reducing the risk of functional or structural failure (Shannon & Wilson, Inc., 2013; SLO County, 2006). This activity focuses on the removal of trees and brush and the subsequent control of sprouts adjacent to bridges. Figure F8.1 shows a medium size tree representing a serious threat to a bridge structure. When vegetation adjacent to a bridge is uncontrolled, different problems and damage can affect the structure, such as creation and expansion of concrete cracks, reduction of sight distance, increment of collision hazards with wildlife or other objects, coverage of bridge signals, obstruction of drainage conducts, and formation of shady spots that facilitate build-up of ice and snow during winter season (Eck & McGee, 2008; MassDOT, 2009; Morré, 2000).

Figure F8.1 Interference of tree with bridge structure (GDOT, 2012).

F8.2. METHODS OF VEGETATION CONTROL

The bridge substructure can experience considerable damage from a plant's root system growing close to the abutments or piers. To provide safety conditions to drivers and avoid damages to the bridge structure, is required to cut brush and small tress on the approaches and near the abutments, as part of vegetation control activities. There are different methods to perform vegetation control (Lowe, Herold, & Kraushar, 2011; Venner Consulting & Parsons Brinckerhoff, 2004) as indicated:

- Cultural control methods: introduce and manage desirable plants.
- Mechanical methods: uses manual and motorized equipment.
- Biological methods: involve the use of living organisms to control plant growth.
- Chemical methods: include components produced on the lab to reduce/eliminate targeted species.
- Integrated vegetation management: includes the use of cultural, mechanical, biological and chemical practices.

While mechanical methods are effective for many maintenance activities, these methods tend to be labor intensive, fuel intensive, and typically require heavy equipment which itself requires maintenance. As an alternative, INDOT has sponsored research in vegetation control (chemical mowing, weed and brush control), performed under the direction of Dr. D. James Morré. According to Morré's (2000) research, "the use of herbicides is not an automatic response to sighting a pest, but rather the result of a "step down" procedure of evaluating all methods of control to maintain public safety and aesthetics." The use of herbicides must to be done under extreme control and following all product specifications, with the aim to preserve the environment.

All vegetation control methods are recommended to be used on bridges located over roads and highways, while it is preferred to avoid chemical methods to control vegetation adjacent to bridges over streams and rivers. When herbicides enter waterways, a rapid spread beyond the target area can occur, contaminating other locations (EA Engineering, Science, and Technology, Inc., & Applied Research Associates, Inc., 2009).

F8.3. FREQUENCY OF VEGETATION CONTROL

The correct timing of vegetation control activities is critical, otherwise it can become counterproductive and less effective, both in terms of cost and environment impact (MassDOT, 2009). The majority of vegetation control activities are most effective when they are performed during the growing season (Dye Management Group, Inc., 2003).

Most Department of Transportation agencies from different states consider vegetation control a preventive maintenance activity that has to be performed regularly. Some states indicate a specific frequency to perform this activity, as indicated in Table F8.1. On the other hand, some transportation agencies consider this activity in their bridge maintenance programs, but the frequency is determined by the opinion of field inspector, or performed as needed. Personnel from INDOT Districts were interviewed as part of this research. Currently this activity is not performed on a regular schedule for Indiana DOT Districts, but, instead, is done only in response to inspector's report when needed.

Ohio Department of Transportation performs mechanical mowing before each major traveling holiday: Memorial Day, the Fourth of July, and Labor Day. A final mowing is performed in late September or early October to remove any unwanted vegetation (Yost, 2013).

F8.4. COST OF VEGETATION CONTROL

From the review of different sources, the cost of vegetation control activities was found to be highly variable. Presented in Table F8.2 is the data corresponding to the cost of mowing grass and brush from Berger (2005).

The Environmental Protection Agency (EPA, 2014) reports the average cost for maintenance roadside vegetation as $100.00/acre/year. As this activity is performed once a year by most of states, then the annual cost can be considered as $100.00/acre.

TABLE F8.1
States that apply vegetation control with specific frequency.

State DOT	Frequency (yr.)	Reference
Michigan	1	MDOT, 2011
Main, Montana, Utah, Washington, W. Virginia, Alberta, Saskatchewan	1	Berger, 2005
Queensland	1	Queensland, 2008
Virginia	2	VDOT, 2014

TABLE F8.2
Unit costs for vegetation control activities (Berger, 2005).

State	Unit	Cost ($)	Labor
Maryland	Per acre per cut	500.00	Employer
Maryland	Per acre per cut	305.00	Contractor
Washington	Per acre per cut	14.00	Employer
Texas	Per acre per cut	22.91	Contractor

F8.5. LIFE-CYCLE COST ANALYSIS

Two scenarios are analyzed, the no maintenance alternative, and a yearly maintenance alternative considering vegetation control. It is assumed that 10 years is the time for a small tree to grow until produce some structural damage. Using a discount rate of 4%, a life-cycle cost analysis can be performed for the two alternatives.

Alternative 1

Considering no vegetation control.

In this scenario structural damage can be produced after 10 years in one of the abutments. The rehabilitation is estimated at a cost of $\$45/\text{ft}^2$ (ODOT, n.d.), and that a total area of 400 ft^2 needs to be repaired. Therefore, a total of $18,000 will be the cost of rehabilitation, and the present value for this alternative is $12,160.

Alternative 2

Considering yearly vegetation control activity.

Performing this preventive maintenance activity every year during 10 years can avoid any structural damage due to growing vegetation under the bridge. Based on the presented costs of vegetation control, the average cost for removal of brush and small trees can be assumed on $300.00 per acre per cut per year. Considering that one acre is the area to be maintained on a typical bridge, and the maintenance is performed once per year, then the total cost of maintenance results to be $300.00 per year. Performing vegetation control, at a cost of $300 per year during 10 years, it will result in a total present value of $2,433.

Under the assumed parameters, the life-cycle cost analysis for these two alternatives illustrates a significant difference in their present value, which indicates that performing vegetation control every year is a cost-effective alternative.

F8.6. CONCLUSIONS AND RECOMMENDATIONS

F8.6.1 Conclusions

Bridge vegetation control is a maintenance activity that ensures safe conditions for motorists and can prevent structural damages to the bridge infrastructure. There are different methods to control the propagation of vegetation around bridge infrastructure. The timing of vegetation control is critical, being more effective when performed during the growing season. Based on the cost benefit evaluation and literature from different states DOT agencies, bridge vegetation control is a convenient and cost effective preventive maintenance activity.

F8.6.2 Recommendations

INDOT should include bridge vegetation control as a preventive maintenance activity every year. INDOT should eliminate all brush, tree branches, and tree limbs that can: obstruct visibility to drivers, obstruct a traffic signals, damage any bridge sub/superstructure member, obstruct or damage any drainage system component, or become a traffic hazard.

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APPENDIX F9: REMOVING DEBRIS FROM PIERS/ABUTMENTS

F9.1. INTRODUCTION

Debris or waterborne debris is any kind of floating or submerged material that is transported by flowing water. Debris from rivers and channels are conformed primarily of whole trees, tree trunks and large branches (Lagasse, Clopper, Zevenbergen, Spitz, & Girard, 2010). During flood events, floating debris accumulates forming debris jams around bridges when they meet elements from the bridge substructure, such as piers and abutments, trapping bigger debris components. As a consequence, the stream flow is obstructed or redirected through the bridge, which in turn, produces scour of the foundation of the bridge substructure, flooding of surrounding areas, and increment of hydraulic forces on the structure.

The dimensions and shape of debris jams can vary, from a relatively small formation around one pier or abutment to a total blockage of a bridge span (Diehl, 1997). After a debris jam has formed, small pieces of different materials, such as brushes, leaves, small branches, weeds, and any other type of floating elements are attached to the jam formation, occupying the interstitial free space and contributing to increase the size of the jam (Parola, Apelt, & Jempson, 2000). Figure F9.1 shows a debris jam over the White River at Paragon, Indiana.

Based on a national survey of DOTs, Chang and Shen (1979) constructed a national distribution of debris problems as shown in Figure F9.2. The distribution shows that the most critical areas for debris problems are the Pacific Northwest and the Mississippi River Valley. In this map the State of Indiana is classified as "severe," the most critical denomination.

A study by Lyn, Cooper, Condon, and Gan (2007) showed that most of the larger debris jams in the State of Indiana are formed downstream of the two major watersheds, the Wabash and White rivers.

F9.2. PROBLEMS ASSOCIATED TO DEBRIS ACCUMULATION

Scour of bed material beneath pier and abutment foundations is the most common cause of bridge collapse. In the United States more than 60% of bridge collapse is due to scour around the bridge foundation (Johnson & Sheeder, 2011). A study sponsored by the Federal Highway Administration indicated that "of 383

Figure F9.1 Blockage of a 27-meter span over White River in Paragon, Indiana, September 25, 1992 (Diehl, 1997).

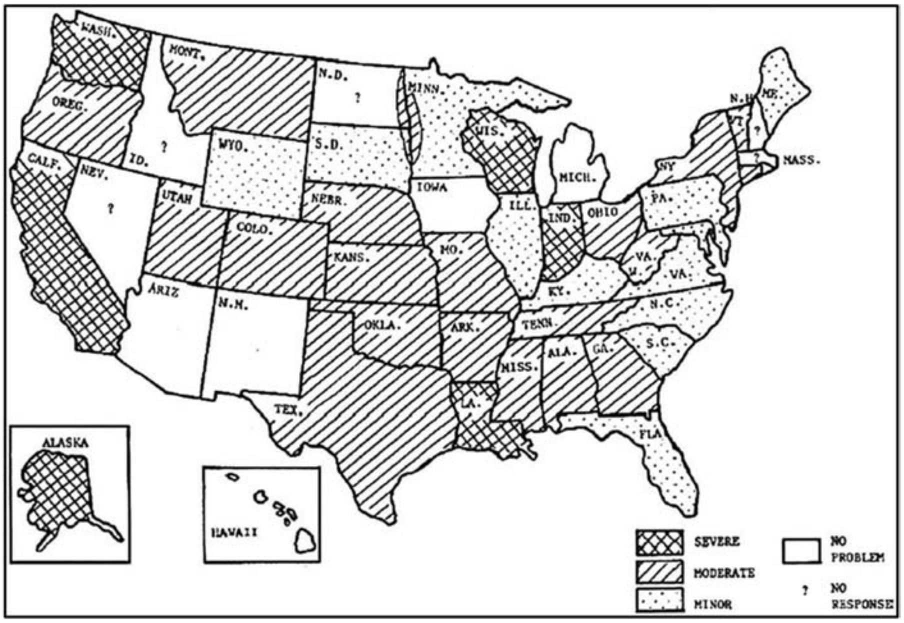

Figure F9.2 Debris problem distribution (after Chang & Shen, 1979; Lagasse et al., 2010).

bridge failures caused by catastrophic floods showed that 25% involved pier damage and 75% involved abutment damage" (Richardson & Davis, 2001).

During heavy storms a great load of debris is transported by the flowing water. Debris accumulates in stages, and typically stars with some logs. If no maintenance is performed, more material, compounded by large and small pieces, are caught forming a bigger jam, which grows at each event. The capacity for trapping more debris is incremented by the types and locations of bridge piers. A pier constructed by a group of columns is more susceptible to trap debris.

Accumulation of debris around bridges can produce various problems. Debris jams can partially or totally block the waterway opening of a bridge, generating: (i) scour at a base of piers and abutments, (ii) flooding of areas upstream and around the bridge, and (iii) increment of hydraulic loads on the bridge structure (Chang & Shen, 1979; Diehl, 1997; Parola et al., 2000). Partial or total blockage of the bridge openings will raise the backwater level upstream, increase the velocity of water passing through the reduced openings under the bridge, and can change the original stream flow path.

The reduction of bridge openings will produce the increment of lateral flow towards the piers and abutments at severe angles of attack. This lateral flow will produce some vortices resulting in scour of foundation material at the base of piers and abutments. The rise of backwater level upstream can produce significant inundation of lands adjacent to the bridge. The increment of surface level can reach the top of the deck and beyond. The pressure of the debris jam over the bridge structure will produce drag forces on piers, girders and deck that can result in the collapse of the bridge either by buckling of vertical elements (piles), shearing of roadway deck supports, or overturning of the structure (Bradley, Richards, & Bahner, 2005). Figure F9.3 shows the collapse of a bridge due to scour additional forces acting on the structure.

Figure F9.3 Failure of a bridge located in Oklahoma due to debris accumulation (Bradley et al., 2005).

F9.3. DEBRIS REMOVAL FROM AROUND PIERS AND ABUTMENTS

Solution to debris problems around bridges has been focused on debris removal at bridges and in stream channels, bank clearing, channel modifications, debris deflectors, and traps (Lagasse et al., 2010). Debris removal is considered a non-structural measure (Bradley et al., 2005) in contrast to structural measures which involve the construction of any type of structure in the stream close to the bridge, with the aim to avoid the accumulation of debris in the bridge structure.

All retired debris should be moved away from the bridge and disposed in a manner that will ensure that the debris will not return to the streambed. It is not acceptable to remove debris from upstream of the bridge to be discharged at the downstream side. Debris can be placed on the banks, but after a short time and before the next flood, it has to be removed to a permanent place away from the stream path. Removed debris can be relocated, buried, burned, or used for structural purposes if possible (Bradley et al., 2005; Lagasse et al., 2010). Tracked vehicles can be used to remove debris from bridges at small streams, while for bridges over large streams some type of boat is required to load the equipment.

Debris removal can be performed with different tools or equipment, based on different factors. The most relevant factors include the size of the jam, the size of the elements in the jam, the span of the bridge, and the depth of the stream flow at the bridge.

Hand-held tools can be used to eliminate short debris jams if the stream conditions allow the access by the maintenance crew to approach the jam. The most common tools used in this activity are axes, chain saws, hand winches, and floats.

Heavy machinery is required to eliminate large debris jams, or when the conditions in the streambed do not allow the maintenance crew to access the jam as depicted in Figure F9.4. The most common machines used to remove debris from around bridges are bulldozers, cranes and hoists, loaders, forks, and boats (Bradley et al., 2005). A combination of this machinery is more efficient in many cases. When access to the debris jam from the deck is not possible, the use of boats to move the machinery is the solution.

F9.4. FREQUENCY OF DEBRIS REMOVAL

Bradley et al. (2005) indicated that "general maintenance practices … should involve regular inspections and cleaning, coupled with emergency removal of debris." Bridges carrying the higher traffic levels, such as interstate or primary highways, should be given the highest priority on maintenance, with more frequency of maintenance than bridges from secondary roads with lower traffic. Also, when a bridge is known to be more prone to debris problems, it should also receive high priority for debris removal.

Some bridges are more prone to debris accumulation problems than others. Factors that influence bridge debris problems include: (i) type of the structure, (ii) length of the structure, (iii) height of the structure, (iv) stability of the river banks, and (v) use of the surrounding land. Bridges affected by some of these factors should require more frequent debris removal. DOT personnel are the individuals responsible to identify those critical structures in their jurisdiction. Field inspectors and crew maintenance personnel are the first source of information about the condition of debris accumulation around piers. These personnel communicate to the DOT when an emergency debris removal is required.

Debris removal from bridge structures can be initiated in two different manners. One type is an emergency removal of debris from piers and abutments due to exceptional flow in the stream, or per the inspector's requirements. The other type is routine debris removal, which is programmed to be performed periodically, during and at the end of the rain season.

In summary, the frequency associated with the removal of debris accumulation should be determined by the DOT personnel. Some bridges with favorable conditions will require less attention than those bridges with more critical conditions, based upon the different factors here presented. But, after an exceptional event, all affected bridges may require emergency maintenance.

F9.5. COST OF DEBRIS REMOVAL

The cost of bridge debris removal is affected by many factors. From the study by Lagasse et al. (2010), it was found that state DOT agencies typically do not store data related to the cost of debris removal, mainly because many DOTs do not apply this activity in a regular way, but only on emergency situations due to larger flood events. The study performed a survey between DOTs personnel in relation to the cost of debris removal. It was found that a reasonable range of cost was 0.5% to 1% of the total annual maintenance budget for a year with little flooding, and perhaps 2% to 5% in years with more severe events.

Figure F9.4 Excavator removes debris that has built up around a bridge pier (Hulcher Services, 2014).

From the document "Solano County Road and Bridge Storm Damage, of the Solano County—California" (Solano County, 2006), a list of maintenance and reparation activities are presented. From the 105 activities identified in the list, 13 correspond to the removal of storm debris from creek/side of pier/abutments. The maximum cost indicated was $5,000 while the minimum cost was $1,000, with an average value of $2,000 per bridge maintained.

A study by Cummings and Pyles (2013) also analyzed the cost data of drift removal (Activity 347) in 240 bridges, from years 1996 to 2009, provided by the Oregon Department of Transportation. Unfortunately, the authors found some inconsistency in the values, as some of the assigned costs were as low as $10 in some cases, something not reliable for any type of debris removal. The maximum cost in the data was $9,028, a value that can be accepted for a medium to large debris jam in difficult conditions. In order to utilize the data provided by the study, all activity with a cost less than $500 was eliminated. In that condition, the data were reduced to 113 events with an average value of $1,650, something much closer to the value provided by the document from Solano County (2006). From the gathered information, an average cost for bridge debris removal can be assumed as $2,000.

F9.6. LIFE-CYCLE COST ANALYSIS

In the previous section it has been indicated that bridge debris accumulation, if not properly attended, can lead to failure of the bridge structure, including the loss of lives and property. Therefore, bridge debris accumulation should be considered a menace to bridge integrity. An economic analysis of performing bridge debris removal gives more support to the fact that this maintenance activity is cost-effective.

A life-cycle cost analysis for two alternatives will be presented. The first alternative corresponds to the no maintenance alternative. The second alternative corresponds when regular debris removal maintenance activities are performed.

For the first alternative it can be assumed that the bridge stands without problems for 25 years, without any maintenance performed. It is further assumed that after 25 years without maintenance, the accumulation of debris has produced a failure in some important structural elements. If the cost of the bridge is estimated as $3,000,000 and the damage produced on the elements cost 30% of the total cost of the structure, the cost of reparation will be $900,000 at year 15. Considering a discount rate of 4%, the present value (PV) of the reparation at year zero will be $499,738.

The second alternative considers the performance of debris removal as a bridge maintenance activity. Assuming a medium level importance for the bridge, this scenario will require bridge debris removal 3 times per year. With a cost of $2,000 for the activity, this alternative will result in a total cost of $6,000 per year, during 15 years. Under these assumptions, the present value of this alternative results in $66,710.

The corresponding result of both present values gives the conclusion that performing a scheduled bridge debris removal 3 times per year is much more cost effective than the no maintenance alternative. Different scenarios can be considered, but it always has to be remembered that failure due to debris accumulation can produce the total collapse of the bridge structure, a life safety issue.

F9.7. CONCLUSIONS AND RECOMMENDATIONS

F9.7.1 Conclusions

The accumulation of debris on bridges, around piers and abutments, can produce failures of important structural elements, or even the collapse of the structure, as documented from different sources. Bridge debris removal is a maintenance activity that can eliminate or reduce the risk of failure. Providing resources for regular bridge debris removal is a cost effective alternative. The no maintenance alternative to eliminate debris accumulation can result in important failures with a very significant cost, including the loss of life.

F9.7.2 Recommendations

INDOT should incorporate bridge debris removal as a routine maintenance activity. Moreover, INDOT should perform debris removal from bridges every year as needed. INDOT should implement routine inspections on the most important bridges after each flooding.

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APPENDIX F10: PIN AND HANGER (OR HINGE) CONNECTION MAINTENANCE

F10.1. INTRODUCTION

A pin and hanger connection is a type of bridge superstructure connection device, which works as a hinge, consisting of two pins and two hangers. (This maintenance activity is also valid for a pin and hinge connection. Therefore, when it is mentioned as a pin and hanger connection, it must be also understood that the maintenance would also apply to a pin and hinge connection.) A hanger plate is located on each side of the web of two girders and connected by two pins; the upper pin attached to a cantilever span and the lower pin connected to a suspended span (DelDOT, 2012; Houcque, 2008; WSDOT, 2012). Figure F10.1 shows a typical pin and hanger connection. This type of connection is designed to transfer loads without a supporting substructure and to accommodate both translation and rotation movements due to traffic loads and thermal expansion or contraction of the bridge superstructure (daily or seasonal; Houcque, 2008).

The loads from the suspended girder web are transmitted to the lower pin, and then to the hanger plates. From the plates the loads are passed then to the upper pin, and from this pin the loads are transmitted to the cantilever girder web. Pins are idealized to be frictionless connections, allowing the rotation of girders and hangers without experiencing torsion stresses (WisDOT, 2011). Pin members should support the shear forces due to the loads transmitted by the girders, while the hanger plates are intended to be tension members only (ConnDOT, 2001; Graybeal, Walther, Washer, & Waters, 2000).

F10.2. PROBLEMS WITH PIN AND HANGER CONNECTIONS

A pin and hanger connection is assumed to be free of torsion stresses, but this assumption is typically valid only for new bridges, when all of the elements are in good condition (South, Hahin, & Telford, 1992). Bridge pin and hanger elements are commonly located under a deck joint and, consequently, exposed to deicing products when the deck seal joint is damaged. Moreover, due to wearing conditions and the lack of appropriate maintenance, the original lubricant dissipates.

After years of service, the exposure to variable weather conditions, deicing products, live loads variations, and routine wear produces “pack-rust” corrosion. This corrosion between the steel surfaces can build up, thereby reducing the free rotation capacity as depicted in Figure F10.2. The reduction of the free rotation ability results in partial or total fixed conditions in the connection, generating what is known as a partial or fully “frozen” connection (ODOT, 2014). This situation produces additional stresses in the pin and hanger, and in the adjacent girders. In extreme cases this may result in the failure of the connection.

Another negative effect from corrosion is the possible reduction of the cross-section of the pin, thereby lowering its loading resistance. Additionally, pitting corrosion can produce the initiation of cracks. The pin commonly breaks due to torsional stresses in a reduced section, while the hanger plate fails at either end adjacent to the hole where the pin is assembled (Rossow, 2009). The failure of a pin and hanger connection can cause a partial failure or the total collapse of the bridge structure (ODOT, 2014).

F10.3. COLLAPSE OF BRIDGES DUE TO FAILURE OF PIN AND HANGER CONNECTION

Pin and hanger members are critical elements of bridge structures, especially for non-redundant bridges. A pin and hanger failure can lead to a partial failure or a total collapse of the

Figure F10.2 Typical pack-rust formation at pin and hanger connection (WisDOT, 2011).

Figure F10.1 Pin and hanger connection at the US-41 White River Bridge, in Hazelton, Indiana (Sherman, Mueller, Connor, & Bowman, 2011).

Figure F10.3 A suspended span collapsed at the Mianus River Bridge in Greenwich, Connecticut due to pin and hanger failure (Morgan, 2015).

structure (Houcque, 2008; South et al., 1992). Examples of critical situations of bridge structures due to pin and hanger failures have been (Houcque, 2008):

- The collapse of one span of the Mianus River Bridge in Greenwich, Connecticut, June 28, 1983. Figure F10.3 shows a view of the catastrophe were 3 people died.
- A nearly catastrophic failure in a bridge on I-55 in St. Louis, Missouri, January 1987.
- The suddenly closed traffic at the Paseo Bridge in Missouri, January 22, 2003.

Pin and hanger connections are problematic since the contact surfaces of pins, hangers, and girders cannot be easily inspected, without disassembly the connection, to detect structural problems (DelDOT, 2012). This situation, added to a lack of maintenance and deficient inspection procedures are the reason for critical conditions that can lead to structural failures and the collapse of the bridge.

F10.4. PIN AND HANGER INSPECTIONS

The use of pin and hanger bearing connections, while once commonplace, now has lost preference due to several negative characteristics. However, many bridges with this type of connections are still in service and functioning. Hence, great attention should be given to these structures. Regular maintenance activities and appropriate inspection procedures are the best alternative to ensure the quality of the connection and, consequently, the service life of the bridge structure.

Damage detection due to corrosion on pin and hanger connections is not an easy task, since regular inspection procedures do not involve the disassembly of the connection itself. This is complicated and impractical to do frequently (Ruzzi, 2014). Visual inspections of pins and hangers are limited and sometimes not useful, because the inspector is not able to examine the contact areas where critical corrosion can be developing. In order to overcome this limitation, ultrasonic testing has become the primary method to identify and to control possible defects on pin and hanger elements in service (South et al., 1992). Since the cost of ultrasonic testing is expensive and complex, frequencies between 48 months to 72 months are commonly prescribed, while hands-on and visual inspections are prescribed on a 24-month interval (WisDOT, 2011).

F10.5. PIN AND HANGER MAINTENANCE ACTIVITIES

Forensic inspection at the remains of the collapsed span at the Mianus River Bridge indicated that formation of pack-rust corrosion in a non-redundant pin and hanger assembly pushed one of the plates off the pin, initiating the collapse of the bridge (Graybeal et al., 2000). The cause of corrosion formation was the lack of maintenance at a drain, which was clogged and caused the leak of deicing products towards the connection elements below a joint (NTSB, 1984). The accumulation of dust, debris, and humidity produce the corrosion of the pin and hanger connection, leading to the failure of the connection and the possible collapse of the bridge structure.

It is widely accepted that the failure of a bridge pin and hanger connection can lead to a catastrophic ending. Therefore, maintenance and inspection of the pin and hanger device must be provided regularly in order to avoid a premature bridge collapse and loss of lives and properties.

Maintenance activities should be mainly oriented to avoid the lack of lubrication in the pin and hanger connection, the leak of deicing products over the elements, and to prevent the formation of pack-rust corrosion in the pin and its bearing surface.

Some efficient preventive maintenance activities that can be performed to protect a pin and hanger connection are described as follow.

F10.5.1 Drainage Maintenance

Clogged drains can produce the accumulation of water and debris over the deck surface. In the case that the seal of the expansion deck joint located over the pin and hanger is in bad condition or damaged, the water can leak through the joint to the elements underneath connection (ConnDOT, 2001). The leak of deicing products towards the connection elements can initiate the corrosion process, leading to the formation of pack-rust in the pin and its bearing surface. Also, damaged drain pipes located beneath the deck joint can misdirect drainage water to the pin and hanger connection, instead of draining it away from the superstructure (FHWA, 1993). Therefore, regular maintenance of the drainage system is an important activity that can help to keep the pin and hanger connection in good conditions. Gutters and pipes that collect the water from the deck surface must be properly maintained.

As was studied previously, the maintenance of the deck drainage system should be done at the same time when the deck is cleaned. The recommended frequency of this activity is at least once every year, at the end of the winter season.

F10.5.2 Expansion Joint Maintenance

An expansion deck joint in good condition is able to avoid the leaking of deicing products to the pin and hanger connection located directly below the joint (FDOT, 2011). Consequently, a good practice to protect a pin and hanger connection is to clean and flush the expansion joint over the connection. Cleaning and flushing a deck joint each year, at the end of the winter season, is a cost effective alternative to keep the joint in good condition and to extent its service life.

F10.5.3 Cleaning and Lubricating the Pin and Hanger

The accumulation of dust, debris and humidity on the surface of a pin and hanger connection will contribute to the initiation of corrosion of steel elements. A way to reduce this process is to properly clean the pin and hanger device, which has been shown to be cost effective. It has been analyzed the convenience of cleaning and flushing the bridge bearing devices every two years. In the same way, the pin and hanger connection should be cleaned and flushed every two years.

To avoid a partial or fully “frozen” pin and hanger connection it is necessary to maintain permanent lubrication of the contact surfaces. Due to cyclic motion, aging, and atmospheric conditions, the lubricant in the connection is depleted, and therefore should be replaced periodically. According to the New York State Department of Transportation a good maintenance practice is to provide lubrication to pin and hanger connections every 4 years (NYSDOT, 2008).

F10.5.4 Spot Painting the Pin and Hanger

Painting maintenance activities are considered an economical option to extend the coating service life of steel bridges. In particular, spot painting, when applied appropriately, is a low cost alternative to more advanced and expensive methods, due to the reduced working area and required resources. According to several DOTs agencies spot painting should be applied in a regular frequency, between ten to fifteen years, to keep steel surfaces free of corrosion problems.

F10.6. CONCLUSIONS AND RECOMMENDATIONS

F10.6.1 Conclusions

Pin and hangers are a connection system that is no longer prescribed, because of numerous shortcomings. However, many bridges with these connections still remain in service. The accumulation of dust, debris, and humidity helps to initiate the corrosion of elements in the pin and hanger connection, reducing the free rotation capacity of the pins, to a partially or totally "frozen" connection. Consequently, additional important stresses arise in the connection members. Inspection of pin and hanger elements is complex and expensive due to the location of the connection and the type of assembly between elements. The failure of a pin and hanger connection can result in the collapse of a section of the bridge, or the entire bridge, especially for non-redundant structures. Scheduling frequent inspections and performing preventive maintenance activities are the most effective options to keep the pin and hanger connections in good condition, thereby extending the service life of the connection and the bridge itself.

F10.6.2 Recommendations

Indiana DOT should incorporate a maintenance program for bridges with pin and hanger connections as indicated:

- Cleaning and flushing the deck drain system every year.
- Cleaning and flushing the expansion joints located over the pin and hanger connections every year.
- Cleaning and flushing the pin and hanger members every two years.
- Provide lubrication to the contact surfaces between elements in the pin and hanger connection. This activity should be done every 4 years.
- Applying spot painting to the damaged surfaces in the pin and hanger connection. This activity should be done regularly each ten years.

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APPENDIX G: METHODOLOGY GUIDE OF BRIDGE PREVENTIVE MAINTENANCE ACTIVITIES

Preventive maintenance is a planned strategy of cost-effective treatments to an existing roadway system (or bridge) and their appurtenance that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity).

Source: AASHTO Subcommittee on Maintenance

This manual has been prepared as a reference for bridge preventive maintenance activities recommended to be performed by INDOT on its bridge inventory. The manual is intended to guide the procedures for the proposed maintenance activities for typical bridges in Indiana, without special considerations, such as treatment for historic bridges or those incorporating new advanced materials.

The procedures presented for each activity are the result of an extensive review from several sources, resulting in the most common practices. Therefore, the proposed procedures are not all-inclusive or limited to the indicated steps. The personnel responsible for maintenance activities should consider the procedures proposed in this guide as a reference to follow, but local conditions or special considerations could require some variations to the prescribed procedures.

Emphasis should be given to the fact that preventive maintenance activities are most effective when applied to a new or replaced structural element, and then applied regularly at the recommended frequency. Also, they can be applied to existing structure elements in good condition. It is strongly recommended that all maintenance activities be performed, and that all elements are kept in good to excellent condition during the service life.

APPENDIX G1. DECK SWEEPING/CLEANING
APPENDIX G2. DECK DRAINAGE CLEANING/FLUSHING
APPENDIX G3. CONCRETE DECK SEALING
APPENDIX G4. CONCRETE DECK CRACK SEALING
APPENDIX G5. CONCRETE DECK PARTIAL PATCHING
APPENDIX G6. DECK JOINTS CLEANING/FLUSHING
APPENDIX G7. BEARING CLEANING/FLUSHING
APPENDIX G8. BEARING LUBRICATING
APPENDIX G9. BEARING SPOT PAINTING
APPENDIX G10. APPROACH SLAB MAINTENANCE
APPENDIX G11. SUPERSTRUCTURE CLEANING/WASHING
APPENDIX G12. SPOT PAINTING
APPENDIX G13. VEGETATION CONTROL
APPENDIX G14. REMOVING DEBRIS FROM PIERS/ABUTMENTS
APPENDIX G15. PIN AND HANGER CONNECTION MAINTENANCE

APPENDIX G1: DECK SWEEPING/CLEANING

G1.1. DESCRIPTION

Deck sweeping and cleaning is performed to collect and eliminate litter, debris, dirt, salt, anti-skid, and other deleterious material from the bridge deck surface. All this material can be a potential hazard for drivers and cause deterioration in the reinforced concrete deck quality. Also cleaning the bridge deck provides an aesthetic road surface. Material should be collected using adequate tools or mechanical equipment and must be appropriately disposed in designated areas.

G1.2. REQUIREMENTS

This activity is recommended to be performed annually, preferably shortly after the end of the winter season. It is highly recommended to perform this activity in conjunction with other maintenance activities, such as cleaning/flushing drainage system and cleaning/flushing deck joints, in order to obtain the maximum benefit. This activity offer its best results when applied to a new deck and then is performed with a regular frequency as indicated. Regular patrols are recommended to remove big debris and dead animals, while working conditions permit this activity.

G1.3. SUPPLIES

G1.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Vacuum sweeper truck
- Dump truck
- Utility or light truck
- Brooms, shovels, hand brushes, wheelbarrows

G1.3.2 Materials

- None

G1.3.3 Labor

- Foreman: 1
- Laborer: 1–3
- Truck driver/operator: 1–2

G1.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Loosen dirt, debris, and any sticky material using scrapers, stiff brushes or shovels.
- Sweep loose material from sidewalks, parapets, and railings, onto bridge deck by manual or mechanical means.
- Collect all material from deck surface by sweeping, shoveling, vacuuming, manually or mechanically.
- Avoid depositing material into drains or deck joints. During maintenance work it is preferable to block bridge drains and scuppers.
- Remove large pieces of debris by hand or using appropriate equipment.
- Load material into containers or dump trucks.
- Minimize discharge of loose material, grit and debris into the water.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G1.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

In the possibility that workers could find bags or packages with unidentifiable material, they should avoid manipulating it and must be reported it to their supervisor.

The crew should try to perform the maintenance activity facing oncoming traffic when possible as a safety measure. Also, all mobile units should be parked between oncoming traffic and workers.

G1.6. PICTURES

Figure G1.1 Bridge sweeping manually (Marracino & Fox, 2009).

Figure G1.2 Bridge sweeping mechanically (DBi Services, n.d.).

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APPENDIX G2: DECK DRAINAGE CLEANING/FLUSHING

G2.1. DESCRIPTION

Deck drainage cleaning/flushing is performed to remove litter, debris, dirt, salt, anti-skid, and other deleterious material from the bridge drainage system. Accumulated material can damage the drainage system or back up water into the system which later could damage the system components. Accumulated material should be eliminated from open components (curbs, gutters, etc.) and closed components (scuppers, inlet boxes, pipes, downspouts, etc.), using adequate tools or mechanical equipment. After dry cleaning and clearing all drainage system components, any remaining material should be removed by pressure washing, air blasting or mechanical devices.

All drainage components should be verified to be unplugged, ensuring drainage water flowing freely. Special consideration must be taken when discharging flushed material to streams under the bridge.

G2.2. REQUIREMENTS

This activity is recommended to be performed annually, preferably shortly after the end of the winter season. It is highly recommended to perform this activity in conjunction with other maintenance activities, such as deck sweeping/cleaning and cleaning/flushing deck joints, in order to obtain the maximum benefit. This activity offer its best results when applied to a new bridge drainage system and then is performed with a regular frequency as indicated. Verify that water and debris discharged to streams during flushing activities are low in contaminant compounds as required by environmental measures.

G2.3. SUPPLIES

G2.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- High-pressure water pump w/hoses
- Dump truck
- Utility or light truck, water trailer
- Sewer snake
- Brooms, shovels, hand brushes, wheelbarrows

G2.3.2 Materials

- Non-potable water

G2.3.3 Labor

- Foreman: 1
- Laborer: 1–2
- Truck driver/operator: 1

G2.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Loosen dirt, debris, and any sticky material using scrapers, stiff brushes or shovels.
- Remove debris from grating and lift grating from scupper.
- Collect all material from open and closed components by sweeping, shoveling, vacuuming, manually or mechanically.
- If debris is trapped into closed components, remove all material with water pressure, sewer snake, or appropriate tools.
- Keep water pressure under control to avoid damage to pipes or other bridge elements. A water pressure of no more than 3,000 psi is recommended, but areas with concern have to be tested before proceeding.
- Water can be obtained from the same stream under the bridge or can be brought from other source when its quality is acceptable.
- Locate pipe outlet and verify outflow is clear.
- Replace grating and clean-out plugs.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G2.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

The crew should perform the maintenance activity facing oncoming traffic when possible as a safety measure. Also, all mobile units should be parked between oncoming traffic and workers.

G2.6. PICTURES

Figure G2.1 Bridge drains have to be open and free of clogging (GDOT, 2012).

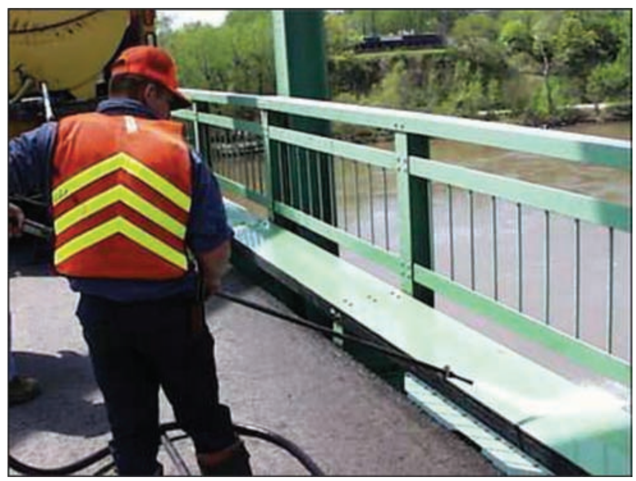

Figure G2.2 Flushing helps to remove dirt and debris from curb outlets and pipe drains (MoDOT, n.d.).

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APPENDIX G3: CONCRETE DECK SEALING

G3.1. DESCRIPTION

Concrete deck sealing is performed to seal the deck surface. Concrete deck sealing is an effective method to protect reinforcing steel from corrosion. The sealant prevents water and chloride compounds from deicing products to penetrate into the deck. The best performance is obtained from penetrating solvent-based silanes, which penetrates deeper into the concrete pore structure, forming a hydrophobic, water-repelling surface.

G3.2. REQUIREMENTS

This activity is recommended to be performed to all new decks and replaced decks. It should be performed no early than three nor later than six months after construction. In this situation the concrete is expected to have developed most of the cracks free of chloride contamination. Consequently, deck sealing has to be scheduled before the first application of deicing products. Lastly, to maximize the effectiveness of the sealant, deck sealing should be re-applied every five years. In order to obtain the maximum benefit, it is highly recommended performing this activity in conjunction with other maintenance activities, such as “concrete deck crack sealing” and “concrete deck partial patching,” to ensure a surface in good conditions before sealing the deck.

G3.3. SUPPLIES

G3.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Compressor with hoses
- Sandblaster/air gun
- Truck with pumps and spray bar
- Paint spray unit, rollers, brushes, etc.
- Shovels, scrapers, brooms, etc.
- General hand tools

G3.3.2 Materials

- Water
- Blasting sand
- Sealer product (silane)

G3.3.3 Labor

- Foreman: 1
- Laborer: 2–4
- Air compressor/operator: 2
- Truck driver/operator: 1–2

G3.4. PROCEDURES

1. Work-zone preparation

- Implement typical Maintenance of Traffic (MOT) procedures appropriate for bridge deck maintenance at the given site, such as traffic control, environmental protection, equipment and material distribution, etc.
- Label all flammable products, and store them in safe places.
- All application equipment has to be clean and free of oil residue and water.

2. Deck cleaning

- Loosen and shovel off heavy dirt deposits.
- Clean the deck by power washing or air-blasting, assuring a clean surface, free of all dirt, sand, oil, grease, and debris.
- For a new deck (corresponding to a new bridge or a replacement deck) it may be adequate to clean the deck from dust and deleterious bodies using only air-pressure.
- Allow the deck surface to dry a minimum of two days, or more depending on adverse weather conditions (i.e. recent rain, low air temperatures, or high relative humidity of air).

3. Repair all surface damage

- Surfaces must be free of irregularities or damage.
- Significant cracks must be sealed (see Concrete deck crack sealing activity).
- Notable spalls should be patched (see Concrete deck partial patching activity).
- Sealing should not be done until all repairs have been completed and concrete has cured.

4. Verify manufacturer’s specifications

- The product should be a solvent-based silane compound to be dissolved with a solvent carrier, creating a hydrophobic surface on the concrete pore structure.
- Prior to the application of the sealer, review all required conditions from the manufacturer, as follows:

  - ✓ Ambient temperature of air and deck,
  - ✓ Temperature range of materials to be used
  - ✓ Wind velocity
  - ✓ No expected extreme weather conditions until sealant cures
  - ✓ C:/Documents and Settings/Myilv/My Documents/Myilv/KGL/SAGE/logo/Sage/C:/Documents and Settings/Myilv/My Documents/Myilv/KGL/SAGE/logo/Sage/Ensure that the deck contains no debris, moisture or oil remnants.

5. Sealer application

- Measure and mark off the area to be sealed in order to estimate the required amount of mix and the correct rate of application.
- Prepare the sealing mix, as required, using the procedure and amounts indicated by the product specifications.

- Apply sealant product by thoroughly saturating the deck surface, using pump tanks or mechanical spray equipment, squeegees, and rollers.
- Apply the sealer starting from the lower areas to the higher, to assure proper saturation.
- For best results, it is preferable to apply the sealer in two coats instead of only one. The second coat should be applied in a direction perpendicular to the first coat.
- Control application rate to avoid runoff.
- Sealed surface should be dry 30–60 minutes after application
- Do not apply the sealer when the temperature of the concrete surface is below 40°F.
- Protect the sealed zones from rain and traffic spray at least for six hours after application.

6. Clear work-zone

- Dispose all collected material at designated locations.
- Remove all equipment and tools.
- Remove all traffic control measures.

Figure G3.2 Topical application of sealer on deck surface (NYSDOT, 2008).

G3.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

G3.6. PICTURES

Figure G3.1 Sandblasting concrete deck surface (Fijones & Picard, 2005).

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APPENDIX G4: CONCRETE DECK CRACK SEALING

G4.1. DESCRIPTION

Concrete deck crack sealing is performed to seal the notable cracks that form in the deck. Concrete deck crack sealing is an effective method to protect reinforcing steel from corrosion. The sealant prevents water and chloride compounds from deicing products to penetrate into the deck. There are several methods to repair cracks. Very thin cracks of 0.002 in. to 0.007 in. thick, typical of cracks that appear early after deck construction, can be sealed at the same time as the deck sealing, using the same penetrating solvent-based silane sealer (see Concrete Deck Sealing activity). For deck cracks from 0.007 in. to 0.016 in. thick, the application of a High Molecular Weight Methacrylate (HMWM) product is recommended. For cracks of 0.016 in. thick or more, the application of an epoxy product is the best alternative.

G4.2. REQUIREMENTS

This activity is recommended to be performed to all new decks and replaced decks. As for deck sealing, perform this activity no earlier than three nor later than six months after construction. In this situation the concrete is expected to have experienced all cracks free of chloride contamination. Consequently, sealing the cracks has to be scheduled before the first application of deicing products. Lastly, to maximize the effectiveness of the sealant, deck cracks sealing should be re-applied every five years. In order to obtain the maximum benefit, it is highly recommended performing this activity in conjunction with other maintenance activities, such as “concrete deck partial patching,” to ensure a surface in good condition before sealing the deck.

Some deck sealant products have been found to produce unfavorable chemical reactions with deck crack sealers (Frosch et al., 2013). Therefore, analyze previously what products will be used to seal the deck and the cracks.

G4.3. SUPPLIES

G4.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Compressor with hoses
- Sandblaster/air gun
- Walk behind concrete crack router
- Hand held grinder
- General hand tools

G4.3.2 Materials

- Water
- Blasting sand
- Deck crack sealant (HMWM or epoxy), or deck sealant (silane)

G4.3.3 Labor

- Foreman: 1
- Laborer: 1–2
- Air compressor/operator: 1
- Truck driver/operator: 1

G4.4. PROCEDURES

The following are the tasks to be accomplished during this activity:

1. Work-zone preparation

- Implement typical Maintenance of Traffic (MOT) procedures appropriate for bridge deck maintenances at the given site, such as traffic control, environmental protection, equipment and material distribution, etc.
- Label all flammable products, and preserve them in safe places.
- All application equipment has to be clean and free of oil residue and water.

2. Deck cleaning

- Loosen and shovel off heavy dirt deposits.
- Clean the deck by power washing or air-blasting, assuring a clean surface, free of all dirt, sand, oil, grease, and debris.
- For a new deck (corresponding to a new bridge or a replacement deck) it may be sufficient to clean the deck from dust and deleterious bodies using only air-pressure.
- Allow the deck surface to dry a minimum of two days, or more depending on adverse weather conditions (i.e. recent rain, low air temperatures, or high relative humidity of air).

3.1 HMWM application

- Combine monomers, promoters, and initiators according to the manufacturer’s recommendations.
- Apply the product with a surface deck temperature ranging from 60°F to 100°F
- Flood the concrete surfaces with the mixed sealer within 5 minutes after completing the mix.
- Begin redistribution of excess material within 5 to 10 minutes after completing the application, using a squeegee or brooms.
- Continue redistribution until the sealer begins to gel.

3.2 Epoxy pressure application

- Prepare epoxy sealer according to manufacturer's specifications.
- Prior to injection, the surface of the crack should be sealed to keep the injection material from leaking out before it has gelled, as follow:

  ✓ Route a 0.25 in. deep vee-notched in the crack using a hand held grinder following the line of the crack.
  ✓ Clean particles of concrete and dust from the deck surface and cracks
  ✓ Fill the groove with an epoxy mortar.

- Drill port holes along the crack at a spacing needed to allow the epoxy to adequately fill the crack between port holes (1 to 3 ft.).
- Inject epoxy sealing material with pressure through those "entry ports" until the crack is completely filled.
- Finally, clean all sealed cracks in the original concrete surface, eliminating the excess material.

4. Clear work-zone

- Dispose all collected material at designated locations.
- Remove all equipment and tools.
- Remove all traffic control measures.

G4.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

G4.6. PICTURES

Figure G4.1 Finished deck crack sealing (NYSDOT, 2008).

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APPENDIX G5: CONCRETE DECK PARTIAL PATCHING

G5.1. DESCRIPTION

Concrete deck partial patching is performed to patch the potholes on the deck surface. Concrete deck partial patching is a method to correct deck surface damage and to provide a measure to protect reinforcing steel from corrosion. Considering an integral concrete deck maintenance program, deck sealing and deck crack sealing should be complemented with concrete deck partial patching. In a concrete deck that has been protected from concrete chloride contamination since construction by the application of regular deck sealing and deck crack sealing, no significant damage should be expected in the deck surface. Concrete deck patching should be performed as early as possible, to prevent the development of a larger contaminated area of deck. The patching process must eliminate all contaminated concrete and corroded reinforcing steel in the damaged area in order to achieve a durable repair.

G5.2. REQUIREMENTS

This activity is recommended to be performed when using shallow deck patching, and when no more than 10% of the total deck area requires patching. To maximize the effectiveness of the partial patching, it should be re-applied every five years or when needed. In order to obtain the maximum benefit, it is highly recommended performing this activity in conjunction with other maintenance activities, such as "concrete deck crack sealing," to ensure a surface in good condition before sealing the deck.

G5.3. SUPPLIES

G5.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Concrete saw
- Compressor with hoses
- Sandblaster
- Concrete mixer
- Pneumatic hammer (<30lb)
- Shovels and pickaxes
- Brooms ad brushes
- General hand tools

G5.3.2 Materials

- Portland Concrete Cement (PCC) or other suitable patching material
- Water
- Blasting sand
- Epoxy bonding compound

G5.3.3 Labor

- Foreman: 1
- Laborer: 4–5
- Operators: 2
- Truck driver/operator: 1

G5.4. PROCEDURES

The following are the tasks to be accomplished during this activity:

1. Work-zone preparation

- Implement typical Maintenance of Traffic (MOT) procedures appropriate for bridge deck maintenances at the given site, such as traffic control, environmental protection, equipment and material distribution, etc.
- Label all flammable products, and preserve them in safety places.
- All application equipment has to be clean and free of oil residue and water.

2. Removing damaged material and preparing the repair area

- "Sound" bridge deck adjacent to visual defects to identify the extent of the damaged areas. This can be done striking the deck with a hammer, chain drag, or similar tool that allows detection of damaged concrete by means of a corresponding peculiar hollow sound.
- Mark the limits of the defective areas with rectangles which are 6 in. larger than the identified unsound concrete area.
- Adjacent marked areas less than 6 in. from each other should be marked as one area.
- Saw-cut the concrete by the marked rectangles with vertical faces 1 in. deep. Take care to avoid any damage to reinforcing steel bars.
- Remove all unsound concrete within the sawed area to 1 in. below the upper steel mat. The concrete can be removed using a pneumatic hammer or by hydrodemolition.
- Clean all exposed reinforcing steel of rust and corrosive products.
- Repair epoxy coating surface as needed.
- Clean all surfaces within the repair areas with water-blasting, sandblasting or air blasting, to remove dust, dirt, oil, slurry from saw operation, and any other contaminants.

3. Placing patching material—accelerated strength concrete

- Begin the placement of patching material when all surfaces within the repair area are dry and totally free of contaminants.
- Apply a coat of epoxy bonding compound over all old concrete surfaces within the repair area to ensure appropriate adherence between new and old concrete.
- Mix the concrete on site in a portable mixer, following specifications for an accelerated mix design from the laboratory.
- Cast the concrete in the repair area while the epoxy is still tacky.
- Vibrate to obtain a dense, uniform mass of concrete that completely fills all the patch hole.
- Finish the patch concrete with a straight edge to level the surrounding concrete surface.
- Apply a proper curing method to the patch concrete, such as the use of wet burlap or membrane curing compound. Allow a continuing cure until accomplish the time specified by laboratory recommendations.

4. Clear work-zone

- Dispose all collected material at designated locations.
- Remove all equipment and tools.
- Remove all traffic control measures.

G5.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

G5.6. PICTURES

Figure G5.1 Partial deck patching (NYSDOT, 2008).

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APPENDIX G6: DECK JOINTS CLEANING/FLUSHING/RESEALING

G6.1. DESCRIPTION

The purpose of this preventive maintenance activity is to clean and flush the bridge deck joints regularly to keep them in outstanding condition. This activity is performed with the aim to eliminate all foreign materials from the joint, such as dirt, debris, and chloride compounds from deicing products. Removing incompressible materials trapped into expansion devices is vital to avoid damage to joint components. The deck joints must keep their integrity with a correct seal to function properly, allowing expected deck movements and ensuring a waterproof condition. A concrete deck can deteriorate when it's free expansion and contraction capacities are suppressed due to damaged joints. Moreover, leaking from joint seals are a path for contaminants from the deck surface to reach the bridge structural elements under the joint, damaging the girders, bearings, support seats, etc. In the case of minor problems in the seal joint, the damaged parts should be resealed during the deck maintenance activities.

G6.2. REQUIREMENTS

This activity is recommended to be performed annually, preferably shortly after the end of the winter season. It is highly recommended to perform this activity in conjunction with other maintenance activities, such as deck sweeping/cleaning and drainage system cleaning/flushing, in order to obtain the maximum benefit. This activity offer its best results when applied to a new joint and then is performed with a regular frequency as indicated.

The maintenance activity is easier to perform during a cool but not freezing day, when the concrete deck is thermally contracted and the joints are widely open. Sometimes incompressible materials are trapped into expansion joints and cannot be eliminated by regular sweeping and flushing, then, hand tools, high pressure water, or compressed air should be used. When small sealant problems are presented, the joint seal can be resealed with appropriate material such as silicone or liquid seal. For more complex sealant problems, rehabilitation or replacement of the joint will be required.

G6.3. SUPPLIES

G6.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- High-pressure water pump w/hoses
- Air compressor
- Sealant melter/hand caulk gun
- Utility or light truck
- Brooms, shovels, hand brushes, wheelbarrows

G6.3.2 Materials

- Non-potable water
- Silicone/liquid seal

G6.3.3 Labor

- Foreman: 1
- Laborer: 2–3
- Truck driver/operator: 1–2

G6.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.

- Sweep loose material from joints. Keep extreme cautions to avoid damage to components when removing debris build up in the joint.
- Collect all extracted material from joints by sweeping or vacuuming, manually or mechanically.
- Flush all joints with water pressure with no more than 3,000 psi
- Minimize discharge of loose material, grit and debris into the stream.
- Avoid depositing material into drains. During this activity it is preferable to block bridge drains and scuppers.
- Remove trapped bodies into expansion joints using hand tools, high pressure water, or oil-free compressed air.
- Perform any small resealing work following manufacturer's recommendations. Be sure the surfaces for resealing are dry and totally clean.
- Load extracted material into containers or dump trucks.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G6.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest
- All mobile units should be parked between oncoming traffic and workers.

G6.6. PICTURES

Figure G6.1 Accumulation of debris in a bridge expansion joint (Kaczinski, 2010).

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APPENDIX G7: BEARING CLEANING/FLUSHING

G7.1. DESCRIPTION

The purpose of preventive bearing maintenance is cleaning and flushing the bridge bearings to keep them in outstanding condition. Because bridge joints always leak, allowing contaminant materials such as dirt, debris, and chloride compounds to leach onto the bearings, it is recommended to clean and flush the bearings frequently. A malfunctioning bearing can produce major distress and/or failures in other bridge elements. Adequate supports or machines have to be used to gain access to all bearings for proper maintenance. Hand tools and equipment are used to clean and pressure water flushes the bearings and the area surrounding the bearings.

G7.2. REQUIREMENTS

This activity is recommended to be performed each two years, preferably shortly after the end of the winter season. This activity should be performed after all deck maintenance activities have been performed, such as deck cleaning/sweeping, deck drainage system washing/flushing, and deck joints cleaning/flushing. Perform this activity for all types of bearings. This activity offers its best results when applied to a new bridge bearing and then is performed with a regular frequency as indicated. Verify that water and debris discharged to streams during flushing activities are low in contaminant compounds as required by environmental measures. Do not flush during ambient temperatures below

40°F. This activity involves only work maintenances that do not require jacking the girders.

G7.3. SUPPLIES

G7.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- High-pressure water pump w/hoses
- Air compressor
- Utility or light truck, water trailer
- Ladders/scaffolding (as required)
- Snooper truck (as required)
- Brooms, shovels, hand brushes, wheelbarrows

G7.3.2 Materials

- Non-potable water

G7.3.3 Labor

- Foreman: 1
- Laborer: 1–3
- Truck driver/operator: 1–2

G7.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Set up ladders, scaffolding, or snooper truck (as required) to reach bearings
- Loosen dirt, debris, and any sticky material from bearings and seat bearings using scrapers, stiff brushes or shovels.
- Collect all materials from seat bearings or bent caps, by sweeping, shoveling, or vacuuming, either manually or mechanically.
- Flush bridge bearings and bearing seats at piers and abutments with clean, non-potable water, at a pressure no more than 3,000 psi.
- Water can be obtained from the same stream under the bridge or can be brought from other source while its quality is acceptable.
- If levels of contamination on the bearing seats are found beyond limits, then it should be prevented that water discharge reaches streams under the bridge. In this situation actions must be taken to collect runoff to eliminate it away from the basin of the watercourse.
- Minimize discharge of loose material, grit and debris into the water.
- Deposit collected material into containers or dump trucks.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G7.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

In the possibility that workers could find bags or packages with unidentifiable material, they should avoid manipulating it and must be reported it to their supervisor.

Brace and connect properly all scaffolding elements prior to being used. The structure should be fixed to the ground by adequate means.

When the use of scaffolding is not an alternative, then a snooper truck will be required. In that case, adequate balance has to be achieved by the truck every time the arm is extended.

G7.6. PICTURES

Figure G7.1 Snooper trucks may be required to reach bearings (DBi Services, n.d.).

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APPENDIX G8: BEARING LUBRICATING

G8.1. DESCRIPTION

The purpose of this preventive maintenance activity is lubricating the metal bridge bearings to keep them in outstanding condition. It is recommended lubricating the bearings frequently to ensure adequate relative movements between metallic pieces. A "frozen" bearing due to corrosion will likely not properly transfer loads from the superstructure to the substructure. It can cause structural distress, and can produce major failures, in some bridge elements. Adequate supports or machines will have to be used to gain access to all bearings located at abutments or piers.

G8.2. REQUIREMENTS

This activity is recommended to be performed each four years, preferably shortly after the end of the winter season. Perform this activity on bearings having metal surfaces in contact to facilitate the relative movement between those surfaces. It is highly recommended to perform this activity after the cleaning/flushing bearing activities have been performed, in order to obtain the maximum benefit. This activity offer its best results when applied to a new bridge bearing and then is performed with a regular frequency as indicated. This activity involves only lubricating bearings that do not require jacking the girders.

G8.3. SUPPLIES

G8.3.1 Equipment/Tools

- Oil applicator
- Wire brushes
- Scaling hammer
- Steel grinder
- Sandblaster
- Ladders/scaffolding (as required)
- Snooper truck (as required)
- Various hand tools

G8.3.2 Materials

- Penetrating oil
- Lubricating oil
- Grease

G8.3.3 Labor

- Foreman: 1
- Laborer: 2–3
- Truck driver/operator: 1

G8.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Set up ladders, scaffolding, or snooper truck (as required) to reach bearings.
- Clean and polish metal bearing surfaces to a smooth finish (when possible).
- Avoid damaging bearing surfaces when removing rust or scale.
- Generously apply oil and grease to all metal surfaces in contact.
- Wipe up all leaked oil and grease.
- Remove all traffic control measures.

G8.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

Brace and connect properly all scaffolding elements prior to being used (if used). The structure should be fixed to the ground by adequate means.

When the use of scaffolding is not an alternative, then a snooper truck will be required. In that case, adequate balance has to be achieved by the truck every time the arm is extended.

G8.6. PICTURES

Figure G8.1 Bridge bearing after lubricating (PennDOT, 2010).

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APPENDIX G9: BEARING SPOT PAINTING

G9.1. DESCRIPTION

The best maintenance for a bridge bearing is to keep the deck expansion joint above the assembly properly maintained. The accumulation of dust, debris, and humidity produce the corrosion of the bearing leading to the failure of the element and the possible failure of other structural elements.

Spot painting the damaged areas in the steel elements helps to reduce the corrosion process. This activity should be performed every ten years, following the procedures for spot painting outlined in: G12. SPOT PAINTING.

APPENDIX G10: APPROACH SLAB MAINTENANCE

G10.1. DESCRIPTION

Concrete bridge approach slabs often develop problems that are related to the loss of support material under the slab. The development of voids beneath the slab have many causes with the same result, the formation of cracks and settlements, which eventually lead to the failure of the approach slab. Considering the concrete approach slab as a special type of bridge concrete deck, the following preventive maintenance activities are required to apply to keep the approach slab in good condition:

1. Clean and wash the approach slab drainage system every year. This activity can be performed following the same procedures noted in the section for:

G1. DECK SWEEPING/CLEANING
G2. DECK DRAINAGE CLEANING/FLUSHING

2. Maintain the slab surface, sealing the slab cracks, sealing the slab surface, and patching small potholes. The slab sealing must be done approximately three to six months after deck construction. Repeat the deck patching, deck crack sealing and deck sealing cyclically at intervals of five years. These activities can be performed following the same procedures noted for:

G3. CONCRETE DECK SEALING
G4. CONCRETE DECK CRACK SEALING
G5. CONCRETE DECK PARTIAL PATCHING

3. Clean and flush the approach slab joints every year. This activity can be performed following the same procedures noted for:

G6. DECK JOINTS CLEANING/FLUSHING

APPENDIX G11: SUPERSTRUCTURE CLEANING/WASHING

G11.1. DESCRIPTION

Superstructure cleaning/washing is performed to collect and eliminate litter, debris, dirt, chloride compounds, bird nesting remains, bird feces, and other deleterious material from the steel bridge superstructure elements, such as beams, girders, stringers, floor beams, etc. Keeping all the superstructure elements free of foreign materials avoids the accumulation of moisture on those materials, which in time can initiate the corrosion process on the steel surfaces and degrading the quality of the elements. Material should be collected by dry clean means, using adequate tools or mechanical equipment and must be appropriately disposed in designated areas. After all material has been collected the superstructure elements should be washed using pressurized water. Adequate supports or machines often need to be used to reach those superstructure elements being washed.

G11.2. REQUIREMENTS

This activity is recommended to be performed every two years, preferably shortly after the end of the winter season, when applications of deicing salts have ceased. This activity should be performed after all deck maintenance activities have been performed, such as deck sweeping/cleaning, drainage system cleaning/washing, and deck joints cleaning/washing. It is highly recommended to perform this activity in conjunction with other maintenance activities, such as cleaning/flushing bearings in order to obtain the maximum benefit from the access means to the superstructure. This activity offers its best results when applied to a new bridge superstructure and then is performed with a regular frequency as indicated.

Verify that water and debris discharged to streams under the bridge, during washing activities, are low in contaminant compounds as required by environmental restrictions, otherwise, appropriate procedures to collect all discharged material and runoff should be considered. Do not wash during ambient temperatures below 40°F.

G11.3. SUPPLIES

G11.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- High-pressure water pump w/hoses
- Air compressor
- Utility or light truck, water trailer
- Mobile vacuum
- Dump truck
- Ladders/scaffolding (as required)
- Snooper truck (as required)
- Brooms, shovels, hand brushes, wheelbarrows

G11.3.2 Materials

- Non-potable water

G11.3.3 Labor

- Foreman: 1
- Laborer: 3–4
- Truck driver/operator: 1

G11.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure safe work conditions. Consider possible controls to passing traffic under the bridge.
- Set up ladders, scaffolding, or snooper truck (as required) to reach superstructure elements.
- Loosen dirt, debris, and any material from superstructure elements using scrapers, stiff brushes or shovels.
- Collect all materials from superstructure elements, by sweeping, shoveling, or vacuuming, either manually or mechanically.
- Flush bridge superstructure elements with clean, non-potable water, at a pressure from 1,000 psi to 3,000 psi.
- Stop washing with water under pressure when damage to steel coating occurs. In that situation, reduce the pressure to a more convenient level or use only hand tools.
- Remove adhered bodies to the elements by using hand tools, high pressure water, or oil-free compressed air.

- Water can be obtained from the stream under the bridge when the quality is acceptable or can be brought to the site from other sources.
- If levels of contamination on the surfaces to be washed are found to be unacceptable, then all runoff should be collected to prevent discharge into the stream.
- Deposit collected material into containers or dump trucks.
- Minimize the amount of debris and drift entering the water body under the bridge.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G11.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

Avoid washing areas where birds have built nests, laying eggs, or breeding. In that situation, coordinate with supervisor to proceed according to requirements for wildlife protection.

In the possibility that workers could find bags or packages with unidentifiable material, they should avoid manipulating it and must report it to their supervisor.

Brace and connect properly all scaffolding elements prior to being used (if used). The structure should be fixed to the ground by adequate means. When the use of scaffolding is not an alternative, then a snooper truck will be required. In that case, adequate balance has to be achieved by the truck every time the arm is extended.

Due to the possible presence of infectious waste, such as bird droppings on the surface to be washed, personnel should be trained to be aware of the danger of breathing such waste. These materials should be properly removed prior to performing this activity.

G11.6. PICTURES

Figure G11.1 Debris, dirt, and waste can be found surrounding superstructure elements (Steele, 2013).

Figure G11.2 Washing superstructure elements with pressure water (Snowden, 2012).

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APPENDIX G12: SPOT PAINTING

G12.1. DESCRIPTION

Spot painting is performed to repair small and localized areas where the steel coating surface is damaged, thereby preventing further corrosion of steel bridge superstructure elements, such as beams, girders, stringers, floor beams, chords, etc. This activity is effective when isolated areas to be painted represent no more than 10% of total area. Preparation of the selected area is very important to achieve adequate bond between the new coat and the steel surface.

G12.2. REQUIREMENTS

This activity is recommended to be performed each ten years. This activity should be performed after all deck maintenance activities have been performed, such as deck sweeping/cleaning, drainage system cleaning/washing, deck joints cleaning/washing, and deck sealing. This activity offer its best results when is performed with a regular frequency as indicated. Do not perform spot painting during ambient temperatures below 40°F. A key factor in this activity is identifying the existing coating system and selecting the appropriate coating system to be used. Take appropriate measures to avoid damage to painting on areas outside the area being painted. When possible match the spot painting color with the original color.

G12.3. SUPPLIES

G12.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Paint thickness tester
- Power chippers
- Power brushes
- Sand blaster
- Air compressor
- Paint brushes
- Rollers
- Sprayer
- Utility or light truck
- Ladders/scaffolding (as required)
- Snooper truck (as required)

G12.3.2 Materials

- Paint products compatible with the existing system
- Solvent
- Sandpaper, wipe-cotton

G12.3.3 Labor

- Foreman: 1
- Laborer: 2–3
- Truck driver/operator: 1

G12.4. PROCEDURES

The work can include, but is not limited to:

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Set up ladders, scaffolding, or snooper truck (as required) to reach superstructure elements.
- Take appropriate measures to protect adjacent structures, vehicles, pedestrians, streams, from leaking paint.
- Establish spot area to be painted
- Remove deteriorated paint, rust, and any foreign body from steel surface using hand or power tools.
- Clean steel surfaces to be painted using solvents or biodegradable cleaners, until reach a surface finish as required by the paint manufacturer.
- Apply a primer coat following the manufacturer's instructions.
- Apply intermediate and finish coat following the manufacturer's instructions.
- Insure that a new coat is applied only when previous coat is totally dried.
- Test thickness of coat.
- Clean down all work area.
- Remove all traffic control measures.

G12.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest

Brace and connect properly all scaffolding elements prior to being used (if used). The structure should be fixed to the ground by adequate means. When the use of scaffolding is not an alternative, then a snooper truck will be required. In that case, adequate balance has to be achieved by the truck every time the arm is extended.

Verify the presence of paint/toxic heavy metals. When lead is present in the original paint system this alternative is not a recommended option due to extreme safety measures to be considered.

Due to the possible presence of infectious waste, such as bird droppings, on the surface to be spot painted, personnel should be trained to be aware of the danger of breathing such waste. These materials should be properly removed prior to the spot painting.

G12.6. PICTURES

Figure G12.1 Steel girder candidate for spot painting (MoDOT, 2010).

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APPENDIX G13: VEGETATION CONTROL

G13.1. DESCRIPTION

Vegetation control is performed to eliminate all brush, tree branches, and tree limbs that can obstruct driver's visibility, can obstruct traffic signals, can damage any bridge substructure/superstructure element, can obstruct elements from the drainage system, or can be a traffic hazard. This activity is performed to eliminate any risk created by excessive vegetation around bridge elements. Also, this activity will provide easy accessibility for bridge inspectors and other bridge crew members. This activity should eliminate targeted vegetation within at least 30 ft. of the bridge structure or as required.

G13.2. REQUIREMENTS

This activity is recommended to be performed annually and preferably when access to abutments is possible for bridges passing streams. It is highly recommended to perform this activity in conjunction with other maintenance activities, such as removing debris from piers and abutments, in order to obtain the maximum benefit. This activity offers its best results when applied to a new bridge and then is performed with a regular frequency as indicated. All collected material should be appropriately disposed in designated areas.

G13.3. SUPPLIES

G13.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Chain saw
- Bush ax
- Winch or pulling
- Brushcutter
- Utility or light truck
- Brooms, shovels, wheelbarrows

G13.3.2 Materials

- Herbicide

G13.3.3 Labor

- Laborer: 1–2
- Flagman: 1
- Truck driver/operator: 1–2

G13.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Collect all debris from around substructure elements
- Cut and eliminate excess of vegetation from around substructure elements, considering at least 30 ft. beyond the structure.
- Cut and remove trees if present near any bridge element.
- Avoid excess of removal to protect habitat loss, reduce erosion and sedimentation.
- Clear all the area from debris produced during this activity.
- Spray herbicide to identified areas when required. Avoid contaminating streams close to the structure.
- Minimize discharge of loose material, grit and debris into the water.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G13.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Protective Footwear
- Hard Hat
- Chain Saw Chaps
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest, Long Sleeve Shirts/Pants (as needed)

In the possibility that workers could find bags or packages with unidentifiable material, they should avoid manipulating it and must be reported it to their supervisor.

G13.5.1 Herbicide Treatment

Do not handle, mix or apply any chemical without adequate safety equipment as designated by label (required) and District management.

G13.6. PICTURES

Figure G13.1 Trees around structure elements are a significant hazard (GDOT, 2012).

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APPENDIX G14: REMOVING DEBRIS FROM PIERS/ABUTMENTS

G14.1. DESCRIPTION

This preventive maintenance activity is performed to eliminate debris jams from around substructure members, using manual and/or mechanical tools. This activity is required especially after heavy rainfalls and runoffs, because the buildup of logjams reduces the openings under the bridge, increasing the hazard of scour and posterior failure of the structure. This activity is performed to prevent scour and erosion of fills under abutments, piers, and approaches. The activity can include collecting and eliminating small pieces from the side of the structure, or collecting large pieces and cutting them in small pieces before eliminating them.

G14.2. REQUIREMENTS

This activity is recommended to be performed at least annually and when required by inspections after each flooding. It is highly recommended to perform this activity in conjunction with other maintenance activities, such as vegetation control, in order to obtain the maximum benefit. This activity offer its best results when applied to a new bridge and then is performed with a regular frequency as indicated. All collected material should be appropriately disposed in designated areas.

G14.3. SUPPLIES

G14.3.1 Equipment/Tools

- Traffic signs, arrow boards
- Personal safety equipment
- Chain saw
- Bush ax
- Winch or pulling
- Brushcutter
- Utility or light truck
- Backhoe
- Front end loader
- Brooms, shovels, wheelbarrows

G14.3.2 Materials

- None

G14.3.3 Labor

- Foreman: 1
- Laborer: 1–2
- Truck driver/operator: 1–2

G14.4. PROCEDURES

- Establish adequate traffic control measures (signs, devices, etc.) to ensure work safety conditions. Consider possible controls to passing traffic under the bridge.
- Drift removal procedures and tools to be used vary from site to site, depending on local conditions, topography, hydraulic characteristics, bridge dimensions, etc.
- For each situation the best equipment and methods have to be selected, such as the use of backhoe, truck with cable winches, dragline, etc. When logjam units are of small size then hand tools can be used.
- Take care when removing big pieces or trees to avoid damage to structure's elements. If necessary to facilitate debris removal, consider cutting large pieces of wood into smaller pieces.

- Remove all debris, trees, and branches from around substructure elements. Load all removed material to trucks or containers.
- Avoid allowing remains to flow down the stream to produce problems to other structures.
- Avoid excess of removal to protect habitat loss, reduce erosion and sedimentation.
- Clear all the area from debris collected during this activity.
- Dispose all collected material at designated locations.
- Remove all traffic control measures.

G14.5. SAFETY

Crew maintenance should use appropriate P.P.E. including:

- Protective Footwear
- Soft Cap
- Respiratory Protection
- Gloves
- Protective Footwear
- Hard Hat
- Chain Saw Chaps
- Eye Protection (as needed)
- Hearing Protection (as needed)
- Safety Vest, Long Sleeve Shirts/Pants (as needed)

G14.6. PICTURES

Figure G14.1 Logjam accumulated next to substructure's elements, which is a hazard to the whole structure (MoDOT, n.d.).

REFERENCES

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APPENDIX G15: PIN AND HANGER (OR HINGE) CONNECTION MAINTENANCE

G15.1. DESCRIPTION

Pin and hanger (or hinge) assemblies present a problem in that corrosion of the pin and its bearing surface cannot be easily detected without disassembly the connection, and this is not feasible. The best maintenance for a pin and hanger bearing assembly is to keep the deck expansion joint above the assembly properly maintained. The accumulation of dust, debris, and humidity produce the corrosion of the pin and hanger connection, leading to the failure of the connection and the possible collapse of the bridge structure. Considering the pin and hanger connection as a special type of bearing, the following preventive maintenance activities are required to apply to keep the connection in good condition:

1. Clean and wash the connection elements every two years. This activity can be performed following the same procedures for:

G7. BEARING CLEANING/FLUSHING

2. Lubricate the steel elements in the connection every four years. This activity can be performed following the same procedures for:

G8. BEARING LUBRICATING

3. Spot painting the damaged areas in the steel elements every ten years. This activity can be performed following the same procedures for:

G12. SPOT PAINTING

G15.2. PICTURES

Figure G15.1 Maintenance to pin and hanger connection (Caltrans, 2008).

REFERENCE

Caltrans. (2008). *Element level inspection manual*. Sacramento, CA: California Department of Transportation. Retrieved from http://www.dot.ca.gov/hq/structur/strmaint/eli.pdf

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

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