

Guide to Preservation of Highway Bridge Decks



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FOREWORD

The AASHTO *Guide to Preservation of Highway Bridge Decks* lists preservation treatments such as deck overlays, surface sealers and deck repairs that can extend the life of bridge decks in service. The Guide considers various deck types and the deck condition that can influence the selection of preservation treatments. The Guide presents the factors in deck capacity and durability that can influence the identification of candidates for deck preservation.

The Guide is for decks in fair or good condition with significant remaining service life. In the United States, there are 1.9 billion square feet of bridge deck in good condition and 2.2 billion square feet of bridge deck in fair condition. There are significant benefits in preservation to extend the service life of the good decks, and to delay the end of service for the fair decks.

The Guide is a collection of existing information. To develop the Guide, practices of U.S. state DOTs in selection of preservation treatments were reviewed. Procedures for application of treatments were collected. Data on performance of treatments were analyzed. Performance of a preservation treatment is measured by the years added to service life of decks due to treatment. Using existing information, the Guide presents a representative practice for deck preservation, general procedures for application of treatments, and, in examples of evaluation of costs and benefits, average performance of treatments.

The guide is a product of research directed by technical committee T-9, Bridge Preservation, of the AASHTO Committee on Bridges and Structures. Committee T-9 worked through the National Cooperative Highway Research Program to produce this Guide and a companion publication, the AASHTO *Guide to Bridge Preservation Actions*.

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SECTION 1

INTRODUCTION

1.1. GENERAL

This is a Guide to preservation of highway bridge decks.

Preservation is a program of treatments applied to bridge decks in service to keep bridge decks in good or fair condition.

Treatments are the materials and actions used to protect or repair bridge decks. Many treatments are intended to protect bridge decks from ingress of chloride ion and from freeze–thaw damage.

This Guide lists treatments for bridge decks, provides procedures for treatments, relates treatments to conditions of bridge decks, reviews methods of evaluation of bridge decks, and presents examples in evaluation of costs and benefits of treatments. Most of the content of the Guide is directed at reinforced concrete bridge decks.

Preservation of bridge decks is one task in the overall preservation of highway bridges. Preservation of highway bridges is addressed in the *Guide to Bridge Preservation Actions* (AASHTO, 2021b).

1.2. PRESERVATION OF BRIDGE DECKS

Preservation of bridge decks is a program of treatments intended to

- Extend service life of bridge decks,
- Keep bridge decks in good or fair condition, and
- Reduce life-cycle costs.

Treatments include surface sealers, overlays, and waterproofing membranes with wearing course. The application of treatments often includes repairs to cracks, spalls, and delaminations.

C1.1.

This Section introduces the content and organization of the Guide.

Treatments are means of preserving bridge decks in service.

C1.2.

Preservation is one part of the program for highway bridges of a transportation agency. The bridge program includes a capital program for bridge rehabilitation and replacement, plus a preservation program for bridge protection and repair. Similar categories are applied to bridge decks. Protection and repair of decks are within preservation programs. Deck replacements are beyond preservation programs.

Programs for bridge preservation establish boundaries on the population of bridge decks that are candidates for preservation, and on the actions that are preservation treatments.

Preservation treatments include protection and repair of existing bridge decks. Projects to improve, replace, or construct bridge decks are beyond the intended scope of a deck preservation program.

Preservation treatments delay or slow deterioration in bridge decks.

Funds available to transportation agencies are limited, and there is competition among needs in preservation, restoration, replacement, capacity expansion, and new construction. Preservation programs are manageable when a defined population of structures is addressed. Preservation programs exist within an agency when decisions in allocation of funds are taken at the program level rather than the project level.

1.3. PRESERVATION CANDIDATES

Preservation programs address a defined population of bridge decks. These are bridge decks that meet criteria in

- Work history,
- Capacity,
- Robustness, and
- Durability.

Work History—The history of preservation work completed on a deck should be considered when selecting bridge decks for preservation.

Capacity—Bridge decks selected for preservation should have adequate traffic capacity and adequate geometry.

Robustness—Bridge decks selected for preservation should have desired resistance to extreme events.

Durability—Bridge decks selected for preservation should have design details and construction materials that provide adequate resistance to deterioration.

An overriding criterion for preservation of a bridge deck is preservation of the bridge. The bridge, as an entire system, should be a candidate for preservation. Candidates for bridge preservation are discussed in AASHTO (2021b).

1.4. ORGANIZATION OF THE GUIDE

The *Guide to Preservation of Highway Bridge Decks* is presented in five sections and three appendices. The sections are:

- Section 1: Introduction
- Section 2: Preservation Treatments for Bridge Decks
- Section 3: Evaluation of Bridge Decks
- Section 4: Selecting Preservation Treatments for Bridge Decks
- Section 5: Costs and Benefits of Deck Preservation

The appendices are:

- Appendix A: Preservation Treatments for Highway Bridge Decks
- Appendix B: Defects in Highway Bridge Decks
- Appendix C: Selection of Preservation Treatments for Bridge Decks

C1.3.

Bridge owners are free to set specific requirements for each of the four criteria: history, capacity, robustness, and durability. General guidance is provided here.

Capacity—Bridge decks should have adequate load rating, adequate number of travel lanes, adequate lane widths and vertical clearances, and adequate alignment.

Criteria for capacity of bridge decks can vary by route functional class and by traffic volume. Low-volume roads may have requirements for capacity that differ from requirements for high-volume roads. For all route functional classes, bridge owners set criteria for adequate decks.

Robustness—Bridge decks should have adequate resistance to earthquakes, floods, storm surges, and tsunamis.

Durability—For reinforced concrete decks, durability is provided by adequate protection for reinforcing steel, by adequate deck thickness, by aggregate that is not vulnerable to alkali-silica reaction, and by mix designs that are not too permeable to water.

1.5. AUDIENCE FOR THE GUIDE

The Guide is intended for staff involved in bridge preservation at bridge-owning agencies.

1.6. RELATED DOCUMENTS

Preservation of bridge decks is related to the design of decks and to the preservation of deck joints. Two AASHTO publications are useful: the *Guide Specification for Service Life Design of Highway Bridges* (AASHTO, 2020), and the *Guidelines for Maintaining Small Movement Bridge Expansion Joints* (AASHTO, 2021a).

1.7. BRIDGE DECKS ADDRESSED IN THE GUIDE

The Guide provides information on the preservation of steel-reinforced concrete bridge decks. The Guide has minimal information on steel grid decks and timber decks. Steel orthotropic decks are covered in Connor et al. (2012).

C1.7.

As of 2018, among bridges subject to U.S. Federal regulation, 86 percent by count and 96 percent by bridge deck area are steel-reinforced concrete bridge decks (FHWA, undated). The Guide is directed at reinforced concrete bridge decks. The Guide has some content on timber decks, and on steel grid decks. Steel orthotropic plate decks and decks for movable bridges are not addressed in the Guide.

1.8. APPLICATION OF THE GUIDE

The Guide presents general information on preservation treatments for highway bridge decks. Bridge owners can adapt information in the Guide to form or to improve their practices in preservation of bridge decks. A necessary step in adapting this Guide is the substitution of owner-specific policies, costs, and performance values in place of the general information in this Guide.

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SECTION 2

PRESERVATION TREATMENTS FOR BRIDGE DECKS

2.1. INTRODUCTION

This Section presents general information on preservation treatments for highway bridge decks.

Detailed information is presented in Appendix A.

2.2. TYPICAL REINFORCED CONCRETE DECKS OF HIGHWAY BRIDGES

Designs for reinforced concrete (RC) bridge decks, typically, are two mats of steel reinforcement in a cast-in-place portland cement concrete slab. Thickness of the slab varies with spacing between supporting beams. Spacings of 4 to 12 ft with slab thicknesses of 7 to 9 in. are common.

Concrete reinforcing steel in bridge decks, in new construction, is typically protected against corrosion or is manufactured of corrosion-resistant alloys. Protection by epoxy coating is widely used. Cathodic protection is available, both as passive or impressed-current systems. Corrosion-resistant reinforcing bars include stainless steel rebars, stainless-clad rebars, zinc-galvanized rebars, and glass fiber reinforced polymer (GFRP) rebars.

Protection for reinforcing steel may be provided at the surface of a deck in the form of a penetrating sealer, a waterproofing membrane with wearing course, or an overlay.

2.3. PRESERVATION TREATMENTS FOR BRIDGE DECKS

Preservation treatments are:

- Deck cleaning,
- Surface sealers,
- Thin polymer overlays,
- Polyester concrete overlay,
- Asphalt wearing surface plus waterproofing membrane,
- Portland cement concrete overlays,
- Crack sealing, and
- Deck spall repair.

Treatments presented in this Guide are listed in Table 2.3-1.

C2.1.

General information provided in this Section includes:

- Type of preservation treatment,
- Materials used for treatment,
- Decks and conditions suitable for treatment, and
- Procedures for treatment.

C2.2.

Among decks built with portland cement concrete, 89,000 by count (24 percent) and 1 billion ft² in area (27 percent) have protection for reinforcing steel (FHWA, undated).

Membranes are reported on 28,000 concrete decks (7 percent) with 234 million ft² in area (6 percent). Overlays are reported on 29,000 (7 percent) concrete decks with 416 million ft² in area (11 percent) (FHWA, undated).

Concrete bridge decks with no reported protection for steel, no membrane, and no overlay number 176,000 (44 percent) with area equal to 1.75 billion ft² (47 percent) (FHWA, undated).

C2.3.

Bridge decks can benefit from periodic cleaning to remove grit and debris, and from periodic washing to remove residues of deicing chemicals and other agents from the deck surface.

Concrete decks in good condition can benefit from surface sealers and renewal of surface sealers at regular intervals. Surface sealers restrict the movement of waterborne agents into concrete decks.

Healer-sealers, surface sealers that adhere to concrete and span narrow cracks, can be useful to decks in good or fair condition. Healer-sealers restrict movement of waterborne agents.

Concrete decks in good or fair condition can benefit from thin polymer overlays. The overlay takes wear from vehicle traffic and can restrict the movement of waterborne agents into decks. For decks in fair condition with some shallow spalls, treatments can include repairs

to spalls followed by thin polymer overlay. The overlay restores skid resistance and uniform appearance to decks that had spalls.

Concrete decks in fair or poor condition can benefit from repairs plus a waterproofing membrane with asphalt wearing course (*OvHma+M*), or a polyester concrete overlay, a portland cement concrete overlay (usually a modified PCC mix), or a high performance concrete overlay.

One step in treatment of a deck may be the removal of a top portion of the deck to remove contaminated or deteriorated concrete.

The various treatments are not restricted to the stages of service life noted here. For example, PCC overlays can be applied to new decks; thin polymer overlays can be applied, after repairs, to decks in poor condition.

Table 2.3-1—List of Preservation Treatments for Bridge Decks

	Treatment	Detail	Abbreviation
	Inspection	Inspection and evaluation in support of selection of treatment for bridge deck	—
Protection	Surface Sealer	Silane, Siloxane	<i>SeSi</i>
		Methyl methacrylate	<i>SeMm</i>
		Epoxy	<i>SeEp</i>
	Thin Polymer Overlay	Epoxy	<i>OvThEp</i>
		Polyester	<i>OvThPe</i>
		Methyl methacrylate	<i>OvThMm</i>
	Polymer Overlay	Polyester concrete	<i>OvPpc</i>
	Hot Mix Asphalt (HMA) + Membrane	Preformed membrane	<i>OvHma+M</i>
		Liquid membrane	
	Portland Cement Overlay	Portland cement concrete, dense	<i>OvPccD</i>
		Portland cement concrete, latex-modified	<i>OvPccLm</i>
		Portland cement concrete, microsilica, or fly-ash	<i>OvPccSm</i>
		Ultra-high-performance concrete	<i>OvUhpc</i>
Repair	Spalls	<i>T0</i> —Shallow spall	¹
		<i>T1</i> —Spall above top mat of reinforcing steel	<i>RpSpT1</i>
		<i>T2</i> —Spall below top mat of reinforcing steel	<i>RpSpT2</i>
		<i>T3</i> —Full depth repair	<i>RpSpT3</i>
	Cracks	Injection of binder	<i>RpCrEp</i>
		Floodcoat of binder	<i>SeMm</i>
			<i>SeEp</i>
	Timber	Local repairs in timber decks	<i>RpTm</i>
	Steel	Local repairs in steel grid decks	<i>RpSt</i>

¹ Repair of T0 spalls is included in treatments in Appendix A, Sections A.1 through A.11.

2.3.1. Protection vs. Repair

Treatments for bridge decks are grouped as protections and as repairs. Protections for decks are surface sealers, waterproofing membranes, wearing courses, and overlays. Repairs include sealing of cracks and repair of delaminations and spalls.

Treatments to protect decks are applied to decks in good or fair condition. Repairs are applied to portions of decks in fair or poor condition.

In this Guide, information on treatments is presented in these groupings. Protective treatments are presented separately from repairs that may be needed to prepare a deck for protective treatment. Repairs are presented separately from the protective treatments that may follow.

2.3.2. Surface Sealers

Surface sealers restrict movement of waterborne agents into concrete. Surface sealers may be applied on bare concrete decks or on concrete overlays.

Materials for surface sealers are silane, siloxane, soluble reactive silicate, epoxy binder, and methyl methacrylate monomer.

Surface sealers are evaluated for their effectiveness per Pfeifer and Scali (1981). Measures are comparative. Surface sealers reduce entry of chloride ion into concrete, compared to concrete without surface sealer.

Bridge decks should be in good condition when surface sealers are applied.

Sweeping or light sandblasting can provide adequate preparation of concrete surfaces. The deck should be clean, free of dust and debris, and free of concrete curing compounds.

Weather during placement of surface sealers should be dry. Air temperature should be above 40°F. The deck should be dry. Deck temperature should be above 40°F.

Silane and siloxane surface sealers are usually applied by spray. Epoxy and methyl methacrylate surface sealers are usually poured onto decks and then spread out with brooms or squeegees.

Sand is broadcast onto tacky sealer to improve initial skid resistance.

Curing times for surface sealers range from 2 to 7 hr depending on the material used and on weather, especially temperature.

C2.3.1.

Protective treatments restrict movement of waterborne agents into bridge decks, or take wear from vehicle traffic, or both. Protective treatment with concrete overlay may also increase structural capacity.

Treatments can be combined. A protective overlay can be applied to a deck in poor condition after the deck is repaired; that is, after the deck is restored to good or fair condition.

C2.3.2.

Detailed information on the use of surface sealers is provided in Appendix A; see:

Article A.19	<i>SeG</i> : Seal Surface, General
Article A.20	<i>SeMm</i> : Seal Surface, Methyl Methacrylate Sealer
Article A.21	<i>SeEp</i> : Seal Surface, Epoxy surface Sealer
Article A.22	<i>SeSi</i> : Seal Surface, Silane Sealer, Siloxane Sealer

The effectiveness of surface sealers may be affected by abrasion of deck surface under traffic with studded tires or tire chains.

Bridge decks in good condition have NBI general condition rating of 7 or higher, and 90 percent or more of deck area in element-level condition state 1. These may be current conditions or conditions after repair. Some bridge owners apply surface sealers to decks that have cracks, but no apparent delaminations. Such decks may have NBI general condition rating equal to 6.

Recommended air temperature and deck temperature can vary with product. Seek manufacturers' recommendation on method of placement and temperature for placement of surface sealer.

Surface sealers reduce water permeability of the surface of a bridge deck. If the deck surface already has low permeability, a surface sealer may not be helpful.

Information on condition data for bridge decks is provided in Section 3.

Surface sealers should be re-applied while decks remain in good condition. Intervals for reapplication vary with sealer material, among other factors.

2.3.3. Thin Polymer Overlay

Thin polymer overlays absorb wear from traffic, and restrict the passage of waterborne agents into the structural deck. Thin polymer overlays have two parts: binder and aggregate. Binder holds the aggregate in place and holds the overlay onto the bridge deck. Aggregate provides skid resistance for traffic.

Thin polymer overlays are between 0.25 and 0.375 in. thick. Thin overlays are lightweight, and have less impact on bridge load rating.

Epoxy binder, epoxy-urethane binder, polyester binder, and methyl methacrylate binder are used for thin polymer overlays. Aggregates are graded stone aggregates.

Thin polymer overlays, after curing, are tested for adhesion to decks.

Concrete decks in good condition are candidates for thin polymer overlays. Decks in fair condition can be candidates for thin polymer overlays if repairs to decks can restore good condition.

Sandblasting, shot blasting, or micromilling may be used to provide the bridge deck with a surface roughness of ICRI CSP 5 to 7. The bridge deck is cleaned with compressed air and vacuum to remove dust and debris.

During placement of thin polymer overlay, weather should be dry, without recent rain or forecast of rain. Temperature of air and temperature of bridge deck should be between 50°F and 85°F.

Thin polymer overlays may be placed as multiple layers of binder and aggregate, or as slurries of binder plus aggregate.

Curing of thin polymer overlay can require 2 to 8 hr. Lower temperature means longer cure time.

2.3.4. Polyester Concrete Overlay

Polyester concrete overlay is a combination of aggregate and polyester resin placed on RC decks that have been prepared with methyl methacrylate primer.

Polyester concrete overlays take wear due to traffic and have low permeability to water.

Polyester concrete overlays are typically 0.75 to 2 in. thick.

C2.3.3.

Detailed information on thin polymer overlays is provided in Appendix A; see:

Article A.1	<i>OvThPG</i> : Thin Polymer Overlay, General
Article A.2	<i>OvThEp</i> : Thin Polymer Overlay, Epoxy + Aggregate
Article A.3	<i>OvThMm</i> : Thin Polymer Overlay, Methyl Methacrylate + Aggregate
Article A.4	<i>OvThPe</i> : Thin Polymer Overlay Polyester + Aggregate

Because they are thin, these overlays cannot be used to alter the grade of a deck or to improve areas with poor drainage.

Thin polymer overlay has a weight density of approximately 135 lb/ft³. A 0.375-in. thick overlay has a self-weight of 4 lb/ft².

Bridge decks in good condition have NBI general condition rating of 7 or higher, and 90 percent or more of deck area in element-level condition state 1. These may be current conditions or conditions after repair.

Information on condition data for bridge decks is provided in Section 3.

ICRI is the *International Concrete Repair Institute*. CSP is Concrete Surface Profile, a scale published by ICRI. CSP equal to 5 to 7 is a surface macrotexture of approximately 0.125 in. (ASTM E965).

Recommended air temperature and deck temperature can vary with product. Seek manufacturers' recommendation on temperature for placement of thin polymer overlay.

One bridge owner reports that polymer overlays applied in multiple layers are porous.

C2.3.4.

Detailed information on use of polyester concrete overlay is provided in Appendix A.5.

Polyester concrete overlays may be thicker than 2 in.

Decks in good, fair, or poor condition are candidates for polyester concrete overlay. Decks in fair condition or poor condition require repairs before polyester concrete overlay is placed.

RC decks are prepared by shotblasting and cleaning.

During placement of polyester concrete overlay, weather should be dry, without recent rain or forecast of rain. Air temperature and deck temperature should be within the range set by owner's specifications or recommended by the manufacturer of the polyester resin.

At each bridge deck, test sections of polyester concrete overlay are constructed to demonstrate deck surface preparation, polyester resin mix proportions and set time, control of grade and cross-section, and bond strength of polyester concrete overlay to bridge deck.

For installation of polyester concrete overlay, the deck surface is cleaned with high-pressure air, methyl methacrylate primer is applied, and polyester concrete is placed.

Mobile mixers are used for components of polyester concrete. Slipform paving machines or rail-mounted screeds are used to achieve grade and cross-section of overlay. Abrasive sand is broadcast at the surface of wet polyester concrete overlay to improve friction.

Curing of polyester concrete is complete in 4 hr.

2.3.5. HMA+Membrane Overlay

HMA plus waterproofing membrane is a system for overlay of bridge decks that takes wear from traffic and prevents movement of waterborne agents into the deck. A waterproofing membrane is applied to the RC bridge deck and an HMA wearing course is placed on top of the membrane. Some membranes require protective boards or fabric between the membrane and HMA wearing course.

The HMA wearing course may be renewed (removed to partial depth, then re-paved) without replacing the waterproofing membrane.

Waterproofing membranes may be preformed membranes or may be liquid membranes spread onto bridge decks and cured.

Routine methods of placement of HMA are used.

Liquid membranes may require curing. HMA paving requires finishing.

Bridge decks in good or fair condition are candidates for *HMA+Membrane*.

Information on condition data for bridge decks is provided in Section 3.

Preparation and inspection of bridge decks prior to overlay is addressed in Article A.5.11.

One bridge owner requires testing by Schmidt hammer to verify that curing is complete.

C2.3.5.

Detailed information on use of HMA plus waterproofing membrane is provided in Article A.6.

Preformed membranes have thickness between 65 mils and 70 mils, tension strength between 50 lb/in. and 90 lb/in., puncture resistance between 200 lb and 300 lb, and permeance between 0.002 perm and 0.05 perm. Preformed membrane remains flexible at cold temperature. Specimens at -25°F can be bent double without cracking.

Temperature of HMA at placement, and tolerance of membrane for high temperature, are concerns in selection of membrane and formulation of HMA.

Information on condition data for bridge decks is provided in Section 3.

Bridge owners differ in their use of *HMA+Membrane*. Some owners apply *HMA+Membrane* on new bridge decks to provide early protection. *HMA+Membrane* will be maintained and renewed for the service life of bridge decks. HMA, possibly without waterproofing membrane,

The deck surface should be clean and should have no sharp protrusions that could puncture the membrane.

During placement of *HMA+Membrane*, air temperatures should be between 50°F and 90°F. Surface temperature of deck should be between 50°F and 120°F. Relative humidity (RH) of the deck should be less than 75 percent (ASTM F2170).

The waterproofing membrane is installed first. HMA is placed on top of the membrane.

2.3.5.1. Membrane, Liquid

Liquid membranes are sprayed or squeegeed on the deck surface.

2.3.5.2. Membrane, Preformed

Preformed membranes are delivered in rolls and are applied directly on the deck after the deck is primed.

2.3.6. Portland Cement Concrete Overlays

Portland cement concrete (PCC) overlays include: dense PCC, latex-modified PCC, silica-modified PCC, and ultra-high-performance concrete.

PCC overlays take wear due to traffic and have low permeability to water.

may be used as a last resort treatment for decks that are programmed for replacement.

Some bridge owners are concerned that the *HMA+Membrane* prevents visual inspection of bridge decks.

Recommended air temperature and deck temperature can vary with product. Seek manufacturers' recommendation on temperature for placement of waterproofing membrane and HMA.

C2.3.6.

Detailed information on use of PCC overlay is provided in Appendix A; see:

Article A.7	<i>OvPccG</i> : PCC Overlay, General
Article A.8	<i>OvPccLm</i> : PCC Overlay, Latex-Modified
Article A.9	<i>OvPccD</i> : PCC Overlay, Dense
Article A.10	<i>OvPccSm</i> : PCC Overlay, Silica-Modified
Article A.11	<i>OvUhpc</i> : PCC Overlay, Ultra-High Performance

Silica-modified concrete includes silica fume concrete and microsilica concrete.

PCC overlays are 1.5 to 2 in. thick.

PCC overlays may be used to alter the grade of a deck or to improve areas of poor drainage.

Concrete for dense PCC overlay has slump between 0.5 and 1 in., water/cement ratio near 0.35, and more than 800 lb of cementitious material per cubic yard.

Concrete for latex-modified concrete has slump between 4 and 7 in., water/cement ratio between 0.3 and 0.4, and more than 650 lb of cementitious material per cubic yard. The latex addition is about 24 gal/yd³ using emulsion that is 50 percent solids.

Concrete for silica-modified concrete has slump between 5 and 7 in., water/cement ratio between 0.37 and 0.40, and 600 lb of cementitious material per cubic yard. The addition of silica solids is about 8 percent of weight of portland cement.

PCC overlays are checked for mix proportions, properties of fresh concrete, finished grade, density, strength (cylinders are tested), and adhesion to the structural deck.

Decks in good, fair, or poor condition are candidates for PCC overlay. Decks in fair condition or poor condition require repairs before overlay.

A portion of the top surface of a bridge deck may be removed in preparation for PCC overlay. Some concrete may be contaminated or compromised. All compromised concrete is removed to avoid rapid deterioration of concrete at repaired areas.

Sand blast or shot blast the deck surface to produce a roughened surface for bond with overlay.

Deck surface should be saturated, surface-dry when PCC overlay is placed.

During placement of PCC overlay, air temperature and deck temperature should be between 35°F and 85°F. The water evaporation rate, an outcome of temperature, relative humidity, and wind speed, should not exceed 0.15 lb/ft²/hr.

PCC overlay is placed using routine methods for concreting. PCC is placed on deck, compacted, and screeded to specified grade.

PCC overlays require wet curing followed by dry curing. One week or more is needed for curing.

Early-age cracking may occur. Repair using healer-sealers, grouting, or deck sealers should be done when most of the cracking has occurred, usually 1 to 2 years after placement.

2.3.7. Repair of Spalls

Spalls are corrected by removal of compromised concrete, cleaning and repair of reinforcing steel, preparation of surfaces, and placement of mortar to rebuild the spalled area to the surface of the surrounding deck.

Spall repair may be done as a sole treatment, but can be more effective as preparation of a bridge deck for placement of a protective sealer or overlay.

Information on condition data for bridge decks is provided in Section 3.

PCC overlays may be applied to new decks or to older decks.

Compromised concrete is discussed in Section 3.5.

Rapid deterioration at repairs, the halo effect, can occur where environment of concrete reinforcing steel differs between older concrete and newer concrete.

Preparation and inspection of bridge decks prior to overlay is addressed in Article A.7.8.

The water evaporation rate can be estimated using ACI charts (ACI 305R).

Follow specifications of bridge owner for air temperature and deck temperature for placement of PCC overlay.

For crack repairs see treatments *SeEp*, *SeMm*, and *RpCrEp* (Appendix A Articles A.13, A.19, A.20, and A.21).

Some bridge owners report that latex-modified PCC overlay can be opened to traffic after curing for less than one day.

C2.3.7.

Detailed information on repair of spalls is provided in Appendix A; see:

Article A.15	<i>RpSpG</i> : Deck, General
Article A.16	<i>RpSpT1</i> : Deck Repair, Spall Type 1 Shallow
Article A.17	<i>RpSpT2</i> : Deck Repair, Spall Type 2 below Top Mat of Rebars
Article A.18	<i>RpSpT3</i> : Deck Repair Spall, Type 3 Full Depth

Lacking protective treatments, repairs may fail or may be undermined by deterioration of concrete adjacent to the repairs.

Zinc anodes may be placed in repaired areas for passive cathodic protection to extend service life. Repair alone, without sealer or overlay, may be useful for decks when deck replacement is programmed or anticipated.

Some bridge owners repair delaminations in decks as well as spalls. Delaminated concrete is removed. Removal creates cavities that are repaired like spalls.

Materials for spall repair include portland cement concrete, magnesium-phosphate concrete, fiber-modified PCC, polymer-modified PCC, epoxy mortar, and mortars made from other binders.

Repair materials are tested for compressive strength, shrinkage, and adhesion to hardened concrete.

Spalls are classified by depth. *T0* spalls have depth less than 0.25 in. *T1* spalls have depth not greater than the concrete cover of the top mat of rebars. *T2* spalls have depth not greater than half the thickness of the deck. *T3* spalls are deeper than half the thickness of the deck.

Compromised concrete at spalls is removed before spall repair, and a cavity is created for placement of repair material. Straight boundaries, in plan, are sawcut into the deck. Within the boundaries, concrete is removed to provide at least a minimum depth of cavity relative to the surface of the surrounding deck.

At placement of repair materials, air temperature and deck temperature should be between 45°F and 90°F. The concrete surface of the cavity should be in saturated, surface-dry condition. The cavity may be prepared with a bonding compound set by owner's specifications or based on manufacturer's recommendations.

Repair material is poured into the cavity and troweled into contact with hardened concrete.

Repair materials in portland cement require wet curing.

2.3.8. Repairs to Cracks

Cracks in concrete decks may be sealed by surface sealers, by gravity-fed binder applied along paths of cracks, or by injection grouting.

Materials for crack sealing are methyl methacrylate, epoxy binder, and epoxy-urethane binder.

Materials for crack sealing are selected for viscosity, pot life, tensile strength, and adhesion to hardened concrete.

Rapid setting and rapid strength development are valued in repair materials. The duration of a lane closure for repair of spalls is related to set and to strength of repair material.

High early strength PCC can achieve adequate strength in 24 hr. Proprietary mortars can achieve adequate strength in as little as 1 hr. R3 concrete (ASTM C928) can achieve compressive strength equal to 3000 psi in 3 hr.

Resistance to chloride ion penetration, or reduction in water permeability may be desirable in repair mortars, but not required. Repairs may be covered by protective overlays.

Information on condition data for bridge decks is provided in Section 3.

All spalls and delaminations are repaired before surface sealer or thin polymer overlay is applied.

T0 and *T1* spalls are filled with overlay when PCC overlay is applied; there is no separate repair.

T2 and *T3* spalls are repaired before protective overlay.

Compromised concrete is concrete that is unsound or contaminated with chlorides, see Article 3.5.

Many repair materials require straight boundaries of a depth of 0.5 in. or greater. Some polymer mortars can be feathered at boundaries of repairs.

Bonding compound can be the repair material itself. A thin layer of material is scrubbed into hardened concrete in the cavity.

Recommended air temperature and deck temperature can vary with product. Seek manufacturers' recommendation on temperature for placement of patch material.

Some repair materials have a limit on thickness of a single placement. To build up thicker repairs, a lift of repair material is placed, then cured, then roughened for the next lift of repair material.

Wet curing may use wet burlap or a membrane-forming curing compound.

C2.3.8

Detailed information on crack sealing is provided in Appendix A; see:

Article A.13	<i>RpCrEp</i> : Crack Repair, Epoxy
Article A.20	<i>SeMm</i> : Seal Surface, Methyl Methacrylate
Article A.21	<i>SeEp</i> : Seal Surface, Epoxy Sealer

Surface sealers and gravity-fed binders have low viscosity. Injection binders may have higher viscosity.

For surface sealers, performance in reduction of intrusion of chloride ion is often reported. These properties are important for surface sealing overall, but less important for crack repair.

Cracks with width less than $\frac{1}{64}$ in. can be sealed using surface sealers. Wider cracks are sealed by application of material along paths of cracks.

For narrow cracks treated with surface sealer, surface preparation is sandblasting or air blasting to clean the deck surface.

For wider cracks, compressed air is used to clear debris from cracks. If gravity-fed binder is used, grooves may be cut into decks along paths of cracks to allow better penetration of binder. If injection is used, resin paste is applied along paths of cracks and injection ports are installed at regular spacing. Once the paste cures, injection of binder into cracks can begin.

Air temperature and deck temperature should be between 40°F and 90°F. Do not begin work if rain is expected within 12 hr of crack sealing.

Gravity-fed binders are poured onto decks along paths of cracks and are applied to refusal.

Injection binders are introduced at one injection port at a time. When binder is expressed at adjacent ports, the injection port is moved.

Curing time ranges from 4 to 24 hr depending on the material used.

For injection grouting, resin paste and injection ports are removed after grout has cured.

Cracks may be resealed while decks remain in good or fair condition. Intervals for reapplication vary with sealer material.

2.3.9. Comparison

Preservation treatments for bridge decks are compared in Table 2.3.9-1. Treatments can require removal of overlays and compromised concrete, and may require additional removals to meet a required roadway grade after treatment. Some treatments require a degree of roughness on surfaces to receive treatment. Treatments can need time to cure after placement.

The decision to seal individual cracks or to seal entire surfaces can be influenced by spacing of cracks. Closely-spaced cracks may be treated with surface sealers.

Static cracks, such as shrinkage cracks, can be sealed.

Cracks that move under load or under seasonal variations in weather cannot be sealed. Moving cracks in decks may occur near piers in moment-continuous superstructures.

Moisture in a bridge deck can interfere with penetrating sealers. Before applying sealers, some bridge owners require a period of 72 hr after exposure to rain and after use of water to clean decks.

Recommended air temperature and deck temperature can vary with product. Seek manufacturers' recommendation on temperature for placement of penetrating sealer.

C2.3.9

The depth, D , for uniform removal of concrete is discussed in Article 3.5.

Spalls should be repaired before applying surface sealer or overlay.

Table 2.3.9-1—Comparison of Preservation Treatments for Bridge Decks

Treatment		Removals			Clean	Roughen	Curing ² , hr
		Existing Overlay	Concrete Depth <i>D</i> ¹	Compromised Concrete			
Sealer <i>Se</i>	<i>Si</i>	✓			✓		2 to 5
	<i>Mm</i>	✓			✓		3 to 7
	<i>Ep</i>	✓			✓		4
Overlay <i>Ov</i>	<i>ThEp</i>	✓			✓	✓	2 to 8
	<i>ThPe</i>	✓			✓	✓	2 to 8
	<i>ThMm</i>	✓			✓	✓	2 to 8
	<i>Ppc</i>	✓	✓	✓	✓		4
	<i>HMA+M</i>	✓	✓	✓	✓		
	<i>Pcc</i>	✓	✓	✓	✓	✓	≥96
Repair <i>Rp</i>	<i>CrEp</i>			✓	✓ ³		4 to 24
	<i>SpT1</i>			✓ ⁴	✓	✓	1 to 24
	<i>SpT2</i>			✓ ⁵	✓	✓	1 to 24
	<i>SpT3</i>			✓ ⁶	✓	✓	72

¹ Depth of uniform removal of concrete² For curing times, seek recommendation of manufacturer³ Along crack⁴ Removal of concrete at shallow repair⁵ Removal of concrete at repair below top mat of rebars⁶ Removal of concrete at full-depth repair**2.4. DECK TREATMENTS, APPENDIX A**

Appendix A lists deck treatments and information on treatments. Appendix A has multiple articles. Each article deals with a treatment.

Appendix A outlines the procedure for each treatment.

C2.4.

Appendix A information for deck treatments includes:

- Name and Abbreviation
- Description
- Candidates
- Constraints
- Materials
- Material Rates
- Equipment
- Job Conditions
- Test Section
- Surface Preparation
- Placement
- Curing
- Acceptance
- Traffic
- Worker Safety
- Site Protection

2.5. TREATMENTS IN COMBINATION

Preservation of a bridge deck can require the use of more than one treatment. An overlay may be installed on a deck in good condition, and few or no repairs to the deck area needed. For a bridge deck in fair condition, repairs must be made before installing an overlay (Table 2.5-1).

Table 2.5-1—Preservation and Treatments

Preservation	Deck Condition	Treatments
Surface Sealer	Good	Surface sealer (<i>SeG</i>)
	Fair	Repair cracks + surface sealer (<i>RpCrEp</i> + <i>SeG</i>)
Overlay	Good	Thin polymer overlay (<i>OvTh</i>)
	Fair	Repair cracks, Repair spalls + thin polymer overlay (<i>RpCrEp</i> , <i>RpSp</i> + <i>OvThPl</i>)
	Poor	Repair cracks, Repair spalls + PPC overlay (<i>RpCrEp</i> , <i>RpSp</i> + <i>OvPpc</i>)
		Repair cracks, Repair spalls + PCC overlay (<i>RpCrEp</i> , <i>RpSp</i> + <i>OvPcc</i>)
		Repair cracks, Repair spalls + waterproofing membrane and asphalt (<i>RpCrEp</i> , <i>RpSpTI</i> + <i>OvHma+M</i>)

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SECTION 3

EVALUATION OF BRIDGE DECKS

3.1. INTRODUCTION

This Section reviews types of deterioration in bridge decks together with standard forms of data used to report conditions of bridge decks. This Section reviews the evaluations of bridge decks needed for decisions in preservation treatments.

3.2. DATA ON CONDITION OF BRIDGE DECKS

Data on condition include national performance management measures, NBI general condition ratings, element-level condition states, and element-level defects.

Data on condition contribute to evaluations of bridge decks, and to decisions on preservation treatments for decks.

Condition data are defined in Federal regulation, FHWA documents, and AASHTO publications. Current versions of regulations, documents, and publications should be followed.

C3.2.

Condition data exist in formal systems of reporting. Condition data in each system can be obtained from observations in routine inspections of bridges. Condition data in each system may be used in time-domain modeling for asset management.

U.S. Federal regulation defines Good, Fair, and Poor performance of highway bridges (23 CFR 490). Performance is defined in terms of National Bridge Inventory (NBI) condition ratings. NBI condition ratings are defined in Federal regulation (23 CFR 650).

Federal regulation defines performance of bridges overall, not bridge decks separately. The identification of good, fair, and poor conditions is useful, and it is employed in this Guide.

The correspondence of performance to NBI condition ratings is shown in Table C3.2-1.

The first two columns of Table C3.2-1 are based on 23 CFR 490. The third, descriptive column is applied by this Guide. Descriptions are consistent with Federal regulation, but are not part of Federal regulation.

Table C3.2-1—Performance of Bridge Decks

Performance	NBI Condition Rating	Description
Good	9, 8, 7	None or minor deterioration.
Fair	5, 6	Minor section loss, cracking, or spalling.
Poor	4, 3, 2, 1, 0	Advanced deterioration.

NBI condition ratings are used in annual reporting by state DOTs to the Federal government (23 CFR 650). Five NBI condition ratings are defined in Federal regulation; one NBI condition rating each for Deck, Superstructure, Substructure, Channel, and Culvert. Deck, Superstructure, and Substructure are often called components of bridges. NBI condition ratings are component condition ratings.

NBI condition ratings are assigned in periodic inspections of bridges. NBI condition ratings are reported on a 9-to-0 scale. “9” is excellent condition (see Table C3.2-2).

Table C3.2-2—NBI Condition Ratings^a

NBI Condition Rating	Description
N	Not Applicable
9	Excellent Condition
8	Very Good Condition No problems noted.
7	Good Condition Some minor problems.
6	Satisfactory Condition Structural elements show some minor deterioration.
5	Fair Condition All primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	Poor Condition Advanced section loss, deterioration, spalling, or scour.
3	Serious Condition Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical Condition Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	Imminent Failure Condition Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	Failed Condition Out of service—beyond corrective action.

^a FHWA (2012).

The *Manual for Bridge Element Inspection* (MBEI) (AASHTO, 2019) defines bridge elements, defects in bridge elements, and condition states for elements and defects. Table C3.2-3 lists MBEI bridge deck elements.

MBEI includes elements for both wearing surface on bridge deck and concrete surface sealer.

Table C3.2-3—MBEI Deck Elements

No.	Element
12	Deck—Reinforced Concrete
13	Deck—Prestressed Concrete
15	Top Flange—Prestressed Concrete
16	Top Flange—Reinforced Concrete
28	Steel Deck—Open Grid
29	Steel Deck—Concrete Filled Grid
30	Steel Deck—Corrugated/Orthotropic/Etc.
31	Deck—Timber
38	Slab—Reinforced Concrete
39	Slab—Prestressed Concrete
54	Slab—Timber
60	Deck—Other Material
65	Slab—Other Material
510	Wearing Surface
521	Concrete Protective Coating

For a deck element, condition is reported as the quantity of deck areas in each of the four condition states. A single deck can have areas in different condition states. The sum of areas in all condition states equals the total area of the bridge deck. No deck area is counted twice. Condition states are defined differently for different defects. Condition states are listed in Table C3.2-4 with approximate definitions.

Table C3.2-4—MBEI Condition States

Condition State	Description
1	Good No problems or minor problems.
2	Fair Deterioration that is minor or has been repaired.
3	Poor Major deterioration that does not require engineering review.
4	Severe Major deterioration that requires engineering review.

MBEI defines defects for bridge elements. Defects are reported as areas of defect in each of the four condition states. The quantity of defect is the sum of areas reported. The severity of defect is evident in the distribution of defective areas among condition states. Defects for bridge decks are listed in Table C3.2-5.

Some bridge element data are reported by state DOTs to the Federal government (23 USC 144). Reports of element-level data on defects are not required.

Table C3.2-5—MBEI Defect for Deck Elements

Deck Element	Defects
RC Deck or PS Deck	Abrasion, Crack, Delamination, Efflorescence, Exposed Prestressing, Exposed Rebar, Patch, Rust Stain, Spall, Wear
Wearing Surface	Crack, Delamination, Effectiveness, Patch, Spall
Timber Deck	Abrasion, Check, Connection, Crack, Decay, Delamination, Section Loss, Shake, Split, Wear
Steel Grid Deck	Connection, Corrosion, Crack, Distortion
Surface Sealer	Effectiveness

Reports of deck performance, condition of decks, deck NBI condition rating, deck element-level condition, and deck element-level defects are reports of the same observations. Often the various codes may be assigned by the same inspectors.

3.3. DEFECTS AND TREATMENTS

Defects, based on their extent and severity, require either treatment or replacement of the bridge deck. Appendix B provides information on defects, the meanings of conditions states for defects, and possible treatments in response to defects.

3.4. EVALUATION OF BRIDGE DECKS

Evaluation of bridge decks is performed by:

- Applying selected methods of inspection.
- Collecting and analyzing material samples (for selected decks, depending on condition of the deck).
- Documenting presence and extent of defects.

3.4.1. Methods of Bridge Deck Inspection

Methods of inspection of bridge decks include:

- Visual inspection
 - Crack mapping with measurements of crack widths
- Sounding, by hammer or by chain drag
 - Mapping of delaminations
- Coring, and examination of cores
 - Compression strength
 - Chloride ion content and profile
 - Petrographic evaluation
 - Freeze-thaw durability
 - Position of reinforcing steel
 - Air content of concrete
 - ASR vulnerability
- Half-cell potential measurement and mapping
- Ground penetrating radar (GPR)
- Infrared thermography (IR)
- Impact echo

Inspection methods are described in Table C3.4.1-1.

C3.4.1.

The common methods of inspection are listed. Bridge owners may use methods not listed here.

Visual inspection is most frequently used. State DOTs provide guidance on the observations to make in visual inspections of bridge decks.

Deck top surface:

- Potholes
- Spalled areas, areas with exposed rebar
- Broken and map-cracked areas in bituminous deck surfaces
- Cracks that may relate to deteriorated areas observed on the bottom of a deck
- Map cracking and other crack patterns
- Deteriorated areas on curbs, medians or parapets
- Bridge rail damage and/or deterioration, including deterioration of the overhang area which may indicate reduced capacity
- Previously repaired areas

Deck soffit:

- Wet or stained areas
- Areas with heavy leaching, stalactites, or both
- Areas of cracking and leaching
- Spalled and delaminated areas
- Exposed reinforcement
- Section loss in reinforcement
- Previously repaired areas

Inspection, by various methods, can detect:

- Surface defects, visible
- Subsurface defects, hidden
- Deterioration process, active
- Contamination, latent deterioration process

Cracks in concrete are most evident in a deck when the cracks show moisture and the adjacent top surface of a deck has dried. This may be observed after rain, or when dew on a deck evaporates in the morning.

A bridge deck's condition and its needs for treatment needs are updated at every cycle of routine inspection, and fully re-evaluated with every (re)application of a treatment.

Table C3.4.1-1—MBEI Defect for Deck Elements

Method	Description
Visual Inspection	The examination of surfaces of bridges, components, and elements. Viewing may be from arm's length distance or greater. Visual inspection finds defects that are visible at surfaces of components or elements.
	Defects in decks, such as spalls and surface cracks, may be hidden if wearing surfaces are placed over unrepaired defects. Visual inspection of underside of decks provides important information for decisions in preservation.
	Defects: Abrasion, Checks, Cracks, Distortion, Efflorescence, Erosion, Holes, Rot, Rust Stains, Rust, Section Loss, Shakes, Spalls, Splits
	Reference: <i>Bridge Inspector's Reference Manual</i> (FHWA, 2012)
Sounding	Chain-drag sounding or hammer sounding can detect delaminations and other internal voids in concrete. Sounding is comparative; a defect must have areas with voids and areas without voids for differences to be apparent.
	Sounding may be automated; see Sack and Olson (2019).
	Defects: Delaminations and other voids
Half-Cell Testing	Electrical potential of reinforcing steel, relative to a standard electrode, indicates the likelihood of active corrosion. Measurement of electrical potential at grid points on a deck can yield a map of areas of active corrosion.
	Process: Corrosion of concrete reinforcing steel
	Reference: ASTM C876

Continued on next page.

Table C3.4.1-1—MBEI Defect for Deck Elements *(continued)*

Method	Description
Material Sampling, Cores	The collection of cores from reinforced concrete bridge decks.
	Cores can be used to find strength of concrete, composition of concrete, crack depth, and position of reinforcing steel.
	Visual examination of cores can reveal delaminations, corrosion of rebars, and section loss of rebars.
	Chemical evaluation can reveal Cl^- concentration, Cl^- profile, and vulnerability to alkali-silica reaction.
	Defects: Delaminations, Rebar Section Loss
	Vulnerability: Cl^- concentration that may promote corrosion of rebars
Infrared Thermography	IR thermography uses an imaging infrared scanner and recorder to detect delaminations and debonded areas on bridge decks and to record the information. The output is a map of delaminated and debonded areas.
	Defects: Delaminations, Debonding
	Reference: ASTM D4788
Ground Penetrating Radar (GPR)	GPR testing collects radar signals reflected from bridge decks and interprets reflected signals as sound concrete, deteriorated concrete, or deteriorated reinforcing steel. GPR can yield a map of deterioration in a bridge deck.
	GPR can find the thickness of bridge deck, thickness of overlay, and depth (from top surface) of reinforcing steel.
	Defects: Concrete Deterioration, Rebar Deterioration
	Reference: ASTM D6087

The level of effort in any inspection, and the set of methods to use, depend on the prior condition of bridge deck, and on the decision(s) that will result from the inspection.

Table 3.4.1-1 relates purposes of inspections with methods of inspection. Routine inspection seeks the discovery of new defects and growth in known defects. Visual inspection is sufficient. Inspection in preparation for preservation treatment seeks detailed information on location and extent of compromised concrete. Sounding, half-cell testing, and material sampling may be needed.

Decks' visible conditions and service histories of decks contribute to decisions on use of testing and sampling for inspection.

Decks of relatively young age and in good visible condition may not require GPS or IR surveys, half-cell testing, or concrete sampling and analysis.

Decks in fair visible condition may warrant testing and sampling, especially if there was no previous testing or previous testing was more than 20 years in the past.

Decks in poor condition can require testing and sampling to determine extent of material removals for preservation of the deck.

Sounding of top surface of decks should be performed every time an overlay is placed or renewed (after surface is prepared and before overlay is placed).

Table 3.4.1-1—Deck Condition, Deck Inspection

Deck Condition Prior	Event	Inspection Method(s)	Deck Condition Now	Follow-On Inspection
Good	Routine Inspection	Visual	Good	—
			Fair	Use sounding Map defects
	Treatment	Visual + sounding Map defects	Good	Proceed with treatment
			Fair	Make repairs Proceed with treatment
Fair	Routine Inspection	Visual	Fair	—
			Poor	Use sounding + half-cell tests + material sampling Map compromised concrete
	Treatment	Visual + sounding Map areas for repair	Fair	Make repairs Proceed with treatment
			Poor	Reconsider choice of treatment
Poor	Routine Inspection	Visual	Poor	—
			Severe	Map areas for repair Make repairs (temporary)
				Replace deck
	Treatment	Visual + sounding + half-cell tests + material sampling Map areas for repair	Poor	Make repairs Proceed with treatment
			Severe	Map areas for repair Make repairs (temporary)
				Replace deck

There are other methods of inspection that are less often used or are currently in development. Information on nondestructive evaluation of bridge decks is available from the FHWA (2015).

3.5. COMPROMISED AREA OF BRIDGE DECKS

The extent of compromised area of a bridge deck affects decisions to preserve or to replace the deck. Deck area is compromised if:

- A defect is present, or
- A deterioration process is active and could cause a defect, or
- An agent is present that could initiate a deterioration process.

C3.5.

For reinforced concrete decks, the defects, processes and agents are:

- Defects: Cracks, spalls, delaminations, exposed reinforcing steel, corroded reinforcing steel, and reinforcing steel with section loss.
- Processes: Active corrosion of reinforcing steel.
- Agents: Chloride ion, Cl^- . The Cl^- concentration in the concrete at the top mat of reinforcing steel is examined.

The Cl^- content that leads to corrosion of reinforcing steel depends on the type of reinforcing steel. Bridge decks currently in service have uncoated rebars, epoxy-coated rebars, or corrosion-resistant rebars.

Compromised areas, by defect, process, or agent, can overlap. Compromised areas are not counted twice. The union of compromised areas is reported.

Maps of compromised concrete for decks are formed as:

- Maps of defects, plus
- Overlaid maps of half-cell potentials, plus
- Overlaid maps of Cl^- content.

3.6. REPORTS

Reports of evaluations of bridge decks should include a summary and detailed findings.

Summaries should include:

- Current classification of performance of deck (Good/Fair/Poor); see 23 CFR 490.
- NBI condition rating.
- Percentage of compromised area of deck.
- Combined map of compromised concrete.
- List of high priority repairs (defects in condition state 3).
- List of defects needing engineering evaluation (defects in condition state 4).

Detailed findings should include:

- Quantities and condition states of all defects.
- Maps of compromised deck area by
 - defect,
 - deterioration process, and
 - agent.
- Depth, D , for removal of concrete.
- Locations in deck of material samples, with results of physical and chemical testing.
- Supporting images and notes.

In element-level reporting (AASHTO, 2019), defects of various types may be discovered, and the quantities and severities of defects are recorded. The report of condition states for a deck is the union of the reports of defects. For multiple defects in the same portion of deck, the worst condition is taken as the condition of that portion of deck.

There can be indirect indications of processes or agents, such as corrosion of reinforcing steel revealed by rust stains at concrete surface, or efflorescence on deck soffit that indicates passage of water through decks.

C3.6.

Treatment of bridge decks may require general removal of concrete for a depth, D . A report of evaluation of a bridge deck should include:

1. Whether general removal is needed, and
2. What depth, D , should be removed.

General removal may be needed when:

- Cracks and spalls are shallow and widespread.
- Concrete is contaminated with Cl^- .
- A thickness of new overlay must be admitted.

Data on defects and on Cl^- content are used to determine D for general removal. D may be different for different traffic lanes, for different spans, or for other contiguous regions of bridge deck. General removal is followed by local, deeper removal at individual spalls or other defects.

SECTION 4

SELECTING PRESERVATION TREATMENTS FOR BRIDGE DECKS

4.1. INTRODUCTION

This Section presents a process for selection of preservation treatments.

Selection of treatment proceeds from:

- Intended duration of service life (after treatment),
- Materials, design, and capacity of existing deck,
- Condition of deck,
- Service, ADT, route functional class,
- Status of the bridge as a candidate for preservation, and
- History of treatments at a deck.

4.2. PRESERVE OR REPLACE?

Preservation is appropriate where continued service of a bridge deck is practical, economical, and desirable.

- *Practical*—Decks may be preserved when available treatments can correct current defects and prevent or retard the appearance of additional defects.
- *Economical*—Decks may be preserved when costs are not greater than monetized benefits, or when relative costs and benefits are acceptable to bridge owners.
- *Desirable*—Decks may be preserved when the number of lanes, alignment, and clearances are adequate for the route and service.

Decisions on preservation of decks are affected by decisions on preservation of bridges. Preservation of the deck is appropriate only if the bridge will remain in service. If a bridge will be reconstructed or replaced, then the deck is no longer a candidate for preservation.

4.3. SELECTION OF TREATMENT

Data on condition of bridges indicate the types, severities, and extents of deterioration. All are important in selecting preservation treatments.

Bridge owners may establish policies on selection of deck treatments using general condition ratings, bridge element condition reports, compromised area of deck, or other inputs. These policies can guide preliminary selection of deck treatment. Final selection will be

C4.2.

Practical Preservation—Design details and materials of bridge decks are important. Concrete cover, concrete permeability, and type of reinforcing steel affect the practicality of preservation.

Economical Preservation—Preservation treatments can reduce life-cycle costs of in-service bridge decks and may yield a net savings in agency costs. Section 5 presents a method of evaluation of costs and benefits of preservation of bridge decks.

Desirable Preservation—Requirements can vary with route class and ADT. It is sufficient but not necessary that lane count, alignment, and clearances meet current design standards. Bridge owners will consider required service specific to a route to identify the bridge decks to preserve.

Bridges in good or fair condition are sometimes reconstructed or replaced when route capacities are increased. Bridge decks that could be preserved will instead be removed.

Bridge decks in poor condition may be preserved but this decision entails all components of bridges, not just decks. The intent to preserve or not preserve a bridge overall is the context for the decision to preserve the bridge deck.

C4.3.

Possible correlations of condition to preservation treatments are shown for deck performance (Table C4.3-1), deck NBI condition rating (Table C4.3-2), deck compromised area (Table C4.3-3), and deck element-level condition (Table C4.3-4).

Taken together, Tables C4.3-1 through C4.3-4 express policies for preservation treatments for bridge decks. Different bridge owners will follow different policies.

influenced by project-level information specific to individual decks.

Bridge owners can modify these tables, both in condition values and in corresponding treatments, to implement their own policies for preservation of bridge decks.

Table C4.3-4 for element-level condition uses sums of quantities in condition states. The headings in the table mean:

$$\Sigma \text{ CS } 2+ = \text{CS } 2 + \text{CS } 3 + \text{CS } 4$$

$$\Sigma \text{ CS } 3+ = \text{CS } 3 + \text{CS } 4$$

where:

CS 2 = percentage of deck area in condition state 2

CS 3 = percentage of deck area in condition state 3

CS 4 = percentage of deck area in condition state 4

Sums of quantities of deck element increase monotonically as decks deteriorate. Threshold values, as shown in Table C4.3-4, require monotonic measures of condition.

The quantities of bridge element in condition states are shown as percentages of total quantity of elements. A bridge element in fair condition will have most of its quantity in condition states 1 and 2. A bridge element in fair condition will have little quantity of defect in condition state 3 and no quantity of defect in condition state 4.

Table C4.3-1—Deck Performance and Preservation Treatments

Performance	Treatment
Good	Preserve. Bare deck: Either repair and apply surface sealer or apply thin polymer overlay or HMA+Membrane. Deck with overlay: Maintain overlay.
	Do nothing.
Fair	Repair, then Preserve. Install or renew overlay.
Poor	Evaluate. If feasible, repair and overlay.

Table C4.3-2—Deck NBI Condition Rating and Preservation Treatments

Condition Rating	Treatment
9, 8, 7	Preserve. Bare deck: Apply surface sealer or thin polymer overlay. Deck with overlay: Maintain overlay.
	Do nothing.
6	Repair, then Preserve. Install or renew overlay.
5	Repair, then Preserve. Install or renew overlay.
4	Evaluate. If feasible, repair and overlay.
3 and lower	Replace deck.

Table C4.3-3—Deck Compromised Area and Deck Treatments

Compromised Area	Treatment
≤10%	Preserve. Bare deck: Apply surface sealer or thin polymer overlay. Deck with overlay: Maintain overlay.
	Do nothing.
≤30%	Repair, then Preserve. Install or renew overlay.
≤70%	Evaluate. If feasible, repair and overlay.
>70%	Replace deck.

Table C4.3-4—Element-Level Condition and Deck Treatments

Σ CS 2+ % Area	Σ CS 3+ % Area	Treatment
0%	0%	Preserve. Bare deck: Apply surface sealer or thin polymer overlay. Deck with overlay: Maintain overlay.
		Do nothing.
$\leq 10\%$	0%	Preserve. Bare deck: Repair and apply surface sealer, or apply thin polymer overlay, or HMA+Membrane. Deck with overlay: Repair defects in overlay.
$\leq 30\%$	$\leq 10\%$	Repair, then Preserve. Install or renew overlay.
$\leq 50\%$	$\leq 30\%$	Repair, then Preserve. Install or renew overlay.
$\leq 70\%$	$> 30\%$	Evaluate. If feasible, repair and overlay. This may involve removal and reconstruction of a portion of deck thickness.
CS 4 > 10%		Replace deck.

4.3.1. Non-Preservation Treatments

Treatments may be applied to extend the service life of bridge decks awaiting replacement.

4.4. EXTENT OF TREATMENT

Treatments such as surface sealing and placement of overlays usually affect the entire deck surface. Other treatments such as spall repairs are local and are applied to limited extent of deck. Repaired areas will extend beyond visible spalls. In part, when creating cavities for repair material, concrete is removed until sound concrete is found. The cavity is larger than the visible spall before treatment. In addition, the sound concrete near a spall may be compromised. Corrosion activity may be detected, or Cl^- concentration may be high.

4.5. TREATMENTS AND CONDITION OF BRIDGE DECKS

Preservation treatments are triggered by condition or by time interval.

Preservation of bridge decks can begin with newly constructed decks and should continue through the entire service life.

New decks and decks in good condition may have few or no defects. Preservation actions in the absence of defects are selected to provide and maintain water-proofing and water-restricting coatings and overlays. Decks may continue in good condition for many years. Renewal of sealers and overlays should continue at regular intervals.

Appendix C presents information on the selection of preservation treatments for highway bridge decks in service. Appendix C is organized by type and condition of deck (Table 4.5-1).

C4.4.

Compromised concrete must be removed. The repair must extend to sound, uncompromised concrete. Inspection and evaluation of concrete at and around spalls is needed to determine the extent of repairs.

C4.5.

Time intervals as triggers for treatment are relevant to decks in good condition and to treatments that are water-proofing or water-restricting. To keep treatments effective, treatments should be renewed without waiting for defects.

Table 4.5-1—Appendix C Guidance on Preservation Treatments for Bridge Decks

Deck	Performance	Potential Treatment
RC Deck, Bare	Good	Surface sealer, thin polymer overlay
	Fair	Repair, overlay
	Poor	Repair, overlay
RC Deck w/Surface Sealer	Good	Surface sealer, thin polymer overlay
	Fair	Repair, overlay
	Poor	Repair, overlay
RC Deck w/Thin Polymer Overlay	Good	Thin polymer overlay
	Fair	Repair, overlay
	Poor	Repair, overlay
RC Deck w/HMA+Membrane	Good	HMA+Membrane
	Fair	Repair, overlay
	Poor	Repair, HMA+Membrane, PPC overlay, or PCC overlay
RC Deck w/ PPC or PCC Overlay	Good	Overlay
	Fair	Repair, overlay
	Poor	Repair, overlay
Steel Grid Deck	Good	—
	Fair	Repair steel grid
	Poor	Repair steel grid
Timber Deck	Good	—
	Fair	Repair timber deck
	Poor	Repair timber deck

Appendix C presents guidance in a standard format (see Figure 4.5-1). At the top of a page, the type of deck is identified in text and as a graphic. Next, the condition of the deck is presented as text, as NBI condition rating, as a generic map of extent of deterioration, as element quantities and condition states, and as defect quantities and condition states.

Options for treatment are shown on the lower half of the page. Treatments are identified. Normalized costs and benefits are listed. Costs and benefits are present-values for the full service life of a bridge deck.

Computations of costs and benefits are presented in Section 5. Appendix C lists present-value costs for deck preservation plus future deck replacement. This is the full cost of service of a bridge deck.

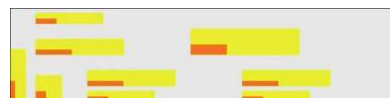
Normalized costs and benefits are computed with a real discount rate equal to 1.5 percent. Discount rate is published by the Office of Management and Budget (2018).

Bare Reinforced Concrete Deck



Fair Condition

T1 spalls or delaminations in not more than 30 percent of deck area.
 T2 spalls in not more than 10 percent of deck area.
 Exposed rebar in not more than 5 percent of deck area. No section loss.
 Exposed prestressing steel in not more than 5 percent of deck area. No section loss.
 Rust staining on not more than 10 percent of deck area.
 RC cracks less than 0.05 in. wide, and spaced more than 5 ft apart.
 PSC cracks less than 0.004 in. wide, and spaced more than 10 ft apart.
 Loose coarse aggregate on not more than 10 percent of deck area.



Deck Condition Rating: 5 or 6

Element-Level Condition:

	CS 1	CS 2	CS 3	CS 4
Deck	≥70%	≤30%	≤10%	0%

Element-Level Defects:

		CS 1	CS 2	CS 3	CS 4
1080	Delamination, Spall	≥70%	≤30%	≤10%	0%
1090	Exposed Rebar	≥95%	≤5%	0%	0%
1120	Efflorescence/Rust Staining	≥70%	≤30%	≤10%	0%
1130	Cracking (RC and Other)	≥70%	≤30%	≤10%	0%
1190	Abrasion/Wear (PSC/RC)	≥70%	≤30%	≤10%	0%
1100	Exposed Prestressing	≥95%	≤5%	0%	0%
1110	Cracking (PSC)	≥70%	≤30%	≤10%	0%

Treatment Options

Repair spalls, seal cracks, then apply an overlay.

Treatment		PV Cost	PV Benefit	
Repair	Protection			
RpSpT1 RpCrEp	OvThEp OvThMm OvThPe	0.44	0.03	
RpSpT1 RpSpT2	OvHma+M	0.40	0.07	
	OvPcc	0.45	0.03	
	OvPpc OvPccD OvPccLm OvPccSm	0.42	0.05	

Figure 4.5-1—Example of Appendix C's Standard Format for Preservation Treatment Guidance

Guidance in Appendix C anticipates the context for decisions by bridge owners. For example, a bridge owner is considering a new application or reapplication of preservation treatment at a bridge deck that has been in service for a period of years. For bare decks, guidance assumes that the years in service are related to the condition of the deck. For decks with prior treatment, such as sealer or overlay, guidance assumes that the years in service are related to the condition of the deck, and also related to the type of treatment; deterioration has been delayed by prior treatment. For untreated decks, the bridge owner is considering whether to begin preservation. For decks with prior treatment, the bridge owner is considering a second application of treatment. The years in service and the prior use of treatments affect the evaluation of normalized costs and benefits. The performance of decks, *good/fair/poor*, is related to the extent of repairs needed as part of treatment.

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SECTION 5

COSTS AND BENEFITS OF DECK PRESERVATION

5.1. INTRODUCTION

This Section applies preservation-cycle cost analysis (PCCA) to evaluate monetized benefits of deck preservation. The PCCA method is presented in the *Guide to Bridge Preservation Actions* (AASHTO, 2021b).

5.2. PRESERVATION-CYCLE COST ANALYSIS

C5.2.

PCCA computes the costs of keeping existing bridge decks in good or fair condition, and in service at current capacities.

Costs are evaluated for service life of a bridge deck. All decks will be replaced eventually. Replacement is sooner if decks are not preserved. Replacement is later if preservation treatments are applied.

Costs are incurred when a treatment is applied and when a deck is replaced. Replacement is the last cost in the preservation cycle for a deck.

All costs are expressed as present-value costs at the start of service of a bridge deck.

PCCA compares present-value costs of deck service without preservation treatment to deck service with preservation treatment.

5.2.1. Untreated Bridge Deck

PCCA is applied to cost of service of an untreated bridge deck. This is the base case for computation of benefits of preservation treatments. An untreated deck has a single cost: deck replacement at the end of service life.

$$\text{Cost}_U = \text{Cost}_{\text{Replace Deck}} \quad (5.2.1-1)$$

where:

Cost_U = cost of service for untreated bridge deck

Costs are normalized. The cost to replace the deck is the basis.

$$\begin{aligned} N \text{ Cost}_U &= \frac{\text{Cost}_{\text{Replace Deck}}}{\text{Cost}_{\text{Replace Deck}}} \\ &= 1 \end{aligned} \quad (5.2.1-2)$$

where:

$N \text{ Cost}_U$ = normalized cost of service of an untreated bridge deck

The present-value normalized cost of service for untreated bridge deck is

$$PV\ N\ Cost_U = \frac{1}{(1+r)^{T_u}} \quad (5.2.1-3)$$

where:

$PV\ N\ Cost_U$ = present-value normalized cost for an untreated bridge deck

r = annual discount rate

T_u = service life of an untreated bridge deck (years)

5.2.2. Treated Bridge Deck

The cost of service of a bridge deck with preservation treatments, $Cost_T$, is the cost of treatments plus the cost of replacement of the deck.

$$Cost_T = Cost_{Replace\ Deck} + \sum Cost_{Treatment} \quad (5.2.2-1)$$

where:

$Cost_{Treatment}$ = cost of one application of a preservation treatment

The summation indicates multiple treatments and treatments at multiple times in service.

Costs are normalized. The cost to replace the deck is the basis for normalization.

$$N\ Cost_T = \frac{Cost_{Replace\ Deck} + \sum Cost_{Treatment}}{Cost_{Replace\ Deck}} \quad (5.2.2-2)$$

where:

$N\ Cost_T$ = normalized cost of service for a deck with preservation treatments

The present-value normalized cost of service for a treated bridge deck, $PV\ N\ Cost_T$, is

$$PV\ N\ Cost_U = \frac{1}{(1+r)^{T_T}} + \sum \frac{(Cost_{Treatment})_i}{Cost_{Replace\ Deck} (1+r)^{T_i}} \quad (5.2.2-3)$$

where:

T_T = service life of a treated bridge deck (years)

T_i = year of application of the i th treatment

The normalized benefit, $N\ Benefit$, of preservation treatment is the difference in normalized present-value costs.

$$N\ Benefit = PV\ N\ Cost_U - PV\ N\ Cost_T \quad (5.2.2-4)$$

Positive benefit indicates that preservation treatments reduce costs of service of bridge decks.

5.3. EXAMPLES IN COSTS AND BENEFITS OF DECK TREATMENTS

C5.3

Examples of computation of costs and benefits of deck treatments are presented. The examples are:

The four examples consider two materials, two types of treatment, four times in service life, and three general conditions.

1. Use of thin polymer overlay on a bridge deck in good condition
2. Reapplication of thin polymer overlay on a bridge deck in good condition
3. Use of a PCC overlay on a deck in fair condition
4. Use of a PCC overlay on a deck in poor condition

5.3.1. Limitation to Examples

Examples in PCCA use average values of costs and service lives for treatments of bridge decks. Average values are taken from NCHRP 14-36 (Hearn, 2020). Bridge owners should apply their own values of costs and service lives when applying PCCA in decisions for their own projects in deck preservation.

Table 5.3.1-1—Examples in Costs and Benefits of Deck Treatments

Example	Treatment	Material	Deck Age at Treatment, yr	Deck Condition
1	New Overlay	Epoxy Overlay	5	Good
2	Reapplication of Overlay	Epoxy Overlay	5 and 23	Good
3	New Overlay	Latex-Modified Concrete	27	Fair
4	New Overlay	Latex-Modified Concrete	50	Poor

5.3.2. Base Case—Cost of Deck Service without Treatment

C5.3.2.

The estimated service life of a deck without preservation treatments is 50 years. Present-value normalized cost of service is Eq. 5.2.1-3.

Service life of untreated bridge deck is estimated by Doolan (2014). The value of service life should adjusted to conform to bridge owner experience for local conditions.

$$PV\ N\ Cost_U = 0.475$$

Computations in this example are made with an annual real discount rate equal to 1.5 percent. Real discount rates are published by the Office of Management and Budget (2018).

The present-value normalized cost is computed at the year the deck enters service: 50 years before deck replacement.

5.3.3. Example 1: Use of Thin Polymer Overlay on a Bridge Deck in Good Condition

C5.3.3.

Cost and benefit of using thin epoxy overlay on a concrete bridge deck in good condition are computed.

Information used in the example:

Age at Treatment	5 yr
Service Life of <i>OvThEp</i>	18 yr
Deterioration	10% <i>Tl</i>
<i>N Cost RpSpTl</i>	0.18
<i>N Cost OvThEp</i>	0.06

A deck in good condition, for this example, has been in service for five years. Before thin epoxy overlay is placed, *Tl* spalls are repaired at 10 percent of deck area. The present-value normalized cost of repair is

$$PV \ N \ Cost_{\text{Repair}} = 0.017$$

Thin epoxy overlay is applied after repairs, at five years into service life. The present-value normalized cost of overlay is

$$PV \ N \ Cost_{\text{Overlay}} = 0.056$$

It is estimated that thin polymer overlay extends the service life of a deck by 18 years. The present-value normalized cost of deck replacement is

$$PV \ N \ Cost_{\text{Replace}} = 0.363$$

Total cost of service of a deck with thin epoxy overlay is Eq. 5.2.2-3.

$$PV \ N \ Cost_T = 0.436$$

The benefit of treatment with thin epoxy overlay is

$$PV \ Benefit = 0.039$$

All values are estimates. Bridge owners will use values specific to their state and bridge inventory.

Normalized unit cost of *Tl* repair is

$$N \ Cost \ RpSpTl = 0.18$$

For repair of 10 percent of deck area

$$N \ Cost \ RpSpTl = 0.018$$

The present-value normalized cost is computed for the year the deck enters service; five years before repairs are made.

$$PV \ N \ Cost_{\text{Repair}} = \frac{0.018}{(1 + 0.015)^{(5 \text{ yr})}}$$

For costs for real decks, the actual areas of repairs, not estimated areas, are used.

The normalized cost of thin epoxy overlay is

$$N \ Cost \ OvThEp = 0.06$$

$$PV \ N \ Cost_{\text{Overlay}} = \frac{0.06}{(1 + 0.015)^{(5 \text{ yr})}}$$

The service life of the deck is extended by 18 years. The cost to replace the deck is incurred after 68 years in service.

$$N \ Cost \ Replace \ Deck = 1.0$$

$$PV \ N \ Cost_{\text{Replace}} = \frac{1.0}{(1 + 0.015)^{(68 \text{ yr})}}$$

Extensions to service life due to treatment are estimated by Kvamme (2018). Extensions to service life should be adjusted to conform to bridge owner experience for local conditions.

Positive benefit indicates that deck service with treatment is lower cost compared to deck service without treatment.