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Chapter 7 - Maintenance and Preservation Techniques for Bridge Decks and Slabs

7.1 Bridge Decks and Slabs Maintenance Introduction

The deck or slab of a bridge is like the roof on a house; it receives the brunt of the storm and shelters the contents below from the harsh elements. The deck is vulnerable to the effects of mechanical wear from traffic induced deflections, tire wear, and from environmental conditions such as rain, snow and ice. Consequently, decks and slabs typically require more maintenance and repair than any other bridge component. The following sections in this chapter will present common maintenance and preservation techniques for concrete, steel, timber and fiber reinforced polymer decks.

7.2 Concrete Decks

7.2.1 Introduction

The most common bridge deck and slab material is concrete. The physical properties of concrete permit placement in various shapes and sizes, providing the bridge designer and the bridge builder with a variety of construction methods. Concrete bridge decks resist wear and weather well, provide good traction and ride quality, and in many designs provide a part of the structural strength of the bridge. Careful design, proper selection of materials, and good construction practices are essential for durable bridge decks and slabs.

Among the design features that improve durability are adequate cover over the reinforcement, good drainage, smaller bridge skews, and thicker slabs. Material and construction practices that contribute to durability include achievement of the specified cover, use of air-entrained concrete in areas subject to freezing, use of concrete with appropriate water-cement ratios, good consolidation, and proper curing procedures that prevent excessive shrinkage cracking.

The main cause of concrete deck and slab deterioration is corrosion of the reinforcing steel within the deck. Corrosion is typically caused by small cracks in the concrete that provide pathways for water and chlorides to penetrate the concrete and attack the steel (see Figure 7.1). Once the steel begins to corrode, the steel corrosion by products expand and cause deck delaminations or spalling. Deck corrosion is particularly problematic in states that use deicing salts to melt snow in the winter. To slow the corrosion cycle, the water and chlorides must be kept from reaching the reinforcing steel.

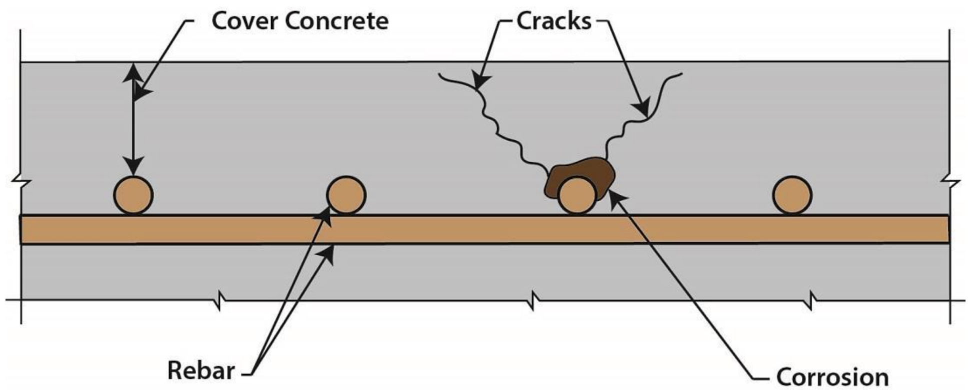

Figure 7.1 Typical Reinforced Concrete Deck and Slab Deterioration

Sealing the bridge deck cracks and overlaying the surface with dense materials will slow the rate of deterioration by limiting the water and salts that reach the reinforcing steel. If a significant amount of chlorides have already reached the reinforcing steel, cathodic protection may be used to stop corrosion from progressing. This section presents various aspects of concrete bridge decks and slabs and the related bridge maintenance activities.

What To Look For

- Cracks
- Spalls
- Leaks on underside of deck
- Efflorescence in edges or underside of deck
- Accumulated debris on deck
- Evidence of ponding on deck

7.2.2 Deck Protection Methods

Proactive deck protection is the best way to preserve the life of any concrete bridge deck or slab. Deck protection systems include a variety of methods that prevent water and chlorides from reaching the reinforcing steel in bridge decks to slow or stop corrosion of the steel.

- Washing and cleaning
- Corrosion resistant reinforcing steel
- Water proofing methods
- Concrete crack control
- Cathodic/Galvanic protection
- Crack sealers and fillers
- Overlays

7.2.2.1 Washing and Cleaning

Bridge washing is a proactive corrosion protection method that utilizes water applied to the bridge deck to flood the deck and rinse away or dilute the accumulation of dirt and chlorides. By flushing the deck with water, the concentration of chlorides in the concrete surfaces is reduced and the potential for corrosion from the salts is minimized. Procedures for washing a bridge deck are provided in Section 7.2.4.1.

7.2.2.2 Corrosion Resistant Reinforcing

One way to protect reinforcing steel against corrosion is to coat the bars with epoxy. The epoxy prevents the water and chlorides from reaching the steel and thereby minimizes the corrosion. Epoxy coated reinforcing steel can also be used in bridge deck and slab repairs in areas where deicing salts are routinely applied. Epoxy coated bars can be identified by their bright colors, typically green or purple. An example of epoxy coated reinforcement is shown in Figure 7.2. Epoxy coated bars have been shown to delay the onset of corrosion when installed properly.

Figure 7.2 Epoxy Coated Reinforcement

Epoxy coated bars can be nicked or cut very easily during delivery, handling, placement and pouring of concrete. These nicks and cuts can minimize the effectiveness of the epoxy coating. When working on decks with epoxy coated bars, any nicks, cuts or breaks in the coating surface should be repaired using brush applied epoxy before placing new concrete. Epoxy coated bars also require longer lap lengths in order to develop the full strength of the bars.

Stainless steel clad and solid stainless steel reinforcing bars have also been used in bridge decks to protect against corrosion. Stainless steel bars are very expensive but will greatly minimize the corrosion concern in the deck. An example of stainless steel reinforcing bars is shown in Figure 7.3.

Figure 7.3 Stainless Steel Reinforcing (Courtesy of FHWA)

Galvanized reinforcing bars can also be used to protect against corrosion and extend the useful life of bridge decks and slabs. Galvanized bars are hot dipped into a bath of zinc that fuses to the steel surface creating a sacrificial coating that prevents corrosion. An example of galvanized bars is shown in Figure 7.4. Galvanized bars stand up well during construction without any special care.

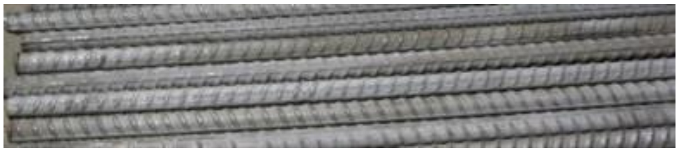

Figure 7.4 Galvanized Bars

Fiber reinforced polymer (FRP) reinforcing steel is another option for a corrosion free bridge deck. FRP is not steel at all and therefore does not corrode. An example of FRP reinforcing steel is shown in Figure 7.5. FRP is well suited for bridge deck applications because it is light and strong and completely corrosion free. The drawbacks to FRP are the initial costs and field workability.

Figure 7.5 FRP Deck Bars (Courtesy of Hughes Bros)

Protection of reinforcing steel may include many types of epoxy or galvanized coatings, the use of stainless steel rebar, or FRP bars.

Other corrosion resistant reinforcing is available under trade names such as MMFX, Z-Bar and special formulations of steel designed to resist corrosion such as low carbon or chromium steel bars. These corrosion reinforcing bars are generally more expensive than conventional rebar but can provide additional corrosion protection. The total life cycle cost of the deck should be considered when considering the additional up front cost of specialty reinforcing bar types.

Any of these methods will improve the corrosion resistance over conventional black bar reinforcing. Reinforcing bar types are compared in Table 7.1:

Table 7.1 Reinforcing Bar Comparison

Reinforcing Bar Type	Corrosion Resistance	Field Workability
Black bars	Fair	Excellent
Epoxy Coated	Good	Good
Galvanized	Good	Good
MMFX, Z-Bar etc.	Excellent	Good
FRP bars	Excellent	Fair
Stainless Steel	Excellent	Excellent

7.2.2.3 Waterproofing and Concrete Sealers

Reinforced concrete bridge decks and slabs can be protected from the penetration of water and chlorides that can lead to corrosion through the application of waterproofing treatments. Common waterproofing treatments include: Epoxies, Silanes and Siloxanes. The sealers can be divided into two general classes: penetrating sealers and film formers. Silanes, siloxanes, and High Molecular Weight Methacrylate (HMWM) penetrate surface cracks and voids in the concrete and limit the penetration of water and salts without leaving a film on the surface. Epoxy healer sealer, methacrylate, and polyurethanes produce a thin film that covers the surface area of the treated deck or slab to protect the concrete from penetrating water and salts. Thin epoxy overlay both penetrates and is a film former. These treatments are typically applied to reinforced concrete decks and slabs that are new or in good overall condition as a preventive treatment. A summary of these treatments is shown in Table 7.2 below.

Table 7.2 Waterproofing and Sealer Summary

Sealer Type	Type	Thickness
Silane	Penetrating	0
Siloxane	Penetrating	0
High Molecular Weight Methacrylate (HMWM)	Penetrating	0
Epoxy Healer Sealer	Penetrating/Film Former	3 - 10 Mils
Thin Epoxy Overlay	Film Former	250 – 375 Mils
Methacrylate	Penetrating/Film Former	20 - 30 Mils
Polyurethanes	Film Former	3 - 5 Mils

7.2.2.4 Concrete Crack Control

Crack control is another proactive deck preservation measure that is carried out during the placement and curing of a concrete deck or slab. Minimizing the extent of concrete cracking from the initial construction and curing will slow down the ingress of water and chlorides and may eliminate the need for future crack sealing. Crack control can be improved through proper concrete mix design, appropriate water cement ratios, quality placement techniques and proper curing.

The temperature of concrete during the curing process can be a significant factor in control of early age deck cracking. The temperature of the curing deck can be controlled by scheduling deck pours during cooler months or times of the day. Proper wet curing techniques and the application of curing compounds can also minimize the rate of water evaporation from the concrete surface during the curing process resulting in less early age deck cracking. Deck and slab cracking can also be minimized through the use of shrinkage control ad mixtures or through the use of fibers mixed into the concrete. The inclusion of fibers in the concrete mix, an example of which is shown in Figure 7.6, has been shown to significantly control early age deck cracking.

Figure 7.6 Concrete Fiber Reinforcement

7.2.2.5 Cathodic and Galvanic Protection

Corrosion protection can also be supplied through the use of cathodic or galvanic protection systems. Galvanic systems utilize sacrificial anodes that will preferentially corrode instead of the deck reinforcing steel. Cathodic protection systems typically involve electrical currents that are imparted on the reinforcing steel or conductive materials applied to the deck effectively breaking the corrosion process. Various attributes of corrosion protection systems for reinforced concrete bridge decks are summarized in Table 7.3:

Table 7.3 Corrosion Protection Methods

Goal	Method	Expected Annual Maintenance	Expected Life	When to Apply
Corrosion Prevention	Sacrificial Anodes	Minimal	10 – 20 years	New concrete
Corrosion Control (After corrosion has initiated)	Sacrificial Anodes	Minimal	10 – 20 years	No corrosion damage in the concrete
Corrosion Protection	Impressed Current	Moderate	Life of Deck	Stop ongoing corrosion

7.2.2.6 Crack Sealing

Cracks in concrete bridge decks and slabs can be sealed using commercially available penetrating sealers appropriate for widespread cracking, as shown in Figure 7.7, or through pressure injection for larger discrete cracking, as shown in Figure 7.8. Sealing deck and slab cracks will reduce the water and chlorides that are able to reach the reinforcing layer and cause corrosion.

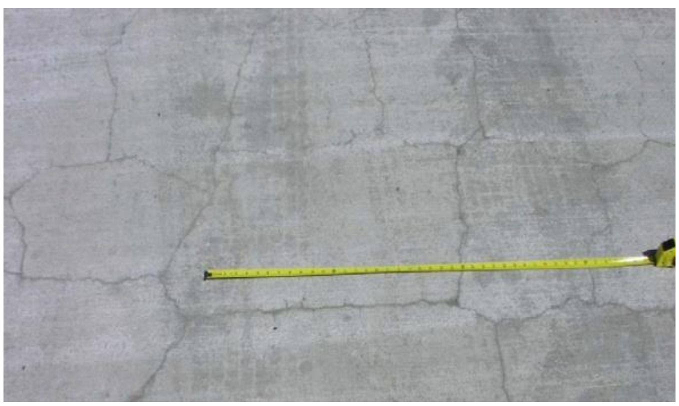

Figure 7.7 Typical Widespread Cracking Pattern on a Bridge Deck (Courtesy of Virginia DOT)

Figure 7.8 Typical Discrete Cracking Pattern on a Deck (Courtesy of Virginia DOT)

Depending on the nature of the cracking observed, a number of methods are available to waterproof, seal or repair the cracks.

Penetrating Sealers

Bridge decks and slabs that have cracks over a large portion of the surface area are good candidates for penetrating sealers. Penetrating sealers are applied to bridge decks and slabs by spraying or pouring on the deck and spreading over the entire area using brooms or squeegees. Penetrating sealers are typically low viscosity which allows them to be drawn into concrete cracks through capillary action. Viscosity is measured by the force per unit area resisting a flow and is measured in the units of centipose.

For comparison, several viscosities are presented:

Water ("low" viscosity): Around 1 centipose

Methacrylates: Around 10 centipose

Epoxy based healer sealers: Around 80 centipose

Epoxy based thin epoxy overlays: Typically 1500 centipose (similar to honey or heavy weight motor oil)

The sealers fill the concrete cracks and voids. On curing, the sealers forms bonds to the walls of the cracks that effectively seal the cracks. The crack sealers significantly reduce the permeability of the concrete. The permeability reduction minimizes the ingress of water and chlorides from road salts or deicing chemicals. There are many commercially available penetrating cracks sealers that are designed for specific applications. The selection of the appropriate crack sealer depends on a number of variables including: crack width, available cure times and desired flexibility of the cured product.

Crack Injection and Epoxy Sealing

Concrete deck and slab cracks that are discrete or localized can be sealed or injected with epoxy resins or other polymers to fill the void and re-bond the concrete surfaces back together. Epoxy injection can restore structural integrity and reduce moisture penetration through concrete cracks 0.002 inches in width and greater. (ACI RAP Bulletin 1: *Structural Crack Repair by Epoxy Injection*).

Full-depth deck cracks must be capped from both the top and below before they are pressure injected from top. Caps have been successfully installed using epoxies, polyesters, paraffin wax, and silicone caulk. The selection of the cap material should consider the following criteria, subject to the type of crack to be repaired: Non-sag consistency (for overhead); Moisture-tolerance; Working life; and Rigidity (modulus of elasticity). (ACI RAP Bulletin 1: *Structural Crack Repair by Epoxy Injection*).

For cracks that are opening and closing under traffic loads, a flexible elastomeric crack sealer may be warranted. The following conditions may indicate a working crack:

- The crack is open and shows evidence of movement
- Has been sealed before and has failed again
- Concrete dust fills the crack

The injected crack sealer material should be designed for the anticipated movement of the deck or slab crack.

A summary of the options for bridge deck crack sealing are presented in Table 7.4:

Table 7.4 Crack Sealer Summary

Attribute	Silane/Siloxane	Heavy Weight Methyl Methacrylate, Polyurethanes	Epoxy Healer Sealer	Thin Epoxy Overlay	Injection Epoxy
Typical Applications*	Waterproofing good condition concrete	Crack sealers for widespread fine cracking	Crack sealers for widespread fine cracking	Crack sealer for widespread discrete larger crack widths	Crack sealer for widespread discrete larger crack widths
Viscosity (Centipoise)	<1	20 - 200	50 - 150	1500 - 3000	500 - 2000
Pot Life (Minutes)	NA	5 - 45	20 - 60	15 - 30	15 - 30
Minimum Cure Time (Hours)	1 - 4	2 - 12	3	1	2
Skid Resistance	Original Surface	Broadcast fine aggregate (sand)	Broadcast fine aggregate (sand)	Broadcast fine aggregate (sand)	Broadcast fine aggregate (sand)
Expected Useful Life (Years)	3 - 5	5 - 10	5 - 10	10 - 15	5 - 10

*Sealers should be formulated specifically for the crack(s) being addressed.

7.2.3 Deck and Slab Overlays

Bridge deck and slab overlays provide a wearing surface that can protect the underlying deck and provide a maintainable layer on the riding surface. Wearing surfaces add protection for the underlying deck or slab but also add dead load weight to the bridge and thus reduce the live load capacity. Adding a new wearing surface or increasing the thickness of an existing wearing surface should be evaluated by an engineer for impact on the live load capacity. Wearing surfaces can generally be categorized into three general classes; asphalt, concrete, and polymer overlays.

When to Call the Engineer

When deciding if an overlay should be applied to an existing deck, an engineer should be consulted to assure that the bridge can handle the extra load.

7.2.3.1 Asphalt Concrete Overlays with Waterproofing Membrane

Asphalt concrete overlays are very common because they are easy to install, relatively inexpensive and most agencies have established mix specifications and a long history of using the product. Asphalt overlays can vary in their performance depending on the density, aggregate and binders used. Asphalt does tend to trap and hold moisture and chlorides that can lead to deterioration of the underlying deck if not properly protected. It is a good practice to include a waterproofing membrane under an asphalt overlay unless the asphalt is a temporary measure to improve ride quality on bridges or bridge decks planned for rehabilitation or replacement.

Water proofing membranes provide a moisture barrier between the asphalt and the underlying deck material. Membranes can be categorized as constructed-in-place or preformed membrane types.

Constructed-in-place membranes include:

- Bituminous
- Spray applied resins

Preformed membranes include:

- Asphalt-impregnated fabrics
- Polymer
- Elastomeric
- Asphalt-laminated board systems

The most commonly used water proofing membranes are bituminous and asphalt-impregnated fabrics. Both common membrane systems consist of a tack coat on the prepared concrete deck, a spray applied or preformed membrane, a protective board, tack coat and then the asphalt applied on top. A schematic of these layers is shown in Figure 7.9.

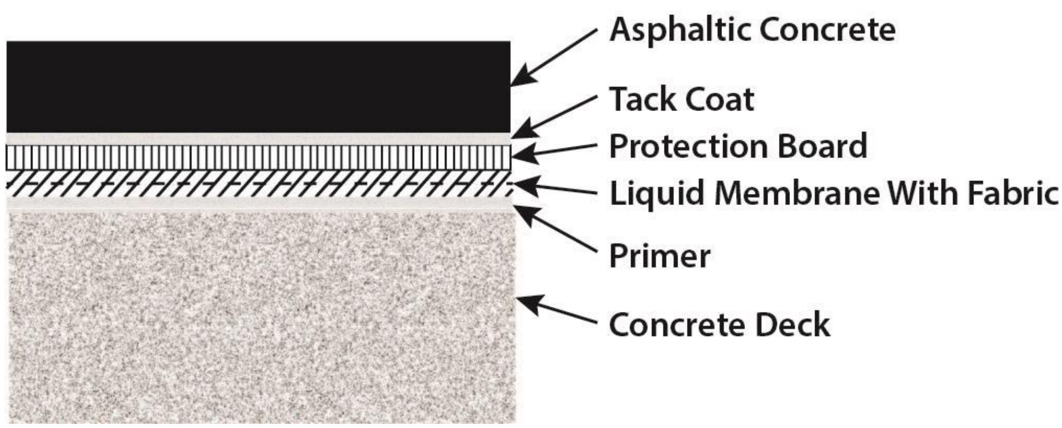

Figure 7.9 Typical Membrane Configuration

7.2.3.2 Concrete Overlays

Rigid concrete overlays are very common on bridge decks and slabs because they have a relatively long life, have quick installation techniques known by most contractors and provide good ride quality when cured. Concrete overlay types include the following concrete variants:

- High performance concrete
- Latex modified concrete
- Silica fume concrete*
- Fly ash modified concrete
- Polymer concretes

*Note that several states have reported bonding issues with silica fume concrete, particularly with patching operations.

Concrete overlays provide a durable wearing surface that stiffens the deck or slab, provides additional cover over reinforcing steel, and reduces permeability of the deck or slab. All of these attributes can slow or eliminate the ingress of water and chlorides that lead to corrosion. Concrete overlays also provide a single step means to patch localized deck spalls and overlay in a monolithic placement of concrete that can lead to improved ride quality.

7.2.3.3 Polymer Overlays

Thin bonded polymer overlays are very common overlays for bridge decks and slabs because they are light weight, result in minimal grade differences, reduce permeability and the bridge can be put back into service quickly. Polymer overlays are typically less than one half inch thick and can be applied in one or more layers. Polymer overlays use resins of epoxy, epoxy urethane, or methyl methacrylate.

A comparison between the overlay options available is presented in Table 7.5:

Table 7.5 Bridge Deck Overlay Summary*

Attribute	Asphalts	Concretes	Polymers
Typical Applications	Thick flexible wearing surface over all common deck materials. With membrane	Durable thicker rigid wearing surface and deck protection	Thinner more flexible deck protection and wearing surface
Typical Thickness Range (inches)	1.5 - 6	1 - 5	0.5 - 1.5
Surface Prep	Clean and milled or roughened	Steel shot, ground or roughened	Steel shot, ground or roughened
Minimum Cure Time for Traffic (hours)	1 - 4	2 - 12	2 - 16
Skid Resistance	Original Surface	Concrete Finish, grind or grooving	Broadcast fine aggregate (sand)
Expected Useful Life (years)	15 - 20	15 - 30	10 - 20

* For more information refer to: International Concrete Repair Institute, Technical Guideline No. 310.2R-2013, *Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair*.

7.2.4 Common Maintenance Activities

7.2.4.1 Bridge Deck Washing

Bridge deck and slab washing is an economical way to remove debris, dirt and chlorides from the roadway surface. Regular flushing can reduce chloride levels in the concrete and improve air circulation and drying. Prior to washing the deck, the local environmental requirements related to the collection of the wash water should be understood. The following procedure can be used for bridge decks and slabs of all materials:

Suggested Procedure

Bridge Deck Washing

1. Sweep the deck to remove accumulated surface debris.
2. Pressure wash the deck at 2700 – 3000 psi (2-3 gallons/minute) starting at the highest point. Water will flow from the high end to the face of lowest rail.
3. Use the pressurized water to flood the deck and push the water, dirt and salt mixture towards the face of the lowest rail (See Figure 7.10).
4. Progress in a back and forth motion, much like mowing a lawn until all the water and debris is along the low rail.
5. Spray clean the rail face or other components that get debris blown onto them.
6. Use water pressure and a vacuum truck to collect all the debris and water from the surface. Local environmental regulations may permit diversion of wash water to the roadway embankment in lieu of collection and disposal.

An example of bridge washing is shown in Figure 7.10.

Figure 7.10 Bridge Washing (Courtesy of DBI Services)

7.2.4.2 Epoxy Crack Injection

Discrete larger deck and slab cracks can be sealed and re-bonded through surface or pressure injection with a material such as epoxy or polyurethane.

Following is a procedure for crack injection:

Suggested Procedure

Epoxy Crack Injection

1. Clean out the cracks to be sealed. Methods to clean cracks include:
   a. Vacuuming
   b. Oil-free compressed air
   c. High pressure water
2. Seal the crack surface. Apply cap sealer epoxy along the dry top surface of the crack and allow it to harden. If the crack has spalled edges or if injection pressures are too high for a surface seal, saw cut the crack first and then, seal the surface by cutting a v-groove and filling it with mortar.
3. Use surface ports or drill injection port holes along the crack.
4. Inject the sealant through the injection ports until the cracks are filled (see Figure 7.11).
5. Allow to cure before returning traffic.

Figure 7.11 Epoxy Injection Repair (Courtesy of Virginia DOT)

For surface sealing with epoxy, the following procedure applies:

Suggested Procedure

Surface Sealing with Epoxy (with Optional Fiber Reinforcement Fabric)

1. Clean out the cracks to be sealed. Methods to clean cracks include:
   a. Vacuuming
   b. Oil-free compressed air
   c. Abrasive blasting (i.e., shot blasting or sandblasting).
2. Apply epoxy onto the clean dry crack on the deck surface.
3. Broom epoxy along the dry top surface of the crack the width of the fiber reinforcement.
4. Roll out the fiber reinforcement fabric onto the wet epoxy surface and press into the epoxy until the fabric is saturated (see Figure 7.12). Overlay as needed for ride quality.
5. Allow to cure before returning traffic.

Examples of surface epoxy sealing with optional fabric are shown in Figure 7.12. Rolling out the fiber reinforcement fabric is shown in Figure 7.12 (left). Detail view of the fabric in-place is shown in Figure 7.12 (right).

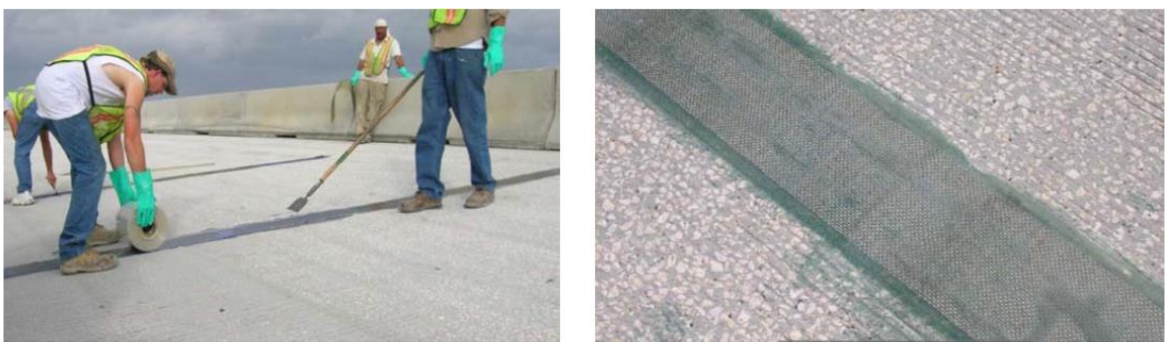

Figure 7.12 Surface Epoxy Sealing with Optional Fabric (Courtesy of Virginia DOT)

7.2.4.3 Applying Penetrating Deck Seals

Widespread smaller cracks can be sealed using penetrating sealers to slow the ingress of water and chlorides into the deck or slab.

The following is a procedure for applying penetrating deck sealers:

Suggested Procedure

Application of Penetrating Deck Sealer

1. Repair any spalled or delaminated areas following the procedure provide below. Do not patch surfaces until fully cured.
2. Clean the surface by shot-blasting to remove all contaminants and to open the surface and cracks (see Figure 7.13).
3. Remove dust and debris by blowing off with oil-free compressed air and vacuuming.
4. Protect the expansion joints, and any other areas not to be sealed, from damage during preparation of the surface. The protection must be removed once the epoxy and aggregate have been applied and prior to initial set. Removing the protection must be done soon enough to ensure no harm to the adjacent sealed surface.
5. Mix components per manufacturer recommendations by volume. Mix only the quantity that can be used within its gel time.
6. Apply mixed product in accordance with manufacturer instructions, typically by pouring or spraying on the surface. Distribute material in accordance with manufacturer instructions, which is often evenly with a squeegee, roller or broom, maintaining a liquid head over cracks. Remove all excess material with squeegee or broom. Most products should be dispensed immediately after mixing to ensure adequate crack penetration time (see Figure 7.14).
7. Broadcast fine aggregate (sand). Application of aggregate must be of sufficient quantity to cover the entire surface in excess. No bleed through or wet spots shall be visible. The aggregate should be clean and moisture free. The broadcast of sand will wear off leaving sealed cracks behind (see Figure 7.15).
8. After initial cure, remove excess sand or aggregate by broom or compressed air. Excess sand may reduce surface friction if not removed.
9. When used as primer or pre-treatment prior to overlay consult manufacturer’s technical representative for appropriate curing before overlay. Some products are designed to act as a primer for a “wet on wet” application; other products should gel or cure prior to the application of overlays.

Figure 7.13 Shot Abrading Deck Preparation (Courtesy of MDOT)

Figure 7.14 Sealer Application (Courtesy of MDOT)

Figure 7.15 Broadcasting Sand (Aggregate) (Courtesy of MDOT)

7.2.4.4 Full and Partial Depth Concrete Spall Repairs

Deck spalls are a common outcome of cracking, vehicular impact, or reinforcing corrosion in the deck or slab. Concrete patching can be used to repair the spalls. The following procedure will result in a quality patch. Note that if unsound concrete is removed to the extent that the bottom mat of reinforcement is exposed, stop the patching partial depth procedure and switch to the full depth procedure.

Suggested Procedure

Concrete Spall Repair

1. Identify the deck or slab location to be repaired.
2. Hammer sound or chain the area around the spall to identify and mark adjacent unsound concrete. Mark off square areas outside the limits of the unsound concrete.
3. Combine patches closer than 1 foot into larger patches.
4. Sawcut to a depth of at least 3/4 to 1 inch in a geometric pattern marked in the previous step. Be careful not to cut through reinforcing steel (see Figure 7.16 and Figure 7.17).
5. If the patch is full depth, protect the area under the work area from falling debris. This can be done by placing wooden or metal forms attached to the girders or soffit of the bridge (see Figure 7.18). Forms may be suspended from reinforcing steel by wire ties for areas of less than 3 square feet. In the case of larger openings, forms shall be supported from below by blocking to ensure the form can support the wet concrete weight.
6. Use a lightweight chipping gun (maximum weight of 30 pounds) to chip the concrete out between the edge of the spall and the sawcut lines. Pneumatic hammers shall be worked at an angle of 45 to 60 degrees to the plane of the concrete being removed. Chip the concrete out max aggregate plus 1/4 inch below the top mat of reinforcing steel or any other exposed reinforcing steel layers (see Figure 7.19). All loose concrete within the limits of the patch should be removed. Do not place chipping gun on the reinforcement.
7. Inspect edge of patch to ensure the limits of the delamination have been removed. If a concrete separation is visible (see Figure 7.20), increase the size of the patch.
8. Use sand blasting equipment to remove any rust from exposed reinforcing steel and to clean the exposed concrete surfaces. Touch up epoxy bars.
9. Replace any missing or corroded steel with new bars providing proper overlap lengths. Consult an engineer as needed. Overlap requirements may require a larger area to be chipped out, or drill and epoxy anchor bars, or mechanically splice.
10. Galvanic anodes may be used for additional corrosion protection in the patch region.
11. Check the repair area one more time for any loose concrete or debris inside the spalled area and remove any found. Blow out the repair area with compressed air (see Figure 7.21). Prepared concrete area is shown in Figure 7.22.
12. Apply a bonding agent as specified by the engineer. A bonding agent may not be specified in all cases.
13. Wet the concrete in the patch area but do not allow standing water (Saturated Surface Dry or SSD condition).
14. Mix rapid setting concrete (or conventional concrete) and place concrete in the patch area up to the surface of the surrounding deck (see Figure 7.23). Vibrate the concrete, especially in the corners and around the reinforcing steel (see Figure 7.24).
15. Screed the newly placed concrete to the level of the surrounding deck (see Figure 7.24). Use concrete finishing tools appropriate for the size of the patch.
16. Use a wet broom to provide a roughened surface in a transverse direction to traffic.
17. Cure the concrete per the manufacturer recommendation before restoring service on the bridge (see Figure 7.25). Concrete patches will continue to harden over time but can often support traffic within 2 to 4 hours for rapid setting patch materials.

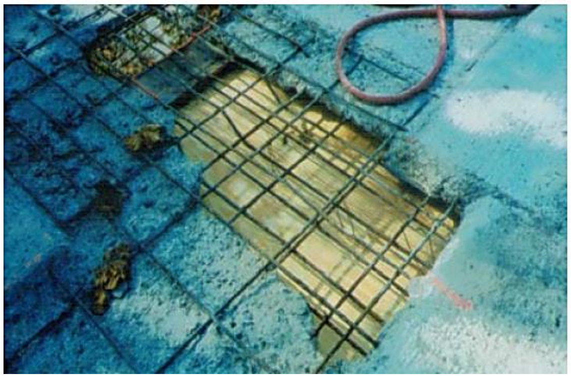


Figure 7.16 Concrete Repair Photos. Full Depth Repair (left) and Partial Depth Repair (right)

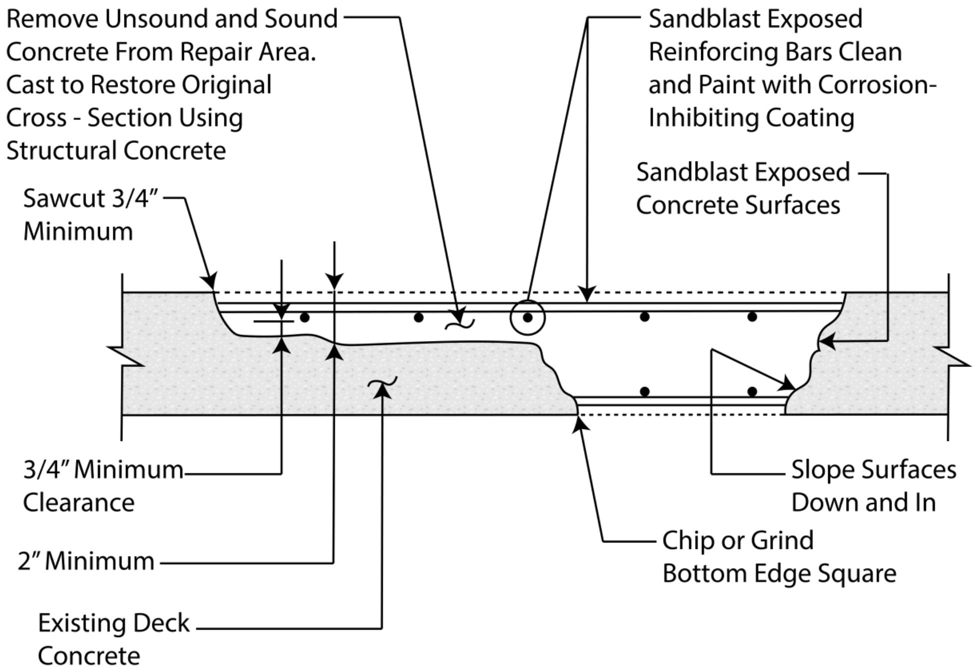

Figure 7.17 Typical Spall Repair Plan

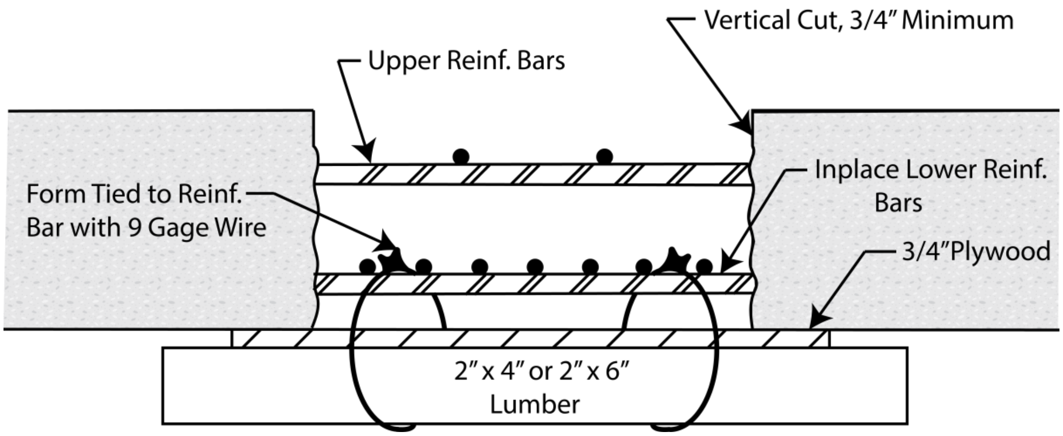

Figure 7.18 Typical Full Depth Repair Forming

Figure 7.19 Concrete Removal (Courtesy of MDOT)

Figure 7.20 Delamination at Edge of Patch (Courtesy of MDOT)

Figure 7.21 Cleaning with Compressed Air (Courtesy of MDOT)

Figure 7.22 Prepared Patch Areas (Courtesy of MDOT)

Figure 7.23 Concrete Placement

Figure 7.24 Vibration and Finishing (Courtesy of MDOT)

Figure 7.25 Concrete Wet Cure Examples. Wet Cure Blanket (left) and Burlap Sheets (right)

7.2.4.5 Concrete Deck and Slab Delamination Repair

Delamination of a concrete deck or slab is typically caused by corrosion of the reinforcing steel that results in corrosion and expansive carbonation at the rebar level that cracks the concrete along rebar lines parallel to the surface of the deck or slab. Delaminations can be identified through acoustic methods such as chaining or impact echo methods or through density test methods such as ground penetrating radar.

The following procedure can be used to repair deck or slab delaminations:

Suggested Procedure

Deck or Slab Delamination Repair

1. Identify the delaminated deck areas using one of the identified location methods. Deck chaining and hammer sounding are the most common methods (see Figure 7.26).
2. Remove the delaminated concrete areas (see Figure 7.27 and Figure 7.28).
   a. For a small percentage of delaminations, repair can be accomplished following the spall repair procedure.
   b. For larger delamination areas, hydro-demolition equipment should be used to remove the concrete and clean the reinforcing steel of corrosion. Follow steps 3 through 11 for Suggested Procedure: Placement of Concrete Overlay in Section 7.2.4.7. See Figure 7.29 and Figure 7.30.

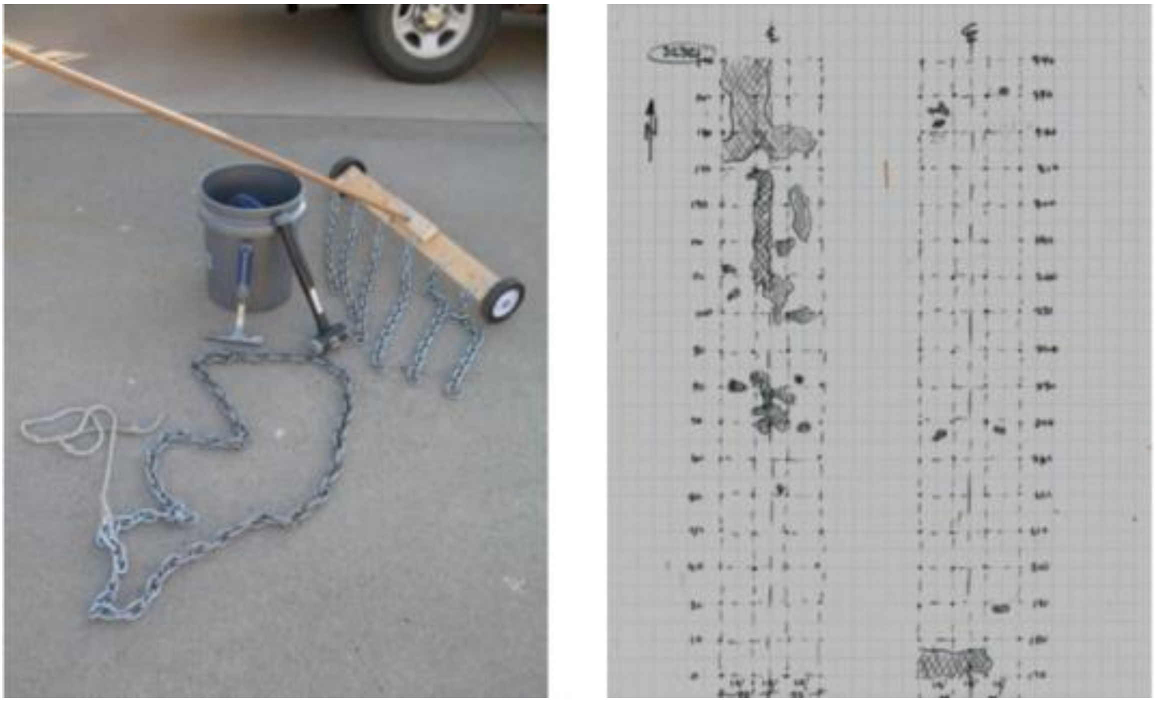

Figure 7.26 Chain Sounding Tools (left) and Delamination Mapping (right)

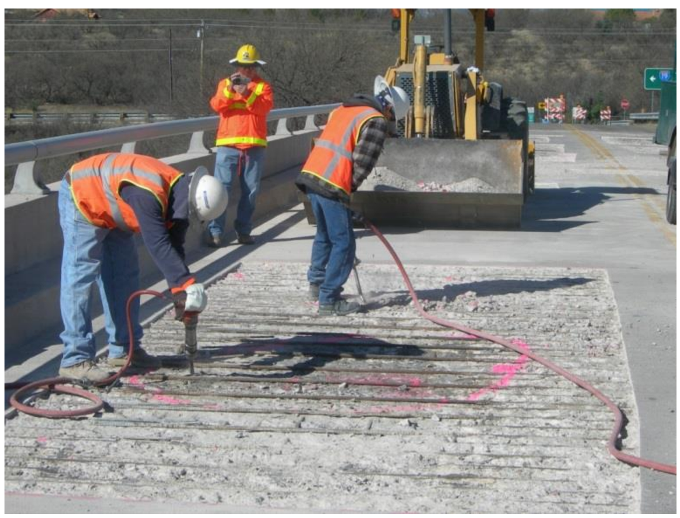

Figure 7.27 Removing the Delaminated Concrete (Courtesy of Kwikbond Polymers)

Figure 7.28 Sawcut, Chipped Out and Cleaned (Courtesy of Truesdell Construction)
Concrete Removal Shown to the Top Mat Only

Figure 7.29 Placing the New Polyester Concrete (Courtesy of Truesdell Construction)

Figure 7.30 Curing the Concrete

7.2.4.6 Placement of Asphalt Overlay with Membrane

Asphalt overlays may be used as an application for waterproofing concrete bridge decks. There are two recommended practices for asphalt overlays on decks.

1. Asphalt overlay with membrane. A membrane is placed, and the asphalt is paved. The membrane is either a pre-formed sheet or a liquid hot-applied rubberized asphalt with polymer resins. See Figure 7.31 for examples of these steps used in placing an asphalt overlay with membrane, where the following are observed: (a) Application of primer to the concrete deck, (b) Laying out the sheet membrane, (c) Heating the sheet membrane with a torch, (d) Sealing the overlap seams with a hand roller, (e) Completed membrane, (f) Compacting the hot mix asphalt.
2. Polymer modified asphalt (PMA). A PMA is paved, and no membrane is used because the PMA has low permeability.

The following suggested procedure applies to asphalt overlay with a membrane.

Suggested Procedure

Asphalt Overlay with Membrane

Before beginning, the deck needs to be swept or air blasted to remove loose material. Any sealers, coatings, or foreign substances that might affect the adhesion or curing of the asphalt or tack coat should be removed.

The steps for applying an asphalt overlay with a pre-formed membrane sheet are:

1. Apply the primer, such as asphalt emulsion.
2. Apply an adhesive, such as oxidized asphalt.
3. Apply an optional ventilating and leveling layer, such as sand asphalt.
4. Place the membrane, lapping the sheets.
5. Place an optional felt protection board.
6. Apply an asphalt tack coat.
7. Apply an asphalt base mixture, which has a life of 30 years.
8. Apply the asphalt surface mixture, which has a life of 10 to 15 years.

Examples of these steps are shown in Figure 7.31.

Polymer Modified Asphalt

The only step with a polymer modified asphalt is to pave the asphalt. Follow the membrane manufacturer recommendations regarding use of a tack coat prior to the placement of a polymer modified asphalt overlay. The most common tack coat used for polymer modified asphalt is a non-diluted asphaltic emulsion.

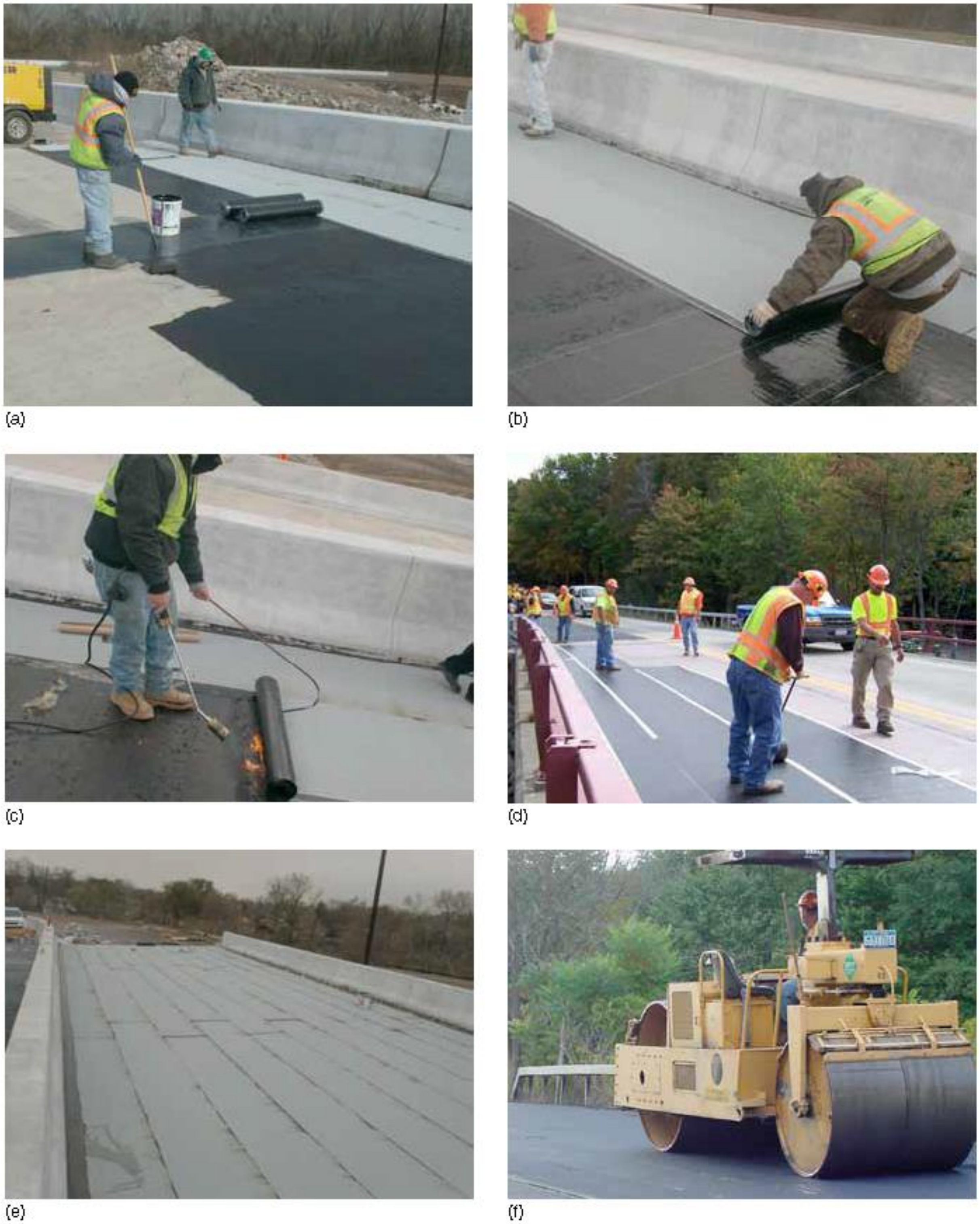

Figure 7.31 Steps in the Installation of a Preformed Sheet Membrane (Courtesy of TRB)

7.2.4.7 Placement of Concrete and Polymer-Modified Concrete Overlay

Overlays can be an effective deck preservation method if the underlying concrete is properly patched and delaminations are addressed prior to the placement of the overlay. Proper hydrodemolition will remove all delaminations. Concrete damaged to or beyond the depth of the bottom layer of reinforcement requires full depth repairs. Partial and full depth repairs may be poured at the same time as the overlay.

The following procedure applies for all concrete and polymer-modified concrete overlays:

Suggested Procedure

Placement of Concrete or Polymer-Modified Concrete Overlay

1. Remove deteriorated concrete and repair any delaminated or spalled areas. Concrete delaminated or spalled to or beyond the depth of the bottom layer of reinforcement requires full depth repairs. Partial depth delaminations or spalls can be repaired with suitable patch materials and overlaid after appropriate curing. Alternatively, partial depth delaminations or spalls as well as full depth repairs may be poured at the same time as the overlay. See spall and delamination procedure. See Figure 7.27.
2. In preparation for the placement of the overlay, clean the entire surface area of the deck by shot blasting or other approved means (see Figure 7.32) within 24 hours of the overlay placement. Protect metal deck drains and areas of the curb or railing above the proposed surface from the shot blast. The Engineer must approve the use of scarifiers or milling machines in lieu of shot blasting. Hydrodemolition may also be used for to prepare the deck for an overlay.
3. Further clean the deck of any debris by air blasting with dry oil free air or vacuuming. Brooming is not acceptable.
4. Remove all loose concrete, dirt, paint, oil, asphalt, laitance carbonation and curing materials from patches and other foreign material from the surface of the deck.
5. Produce a surface relief equal to the International Concrete Repair Institute (ICRI) Surface Preparation Level 6 to 7 or ASTM E 965 Pavement Macro texture depth of 0.04 to 0.08 inch.
6. Remove any contamination of the prepared deck surface or surface of subsequent courses. Sand blast contaminated areas to produce an acceptable surface for placement of the overlay.
7. Protect deck drains so the overlay material shall not pass into the drains.
8. Rain will not necessarily contaminate the surface. However, care must be taken that no contamination occurs.
9. For conventional concrete overlays, the surface shall be thoroughly water soaked without allowing standing water prior to the placement of the new concrete. For polymer-modified concrete, follow the manufacturer instructions.
10. Place the first course within 24 hours of preparing the deck surface. Deck surfaces exposed for more than 24 hours must be sand blasted and step 3 repeated prior to application of the overlay (see Figure 7.33).
11. Cure overlay as specified.

Figure 7.32 Preparing the Deck with Shot Blasting (Courtesy of Kwikbond Polymers)

Figure 7.33 Placing the Concrete Overlay (Courtesy of Truesdell Construction)

7.2.4.8 Placement of Polymer Overlay

The following procedure applies to epoxy polymer overlays.

Suggested Procedure

Placement of Epoxy Polymer Overlay

1. Remove deteriorated concrete and repair any delaminated or spalled areas. Concrete delaminated or spalled to or beyond the depth of the bottom layer of reinforcement requires full depth repairs. Full or partial depth areas can be repaired with suitable patch materials and overlaid after appropriate curing. See spall and delamination procedure. See Figure 7.27.
2. In preparation for the placement of the overlay, clean the entire surface area of the deck by shot blasting or other approved means (see Figure 7.32 and Figure 7.34a) within 24 hours of the overlay placement, to produce a surface relief consistent with epoxy overlay manufacturer requirements. Protect metal deck drains and areas of the curb or railing above the proposed surface from the shot blast. The Engineer must approve the use of scarifiers or milling machines in lieu of shot blasting. Hydrodemolition may also be used for to prepare the deck for an overlay.
3. Remove any contamination of the prepared deck surface such as traffic striping. Sand blast contaminated areas to produce an acceptable surface for placement of the overlay.
4. Further clean the deck of any debris by air blasting with dry oil free air or vacuuming.
5. Protect deck drains so the overlay material shall not pass into the drains.
6. Deck must typically be dry for a specified period of time in accordance with epoxy manufacturer's recommendations, and must remain dry during the cure period. As such, epoxy overlay should not be placed if rain is forecast before completion of cure, typically 6 to 24 hours depending on manufacturer.
7. Mix epoxy as specified by manufacturer in batches (see Figure 7.34b) that can be mixed and applied while maintaining a "wet edge" for beginning to spread the next batch.
8. Spread the mixed epoxy onto the substrate with a notched squeegee at the recommended rate (see Figure 7.34c and Figure 7.34d). Place the epoxy to permit a continuous operation. Apply the second batch immediately behind the first batch.
9. Broadcast the aggregate immediately (see Figure 7.34e), but stop to maintain a wet edge. Broadcast the aggregate to complete saturation (approximately 1.1 pound per square foot. If wet spots develop, immediately broadcast additional aggregate until a dry surface is re-established. Cure overlay as specified.
10. Once the epoxy has cured, sweep the bridge deck to remove any loose aggregate (see Figure 7.34f).
11. Apply the second coat in the same matter but at a rate that is typically double the rate of the first coat due the roughness of the aggregate. The maximum recoat window is 24 hours.
12. Allow to cure, and sweep any loose aggregate from deck, prior to opening to traffic.

The photo sequence in Figure 7.34 shows several steps in the installation of a polymer overlay (i.e., a two part epoxy resin in this example). The following steps are shown in the figure: (a)

Shotblasting to clean the deck surface, (b) Mixing the two part epoxy, (c) Pouring the epoxy from buckets, (d) Spreading the epoxy with notched squeegee brushes, (e) Broadcasting aggregate onto the epoxy surface, (f) Sweeping up loose aggregate prior to opening the bridge to traffic.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 7.34 Common Steps in Epoxy Polymer Overlay

7.2.4.9 Steel Corrosion Mitigation

Corrosion of reinforced concrete steel is a common problem faced by bridge owners. Strategies to minimize deck steel corrosion have been discussed within this chapter. For decks that already have active corrosion of the reinforcing steel occurring, the following can be used to address the situation:

- Determine if the steel corrosion is in discrete areas or throughout the deck. Delamination surveys can be used to establish the extent of rebar corrosion damage.
- For widespread corrosion damage (greater than 25 percent of the surface area), a partial depth deck replacement should be considered as this repair will remove active corrosion and replace chloride contaminated concrete.
- Hydro-demolition is very effective at removing varying depths of concrete and cleaning the reinforcing steel in preparation for a partial depth deck replacement.

For localized areas of rebar corrosion (see Figure 7.35), the area may be repaired using the procedure presented for spall repair, with the addition of galvanic anodes being attached to the reinforcing in the repair area prior to the placement of the new concrete (see Figure 7.36). The anodes are typically tied on the side of the exposed rebar as close as practical to the surrounding concrete making sure that enough space is left to fully encapsulate the anodes in the repair.

Figure 7.35 Localized Repair Area

Figure 7.36 Placement of Galvanic Anodes (Courtesy of Vector Corrosion Technologies)

For widespread steel corrosion, consideration should be given to adding a cathodic protection system to slow the corrosion of the repaired deck.

7.3 Steel Decks

7.3.1 Introduction

What To Look For

- Cracks
- Broken welds, rivets, bolts
- Failed coatings
- Corrosion
- Section loss
- Loose Elements

Steel bridge decks are common on moveable bridges and other bridge designs that require a lightweight deck. The weight of a steel deck per unit area is much less than that of concrete. This weight reduction of the deck means the machinery that lifts the bridge can be economized. For open grid steel decks, water passing through the deck and onto the superstructure and substructure elements can lead to deterioration. Steel grid decks can be filled or partially filled with concrete to prevent the water from passing through and causing deterioration. Steel bridge decks can be found in design situations where forming concrete is difficult or rapid deck construction is required. In these situations, corrugated, orthotropic or exodermic steel sections may be used by the designer. There are four general types of steel bridge decks commonly encountered:

- Grid decks
- Orthotropic decks

- Corrugated steel decks
- Exodermic Bridge Decks

7.3.1.1 Grid Decks

Welded grid decks have their components welded together in various patterns (see Figure 7.37). These components consist of bearing bars, cross bars, and supplementary bars. The bearing bars support the grating. Bearing bars are laid on top of the beams or stringers perpendicularly and are then field-welded or bolted to the superstructure.

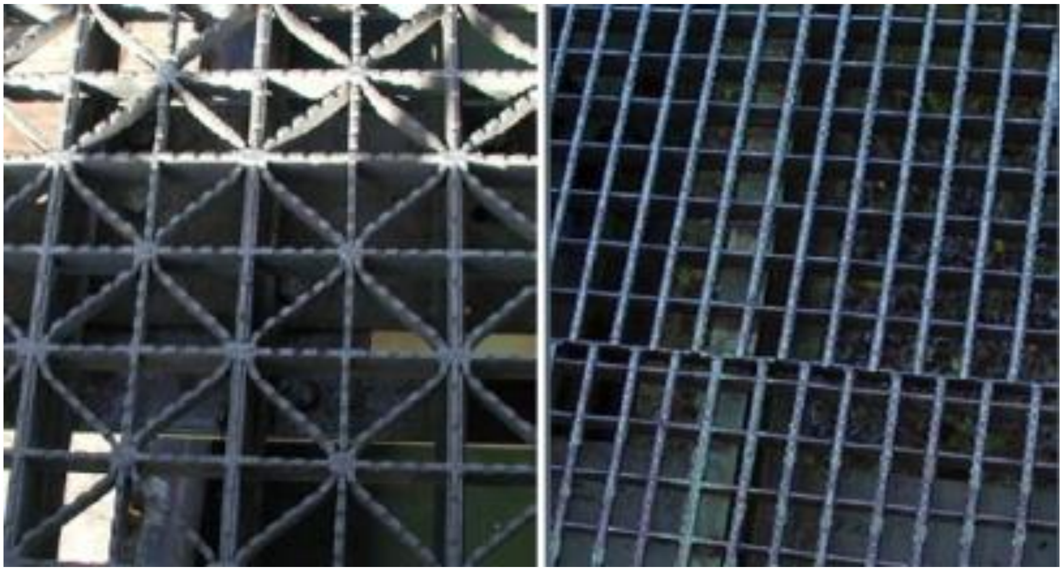

Figure 7.37 Open Grid Decks. Diamond (left) and Rectangular (right)

A riveted grid deck consists of bearing bars, crimp bars, and intermediate bars (see Figure 7.38). Bearing bars run perpendicular to the superstructure and are attached to the beams or stringers by either welds or bolts. Crimp bars are riveted to the bearing bars to form the grating. Intermediate bars are parallel to the bearing bars but are not as long. The crimp bars are riveted to intermediate bars.

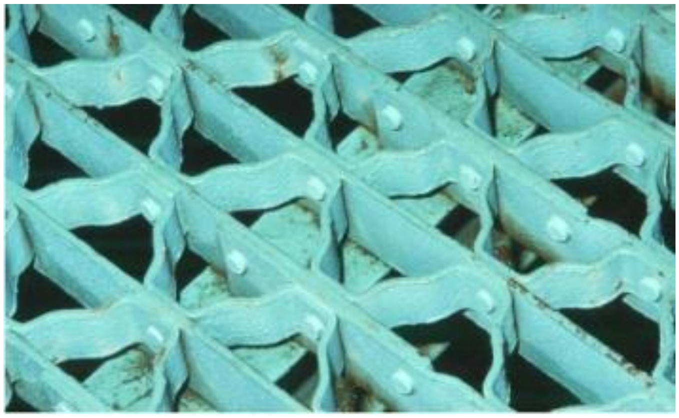

Figure 7.38 Riveted Steel Grid Deck

Welds and rivets used to construct steel grid decks have a long history of cracking from fatigue or deterioration caused by vehicle tires. To minimize cracking, steel grid decks have been fabricated with slotted holes to eliminate the use of welds or rivets (see Figure 7.39). Transverse distribution bars are inserted into the slots rotated into position and locked into place without the use of any welds or rivets.

Figure 7.39 Slotted Grid Deck

Concrete filled grid decks are commonly used to provide added protection from grid damage and to protect the superstructure and substructure from damage caused by surface water and chlorides. An example of a concrete filled grid deck is shown in Figure 7.40. Filling the grids with concrete can add considerable weight to the deck. The weight of filling the grids can be limited by filling portions of the grids that are in the wheel lines or near bearings or other structural components that need added protection from the elements.

Figure 7.40 Filled Grid Deck (Courtesy of Florida DOT)

7.3.1.2 Orthotropic Decks

An orthotropic deck consists of thin steel plate stiffened by a series of closely spaced ribs placed perpendicular to their supporting members (see Figure 7.41). The deck acts integrally with the steel superstructure. An orthotropic deck becomes the top flange of the entire floor system.

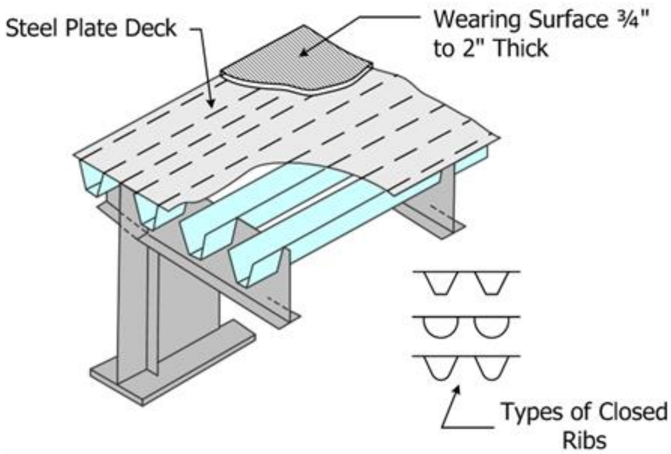

Figure 7.41 Orthotropic Bridge Deck

7.3.1.3 Corrugated Decks

Corrugated steel flooring is popular because of its light weight and high strength. Corrugated decks consist of thin steel plate material bent into ribs and covered by a layer of bituminous wearing surface or polymer concrete. A schematic of the corrugated deck surface is shown in Figure 7.42. The corrugated flooring spans transversely between the supporting superstructure members and it typically welded to steel members or nailed or bolted to timber and concrete superstructures. The wearing surface thickness varies from the centerline of the deck to the edge of the roadway to achieve proper cross slope. There are no reinforcement bars utilized in this deck type.

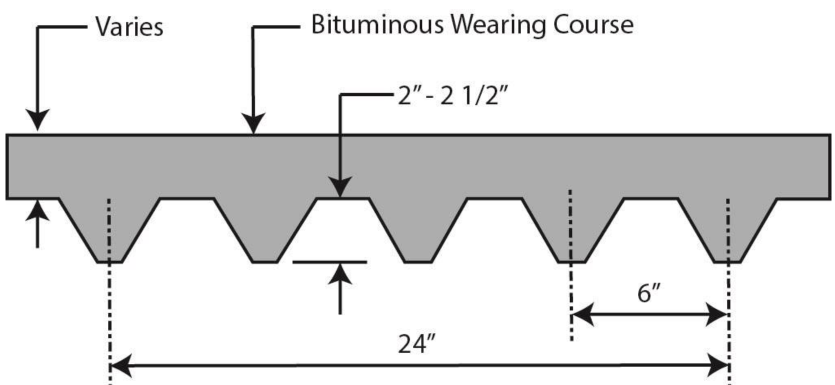

Figure 7.42 Corrugated Bridge Deck

7.3.1.4 Exodermic Bridge Decks

Exodermic decks are a variant of the tradition grid deck that use steel grids with concrete attached to the superstructure. Composite action is achieved by studs that extend into the reinforced concrete deck and are welded to the grid deck below (see Figure 7.43). Galvanized sheeting is used as a bottom form to keep the concrete from falling through the grid holes. Exodermic decks generally weigh 50 to 65 percent less than precast reinforced concrete decks.

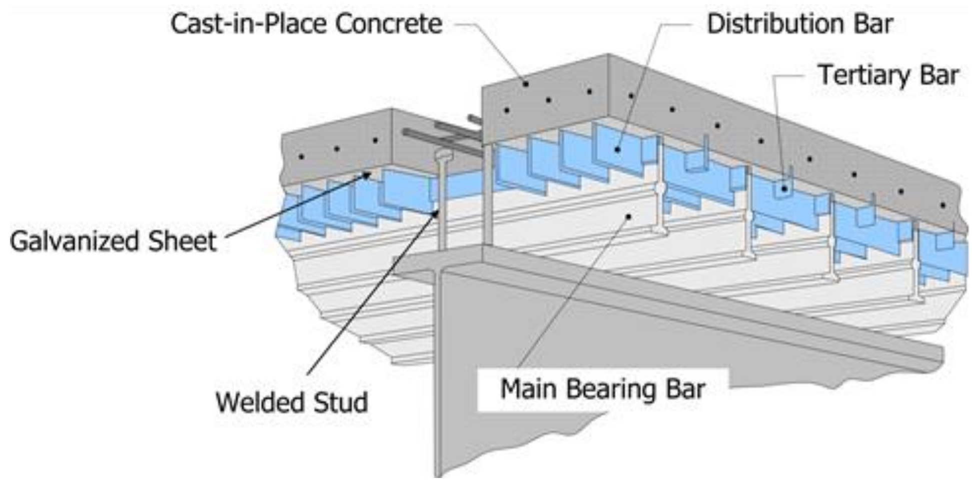

Figure 7.43 Exodermic Bridge Deck

7.3.2 Deck Protection Methods

Steel decks are subject to corrosion that can be minimized using many of the same techniques used to control reinforced concrete rebar corrosion. These techniques include removing debris and chlorides through regular flushing, applying protective coatings, and utilizing cathodic protection systems.

7.3.2.1 Washing and Cleaning

Bridge deck and slab washing is and economical way to remove debris, dirt and chlorides from the roadway surface. Regular flushing can reduce chloride levels and improve air circulation and drying.

7.3.2.2 Coating Systems – Paint and Galvanization

Paints provide protection from moisture, oxygen, and chlorides. Usually three coats of paint are applied. The first coat is the primer, the next is the intermediate coat, and the final coat is the topcoat. Various types of paint are used, such as oil/alkyd, vinyl, epoxy, urethane, zinc-rich primer, and latex paints.

Galvanizing can be used to protect steel decks. The galvanized coating retards the corrosion process and lengthens the life of the steel deck. The two dissimilar metals form an electrical current which reduces the corrosion in the steel. There are two methods of galvanizing steel decks (shop applied and field applied). Hot-dipping the steel deck member usually takes place at a fabrication shop prior to the initial placement of the steel deck. Steel sections are placed into a molten bath of zinc fusing the zinc to the surface of the steel.

When sections of the deck are too large or when field coating is required, the metallizing process is used. Metallizing is a thermal spray of zinc protective coating for steel. Zinc or aluminum wire is continuously melted in an electric arc spray or gas flame spray gun. Droplets of molten metal from the wire are deposited onto the steel forming the protective coating. This sprayed metal coating is both a barrier coating and a galvanic coating in one. The coating provides protection to the steel similar to galvanizing. Metallized coatings often have a top coat (sealer) to extend service.

7.3.2.3 Cathodic Protection

Steel bridge decks are subject to corrosion that can be minimized through the use of cathodic protection systems. Both sacrificial anodes and active current systems can be designed to control the rate of corrosion. These systems should be designed by a corrosion professional.

7.3.3 Common Maintenance Activities

7.3.3.1 Pressure Washing

Pressure washing will remove debris and chlorides from the steel and promote air circulation and drying. The following procedure can be used for bridge decks and slab of all materials:

Suggested Procedure

Pressure Washing Decks and Slabs

1. Sweep the deck to remove accumulated debris.
2. Pressure wash the deck starting at the highest point. Follow concrete deck washing procedures.
3. Use the pressurized water to flood the deck and push the water, dirt and salt mixture towards the face of the lowest rail.
4. Progress in a back and forth motion, much like mowing a lawn until all the water and debris is along the low rail.
5. Spray clean the rail face or other components that get debris blown onto to them.
6. Use water pressure and a vacuum truck to collect all the debris and water from the surface.

7.3.3.2 Repairing Broken Connections

The welds or rivets that join the deck grids and hold them down may break over time (see Figure 7.44). It may be necessary to reinforce or replace damaged grid plates. When several plates have been damaged or dislodged it is best to cut out and replace that portion of the deck.

When to Call the Engineer

Call the Engineer before cutting out parts of deck.

Figure 7.44 Typical Broken Grid Section

The following procedure can be used to repair a broken grid section:

Suggested Procedure

Broken Grid Section Repair

1. Closely inspect the damaged area around the broken members for additional cracking or bent grid sections.
2. Determine a rectangular section that will address all localized damage.
3. Cut the grid section out within the identified repair area.
4. Cut a replacement grid section to fit within the newly created repair area.
5. Weld the repair section into the prepared hole in the grid deck. Welding should be done on both sides of every grid member.
6. Protect the newly welded connections with zinc rich primer or by metalizing.

7.3.3.3 Filling the Deck with Concrete

Another method of repair commonly used is to fill or partially fill the steel grid with concrete or lightweight concrete. The engineer should evaluate the effects of the additional dead load from the concrete prior to placing. The additional dead load may require rebalancing of moveable bridges. The concrete filled grid acts as a reinforced concrete deck. The steel grid provides the steel reinforcement and the concrete fill provides stiffness to help carry the load. This repair technique has several advantages including: increased deck strength, reduction in the effect of weathering by limiting the water penetration, support of the welded grid joints, and increased skid resistance.

When to Call the Engineer

Call the Engineer before adding dead load to the bridge.

7.3.3.4 Mitigating Steel Corrosion

Steel deck corrosion is primarily mitigated through the use of surface protection system such as paint or galvanization. Paints can be applied to deck sections that are properly prepared using the following steps:

Suggested Procedure

Paint Application

1. Some states recommend pressure washing for chloride removal prior to proceeding with SSPC surface preparation guidelines.
2. Allow the steel to fully dry.
3. Apply zinc rich primer, followed by base and top coat applications of paint.
4. Grid decks can be difficult to paint due to the number of edges and tight angles. Special care should be taken to adequately cover all areas.

For spray applied zinc (metallizing), consult a professional. Light sand blasting may also be in order if there is corrosion present.

7.3.3.5 Restoring Surface Friction

Both open grids and concrete-filled grids without a wearing surface are subject to decreased skid resistance over time.

Open Grid Decks - Some agencies apply studs to the deck surface to improve traction. The studs are typically 5/16 inches in diameter and 3/8 inches high and welded on intersections of the cross members to provide surface friction.

Filled Grid Decks - Filled grids can develop cupping or wear of the concrete between the grid bars, which exposes the grid to direct wheel loads. The surface of the filled grid then becomes similar to that of an open grid, and skid resistance quality declines. In wet weather, this is dangerous as water is held in the cups. In freezing weather the hazard increases due to ice formation. This condition is best addressed through the application of a thin bonded polymer overlay. See Section 7.2 of this chapter.

7.4 Timber Decks

7.4.1 Introduction and Deck Types

What To Look For

- Decay
- Crushing of wood
- Loose connections
- Loose wood members
- Cracks in wood
- Cupping, curling of planks

Timber can be desirable for use as a bridge decking material because it is resistant to deicing agents that can deteriorate concrete and steel decks. Timber is abundant in parts of the country, is easy to fabricate in any weather condition, it is light weight, and it is a renewable material source.

Timber deck performance is directly related to the ability to control moisture and pest infestation. Moisture fluctuations in timber members can lead to decay or crushing of the member. Controlling the moisture is the simplest, most economical method of slowing decay in timber bridge decks. When exposure to wetting is reduced, members can dry to moisture contents below that which will support most fungal and insect growth. Moisture control was the only method used for protecting many covered bridges constructed of untreated timber, some of which have provided service lives of 100 years or more. Moisture control involves a common sense approach of identifying areas with visibly high moisture, locating the source of water, and taking corrective action to eliminate the source. For example, drainage patterns on approach roadways can be rerouted to channel water away from the bridge rather than onto the deck. Cleaning dirt and debris from the deck surface and drains also reduces moisture and improves air circulation limiting decay.

Timber decks are classified into four major types (plank systems, nail laminated, glue laminated, and stress laminated) as described in the following sections.

7.4.1.1 Plank Systems

Plank decks consist of timber planks laid transversely across the bridge on their side (see Figure 7.45). The planks are individually attached to the bridge beams using spikes or bolt clamps.

Figure 7.45 Plank Decking

7.4.1.2 Nail Laminated

Nailed laminated decks consist of timber planks with the wide dimensions of the planks in the vertical position and laminated by nailing to the adjacent planks (see Figure 7.46). On timber beams, each lamination is toenailed to the beam. On steel beams, clamp bolts are used as required. In either case, laminates are generally perpendicular to the roadway centerline.

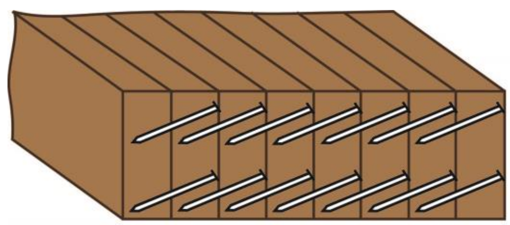

Figure 7.46 Nail Laminated Deck Cross Section

7.4.1.3 Glue-Laminated (Glulam)

Glulam is an engineered wood product in which pieces of sawn lumber are glued together with waterproof adhesives. Glue-laminated deck panels come in sizes usually 4 feet wide. The panels are laid transverse to the traffic and are attached to the superstructure. In some applications, the panels are interconnected with dowels. There are several techniques used to attach glue-laminated decks to the superstructure or a floor system, including nailing, bolting, reverse bolting, clip angles and bolts, and nailer planks (see Figure 7.47).

Figure 7.47 Glulam Members Attached with Metal Clips

7.4.1.4 Stress-Laminated

Stress-laminated decks are constructed of sawn lumber glulam wood post tensioned transversely utilizing high strength steel bars. Stressed timber decks consist of thick, laminated timber planks which usually run longitudinally in the direction of the bridge span. The timber planks vary in length and size. The laminations are squeezed together by high strength steel bars that are passed through predrilled holes in the laminations (see Figure 7.48). Steel channel bulkheads or anchorage plates are then used to anchor the bars on the sides of the bridge. This stressing operation creates a friction connection between the laminations, thereby enabling the laminated planks to span longer distances. Stress-laminated decks can be used as the superstructure for shorter span bridges.

Figure 7.48 Stress-Laminated Deck with Stressing Bolts Shown

Regardless of the design type, timber decks and slabs are subject to decay and infestation if not properly maintained. Nailed and laminated decks are also subject to loosening of the laminations over time.

7.4.2 Protection Methods - Timber Treatments and Preservatives

Protective systems are necessary to resist decay and extend the useful life of timber bridge decks. Common timber deck protection methods include surface applied and impregnated chemicals and sealants. The most common timber protection treatments are:

- Water repellents

- Timber Preservatives
- Fumigants
- Fire retardants
- Paints

7.4.2.1 Water Repellents

Water repellents help to prevent water absorption in timber decks which will lead to slow decay from molds and weathering. The amount of water in wood directly affects the amount of expansion and contraction of the member. Water repellents are used to lower the absorbed water content of timber deck members and will need to be reapplied periodically. Because it needs to be applied rather frequently, it is not the best means of protecting timber structures. Care should be taken when using water repellents on bridge decks to avoid reducing the surface friction of the deck.

7.4.2.2 Preservatives

Timber preservatives are usually applied by pressure, which forces the preservative into the timber deck member (see Figure 7.49). Surface applied preservatives are also available. Preservatives are the best way to protect against decay.

Figure 7.49 Typical Pressure Treated Markings (Courtesy of Michael B. Johnson)

Preservatives protect the timber from moisture penetration, fungus development and pest infestation. Preservatives are either oil-based or water-based. Some common oil-based preservatives are:

- Coal-tar creosote - Coal-tar creosote poses potential health concerns and is no longer used in new construction, but can be readily found in existing bridge decks. Care should be taken when burning or cutting creosote to not breathe in the smoke or dust.
- Pentachlorophenol - Pentachlorophenol is used as an above-ground decay inhibitor.
- Copper naphthenate - Copper naphthenate can be used for above-ground, ground contact and only freshwater applications
- Oxine copper - Gloves and dust masks should be used when working with wood treated with oxine copper.

Common water based preservatives include:

- Chromated copper arsenate (CCA) - CCA was the most popular preservative used from the late 1970's until 2004
- Ammonical copper zinc arsenate (ACZA) – No longer available in the United States
- Alkalkine copper quaternary (ACQ) – Newer preservative to replace CCA.
- Copper azole - Newer preservative to replace CCA.

Surface treatments are applied to existing bridge members to protect newly exposed, untreated wood from decay or to supplement the initial treatment some years after installation. This type of treatment is most effective when applied before decay begins and is commonly used for treating checks, splits, delaminations, mechanical damage, or areas that were exposed during construction. The ease of application and effectiveness of surface treatments make them useful in preventive maintenance, however the shallow penetration limits their effectiveness against established internal decay.

Conventional liquid wood preservatives are applied by brushing, squirting, or spray-flooding the wood surface. Creosote used to be the most commonly used preservative, but penta and copper naphthenate are used more commonly today. The wood surface should be thoroughly saturated with preservative so that all crevices are treated.

The effectiveness of surface treatments depends on the thoroughness of application, wood species, size, and moisture content at the time of treatment. Wet wood absorbs less preservative than does dry wood. This factor is significant in timber bridges because many areas requiring treatment are subject to wetting. Tests indicate that improved treatment of wet wood was obtained by using preservatives at double the normal 3- to 5-percent concentration. Although field tests show that surface treatments in above ground locations can prevent decay infections for up to 20 years or more, it is recommended that treatments used for bridge applications be systematically reapplied at intervals of 3 to 5 years to ensure adequate protection from decay.

7.4.2.3 Fumigants

Fumigants are specialized preservative chemicals that are placed in pre-bored holes to control internal decay. Over a period of time, the fumigants volatilize into toxic gases that move through the wood, eliminating decay fungi and insects. Fumigants can diffuse in the direction of the wood grain for 8 feet or more from the point of application in vertical members, such as posts. In deck and slab members, the distance of movement is approximately 2 to 4 feet from the point of application.

The three chemicals most commonly used as liquid fumigants are Vapam, Vorlex and chloropicrin. Solid fumigants are available in capsules. These fumigants are very hazardous and should be handled with extreme care utilizing full personal protective equipment. Solid fumigants provide increased safety, reduce the risk of environmental contamination, and permit fumigant use in previously restricted applications.

To be most effective, fumigants must be applied to sound wood (free of decay or infestation). When applied in very porous wood or close to surfaces, some of the fumigant is lost by diffusion to the atmosphere. Before applying fumigants, the condition of the member should be carefully assessed to identify the optimal boring pattern that avoids fasteners, seasoning checks and decayed structure.

7.4.2.4 Fire Retardants

Fire retardants slow the spread of fire and prolong the time required to ignite the wood. The fire retardant can be applied under pressure at a wood treating plant or can as a surface coating. In both cases, the treatment provides a physical barrier slowing the spread of flames. The treated wood chars but does not oxidize slowing the progress of fire to the material. There are several commercially available wood-based construction materials using pressure-treatment sold under trade names of “Dricon”, “D-Blaze”, and “Pyro-Guard”, as well as factory-applied coatings under the trade names of “PinkWood” and “BluWood”.

7.4.2.5 Paints

Paints applied to timber surface can help to keep some moisture out of timber members if all areas of the members can be completely coated. As the timber members swell and shrink with seasonal changes, the paint systems will generally begin to crack and allow additional moisture into the wood that will accelerate the breakdown of the painted coating and lead to decay in the timber member. For paints to be effective, they must completely cover the surface area of the timber and must be reapplied regularly. Tire wear on bridge decks and slabs will quickly wear away and applied paints in the wheel lines limited the usefulness of paints on the surface.

7.4.3 Timber Deck Overlays

Timber decks are often overlayed with a wearing surface to protect the wood from abrasion and to better distribute the load imparted by vehicle tires. Timber decks have similar overlay options to other materials with a few exceptions. Timber decks often have timber wearing surfaces or “runners” applied to protect the underlying deck members (see Figure 7.50). Timber runners are typically placed perpendicular to the deck timbers along the length of the bridge in the normal traffic wheel lines. Timber runners offer the benefit of better distributing the vehicle load and protecting the underlying deck from abrasion from vehicle tires. Timber runners are easily removed and replaced when they wear out.

Figure 7.50 Typical Timber Deck Runners

Other common overlays for timber decks include asphalt, concrete and polymer overlays. See Section 7.2 for more information of these overlays.

Timber members can deteriorate more rapidly if the wood remains wet for long periods of time. To minimize trapped moisture on timber decks, most overlays utilize a waterproofing membrane under the wearing surface material. Section 7.2 covers typical membrane systems. The application of the waterproofing membrane to a timber deck can be accomplished using the procedure presented in the common maintenance activities portion of this section.

7.4.4 Common Maintenance Activities

7.4.4.1 Washing and Cleaning

Bridge deck and slab sweeping and washing is and economical way to remove debris and dirt from the timber members and joints between members. Regular washing can improve the air circulation and drying around the member reducing the moisture content and rate of decay. The following procedure can be used for timber bridge decks and slabs:

Suggested Procedure

Washing Timber Bridge Decks and Slabs

1. Sweep the deck to remove accumulated debris.
2. Pressure wash the deck starting at the highest point. Use the water pressure to blast out the crevices and butt edges around the timber members.
3. Use the pressurized water to flood the deck and push the water and dirt towards the face of the lowest rail or off the bridge if permitted.
4. Progress in a back and forth motion, much like mowing a lawn until all the water and debris is along the low rail or off the bridge.
5. Spray clean the rail face or other components that get debris blown onto to them during the operation.
6. Use water pressure and a vacuum truck to collect all the debris and water from the surface or blow it off the bridge if allowed by local environmental regulations.

Note that pressure washing timber may not be appropriate, as high pressure can abrade or roughen the surface, as well as force water into the cracks and checks.

7.4.4.2 Treating Timber Deck and Slab members with Fumigants and Preservatives

Surface treatments are applied to existing bridge members to protect newly exposed, untreated wood from decay or to supplement the initial treatment some years after installation. This type of treatment is most effective when applied before decay begins and is commonly used for treating checks, splits, delaminations, mechanical damage, or areas that were exposed during construction.

7.4.4.3 Applying Water Proofing and Surface Preservatives

Suggested Procedure

Applying Waterproofing and Surface Preservatives

1. Clean and dry the timber area to be treated. Special attention should be placed on sawn ends, splits, checks and timber sections that touch the soil.
2. Apply the desired sealer or preservative to the surface of the wood by brush or sprayer. The wood surface should be thoroughly saturated with preservative so that all crevices are treated.
3. Allow the sealer or preservative to penetrate the surface of the wood.
4. Reapply at intervals of 3 to 5 years to ensure adequate protection from decay.

7.4.4.4 Using Fumigants

Fumigants are specialized preservative chemicals that are placed in pre-bored holes to prevent or arrest internal decay. Over a period of time, the fumigants volatilize into toxic gases that move through the wood, eliminating decay fungi and insects.

Suggested Procedure

Fumigant Application

1. Identify the timber members that require fumigant treatment
2. Bore holes in the timber as specified by the fumigant manufacture, typically 2 to 4 feet apart for bridge deck and slab members. Avoid splits, knots and fasteners.
3. Inject liquid fumigant (Vapam, Vorlex or chloropicrin) or solid fumigant capsules into the bored holes. Solid fumigants provide increased safety, reduce the risk of environmental contamination, and permit fumigant use in previously restricted applications.
4. Seal the bored holes with treated wood plugs.

7.4.4.5 Replacing Deck Planks

Maintenance crews can easily replace a timber plank deck and this may be the most cost effective alternative when the deck has deteriorated to the stage that repeated plank replacements would be necessary. Following is a procedure for replacing plank decks:

Suggested Procedure

Replacing Deck Planks

1. Remove and store deck-mounted curbs, parapets, wheel guards and railings.
2. Remove existing deteriorated planks that can be repaired or replaced in the same day.
3. Clean and apply preservative to the top flanges of stringers as described above.
4. Place new planks. Planks should be laid with the heart side down because it is more resistant to decay. ¼-inch spacing should be provided between planks for drainage, expansion, and air circulation. Structural grade hardwood planks, 6 to 10 inches wide, are preferred as decking material because wider planks have a tendency to curl. Planks of the same thickness should be placed adjacent to each other with a full, even bearing on the stringers. Wedges should not be used to level flooring be-cause they are easily dislodged and leave the flooring in a loose and uneven condition.
5. Planks are attached to supporting beams with 1/4 to 1/2 inch diameter galvanized steel spikes or stainless steel screws (recommended), approximately twice as long as the deck planks are thick. If spikes are used, resistance to withdrawal is improved if spikes are driven at a slight angle rather than perpendicular to the beam. Where space allows, two screws/spikes are typically placed in each plank at each beam.
6. Apply wood preservative to the ends of any plank that is field cut.
7. Apply a membrane and wearing surface. (Optional)
8. Replace deck-mounted appurtenances.
9. If this requires drilling into the planks, then treat the holes with fumigants or preservatives before installing the hardware.

7.4.4.6 Installation of a Waterproofing Membrane and Asphalt Overlay

The following procedure can be used to effectively apply a water proofing membrane to a timber deck for an asphalt overlay. Overlays of concrete or polymers will follow a similar step with the exception of the tack coat material.

Suggested Procedure

Applying a Waterproofing Membrane to a Timber Deck

1. Repair any split, broken or decayed timber deck members.
2. Clean the deck surface completely with compressed air and vacuums.
3. Apply a layer of hot mix asphalt concrete over the deck 1 ½ to 2 inches thick (treated wood) or liquid asphalt sprayed directly onto a bridge deck (untreated wood). A timber bridge deck treated with creosote, penta, or copper naphthenate carried in a heavy oil solvent already has an oily surface. The asphalt emulsion will not penetrate the timbers well. A diluted application rate of 0.05 to 0.10 gallons of asphalt per square yard is more appropriate for a treated timber bridge deck.
4. Roll membrane starting at the lowest points and working toward the highest points so that water would drop off the higher layer without getting under the membrane like the shingles on a roof. A paving membrane is a fabric with polymer-modified (or rubberized) asphalt on one or both sides. This asphalt melts when hot asphalt is applied over it. The melted paving membrane provides a waterproof layer between the pavement overlay and the underlying structure.
5. Roll the deck with pneumatic roller to insure good contact and adhesion to the pavement surface. Bubbles and wrinkles should be slit and smoothed.
6. Trowel a bead of rubberized mastic or other suitable sealing compound along the edge of the membrane at the curb.
7. Apply a standard pre-paving tack coat usually asphalt emulsion diluted one to one with water, applied to ensure a bond between the surface being paved and the overlying asphalt pavement course.
8. Place the hot asphalt concrete wearing surface according to the project specifications. When the hot asphalt is placed on an asphalt-impregnated paving membrane the membrane immediately melts, forming a pool of liquid asphalt between the deck and the asphalt pavement.

7.5 Fiber Composite Decks

7.5.1 Introduction

Fiber Reinforced Polymer (FRP) is a newer bridge material that is becoming more popular for use in bridge decks and slabs. FRP is growing in use because this material offers several advantages over more traditional bridge deck materials:

- FRP is very light
- FRP is very strong
- FRP will not corrode

FRP deck sections are particularly well suited for moveable bridges and for decks and slabs subject to highly corrosive environments.

Modern FRP composite decks are typically made of pultruded sections (e.g., honeycomb shaped, trapezoidal, or double-web I-beams). Examples of open honeycomb FRP composite decks are shown in Figure 7.51. Slabs are often made using a vacuum assisted process.

Figure 7.51 Open Honeycomb (Left and Right)

Solid core sandwich decks contain foam or other fillers at the core. This type of deck is manufactured by using a process called Vacuum-Assisted Resin-Transfer Molding (VARTM); Examples are shown in Figure 7.52.

Figure 7.52 Solid Core Sandwich (Left - Single Grid, Right - Double Grid)

Hollow core sandwich decks consist of deck sections that contain pultruded shapes that are fabricated together (see Figure 7.53).

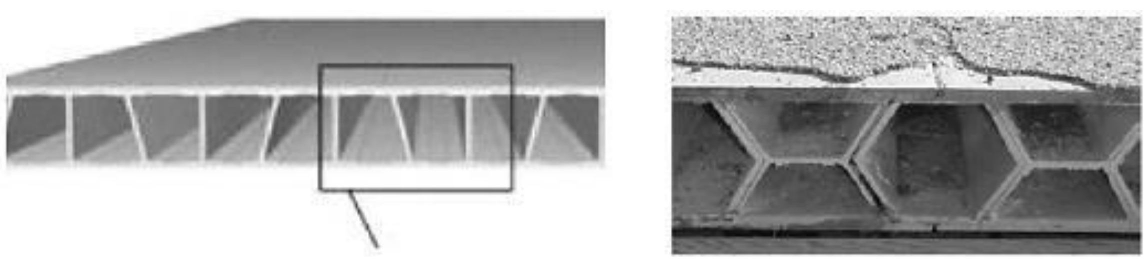

Figure 7.53 Hollow Core (Left - Rectangular Grid, Right - Hexagonal Section)

7.5.2 Deck Protection

FRP deck and slab sections are almost always covered with a wearing surface material to provide enhanced friction and fire protection of the FRP. FRP can lose strength when exposed to high heat that could result from vehicle accident and resulting fire. Wearing surfaces can be asphalt, concrete based products or polymer overlays. Concrete and polymer wearing surfaces also provide protection from chemical attack of the FRP in deicing environments. Wearing surfaces on FRP decks can be repaired using the common methods used with other deck and slab materials. Care should be taken during the wearing surface repair to avoid saw cutting or chipping into the FRP deck surface.

Call the engineer if any of the following situations are observed in the field:

- Delaminations between fiber layers of the section
- Blistering on the surface or debonding of the material
- Cracking or fiber exposure
- Voids, wrinkling or discoloration

7.5.3 Repairs

FRP deck and slab sections can be constructed of a variety of fiber material and resins. The most common systems are Carbon, Glass, and Aramid FRP. Common resins used in FRP decks and slabs include epoxies, polyesters and vinyl esters. Because of the variety of resins and fibers used in the fabrication of FRP sections, repair of FRP sections is not advised for bridge maintenance crews unless they have had special training in the repair of FRP and are capable of wet lay-up repairs. Wet lay-up repairs for decks and slabs have been shown to restore load capacity to the section; however the durability of wet lay-up repairs is not well documented.

Emergency repairs of localized deterioration of an FRP deck or slab sections can be accomplished with the use of steel plating to cover a small deck delamination or similar deterioration until the engineer can assess the situation.

7.6 Chapter 7 Reference List

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