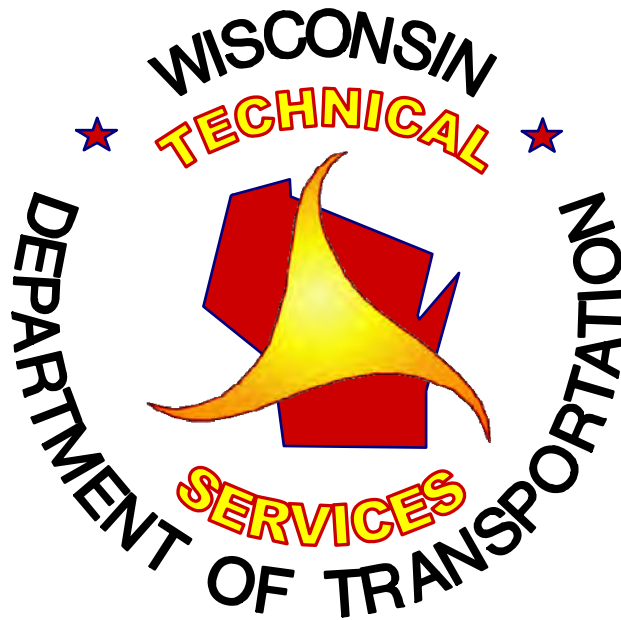


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An Evaluation of Concrete Bridge Deck Overlays and HMA Bridge Deck Overlays with Waterproof Membranes

FINAL REPORT



March 2012

An Evaluation of Concrete Bridge Deck Overlays and
HMA Bridge Deck Overlays with Waterproof Membranes
Research Study # WI-94-01

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16. Abstract <p>When a bridge deck is in need of rehabilitation, a concrete overlay, an HMA overlay, or an HMA overlay with an underlying waterproof membrane are all rehabilitation options. The purpose of the latter system is to prevent water and other deleterious materials from seeping through cracks in the concrete bridge deck.</p> <p>In 1994, the Wisconsin DOT began an evaluation of bridge decks overlaid with concrete and with HMA over a waterproof membrane. Both types of overlays demonstrated good performance and remained in service for up to 20 years. Proper installation of the waterproof membrane and HMA overlay was critical to long-term performance.</p> <p>In the time since this research study was initiated, Wisconsin guidelines have evolved, and use of HMA overlays with waterproof membranes is no longer specified for bridge deck rehabilitation on the Wisconsin State Trunk Network. Concrete bridge deck overlays are typically constructed. Polymer modified asphaltic overlays and micro-silica overlays are also constructed as experimental alternatives to concrete overlays. Standard special provisions for construction of HMA overlays with waterproof membranes exist if this rehabilitation option is reinstated in the future.</p>					
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Commonly Used Abbreviations

Initializations

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
BAD	Base aggregate dense
CABC	Crushed aggregate base course
CRCP	Continuously reinforced concrete pavement
CTH	County trunk highway
DOT	Department of Transportation
EBS	Excavation below subgrade
FDM	Facilities Development Manual
FWD	Falling weight deflectometer
HMA	Hot mix asphalt
IRI	International roughness index
JPCP	Jointed plain concrete pavement
JRCP	Jointed reinforced concrete pavement
M-E	Mechanistic-empirical
MEPDG	Mechanistic-empirical pavement design guide
NB	Northbound
PCC	Portland cement concrete
PCI	Pavement condition index
PDI	Pavement distress index
PDR	Pavement design report
SB	Southbound
SMA	Stone matrix asphalt
SN	Structural number
STH	State trunk highway
STN	State trunk network
TSR	Transportation Synthesis Report
USH	United States highway
WisDOT	Wisconsin Department of Transportation

Units

ksi	kips per square inch
in	inch/inches
psi	pounds per square inch
m/km	meters per kilometer
ft	foot/feet
ft ²	square feet
CY	cubic yards

1. Introduction and Background

1.1 History and Objectives of Research Study

When a bridge deck is in need of rehabilitation, an overlay is often constructed to provide additional years of service. The overlay can be constructed with hot mix asphalt (HMA) or Portland cement concrete.

In 1994, the Wisconsin Department of Transportation (WisDOT) began an evaluation of HMA bridge deck overlays that had been constructed with underlying waterproof membrane systems. This type of overlay system has been an option for bridge deck rehabilitation since the 1970s. The intent of the waterproof layer is to protect the bridge deck from penetration of water and deleterious materials. The membrane system consists of rubberized sheeting placed on the original concrete bridge deck, followed by the HMA overlay.

HMA overlays with waterproof membrane systems typically had good performance in Wisconsin. However, some construction and serviceability issues were noted in the early 1990s, which motivated the 1994 evaluation. This evaluation compared the cost and performance of HMA overlays with waterproof membranes to concrete bridge deck overlays. An interim report on this subject was prepared by WisDOT in 1995 but never published. According to this report, the original objective of the research study was to "determine when and where a membrane with an asphaltic overlay is a viable and cost effective technique for bridge deck rehabilitation." [1]

The intent of this report is to finalize the original 1994 evaluation of HMA bridge deck overlays with waterproof membranes and concrete bridge deck overlays. The results of the 1994 field investigations and cost analyses are summarized. Current WisDOT practices are outlined and compared to the practices investigated in the original research study.

1.2 Bridge Deck Rehabilitation

The main cause of bridge deck deterioration is penetration of deicing salts, particularly chlorides. Steel reinforcing bars corrode when contacted by these salts as they penetrate through the concrete deck. Expansion of the corroded steel causes the concrete deck to crack and delaminate. Traffic wear disturbs the broken concrete and can leave potholes on the deck surface. If chlorides penetrate through the bridge deck, other parts of the structure could be damaged as well. [2]

Bridge deck rehabilitation methods reviewed in this evaluation included concrete overlays and HMA overlays with waterproof membranes. These methods are briefly outlined in the following sections.

1.3 HMA Overlay with Waterproof Membrane

This rehabilitation technique involves preparing the deck surface, installing the waterproof membrane, and overlaying with HMA. Deck surface preparation includes concrete repair of potholes and other

deteriorated areas, followed by shot blasting to clean the surface. Using a roller, sprayer or brush, a liquid asphalt primer is then applied to the deck and all other surfaces that will be waterproofed. The primer must cure to a tack-free condition (typically 20 to 45 minutes) and be covered with the membrane during the same working day. The waterproof membrane is a thin (0.06 to 0.11 inch thick) sheet of rubberized asphalt that is delivered in large rolls and is installed by hand rolling or with a mechanical applicator. The membrane should be applied from the lowest deck elevation to the highest, and overlapped at ends and edges, to provide a shingled effect. The membrane is then rolled with a rubber-tired roller. No bubbles or wrinkles should be present. The HMA overlay should be paved within five days. The HMA temperature should be between 300°F and 350°F during paving, and should not fall below 280°F before roller compaction. [3, 4]

1.4 Concrete Overlay

This rehabilitation technique involves preparing the deck surface and overlaying with concrete. The entire bridge deck surface is cleaned by scarification, and the deck surface is removed to a depth of at least one inch. Asphaltic patches, unsound concrete, and all loose materials are removed. Immediately prior to placing the concrete overlay, the bridge deck surface is coated with cement bonding grout. Concrete overlays are constructed with WisDOT Grade E concrete, which is specified for overlays and repairs on decks of structures and approaches. The concrete must be mixed on site and have a slump between one and two inches. Concrete for the overlay should not be placed when its temperature exceeds 90°F, or if the air temperature is above 88°F. The overlay is cured with fogging for at least three days. [5, 6]

2. Bridge Deck Evaluations

In the 1994 bridge deck overlay evaluation, several structures were noted that incorporated HMA overlays with waterproof membranes. Some locations had comparison decks with concrete overlays. [1] The locations and details for these structures are provided in Table 1.

These bridge decks were not specifically tracked as research test sections. However, limited performance information was available for these locations in the Department's Highway Structures Information System. This information, along with construction histories, is summarized in the following sections.

A cost evaluation was conducted for the overlays in Rock County and on the Marquette Interchange. Notes from these evaluations are summarized in Sections 2.2 and 2.6, respectively.

Table 1. Structures Utilizing HMA Overlays with Waterproof Membranes

Structure ID	County	Feature On	Feature Under	Concrete Overlay Comparison?
Various	Milwaukee	I-94	Various	Yes
B-53-111, B-53-112, B-53-113, B-53-120	Rock	I-43	CTH J & CNW Railroad	Yes*
B-13-221, B-13-222, B-13-219, B-13-239	Dane	USH 12/14 (Madison Beltline)	Mineral Point Rd & Gammon Rd	No
Various	Milwaukee	I-794 (Lake Freeway, Hoan Bridge)	Various	No
B-11-22, B-11-23	Columbia	I-90/94	Wisconsin River	No
Various	Milwaukee	Marquette Interchange	Various	No
B-13-433, B-13-434	Dane	STH 69	Sugar River	No

* Structures B-53-112 and B-53-120 had concrete overlays

2.1 I-94, Milwaukee County

A series of bridge deck overlays constructed on I-94 between 1974 and 1976 were evaluated after twenty years in service. Thirty-four bridge deck overlays were monitored; 22 were HMA overlays with waterproof membranes, and 12 were low-slump concrete overlays.

At the 20-year evaluation, all of the overlays had extensive cracking on the surface. Most cracks in the HMA overlays had been sealed, while cracks in the concrete overlays were typically not sealed. The underside of the bridge decks were visually inspected for signs of deterioration due to water penetration. Results of the underside inspections are shown in Figure 1. The subjective rating descriptions were as follows:

- Good condition - No distress, no staining
- Fair condition - Small, scattered areas of staining
- Poor condition - Large areas of heavy staining

A large proportion of the decks with concrete overlays had heavy staining on the underside, indicating water penetration through the deck. The undersides of most decks with HMA overlays and waterproof membranes were in "good" or "fair" condition (77 percent). Only 33 percent of the decks with concrete overlays were in good or fair condition on the underside. This indicates that the HMA overlay with waterproof membrane was more effective at preventing water penetration than the unsealed concrete overlay.

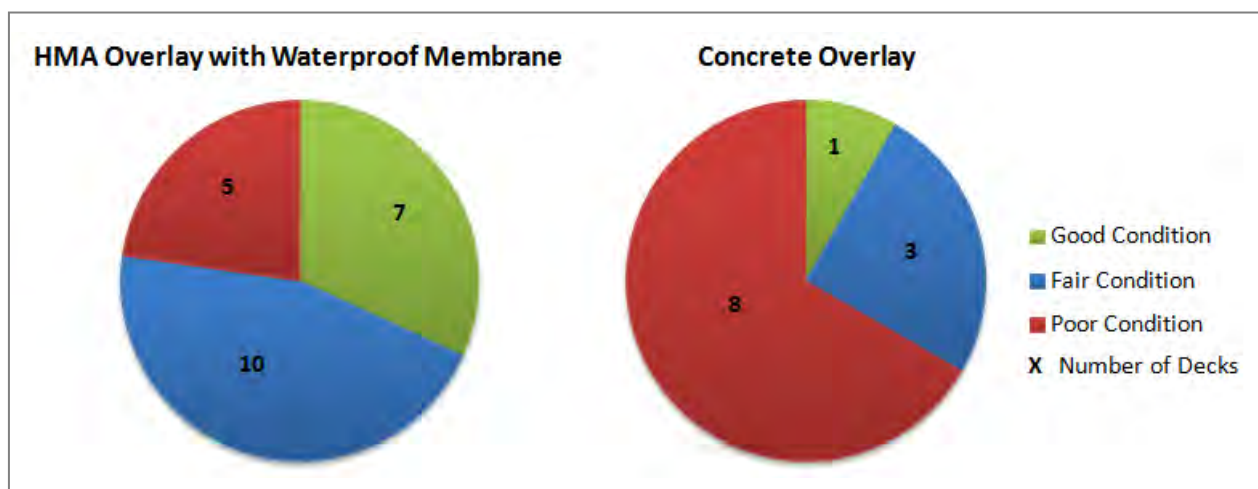


Figure 1. Twenty-year condition rating - underside of bridge decks, I-94, Milwaukee County.

2.2 I-43, Rock County

In 1994, four bridge decks on I-43 were overlaid. These structures, originally constructed in 1975, span the CNW railroad and CTH J in Rock County. The two northbound bridge decks were overlaid with HMA and a waterproof membrane. The two southbound decks were overlaid with low-slump concrete.

After several months in service, the HMA overlays developed alligator cracking. It was hypothesized that this failure was due to incorrect installation of the waterproof membrane, including installing the membrane over a rough (milled) surface and not adequately adhering the membrane to the deck surface. The failed portions of HMA were removed and replaced. [7]

To gain further insight on the performance of these deck overlays, structure inspection reports were reviewed from 2010 and 2011 (most recent available). [8] Details from the inspection reports are provided in the Appendix. Maintenance and performance histories were recorded in the inspection reports as follows:

- The HMA overlay/membrane systems received new HMA wearing surfaces in 2004 (CTH J) and 2009 (CNW railroad).
- The concrete overlay on the CNW railroad overpass had concrete surface repair in 2009. No work was documented for the concrete overlay over CTH J.
- The underside of all bridge decks had light longitudinal cracking.
- Light leaching was noted on the underside of three of the four bridge decks (two with concrete overlays and one with an HMA overlay/membrane).

In summary, the HMA overlays with waterproof membranes required rehabilitation after 10 to 15 years in service. These membrane systems might not have been installed correctly. One concrete overlay

required maintenance after 15 years in service, and no work was documented on the second concrete overlay after 16 years in service. One bridge deck with a waterproof membrane did not exhibit leaching.

A cost analysis was conducted at the time of overlay construction (1994). The awarded bid prices were compared for installation of the two types of overlays. The HMA overlay with waterproof membrane systems cost 19 to 35 percent less than the concrete overlays. [1]

2.3 USH 12/14, Dane County (Madison Beltway)

Four structures on USH 12/14 over Gammon Road and Mineral Point Road were overlaid with HMA and waterproof membranes in 1994 and 1995, respectively. The overlays were intended to provide a short-term performance boost until the bridge decks were replaced during bridge widening projects. The structure widening took place in 2000.

Structure inspection reports from July 1999 (prior to structure widening) were reviewed. [8] Details from these reports are provided in the Appendix. Cracks were noted on three of the HMA overlay surfaces; these cracks had been sealed with hot rubber. No cracks were present on the underside of these decks. The surface of the fourth deck had no record of cracking. However, the underside of this deck had a few diagonal leaching cracks.

2.4 I-794, Milwaukee County (Lake Freeway, Hoan Bridge)

In 1996, bridge decks on the majority of the Hoan Bridge and Lake Freeway spans in Downtown Milwaukee were rehabilitated with HMA overlays and waterproof membranes. Waterproofing layers were specified because the original decks were constructed with black steel, which had corroded and contributed to delamination of the concrete. [1]

According to the WisDOT Bureau of Structures bridge inventory, the HMA overlays were removed on approximately one third of the spans in 2003. These overlays had been in service for seven years. New HMA overlays were then placed on the majority of these spans; one concrete overlay and one epoxy overlay were also constructed. [8] It is unknown whether the waterproof membranes were replaced along with the HMA overlays in 2003.

No further rehabilitation was reported for the remainder of the HMA overlay and waterproof membrane systems constructed in 1996. [8] These overlays have been in place for 16 years.

2.5 I-90/94, Columbia County

In 1993, bridge decks on the I-90/94 structures over the Wisconsin River in Columbia County were rehabilitated with HMA overlays and waterproof membrane systems to address premature cracking and leaching. [1]

WisDOT as-built plans show that the membrane systems were removed in 1998 and replaced with Roysphalt-50 asphaltic overlays with adhesive tack coats. Structure inspection reports from June 1997

(prior to the 1998 overlay) were reviewed. [8] Details from these reports are provided in the Appendix. The underside of both bridge decks showed "numerous transverse cracks with efflorescence." There were no comments regarding the condition of the overlay surface. It is unknown why the HMA overlay and waterproof membrane systems were replaced after only five years in service.

2.6 Marquette Interchange structures, Milwaukee County

From 1991 to 1994, a series of structures were rehabilitated with HMA overlays and waterproof membranes. The overlays were anticipated to provide approximately ten years of service until scheduled replacements took place. [1] The actual structures that received this rehabilitation were not documented, so specific performance information was not available. The Marquette Interchange was reconstructed between 2004 and 2008, at which point these structures were removed and replaced. The waterproof overlay systems therefore provided 10 to 17 years of service.

A cost evaluation was conducted in 1994 to compare the costs of low-slump concrete overlays and HMA overlays with waterproof membrane systems. The concrete overlay cost was calculated based on statewide averages for 1992. The comparison cost used for a waterproof membrane system was from the actual unit price of a 1992 Marquette Interchange overlay. This comparison showed that the waterproof overlay system cost 16 percent less than a concrete overlay. [1]

2.7 STH 69, Dane County

In 1993, HMA overlays and waterproof membranes were constructed on the bridge decks of the STH 69 structures over the Sugar River in Paoli. The overlays were constructed as a short-term rehabilitation measure to keep the structures in service until replacement could be programmed. As of 1995, the overlays were performing well. [1] The structures were replaced in 1998. [8]

3. Current Department Practices (2012)

The typical service life of a bridge deck is 40 years for a low-volume highway with normal environmental conditions. The bridge deck service life is reduced to 15 to 20 years for most interstate and freeway bridges, due to higher traffic volumes and/or harsher environmental conditions. [2]

The WisDOT Bridge Manual lists five options for deck rehabilitation: [9]

1. Asphalt patching
2. Concrete patching
3. HMA overlay
4. Polymer modified asphaltic overlay
5. Concrete overlay

Rehabilitation options 1 through 3 can extend the service life of the bridge deck by 3 to 7 years. These methods are appropriate if the bridge is a candidate for replacement within the next 7 years. A polymer

modified asphaltic overlay or a concrete overlay can provide 15 to 20 years of additional service life. These options are considered when the bridge deck is structurally sound and is not scheduled for replacement. If the deck remains structurally sound, the overlays could be removed and replaced for an additional service life extension. [10]

Concrete overlays are considered when there is little risk for leaching at bridge deck cracks. The total distressed area on the bridge deck should be less than 25 percent. If delamination is present, concrete might be the only alternative for overlay. It is also critical to keep concrete cracks sealed to prevent salt penetration; periodic crack sealing will likely be necessary. The minimum thickness for concrete overlays is 1.5 inches. [10]

Polymer modified asphaltic overlays are classified as an "experimental alternative" to the concrete overlay option described above. A micro-silica concrete overlay is another experimental alternative; this material has low permeability and thus provides resistance to chloride penetration. [10]

The HMA overlay with waterproof membrane alternative was recently removed as a rehabilitation option for bridge decks on the Wisconsin State Trunk Network. This alternative is still mentioned in the WisDOT Bridge Manual, but it is designated as an overlay option that is "currently not used." [10] The waterproof membrane system is occasionally used as a maintenance procedure on local bridges. [11] Current WisDOT standard special provisions exist to specify construction practices if this overlay option is selected. [3, 12]

4. Conclusions and Recommendation

The HMA overlays with waterproof membrane systems monitored in this study provided five to twenty years of service before rehabilitation or removal. Some of these overlays were only intended to provide a temporary boost in serviceability before bridge deck replacement, while others were constructed as longer-term rehabilitation solutions. Therefore, there was a wide range of observed service life for this type of overlay. Concrete overlays were monitored at two test locations; these overlays were in service for 15 to 20 years before additional rehabilitation was necessary.

When properly installed, HMA overlays with waterproof membranes demonstrated good resistance to water penetration. The following construction and installation procedures have led to satisfactory performance with the waterproof systems: [1, 3, 12, 13, 14]

- The concrete bridge deck surface must be smooth, dry and clean prior to priming and installation of the waterproof membrane.
- To prevent air and moisture infiltration, the waterproof membrane system must be adequately bonded to the bridge deck. Bonding is achieved by maintaining an appropriate HMA mixture temperature as it is being placed (300-350°F) and compacted (280°F minimum).
- Specifications and manufacturer guidelines must be followed closely.

Continued use of current guidelines and specifications is recommended for bridge deck rehabilitation in Wisconsin. These guidelines do not include use of HMA overlays with waterproof membrane systems. If this rehabilitation approach is reinstated in the future, it is recommended that care be taken during the membrane installation, as described above. Use of proper materials and construction practices are critical for long-term performance.

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Appendix - Bridge Deck Inspection Report Summaries

Table A-1. I-43, Rock County

Bridge Description	Structure ID	Construction History	Inspection	
			Date	Notes
I-43 NB over CNW RR	B-53-111	1975 - New structure 1994 - HMA overlay with waterproof membrane 2009 - New HMA wearing surface	3/18/2011	<u>Underside</u> : "Couple light longitudinal cracks but are dry. Underside looks good." <u>Deck</u> : No comments
I-43 SB over CNW RR	B-53-112	1975 - New structure 1994 - Concrete overlay 2009 - Concrete surface repair	3/4/2010	<u>Underside</u> : "Couple hairline longitudinal cracks at centerline with light leaching." <u>Deck</u> : No comments
I-43 NB over CTH J	B-53-113	1975 - New structure 1994 - HMA overlay with waterproof membrane 2004 - New HMA wearing surface	3/2/2011	<u>Underside</u> : "Couple light longitudinal leaching cracks in spans 1 & 3. Spall with exposed rebar at P1, col. 1." <u>Deck</u> : "Cracks sealed with hot rubber."
I-43 SB over CTH J	B-53-120	1975 - New structure 1994 - Concrete overlay	3/4/2010	<u>Underside</u> : "Couple hairline longitudinal and random cracks with lite leaching and rust stain. Span 1. HL transverse cracks also. North span has cracks & delam- 2ft x 20ft w/spalls." <u>Deck</u> : No comments

Table A-2. USH 12/14, Dane County (Madison Beltline)

Bridge Description	Structure ID	Construction History	Inspection	
			Date	Notes
USH 12/14 EB over Mineral Point Rd	B-13-221	1968 - New structure 1991 - HMA overlay* 1995 - HMA overlay with waterproof membrane 2000 - Widen structure	7/15/1999	<u>Underside</u> : "NW corner at W abutment small spalled area." <u>Deck</u> : "Random/mapping cracks in overlay, cracks are sealed with hot rubber."
USH 12/14 WB over Mineral Point Rd	B-13-222	1968 - New structure 1991 - HMA overlay* 1995 - HMA overlay with waterproof membrane 2000 - Widen structure	7/15/1999	<u>Underside</u> : No comments <u>Deck</u> : "Random cracking in asphalt overlay, cracks have been hot rubber sealed."
USH 12/14 EB over Gammon Rd	B-13-219	1968 - New structure 1994 - HMA overlay with waterproof membrane 2000 - Widen structure	7/15/1999	<u>Underside</u> : "Few diagonal leaching cracks at deck end." <u>Deck</u> : No comments
USH 12/14 WB over Gammon Rd	B-13-239	1968 - New structure 1994 - HMA overlay with waterproof membrane 2000 - Widen structure	7/15/1999	<u>Underside</u> : No comments <u>Deck</u> : "Couple transverse cracks, sealed with hot rubber."

*Waterproof membrane - unknown

Table A-3. I-90/94, Columbia County

Bridge Description	Structure ID	Construction History	Inspection	
			Date	Notes
I-90/94 EB over Wisconsin River	B-11-22	1961 - New structure 1975 - Repair superstructure 1981 - Strengthen superstructure 1984 - Widen structure 1993 - HMA overlay with waterproof membrane 1998 - Roysphalt-50 overlay with adhesive tack coat	6/17/1997	<u>Underside</u> : " Numerous transverse cracks with efflorescence." <u>Deck</u> : No comments
I-90/94 WB over Wisconsin River	B-11-23	1961 - New structure 1975&76 - Repair superstructure 1984 - Widen structure 1993 - HMA overlay with waterproof membrane 1998 - Roysphalt-50 overlay with adhesive tack coat	6/17/1997	<u>Underside</u> : "Numerous transverse cracks with efflorescence." <u>Deck</u> : No comments