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Evaluation of Concrete Inlay for Continuously Reinforced Concrete Pavement Rehabilitation

FINAL REPORT

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Research Study # FEP-96-01

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16. Abstract

In 1996, WisDOT constructed a concrete inlay test section on I-43 in Manitowoc County. The existing pavement was CRCP constructed in 1978 and was badly deteriorated with punch-outs. In the area of the 2777-foot test section, the existing pavement was removed, the foundation was replaced with a drained system, and an 11-inch JPCP concrete inlay was constructed. The remainder of the project, including a control section, received CRCP patching and an HMA overlay ranging in thickness from 3 to 6 inches.

The pavement was evaluated after 14 years in service. The concrete inlay was in excellent condition. Only isolated slab cracking was noted. The 6-inch HMA overlay control section had more distresses, most notably transverse cracking. The PDI values for the test and control sections were 7 and 43, respectively. A series of LCCAs using 1996 construction costs showed that the HMA overlay rehabilitation alternative was more cost-effective than concrete inlay.

Because it is not the most cost-effective large-scale pavement rehabilitation alternative, concrete inlay is not recommended for routine use on Wisconsin roadways.

17. Key Words Concrete inlay, continuously reinforced concrete pavement, CRCP, concrete pavement rehabilitation, HMA overlay		**18. Distribution Statement** Distribution unlimited, approved for public release	
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1. Introduction

When pavements become deteriorated beyond a level that is safe and acceptable to the traveling public, a rehabilitation effort is typically performed. Depending on the pavement type, the rehabilitation might be a joint repair and grind, a hot mix asphalt (HMA) overlay or an HMA mill and relay. A concrete inlay is another rehabilitation option for deteriorated pavements.

When a concrete inlay is performed, the existing pavement is removed and replaced with concrete pavement. The new pavement can be any of the common concrete pavement types: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP) or continuously reinforced concrete pavement (CRCP). A concrete inlay can be used to rehabilitate existing concrete or HMA pavements. Unlike an HMA overlay, a concrete inlay does not require an increase in the pavement elevation. [*1*]

Prior to this study, concrete inlay had not been used as an extensive rehabilitation method on Wisconsin roadways. Other states had used concrete inlay as a rehabilitation strategy and experienced mixed performance. It has been determined that a positive drainage system is essential for good concrete inlay performance. [*2*] European countries have also successfully used concrete inlay systems. [*1*]

The Illinois Department of Transportation tracked the performance of a concrete inlay constructed in 1986. The existing pavement was a badly faulted 10-inch JRCP constructed in 1964. The existing pavement was removed and inlayed with 10 inches of CRCP over 7 inches of cement-stabilized subbase. Existing shoulders and underdrains remained in place. After 6 years in service, the CRCP inlay was in good condition with little to no distress. [*3*]

The Illinois concrete inlay was monitored again after 20 years in service. At this time, the inlay exceeded the performance of 50 percent of same-age 10-inch CRCPs in Illinois. It exceeded the performance of 25 percent of 10-inch CRCPs with similar traffic conditions (29.1 million ESALs over 20 years). Therefore, the concrete inlay performed at an equal, or slightly lower, level compared to similar CRCPs in Illinois. The prominent distress noted in the concrete inlay section was longitudinal cracking. However, it was suspected that this distress was a result of tube feeding of longitudinal reinforcing steel during construction, and not due to the concrete inlay method itself. [*4*]

Because concrete inlays had not been used extensively in Wisconsin, a test section was an opportunity for the Wisconsin Department of Transportation (WisDOT) to evaluate this type of rehabilitation method. This report documents the construction, performance and cost considerations of a concrete inlay test section constructed during rehabilitation of an existing CRCP.

2. Study Description

2.1 Motivation

Punch-outs, a type of structural failure common with CRCP, occur when concrete fails between two closely-spaced transverse cracks. Under repeated traffic loadings, a wide, spalled longitudinal crack results. This type of distress is often caused by lack of foundation support or corrosion of reinforcing steel. Punch-outs were typically addressed on Wisconsin roadways by patching the distressed areas and, if the distresses were widespread, overlaying with hot mix asphalt (HMA). A number of these distresses were noted in a CRCP on Interstate 43, the major north-south highway in Eastern Wisconsin. As other states had successfully used concrete inlay to repair CRCP with punch-outs, this rehabilitation method was suggested for review on the I-43 project.

At the time of construction, the Pavement Distress Index (PDI) of the CRCP in the area of the planned test and control sections was 95 on a scale of 100, with 100 indicating severely deteriorated pavement. This high value was due primarily to the presence of punch-outs and wide cracks.[1]

2.2 Objectives

Prior to this research effort, concrete inlay for CRCP had not been used extensively on the Wisconsin State Trunk Network. The objective of this study was to assess the performance of a JPCP inlay and determine if it is a cost-effective rehabilitation method that can successfully be used to extend the service life of additional pavements.

2.3 Project Location

The JPCP inlay test section was constructed as part of a rehabilitation project on I-43 in Manitowoc and Brown Counties. The 2777-foot test and control sections were located in the northbound driving lane of a portion of I-43 in Manitowoc County. The test area is located near County Trunk Highway (CTH) V in the village of Francis Creek, as shown in Figures 1 and 2.

[1] A wide crack is defined as any transverse or diagonal crack over ¼-inch in width.

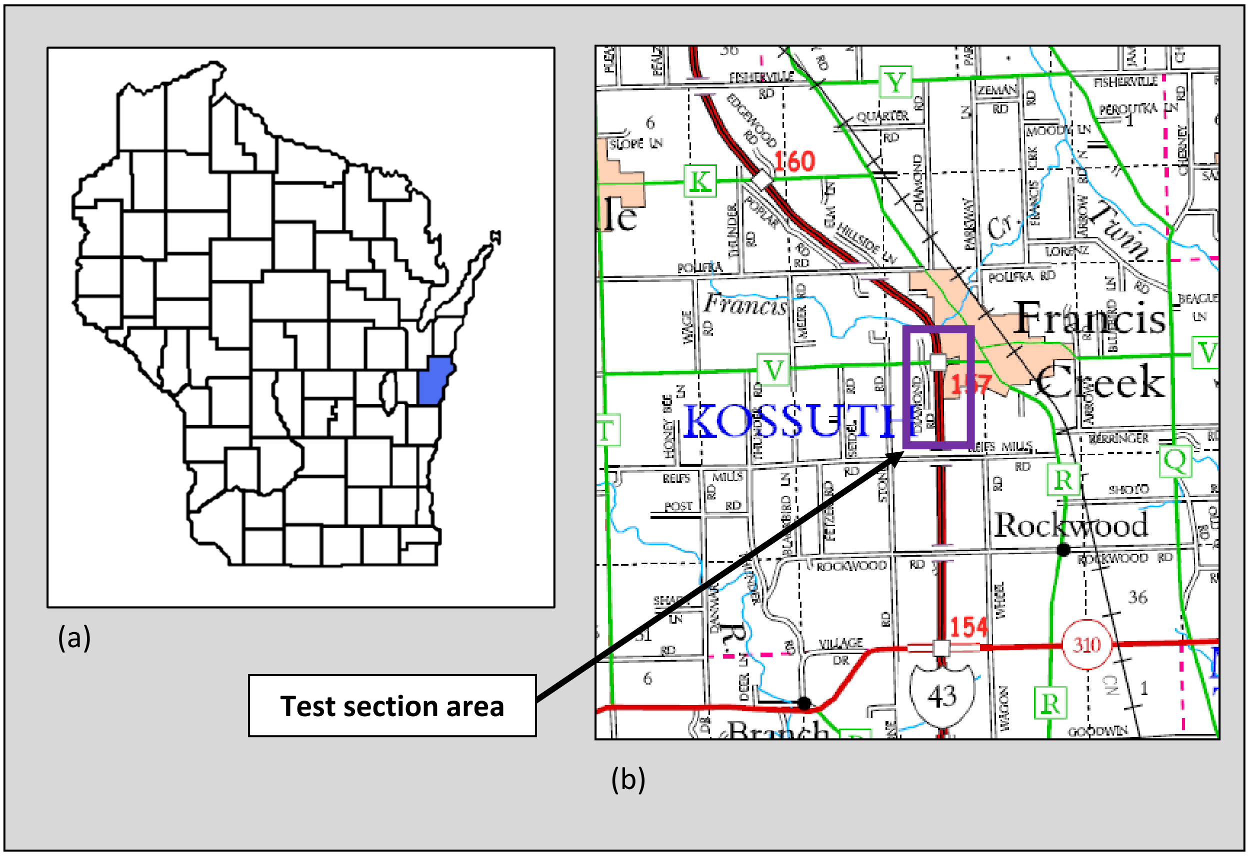

Figure 1. Location of test section: (a) Manitowoc County; (b) test section area.

2.4 Test Section Description

The test section for this study was designed for 2777 feet in the northbound driving lane on the I-43 rehabilitation project. The existing 8-inch CRCP was removed full-depth, along with a portion of the existing crushed aggregate base course (CABC). The CABC was replaced with 4 inches of open graded base course (OGBC) along with a geotextile fabric layer and a 6-inch pipe underdrain system to provide drainage. Eleven inches of new JPCP was paved and tied to the existing driving lane shoulder. The shoulder was overlaid with 3 inches of HMA (see Figure 3). Joints in the inlay test section were doweled, skewed, unsealed and spaced at approximately 20 feet.

The control section was constructed in the northbound driving lane, just north of the test section. The control section began at a point where the HMA overlay thickness transitioned from 3 to 6 inches; the control section HMA overlay thickness was 6 inches. In the control section, and for the remainder of the I-43 rehabilitation project, doweled concrete patches were used to repair distressed areas. The entire lane was then overlaid with HMA (6 inches in the control section and 3 to 6 inches elsewhere). The existing passing lane shoulder was also overlaid with HMA (see Figure 3).

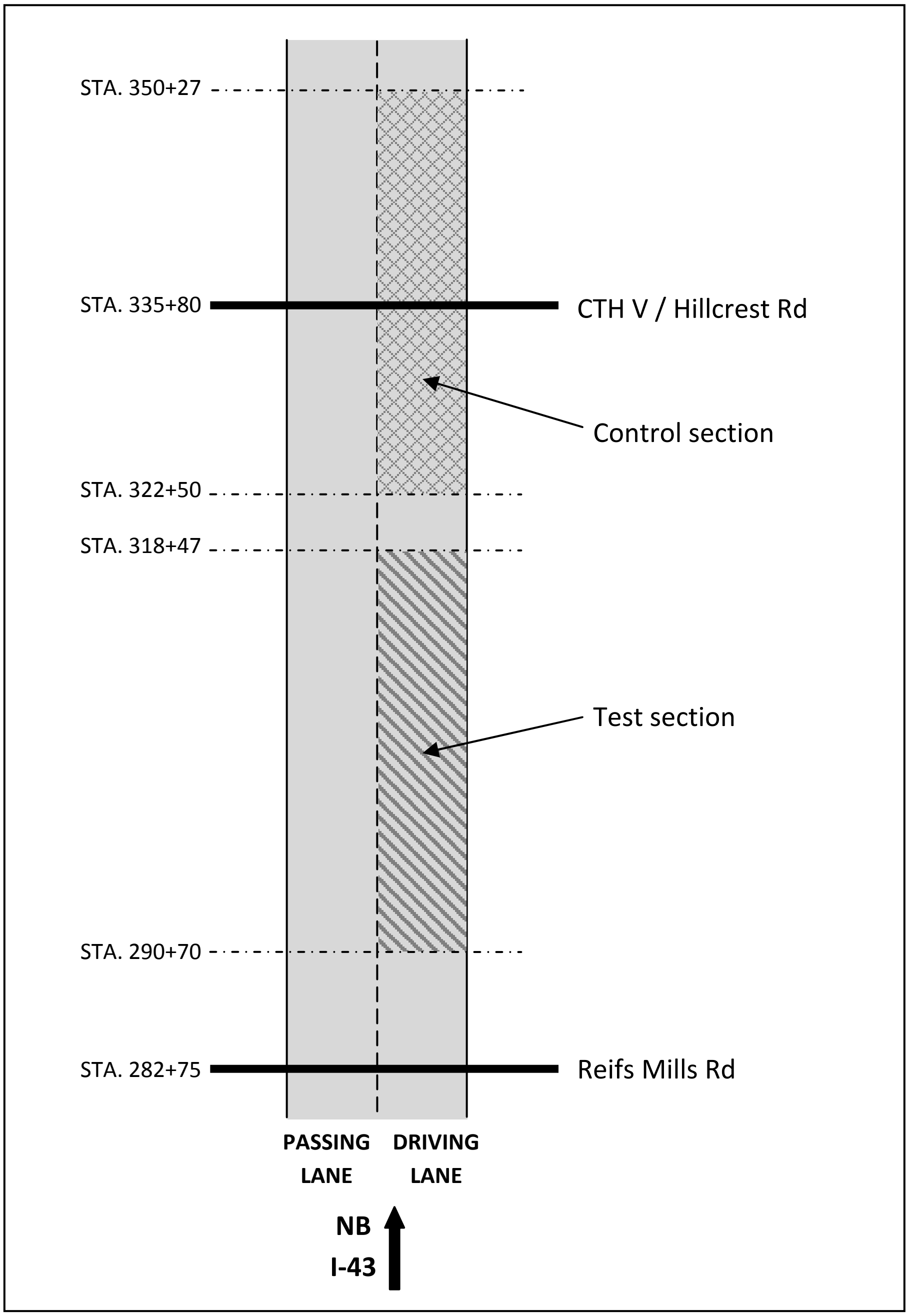

Figure 2. Test and control section stationing.

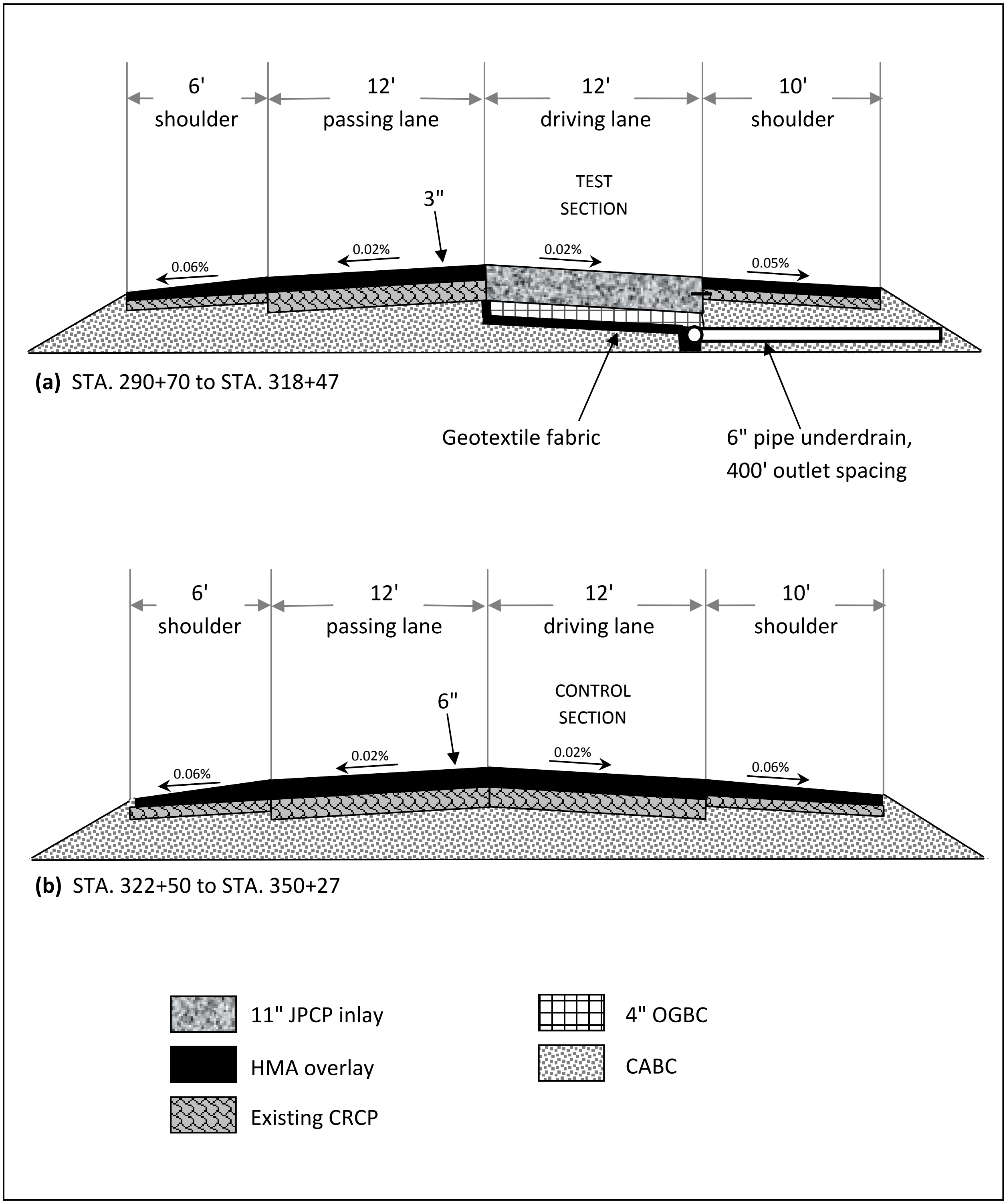

Figure 3. Pavement cross sections: (a) test section; and (b) control section.

3. Construction

The concrete inlay test section was completed as part of state project I.D. 1225-02-71 on I-43 in Manitowoc and Brown Counties. The overall project consisted of rehabilitation of 16 miles of 4-lane divided highway pavement between State Trunk Highway (STH) 310 in Manitowoc County (southern limit) and STH 96 in Brown County (northern limit). The existing 8-inch CRCP was constructed in 1978 and was therefore 18 years old at the time of rehabilitation.

Construction in the area of the test and control sections took place in July 1996. The prime contractor was B.R. Amon & Sons of Elkhorn, WI, and the CRCP patching and concrete inlay work was completed by Vinton Construction of Manitowoc, WI. The test section was constructed between stations 290+70 and 318+47, and the control section between stations 322+50 and 350+27 (Figure 2).

Work on the test section began with removal of the existing CRCP and some of the existing CABC. Full-depth sawcuts were required at the centerline and existing shoulder. The foundation was graded, and the 6-inch pipe underdrain was placed, with outlets spaced every 400 feet. The grade was covered with type SAS geotextile fabric, and 4 inches of OGBC were placed. The base was trimmed, and dowel baskets were set in preparation for paving.

Paving of the 11-inch concrete inlay took place on July 19, 1996. The weather was cloudy, and the high temperature was 69°F. Concrete was trucked from a batch plant in Manitowoc, which was about 20 minutes away from the job site. The work was performed with traffic in the adjacent lane, which also added time to the paving operation. Concrete trucks were backed down the existing shoulder and then transferred their loads to a belt placer. The concrete was then placed in front of the paver, which was guided with a string line. Twenty-one men worked for 8.5 hours to place the 3700 square yards of concrete.

The tining pattern recommended by WisDOT was random with spacing ranging from 0.375-inch to 1.75-inch and 50 percent of spacing less than 1 inch. A rake with this tining pattern was difficult for the contractor to obtain due to the short notice they had been given. The contractor did, however, obtain a random tining rake from a manufacturer in Oklahoma that closely resembled the recommended parameters. The concrete was cured, joints were cut, and the test section was opened to traffic.

Several problems were encountered during construction of the concrete inlay. Because the loaded concrete trucks used the existing concrete shoulder as a haul road, the shoulder became severely damaged. Extensive replacement of the shoulder was required before it could be overlaid with HMA. This issue had not been considered during the design process, and it resulted in an overrun of the pavement removal and shoulder bid items. Performing the work under traffic also posed slight problems, as trucks leaving and entering the highway caused congestion and backups for both the contractor and motorists. In addition, it was difficult for the contractor to maintain a string line alongside the live traffic lane. The contractor suggested that for future concrete inlay work, WisDOT construct median cross-overs and run both directions of traffic in the opposite lanes so that the inlay work could be bypassed until it was completed. A final problem encountered was that the necessary cure time for the concrete inlay caused timing problems for adjacent HMA paving.

The control section was paved after the test section. Distressed areas were patched with doweled concrete. Four patches were required in the control section, near stations 330+10, 334+95, 335+90, and 345+90.[2] For the overall construction project, the average area of one patch was 27 square yards. The existing CABC was left in place in the control section, and no underdrain system was installed. The patched CRCP was overlaid with 6 inches of HMA.

4. Test Section Performance

A visual inspection of the concrete inlay test site was conducted in May 2010, after the test and control sections had been in service for approximately 14 years. The concrete inlay was in excellent condition. One cracked slab and one corner crack were noted in the 2777-foot test section. Some minor chipping was also present at several transverse joints. Based on these distresses, the calculated PDI value was 7.

The control section displayed more deterioration. Transverse cracks were noted, most of which had been sealed. Several of the transverse cracks had deteriorated further and were patched with asphalt. In some areas, minor edge raveling was present at the longitudinal paving joints. In the lane adjacent to the concrete inlay, banded longitudinal cracking had also occurred, most commonly in the right wheel path and at the center of the lane. The 2008 (the most recent year for which data were available) PDI of the control section, as measured by the Department's automated survey equipment, was 43.

In this study's test section, the concrete inlay is very similar to a new JPCP paved over a drained base. The service life estimated in a WisDOT life cycle cost analysis (LCCA) for this type of pavement is 31 years. [*5*] Given the excellent performance and low PDI of this pavement after 14 years in service, it is anticipated that the test section will meet the expected service life.

The pavement on the remainder of the I-43 project, including the control section, is scheduled for rehabilitation in 2010. The proposed work includes a 2-inch mill followed by a 2-inch HMA overlay. (No work will be performed on the concrete inlay test section.) This is the first rehabilitation to be performed on the pavement since the 1996 rehabilitation (routine maintenance such as crack filling had been performed regularly). The service life estimated in a WisDOT LCCA for an HMA overlay of CRCP is 8 years. [*5*] Therefore, the control section pavement exceeded the expected service life of a CRCP pavement with an HMA overlay.

[2] No patches would have been required in the length of the test section.

5. Cost Considerations

To determine whether the concrete inlay rehabilitation method is cost-effective, a series of LCCAs were performed. The WisDOT pavement design software program WisPave was used for the LCCAs. In this type of analysis, expected service life and initial construction and rehabilitation costs were required inputs. The parameters used for the LCCA in this study are summarized in Table 1. Costs were based on actual costs from the construction of the test and control sections in this study, and on average bid costs from similar projects constructed in 1996. A summary of these costs is provided in the Appendix. The cost of each rehabilitation method was calculated for a 2777-foot single-lane pavement. A 50-year analysis period and a 5 percent discount rate were used as defined by WisDOT policy. [*5*]

The initial design life used in WisDOT LCCAs for concrete pavements over CABC is 25 years. [*5*] However, because rehabilitation for the pavement in this study occurred after the CRCP was in service for 18 years, two separate analyses were performed (LCCA 1 and 2 for initial service lives of 18 and 25 years, respectively). In addition, the design life defined for an HMA overlay of CRCP pavement is 8 years. [*5*] For this particular pavement, the first HMA overlay of the CRCP was in service for 14 years; therefore two different design alternatives were entered in each LCCA (HMA Overlay 1 and 2 for 14 and 8 years of service, respectively). The sequence of rehabilitation methods and service lives used in the LCCAs for each alternative is shown in Table 1.

The LCCA results are presented in Table 2. In all scenarios, the HMA overlay option was the most cost-effective option, with the lowest total facility cost over the 50-year design period. As expected, a lower total facility cost was achieved if the first HMA overlay was in service for 14 years compared to the 8-year expected service life (HMA Overlay 1 versus 2, Table 2). Increasing the initial CRCP service life from 18 to 25 years brought the total facility cost of the Concrete Inlay alternative slightly closer to that of the HMA Overlay 1 alternative, but it was still a more costly rehabilitation option overall (LCCA 1 versus 2, Table 2). The unanticipated expense of shoulder repairs required in the test section was not included in the LCCA; this would have further increased the cost of the Concrete Inlay alternative.

Another point to consider in the cost evaluation is that for this study's test section, the foundation was upgraded to a drained system at the time of the concrete inlay. Concrete inlay could be performed by replacing the pavement only, and not changing the existing foundation. Installation of the drained pavement system cost approximately $21,000. If these costs were not required, the initial cost of the 2777-foot concrete inlay would have been reduced to approximately $167,000. The LCCAs were performed again using this lower concrete inlay cost. The total facility costs were reduced by about four percent, but the HMA Overlay alternative was still the most cost-effective rehabilitation method.

Table 1. LCCA Service Life and Cost Inputs

Construction or Rehabilitation Alternative	Service Life		Cost
	LCCA #1	LCCA #2	
Concrete Inlay			
CRCP construction	18	25	$200,000
Concrete inlay	31	31	$187,819
Concrete joint repair and grind	8	N/A	$21,325
HMA Overlay 1			
CRCP construction	18	25	$200,000
CRCP patching and HMA overlay	14	14	$28,929
HMA mill and overlay	8	8	$17,328
Reconstruct with JPCP	25	25	$148,164
HMA Overlay 2			
CRCP construction	18	25	$200,000
CRCP patching and HMA overlay	8	8	$28,929
HMA mill and overlay	8	8	$17,328
Reconstruct with JPCP	25	25	$148,164

Table 2. LCCA Results

	Concrete Inlay	HMA Overlay 1	HMA Overlay 2
LCCA #1			
Initial CRCP Construction Cost	$200,000	$200,000	$200,000
Rehabilitation Costs	$79,995	$36,703	$45,098
Rehabilitation Salvage Value	-$1,627	-$7,752	-$4,651
Total Facility Costs	$278,368	$228,951	$240,446
	+21.58%	**Lowest**	**+5.02%**
LCCA #2			
Initial CRCP Construction Cost	$200,000	$200,000	$200,000
Rehabilitation Costs	$55,463	$26,084	$32,050
Rehabilitation Salvage Value	-$3,170	-$11,370	-$8,269
Total Facility Costs	$252,293	$214,714	$223,781
	+17.50%	**Lowest**	**+4.22%**

6. Summary and Conclusions

In 1996, a 2777-foot concrete inlay test section was constructed as part of a CRCP rehabilitation project on I-43 in Manitowoc County. The foundation for the concrete inlay test section was replaced with a drained system consisting of OGBC and a pipe underdrain network. An 11-inch JPCP concrete inlay was then constructed. The remainder of the project, including a 2777-foot control section, received CRCP patching and an HMA overlay ranging in thickness from 3 to 6 inches.

Problems during construction were noted due to live traffic in the adjacent passing lane while the concrete inlay was completed in the driving lane. Total work time was increased, and maintaining the paver's string line was difficult under these conditions. In addition, loaded concrete trucks caused unanticipated damage to the existing shoulders, which escalated shoulder repair costs.

The test and control sections were evaluated in 2010 after 14 years in service. The concrete inlay was in excellent condition, with isolated distresses such as corner cracking. The control section exhibited greater deterioration; transverse cracking was the primary distress. The PDI values for the test and control sections were 7 and 43, respectively.

A series of LCCAs performed using costs based on 1996 construction showed that the HMA overlay rehabilitation option was more cost-effective than concrete inlay. The LCCAs did not include shoulder repair costs in the concrete inlay section, which would have further widened the difference in cost. If the costs of installing the drained foundation system were subtracted from the initial cost of the concrete inlay, the total facility costs were still lower for the HMA overlay alternative.

7. Recommendations

Although the concrete inlay test section had excellent performance during the 14-year evaluation period, this type of pavement rehabilitation is not recommended for routine use in Wisconsin. For restoration of a safe riding surface on a deteriorated CRCP, an HMA overlay is a more cost-effective alternative. Concrete inlay could be feasible for small-scale rehabilitation efforts that are scheduled prior to a full HMA overlay project. For instance, full-depth concrete repair is commonly used on Wisconsin roadways to repair joints or isolated distresses. A large-scale concrete inlay could also be practical for severely deteriorated CRCP, where an HMA overlay would likely fail quickly. However, the prevalent practice of HMA overlay is recommended for most large-scale pavement rehabilitation projects.

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Appendix - Bid Costs for LCCA

Table A-1. Bid Item Unit Costs Used in LCCA, 1996 Dollars

Item	Units	Price
Asphaltic concrete pavement, type HV	TON	$16.09
Asphaltic material for plant mixes	TON	$125.00
Asphaltic material for tack coat	GAL	$0.85
Concrete joint repair	LF	$8.49
Concrete pavement, 10-inch	SY	$19.85
Concrete pavement, 11-inch	SY	$26.78
Concrete pavement, 8-inch	SY	$29.20
Continuous concrete pavement reinforcement	SY	$14.00
Continuous diamond grinding	SY	$5.06
Crushed aggregate base course	TON	$6.80
Dowel bars	EA	$8.91
Geotextile fabric, type SAS	SY	$1.30
Open graded base course, number 1	TON	$7.90
Pavement ties	EA	$5.00
Pipe underdrain, 6-inch	LF	$1.10
Pipe underdrain, unperforated, 6-inch	LF	$8.00
Preparation of foundation for asphaltic paving	Lump sum	$10,000.00
Preparation of foundation for concrete pavement	Lump sum	$800.00
Preparation of foundation for open graded base course	Station	$80.00
Reinforced concrete apron endwalls for 6-inch underdrain	EA	$150.00
Removing asphaltic surface, milling	SY	$2.18
Removing pavement	SY	$9.98
Sawing concrete pavement, full depth	LF	$1.95
Sawing existing pavement	LF	$0.75
Unclassified excavation	CY	$4.50

Abbreviations:

CY	Cubic yard
EA	Each
GAL	Gallon
LF	Linear foot
SY	Square yard
TON	Ton