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Partial Depth Repair of Concrete Pavements in Wisconsin

FINAL REPORT

September 2012

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Research Study # 98-03

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16. Abstract

Partial depth repair (PDR) is a concrete pavement rehabilitation method used to address surface spalling and top-down deterioration at joints and cracks. During the repair, deteriorated concrete is removed and replaced in the top half of the slab. In 2000, WisDOT initiated a research study to evaluate the PDR rehabilitation method. Three PDR test sections were constructed, along with three control sections using alternative rehabilitation methods: bonded concrete overlay, HMA overlay, and full depth concrete repair.

Performance of the test and control sections was monitored between 2000 and 2012. Additional PDR rehabilitation projects constructed between 2003 and 2008 were also evaluated. Low- to moderate-severity spalling was observed after 2 to 4 years in service, and patching of the PDR was necessary after 4 to 6 years in service. After 10 to 12 years in service, the test areas were in need of major repair or rehabilitation. The PDR failures were likely a result of deficient construction materials and/or improper construction techniques. The full depth concrete repairs had failures similar to those in the PDR test sections. The best performance was noted in the bonded concrete overlay. Adequate performance was observed in the HMA overlay, although extensive reflective cracking was present after 9 years in service.

Based on these observations, future application of the PDR rehabilitation method by WisDOT regions and engineers should be coupled with possible material and specification revisions; as well as adequate construction oversight.

17. Key Words Partial depth repair, concrete pavement rehabilitation, HMA overlay, bonded concrete overlay, full depth concrete repair		**18. Distribution Statement** Distribution unlimited, approved for public release	
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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 Motivation for Research

Beginning in the late 1990s, rapid deterioration of concrete pavements at joint and crack locations was a cause for concern on Wisconsin highways. This type of distress was prevalent in jointed plain concrete pavement (JPCP) built in northern Wisconsin in the late 1980s and early 1990s. The distress propagated from the top of the slab downward and was characterized by surface concrete deterioration and spalling. The distress began at the joints and cracks and formed V-shaped troughs in the pavement surface.

It was determined that this type of distress was caused by sulfate attack, which reduced the effectiveness of the air void system in the paste. As a result, the concrete deteriorated when subjected to freeze-thaw cycles. The cause of this problem was resolved by using sulfate resistant cements and fly ashes, but many miles of concrete pavements with this type of distress remained in service and were in need of repair.

Pavements with this type of distress were typically rehabilitated with full depth repairs at the deteriorated joints and cracks, and/or a hot mix asphalt (HMA) overlay. A rehabilitation technique called partial depth repair (PDR) was an alternative repair method for the distressed concrete sections. In this technique, concrete is removed and replaced to a depth of less than half the thickness of the slab. It was therefore considered a practical repair for concrete surface distress and minor deterioration at joints and cracks.

A number of organizations including the FHWA, several state highway agencies, local units of government, and the American Concrete Pavement Association (ACPA) reported good results with PDR of concrete pavements. The Wisconsin Department of Transportation (WisDOT), however, had no experience with this technique.

In 1998, WisDOT initiated a research study to evaluate the effectiveness of PDR compared to other rehabilitation techniques used to correct the premature distress noted in northern Wisconsin. The scope of the research study called for the construction and evaluation of test sections using several rehabilitation methods. The techniques evaluated were PDR, full depth repair, bonded concrete overlay, and HMA overlay. Three test sections and three control sections were constructed in 2000 on two separate project sites in Washburn and Sawyer Counties in Wisconsin.

1.2 Research Objectives

The primary objective of this study was to determine the optimal rehabilitation technique for concrete pavements with surface deterioration at joints and cracks. To accomplish this objective, PDR was compared to full depth concrete repair, an HMA overlay, and a bonded concrete overlay. Additional goals of this study were to introduce WisDOT's regional office personnel and Wisconsin contractors to

the PDR procedure through demonstration projects, and to determine if PDR is a suitable and cost effective rehabilitation technique for concrete pavements.

1.3 Partial Depth Repair Background

The PDR rehabilitation technique involves removal and replacement of deteriorated concrete on the surface of a slab. PDR is suitable for distress located to a depth of one third to one half the slab thickness. Distresses that are appropriate for PDR rehabilitation include: [*1*]

- Spalling caused by the intrusion of incompressible materials into the joints and cracks
- Spalling caused by poor consolidation or inadequate curing
- Spalling caused by localized areas of scaling, weak concrete, clay balls, or high steel
- Surface scaling or deterioration in the top third of the slab caused by an inadequate air void system

Some distresses cannot be appropriately remedied by PDR, including spalling caused by dowel bar misalignment or lockup, spalling of cracks caused by shrinkage, fatigue or foundation movement, and spalling caused by D-cracking or reactive aggregate. [*1*]

When properly installed using durable materials, PDR can provide 5 to 15 years of service before additional repairs are necessary. Early studies of PDR showed that 80 to 100 percent of properly installed repairs should perform well after 3 to 10 years. However, failure in as little as 2 or 3 years is possible if PDR is constructed with unsound materials or poor workmanship. [*1*, *2*] The most frequent causes of early PDR failure include: [*2*]

- Improper repair materials
- Inadequate bond between the patch and existing pavement
- Insufficient consolidation
- Compression failure[1]
- Incompatible thermal expansion between the patch and existing pavement
- Feathering of the patch material[2]

At the time that this research study was initiated, the Minnesota Department of Transportation (MnDOT) was among the states with the most experience with PDR. A high success rate had been noted on MnDOT concrete pavements rehabilitated with PDR. However, careful attention to detail was an important factor in achieving excellent performance. The MnDOT Concrete Manual states that "PDR is the most workmanship dependent operation" performed for concrete pavements. [*3*]

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[1] The crushing of a repair due to expansion of the surrounding pavement during a freeze-thaw cycle. [*2*]
[2] Thin placement of patch materials because of shallow patch edges that do not allow adequate depth of placement. [*2*]

The following are important instructions outlined in the MnDOT Concrete Manual that contribute to successful PDR: [*3*]

- Sever misaligned dowel bars. Coat the remaining exposed dowels with a release agent.
- Fill voids in the concrete below the dowel bars with sand or foam.
- Maintain compression relief. Edge the concrete around the compression relief inserts.
- Re-establish all cracks and joints in the exact location as in the original pavement.
- Apply curing compound immediately after placement of the patch material to prevent shrinkage and debonding.

MnDOT continues to perform PDR on its highways. A new guide for this rehabilitation method is in the process of being developed. An evaluation of PDR materials is also underway at MnROAD, Minnesota's road research facility, but results were not available at the time of this report. [*4*]

2. Rehabilitation Methods

The PDR rehabilitation method was evaluated in three test sections on two separate Wisconsin highway construction projects. Three control sections were also evaluated. The rehabilitation methods in the control sections included bonded concrete overlay, HMA overlay, and full depth concrete repair. The following report sections provide a brief description of these rehabilitation methods as they were constructed for this study's test areas.

2.1 Partial Depth Repair

Two types of PDR were performed on the pavement evaluated in this study: PDR joint repair and PDR crack repair. The procedures for both types were similar, as described below.

Deteriorated concrete was removed by u-shaped milling. The depth of concrete removal was a minimum of two inches, up to a maximum of half the thickness of the concrete. The exposed surfaces were sandblasted, and the repair area was air blasted to remove loose material. Cardboard was used as a compression relief material to maintain existing cracks (see Figure 1).

Figure 1. Compression relief material.

Immediately prior to placement of the new concrete, the repair surface was coated with a bonding grout, a slurry of sand, cement and water. The concrete was placed, vibrated, struck off flush to the adjacent concrete, and coated with curing compound. After curing, the joints and cracks were cleaned. Joints were sealed with silicone joint sealant in two test sections and left unsealed in the remainder of the highway. Repair areas were inspected for debonding; presence of debonding required removal and replacement of the PDR area. The contractor

was also required to remove and replace any PDR that failed due to spalling or cracking within one month of construction.

The concrete specified for repairs contained 850 pounds of Type I or Type III Portland cement per cubic yard. The required air content was 6 percent ± 1.5 percent, and the maximum allowable slump was one inch.

Both of the existing concrete pavements evaluated in this study were non-doweled. PDR procedures for doweled concrete are similar, with an additional step of coating exposed dowel bars to prevent bonding of the repair material.

The maximum width of joint and crack repairs performed on the pilot projects was ten inches. Repairs greater than this width were considered surface repairs. In the WisDOT standard special provision (STSP) for PDR, the maximum joint and crack repair width is 12 inches. [*5*]

Payment for PDR joint and crack repair was by the lineal foot (LF) for removing concrete, disposing of materials, furnishing and placing sand where required, furnishing and placing compression relief material where required, furnishing and placing joint filler where required, placing and curing of the concrete, and reestablishing cracks and joints.

2.2 Bonded Concrete Overlay

Joints and other deteriorated areas in the existing pavement were repaired prior to placing the overlay. The repair procedure consisted of partial depth removal of the deteriorated concrete to sound concrete. Shotblasting or milling was used for this procedure. Areas where the depth of deteriorated concrete exceeded two inches were filled with concrete before placing the overlay. The areas less than two inches deep were filled during the paving operation. Following these repairs, the entire pavement surface was milled or shotblasted to provide a coarse surface texture capable of providing adequate bond strength. The surface was then cleaned by sandblasting. The exact locations of existing joints were marked on each side of the pavement. A cement and water (neat cement) mixture was mechanically sprayed on the dry pavement at a minimal distance ahead of the paving operation to help increase the bond strength. The three-inch concrete overlay was placed, and the surface was finished with random spaced transverse tining.

Joints were cut in the overlay at locations of existing underlying joints and cracks. The typical saw cut depth in concrete pavement is one third the pavement thickness; however, joints in the three-inch overlay were cut through the full thickness of the overlay. The overlay joints were not sealed.

In comparison to the other rehabilitation methods, the bonded concrete overlay procedure was the most time consuming.

Payment for the bonded concrete overlay was by the cubic yard (CY) for supplying the material and by the square yard (SY) for placing, finishing, texturing, curing, and saw-cutting the overlay. Payment for surface preparation and pre-overlay repair procedures were separate bid items.

2.3 HMA Overlay

Existing concrete pavement repair prior to placing the HMA overlay was performed using the same procedures as those for the bonded concrete overlay. The existing surface of the concrete pavement was swept prior to overlay placement. A tack coat was mechanically sprayed on the concrete surface ahead of the paving operation. The 3-inch HMA overlay was placed in two 1.5-inch layers using virgin Type High-Volume (HV) and Low-Volume (LV) mixtures. The overlay was compacted using a minimum of two passes with a vibratory roller. The roadway could then be opened to traffic.

Payment for the asphaltic concrete overlay was by the CY for supplying the material and by SY for placing and rolling the overlay. Payment for the pre-overlay repairs was a separate bid item.

2.4 Full Depth Repair

Two transverse saw cuts were made parallel to the existing joint or crack at a distance of three feet on both sides. Concrete was removed full depth for the entire lane width. The work was completed as a single lane repair so the adjacent lane could be left open to traffic. Low or depressed areas in the underlying base were filled with either compacted aggregate or additional concrete. Drilled dowel bars were installed on each sawn transverse joint of the full depth repair. The new concrete was placed and consolidated, and the repair area was finished flush with the remaining existing concrete. High early strength (HES) concrete was used so the pavement could be reopened to traffic during the same working day.

This rehabilitation method was more time consuming than PDR, but faster than the overlay options.

Payment for the full depth repairs was by the SY for furnishing, hauling, preparing, placing, curing, and protecting materials; for repairing damage to existing pavement designated to remain in place; for removing and disposing of materials; for repairing asphaltic shoulders where necessary; for preparing the foundation; for backfilling; and for testing concrete cylinders for strength. [*6*] Dowel bars and sawing joints were separate bid items.

3. Test Section Descriptions

3.1 USH 53, Washburn County

This 5.6-mile rehabilitation project was constructed in summer 2000 on USH 53 between CTH H and Ross Rd, north of the city of Spooner, WI (Project ID: 1197-14-60, Contract ID: 20000314039). The existing pavement was non-doweled JPCP constructed in 1987. The concrete was 9 inches thick, constructed over 6 inches of base aggregate dense (BAD) over a 12-inch subbase consisting of 2- to 3-inch pit run. Transverse joints were randomly spaced, skewed and sealed. Prior to rehabilitation, premature distress was present in the form of surface deterioration at the joints and cracks. The pavement was in relatively good condition otherwise, and there was no slab faulting.

Rehabilitation was conducted in the northbound lanes of the four-lane divided highway. The following PDR quantities were specified for the entire project: PDR at joints (16,600 LF) and PDR at cracks (900 LF). Three evaluation segments were specified in the northern portion of the project. The segments were constructed as follows, and as shown in Figure 2:

- Test Section 1 - PDR with sealed joints
- Control Section 1 - Bonded concrete overlay
- Control Section 2 - HMA overlay

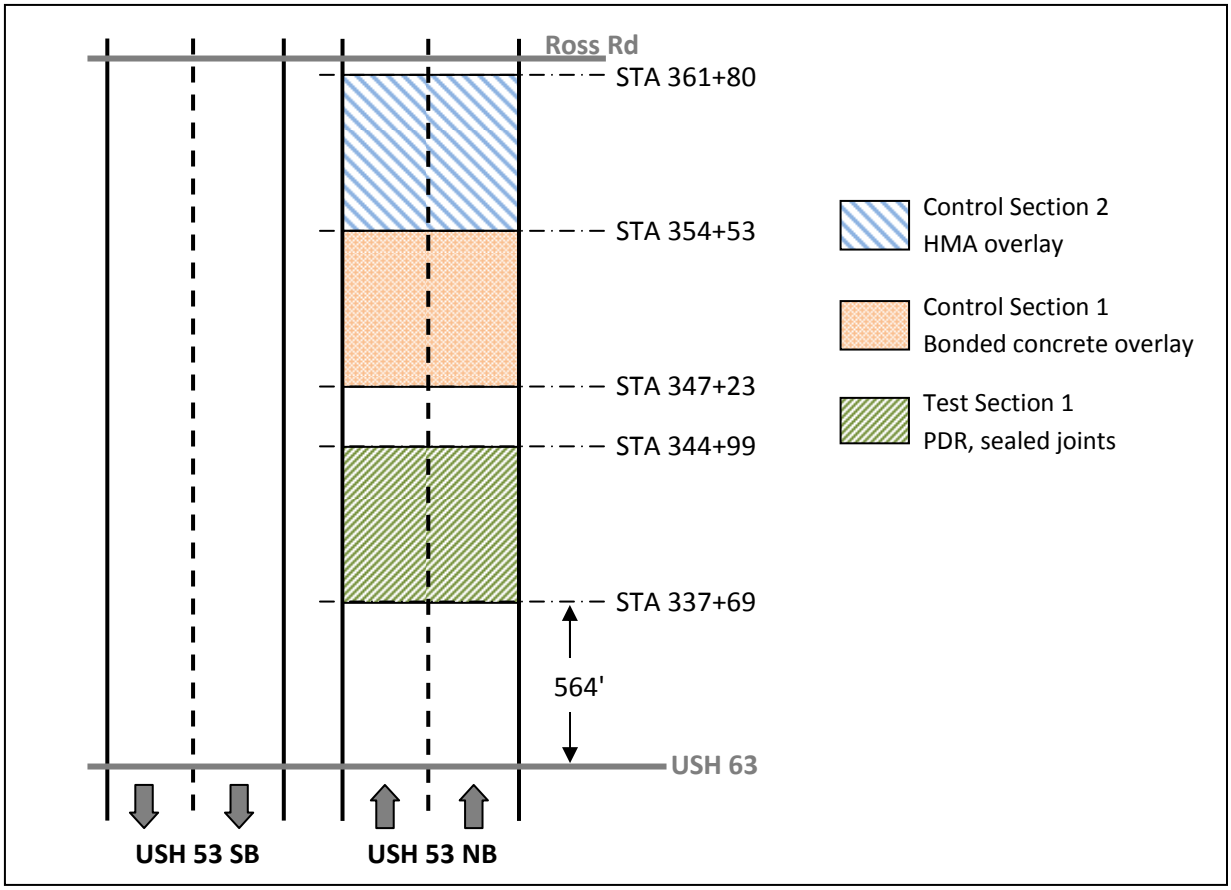

Figure 2. USH 53 test and control sections.

3.2 USH 63, Sawyer County

This 7-mile rehabilitation project was constructed in summer 2000 on USH 63 north of the city of Hayward, WI (Project ID: 1560-19-71, Contract ID: 20000314039). The existing pavement was non-doweled JPCP constructed in 1976. The concrete was 9 inches thick, constructed over 6 inches of BAD. Transverse joints were randomly spaced, perpendicular to the centerline, and sealed. Prior to rehabilitation, premature distress was present in the form of surface deterioration at the joints and cracks. The degree of deterioration present at these joints and cracks was greater than on the USH 53 project described in the previous section. The USH 63 pavement was in relatively good condition otherwise, and there was no faulting.

Rehabilitation was conducted in both lanes of the two-lane highway. The following PDR quantities were specified for this project: PDR at joints (24,000 LF) and PDR at cracks (1000 LF). Three evaluation segments were defined as follows:

- Test Section 2 - PDR with unsealed joints
- Test Section 3 - PDR with sealed joints
- Control Section 3 - Full depth repair

The test and control section layouts are shown in Figure 3.

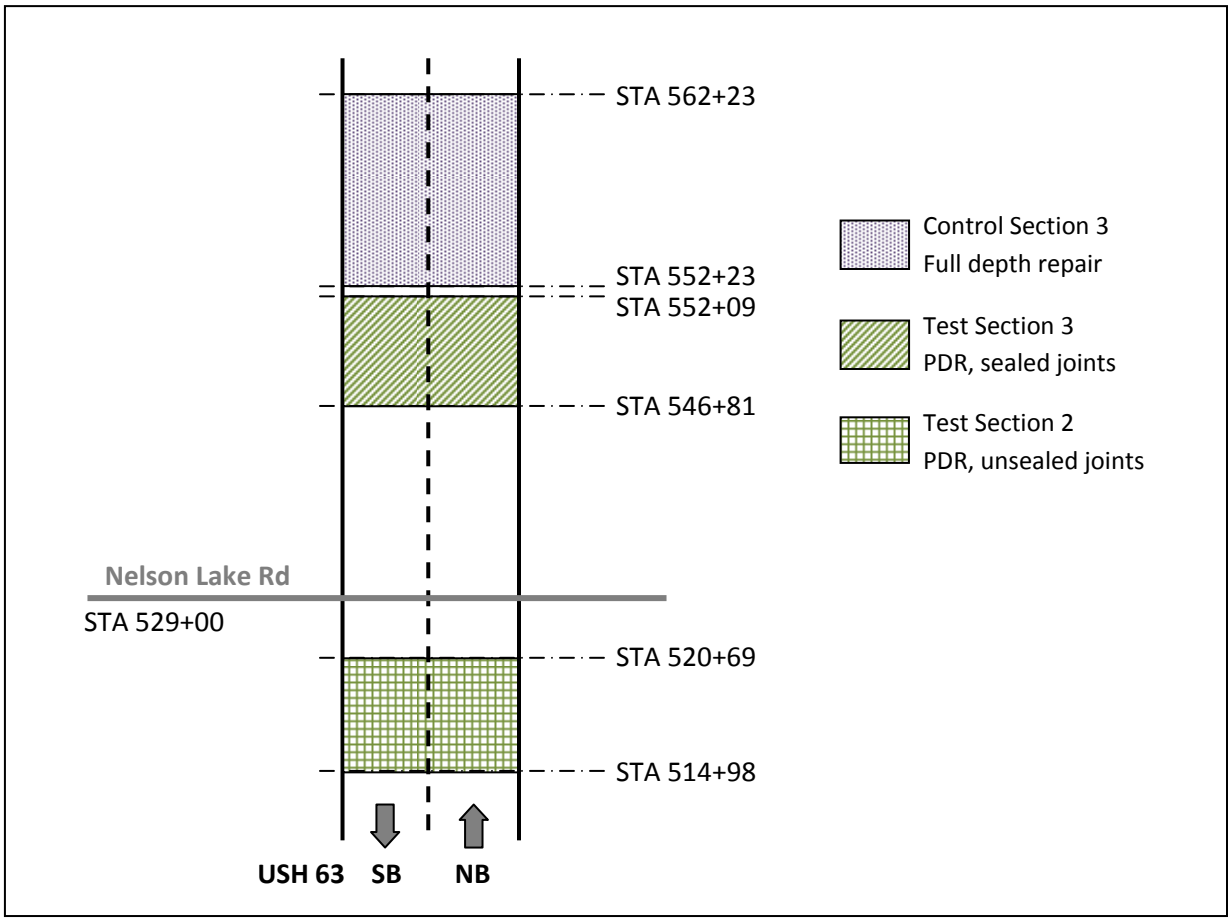

Figure 3. USH 63 test and control sections.

4. Test Section Evaluations

The test and control sections were evaluated periodically to note any distresses and to compare the performance of each rehabilitation method. Field reviews were conducted on each highway at the times listed in Table 1. The rehabilitated section on USH 53 was reconstructed in 2010 and was therefore not reviewed in 2012.

Table 1. Test and Control Section Review Schedule

Review date	Years since rehabilitation	USH 53	USH 63
April 2001	1	✓	✓
September 2002	2	✓	✓
October 2009	9	✓	✓
March 2012	12		✓

4.1 USH 53 Test and Control Sections

During the April 2001 field review, low-severity spalling was noted in the PDR patch material in Test Section 1 (PDR with sealed joints). Spalling was present in the patch material at 37 of the 48 joints (77 percent). The joints were in otherwise good condition. Similar performance was noted during the September 2002 review. Also in 2002, repairs were conducted by the original contractor at some PDR locations in the initial construction area between CTH H and Ross Rd. It is unknown whether any repairs were made within the limits of Test Section 1.

The third and final review of Test Section 1 took place in October 2009, after the test sections had been in service for 9 years. The condition of the PDR in Test Section 1 had worsened, particularly at the transverse and centerline joint intersections. Asphalt patches were present at all transverse and centerline joint intersections, where pieces of the PDR patch material had spalled away (see Figure 4).

Figure 4. Asphalt patches at intersection of transverse and centerline joints, Test Section 1, 2009.

At least four joints also had pieces of PDR material missing from the passing lane transverse joint; asphalt patches had been placed here, as well. The date of asphalt patching is unknown. Slight spalling was present in the intact PDR material, similar to what was observed during the 2001 and 2002 surveys. In some locations, the PDR material was still in good condition. The overall pavement condition was poor, however. Along with the spalled PDR patch material, additional spalling had occurred at joint locations that did not receive PDR in 2000. These areas had also been patched with asphalt (see Figure 5).

Figure 5. Additional spalling at joint locations that were not repaired with PDR, Test Section 1, 2009.

The bonded concrete overlay (Control Section 1) had excellent performance during all field reviews (2001, 2002 and 2009). In September 2002, one transverse crack was noted. The overlay is shown in Figure 6; this picture was taken during the 2009 field review.

Figure 6. Bonded concrete overlay, 2009.

In the HMA overlay section (Control Section 2), reflective cracks were noted at transverse joint and crack locations during the 2001 field review. There were 11 and 25 cracks in the driving and passing lanes, respectively. In 2002, the crack counts had increased to 16 and 34 cracks in the driving and passing lanes, respectively. These were Type 1 cracks, with widths less than ½ inch. During the 2009 review, 52 reflective cracks were counted that extended across both lanes. Several longitudinal cracks were also noted. These cracks were primarily Type 2 cracks (greater than ½ inch in width), and some cracks were banded.

By 2010, the overall pavement condition on the USH 53 rehabilitation segment had deteriorated to an unserviceable level. The pavement was reconstructed within the original 5.6-mile PDR construction project limits (CTH H to Ross Rd). The PDR had been in service for 10 years. The HMA overlay and bonded concrete overlay sections were also reconstructed.

4.2 USH 63 Test and Control Sections

In Test Section 2 (PDR with unsealed joints), all existing joints and cracks (40 total) received PDR in the 2000 rehabilitation project, along with 9 longitudinal joint segments (between transverse joints). During the 2001 field review, low-severity spalling was noted at 12 transverse joints (30 percent). The 2002 field review noted similar performance, with the joints in overall good condition.

In Test Section 3 (PDR with sealed joints), PDR was performed at 36.5 transverse joints, 9 longitudinal cracks, and 8 longitudinal joint segments. In 2001, low-severity spalling was noted at 16 transverse joints (44 percent). In 2002, it was noted that the PDR spalling in Test Section 3 (sealed joints) was less severe than in Test Section 2 (unsealed joints). However, a higher percentage of PDR had spalling in Test Section 3.

In 2009, Test Sections 2 and 3 were performing adequately, but the PDR was showing early signs of failure at several joints. Several significantly spalled portions had been patched with asphalt, as shown in Figure 7.

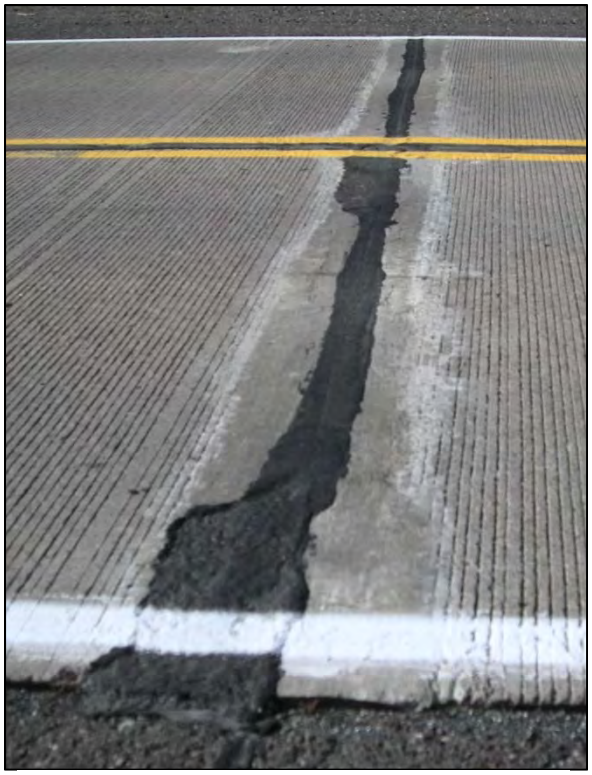

Figure 7. Asphalt patches in spalled PDR, Test Section 3, 2009.

During the 2012 field review, it was noted that in the southern portion of the project, the PDR lengths ranged from 1' in width to full pavement width and exhibited a failure rate of approximately 70%. While in the northern section of the project, the majority of the PDR lengths were full width and exhibited a failure rate of approximately 95%. Overall, PDR failures were noted at an average of approximately 75 percent of the joints. Spalls that had previously been patched with asphalt had lost material (see Figure 8). Additional PDR locations were noted where patch material had cracked, leaving pieces that would soon spall away (see Figure 9). Some of the joints that received PDR that were not full width exhibited signs of deterioration in the concrete that was not repaired. However, some of the pavement joints that had not required repair were still performing very well. All of the joints had been sealed, essentially eliminating Test Section 2. Prior to that point, it does not appear that sealing the concrete joints had improved the performance of the PDR.

Figure 8. Deteriorated asphalt patch in PDR, USH 63, 2012.

Figure 9. Cracked PDR, USH 63, 2012.

In Control Section 3, full depth repair was performed at 64 joints in the northbound lanes and 66 joints in the southbound lanes. In 2001, after only one year in service, slight spalling was noted at the edges of about 25 percent of the full depth repairs. The frequency of spalling had increased at the time of the 2002 review, and in 2009, the spalled edges of the full depth repairs had deteriorated further. Most joints had been filled with rubberized asphaltic sealant, and some were patched with asphalt and sealed (see Figure 10-a). By 2012, additional spalling was present and nearly all of the joints in Control Section

3 were exhibiting significant distress. Based on the observations and as can be seen in Figures 10-a and 10-b, the distress was limited to the full depth repair concrete and appeared to be a material issue. It was also noted that by the 2012 review most of the asphalt patching and sealant had worn away (see Figure 10-b).

Figure 10. Spalling at edges of full depth repairs; (a) 2009, and (b) 2012.

Based on the 2012 review it was difficult to ascertain which sections performed better or worse. In general the project got progressively worse from south to north, regardless of the repair method used. That being the case, the full depth repair locations, on the north end of the project, were viewed to be the poorer performing because there were two severely distressed joints instead of one. Overall, the NW region considered this project a success, as it extended the life of the pavement approximately 12 years.

5. Rehabilitation Costs

Actual bid prices and paid quantities were used to calculate the materials and construction cost for each test section evaluated in this study. Bid prices and material quantities are provided in Appendix 1. The total cost per lane-mile for each rehabilitation method is shown in Table 2. The values are reported in 2000 dollars and therefore do not accurately represent current costs. For comparison purposes, the costs were scaled to the cost of rehabilitation with unsealed PDR, which had the lowest repair cost. The cost increase factors are reported in Table 2 and shown in Figure 11.

PDR with sealed and unsealed joints were the least costly rehabilitation methods evaluated in this study. Full depth repairs were the most expensive option, costing approximately three times that of PDR. The HMA overlay and concrete overlay options were 61% and 130% more expensive than PDR, respectively.

Table 2. Rehabilitation Construction Costs

Rehabilitation Type	Cost per lane-mile	Percent cost increase over PDR, unsealed
PDR, Unsealed	$83,458	--
PDR, Sealed*	$90,729	8.7%
Bonded Concrete Overlay	$192,172	130%
HMA Overlay	$134,495	61%
Full Depth Repairs	$254,050	204%

*Average cost of Test Sections 1 and 3.

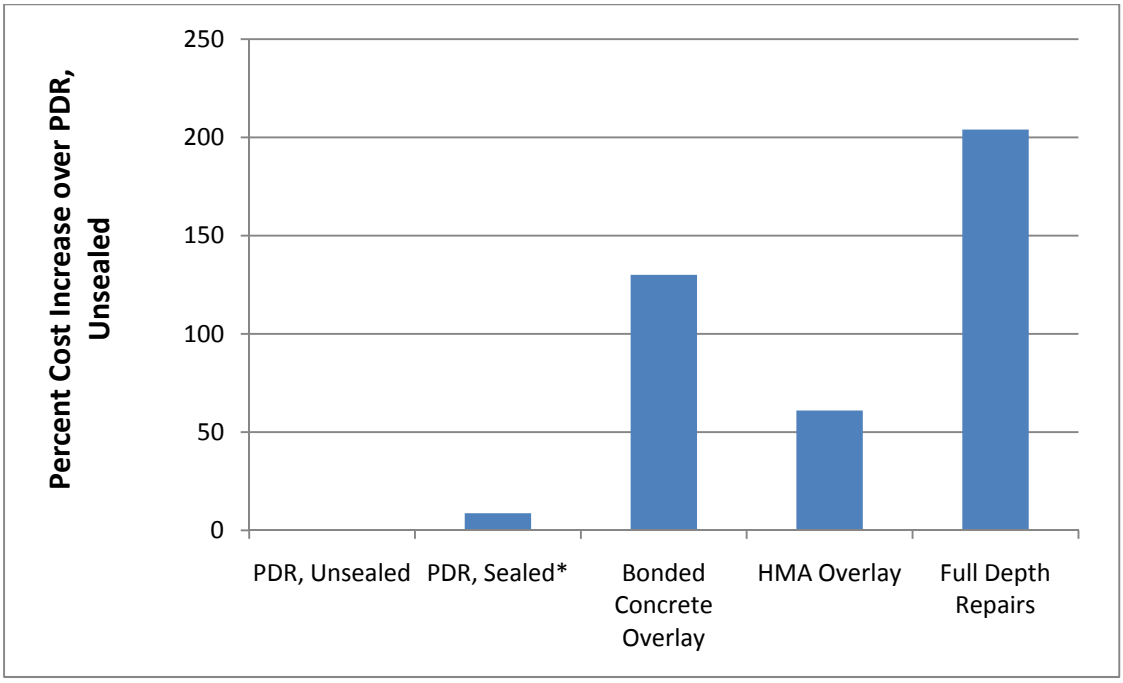

Figure 11. Relative cost comparison for rehabilitation methods.

6. Additional PDR Project Performance

In 2012, PDR rehabilitation projects were reviewed at several additional highway locations in northwestern Wisconsin. These locations were not tracked as research sections for this study, but performance at these sites is noteworthy.

6.1 USH 8, Ladysmith - 2003 PDR construction
Project ID: 1580-10-61, Contract ID: 20030812025

The PDR on this project had been in service for 9 years at the time of the field review in 2012. Although some of the joints are in great condition, as shown in Figure 12, overall the project performance is poor and further rehabilitation is necessary to restore the deteriorated joints. Many of the repaired joints had spalled and lost PDR patch material at the joint (Figure 13). Additional PDR patch material was breaking up and would soon spall out of the joint (Figure 14). Asphalt patches were located at some joints where existing concrete had spalled away (Figure 15). These locations had not received PDR.

Figure 12. Good PDR joint (USH 8, 2003 construction)

Figure 13. Spalled PDR patch material (USH 8, 2003 construction)

Figure 14. Broken PDR patch material and distress along longitudinal joint of original concrete (USH 8, 2003 construction).

Figure 15. Asphalt patches in existing concrete (USH 8, 2003 construction).

6.2 USH 53, CTH V to Yellow River Bridge (Rice Lake to Spooner) - 2005 and 2007 PDR construction
Project IDs: 1197-15-71/1197-19-71/1197-20-71
Contract IDs: 20050614044/20070612040/20070612041

These PDR rehabilitations were performed on USH 53 for the 19 miles directly south of the formal test project evaluated in this study. The PDR in the southern portion of the project had been in service for 5 years when the project was reviewed in 2012. Overall, the PDR performed well with early signs of spalling and deterioration noted at localized joints (Figure 16).The PDR in the northern portion of this project had been in service for 7 years when the project was reviewed in 2012. Overall, it was in worse condition than the southern portion. This may be attributable to the fact that the northern portion of the project has been in service an additional two years. The PDR at some joints was performing fairly well, while advanced spalling had occurred at other locations (Figure 17).

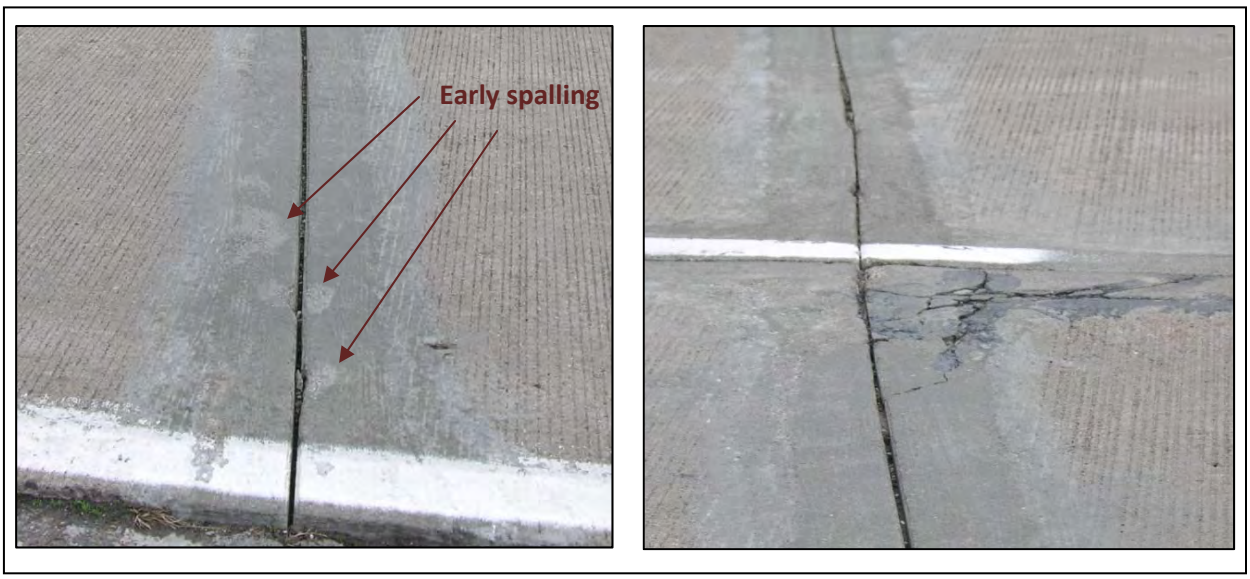

Figure 16. Early spalling and deterioration (USH 53, 2005 construction).

Figure 17. Spalling of PDR material (USH 53, 2007 construction).

6.3 USH 53, CTH S northwest ramp, Chippewa Falls - 2006 PDR construction
Project ID: 1191-09-73, Contract ID: 20060110025

PDR was performed on this concrete ramp section as part of a larger reconstruction project on mainline USH 53. The PDR was 6 years old at the time of evaluation. Early signs of deterioration and loss of PDR patch material were noted at 100% of the repaired joints at this location during a March 2012 review (Figure 18). A second review was completed in July 2012, at which time all of the PDR locations had received asphalt patching.

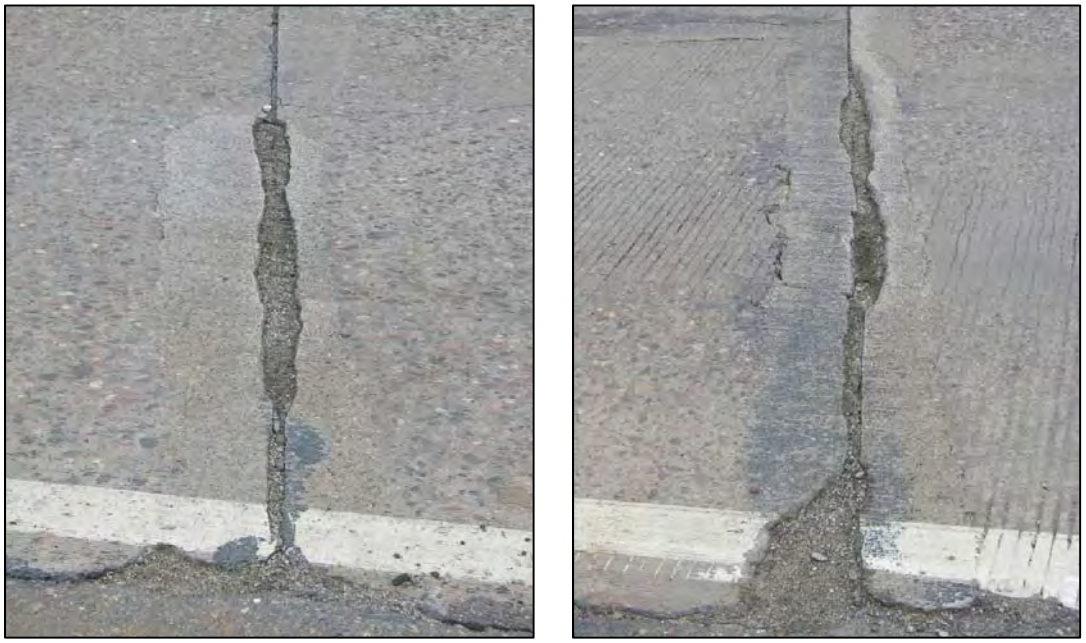

Figure 18. Early deterioration and loss of PDR patch material (USH 53 ramp, 2006 construction).

6.4 USH 12 and STH 37, Eau Claire County - 2007 PDR construction
Project IDs: 7080-00-61/7110-05-61, Contract ID: 20070710024

PDR was performed at joints and cracks on USH 12 and STH 37 in 2007. The PDR was 5 years old when it was reviewed in 2012. Cracking and spalling of the PDR patch material was observed at numerous repair locations (Figure 19, 20), at a rate of approximately 63% and 81% for USH 12 and STH 37 respectively. In several locations on STH 37, existing concrete had continued to deteriorate at a distance of 1 to 2 feet from the joint or crack. Spalling of the existing concrete appeared to be affecting the performance of adjacent PDR (Figure 21).

Figure 19. Spalling of PDR patch material (USH 12, 2007 construction).

Figure 20. Cracking of PDR patch material (STH 37, 2007 construction).

Figure 21. Deterioration of existing concrete adjacent to PDR (STH 37, 2007 construction).

6.5 USH 53 and I-94, Rest Area Ramps - 2008 PDR construction
Project ID: 1022-04-70, Contract ID: 20080610039

In 2008, rest area improvements were conducted at Wisconsin rest area locations 61 and 62 on I-94, eastbound (EB) and westbound (WB) respectively, near Menomonie and rest area locations 33 and 34 on USH 53, southbound (SB) and northbound (NB) respectively, near Chetek. PDR was performed at joints and cracks on the ramps and in parking lots, by the same contractor, at all four locations. The joints and cracks were diamond ground after PDR. After 4 years in service, cracks and spalling were present in many of the PDR locations. It also appears as though some of the failed PDR locations had been patched with concrete (Figure). The I-94 rest areas were determined to have a distress rate of 42% (WB) and 57% (EB) during a 2012 site review.

Figure 22. Cracks and spalling in PDR patch material (I-94 rest area, 2008 construction).

The PDR was in relatively good condition at the USH 53 SB rest stop location. A site review in 2012 determined that at the USH 53 rest areas, the PDR locations experienced a distress rate of approximately 24% (SB) and 63% (NB). However, some existing concrete that did not receive PDR was beginning to spall at the joints. If deterioration continues, performance of adjacent PDR could be affected (Figure).

As can be noticed by the aforementioned distress rates, performance of the PDR repairs completed under the same contract at all four rest areas was highly variable.

Figure 23. Spalling at existing concrete joint (USH 53 rest area, 2008 construction).

7. Summary and Recommendations

Partial depth repair (PDR) was evaluated as a rehabilitation method for JPCP with surface deterioration at joints and cracks. Three PDR test sections, two with the sealed joints and one without sealant, were constructed in 2000 within larger highway rehabilitation projects where PDR was used to repair deteriorated joints. Three control sections were constructed with alternative rehabilitation methods: bonded concrete overlay, HMA overlay, and full depth concrete repair. Performance of the test and control sections was monitored between 2000 and 2012. Additional PDR rehabilitation projects constructed between 2003 and 2008 were also evaluated.

Variable PDR performance was observed on all the PDR projects constructed in Wisconsin to date. At each of the project locations, there were some PDR repairs in very good condition and not showing any signs of deterioration. However, within the PDR projects approximately half of all PDR repairs have experienced some type of distress. These distresses were determined to be due to poor material quality, improper construction techniques, or a combination of both.

The PDR test sections, constructed on USH 53 and USH 63, exhibited slight spalling during the first year in service. This progressed into severe spalling and deterioration prior to 9 years in service. The deteriorated areas were typically patched with asphalt. The PDR test section of USH 63 was approaching the end of its serviceable life 12 years after construction. The PDR sections on USH 53 required reconstruction after 10 years of service. However, some of the distresses leading to this reconstruction were attributable to deteriorated concrete that had not received PDR in 2000.

Spalling was often observed in existing, immediately adjacent, concrete that had not been repaired with PDR. This failure in the existing concrete contributed to a decline in overall pavement condition, making repair or reconstruction necessary. In some cases, existing concrete deterioration also appeared to contribute to cracking and spalling of adjacent PDR. Performing PDR along the entire length of each joint or crack, much like is done with the full depth repairs, may alleviate these issues.

The test sections also attempted to differentiate between performance of sealed and unsealed joints. Sealing the joint or crack after PDR repair did not affect performance. Concrete joint sealing is no longer a routine practice on WisDOT highways.

The control sections exhibited varying levels of success. The full depth repair control section followed a progression of deterioration similar to the pavements with PDR. This rehabilitation method was three times as expensive as PDR and was therefore not a cost effective technique. However, it should be noted that the deterioration of the full depth repairs on this project were not representative of typical performance of full depth repairs in Wisconsin and seemed to be due to the concrete's freeze/thaw durability characteristics.

The best performance was observed in the bonded concrete overlay control section. This segment had no distress up to 9 years in service, after which point it was removed as part of the USH 53 reconstruction project. The HMA overlay control section had fair performance for 9 years; it was also removed during USH 53 reconstruction. Reflective cracking was noted after 9 years in service, but with routine crack sealing, the pavement would have likely provided several more functional years. Both overlay types, placed on properly repaired deteriorated concrete, are therefore viable rehabilitation options for concrete pavements with surface deterioration at joints and cracks.

Troublesome observations were made at additional PDR rehabilitation projects constructed more recently. PDR patch material at two rest area locations on USH 53 and I-94 exhibited bad cracking at some of the PDR locations after just 4 years in service; the PDR will need to be repaired, before the distressed concrete becomes dislodged. Additional PDR constructed at other locations between 2005 and 2007 had been patched or were in need of immediate repair during the 2012 review.

Due to the unreliable results obtained thus far, Wisconsin's Northwest Region, which has administered all of the aforementioned PDR projects, has chosen to discontinue the use of PDR, and has instead chosen to utilize the HMA overlay repair option. The region considers this option to be the most cost effective.

In summary, Wisconsin PDR projects constructed between 2000 and 2008 varied significantly in performance between projects and even within the same project. Although successful PDR has been demonstrated, both outside of and within Wisconsin; the performance of the projects monitored in this study was extremely inconsistent. Based on this mixed performance, it is recommended that WisDOT's regional offices and project engineers who choose to use PDR as a rehabilitation method for concrete pavements with surface deterioration at cracks and joints, consider material and specification changes. Recommended changes include the requirement of a quality control plan/process, and the potential need for additional construction oversight.

References

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3. Minnesota Department of Transportation Concrete Pavement Manual. Chapter 9, "Concrete Pavement Rehabilitation;" Section 5-694.922, "Important Points of Partial Depth Repairs." September, 2003.

4. Electronic mail correspondence with M. Jensen, Road Research Manager, Minnesota Department of Transportation. May 29, 2012.

5. Wisconsin Department of Transportation Standard Special Provisions (STSP). STSP 416-015, "Concrete Pavement Partial Depth Repair." June 2011.

6. Wisconsin Department of Transportation Standard Specifications for Highway and Structure Construction. Part 4, "Pavements;" Section 416, "Concrete Pavement - Appurtenant Construction." 2012 Edition.

Appendix 1 - Rehabilitation Method Cost Information

Test Section 1 (PDR with sealed joints)

In Test Section 1, a total of 979 LF of PDR was performed. All work was performed at joints (no cracks were repaired).

Concrete Pavement PDR, Joint Repair - $10.75/LF	x 979 LF	= $10,524.25
Sealing Joints, Concrete Pavement - $4.65/LF	x 979 LF	= $4,552.35
	TOTAL	= $15,076.60
		÷ 0.277 lane-miles
		= $54,524/lane-mile

Test Section 1 was 730 feet long, for a total of 1460 lane-feet, or 0.277 lane-miles. The total cost of PDR with sealed joints in Test Section 1 was therefore $54,428 per lane-mile.

Test Section 2 (PDR with unsealed joints)

In Test Section 2 a total of 1649.5 LF of PDR was performed. Approximately 75 LF were crack repairs, and 1574.5 LF were joint repairs.

Concrete Pavement PDR, Joint Repair - $10.75/LF	x 1574.5 LF	= $16,925.88
Concrete Pavement PDR, Crack Repair - $15/LF	x 75 LF	= $1,125
	TOTAL	= $18,050.88
		÷ 0.216 lane-miles
		= $83,458/lane-mile

Test Section 2 was 571 feet long, for a total of 1142 lane-feet, or 0.216 lane-miles. The total cost of PDR with unsealed joints in Test Section 2 was therefore $83,569 per lane-mile.

Test Section 3 (PDR with sealed joints)

In Test Section 3 a total of 1510.5 LF of PDR was performed. Approximately 500 LF were crack repairs, and 1010.5 LF were joint repairs.

Concrete Pavement PDR, Joint Repair - $10.75/LF	x 1010.5 LF	= $10,862.88
Concrete Pavement PDR, Crack Repair - $15/LF	x 500 LF	= $7,500
Sealing Joints, Concrete Pavement - $4.65/LF	x 1510.5 LF	= $7,023.83
	TOTAL	= $25,386.71
		÷ 0.2 lane-miles
		= $126,934/lane-mile

Test Section 3 was 528 feet long, for a total of 1056 lane-feet, or 0.2 lane-miles. The total cost of PDR with sealed joints in Test Section 3 was therefore $126,934 per lane-mile.

Control Section 1 (Bonded concrete overlay)

The total paid quantity for surface preparation and construction of the bonded concrete overlay was 1946 SY. The total paid quantity for removal of concrete butt joints was 800 SY.

Surface Preparation for Concrete Overlay - $3.80/SY	x 1946 SY	= $7,394.8
Bonded Concrete Masonry Overlay, 3 Inches - $19.90/SY	x 1946 SY	= $38,725.40
Removing Concrete Pavement, Butt Joints - $8.50/SY	x 800 SY	= $6,800
	TOTAL	= $52,920.20
		÷ 0.275 lane-miles
		= $192,172/lane-mile

Control Section 1 was 727 feet long, for a total of 1454 lane-feet, or 0.275 lane-miles. The total cost of the bonded concrete overlay was therefore $192,437 per lane-mile.

Control Section 2 (HMA overlay)

The materials required for the HMA overlay included HMA mixture, asphaltic material, tack coat, and QMP (quality management program) costs. At the time of construction, the HV/MV/LV mixture designation was in use.

Asphaltic Material for Plant Mix LV - $210/TON	x 25 TON	= $5,250
Asphaltic Material for Plant Mix HV - $280/TON	x 27 TON	= $7,560
Asphaltic Material for Plant Mix Type LV - $26.34/TON	x 448 TON	= $11,800.32
Asphaltic Material for Plant Mix Type HV - $25.89/TON	x 412 TON	= $10,666.68
Tack Coat - $4.00/GAL	x 225 GAL	= $900
QMP Asphaltic Mixture - $1.00/TON	x 860 TON	= $860
	TOTAL	$37,037
		÷ 0.275 lane-miles
		= $134,495/lane-mile

Control Section 2 was 727 feet long, for a total of 1454 lane-feet, or 0.275 lane-miles. The total cost of the HMA overlay was therefore $134,680 per lane-mile.

Control Section 3 (Full depth repair)

Each 6-foot long full depth repair spanning one lane required 2 CY of concrete, 16 drilled dowel bars and 24 LF of saw cutting. A total of 130 full depth repairs were performed in Test Section 3 (64 and 66 joints in the northbound and southbound directions, respectively). Therefore, 260 CY of concrete, 2080 drilled dowel bars, and 3120 LF of saw cutting was required for Test Section 3.

Concrete Pavement Repair - $225/CY	x 260 CY	= $58,500
Drilled Dowel Bars - $10.64/EACH*	x 2080 EACH	= $22,131.20
Sawing Concrete Pavement, Full Depth - $5/L.F.	x 3120 LF	= $15,600
	TOTAL	$96,231.20
		÷ 0.379 lane-miles
		= $254,050/lane-mile

Control Section 3 was 1000 feet long, for a total of 2000 lane-feet, or 0.379 lane-miles. The total cost of the full depth repair segment was therefore $253,908 per lane-mile.

*Average bid price for 2000.