NDOT Research Report

# Exploring Alternative Strategies for the Rehabilitation of Low-Volume Roads in Nevada

## Final Management Report

**January 2008**

A Report on Research Sponsored by

Nevada Department of Transportation
Carson City, Nevada

and

Federal Highway Administration

# TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract
Nevada has been among the fastest-growing states in the nation for over two decades. Due to this growth, the Nevada Department of Transportation (NDOT) is faced with the challenge of how to balance its available funding between pavement preservation and capacity improvement projects. This challenge is even greater for the low-volume roads network. Low-volume roads upkeep has been delegated to NDOT maintenance personnel and allocated funds have not been sufficient to address the distress modes on these roads. Thus, more cost-effective methods for pavement rehabilitation and maintenance must be determined and evaluated for inclusion in NDOT's pavement preservation program.

A total of 29 combinations of pavement surface and structural rehabilitation strategies were constructed on 111 centerline miles of low-volume roads throughout Nevada. The strategies included full depth reclamation, cold mix asphalt concrete pavement, cold in-place recycling, and various surface treatments. The test sections were monitored with roughness surveys, condition surveys, falling weight deflectometer testing, and core evaluations for resilient modulus, strength, and rutting susceptibility.

A life-cycle cost analysis was conducted for the constructed rehabilitation strategies and compared to NDOT's conventional practice of placing hot mix asphalt concrete pavement and chip seal wearing course on low-volume roads. The analysis indicated that a $104,000 per centerline mile saving might be realized if a 3 in. cold in-place recycling and double chip seal wearing course were used instead of hot mix asphalt concrete pavement to rehabilitate pavement with functional deficiency. An additional benefit of cold in-place recycling is that reflective cracking is interrupted. Furthermore, savings of $38,000 to $93,000 per centerline mile may be achieved if full depth reclamation, cold mix asphalt concrete pavement, and cold in-place recycling with stockpiled millings were used in lieu of hot mix asphalt concrete pavement to rehabilitate pavement with structural deficiency. There is a potential network level saving of $8,400,000 per year if rehabilitation strategies other than hot mix asphalt concrete pavement were used to manage and maintain NDOT's low-volume roads network at an acceptable level of service.

The primary deliverable was proposed low-volume roads rehabilitation guidelines. The guidelines were based on whether the pavement exhibits structural or functional deficiencies. The guidelines provide systematic and cost-effective alternatives for pavement managers when tasked with choosing among rehabilitation options. Project results included the modification of NDOT's conventional pavement preservation practices for low-volume roads, specification improvements, and construction experience with new to NDOT rehabilitation strategies and products.


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# EXPLORING ALTERNATIVE STRATEGIES FOR THE REHABILITATION OF LOW-VOLUME ROADS IN NEVADA

## FINAL MANAGEMENT REPORT


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A Report on Research Sponsored by

NEVADA DEPARTMENT OF TRANSPORTATION
Carson City, Nevada

and

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## NOTICE



## DISCLAIMER

**ACKOWLEDGEMENTS**

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The authors acknowledge the Federal Highway Administration for providing funding for this project; NDOT's Research Division and Low-Volume Roads Task Force for contributing technical support; NDOT's Pavement Analysis Section for supplying pavement roughness information, field cores, and FWD data; and the University of Nevada, Reno for furnishing the material properties laboratory testing.

The combined effort of these individuals made it possible for the authors to develop practical and cost-effective low-volume roads rehabilitation guidelines that can be constructed using recognized industry practices.

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## ACRONYMS

| Acronym | Definition |
|---|---|
| 3R | Resurfacing, Restoration, and Rehabilitation |
| ADT | Average Daily Traffic |
| CIR | Cold in-Place Recycling |
| ESAL | Equivalent Single Axle Load |
| F | Fahrenheit |
| FDR | Full Depth Reclamation |
| FHWA | Federal Highway Administration |
| Ft | Feet |
| FWD | Falling Weight Deflectometer |
| GPR | Ground Penetrating Radar |
| In. | Inch(es) |
| IRI | International Roughness Index |
| K | Dollars in Thousands |
| LCCA | Life-Cycle Cost Analysis |
| M | Dollars in Millions |
| Mi | Mile |
| NDOT | Nevada Department of Transportation |
| No. | Number |
| ODOT | Oregon Department of Transportation |
| PSR | Present Serviceability Rating |

# EXECUTIVE SUMMARY

The Nevada Department of Transportation's (NDOT's) low-volume roads network has been delegated to maintenance personnel. Maintenance personnel are responsible for the repair and preservation of the sizeable 3,385 lane mile network. Higher trafficked roadways have received the majority of the available funding for many years leaving insufficient funding to address the considerable need of the low-volume roads network using conventional rehabilitation strategies. Since the amount of funding required to preserve the network at an acceptable level of service is not available, more cost-effective rehabilitation alternatives must be determined and included in the pavement preservation program for the low-volume roads network.

The objective of this research project was to develop rehabilitation guidelines to be used for NDOT's low-volume roads network. The guidelines are intended to be recommendations for pavement managers tasked with managing the network with limited budgets. Use of the guidelines will provide consistent and cost-effective solutions for repairing and preserving the network.

A total of 29 combinations of pavement surface and structural rehabilitation strategies were constructed on 111 centerline miles of low-volume roads throughout the state. The strategies included full depth reclamation, cold mix asphalt concrete pavement, cold in-place recycling, and various surface treatments. The test sections were evaluated with standard engineering practices including pavement roughness and condition surveys, falling weight deflectometer testing, and laboratory testing for resilient modulus, strength, and rutting susceptibility.

The construction of the test sections resulted in specification improvements, construction experience with new to NDOT rehabilitation methods and products, and potential for rehabilitating the low-volume roads network at substantial cost saving. Solvent free and polymer modified recycling agents were used successfully in the cold in-place recycling process. NDOT has used a standard recycling agent for many years and recent formula innovations in recycling agents were cause to re-evaluate whether the standard recycling agent was still the best option for NDOT to use with its cold in-place recycling operations. Some advantages of the solvent free and polymer modified recycling agents include the purported ability to retard many types of cracking for longer time periods, performance in a wider range of temperature extremes, better aggregate coating, and expedited set times.

The cold in-place recycling and chip seal wearing course strategy was used to successfully rehabilitate pavement with functional deficiency at approximately half the total cost of the conventional hot mix asphalt concrete pavement used to rehabilitate low-volume roads in the past. Much of NDOT's low-volume roads infrastructure has deteriorated to a point where hot mix asphalt concrete pavements are no longer effective because the cracks in the underlying pavement structure reflect through the new hot mix asphalt concrete pavement layer within several years. Maintenance personnel are left with the same situation of maintaining severely distressed pavement after spending substantial amounts of money. Reasonable alternative rehabilitation options include those strategies that can eliminate or retard reflective cracking long enough to justify practical life-cycle costs.

The cold in-place recycling strategy was used with stockpiled millings to rehabilitate a pavement with structural deficiency and nominal pavement structure. The pavement was milled one inch, stockpiled millings were placed in windrow, and the materials were effectively recycled. The capacity of the pavement structure was increased with use of materials that otherwise would have been hauled to landfill for disposal.

There is a potential network level saving of $8,400,000 per year if alternative rehabilitation strategies were used to manage, preserve, and repair the low-volume roads network to an acceptable level of service. A possible life-cycle cost saving of $104,000 per centerline mile may be achieved if cold in-place recycling and chip seal wearing course were used instead of hot mix asphalt concrete pavement and chip seal wearing course for pavement with functional deficiency. Potential life-cycle cost savings of $38,000 to $93,000 per centerline mile might be obtained if full depth reclamation, cold mix asphalt concrete pavement, or cold in-place recycling with stockpiled millings were used in lieu of hot mix asphalt concrete pavement and chip seal wearing course for pavement with structural deficiency. These alternative rehabilitation strategies can prevent or retard the reflective cracking that is prevalent when hot mix asphalt concrete pavement is used to rehabilitate a low-volume road.

There is a major challenge to overcome if NDOT is to optimally maintain the low-volume roads network in a cost-effective manner. This challenge is to secure dedicated low-volume roads funding that district engineers can rely on each year for required contractor and maintenance work. The integrity of the entire low-volume roads network is important and neglecting the system will cost more in the future if functional distresses are allowed to deteriorate into structural deficiencies. Pavement management and preservation are more than just an assortment of rehabilitation strategies. Pavement management and preservation are controlling factors in the financial planning process.

The primary project deliverable was low-volume roads rehabilitation guidelines for NDOT personnel to use and incorporate into their long-term pavement preservation plan for low-volume roads. It is proposed that alternative rehabilitation strategies including full depth reclamation, cold mix asphalt concrete pavement, and cold in-place recycling be used in NDOT's pavement preservation program to maintain and repair the low-volume roads network. It is recommended that pavement managers employ the following directives to assist with effectively managing the network:

1) Adopt the proposed low-volume roads rehabilitation guidelines in Figure E.1. These guidelines were developed for both structural and functional pavement deficiencies. The guidelines are the outcome of group consensus between engineers and managers to advance low-volume roads rehabilitation techniques to better serve state needs using recognized construction practices. The guidelines will provide systematic and cost-effective alternatives for pavement managers when tasked with choosing among numerous rehabilitation options.

2) Utilize the life-cycle cost analysis examples in Table E.1 to assist with selecting the most practical rehabilitation option.

3) Use solvent free and polymer modified recycling agents for cold in-place recycling operations.

4) Implement the additional specification, constructability, and material modifications as recommended in the report.

5) Secure $12,000,000 per year in the Maintenance and Operations Division's budget to address low-volume roads rehabilitation and maintenance in a timely manner. This amount should be inflation adjusted to compensate for shrinking buying power in future years. It is anticipated that $12,000,000 per year would be required to maintain the low-volume roads network at an acceptable level of service. Under ideal conditions, this amount of money would provide stability of the network. The network has been deteriorating faster than NDOT is administering rehabilitation.

Implementing project directives should result in a well managed and maintained low-volume roads network that will be viable for the next generation of Nevadans.

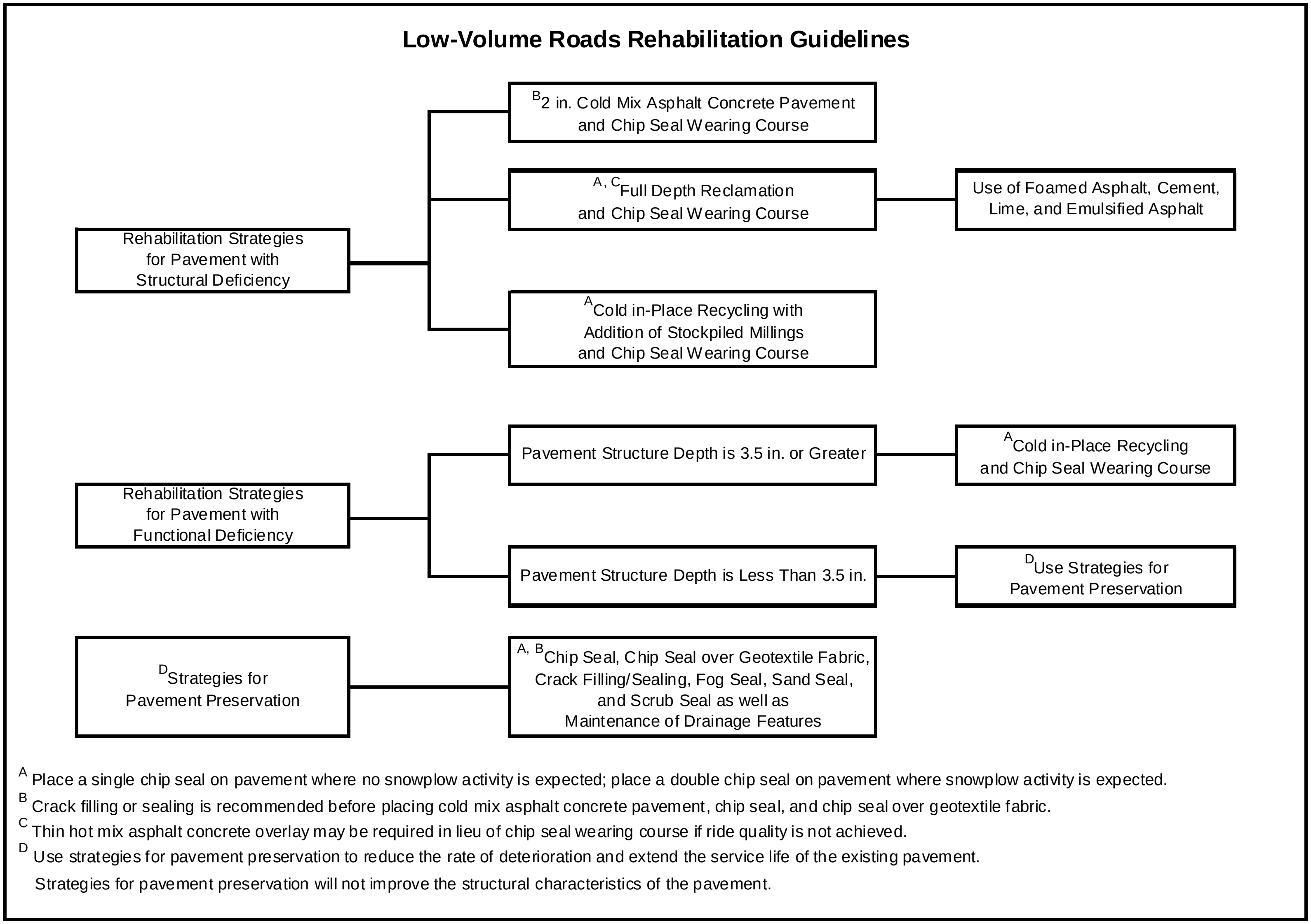



**FIGURE E.1 Proposed low-volume roads rehabilitation guidelines.**

**TABLE E.1 20 Year Life-Cycle Costs for One Low-Volume Road Centerline Mile**

| Initial Rehabilitation Strategy | Initial Cost ($1,000) | Future Maintenance Costs Discounted 4% ($1,000)<br>Fog Seal (FS), Chip Seal (CS), Crack Filling/Sealing (CF/S), and Patching (P) | | | | | Net Present Value ($1,000) |
|---|---|---|---|---|---|---|---|
| | Year 0 | Year 3 | Year 7 | Year 10 | Year 13 | Year 17 | |
| 2 in. Hot Mix Asphalt Concrete Overlay and Single Chip Seal | 193 | 3.4<br>FS | 16.7<br>CF/S & CS | 9.5<br>CF/S, FS, P | 16.8<br>CF/S, CS, P | 7.2<br>CF/S, FS, P | 247 |
| Blade Lay 2 in. Cold Mix Asphalt Concrete Overlay and Single Chip Seal | 161 | 3.4<br>FS | 15.2<br>CF/S & CS | 6<br>CF/S, FS, P | 13.8<br>CF/S, CS, P | 4.5<br>CF/S, FS, P | 204 |
| Full Depth Reclamation using Foamed Asphalt and Double Chip Seal | 173 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 209 |
| Full Depth Reclamation using Cement and Double Chip Seal | 118 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 154 |
| Full Depth Reclamation using Lime and Double Chip Seal | 128 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 164 |
| 3 in. Cold in-Place Recycling with Addition of Millings and Double Chip Seal | 146 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 182 |
| 3 in. Cold in-Place Recycling and Double Chip Seal | 107 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 143 |

## CHAPTER 1

### 1.1 Introduction

Nevada has been among the fastest-growing states in the nation for over two decades. Due to this continuing growth, the Nevada Department of Transportation (NDOT) is faced with the challenge of how to balance its available funding between pavement preservation and capacity improvement projects. This challenge is even greater for NDOT's low-volume roads network. NDOT is responsible for over 13,000 lane miles of roadway, of which 3,385 lane miles, or 26%, qualify as low-volume roads. The low-volume roads have a two-directional average daily traffic (ADT) of 400 or less.

Based on experience, spending an average of $247,000 per centerline mile is required for the expected 20 year life-cycle of a low-volume road. This cost is based on NDOT's conventional practice of placing a 2 in. hot mix asphalt concrete overlay and chip seal, and additional maintenance of two chip seals, three fog seals, and isolated patching and crack filling over a 20 year period. If NDOT continues to use its conventional practice, about $21,000,000 per year in expenditures would be required to maintain the low-volume roads network at a high level of service.

Capacity improvement, resurfacing, restoration, and rehabilitation projects on higher trafficked roadways have received the majority of NDOT's funding for many years. The low-volume roads have been delegated to NDOT maintenance personnel to repair and maintain. Allocated funds have not been sufficient to address the typical distress modes on these roads. Subsequently, maintenance personnel are frequently required to repair the roads using short-term maintenance strategies such as hand and machine patching. These strategies may be effective to address short-term problems. However, the strategies are not the most cost-effective remedies for long-term pavement preservation.

NDOT tax revenue does not allow for stable funding to maintain the low-volume roads network at a high level of service using conventional rehabilitation practices. Thus, more cost-effective methods for pavement maintenance and rehabilitation must be determined and evaluated for inclusion in NDOT's pavement preservation program. *Exploring Alternative Strategies for the Rehabilitation of Low-Volume Roads in Nevada* is a summary of an investigation into finding more cost-effective methods to maintain and preserve the low-volume roads network. A total of 29 combinations of pavement surface and structural rehabilitation strategies were identified and test sections were constructed on 111 centerline miles throughout the state. Full depth reclamation (FDR), cold mix asphalt concrete pavement, cold in-place recycling (CIR), and various surface treatments were constructed and evaluated according to standard engineering practices. A review of the constructability issues and lessons learned were also discussed.

Field practices used to evaluate the test sections included pavement roughness and condition surveys. These surveys were conducted before construction, after construction, and annually. Falling weight deflectometer testing was performed to determine if structural remediation improved the structural capacity of the test sections. Additionally, laboratory testing consisting of resilient modulus, indirect tensile strength, retained strength, and rutting susceptibility was accomplished.

Proposed low-volume roads rehabilitation guidelines were developed that lists the recommended strategies to be used to manage and maintain NDOT's low-volume roads network. The recommendations are based on whether the pavement condition indicates functional or structural deficiencies. A life-cycle cost analysis was formulated to compare NDOT's conventional low-volume roads rehabilitation practice with the recommended rehabilitation strategies to determine if a cost saving could be realized through use of the alternatives. The construction of project test sections resulted in improved specifications, construction experience with new to NDOT rehabilitation strategies and products, and potential for maintaining the low-volume roads network at a considerable cost saving.

### 1.2 Test Sections

Five low-volume roads located throughout the state were chosen as demonstration test sections. The roads were age hardened, brittle, and contained distresses such as block, nonwheel path longitudinal, transverse, and fatigue cracking. Raveling was noticeable in some areas. Figure 1.2a shows examples of common distresses evident on these roads.

Condition surveys and core samples were taken before construction to determine if the roads had sound pavement structures. Roads with pavement structures that lacked integrity or were considered to be unsound were determined to require structural improvement. FDR, cold mix asphalt concrete overlay, and CIR with stockpiled millings were used as methods for rehabilitating inadequate pavement structures. Roads that displayed functional deficiency and had adequate or sound pavement structures were determined to be good candidates for CIR rehabilitation.

Approximately 12 lane miles of SR230 were rehabilitated using FDR strategies. In addition, six lane miles of SR230 were rehabilitated using cold mix asphalt concrete overlays. A total of 188 lane miles on US006, SR226, SR168, and SR892 were rehabilitated using CIR with various surface treatments and recycling agents as well as stockpiled millings. Sixteen lane miles of surface treatments including chip seals, chip seal over polypropylene geotextile fabric, fog seals, and sand seal were constructed on SR230 and US006. Table 1.2a contains the route descriptions, construction and maintenance histories, and pre-construction core data for the roads rehabilitated through this effort. Table 1.2b is a summary of the types of construction strategies, wearing courses, and surface treatments used to rehabilitate the roads. Figure 1.2b shows where the test sections are located throughout the state.

**FIGURE 1.2a  Common low-volume road distresses.**

**TABLE 1.2a  Descriptions of Routes**

| ROUTE | COUNTY | MILEPOST | ADT | ESAL (PER/DAY) | AVERAGE ELEVATION OF ROUTE (FEET) | PRECIPITATION PER YEAR (INCH) | FREEZE THAW DAYS (PER/YEAR) | CONSTRUCTION AND MAINTENANCE HISTORY | AVERAGE PRE-CONSTRUCTION CORE DEPTH (INCH) |
|---|---|---|---|---|---|---|---|---|---|
| SR230 | Elko | 0.30 - 12.60 | 130 | 12 | 5500 | 8 | 216 | Originally constructed in 1925 with gravel and roadmix. Additional roadmix in 1958. Maintenance has consisted of chip seals, crack filling, and machine patching. | 3.25 |
| US006 | Nye | 73.80 - 98.00 | 210 | 46 | 5500 | 7 | 145 | Last major rehabilitation was an 8 in. FDR, 3.5 in. hot mix asphalt concrete overlay, and chip seal in 1986. Maintenance has consisted of crack filling and fog seals. | 5.00 |
| SR226 | Elko | 0.00 - 20.00 | 130 | 20 | 6250 | 14 | 165 | Originally constructed in 1952 with base and roadmix. A 2 in. hot mix asphalt concrete overlay was placed in 1975. Maintenance has consisted of machine patching and fog, sand, and chip seals. | 6.00 |
| SR168 | Clark | 3.26 - 25.82 | 150 | 18 | 2000 | 4 | 70 | Originally constructed in 1935 with base and roadmix. A 3 in. hot mix asphalt concrete overlay and chip seal was constructed in 1967. Maintenance has consisted of machine patching and chip seals. | 3.25 |
| SR892 | White Pine | 1.36 - 35.48 | 80 | 4 | 6000 | 12 | 170 | Originally constructed in 1949 with base and roadmix. Maintenance has consisted of machine patching, areas of thin hot mix asphalt overlay, and several chip seals. | 3.50 |

**TABLE 1.2b Types of Rehabilitation Strategies and Surface Treatments Constructed**

| Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment | Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment |
|---|---|---|---|---|---|---|---|---|---|
| | | | | [a]SR230 | | | | | |
| SR230 | 0.30 - 2.00 | Eastbound | ---------- | Double Chip Seal | SR230 | 0.30 - 2.00 | Westbound | Nonwoven Polypropylene Geotextile Fabric | Double Chip Seal |
| SR230 | 2.00 - 3.30 | Eastbound | FDR with CMS-2S and Lime (8 in. pulverized and mixed with quicklime at a rate of 3.0% by mass; and type CMS-2S emulsified asphalt added at a rate of 1.5% by mass to the top 2.5 in. of material); **1.5 in. Hot Mix Asphalt Concrete Overlay | Single Chip Seal | SR230 | 2.00 - 3.30 | Westbound | ---------- | Double Chip Seal |
| SR230 | 3.30 - 4.80 | Eastbound | FDR with Proprietary Liquid Stabilizer (6 in. pulverized and liquid stabilizer added to top 3 in. of material); **1.5 in. Hot Mix Asphalt Concrete Overlay | Single Chip Seal | SR230 | 3.30 - 4.80 | Westbound | FDR with Foamed Asphalt (5 in. pulverized and mixed with AC-10 asphalt at a rate of 3.0% by mass and cement added at a rate of 2.0% by mass) | Single Chip Seal |
| SR230 | 4.80 - 6.30 | Eastbound | 2 in. Cold Mix Asphalt Concrete with CMS-2S (Emulsified asphalt added at a rate of 7.4% by mass to specially graded aggregates) | Single Chip Seal | SR230 | 4.80 - 6.30 | Westbound | 2 in. Cold Mix Asphalt Concrete with MC-800 (Liquid asphalt added at a rate of 5.8% by mass) | Single Chip Seal |
| SR230 | 6.30 - 7.80 | Eastbound | FDR with Foamed Asphalt (5 in. pulverized and mixed with AC-10 asphalt at a rate of 3.0% by mass and cement added at rate of 2.0% by mass) | Single Chip Seal | SR230 | 6.30 - 7.80 | Westbound | FDR with 4.5% Cement (8 in. pulverized and mixed with cement at a rate of 4.5% by mass) | Double Chip Seal |

| TABLE 1.2b Continued | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Route** | **Milepost** | **Direction** | **Type of Rehabilitation Strategy** | **Type of Wearing Course/ Surface Treatment** | **Route** | **Milepost** | **Direction** | **Type of Rehabilitation Strategy** | **Type of Wearing Course/ Surface Treatment** |
| SR230 | 7.80 - 9.30 | Eastbound | Nonwoven Polypropylene Geotextile Fabric | Double Chip Seal | SR230 | 7.80 - 9.30 | Westbound | FDR with Proprietary Liquid Stabilizer (7 in. pulverized and liquid stabilizer added to top 6 in. of material); **1.5 in. Hot Mix Asphalt Concrete Overlay | Single Chip Seal |
| SR230 | 9.60 - 11.10 | Eastbound | 2 in. Cold Mix Asphalt Concrete with HFMS-2S (Emulsified asphalt added at a rate of 7.0% by mass) | Single Chip Seal | SR230 | 9.60 - 11.10 | Westbound | 2 in. Cold Mix Asphalt Concrete with CMS-2S (Emulsified asphalt added at a rate of 7.4% by mass to specially graded aggregates) | Single Chip Seal |
| SR230 | 11.10 - 12.60 | Eastbound | FDR with 3.0% Cement (8 in. pulverized and mixed with cement at a rate of 3.0% by mass) | Double Chip Seal | SR230 | 11.10 - 12.60 | Westbound | FDR with Proprietary Emulsion (5 in. pulverized and mixed with asphalt emulsion at a rate of 4.0% by mass); **1.5 in. Hot Mix Asphalt Concrete Overlay | Single Chip Seal |
| **[b]US006** | | | | | | | | | |
| US006 | 73.80 - 75.00 | Eastbound | ---------- | 1/2 in. Single Chip Seal with Polymer Modified Emulsified Asphalt | US006 | 73.80 - 75.00 | Westbound | ---------- | 1/2 in. Single Chip Seal with Polymer Modified Emulsified Asphalt |

*TABLE 1.2b Continued*

| Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment | Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment |
|---|---|---|---|---|---|---|---|---|---|
| US006 | 75.00 - 78.00 | Eastbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | 1/2 in. Single Chip Seal with CRS-2NV Emulsified Asphalt and Type 3 Slurry Seal | US006 | 75.00 - 78.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | 1/2 in. Single Chip Seal with CRS-2NV Emulsified Asphalt and Type 3 Slurry Seal |
| US006 | 78.00 - 84.00 | Eastbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | *Double Chip Seal with Polymer Modified Emulsified Asphalt | US006 | 78.00 - 84.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | *Double Chip Seal with Polymer Modified Emulsified Asphalt |
| US006 | 84.00 - 85.00 | Eastbound | 3 in. Cold in-Place Recycling with Solvent Free Emulsified Asphalt and No Lime | *Double Chip Seal with Polymer Modified Emulsified Asphalt | US006 | 84.00 - 85.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | *Double Chip Seal with Polymer Modified Emulsified Asphalt |
| US006 | 85.00 - 88.00 | Eastbound | 3 in. Cold in-Place Recycling with Solvent Free Emulsified Asphalt and No Lime | Double Chip Seal with CRS-2NV Emulsified Asphalt | US006 | 85.00 - 88.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double Chip Seal with CRS-2NV Emulsified Asphalt |
| US006 | 88.00 - 90.00 | Eastbound | 3 in. Cold in-Place Recycling with Solvent Free Emulsified Asphalt and No Lime | Type 3 Microsurfacing | US006 | 88.00 - 90.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Type 3 Microsurfacing |

*TABLE 1.2b Continued*

| Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment | Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment |
|---|---|---|---|---|---|---|---|---|---|
| US006 | 90.00 - 91.00 | Eastbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double Chip Seal with Polymer Modified Emulsified Asphalt | US006 | 90.00 - 91.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double Chip Seal with Polymer Modified Emulsified Asphalt |
| US006 | 91.00 - 94.00 | Eastbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double 3/8 in. Chip Seal with Polymer Modified Emulsified Asphalt | US006 | 91.00 - 94.00 | Westbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double 3/8 in. Chip Seal with Polymer Modified Emulsified Asphalt |
| US006 | 94.00 - 96.00 | Eastbound | ---------- | Single 3/8 in. Chip Seal with Polymer Modified Emulsified Asphalt and Type 3 Slurry Seal | US006 | 94.00 - 96.00 | Westbound | ---------- | Single 3/8 in. Chip Seal with Polymer Modified Emulsified Asphalt and Type 3 Slurry Seal |
| US006 | 96.00 - 97.00 | Eastbound | ---------- | Single 3/8 in. Chip Seal with Polymer Modified Emulsified Asphalt | US006 | 96.00 - 97.00 | Westbound | ---------- | Single 3/8 in. Chip Seal with Polymer Modified Emulsified Asphalt |

*TABLE 1.2b Continued*

| Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment | Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment |
|---|---|---|---|---|---|---|---|---|---|
| US006 | 97.00 - 97.50 | Eastbound | ---------- | Sand Seal with Restorative Seal | US006 | 97.00 - 97.50 | Westbound | ---------- | Fog Seal with Polymer Modified Emulsified Asphalt |
| US006 | 97.50 - 97.80 | Eastbound | ---------- | Fog Seal with CSS-1H Emulsified Asphalt | US006 | 97.50 - 97.80 | Westbound | ---------- | Fog Seal with CSS-1H Emulsified Asphalt |
| US006 | 97.80 - 98.00 | Eastbound | Do Nothing Section | Do Nothing Section | US006 | 97.80 - 98.00 | Westbound | Do Nothing Section | Do Nothing Section |
| **[c]SR226** | | | | | | | | | |
| SR226 | 0.00 - 20.00 | Northbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double Chip Seal | SR226 | 0.00 - 19.00 | Southbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime | Double Chip Seal |
| | | | | | SR226 | 19.00 - 20.00 | Southbound | 3 in. Cold in-Place Recycling with Solvent Free Emulsified Asphalt and No Lime | Double Chip Seal |
| **[d]SR168** | | | | | | | | | |
| SR168 | 3.26 - 23.82 | Northbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime (Mill 1 in. and add by windrow stockpiled cold millings from local interstate project for total of 3 in. cold in-place recycling) | Single Chip Seal | SR168 | 3.26 - 23.82 | Southbound | 3 in. Cold in-Place Recycling with CMS-2S and Lime (Mill 1 in. and add by windrow stockpiled cold millings from local interstate project for total of 3 in. cold in-place recycling) | Single Chip Seal |

*TABLE 1.2b Continued*

| Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment | Route | Milepost | Direction | Type of Rehabilitation Strategy | Type of Wearing Course/ Surface Treatment |
|---|---|---|---|---|---|---|---|---|---|
| **[e]SR892** | | | | | | | | | |
| SR892 | 1.32 - 30.00 | Northbound | 2 in. Cold in-Place Recycling with Polymer Modified Emulsified Asphalt and No Lime | Double Chip Seal | SR892 | 1.32 - 30.00 | Southbound | 2 in. Cold in-Place Recycling with Polymer Modified Emulsified Asphalt and No Lime | Double Chip Seal |
| SR892 | 30.00 - 35.92 | Northbound | 2 in. Cold in-Place Recycling with Solvent Free Emulsified Asphalt and No Lime | Double Chip Seal | SR892 | 30.00 - 35.92 | Southbound | 2 in. Cold in Place Recycling with Solvent Free Emulsified Asphalt and No Lime | Double Chip Seal |

NOTES:

[a]The SR230 test sections were constructed in 2002.

[b]The US006 test sections were constructed in 2003.

[c]The SR226 test sections were constructed in 2004.

[d]The SR168 test section was constructed in 2005.

[e]The SR892 test sections were constructed in 2005.

Dash (-----) denotes not applicable.

Asterisk ( * ) denotes use of stockpile or “dirty” chip seal aggregates.

Two asterisks ( ** ) denotes the placement of a 1.5 in. hot mix asphalt concrete overlay to correct surface deficiencies because of inadequate construction practices or materials.

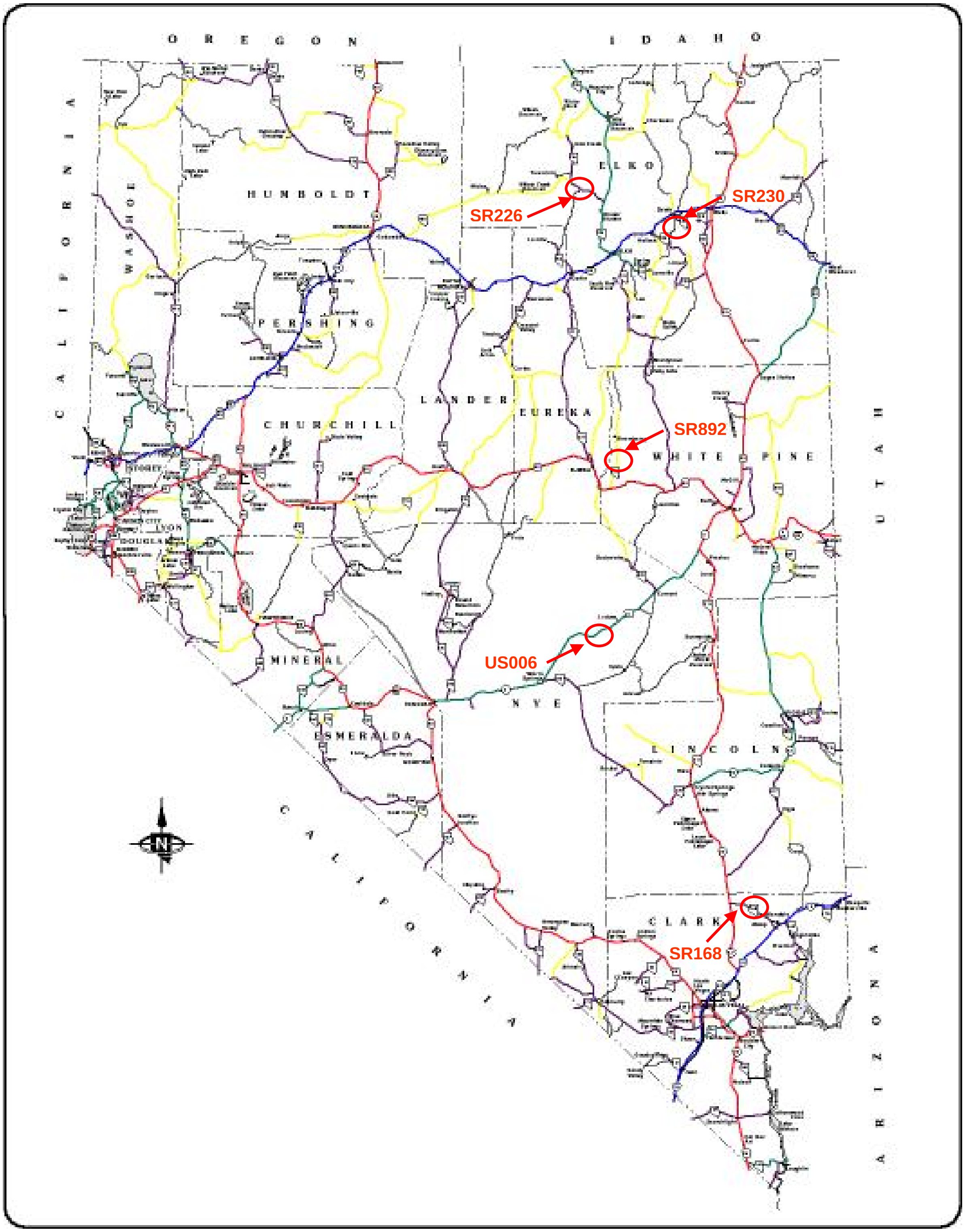



**FIGURE 1.2b Low-volume roads test section locations.**

# CHAPTER 2 FULL DEPTH RECLAMATION

## 2.1 Full Depth Reclamation Introduction

Full depth reclamation (FDR) is defined as a recycling method where all of the asphalt structural section and a predetermined amount of underlying materials are pulverized and treated to produce a stabilized base course (*1*). A variety of additives can be used to stabilize the material. Additives such as pozzolans, lime, cement, and asphalt emulsion are used to achieve satisfactory results. Five steps are used in the construction of FDR projects:

1. Material is pulverized to the desired depth; depths of 4 in. to 12 in. are typical.
2. An additive is introduced and mixed.
3. The pulverized material with additive is graded to required roadway geometrics.
4. The shaped material is compacted.
5. A wearing course is required.

FDR has several advantages:

- The capacity or integrity of the pavement structure is improved without significantly changing roadway geometrics.
- A uniform pavement structure is achieved in addition to eliminating all surface and structural deficiencies.
- Ride quality can be restored with use of proper equipment techniques.
- Production cost is low as compared with the cost of construction with the use of new materials.
- The process can be more environmentally friendly than some rehabilitation methods and there are no disposal issues.

FDR is recommended for pavement structures that lack capacity or integrity, including pavements with base or subgrade problems. These pavements have deteriorated beyond a point where preventive maintenance strategies can repair the road. Pavements that experience base failure, stripping, rutting, and fatigue cracking indicate that FDR rehabilitation may be required. FDR provides a long-term pavement rehabilitation option for a deteriorated roadway at the end of its service life.

Several FDR strategies were constructed in an effort to find cost-effective methods to eliminate structural deficiencies. The strategies were constructed on SR230 in Elko County. Approximately 12 lane miles of FDR using lime and emulsified asphalt, a proprietary liquid stabilizer, cement, a proprietary asphalt emulsion, and foamed asphalt were constructed in 2002. The following is a discussion of the constructability issues and lessons learned during the construction of the FDR strategies placed on SR230. Test section performance is reviewed in Chapter 6.

## 2.2 FDR with Lime and Emulsified Asphalt

A 1.3 lane mile FDR test section with lime and CMS-2S emulsified asphalt was constructed. The pavement structure was pulverized 8 in. and quicklime was introduced at a rate of 3.0% by mass to the pulverized material. After preliminary grading, type CMS-2S emulsified asphalt was added at a rate of 1.5% by mass to the top 2.5 in. of material before final compaction with rollers and grading operations using a motor grader.

It was immediately apparent that the surface material was too dry for intended purposes and the surface started to ravel. Repeated efforts to fog seal the area and maintain the integrity of the pavement structure failed. The section continued to ravel over several weeks before the scheduled chip seal. Due to a variety of circumstances, the ride quality deteriorated to a point where a 1.5 in. hot mix asphalt concrete overlay was placed instead of the scheduled chip seal wearing course to remedy the situation. The strategy may have been successful if the CMS-2S emulsified asphalt were added at a rate of 2.5% to 3.0% by mass and if the chip seal wearing course were applied within a week.

### 2.3 FDR with Proprietary Liquid Stabilizer

A proprietary liquid stabilizer with non-ionic formulation was introduced into two separate 1.5 lane mile test sections. The product was marketed as having broad-spectrum effectiveness to increase density, moisture resistance, bearing and shear strength, and stability on low-volume roads. The product was purported to work in any soil condition, need no cure time or seal coat, and be able to handle traffic immediately after final compaction operations. The stabilizer was added at the manufacturer recommended rate as a dilute solution during normal wetting, mixing, compaction, and grading operations. The stabilizer was added to pulverized material in both 3 in. and 6 in. layers.

Unfortunately, the test sections raveled, did not cure as expected, and deteriorated to a point where the surfaces were not suitable to receive the scheduled chip seal wearing course. A thin hot mix asphalt concrete overlay was placed to remedy the situation.

The 6 in. stabilized test section may have been effective if a seal coat were placed after final compaction, the area cured for 24 hours before traffic was allowed, and the chip seal wearing course placed within one week. The mixing depth of 3 in. was insufficient and posed problems during compaction due to rapid drying and the workability challenge for the motor grader operator. The 3 in. depth treatment had insufficient fines content and was prone to rock pockets. Due to this experience, the material supplier will discontinue recommendation for 3 in. treatments using this product.

The material supplier reviewed the project and determined that the product would work optimally if there were a minimum of 5% fine aggregates in the pulverized material. The pulverized asphalt surface over base material did not have the minimum fines content in either test sections. In the future, the material supplier will recommend a seal coat and minimum 24 hour cure time before traffic is allowed. The material supplier refunded the cost of the product.

### 2.4 FDR with Cement

NDOT has over 20 years of experience with FDR and cement. Standard practice has been to add cement at the rate of 2.0% by mass for all soil conditions in Nevada. FDR with the addition of cement at rates of 3.0% and 4.5% by mass were constructed to determine if additional cement would be more effective. A double chip seal was placed as a wearing course for these strategies. FDR with cement is a very effective strategy for eliminating reflective cracking for many years, as long as the stiffness of the layer is kept to a minimum level. Based on these test sections, the use of cement should be limited to 2.0% by mass. The test sections are already showing signs that that the layers are too stiff as low severity transverse cracking has occurred.

A 1.5 lane mile FDR test section with cement added at a rate of 3.0% by mass was constructed. A thin hot mix asphalt concrete overlay was placed on approximately 1300 ft (0.25 mi) of the section to improve the ride quality before NDOT placed a double chip seal. It is essential that a very experienced motor grader operator be retained for this type of construction work. The required ride quality and success of the strategy is mostly dependent upon the operator's skill at producing a smooth road surface during final grading operations.

A 1.5 lane mile FDR test section with cement added at a rate of 4.5% by mass was constructed. A thin hot mix asphalt concrete overlay was placed on approximately 1300 ft (0.25 mi) of the section to improve the ride quality before NDOT placed a double chip seal. An acceptable ride quality can only be obtained by an experienced motor grader operator.

### 2.5 FDR with Proprietary Emulsion

An asphalt manufacturer supplied a proprietary asphalt emulsion purported to have excellent stabilization properties. A 1.5 lane mile FDR test section was constructed and the proprietary asphalt emulsion added at a rate of 4.0% by mass.

The homogenous mixture did not set up or cure properly and the road was pliable for days. There was saturation in the right wheel path because the water added during moisture conditioning drained into the right wheel path. The shoulder area was not pulverized and acted as a barrier. Hence, the water could not drain out of the right wheel path. Consequently, the test section had to be reworked to allow the mixture to dry. This was accomplished by pulverizing the section, adding bags of cement, and the mixture was remixed, graded, and compacted. After reworking, the pavement structure remained in a pliable condition and there was an unacceptable ride quality. The company providing the asphalt emulsion supplied the funding necessary for a thin hot mix asphalt concrete overlay to correct the situation.

### 2.6 FDR with Foamed Asphalt

Foamed asphalt is a form of FDR that involves injecting cold water into hot asphalt bitumen. The cold water and hot bitumen mixture expands 15 to 20 times the volume of the materials used separately (Figure 2.6a). Foamed asphalt is not an experimental process and has been used worldwide for over 10 years. A mix design is required and usually 3.0% by mass of asphalt cement and 4.0% by mass of water are added. Additionally, 2.0% by mass of cement can be added when marginal fines content is encountered. The foamed asphalt does not coat the aggregate. The foamed asphalt attaches and binds between the fine aggregates. Approximately 15% to 20% fine aggregates are required for an optimal mix design. Foamed asphalt is not used with clay type materials and the addition of lime was not recommended at the time of this application. The advantages of foamed asphalt are that traffic can be placed on the road immediately, the material can be easily remixed and recompacted, and no special rolling pattern is required.

Foamed asphalt can be used with millings. Some agencies mix foamed asphalt with millings, the material is covered, and stockpiled indefinitely. The material can be used in place of cold mix for patching roadways.

Two 1.5 lane mile foamed asphalt test sections were constructed on SR230. This work consisted of a 5 in. deep process whereby the existing asphalt surface and a portion of the underlying base materials were pulverized, graded, moisture conditioned, and compacted prior to foamed asphalt stabilization. Thereafter, the section was stabilized with foamed asphalt and mixed into a homogenous mixture. The homogenous mixture was compacted and finish graded. Figure 2.6b is an example of typical foamed asphalt equipment used in the construction of the foamed asphalt process. NDOT used a two step process for accomplishing the foamed asphalt because the contractor advised that the final homogenous mixture would be more consistent and of better quality.

The foamed asphalt test sections were built without difficulty and the chip seal wearing course adhered well to the stabilized surfaces. One section required some corrective action to improve the ride quality due to inadequate motor grader operations. A thin hot mix asphalt concrete overlay was placed on approximately 17% of the test section.

**FIGURE 2.6a Foamed asphalt expands 15 to 20 times the volume of materials used separately (*2*).**


**FIGURE 2.6b Example of typical foamed asphalt equipment (*3*).**

## 2.7 Lessons Learned

The experience gained by constructing the FDR test sections will help to improve ride quality and construction practices on similar projects in the future. The following lessons were learned:

- NDOT has refined expectations of what constitutes an acceptable ride quality for low-volume roads. Personnel have been comfortable with the ride quality of a hot mix asphalt concrete overlay and open-grade wearing course. This ride quality is often denoted as Type A according to Subsection 402.03.05 of the *Standard Specifications* (*4*). A Type A ride quality is defined as having a profile index of 5 in./mi. Spending substantially less money on stabilization strategies that are constructed with motor graders rather than pavers requires a compromise in ride quality expectations. A Type C ride quality with a defined profile index of 10 in./mi is adequate for low-volume roads and can be achieved with good operator skills. A Type C ride quality meets national standards for acceptable roadways (*5*).

- High quality motor grading or blading techniques are crucial for obtaining a smooth roadway with an acceptable ride quality. Inexperienced operators do not have the capability of providing an acceptable ride quality or good roadway geometrics.

- Better compaction techniques can be realized on future projects. Several compaction problems occurred including undulations due to excessive rolling, overweighted rollers, and disagreement over proper order of rollers. Compaction equipment works within the specified width of roadway and extra material or “fluff” is bladed off onto the shoulder area. Shoulder compaction and grading should be required in future specifications as part of the bid item.

- A wearing course should be placed within one week of FDR operations. The need to place a 1.5 in. hot mix asphalt concrete overlay as corrective action for poor rideability was due to the fact that the FDR was left without the wearing course for up to six weeks. Traffic and construction equipment driving over the FDR caused continual deterioration over time. Most test sections were in good condition for at least two weeks after construction. The chip seal wearing course would have been adequate if the wearing course had been applied within one week. The logistical aspects of placing the chip seal wearing courses, including labor and materials, were not planned well.

- Too much moisture was added to several of the FDR strategies, requiring extra work or corrective measures. It will be necessary to monitor water introduction more carefully in future projects.

- Vendors market soil stabilization products to agencies using claims that the product will improve the engineering properties of in situ materials. It is important to have a technical representative on the project site during construction operations to make the necessary adjustments and recommendations required for a successful project. If the product does not perform as purported, the material suppliers should be made responsible for correcting the problem.

## CHAPTER 3 COLD MIX ASPHALT CONCRETE PAVEMENT

### 3.1 Cold Mix Asphalt Concrete Pavement Introduction

Cold mix asphalt concrete pavement is a mainstream rehabilitation alternative to hot mix asphalt concrete. The pavement can improve both functional and structural performance of a roadway. Cold mix asphalt concrete pavement is a combination of unheated aggregates, fillers or additives, and asphalt bitumen. Gravel and sand are the most commonly used aggregates in cold mix asphalt concrete. However, asphalt millings can also be used. With good quality control, cold mix asphalt concrete can be produced from a wide variety of materials. Cold mix asphalt concrete is a cost-effective alternative used in lieu of hot mix asphalt concrete in areas where there is a long haul distance to the nearest hot mix plant. Unlike hot mix, cold mix can be used year-round and stockpiled for days or months before use. A hot plant and paver is not always required (*6*). Advantages of cold mix asphalt concrete pavement include:

- Minimal disruption to public traffic and good long-term service.
- Retards reflective cracking better than hot mix asphalt concrete.
- Roads will “self-heal” due to solar heat and traffic.

Cold mix produced with slow or medium setting asphalt is more pliable than hot mix. This characteristic aids in compaction and reduces the potential for reflective cracking. Thus, a cold mix will generally retard reflective cracking better than a hot mix when used on badly cracked pavement, and is a better alternative for low-volume roads when compared to the use of a hot mix overlay. Also, cold mix lends itself to applications where frost heave distortions or poor subgrade are problems. Disadvantages include the need for quality control procedures and geometric adjustments because of the raised profile. When this research project was initiated, the cost of a cold mix asphalt concrete pavement was far more cost-effective than the cost of a hot mix asphalt concrete overlay. However, with the dramatic cost increase of road construction materials the last few years, the cost saving when using cold mix versus hot mix is negligible in most circumstances. A $30,000 per centerline mile cost saving can be realized if the cold mix is placed with a motor grader rather than placed with a paver.

Three types of cold mix asphalt concrete pavements were placed for comparison purposes on SR230. Six lane miles of 2 in. cold mix asphalt concrete using CMS-2S emulsified asphalt added at a rate of 7.4% by mass to specially graded aggregates, MC-800 liquid asphalt added at a rate of 5.8% by mass of aggregates, and HFMS-2S emulsified asphalt added at a rate of 7.0% by mass of aggregates were constructed in 2002. Although mineral filler is recommended in cold mix asphalt concrete pavement, the mineral filler was eliminated in these instances due to the hardship of adding the mineral filler properly in a remote area with limited equipment.

The original construction plan included the manufacture of the cold mix asphalt concrete material on site with a portable pugmill. The material was to be windrowed, bladed with a motor grader to intended profile and grade, and compacted. The reason for this application method was due to expectation that NDOT’s maintenance personnel would blade lay cold mix material in future projects. However, a paver was required to place the CMS-2S cold mix asphalt concrete material due to workability issues. With the paver on site, it was also practical to place the MC-800 and HFMS-2S cold mix asphalt concrete test sections with the paver as well. More experience with cold mix asphalt concrete materials, equipment, and placement procedures are required to realize the potential of this rehabilitation method.

The following is a discussion of the constructability issues encountered and lessons learned during the construction of the cold mix asphalt concrete pavements placed on SR230. Due to budget constraints, additional cold mix test sections were not utilized on other low-volume roads included in the investigation. Test section performance is evaluated in Chapter 6.

### 3.2 Cold Mix Asphalt Concrete with CMS-2S Emulsified Asphalt

The CMS-2S cold mix asphalt concrete material was too sticky to blade lay and did not cure properly. The material was considered to be soft and labeled “unstable” by construction personnel. A paver was used instead of a motor grader to place and level the material and constructability issues developed despite use of a paver. The screed sank into the cold mix material every time the paver stopped for the addition of another load of cold mix material. The undulations caused by the settling screed were cause for poor rideability and corrective measures were needed. Profile grinding was used to correct the smoothness deficiency. The profile grinder was difficult to use due to the fragile cold mix material during the heat of the day. The grinder would settle into the pavement structure. Workers did a good job of getting the best ride possible despite the challenges. A single chip seal wearing course was placed after the profile grind and unfortunately, the chips did not bond well with the cold mix asphalt concrete pavement. The lack of bonding between chip seal and cold mix asphalt concrete pavement was due to the fact that the test sections were not allowed to cure for the recommended amount of time to allow the diluents to disperse. The cure time is necessary to allow the volatiles to evaporate from the cold mix material.

The aggregates used for the CMS-2S cold mix material were specially crushed and graded based on information from a mix design used by the Oregon Department of Transportation (ODOT). The state reported great success with the open-graded cold mix and mentioned that the cold mix worked well to retard reflective cracking. The cold mix design was based on three parameters: air voids from 15% to 30%, a 90% minimum asphalt coating, and an index of retained strength with a minimum of 40 by ODOT test method. The recommended asphalt content for the cold mix was the lowest emulsion content at which all the criteria were met, but no lower than 5% by weight of the dry aggregate. The aggregate gradation of the CMS-2S cold mix was different than NDOT’s Type 2 and Type 3 cold mix aggregate gradations. Crushing aggregate for use in the CMS-2S cold mix was expensive and produced a large amount of waste material. Table 3.2 contains a comparison of the CMS-2S cold mix aggregate gradation used on SR230 versus NDOT’s Type 2 and Type 3 cold mix aggregate gradations.

**TABLE 3.2 Cold Mix Asphalt Concrete Aggregate Gradation Comparisons**

| SIEVE SIZE | ODOT CMS-2S COLD MIX | NDOT TYPE 2 COLD MIX | NDOT TYPE 3 COLD MIX |
|---|---|---|---|
| | Percent Passing By Mass | | |
| 1 in. | 100 | 100 | ---- |
| 3/4 in. | 95-100 | 90-100 | ---- |
| 1/2 in. | 70-90 | ---- | 100 |
| 3/8 in. | ---- | 63-85 | 85-100 |
| No. 4 | 15-30 | 45-63 | 50-75 |
| No. 10 | 0-7 | 30-44 | 32-52 |
| No. 16 | ---- | --- | ---- |
| No. 40 | ---- | 12-22 | 12-26 |
| No. 200 | 0-2 | 3-8 | 3-8 |

NOTE: Dash (----) denotes not applicable.

### 3.3 Cold Mix Asphalt Concrete with MC-800 Liquid Asphalt

Cold mix asphalt concrete material produced with MC-800 liquid asphalt and Type 2 aggregates is a standard type of cold mix used by NDOT's maintenance personnel. The cold mix material was produced in a portable pugmill and placed with paving equipment. The MC-800 cold mix was placed easily and displayed the best workability of the three cold mix asphalt concrete test sections. The only constructability issue was that pneumatic rollers did not work well and a steel wheel roller was used to compact the material. The tires on the pneumatic roller were picking up the material despite the use of excessive water. Since NDOT personnel have the most amount of experience with this type of cold mix, it is reasonable that the material was able to be produced and placed with greater ease than the other types of cold mix material tried in this investigation.

### 3.4 Cold Mix Asphalt Concrete with HFMS-2S Emulsified Asphalt

Cold mix asphalt concrete material produced with HFMS-2S has been used successfully by other state agencies and is purported to retard reflective cracking. HFMS-2S emulsified asphalt is known for good aggregate coating under extreme temperature conditions. Cold mix material was produced with HFMS-2S emulsified asphalt and Type 2 aggregates in a portable pugmill and placed with paving equipment. The cold mix seemed to drag rather than flow through the paving equipment. After compaction, the cold mix did not set up enough to open the area to public traffic. Thus, the cold mix was bladed into a windrow along the shoulder of the roadway and allowed to dry for a few days. After much of the water evaporated from the material, placement procedures including compaction were more successful. A single chip seal wearing course was placed. The chips did not bond well with the cold mix asphalt concrete pavement due to the fact that the cold mix asphalt concrete pavement was not cured for the appropriate amount of time to allow the diluents to disperse. The cure time is necessary to allow the volatiles to evaporate from the cold mix material.

### 3.5 Lessons Learned

The constructability of the test sections was a challenge due to limited experience of personnel with cold mix asphalt concrete placement procedures using a motor grader as well as material expectations. The material may have been more workable and easier to place if mineral filler were used, less water added, and asphalt content increased. The portable pugmills used in the field to make cold mix material do not have the advantages of calibrated gauges and scales like a commercial plant. Thus, there is more cause for error when estimating asphalt percentages and weights of materials. Additionally, the chip seal wearing courses would have bonded better if the cold mix asphalt concrete test sections were allowed to cure for six months to a year before chip seal placement, rather than placing the chip seals within a month.

Cold mix asphalt concrete pavement is a viable alternative for rehabilitating low-volume roads. As personnel gain experience with manufacturing and workmanship issues, the placement procedures will become more successful. The test sections are performing well despite the difficulties with material placement. Test section performance is evaluated in Chapter 6.

# CHAPTER 4 COLD IN-PLACE RECYCLING

## 4.1 Cold in-Place Recycling Introduction

Cold in-place recycling (CIR) is a recycling method that rehabilitates asphalt pavement into a restored pavement layer without the application of heat during the recycling process (*1*). CIR is accomplished on-site with equipment that consists of a milling machine, crusher, pugmill mixer, paver, and rollers. The combination of milling machine, crusher, and pugmill mixer required for CIR is typically called a "recycle train." There are six steps used in the construction of CIR projects:

1. A cold milling machine mills 2 in. to 4 in. of the asphalt pavement.
2. The milled material is crushed to the specified aggregate gradation.
3. The aggregates are mixed with recycling agents in the pugmill mixer.
4. The rejuvenated material is deposited on the milled pavement in a windrow, and a standard asphalt paver machine places the material to desired grade and elevation.
5. Rollers are used to compact the material to the required density.
6. An overlay or surface treatment is placed as a wearing course.

CIR has several advantages:

- A process that is environmentally friendly with no disposal issues.
- A uniform pavement structure that retards reflective cracking.
- Improved ride quality with use of proper equipment techniques.
- Lower life-cycle cost as compared to the life-cycle cost of new materials.
- A process that is cost-effective with good long-term performance.

CIR is recommended for older pavements that have structural capacity or integrity, but need a new wearing surface due to poor rideability or excessive cracking. CIR can be used on pavements that have functional deficiencies such as raveling, rutting, corrugations, and transverse thermal cracking.

NDOT has constructed over 1200 centerline miles of CIR since the late 1990s. This experience has caused NDOT to develop its own standard specification (*4*). NDOT uses CMS-2S emulsified asphalt as the preferred recycling agent. Additionally, lime is added to improve the constructability of the rejuvenated material and expedite cure time. Both the emulsified asphalt and lime are introduced at a rate of up to 1.5% by mass of the milled material. The contractor is required to adjust the application rate of the recycling agent based on the condition of the deposited material.

Recent formula innovations in CIR recycling agents were cause to re-evaluate whether CMS-2S emulsified asphalt is still the best option for NDOT's CIR operations. Purported innovations include the ability to retard many types of cracking for longer time periods because the material itself is more flexible. This characteristic is especially important if a wearing course, such as a chip seal, is used rather than a hot mix asphalt concrete pavement overlay. Other innovations include formulas that are solvent free or polymer modified. A solvent free recycling agent is more environmentally friendly and a polymer modified agent performs in a wider range of temperature extremes. A recycling agent that can be used in lower temperatures allows for an extended construction season. Additionally, newer formulas provide better aggregate coating and traffic can be placed on the recycled pavement structure faster because curing or set times are expedited. The following is discussion about the CIR test sections constructed and lessons learned through this research effort. Test section performance is presented in Chapter 6.

### 4.2 CIR Test Sections

*CIR with CMS-2S, Solvent Free, and Polymer Modified Recycling Agents*

There were 188 lane miles of CIR constructed on four different low-volume roads. This strategy was the most common rehabilitation method used in the research project. Approximately 111 lane miles of CIR using NDOT's conventional CMS-2S recycling agent were constructed on US006, SR226, and SR168. There were 19 lane miles of CIR using solvent free emulsified asphalt constructed on US006, SR226, and SR892. Additionally, 58 lane miles of CIR using polymer modified emulsified asphalt were constructed on SR892.

The CIR with use of CMS-2S recycling agent and lime requires a one to two hour wait before compaction can begin after recycle operations. This wait is to allow the moisture to evaporate out of the recycled surface. Also, the newly recycled pavement structure must be fog and sand sealed before traffic is allowed at the end of each day. The recycled surface must be cured for a minimum of 10 days and recompacted within 14 days after initial CIR operations. With use of the solvent free and polymer modified recycling agents, the before-mentioned construction steps can be eliminated.

A solvent free recycling agent that was purported to be less susceptible to cracking was tried on US006, SR226, and SR892. Although there were initial workability issues with the asphalt emulsion, the issues were eliminated after contractors gained experience with the product and the formula was adjusted to extend the set time. Solvent free products are more environmentally friendly and this benefit is important in a society concerned with resource preservation.

A polymer modified recycling agent was used to construct a CIR test section on SR892. The polymer modified emulsified asphalt can be used with pavement surface temperatures as low as 40º F. Traditionally, NDOT has been able construct CIR projects when pavement surface temperatures are a minimum of 60º F and rising. An extended pavement surface temperature window is significant as it allows for the extension of the CIR construction season in Nevada. CIR is usually accomplished from June through August when the CMS-2S recycling agent is used. CIR with use of the polymer modified recycling agent allows the recycle season to be extended from late April through mid September. This extension is a great benefit for NDOT and contractors working to increase production rates while struggling with the demands of the construction season.

NDOT has successfully used solvent free and polymer modified recycling agents in place of its conventional CMS-2S recycling agent. A purported advantage of the solvent free recycling agent is already evident in the 5 year evaluation of test sections on US006. There is reduced transverse cracking in the solvent free test section in a side-by-side comparison with the CIR and CMS-2S with lime test section.

In the past, NDOT placed a hot mix asphalt concrete overlay and wearing course on all CIR projects. CIR with hot mix asphalt concrete overlay was used on high volume roads with good results. The significance of this research effort is that NDOT has advanced its use of the CIR rehabilitation strategy by eliminating the use of hot mix asphalt concrete overlay on CIR projects. Low-volume roads do not require the additional structural capacity of higher volume roads and most low-volume road pavement structures can be rejuvenated with the use of CIR and chip seal wearing course.

*CIR with Stockpiled Millings*

The CIR rehabilitation strategy was used with stockpiled millings to construct an improved pavement structure on SR168 (Figure 4.2a). Pre-construction core data revealed that the pavement structure was marginal for CIR operations and the use of recycled millings and chip seal wearing course was recommended. Millings that were leftover from a local interstate project were placed in a windrow in front of the recycle train. The roadway was milled 1 in. to provide for an adequate bond between the existing and new pavement structure. The freshly milled material and windrowed millings from stockpile were recycled using the train and a paver was used to place the 3 in. pavement structure (Figure 4.2b). This project was NDOT's first attempt at using a CIR operation with stockpiled millings for creating an improved pavement structure. Preliminary results are encouraging and this strategy will be used on future projects where logistics are feasible for incorporating stockpiled millings into CIR operations on low-volume roads.

**FIGURE 4.2a Stockpiled millings.**

**(a)**

**(b)**

**(c)**

**FIGURE 4.2b CIR using stockpiled millings (a) millings hauled for windrow, (b) CIR train mills 1 in. and recycles material with millings in windrow, and (c) paver places 3 in. recycled pavement structure.**

*CIR with Various Wearing Courses*

Various surface treatments were used as wearing courses for the CIR test sections on US006 in an effort to find the most advantageous CIR and wearing course combination. Double chip seals using different asphalts and aggregate gradations, microsurfacing, and cape seal were constructed on the recycled surface. Based on test section performance, a CIR and chip seal wearing course provides the most economical solution. It is too premature to determine which chip seal asphalt and aggregate combination performs more optimally with CIR, as all double chip seal test sections are still functioning well.

*CIR and Constructability Issues*

There were several common constructability issues that occurred when the CIR test sections were constructed. These issues included pavement structures that were too thin, fast setting recycling agent, raveling after the CIR pavement structure was opened to traffic, and rutting.

A pavement structure with enough depth to support the heavy recycle train is required. It is recommended that at least 1.5 in. of pavement structure be left in-place after milling operations. This in-place pavement structure will help ensure that the recycle train does not break through to the base material as it is not desirable for base material to be introduced into the recycled material. Cores should be taken from the centerline to the edge of pavement to ensure that a minimum pavement depth is encountered full width. Isolated areas on SR892 required premixed bituminous paving material for repairs to the roadway surface. There is a standard haul and place premixed bituminous paving material bid item added to every NDOT CIR project for this type of issue.

The solvent free recycling agent set too fast on one of the test sections on US006. The material clogged the screed and paver repeatedly. Great effort was required to remove the material from the equipment and the expected daily production rates were not realized. Therefore, it is important that a representative from the material supplier be on site to make adjustments to the set time until construction personnel become familiar with this type of recycling agent and can request formula adjustments from the material suppliers in the field. It is possible that the addition of water can provide better aggregate coating and extend the set time. Equipment is required that can handle the volume of water required to moisture condition the material properly in these instances. However, this solution does not provide remedy for all cases when set time is a controlling factor in construction operations and sometimes the recycling agent formula requires modification.

Raveling can occur when an insufficient amount of recycling agent is added to the CIR material. Reprocessing the pavement structure can correct raveling or application of a fog seal can prevent further damage from traffic. If the raveled areas are severe and isolated, the contractor can remove the raveled area and replace with premixed bituminous paving material. Minor raveling occurred at several intersections on SR226 because of truck turning movements and a fog seal was applied to prevent further damage.

Rutting can occur if too much recycling agent is added to the milled material or if there is not adequate compaction during construction operations. Rutting usually happens at intersections or areas where there are excessive turning movements. This problem can be mitigated by recompaction effort. If severe rutting occurs, the area may need to be reprocessed or replaced with premixed bituminous paving material. Low severity rutting occurred in isolated areas of several test sections and recompaction effort was used to mitigate this problem.

### 4.3 Lessons Learned

The experience gained by constructing the CIR test sections will help to improve construction practices on similar projects in the future. The following lessons were learned:

- Traffic control operations should be the contractor's obligation rather than NDOT's responsibility. NDOT maintenance personnel provided traffic control operations for several low-volume road test sections in a partnering effort with contractors to reduce overall costs. Using NDOT labor for traffic control operations reduces the resources required for other items of work at critical times of the year. Construction work is notorious for long days and NDOT spent a substantial amount of money to fund overtime traffic control operations. In addition, with contractor supplied traffic control, construction operations can be expedited because the contractor can hire more crews or work on weekends if necessary.

- The road will only be as smooth as the recycled pavement structure since the wearing course does not provide improved rideability, nor can it correct rideability deficiencies. Adequate rideability is an important concern in the construction of CIR projects. A Type C profile index of 10 in./mi can easily be accomplished with good equipment technique. If corrective action is required, the following methods may prove useful for smoothing areas with poor rideability:

    - Experienced operators can gently blade the chatter or washboarding and high points out of a recycled pavement structure with a scarifier blade. This remedy for improving ride quality can be as effective as more expensive methods of remediation such as profile grinding or reprocessing. Blading is best accomplished in warm afternoon temperatures, to be followed by additional compaction and fog seal.

    - The milling machine can accomplish profile grinding. The machine can be adjusted to mill 1/4 in. off the pavement structure. The pavement structure should be swept, compacted, and fog sealed after the deviations are corrected. This procedure is best accomplished in cool morning temperatures so that the weight of the milling machine does not cause rutting or additional distress on the newly recycled pavement structure.

    - Often, small irregularities in the CIR pavement structure can be effectively removed with additional compaction effort.

- The rolling patterns required to properly compact CIR projects with solvent free and polymer modified recycling agents are quite different than the rolling patterns used with CMS-2S recycling agent. An additional vibratory steel-wheeled roller is needed and should be required in future special provisions. Equipment operators and construction inspectors will need to gain additional experience with the rolling patterns used for the solvent free and polymer modified recycling agents.

- The use of polymer modified recycling agent can extend the recycling season significantly. The product can be used with pavement surface temperatures as low as 40º F. An extended recycling season is a great benefit for personnel working to increase production rates while struggling with the demands of the construction season.

- The recycling agent content for CIR with stockpiled millings should be increased to 2.5% for estimate purposes. The CIR could have used more recycling agent in the recycled mixture when the road was constructed. Both the resident engineer and contractor recognized that the mix was too dry as the road was constructed. Unfortunately, there was no additional funding available to buy additional recycling agent and construction proceeded with the estimated project quantity of 1.5% by mass for the recycling agent.

- The estimate for CIR with stockpiled millings should include an additional pay item to “Haul and Place Material in Windrow from Stockpile,” with a pay unit of “Ton.” This pay item will help to guarantee that the appropriate amount of material is used for the specified depth of the recycle. The item should be discussed in the planning stage for each project because the expense and time required certifying scales must be addressed and could be cause for concern on projects in remote locations.

- Millings can be used cost-effectively in CIR operations. A value engineering analysis should be accomplished to determine cost-effective haul distances. Engineers should plan ahead to effectively stockpile and utilize millings for future projects.

# CHAPTER 5 SURFACE TREATMENTS

## 5.1 Surface Treatments Introduction

Surface treatment is a general term that includes many types of asphalt and aggregate applications. Surface treatments are pavement preservation strategies that are placed to improve or extend the functional service life of the pavement. The treatments protect the surface characteristics of the roadway and will slow down the rate of deterioration. However, the applications do not provide pavement structural improvement. The applications are usually less than 1 in. thick. Examples of surface treatments include many types of seals such as chip, cape, fog, slurry, sand, and scrub. An open-graded friction course is considered to be a surface treatment. Surface treatments should be applied at periodic intervals in pavement preservation programs. Surface treatments can:

- Provide a new wearing surface.
- Seal minor cracks.
- Waterproof the underlying pavement layers.
- Improve skid resistance and appearance.
- Rejuvenate the top 1/4 in. of pavement structure.

Surface treatments can also be used as wearing courses for stabilized bases, recycled pavement structures, and full depth reclamation strategies. When used for this purpose, the treatment provides a wearing surface and prevents ingress of water into the stabilized base below.

Surface treatments were constructed as pavement preservation strategies and as wearing courses for the full depth reclamation (FDR), cold in-place recycling (CIR), and cold mix asphalt concrete rehabilitation strategies. The surface treatments applied for pavement preservation purposes included chip seals with various aggregate gradations and asphalts, a double chip seal over nonwoven polypropylene geotextile fabric, cape seal, fog seal, and sand seal. The surface treatments applied as wearing courses for the FDR, CIR, and cold mix asphalt concrete test sections included single and double chip seals with various aggregate gradations and asphalts, cape seal, and microsurfacing. A description of the applied surface treatments is followed by discussion of the constructability issues and lessons learned. Test section performance is evaluated in Chapter 6.

*Chip Seal*

A chip seal is a layer of asphalt binder that is covered with a layer of aggregates. The aggregates are compacted or embedded into the binder. A single chip seal is a layer of asphalt binder with 1/2 in. or 3/8 in. size aggregates embedded into the binder. A double chip seal is two consecutively applied single chip seals and usually, both 1/2 in. and 3/8 in. size aggregates are used. Typically, the smaller size aggregate layer is placed on top of the larger size aggregate layer. Single or double chip seal surface treatments can provide an average of five or more years of service life. Double chip seals are more durable than single chip seals in areas where rigorous snowplow use is anticipated. Single and double chip seals were placed as pavement preservation strategies on the existing pavement surface on SR230 and US006. Single and double chip seal surface treatments were applied as wearing courses on the FDR, CIR, and cold mix asphalt concrete test sections constructed on SR230, US006, SR226, SR168, and SR892.

Successful chip seal placement has been considered both art and science as success is based on local empirical experience. The variability of local materials and existing pavement surfaces causes conditions that require asphalt binder rate adjustments in the field at the time of construction. An experienced crew is essential for obtaining a high quality product. NDOT's maintenance personnel placed all the chips seals for the low-volume roads test sections.

*Chip Seal over Nonwoven Polypropylene Geotextile Fabric*

A chip seal can be used in combination with other products such as nonwoven polypropylene geotextile fabric. The fabric is seated in a tack coat and a single or double chip seal is placed on top of the fabric. The fabric acts as a waterproof interlayer that prevents water from penetrating into the pavement structure and also acts as a crack retardant. This strategy was placed on SR230 for a side-by-side comparison with a double chip seal surface treatment without fabric. Figures 5.1a and 5.1b show a nonwoven polypropylene geotextile fabric seated in the tack coat and maintenance personnel placing a chip seal over the fabric.

**FIGURE 5.1a Nonwoven polypropylene geotextile fabric seated in tack coat.**

**FIGURE 5.1b Maintenance personnel place chip seal.**

*Fog Seal*

A fog seal is a light application of asphalt diluted with water and placed on the existing pavement surface. This type of seal will rejuvenate an oxidized pavement structure and can seal small cracks. However, the treatment does not provide a new wearing surface nor does it improve skid resistance. The proper application rate must be carefully applied or skid resistance may be compromised. Two types of fog seal were applied on US006 for comparison purposes.

*Microsurfacing*

Microsurfacing is a slurry type resurfacing mixture that is dense graded, cold mixed, and quick setting. The mixture is applied in a semi-liquid condition with special equipment. The mixture changes from a semi-liquid state to a dense cold mix material within one hour of application. Public traffic is allowed shortly thereafter. The mixture is made of polymer modified asphalt emulsion, aggregates, mineral filler, water, and set-control additives. Microsurfacing is a more robust resurfacing mixture than slurry seal and applied in two layers if rut filling is required. Microsurfacing was applied as a wearing course on the CIR pavement structure on US006.

*Sand Seal*

A sand seal is a surface treatment constructed by spraying an asphalt binding agent on the existing pavement structure. A thin layer of sand type aggregates is immediately spread on the asphalt binding agent and the aggregates are rolled into the asphalt binding agent. The maximum aggregate size is usually smaller than a No. 10 sieve. A sand seal was placed in the vicinity of the fog seals on US006 for comparison purposes.

*Scrub Seal*

Scrub seals are surface treatments used to preserve pavements. A scrub seal is constructed by spraying emulsified asphalt, scrubbing the emulsion into cracks with a broom, spreading fine aggregates, scrubbing the aggregates into cracks with a broom, and rolling the surface. Scrub seals are useful on pavements with small cracks, raveling, and oxidation. NDOT uses a scrub seal as a mechanized crack filling operation and a chip seal is usually placed one to three years after the scrub seal.

*Slurry Seal over a Chip Seal (Cape Seal)*

Slurry seal is a resurfacing mixture comprised of asphalt emulsion, aggregates, water, and additives such as mineral fillers or set control additives. The mixture is applied in a semi-liquid condition and changes into a dense cold mix material within three or more hours of application. There are three types of slurry seal and the type of slurry seal is dependant on aggregate gradation and amount of aggregate applied. Type 1 slurry seals are used on pavements for maximum crack penetration in low traffic areas. Type 2 slurry seals are used to correct medium to high severity raveling, oxidation, and improve skid resistance. Type 3 slurry seals are used to correct severe distresses in heavy traffic conditions. Slurry seals provide all the benefits of surface treatments. When a slurry seal is placed over a newly constructed chip seal, the layering system is called a cape seal. Cape seals are proven surface treatment options. A cape seal was placed as a wearing course on the CIR pavement structure on US006. A cape seal was also used on US006 as a pavement preservation strategy for the existing pavement surface.

### 5.2 Constructability Issues

Surface treatments were constructed as pavement preservation strategies as well as for wearing courses on the CIR, FDR, and cold mix asphalt concrete test sections. Table 5.2 lists the type of surface treatment, purpose of surface treatment, and lane miles constructed.

**TABLE 5.2**
**Type of Surface Treatment, Purpose, and Number of Lane Miles Constructed**

| TYPE OF SURFACE TREATMENT | PAVEMENT PRESERVATION (LANE MILES) | WEARING COURSE FOR CIR, FDR, AND COLDMIX BITUMINOUS SURFACE (LANE MILES) |
|---|---|---|
| Single chip seal with 1/2 in. size aggregates | 2.4 | 54.4 |
| Single chip seal with 3/8 in. size aggregates | 2.0 | ---- |
| Double chip seal | 3.0 | 141.7 |
| Double chip seal over geotextile fabric | 3.2 | ---- |
| Cape seal | 4.0 | 6.0 |
| Fog seal | 1.1 | ---- |
| Sand seal | 0.5 | ---- |
| Microsurfacing | ---- | 4.0 |
| **TOTAL** | **16.2** | **206.1** |

NOTE: Dash (----) denotes not applicable.

*Single Chip Seal*

Single chip seal test sections with 3/8 in. and 1/2 in. size aggregates were placed on US006 as pavement preservation strategies. The sections were constructed uneventfully with a polymer modified asphalt emulsion and new or stockpiled aggregates. NDOT maintenance crews found the polymer modified asphalt emulsion easy to work with and had no complaints concerning its use.

Single chip seals were placed as wearing courses for several FDR, CIR, and cold mix asphalt concrete test sections on SR230 and SR168. Placement was successful with exception of the cold mix asphalt concrete test sections. The chip seal aggregates did not bond well with the cold mix asphalt concrete pavement due to the fact that the cold mix asphalt concrete pavement was not allowed to cure for the recommended amount of time to allow the diluents to evaporate. Typically, a six month to one year curing period is advised before placing a chip seal wearing course on a cold mix asphalt concrete pavement. The chip seals were placed on the cold mix asphalt concrete pavement within six weeks of construction and no bonding occurred. The cold mix asphalt concrete pavement test sections required additional chip seal wearing courses in the subsequent years since original construction.

*Double Chip Seal*

NDOT maintenance crews placed double chip seal test sections on SR230 as pavement preservation strategies. These test sections were constructed to compare the performance of the double chip seal test sections with the performance of the nonwoven polypropylene geotextile fabric and double chip seal test sections.

Double chip seals were successfully constructed as wearing courses for the FDR and CIR test sections located on SR230, US006, SR226, and SR892. The double chip seal provides a more robust wearing surface in snow country where winter maintenance activities are anticipated.

*Double Chip Seal over Nonwoven Polypropylene Geotextile Fabric*

A nonwoven polypropylene geotextile fabric was embedded in a bonding asphalt cement layer and capped with a double chip seal on two test sections on SR230. Contractors placed the fabric and NDOT maintenance personnel placed the double chip seals. These test sections were NDOT's first attempt at constructing this type of strategy and several constructability issues developed despite due diligence with researching placement techniques.

It is important to place enough asphalt to embed the fabric properly so that the chip seal asphalt does not absorb into the fabric, thus preventing adequate film thickness to maintain the integrity of the chip seal. After the fabric was successfully embedded in the asphalt layer, sand was used as a bond breaker to prevent equipment from tracking on the fabric. The only sand available for use as the bond breaker was wet and logistics did not allow for the timely drying of the sand. Because of the wet condition of the sand and the character of the sanding equipment, approximately three times as much sand cover as required was placed on the fabric. Removal of the excess sand cover was premature at several locations and this removal caused the fabric to be left in the sun uncovered. Hence, the asphalt layer that the fabric was embedded in seeped through the fabric. Tracking problems occurred since there was no bond breaker left on the fabric. In the future, sand cover should be left on the fabric until immediately before chip seal operations.

Another construability issue was caused by the nominally sized tractor used to place the fabric. The tractor was unable to handle the weight of the fabric roll, and the fabric roll sagged in the center while the fabric was placed. This resulted in excessive wrinkling of the fabric and due diligence was required to remove the wrinkles. An adequately sized tractor should be specified in future contract provisions.

*Cape Seal and Microsurfacing*

Cape seal was used as a pavement preservation strategy and as a wearing course on the CIR surface on US006. A Type 3 slurry seal was applied over a 3/8 in. single chip seal as a pavement preservation treatment. Additionally, a slurry seal was placed on a 1/2 in. single chip seal and used as a wearing course on the CIR surface. Contractors placed the slurry seal and NDOT's maintenance personnel placed the chip seals. It is not recommended that slurry seals or cape seals be used on low-volume roads in the future because of the long length of cure time required before traffic is allowed on the sealed surface. Microsurfacing cures much faster than slurry seal and is the preferred alternative.

There were no construction related problems reported in the placement of a Type 3 microsurfacing wearing course for the CIR surface on US006. A portion of the microsurfacing test section was scraped up due to snowplow activity in the first winter season after construction. The contractor returned the following spring and repaired the damage. The test section has remained intact since the repair and has survived numerous winter activities since original construction.

*Fog Seal and Sand Seal*

Test sections with two types of fog seals and a sand seal were placed in a side-by-side comparison along with a "do nothing" test section on US006. The test sections included a CSS-1H fog seal, polymer modified asphalt emulsion fog seal, and sand seal using a restorative seal. A CSS-1H fog seal is the type of fog seal commonly used by NDOT. The test sections were applied easily without incident. The test sections have been reviewed and there was substantial evidence that the polymer modified asphalt emulsion fog seal outperformed the CSS-1H fog seal and sand seal using a restorative seal.

## 5.3 Lessons Learned

Surface treatments used as pavement preservation strategies are very cost-effective methods for extending pavement service life if the right strategy is applied at the right time for each specific project. The double chip seal placed on the nonwoven polypropylene geotextile fabric was not constructed in an appropriate environment for its intended function. The benefit of using a geotextile fabric is to keep water from entering the aggregate base, which has a 40% higher load bearing capacity than the same section when saturated. The strategy was improperly used in an area that consisted of heavily irrigated agricultural land and wetland type areas. There was water saturating the base through capillary action from below and summer heat caused steam to rise and get trapped by the fabric. The force of the trapped air caused bubbles in the fabric and the chip seal stripped off the fabric in the areas on and around the bubbles. Despite the fact that the strategy was constructed in a poorly chosen environment, it was noticeable that that the surface treatment functioned for its intended purpose.

Surface treatments that were constructed for wearing course purposes were used successfully for the FDR and CIR test sections. However, it is recommended that newly constructed cold mix asphalt concrete pavement be allowed to cure for at least six months to a year before placing a chip seal wearing course on it. The chips did not bond well with the cold mix pavement due to the fact that the cold mix was not cured for the appropriate amount of time to allow the diluents to disperse. The cure time is necessary to allow for the volatiles to evaporate from the cold mix material.

# CHAPTER 6 PAVEMENT EVALUATION AND PERFORMANCE

## 6.1 Pavement Evaluation and Performance Introduction

Pavement roughness and condition surveys were conducted for each test section before construction, after construction, and annually thereafter. These surveys measured the functional and structural characteristics of the pavement structure. A high-speed profiler with three laser sensors was used to collect rut and International Roughness Index (IRI) data. Ruts are defined as longitudinal surface depressions in the wheel paths. Often, shoving or pavement uplift occurs along the sides of the ruts. Rutting is considered severe if the rutting is 1/2 in. or deeper (*7*). The IRI is a worldwide standard for measuring pavement smoothness. The IRI measures the cumulative deviation from a smooth surface in inches per mile. A lower IRI number is indicative of a smoother ride. The ride quality is a function of the type of equipment used as well as the type of workmanship. Higher quality equipment and experienced construction personnel can produce more consistent ride quality results.

NDOT uses specification requirements for ride quality in most contract special provisions. The maximum allowable profile index for the full depth reclamation (FDR) and cold in-place recycling (CIR) test sections was 10 in./mi using the California type profilograph for measurement. This quality control measure assured NDOT that the ride quality would meet expectations for the low-volume roads network. If the ride quality did not meet minimum specifications, the contractor was required to correct the deviations.

The Present Serviceability Rating (PSR) is a pavement rating system based on a scale of zero to five. The rating system is divided into five categories with corresponding descriptions. PSR data can be derived mathematically from IRI data and NDOT collects both IRI and PSR data in its pavement management database.

Pavement condition data was systematically collected through use of NDOT's *Flexible Pavement Distress Identification Manual*. The manual provided instruction and guidelines for the collection of accurate, consistent, and repeatable pavement condition data. Condition data was grouped into categories such as cracking, surface deformation, patching, and surface defects. The type and severity of the identified distresses can indicate whether the pavement is experiencing structural or functional deficiencies (*7*).

The structural properties of the FDR and cold mix asphalt concrete test sections were evaluated through use of the falling weight deflectometer (FWD). FWD was conducted to determine the structural capacity of the pavement structures.

Field cores were sampled to determine the aging characteristics of the foamed asphalt and CIR materials. Laboratory evaluations for air voids, resilient modulus, indirect tensile strength, retained strength, and rutting susceptibility properties were performed (*8, 9, 10, 11*). The depth of the pavement structure, condition, and quality of the materials were also determined by the field cores. Appendix A contains pictures of selected core samples before and after construction.

A ground penetrating radar (GPR) survey was performed on SR892 because the technology showed promise for determining the depth of structural sections with noninvasive and nondestructive technology. The technology has some limitations and much of the effectiveness of GPR technology is a function of the skill of the GPR operator and skill of the data interpreter.

## 6.2 Roughness and Condition Surveys

The Federal Highway Administration (FHWA) set threshold values for acceptable IRI and PSR in the *Performance Plan for the National Highway System*. Previous terms for rating interstate and other roads included very good, good, fair, mediocre, and poor. Poor was indicated when roads other than interstates had a PSR of less than 2.0 and an IRI rating that was greater than 220. Updated ride quality terms include good, acceptable, and not acceptable for all functional classifications. Agencies may use less stringent standards for lower functional classification highways. A PSR rating equal to or over 2.5 is considered acceptable and an IRI rating equal to or less than 170 is considered acceptable for all functional classifications (*5, 12*).

### *IRI Evaluation*

The roughness survey results indicate that there was only 0% to 6% improvement in the foamed asphalt and cement FDR test sections. The FDR test sections using lime and emulsified asphalt, proprietary emulsified asphalt, and proprietary liquid stabilizer were improved from 10% to 36% because of a thin hot mix asphalt concrete overlay used to correct complications resulting from constructability and material issues. The improvements are characteristic of the equipment techniques used for these types of rehabilitation strategies. A motor grader was used to define the shape and grade of the roadway geometrics. An experienced motor grader operator is crucial for optimizing the rideability characteristic of the roadway. Since the operator did not have extensive experience with these types of rehabilitation strategies, the outcome is reflected in the IRI results. The IRI results are higher in the areas where paving equipment was used for the hot mix asphalt concrete overlay.

The CIR test sections showed rideability improvements from 19% to 32% in five of the seven test sections. Two of the CIR test sections on US006 had no improvement and the rideability was considered adequate prior to construction operations. A review of IRI improvement for the SR168, SR226, and SR892 CIR test sections suggests that ride quality can be expected to be approximately 100 to 120 after construction. These values are well below the FHWA's criteria for an acceptable rating to be equal to or less than 170. The CIR rideability improvement is the result of the type of equipment used to shape and grade the roadway. Since a paver was used to lay the windrowed CIR material, there was better control over roadway geometrics, and this is revealed in the IRI results. There were no significant improvements for the surface treatments or cold mix asphalt concrete test sections on SR230 and US006.

Rut depth evaluations indicate that the four and five year old surfaces on SR230 and US006 are stabilized since there were no substantial changes in rut depth since post-construction data was collected. The SR168, SR226, and SR892 test sections are stabilized as well since there were insignificant changes in rut depth after two and three years. Table 6.2 lists the average reported results for IRI and rut depth data.

### *PSR Evaluation*

The PSR for the FDR rehabilitation strategies on SR230 improved 2% to 31% after construction, with exception of the 3.0% cement test section. Much of this improvement is due to the thin hot mix asphalt concrete overlay used to correct complications resulting from constructability and material issues. The five year evaluation for the FDR test sections demonstrates that three of six test sections continued to improve by up to 10% after construction. The CIR test sections on SR168, SR226, and SR892 were improved by 10% to 25% post-construction. The cold mix asphalt concrete pavements and surface treatments on SR230, surface treatments on US006, and CIR on US006 demonstrated no PSR improvement. Table 6.2 lists the average reported results for PSR data.

*Condition Evaluation*

Pavement distresses including transverse, nonwheel path, and block cracking were eliminated on all routes post-construction. Some transverse cracking has occurred in three FDR test sections on SR230 that were completed over five years ago. The extent of the cracking is evidence of the rigidity of the pavement structure. For example, the section that contains cement added at a rate of 3.0% by mass is experiencing 8% transverse cracking and the foamed asphalt section that has cement added at a rate of 2.0% by mass has 5% transverse cracking. Minimal amounts of cracking distress were observed in the four and five year evaluations for a cold mix asphalt concrete pavement test section on SR230 and several surface treatment test sections on SR230 and US006. There were no distresses observed in the two and three year evaluations on SR168, SR226, and SR892. Table 6.2 contains the average reported distress data collected in the condition surveys.

**TABLE 6.2 Average Reported Results for PSR, IRI, Rut Depth, and Distresses (Before and After Construction)**

| Route and Strategy | Timing and Improvement | PSR Average | IRI Average | Rut Depth Average | Transverse Cracking Average | Nonwheel Path Cracking Average | Block Cracking Average |
|---|---|---|---|---|---|---|---|
| SR230 FDR with Lime and Emulsified Asphalt | Before Construction | 2.29 | 190 | 0.26 in. | 7% | 1% | 0% |
| | After Construction | 2.90 | 133 | 0.00 in. | 0% | 0% | 0% |
| | Percent Improvement | 26% | 30% | 100% | 100% | 100% | -- |
| | 5 Year Evaluation | 2.74 | 147 | 0.05 in. | 3% | 0% | 0% |
| SR230 FDR with Proprietary Liquid Stabilizer (6 in.) | Before Construction | 2.35 | 184 | 0.16 in. | 0% | 0% | 20% |
| | After Construction | 3.09 | 117 | 0.07 in. | 0% | 0% | 0% |
| | Percent Improvement | 31% | 36% | 56% | --- | --- | 100% |
| | 5 Year Evaluation | 3.13 | 114 | 0.06 in. | 0% | 0% | 0% |
| SR230 FDR with 3.0% Cement | Before Construction | 2.58 | 161 | 0.26 in. | 0% | 0% | 20% |
| | After Construction | 2.44 | 175 | 0.07 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | 73% | -- | -- | 100% |
| | 5 Year Evaluation | 2.62 | 158 | 0.03 in. | 8% | 0% | 0% |
| SR230 FDR with 4.5% Cement | Before Construction | 2.29 | 190 | 0.18 in. | 4% | 5% | 0% |
| | After Construction | 2.41 | 178 | 0.09 in. | 0% | 0% | 0% |
| | Percent Improvement | 5% | 6% | 50% | 100% | 100% | --- |
| | 5 Year Evaluation | 2.38 | 181 | 0.08 in. | 0% | 0% | 0% |
| SR230 FDR with Proprietary Emulsified Asphalt | Before Construction | 2.58 | 161 | 0.18 in. | 0% | 0% | 20% |
| | After Construction | 2.76 | 145 | 0.05 in. | 0% | 0% | 0% |
| | Percent Improvement | 7% | 10% | 72% | --- | --- | 100% |
| | 5 Year Evaluation | 3.09 | 117 | 0.03 in. | 0% | 0% | 0% |
| SR230 FDR with Foamed Asphalt | Before Construction | 2.37 | 182 | 0.23 in. | 7% | 0% | 25% |
| | After Construction | 2.42 | 177 | 0.08 in. | 0% | 0% | 0% |
| | Percent Improvement | 2% | 3% | 62% | 100% | -- | 100% |
| | 5 Year Evaluation | 2.34 | 185 | 0.05 in. | 5% | 0% | 0% |
| SR230 Cold Mix Asphalt Concrete (CMS-2S) | Before Construction | 2.71 | 149 | 0.27 in. | 3.5% | 0% | 7% |
| | After Construction | 2.27 | 193 | 0.08 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | 70% | 100% | --- | 100% |
| | 5 Year Evaluation | 2.16 | 205 | 0.08 in. | 1% | 0% | 0% |

*Table 6.2 Continued*

| Route and Strategy | Timing and Improvement | PSR Average | IRI Average | Rut Depth Average | Transverse Cracking Average | Nonwheel Path Cracking Average | Block Cracking Average |
|---|---|---|---|---|---|---|---|
| SR230 Cold Mix Asphalt Concrete (HFMS-2S) | Before Construction | 2.73 | 148 | 0.26 in. | 3% | 0% | 25% |
| | After Construction | 2.30 | 189 | 0.14 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | 46% | 100% | --- | 100% |
| | 5 Year Evaluation | 3.39 | 95 | 0.09 in. | 0% | 0% | 0% |
| SR230 Cold Mix Asphalt Concrete (MC-800) | Before Construction | 2.61 | 159 | 0.25 in. | 0% | 0% | 50% |
| | After Construction | 2.38 | 181 | 0.11 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | 56 % | --- | --- | 100% |
| | 5 Year Evaluation | 2.69 | 151 | 0.02 in | 0% | 0% | 0% |
| SR230 Double Chip Seal | Before Construction | 2.50 | 169 | 0.16 in. | 3% | 0% | 25% |
| | After Construction | 2.47 | 172 | 0.13 in. | 3% | 0% | 0% |
| | Percent Improvement | --- | --- | 19% | --- | --- | 100% |
| | 5 Year Evaluation | 2.33 | 186 | 0.12 in. | 10% | 3% | 0% |
| SR230 Double Chip Seal with Fabric | Before Construction | 2.39 | 180 | 0.23 in. | 4% | 2% | 50% |
| | After Construction | 2.44 | 175 | 0.16 in. | 0% | 0% | 0% |
| | Percent Improvement | 2% | 2% | 30% | 100% | 100% | 100% |
| | 5 Year Evaluation | 2.44 | 175 | 0.19 in | 2% | 0% | 0% |
| US006 Cold in-Place Recycling with CMS-2S | Before Construction | 3.63 | 78 | 0.10 in. | 2% | 0.4% | 0.4% |
| | After Construction | 3.57 | 82 | 0.11 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | --- | 100% | 100% | 100% |
| | 4 Year Evaluation | 3.41 | 93 | 0.09 in. | 1% | 0% | 0% |
| US006 Cold in-Place Recycling with Solvent Free Emulsified Asphalt | Before Construction | 3.68 | 75 | 0.12 in. | 1.2% | 2.6% | 0% |
| | After Construction | 3.60 | 80 | 0.12 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | --- | 100% | 100% | --- |
| | 4 Year Evaluation | 3.40 | 94 | 0.09 in. | 0.6% | 0% | 0% |
| US006 Surface Treatments | Before Construction | 3.72 | 72 | 0.11 in. | 2.3% | 1.3% | 0% |
| | After Construction | 3.59 | 81 | 0.11 in. | 0% | 0% | 0% |
| | Percent Improvement | --- | --- | --- | 100% | 100% | --- |
| | 4 Year Evaluation | 3.44 | 91 | 0.04 in. | 2% | 0.2% | 0% |
| SR226 Cold in-Place Recycling with CMS-2S | Before Construction | 3.07 | 119 | 0.29 in. | 2% | 1% | 6% |
| | After Construction | 3.39 | 95 | 0.06 in. | 0% | 0% | 0% |
| | Percent Improvement | 10% | 21% | 79% | 100% | 100% | 100% |
| | 3 Year Evaluation | 3.40 | 94 | 0.06 in. | 0% | 0% | 0% |

| *Table 6.2 Continued* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Route and Strategy** | **Timing and Improvement** | **PSR Average** | **IRI Average** | **Rut Depth Average** | **Transverse Cracking Average** | **Nonwheel Path Cracking Average** | **Block Cracking Average** |
| SR226 | Before Construction | 3.15 | 113 | 0.06 in. | 0% | 0% | 51% |
| Cold in-Place Recycling | After Construction | 3.59 | 81 | 0.04 in. | 0% | 0% | 0% |
| with Solvent Free | Percent Improvement | 14% | 28% | 33% | --- | --- | 100% |
| Emulsified Asphalt | 3 Year Evaluation | 3.59 | 81 | 0.06 in. | 0% | 0% | 0% |
| SR168 | Before Construction | 3.02 | 123 | 0.17 in. | 1% | 0% | 13% |
| Cold in-Place Recycling | After Construction | 3.32 | 100 | 0.10 in. | 0% | 0% | 0% |
| with Millings and | Percent Improvement | 10% | 19% | 41% | 100% | --- | 100% |
| CMS-2S | 2 Year Evaluation | 3.33 | 99 | 0.02 in. | 0% | 0% | 0% |
| SR892 | Before Construction | 2.46 | 173 | 0.23 in. | 6% | 4% | 1% |
| Cold in-Place Recycling | After Construction | 3.08 | 118 | 0.02 in. | 0% | 0% | 0% |
| with Polymer Modified | Percent Improvement | 25% | 32% | 91% | 100% | 100% | 100% |
| Emulsified Asphalt | 2 Year Evaluation | 3.17 | 111 | 0.04 in. | 0% | 0% | 0% |
| SR892 | Before Construction | 2.55 | 164 | 0.24 in. | 6% | 3% | 1% |
| Cold in-Place Recycling | After Construction | 2.92 | 131 | 0.03 in. | 0% | 0% | 0% |
| with Solvent Free | Percent Improvement | 14% | 20% | 87% | 100% | 100% | 100% |
| Emulsified Asphalt | 2 Year Evaluation | 2.97 | 127 | 0.03 in. | 0% | 0% | 0% |

NOTE: Dash (----) denotes not applicable.

### 6.3 FWD Testing

The FWD is used to determine the magnitude of surface deflections. Surface deflections are an indication of the capacity or integrity of the pavement structure. FWD measurements were taken both before and after construction for the FDR and cold mix asphalt concrete pavement test sections on SR230 to determine if the rehabilitation treatments improved the integrity of the pavement structure. The surface deflections were evaluated using sensor number one, D1, corrected to 70°F and normalized to 11,000 pounds.

The SR230 pavement structure was considered to have been in a failed condition previous to rehabilitation attempts. A structural failure is classified as the collapse of the pavement structure that renders the pavement incapable of sustaining traffic loads imposed upon its surface. After the FDR rehabilitation strategies were constructed, the pavement structure improved by 35% to 73% and was considered to be in a fair condition. The FDR with cement treated pavement structures showed the most improvement. The cold mix asphalt concrete test sections were improved by 22% to 37% and the MC-800 test section was the most improved. The CMS-2S cold mix asphalt concrete test sections with specially graded aggregates did not improve the pavement structure enough to be considered acceptable. Table 6.3 lists the surface deflections before construction, the surface deflections after construction, and the percent improvement for the selected rehabilitation strategies.

**TABLE 6.3 Summary Table of Surface Deflections and Percent Improvement**

| Type of Rehabilitation Strategy | D1 Before Construction (Mils) | D1 After Construction (Mils) | Percent Improvement |
|---|---|---|---|
| FDR with Lime and CMS-2S | 51 | 20 | 60 |
| FDR with Proprietary Emulsified Asphalt | 39 | 25 | 35 |
| FDR with Foamed Asphalt | 41 | 19 | 53 |
| FDR with 3.0% Cement by Mass | 34 | 12 | 64 |
| FDR with 4.5% Cement by Mass | 30 | 8 | 73 |
| Cold Mix Asphalt Concrete with CMS-2S Emulsified Asphalt | 42 | 32 | 24 |
| Cold Mix Asphalt Concrete with HFMS-2S Emulsified Asphalt | 31 | 24 | 22 |
| Cold Mix Asphalt Concrete with MC-800 Liquid Asphalt | 32 | 20 | 37 |

### 6.4 Core Evaluation of Material Properties

Field cores were sampled in early 2006 from the following locations to determine the aging characteristics of the foamed asphalt and CIR materials:

- SR230 (Foamed asphalt)
- US006 (CIR with CMS-2S and solvent free recycling agents)
- SR226 (CIR with CMS-2S and solvent free recycling agents)
- SR168 (CIR with stockpiled millings and CMS-2S recycling agent)
- SR892 (CIR with solvent free and polymer modified recycling agents)

The materials were tested for air voids, resilient modulus, indirect tensile strength, and rutting susceptibility. The results for resilient modulus and indirect tensile strength were averaged from eight core samples per location. Reported data for rutting susceptibility were averaged from four core samples per location. The results varied significantly for each strategy and for each test section. At this time, the data are inconclusive and there is no direct correlation between field performance and laboratory testing. Table 6.4 presents a summary of the post-construction material properties for the foamed asphalt and CIR materials.

TABLE 6.4 Summary of Post-construction Material Properties

| Property | SR230 | | US006 | | SR226 | | SR168 | | | SR892 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Foamed Asphalt | | CIR | | CIR | | CIR with Stockpiled Millings | | | CIR | |
| | (Section 1) | (Section 2) | Solvent Free Emulsified Asphalt No Lime | CMS-2S Emulsified Asphalt With Lime | Solvent Free Emulsified Asphalt No Lime | CMS-2S Emulsified Asphalt With Lime | CMS-2S Emulsified Asphalt With Lime (Section 1) | CMS-2S Emulsified Asphalt With Lime (Section 2) | CMS-2S Emulsified Asphalt With Lime (Section 3) | Solvent Free Emulsified Asphalt No Lime | Polymer Modified Emulsified Asphalt No Lime |
| | Core Sample Age 3.5 Years | | Core Sample Age 2.5 Years | | Core Sample Age 1.5 Years | | Core Sample Age 0.5 Years | | | Core Sample Age 0.5 Years | |
| Air Voids (%) | 13.9 | 11.4 | 11.0 | 13.7 | 12.7 | 11.7 | 14.7 | 13.5 | 14.4 | 17.8 | 12.4 |
| Height (in.) | 2.47 | 2.49 | 2.55 | 2.59 | 2.24 | 2.38 | 1.90 | 2.50 | 2.47 | 1.4 | 1.7 |
| Resilient Modulus Dry at 77 °F (ksi) | 380 | 818 | 345 | 381 | 135 | 342 | 342 | 326 | 433 | 134 | 924 |
| Resilient Modulus Wet at 77 °F (ksi) | 408 | 439 | 229 | 254 | 76 | 255 | 215 | 230 | 354 | * | 529 |
| Resilient Modulus Ratio (%) | 100 | 54 | 66 | 67 | 56 | 75 | 63 | 71 | 82 | * | 57 |
| Indirect Tensile Strength (Unconditioned) at 77 °F (psi) | 50 | 96 | 88 | 79 | 30 | 51 | 59 | 55 | 63 | 23 | 139 |
| Tensile Strength (Conditioned) at 77 °F (psi) | 53 | 67 | 45 | 46 | 31 | 41 | 39 | 33 | 56 | * | 66 |
| Indirect Tensile Strength (%) (Retained Strength) | 100 | 70 | 51 | 58 | 100 | 80 | 65 | 59 | 89 | * | 48 |
| APA Permanent Deformation (mm) | 3.6 | 4.3 | 14.0 | 3.6 | 13.0 | 8.9 | 5.5 | 3.2 | 8.4 | 9.8 | 6 |

NOTE: Asterisk ( * ) denotes that samples disintegrated after moisture conditioning.

## 6.5 Core Evaluation for Depth, Quality, and Condition

Field cores are sampled to determine the depth of the pavement structure as well as the quality and condition of the materials. The depth of the core represents the history of the pavement structure and shows the various rehabilitation and surface treatment strategies that have been applied over the years. The quality and condition of a core is noticeable. Standard terms and severity levels have been developed to describe the quality and condition of a core. Stripped, delaminated, broken, and stripped and fell apart are a few of the terms used to describe cores. Severity levels include light, medium, and heavy. A description of the type and severity of cracking is also recorded for each core sample. Appendix A contains pictures of selected core samples retrieved both before and after construction for several test sections.

An inspection of the post-construction cores for SR230 show that the FDR test sections using foamed asphalt and 3% cement have the most substantial core depth after three years. One of the CMS-2S cold mix asphalt concrete test sections delaminated at placement depth and all cold mix asphalt concrete test sections displayed stripping with various severity levels. A two year evaluation of the US006 cores reveal that the CIR with solvent free recycling agent delaminated at placement depth and had light stripping. The CIR cores using the conventional CMS-2S recycling agent were in good condition and bonded well with the pavement structure below. A one year evaluation of the SR226 cores show that the CIR with solvent free recycling agent was delaminated at placement depth and had light stripping. The cores with CIR and CMS-2S recycling agent also had light stripping. A review of the SR168 cores demonstrates the improvement in pavement structure that can occur with use of CIR and stockpiled millings. The SR892 cores had stripping and delamination with use of the polymer modified recycling agent.

## 6.6 Ground Penetrating Radar

GPR is a noninvasive and nondestructive technology used to measure pavement structure thickness. The technology has been used for many purposes including the location of voids beneath pavements, measuring base and subbase thicknesses, and the detection of bridge deck delamination. The technology was initially developed in the 1960s for the United States military for the purpose of detecting shallow tunnels. The technology became commercially available in the 1970s and a large amount of literature has been published that addresses GPR for transportation related uses.

The technology detects changes in the electromagnetic properties of materials. The changes in properties create reflections of the GPR signal. The layer thickness is determined by the travel time of the reflection and the dielectric constant of the material. The constant is found by processing techniques based on subtraction of the perfect reflection from a metal plate and ratios of the reflection amplitude (*13*).

The effectiveness of the technology is dependant upon the skills of the data operators and interpreters. Use of the correct equipment is essential as the reflection penetration depth is a function of the radar operating frequency and material characteristics. Lower frequencies penetrate deeper and higher frequencies have better resolution. For pavement related uses, the best results are obtained with antenna frequencies in the 500 MHz to 2.5 GHz range. Determining pavement layers as thin as 2 in. reliably requires an antenna with a frequency of 2.5 GHz. However, each antenna frequency has its disadvantages and a 2.5 GHz antenna has a limited penetration depth. A lower frequency antenna is required to properly profile base and subbase layers. Thus, two separate GPR antennas are required to properly perform a complete pavement survey (*14*).

A GPR survey was performed on SR892 to determine if GPR would be a reliable and cost-effective method for determining the pavement structure depth of the low-volume roads network. The survey was performed by collecting data continuously at 30 mi/hr with a 1.0 GHz air-coupled antenna. GPR data was collected for the outer wheel path in both directions and along the centerline. The data was analyzed using commercially available GPR analysis software and the results were compared to field core samples.

Table 6.6 contains a summary of the comparison of GPR interpreted pavement thickness and core sample thickness.

**TABLE 6.6 GPR Data and Core Sample Thickness Comparison**

| NORTHBOUND<br>GPR AND CORE THICKNESS COMPARISON ACCURACY RANGE | NUMBER OF CORES | SOUTHBOUND<br>GPR AND CORE THICKNESS COMPARISON ACCURACY RANGE | NUMBER OF CORES | CENTERLINE<br>GPR AND CORE THICKNESS COMPARISON ACCURACY RANGE | NUMBER OF CORES |
|---|---|---|---|---|---|
| ≤ 10% | 5 | ≤ 10% | 7 | ≤ 10% | 2 |
| 10% ≤ 15% | 8 | 10% ≤ 15% | 9 | 10% ≤ 15% | 9 |
| 15% ≤ 20% | 3 | 15% ≤ 20% | 3 | 15% ≤ 20% | 5 |
| > 20% | 6 | > 20% | 4 | > 20% | 7 |
| Total | 22 | Total | 23 | Total | 23 |

There were 68 GPR and core thickness comparisons. There were only 14 pairs or 20% within the accuracy range of ± 10%. This accuracy or level of agreement was determined to be unacceptable for low-volume roads due to the nominal pavement structure anticipated for many of the routes. Choosing expensive rehabilitation options based on this level of agreement could have devastating financial consequences for already strained budgets.

This proven technology has been useful for many transportation related applications. Despite the results of the investigation on SR892, there is potential for refining the GPR application for use on low-volume roads. Several lessons were learned during the investigation and overcoming these challenges should result in better levels of agreement:

- A combination of more appropriate antenna frequencies would probably result in better levels of agreement. The contractor used the same antenna for the low-volume road investigation that the contractor normally uses for determining concrete pavement thickness.

- The SR892 investigation was conducted during snowy and rainy weather. The weather was an external variable that impacted field work. Future work should be conducted during weather without precipitation and when the roadway structure is dry.

- The contractor should obtain a couple of core samples directly below the radar apparatus to validate equipment calibration.

# CHAPTER 7 SELECTING AN OPTIMUM LOW-VOLUME ROADS REHABILIATION STRATEGY USING PROPOSED GUIDELINES

## 7.1 Background

Pavement managers are tasked with the challenge of preserving pavements and selecting strategies to rehabilitate pavement structures. This challenge is compounded when resources are limited and the road network is extensive. The optimal pavement preservation or rehabilitation strategy must be constructed at the right time and for the correct environmental condition in order to be cost-effective and function well. The importance of choosing the best alternative for pavement preservation and rehabilitation cannot be over emphasized because the financial consequence of choosing an inadequate alternative can have a devastating effect on a budget.

The primary objective of this research project was to develop low-volume roads rehabilitation guidelines for pavement managers. The guidelines are intended to assist managers with making appropriate and cost-effective decisions for NDOT's low-volume roads network. Managers should review the steps in 7.2 Pavement Distress, Deficiency, and Field-testing before using the guidelines.

The proposed guidelines were not exclusively developed as a consequence of this research project. The guidelines are the outcome of group consensus between engineers and managers to advance low-volume roads rehabilitation techniques to better serve state needs using recognized construction practices. The guidelines are provided to give direction to personnel challenged with maintaining the low-volume roads network while coping with diminishing funding levels. When guidelines are implemented, personnel can be assured that suitable and cost-effective rehabilitation strategies are constructed based on deficiencies relevant to individual projects.

It is important to note that although there were some constructability issues when the rehabilitation strategies were constructed, the strategies are proven industry standards. Typically, there are workability and constructability issues when implementing any new construction process and the project test sections proved to be no exception. As construction personnel gain experience with the various recommendations, there is sure to be additional satisfaction with future outcomes.

## 7.2 Pavement Distress, Deficiency, and Field-testing

Review the following steps for assistance with identifying pavement distress, causes for pavement deficiency, and field-testing methods that can be used to validate deficiency determinations:

*Step 1: Conduct an in-depth pavement distress identification survey:*

Use a flexible pavement distress identification reference manual to determine the type, extent, and severity of the pavement distresses. Reference manuals have been developed to assist with collecting accurate and repeatable pavement condition data. The pavement distresses are categorized into specific types and have defined severity levels and methods for measurement. Knowing distress types will assist the reviewer with identifying the cause for pavement deterioration.

*Step 2: Determine if the cause of pavement deficiency is structural or functional:*

Use the pavement condition data collected in Step 1 to assist with determining whether the cause of pavement deterioration is structural or functional. Fatigue or alligator cracking located in the wheel paths, rutting, flushing, and patching can be indicative of structural inadequacy. Nonwheel path longitudinal cracking, block cracking, poor rideability, flushing, and raveling can be considered functional distress. Proper field-testing can be used to validate structural or functional deficiency determinations.

An agency can spend substantially more money than is required for pavement rehabilitation if the correct rehabilitation strategy is not selected. For example, if block cracking exists and there is evidence of oxidation of the binder, then a functional rehabilitation strategy such as cold in-place recycling (CIR) would be the most cost-effective strategy. However, if full depth reclamation (FDR) is used to correct the block cracking, the result will be a significantly higher project cost. Likewise, if FDR is required for pavement rehabilitation and the CIR strategy is used, there will be premature failure of the pavement. Therefore, it is important that the right strategy be used to accommodate the corrective action required for each specific project.

*Step 3: Conduct field-testing to validate deficiency determinations:*

Review available construction and maintenance history and use the information to help establish the type and frequency of any required field-testing. Appropriate testing should be conducted to validate deficiency determinations and to ensure successful construction practices. Testing is also used to minimize the risk associated with selecting the appropriate rehabilitation strategy.

Suggested field-testing methods include core sampling and falling weight deflectometer (FWD) for pavement experiencing structural deficiency. Core samples are pavement quality indicators that appraise the condition and actual depth of the pavement structure layers. Stripped, delaminated, and broken cores are noted insufficiencies. Cores are used in laboratory analysis to determine material properties including resilient modulus, moisture sensitivity, and strength.

Cores are required to ensure that there is adequate hot mix asphalt concrete pavement depth for the CIR process. A general application rule is that the existing pavement structure must be a minimum of 1.5 in. plus the intended CIR depth. Therefore, a minimum 4.5 in. of pavement structure is required for a 3 in. CIR. Likewise, a minimum 3.5 in. pavement structure is required to complete a 2 in. project. The intact 1.5 in. pavement structure is required to accommodate the weight of the CIR train.

The procedure for taking cores or depth checks should be established based on the pavement distress identification survey identified in Step 1. Cores should be sampled on cracks to determine whether the crack extends through the entire depth of the pavement structure. Cores should be sampled at different locations in relation to the pavement width in order to assess the cross section of the roadway. This is important on low-volume roads because roadway widening may have occurred in some areas and inconsistent pavement structures could exist.

FWD is a noninvasive testing method that detects the strength or weakness of the asphalt, base, and subgrade materials. Dynamic loads are applied to the pavement surface and the vertical deformation is measured. The FWD data in combination with layer thickness can be used to obtain the resilient modulus. About 15% of NDOT's low-volume roads network has structural deficiency. This estimate is based on a review of the historical construction database.

## 7.3 Low-Volume Roads Rehabilitation Guidelines

Figure 7.3 contains the proposed guidelines to be used for rehabilitating NDOT's low-volume roads network. The guidelines are divided into options that are contingent on whether the flexible pavement is experiencing structural or functional deficiency. Structural deficiency is an indication of the physical condition of the pavement. When a pavement structure has reached the limit of its load carrying capacity and is compromised, the pavement requires major rehabilitation. Pavement often has sound structure but does not serve drivers well. The drivers' comfort levels are not met due to a rough riding road surface. A rough ride or poor ride quality is known as a functional deficiency. Other functional surface characteristics include durability, texture, and appearance.

*Pavement with Structural Deficiency*

The rehabilitation guidelines recommend the following alternatives be used to rehabilitate flexible pavement with structural deficiency:

- Cold mix asphalt concrete overlay and chip seal wearing course.
- FDR and chip seal wearing course.
- CIR with the addition of stockpiled millings and chip seal wearing course.

A cold mix asphalt concrete overlay will add to the effective structural capacity of the pavement. A cold mix asphalt concrete overlay and chip seal wearing course can last from 15 to 20 years with subsequent maintenance activities. The service life is dependant on the type of distress mode of the pavement on which the cold mix asphalt concrete overlay is placed.

The use of FDR with foamed asphalt, cement, lime, and emulsified asphalt will increase the capacity of the pavement structure. The type of additive is dependent on material properties. Typically, foamed asphalt performs best with material that has a 10% to 20% fine aggregate content along with well-graded, silty, or clayey gravel. Cement is compatible with many material types including those with a plasticity index of less than ten. Lime works well with material that has a plasticity index greater than ten including many clay-containing materials. Emulsified asphalt can be used successfully in conditions similar to those of foamed asphalt including poorly graded gravel and sand. It is important to verify material properties before choosing an FDR additive. A FDR strategy can last anywhere from 14 to 20 years depending on the quality of original construction and the amount of subsequent corrective maintenance work.

A CIR with addition of stockpiled millings can be used to increase the pavement structure**.** Substantial costs have been paid to haul off and waste surplus millings from large rehabilitation projects. When millings are stockpiled locally it is possible to reduce haul costs, recycle material into a useful product, and rehabilitate a pavement for less cost than a new material overlay.

A single chip seal can be placed as a wearing course for these alternatives. A double chip seal wearing course is more effective in snow country with high-count snowplow passes. The type of chip seal is determined by the amount of moisture and freeze thaw conditions that the pavement is expected to experience. It may be necessary to place a thin hot mix asphalt concrete overlay on FDR alternatives if the ride quality is not achieved during construction operations.

*Pavement with Functional Deficiency*

A CIR and chip seal wearing course can be used to rehabilitate flexible pavement with functional deficiency when the existing pavement structure is 3.5 in. or greater. A CIR is optimally constructed with a 3 in. recycle depth and a minimum 4.5 in. depth of pavement structure. However, a 2 in. recycle depth can be used when the pavement structure has nominal depth. It is necessary to have at least 1.5 in. of the existing asphalt pavement structure intact so that the weight of the CIR train does not break through the pavement structure. The underlying base material should not be introduced into the recycled material.

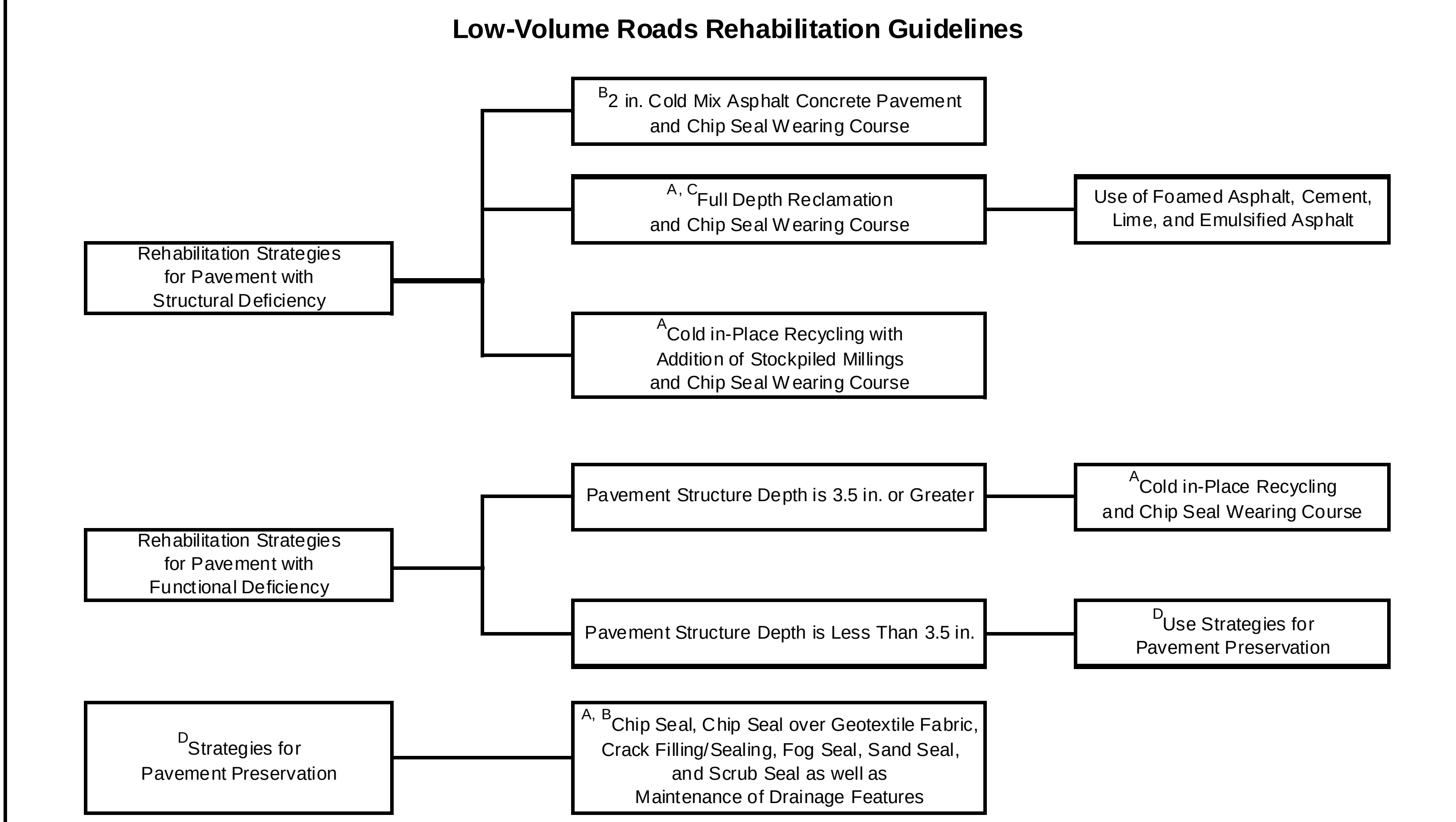
A pavement with up to 10% structural insufficiency can be recycled if the agency plans to correct the deficit areas. This situation occurred on the SR892 demonstration project. The pavement did not have adequate depth in some locations for optimal CIR operations. A cold mix stockpile was processed as part of the contract specifications and used for the deficit areas. The project was recycled successfully without excessive use of the stockpile and this was due to timeliness of construction operations. The project was completed in late August when the base and subgrade was relatively dry.

Use strategies for pavement preservation to rehabilitate pavement with functional distress and existing pavement structure depth of less than 3.5 in. Options include chip seal, chip seal over geotextile fabric, crack filling/sealing, fog seal, sand seal, and scrub seal. These strategies are proven and cost-effective surface treatments for low-volume roads.

Well maintained drainage features can help to extend pavement service life. If there are drainage problems occurring on roadways, ensure that corrective measures are taken to prevent similar problems in the future. Inadequate drainage is a common cause of pavement deterioration. If adequate drainage is not addressed, the same problem will reoccur and premature pavement failure can be expected. The use of strategies for pavement preservation may be the only alternative for pavement with functional deficiency if adequate hot mix asphalt concrete depth does not exist and funding is limited.

*Pavement Preservation*

Pavement preservation includes the timely application of surface treatments to extend the service life of the pavement structure. The treatments do not include new and reconstructed pavements or treatments that increase the structural capacity of the pavement structure. Items to consider when choosing an appropriate surface treatment include durability, service life expectancy, material availability, weather limitations, context compatibility, and availability of skilled labor. Surface characteristics, construction impacts, safety, and long-term life-cycle cost should also be examined.




[A] Place a single chip seal on pavement where no snowplow activity is expected; place a double chip seal on pavement where snowplow activity is expected.
[B] Crack filling or sealing is recommended before placing cold mix asphalt concrete pavement, chip seal, and chip seal over geotextile fabric.
[C] Thin hot mix asphalt concrete overlay may be required in lieu of chip seal wearing course if ride quality is not achieved.
[D] Use strategies for pavement preservation to reduce the rate of deterioration and extend the service life of the existing pavement. Strategies for pavement preservation will not improve the structural characteristics of the pavement.

**FIGURE 7.3 Proposed low-volume roads rehabilitation guidelines.**

# CHAPTER 8 PROJECTED ECONOMIC BENEFITS

## 8.1 Economic Benefits Introduction

Life-Cycle Cost Analysis (LCCA) is an analysis method based on principles of sound economics to evaluate the long-term efficacy between alternative investment options. The analysis incorporates initial and discounted future agency and user costs over the service life of alternative options. The analysis is used to determine the best value or the lowest long-term cost that satisfies the performance objective being sought for investment expenditures (*15*). A LCCA was performed for the strategies listed in the proposed low-volume roads rehabilitation guidelines to determine how potentially cost-effective the alternatives may be in comparison to NDOT's conventional practice of placing a 2 in. hot mix asphalt concrete overlay every 20 years. This analysis will assist pavement managers with the ability to quantify judgments based on economics.

NDOT's conventional practice of using a 2 in. hot mix asphalt concrete overlay and chip seal wearing course as the minimum rehabilitation strategy for low-volume roads is not a feasible option anymore. The recent trend of diverting the majority of funding into capacity improvement projects has left limited funds available for the 3R Program and limited funds for maintenance personnel to maintain the low-volume roads network. Despite increasing traffic volumes and the need to expand the roadway network, NDOT is still required to maintain its aging 3,385 lane miles of low-volume roads. Based on experience, spending an average of $247,000 per centerline mile is required for the expected 20 year service life of a low-volume road. This cost is based on the practice of placing a 2 in. hot mix asphalt concrete overlay and chip seal, with additional maintenance of two chip seals, three fog seals, and isolated patching and crack filling/sealing over a 20 year period. If this practice were continued to be used, approximately $21,000,000 a year in expenditures would be required to maintain the low-volume roads network.

One objective of this research project was to investigate proven rehabilitation strategies to determine if there are other alternatives for managing the network in a more cost-effective manner. The following factors were used in a deterministic LCCA of rehabilitation alternatives based on structural and functional deficiencies:

- Analysis period - A 20 year analysis period was used for rural areas.
- Discount rate - A 4% real discount rate was used with no inflation premium.
- Rehabilitation strategy - The strategy included initial and anticipated maintenance effort required to maintain the roadway at an acceptable level of serviceability through the analysis period.
- Costs - All costs necessary to carry the alternative through the analysis period should be considered. Costs included initial construction, maintenance, salvage value, and user costs. The user costs in rural areas of Nevada are minimal and were not considered for this analysis.
- Present Worth Method - The present worth method is an economic analysis method involving the conversion of all present and future expenses to a net present value.

### 8.2 Life-Cycle Cost Analysis

A 20 year LCCA was performed for one low-volume road centerline mile using the conventional 2 in. hot mix asphalt concrete overlay and chip seal wearing course as well as alternative rehabilitation strategies for managing both structural and functional deficiencies. The net present values include initial rehabilitation costs and all anticipated future maintenance costs necessary to carry the alternative through the 20 year analysis period. The design life or service life of rehabilitation strategies can vary considerably and is dependent on numerous considerations including the quality of construction, subgrade, climate, desired level of service, materials, traffic load, drainage, and context sensitivity.

The roadways will begin to show signs of distress during the analysis period and there is assumption that the roads will be maintained with timely pavement preservation treatments to sustain serviceability and extend the effective service life through the analysis period. It is anticipated that a low-volume road will be maintained and managed by constructing a major rehabilitation every 20 years and applying timely maintenance treatments. Constructing more than one major rehabilitation strategy every 20 years will not be practical due to limited resources and the size of the low-volume roads network. Table 8.2 contains the net present values for the recommended rehabilitation strategies and maintenance treatments to be used for the low-volume roads network. The cost of a 2 in. hot mix asphalt concrete overlay is shown for comparison purposes. Figure 8.2 is a diagram of the 20 year LCCA.

**TABLE 8.2 20 Year Life-Cycle Costs for One Low-Volume Road Centerline Mile**

| Initial Rehabilitation Strategy | Initial Cost ($1,000) | Future Maintenance Costs Discounted 4% ($1,000)<br>Fog Seal (FS), Chip Seal (CS), Crack Filling/Sealing (CF/S), and Patching (P) | | | | | Net Present Value ($1,000) |
|---|---|---|---|---|---|---|---|
| | Year 0 | Year 3 | Year 7 | Year 10 | Year 13 | Year 17 | |
| 2 in. Hot Mix Asphalt Concrete Overlay and Single Chip Seal | 193 | 3.4<br>FS | 16.7<br>CF/S & CS | 9.5<br>CF/S, FS, P | 16.8<br>CF/S, CS, P | 7.2<br>CF/S, FS, P | 247 |
| Blade Lay 2 in. Cold Mix Asphalt Concrete Overlay and Single Chip Seal | 161 | 3.4<br>FS | 15.2<br>CF/S & CS | 6<br>CF/S, FS, P | 13.8<br>CF/S, CS, P | 4.5<br>CF/S, FS, P | 204 |
| Full Depth Reclamation using Foamed Asphalt and Double Chip Seal | 173 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 209 |
| Full Depth Reclamation using Cement and Double Chip Seal | 118 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 154 |
| Full Depth Reclamation using Lime and Double Chip Seal | 128 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 164 |
| 3 in. Cold in-Place Recycling with Addition of Millings and Double Chip Seal | 146 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 182 |
| 3 in. Cold in-Place Recycling and Double Chip Seal | 107 | 3.4<br>FS | 13.7<br>CS | 4<br>CF/S, FS | 12<br>CF/S, CS | 3<br>CF/S, FS | 143 |

The LCCA indicates that a $104,000 per centerline mile saving may be realized when 3 in. cold in-place recycling (CIR) and double chip seal wearing course are used in place of 2 in. hot mix asphalt concrete overlay and single chip seal wearing course to rehabilitate roads with functional deficiency. An additional benefit of CIR is that reflective cracking is interrupted. Furthermore, savings of $38,000 to $93,000 per centerline mile might be achieved if cold mix asphalt concrete overlay, full depth reclamation (FDR), and CIR with addition of stockpiled millings were used to rehabilitate roads that exhibit structural deficiency.

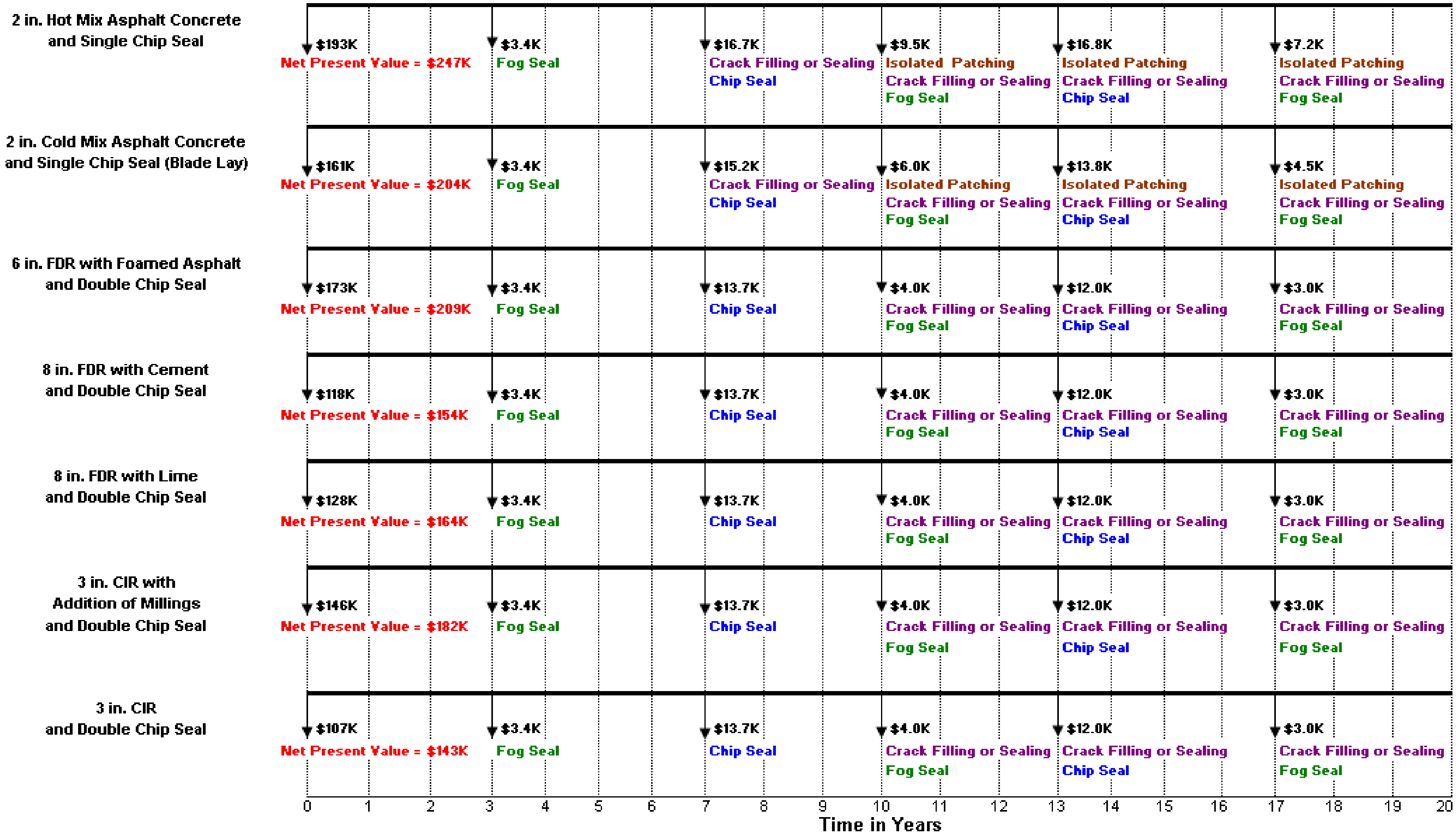



**FIGURE 8.2 20 year life-cycle costs for one low-volume road centerline mile.**

## 8.3 Network Level Saving Analysis

A saving of $8,400,000 per year could be realized at the network level if rehabilitation strategies other than hot mix asphalt concrete overlays and chip seal wearing course were used on the low-volume roads. An investigation into the status of the low-volume roads pavement structures, using the construction history and pavement management databases, confirms that approximately 85% have sound pavement structures. The roads display functional deficiency and structural remediation is not required. A 3 in. CIR and double chip seal wearing course would adequately rehabilitate these roads.

Approximately 15% of the low-volume roads network has structural deficiency and requires more extensive rehabilitation. Strategies such as cold mix asphalt concrete overlay, FDR, or CIR with the addition of stockpiled millings could be used to improve the pavement structures and alleviate the reflective cracking problem that occurs with the use of hot mix asphalt concrete overlays on badly distressed pavement structures. Table 8.3 shows a cost estimate for the possible network level saving if alternative rehabilitation strategies were used for the low-volume roads network rather than the conventional hot mix asphalt concrete overlay method that NDOT has employed over the years.

**TABLE 8.3 Cost Estimate of Network Level Saving**

| Rehabilitation Strategy | Number of Centerline Miles | *Net Present Value (Per 20 Years) | *Net Present Value (Per Year) |
|---|---|---|---|
| 2 in. Hot Mix Asphalt Concrete Overlay and Single Chip Seal | 1693 | $247K x 1693 mi = $418M | $21M |
| 3 in. Cold in-Place Recycling and Double Chip Seal | (0.85)1693 = 1439 | $143K x 1439 mi = $206M | $10.3M |
| Cold Mix Asphalt Concrete, Full Depth Reclamation, or 3 in. Cold in-Place Recycling with Millings and Chip Seal | (0.15)1693 = 254 | $183K x 254 mi = $46.5M<br><br>($183K is average cost of cold mix asphalt concrete overlay, full depth reclamation, and cold in-place recycling with millings rehabilitation strategies) | $2.3M |
| **$21M – ($10.3M + $2.3M) = $8.4M in Saving** | | | |

NOTE: Asterisk ( * ) denotes cost in thousands of dollars (K) and millions of dollars (M).

## 8.4 Preventive Maintenance Treatment Costs

In the event that CIR cannot be used for rehabilitating a low-volume road, the application of preventive maintenance treatments may be the only option for pavement preservation. Preventive maintenance treatments are designed to preserve or maintain the existing roadway, slow down the rate of deterioration, and improve the functional condition of the road. Additional benefits usually include higher customer satisfaction and increased safety.

It is important that the correct treatment be used at the right time and for the appropriate reason in order to optimize return on investment. Treatments applied too early have nominal benefit and treatments applied too late are not effective. The same treatment will perform differently depending on when the treatment is applied in the service life of the pavement. For example, chip seal application on a newer pavement will not increase pavement service life because the chip seal will wear off before structural deterioration has started. Placing a chip seal at the end of a pavement service life will not provide any benefit because the pavement will already have structural deterioration and the underlying pavement will control the performance of the chip seal. Therefore, there is an optimal timing, age, and condition of the pavement for which to apply preventive treatments. Care should be used to maximize benefits for each treatment (*16*).

There are many considerations when selecting a preventive maintenance treatment including product limitations, construction issues, and intended serviceability. Product limitations include climate, terrain, traffic, and weather issues. Construction issues consist of materials, equipment, and availability of skilled workers. Additionally, the reliability, performance history, life expectancy, and ride quality should not be neglected. The treatment selection should be based on pavement condition and there are references available that can assist decision makers (*6, 17*). If in doubt, seek guidance regarding this matter. Table 8.4 contains estimated preventive maintenance treatment costs. The data are provided for informational purposes only.

**TABLE 8.4 *Preventive Maintenance Treatment Costs**

| Type of Treatment | Cost per Square Yard | Cost per Centerline Mile (26 feet wide) |
|---|---|---|
| Cape Seal | $3.45 | $53,000 |
| Chip Seal (Single) | $1.20 | $18,000 |
| Chip Seal (Double) | $2.40 | $36,000 |
| Chip Seal (Double) Over Geotextile Fabric | $4.65 | $70,000 |
| Crack Seal | Varies | Varies |
| Fog Seal | $0.25 | $3,800 |
| Microsurfacing | $3.00 | $46,000 |
| Sand | $0.80 | $12,000 |
| Scrub Seal | $0.90 | $14,000 |
| Slurry Seal | $2.25 | $34,000 |
| Drainage Feature Maintenance | Varies per Feature | Varies |

NOTE: Asterisk ( * ) denotes work performed by NDOT's maintenance personnel, with the exception of slurry seal and microsurfacing. Contractor performed treatment costs will be higher.

# CHAPTER 9 SUMMARY AND RECOMMENDATIONS

## 9.1 Summary

The *Exploring Alternative Strategies for the Rehabilitation of Low-Volume Roads in Nevada* research project was the cornerstone of NDOT's effort to find reliable and more cost-effective rehabilitation strategies to accommodate the considerable need of the low-volume roads network. The project challenged pavement managers and engineers to discover different methods for managing the network rather than relying on conventional practice that was no longer feasible due to budget constraints and the age of the infrastructure. Placing a hot mix asphalt concrete overlay on a low-volume road is expensive and the return on investment is difficult to justify at a time when urban area growth causes need for multiple capacity improvement projects. Additionally, much of the low-volume roads infrastructure is deteriorated to a point where hot mix asphalt concrete overlays are no longer effective because the cracks in the underlying pavement reflect through the new pavement layer within several years. Maintenance personnel are left with the same situation of maintaining severely distressed pavement within a short amount of time after spending a significant amount of money. The only reasonable rehabilitation options are those strategies that can eliminate or retard reflective cracking long enough to justify practical life-cycle costs.

The rehabilitation strategies constructed through this research effort were chosen through group consensus of pavement managers and engineers aspiring to advance low-volume roads rehabilitation techniques to better serve state needs. After monitoring the test sections for several years, it is already evident to personnel that there are other alternatives to hot mix asphalt concrete overlays that have credible potential to rehabilitate the low-volume roads network in an efficient and cost-effective manner. NDOT's Maintenance and Operations Division has begun advertising statewide cold in-place recycling (CIR) contracts whereby a contractor is retained for CIR operations and maintenance personnel assist by placing chip seal wearing course. In 2006, 70 lane miles of CIR was accomplished using a solvent free recycling agent. A contract for the construction of 100 lane miles of CIR was advertised and awarded in 2007. Additional CIR contracts are in the planning stage. The foamed asphalt technology that was introduced through this research project has been considered as a viable option for future construction projects. Additionally, statewide microsurfacing contracts have been advertised each year since the introduction of this surface treatment on the US006 test section.

The construction of project test sections resulted in improved specifications, construction experience with new to NDOT rehabilitation strategies and products, and potential for maintaining the low-volume roads network at considerable cost saving. The following list of achievements was realized through this research effort:

*Specification Improvements*

- Created a specification for foamed asphalt.
- Established specifications for solvent free and polymer modified recycling agents.
- Developed a specification for nonwoven polypropylene geotextile fabric.
- Improved the microsurfacing specification.

*Construction Experience*

- Constructed test sections that provided experience with various full depth reclamation (FDR) additives including lime, cement, emulsified asphalt, liquid soil stabilizer, and foamed asphalt.
- Obtained familiarity with manufacturing and placing cold mix asphalt concrete pavements using HFMS-2S and CMS-2S emulsified asphalts.

- Identified solvent free and polymer modified recycling agents that can be used successfully for CIR operations in place of NDOT's conventional CMS-2S recycling agent. The polymer modified agent can be used in lower temperatures and can extend the construction season.
- Constructed CIR and chip seal wearing course test sections that successfully rehabilitated functional deficient pavement at approximately half the cost of a hot mix asphalt concrete overlay.
- Built a CIR and chip seal wearing course test section that utilized stockpiled millings to rehabilitate structural deficient pavement thereby reducing haul cost and recycling material into a useful product.

*Potential Cost Saving*

- Possible saving of $104,000 per centerline mile if CIR and chip seal wearing course were used rather than hot mix asphalt concrete overlay and chip seal wearing course to rehabilitate low-volume roads with functional deficiency.
- Potential savings of $38,000 to $93,000 per centerline mile if cold mix asphalt concrete pavement, FDR, or CIR with stockpiled millings were used instead of hot mix asphalt concrete overlay and chip seal wearing course to rehabilitate low-volume roads with structural deficiency.
- Possible network level saving of $8,400,000 per year if alternative rehabilitation strategies were used in place of NDOT's conventional method of managing the low-volume roads network by placing hot mix asphalt concrete overlay every 20 years.

## 9.2 Recommendations

The investigation into exploring alternative strategies to rehabilitate low-volume roads was an opportunity for NDOT to examine its conventional business practice. Many lessons were learned that will assist NDOT with its mission of providing a better transportation system for the traveling public. By delivering transportation solutions that meet NDOT's goals of innovation and effectively preserving and managing assets, valuable resources can be used to the best advantage.

Pavement preservation and management requires a commitment to monitoring roadway conditions for extended periods because pavement deterioration is a long-term process. Although preliminary CIR results are encouraging, the long-term consequences of implementing project recommendations must be documented and verified so the agency can quantify the benefits. NDOT must remain vigilant, continually refine construction techniques, and recognize more low-volume roads rehabilitation opportunities as transportation technology advances.

The test sections should be monitored for at least 10 more years using pavement roughness surveys, condition surveys, and core sampling as necessary. The test sections should be monitored to verify that the solvent free and polymer modified recycling agents are acceptable replacements for CMS-2S recycling agent. Many of the test sections are performing well as the test sections are in the early stage of the anticipated service life and more time is required to distinguish between the most optimal CIR and wearing course combination. It would be beneficial to document all future maintenance activities on the test sections to verify the anticipated 20 year life-cycle costs.

The following modifications are recommended to further advance NDOT's low-volume roads pavement management practices:

*Specification Improvements*

- Require a Type C profile index of 10 in./mi using the profilograph measurement rather than a straightedge measurement for all future FDR, CIR, and cold mix asphalt concrete overlay projects. The criteria should be thoroughly advertised and discussed in the pre-construction phase so that contractors are not caught off guard during construction operations and can plan accordingly.
- Specify that haul trucks or heavy equipment be kept off the CIR pavement structure for a minimum of 48 hours after construction operations.
- Add the additional bid item of "Haul and Place Material in Windrow from Stockpile" with a pay unit of "Ton" to future CIR with stockpiled millings projects.
- Use a 2.5% recycling agent content for quantity purposes on CIR with stockpiled millings projects.

*Constructability Enhancements*

- Adopt the low-volume roads guidelines proposed in Figure 7.3.
- Use the life-cycle cost analysis in Table 8.2 and Figure 8.2 to assist with choosing rehabilitation alternatives.
- Place a wearing course within one week of FDR or CIR operations.
- Provide high quality motor grader techniques on FDR and cold mix asphalt concrete overlay projects.
- Allow cold mix asphalt concrete overlays to cure for a minimum of six months to a year before placing a wearing course. The cure period will allow diluents to evaporate and the wearing course will bond well with the pavement surface.
- Recommend that traffic control be provided by the contractor rather than maintenance personnel.
- Establish proper rolling and compaction techniques for CIR with solvent free and polymer modified recycling agents.
- Schedule preconstruction meetings that will provide solutions for the anticipated constructability challenges learned through this research effort.
- Provide workshops, training, and checklists for both contractor and NDOT personnel when using alternative strategies for the rehabilitation of low-volume roads.

*Materials*

- Use solvent free and polymer modified recycling agents for CIR operations.
- Confirm material properties with laboratory testing before choosing additives for FDR operations.
- Ensure that material suppliers are on site to make adjustments and be responsible for the successful construction of projects when new products are specified.

There is a major challenge to overcome if NDOT is to optimally maintain the low-volume roads network in a cost-effective manner. This challenge is to secure dedicated low-volume roads funding that district engineers can rely on each year for required contractor and maintenance work. The integrity of the entire low-volume roads network is important and neglecting the system will cost more in the future if functional deficiencies are allowed to deteriorate into structural deficiencies. Pavement management and preservation are more than just an assortment of rehabilitation strategies. Pavement management and preservation are controlling factors in the financial planning process.

This research has provided an alternative for preserving the low-volume roads network in a more cost-effective manner than conventional practice has allowed. It is anticipated that $12,000,000 per year would be required to maintain the low-volume roads network at an acceptable level of service. Under ideal conditions, this amount of money would provide stability of the network. Under current income levels, work on the low-volume roads will require prioritization of projects network wide and it is unlikely that the required funds will be available to meet the needs of the system.

It is recommended that adequate funding of $12,000,000 per year be provided for NDOT's Maintenance and Operations Division's budget to address pavement rehabilitation and preservation in a timely and cost-effective manner. This amount should be inflation adjusted to compensate for shrinking buying power in future years. The funding will allow NDOT to secure the services needed to maintain the low-volume roads for the next generation of Nevadans.

## REFERENCES


1. Asphalt Recycling and Reclaiming Association. *ARRA Basic Asphalt Recycling Manual*. Annapolis, Md., 2001.
2. Wirtgen America, Inc. Accessed on the World Wide Web in July 2007: http://www.wirtgenamerica.com/fa/aboutfa.html.
3. Western Stabilization. Accessed on the World Wide Web in July 2007: http://www.roseville.ca.us/civica/filebank/blobdload.asp?BlobID=4256.
4. Nevada Department of Transportation. *Standard Specifications for Road and Bridge Construction*. State of Nevada Department of Transportation. Carson City, Nv., 2001.
5. Federal Highway Administration. *Status of the Nation's Highways, Bridges, and Transit: 2004 Conditions and Performance Report*. Federal Highway Administration. Washington, D.C., 2006.
6. Maher, M., C. Marshall, F. Harrison, and K. Baumgaertner. *Context Sensitive Roadway Surfacing Selection Guide*. Report No. FHWA-CFL/TD-0x-004. Central Federal Lands Highway Division. Lakewood, Co., 2005.
7. Nevada Department of Transportation. *Flexible Pavement Distress Identification Manual*. State of Nevada Department of Transportation Materials Division. Carson City, Nv., 2002.
8. AASHTO T 269-97, "Percent Air Voids in Compacted Dense and Open Asphalt Mixtures," American Association of State Highway and Transportation Officials. Washington, D.C., 2006.
9. ASTM D 4123, "Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures," ASTM International. West Conshohocken, Pa., 2002.
10. AASHTO T 283-03, "Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage," American Association of State Highway and Transportation Officials. Washington, D.C., 2006.
11. AASHTO TP 63-03, "Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer (APA)," American Association of State Highway and Transportation Officials. Washington, D.C., 2006.
12. Federal Highway Administration*. Status of the Nation's Highways, Bridges, and Transit: 2002 Conditions and Performance Report*. Federal Highway Administration. Washington, D.C., 2003.
13. Miller, J. S. and R. Van Horn. *Ground Penetrating Radar & Pavement Engineering Services Project No. 64041263*. Terracon. Las Vegas, Nv., 2005.
14. Morey, M.M. *National Cooperative Highway Research Program Synthesis 255: Ground Penetrating Radar for Evaluating Subsurface Conditions for Transportation Facilities*. Transportation Research Board. Washington, D.C., 1998.
15. Walls, J. and M.R. Smith. *Life-Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin*. Report No. FHWA-SA-98-079. Federal Highway Administration Pavement Division. Washington, D.C., 1998.
16. Peshkin, D.G., T.E. Hoerner, and K.A. Zimmerman. *National Cooperative Highway Research Program Report 523: Optimal Timing of Pavement Preventive Maintenance Treatment Applications*. Transportation Research Board. Washington, D.C., 2004.
17. Foundation for Pavement Preservation. *Pavement Preventive Maintenance Guidelines*. Accessed on the World Wide Web: http://www.fp2.org/pdffiles/PavPrevMainGuides.pdf. 2001.

## APPENDIX A: CORE PICTURES

**CONTENTS**

## APPENDIX A: CORE PICTURES

**CONTENTS**


Before Construction: Medium Stripping
Pavement Condition: High Severity Transverse Cracking

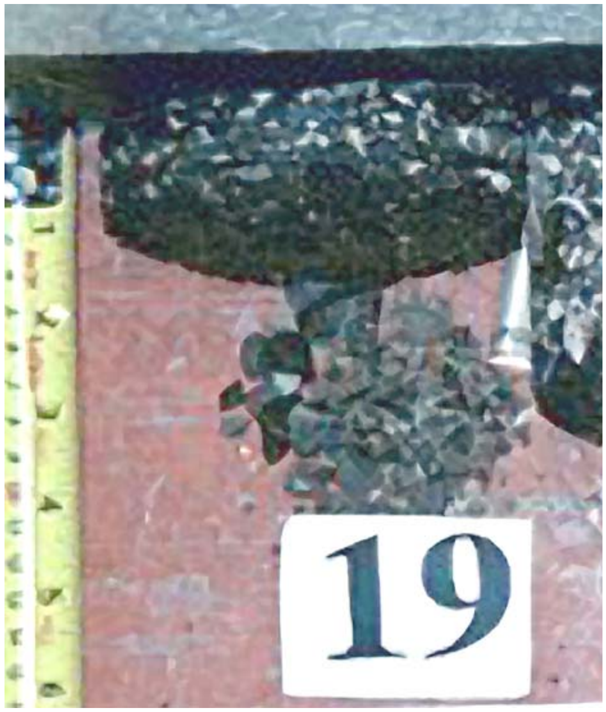

3 Years after Construction: Broke at 2.25 in.
Pavement Condition: Low Severity Transverse Cracking

**FIGURE A.1 SR230: Full depth reclamation with CMS-2S and lime, 1.5 in. hot mix asphalt concrete overlay, and single chip seal.**


Before Construction: Stripped and Fell Apart
Pavement Condition: Transverse and Fatigue Cracking


3 Years after Construction: Stripped and Fell Apart
Pavement Condition: Good Condition

**FIGURE A.2 SR230: 3 in. full depth reclamation with proprietary liquid stabilizer, 1.5 in. hot mix asphalt concrete overlay, and single chip seal.**

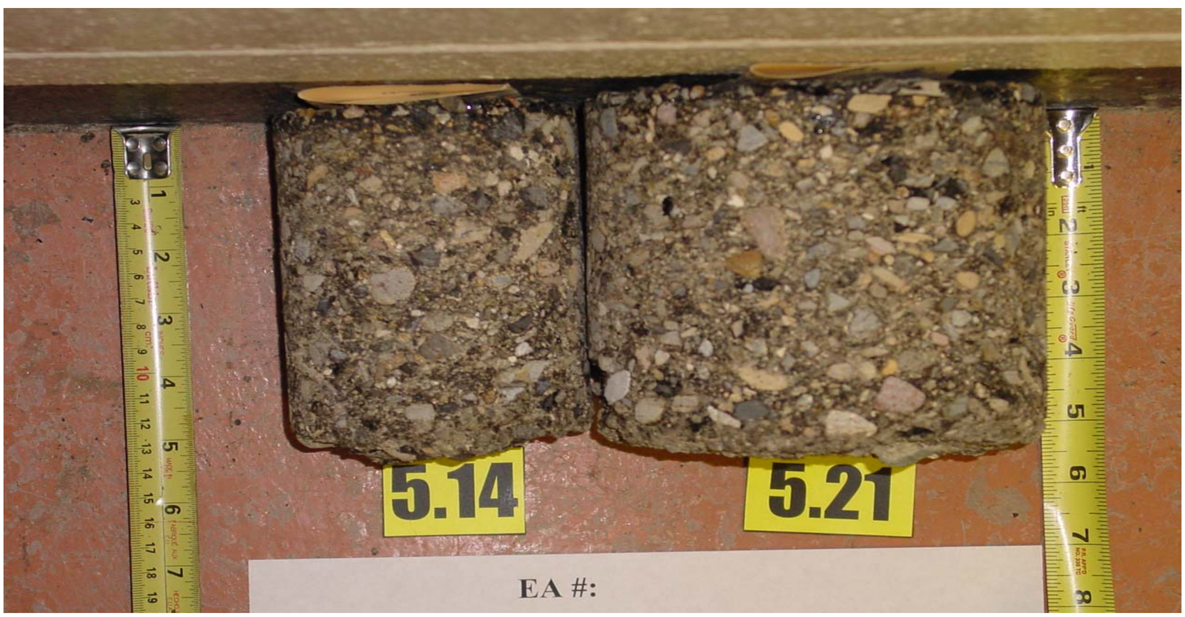



Before Construction: Stripped and Fell Apart
Pavement Condition: Transverse and Fatigue Cracking


3 Years after Construction: Stripped and Fell Apart
Pavement Condition: Good Condition

**FIGURE A.3 SR230: 6 in. full depth reclamation with proprietary liquid stabilizer, 1.5 in. hot mix asphalt concrete overlay, and single chip seal.**


Before Construction: Medium Stripping
Pavement Condition: High Severity Transverse Cracking




3 Years after Construction: Light Stripping
Pavement Condition: Low Severity Transverse Cracking

**FIGURE A.4 SR230: Full depth reclamation with foamed asphalt and single chip seal (eastbound).**


Before Construction: Heavy Stripping
Pavement Condition: High Severity Transverse Cracking


3 Years after Construction: Light to Medium Stripping
Pavement Condition: Low Severity Transverse Cracking

**FIGURE A.5 SR230: Full depth reclamation with foamed asphalt and single chip seal (westbound).**


Before Construction: Medium Stripping
Pavement Condition: High Severity Transverse Cracking

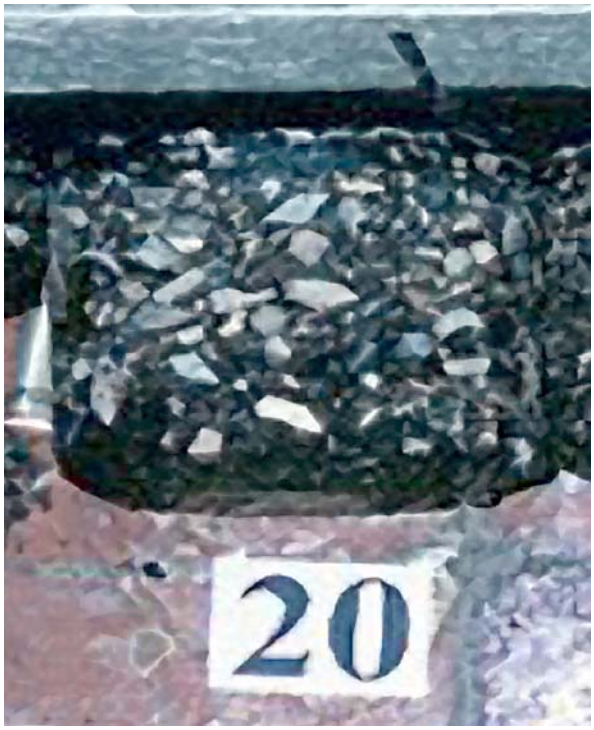

3 Years after Construction: Stripped and Fell Apart
Pavement Condition: Good Condition

**FIGURE A.6 SR230: Full depth reclamation with proprietary emulsion, 1.5 in. hot mix asphalt concrete overlay, and single chip seal.**


Before Construction: Medium Stripping
Pavement Condition: High Severity Transverse Cracking


3 Years after Construction: Broke from 6.0 in. to 7.3 in.
Pavement Condition: Low Severity Transverse Cracking

**FIGURE A.7 SR230: Full depth reclamation with 3.0% cement and double chip seal.**




Before Construction: Medium Stripping
Pavement Condition: Fatigue Cracking


3 Years after Construction: Broke and Fell Apart
Pavement Condition: Good Condition

**FIGURE A.8 SR230: Full depth reclamation with 4.5% cement and double chip seal.**


Before Construction: Heavy Stripping and Fell Apart
Pavement Condition: Fatigue Cracking


3 Years after Construction: Delaminated at 2.3 in. with Medium to Heavy Stripping
Pavement Condition: Good Condition

**FIGURE A.9 SR230: 2 in. cold mix asphalt concrete with CMS-2S and single chip seal (eastbound).**


Before Construction: Light Stripping
Pavement Condition: High Severity Transverse Cracking


3 Years after Construction: Light to Medium Stripping
Pavement Condition: Good Condition

**FIGURE A.10 SR230: 2 in. cold mix asphalt concrete with CMS-2S and single chip seal (westbound).**


Before Construction: Heavy Stripping and Fell Apart
Pavement Condition: Transverse and Fatigue Cracking

3 Years after Construction: Light to Medium Stripping
Pavement Condition: Good Condition

**FIGURE A.11 SR230: 2 in. cold mix asphalt concrete with HFMS-2S and single chip seal.**


Before Construction: Heavy Stripping and Fell Apart
Pavement Condition: High Severity Transverse Cracking


3 Years after Construction: Light to Medium Stripping
Pavement Condition: Good Condition

**FIGURE A.12 SR230: 2 in. cold mix asphalt concrete with MC-800 and single chip seal.**


(a) 2 Years after Construction: Delaminated at 3.6 in. with Light to Medium Stripping
Pavement Condition: Good Condition


(b) 2 Years after Construction: Cores in Good Condition
Pavement Condition: Good Condition

**FIGURE A.13 US006: 3 in. cold in-place recycling with (a) solvent free emulsified asphalt, no lime, and double chip seal and (b) CMS-2S, lime, and double chip seal.**


Before Construction: Light to Heavy Stripping, Delaminated, and Fell Apart
Pavement Condition: Transverse and Nonwheel Path Cracking

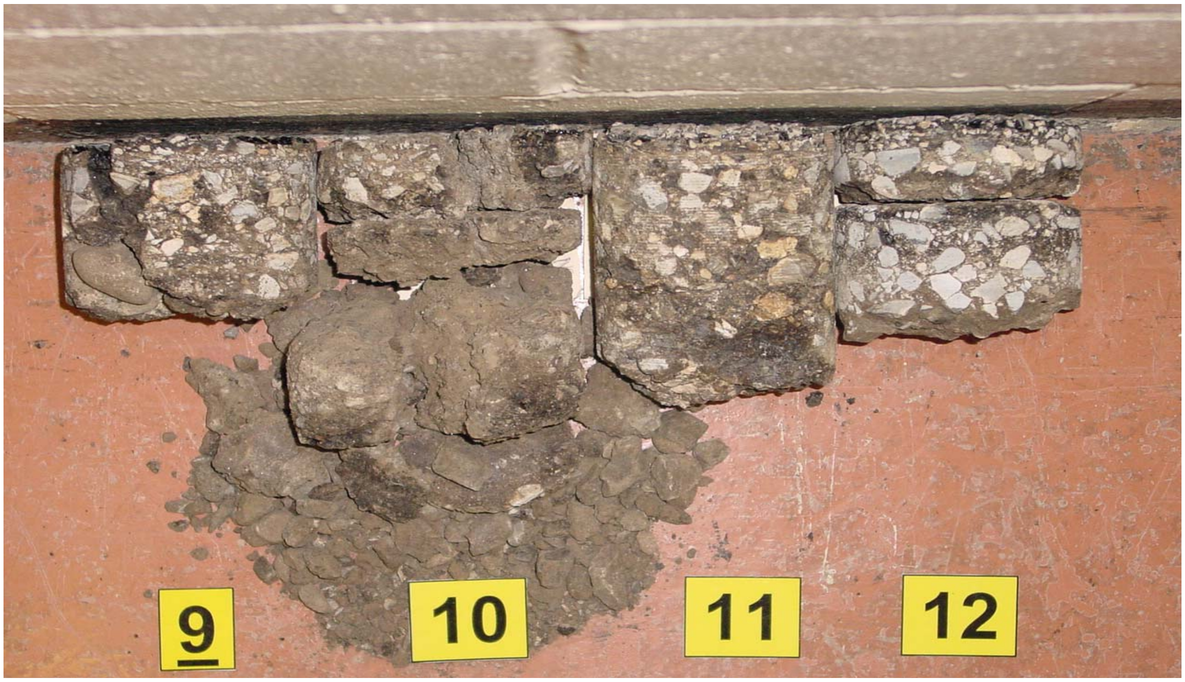

1 Year after Construction: Light Stripping
Pavement Condition: Good Condition

**FIGURE A.14 SR226: 3 in. cold in-place recycling with CMS-2S, lime, and double chip seal.**


Before Construction: Light to Heavy Stripping and Fell Apart
Pavement Condition: Transverse and Nonwheel Path Cracking


1 Year after Construction: Light to Medium Stripping and Delaminated at 3.0 in.
Pavement Condition: Good Condition

**FIGURE A.15 SR226: 3 in. cold in-place recycling with solvent free emulsified asphalt, no lime, and double chip seal.**




Before Construction: Light to Heavy Stripping, Delaminated, and Fell Apart
Pavement Condition: Transverse and Block Cracking


2 Months after Construction: Cores in Good Condition
Pavement Condition: Good Condition

**Figure A.16 SR168: 3 in. cold in-place recycling with stockpiled millings and CMS-2S, lime, and single chip seal.**


Before Construction: Light Stripping
Pavement Condition: Transverse and Fatigue Cracking


Before Construction: Light Stripping
Pavement Condition: Transverse Cracking

**FIGURE A.17 SR892: Before construction.**


(a) 4 Months after Construction: Light to Medium Stripping and Delaminated
Pavement Condition: Good Condition


(b) 4 Months after Construction: Light Stripping
Pavement Condition: Good Condition

**FIGURE A.18 SR892: 2 in. cold in-place recycling with (a) polymer modified emulsified asphalt, no lime, and double chip seal and (b) solvent free emulsified asphalt, no lime, and double chip seal.**

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