Rehabilitation Techniques for Stripped Asphalt Pavements in Montana

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Asphalt stripping is a fairly common form of distress for pavements in Montana. Currently, the standard technique for rehabilitating these pavements involves the costly removal of most or all of the stripped material before placement of an overlay. The goal of this research is to determine whether the stripped material can remain in place, serving as a structural layer within the rehabilitated pavement. This study has involved the construction of five test sites throughout Montana that have been incorporated into larger overlay projects. At each of these sites, stripped material was removed and replaced from a control section and stripped material was left in place on a test section before placement of an overlay. Only the driving course (chip seal or an open-graded friction course) was removed from the test sections. Background information on the test sites is provided, and the methods (visual, nondestructive testing, and destructive testing) that are being used to monitor the performance of experimental pavement sections are described. Performance results are provided for up to 4 years of service.

The deterioration of asphalt concrete in the form of stripping is caused by separation of asphalt binder from aggregate. This loss of adhesion causes the asphalt concrete to ravel under traffic loads. Stripping occurs in the presence of water, so it is often referred to as moisture damage.

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Currently, the most common method for rehabilitating a stripped pavement in Montana involves removing and replacing most of the stripped material. This practice is expensive because it requires milling and hauling operations in addition to normal paving activities. The Montana Department of Transportation (MDT) initiated this project to investigate the possibility of allowing all stripped material to remain in place. The premise is that the stripped asphalt can retain sufficient integrity to be used effectively within the rehabilitated pavement structure.

Scope of Work

Two methods of rehabilitating stripped asphalt pavements were studied by comparing the performance of full-scale rehabilitated pavement structures. The first method of rehabilitation involved removing and replacing most of the stripped asphalt concrete. Under this approach, the stripped asphalt concrete layer is presumed to have little structural value (less than the value of an equivalent thickness of standard base course material). The second method of rehabilitation required minimal treatment of the in-place stripped asphalt concrete layer. Only existing surface treatments and open-graded friction courses (OGFCs) were removed and then the stripped asphalt concrete layer was overlaid with a new surface course. This approach presumed that the stripped asphalt concrete maintained a structural value at least as high as a standard base course material.

The construction phase of this study began with the identification of five stripped pavements among MDT

Interstate highway resurfacing projects. Plans for each site involved implementing the two rehabilitation methods presented previously. Once sites were identified, historical data were obtained for each site regarding soils information, original structural design, and previous overlays. The condition of the pavements needing rehabilitation was also quantified in general terms.

The five rehabilitated pavement test sections are currently being monitored visually, structurally, and in terms of roughness. Monitoring periods will last for 3 to 5 years. Upon completion of the long-term monitoring phase, the two methods of rehabilitation will be compared economically.

FIGURE 1 Montana test locations.

Test Sites

Five test sites were selected on Interstate highways across the state of Montana. All the test sites were constructed as part of larger pavement rehabilitation contracts. Test sites were chosen based on the following criteria:

- The sites had to be well distributed across the state,
- Each pavement had to be determined as stripped according to MDT test procedures, and
- The timing for rehabilitation construction had to be appropriate.

The test sites are indicated in Table 1 and their locations are presented in Figure 1. The rehabilitation projects were conducted between 1994 and 1997. The total lengths of the rehabilitation projects ranged from 8 to 27.4 km (5 to 17 mi). Among the chosen test sites, the Rocky Canyon area experiences the most precipitation, and the Lincoln Road–Sieben area experiences the least. The Custer County Line West area experiences the hottest summers. The Tarkio East area experiences relatively mild winters. The five sites rank in the following order in terms of increasing average daily traffic and increasing equivalent single-axle loads: Custer County Line West, Lincoln Road–Sieben, Tarkio East, Bearmouth–Drummond, and Rocky Canyon.

Each test site included one or two test sections and one or two control sections. The control sections employed the remove-and-replace method of rehabilita-

TABLE 1 General Information for Test Sites

Characteristic	Bearmouth-Drummond	Rocky Canyon	Lincoln Road-Sieben	Custer County Line West	Tarkio-East
Project Number	IM 90-3(74) 135	IM 90-6(70) 313	IM 15-4(69) 200	IM 94-4(49) 154	IM 90-1(118) 64
County	Granite	Gallatin	Lewis and Clark	Custer	Mineral
Interstate	I-90	I-90	I-15	I-94	I-90
Length of Project (mi)	15.2	5.3	17.1	8.9	10.5
Date of Rehabilitation	1994–95	1995	1996	1996	1996–97
Climatic Data					
Mean Precipitation (in.)	13.5	18.6	11.4	14.0	14.5
Mean Temperatures[a] (°F)					
7-Day-Average High[b]	91 (3.0)	88 (4.8)	88 (4.8)	97 (4.6)	93 (4.7)
Single-Day Low[b]	−27 (4.2)	−24 (3.4)	−26 (3.1)	−29 (3.8)	−15 (3.5)
Traffic Data					
ADT (Year)	6800 (1991)	8100 (1991)	3700 (1993)	2800 (1991)	4500 (1991)
ADT[c] (Letting Year)	7500 (1993)	9200 (1996)	4000 (1996)	3000 (1993)	5000 (1993)
ADT[c] (Design Year)	13500 (2013)	16500 (2016)	7200 (2016)	4400 (2013)	8600 (2013)
Percent Trucks	20.2	20.3	17.2	20.7	23.8
Average Daily ESALs (over design life)	1090	1590	520	440	900

NOTE: ADT = average daily traffic; ESALs = equivalent single-axle loads; 1 mi = 1.6 km; °C = (°F −32)/1.8.

[a] From SHRP weather database (at least 20 years of data).

[b] Mean (standard deviation).

[c] Projected.

tion, and the test sections incorporated all the existing stripped asphalt concrete into the new structure. The test and control sections are 152.4 to 417.6 m (500 to 1,370) ft long and include both the driving and passing lanes. Locating test and control items adjacent to each other allowed unwanted variables to be minimized by maintaining similarities between

- Existing soil conditions,
- Existing pavement structure dimensions and properties,
- Drainage,
- Horizontal and vertical road geometry, and
- Types and severity of pavement distress.

Information related to previous construction for the test sites is presented in Table 2. The original pavement structures were built between 1964 and 1982. Each original structure included two layers over the subgrade: a crushed aggregate base course and an asphalt concrete surface course. All the reported subgrade types could be expected to provide adequate pavement foundations, without potential for volume changes. Each site had received a single overlay since original construction. The overlays were placed between 1981 and 1985 and each was topped with an OGFC.

Pre-Rehabilitation Evaluations

Before a rehabilitation project, the MDT evaluates the condition of the existing pavement. The nondestructive testing (NDT) team visits the site to evaluate its structural condition and to document their impressions about any visual distress. An additional source of pre-rehabilitation information is the MDT pavement management system, which retains condition data for all state-maintained pavements within Montana. As a supplement for these sources, representatives of Montana State University (MSU) visited the sites and conducted visual inspections specifically for the test sections.

Structural Evaluations

Structural information was obtained with a Road Rater, which provided estimates for the elastic moduli of pavement layers. The reduction of Road Rater data assumes that the pavements consist of multiple layers of linear elastic materials. The reported modulus values, assuming three linear elastic layers for each pavement, are presented in Table 3. These values are conservative estimates for each project because they were obtained by subtracting 0.7 of the calculated standard deviation from the calculated mean. The NDT team impressions on material adequacy, based on estimated moduli, are also presented in Table 3. Surface moduli were lowest at Custer County Line West and were highest at Bearmouth–Drummond, although all were judged to be either adequate or good. Base course moduli were lowest at Lincoln Road–Sieben (judged to be weak) and were highest at Bearmouth–Drummond (judged to be weak). Subgrade moduli were lowest at Bearmouth– Drummond and Tarkio East (both judged to be weak) and were highest at Rocky Canyon (judged to be good). Only two sites had both a base course modulus and a subgrade modulus that were judged to be either weak or marginal: the Lincoln Road–Sieben and the Custer County Line West sites.

Visual Examinations

Visual condition information as obtained from the MDT is presented in Table 4. This information reflects the condition of the entire projects and not just the test sections. All sites were experiencing some degree of raveling of the

TABLE 2 Pre-Rehabilitation Construction Information for Test Sites

Characteristic	Bearmouth-Drummond	Rocky Canyon	Lincoln Road-Sieben	Custer County Line West	Tarkio-East
Original Pavement					
Date of Construction	1971	1964	1964	1971	1982
AC Thickness (ft.)	0.35	0.35	0.50	0.35	0.35
CAB Thickness (ft.)	1.7	2.0	2.4	1.5	1.5
Subgrade Type[a]	A-1-a (GW, GP)	A-2-4 (GM, GS)	A-2-4 (GM, GS)	A-1-b to A-4(0) (SW, SP, SM, ML)	A-1-a to A-3 (GW, GP, SP)
First Overlay					
Date of Construction	1985	1983	1983	1981	1985
AC Thickness (ft.)	0.15	0.30	0.15	0.15	0.15
OGFC (ft.)	0.05	0.05	0.05	0.05	0.05

NOTE: AC = asphalt concrete; CAB = crushed aggregate base; OGFC = open graded friction course (approximately 1/2 in. to 3/4 in. thick); 1 in. = 2.54 cm; 1 ft = 0.3 m.

[a] AASHTO Classification with most probable soil in Unified System shown in parentheses ( ).

TABLE 3 Preconstruction Road Rater Evaluations

Characteristic	Bearmouth-Drummond (westbound)	Bearmouth-Drummond (eastbound)	Rocky Canyon (eastbound)	Lincoln Road-Sieben (northbound)	Custer County Line West (westbound)	Tarkio-East (eastbound)
Date Tested	July 1992	July 1992	July 1991	May 1990	Sept. 1992	Aug. 1992
Location of Tests (Range of Mileposts)	135 to 150	135 to 150	313 to 318	200 to 217	155 to 163	64 to 74
Surface Modulus [a] (psi)	324,000 [Good]	216,000 [Good]	248,000 [Good]	216,000 [Good]	191,000 [Adequate]	233,000 [Good]
Base Modulus [a] (psi)	36,700 [Good]	27,900 [Good]	25,100 [Good]	14,600 [Weak]	21,200 [Marginal]	29,800 [Good]
Subgrade Modulus [a] (psi)	5,090 [Weak]	9,750 [Marginal]	11,900 [Good]	6,670 [Weak]	6,420 [Weak]	5,210 [Weak]

NOTE: Modulus values presented = mean – 0.70 (standard deviation); 1 psi = 6.89 kPa; 1 mi = 1.6 km.

[a]NDT team impression on the quality of material is shown in brackets.

OGFC. Bearmouth–Drummond, Lincoln Road–Sieben, and Tarkio East sites all had transverse cracks. Lincoln Road–Sieben also had longitudinal cracking throughout its length. None of the sites had extensive pothole problems. All sites except Lincoln Road–Sieben had some measurable rutting. All sites had some degree of fatigue cracking; Tarkio East had the most.

Pavement condition information, obtained by MSU specifically for the test sections, generally agreed with the MDT findings. The MSU findings are summarized in the following paragraphs. This section concludes with a characterization of each site in terms of its predominant distress.

At Bearmouth–Drummond, the areas of raveling for the OGFC were about 5 percent for the driving lanes and 9 percent for the passing lanes. Relative to the MDT findings for the entire project, rutting within the test sections did not appear to be as severe. Ruts of 1.27 to 1.9 cm (0.5 to 0.75 in.) were evident in fewer than 5 percent of the wheelpaths. Alligator cracking was also observed in fewer than 5 percent of the wheelpaths. Similar to the MDT findings, transverse cracking was found throughout the test sections; it had progressed to moderate severity in many cases. Longitudinal cracks, generally of low severity, were also found within the test sections.

TABLE 4 Distress Information for Total Project Length

Distress	Bearmouth-Drummond	Rocky Canyon	Lincoln Road-Sieben	Custer County Line West	Tarkio-East
Raveling of OGFC	5% coarse	70% medium to coarse	50% fine	10% coarse	40% coarse
Transverse Cracks	100% 1-3 cracks per 100 ft (< 1/8" to 1/4")	None	100% 5 cracks per 100 ft (1/8" to 1/4")	None	40% 2 cracks per 100 ft (1/8" to 1/4")
Longitudinal Cracks	2% (1/8" to 1/4") centerline	None	100% centerline	None	None
Potholes / Patches	Isolated spots (fair condition)	None	None	< 10% patched (good condition)	None
Ruts	100% (½")	25% (1/2" to 3/4")	None	25% (1/2" to 3/4")	100% (1/2" to 3/4")
Fatigue Cracking	2% initial stage	10% at some stage	> 15% initial stage	20% at some stage	40% initial stage
Date of NDT Team Visit	July 1992	July 1991	May 1990	Sept. 1992	Aug. 1992

NOTE: All percentages indicate percent of total project area or length; 1 in. = 2.54 cm; 1 ft = 0.3 m.

By 1995 when MSU performed a visual condition survey, the alligator cracking at Rocky Canyon had worsened from the time of the MDT inspection in 1991. Alligator cracking, or at least longitudinal cracks in the wheelpaths, were observed along most of the test site. Transverse cracks and longitudinal crack between paving lanes were observed, although they were generally low severity.

A description of the test site at Lincoln Road–Sieben would be similar to that provided by MDT for the entire project. Some slight modifications follow. The longitudinal cracks at centerline were severe for about one-third of the project length. Parallel cracks had formed and raveling had become severe within 0.3 m (1 ft) of the longitudinal crack. Low-severity rutting was also noted to have occurred in the driving lane.

Although cracks were not mentioned at the time of the NDT team visit to Custer County Line West, many transverse cracks had formed within the test site by the year 1995. Moderate-to-high-severity cracks were observed on the order of three per 30.5 m (100 ft) of pavement length. Isolated potholes, both unimproved and patched, were found in the driving lane. The potholes accounted for less than 10 percent of the pavement area. Low-severity rutting was also noted to have occurred in the driving lane.

The condition of the original pavement at the Tarkio East test site was generally poor. Similar to the NDT team report, raveling and alligator cracking were found to be extensive. Ruts were also found in both the driving and passing lanes. Although the MDT had found transverse cracks along the project, they were nearly absent within the test sections. However, the test site did have longitudinal cracking between paving lanes throughout its length. The longitudinal cracks had promoted additional deterioration in the form of small parallel cracks and intermittent potholes.

Distress types found at the various sites are presented in Table 5. Those found by the MDT during their inspections of the entire projects are indicated with a "P." Those found by MSU during their inspections of the test sections are indicated with a "T." Accounting for both MDT and MSU findings, the predominant forms of distress at the various test sites are also presented in Table 5. Bearmouth–Drummond, Lincoln Road–Sieben, and Custer County Line West had extensive transverse cracking and longitudinal cracking. Rocky Canyon and Tarkio East had extensive rutting and fatigue cracking.

Stripping Evaluations

The MDT procedure for evaluating asphalt cores for stripping involves visually inspecting core faces produced by indirect tensile splitting. Cores 10.2 cm (4 in.) in diameter were removed from within the projects included in this study in order to quantify the levels of stripping. If a core disintegrated during removal, this condition was noted. If the core remained intact during removal, the various asphalt concrete layers were separated. The core for each layer was then split along its diameter by indirect tension. Finally, the degree of stripping for each lift was estimated by inspecting the two exposed faces. The MDT procedure uses an integer rating scale, ranging from zero to four, as indicated in Table 6. To minimize subjectivity, the MDT maintains a reference booklet of color photographs showing split core faces, along with their designated ratings.

Results from stripping the inspections are presented in Table 7. Following the MDT approach, all five sites had severe stripping damage. Generally, the overlays received ratings that were similar to or worse than those for the original asphalt surface layer. There were no substantial differences between the driving lanes and the passing lanes. In terms of severity of stripping, the sites grouped are as follows: Custer County Line West and Tarkio East (worst),

TABLE 5 Summarized Distress Information for Entire Projects and Test Sites

Distress	Bearmouth-Drummond	Rocky Canyon	Lincoln Road-Sieben	Custer County Line West	Tarkio-East
Raveling of OGFC	P, T	P, T	P, T	P, T	P, T
Transverse Cracks	P, T	T	P, T	T	P
Longitudinal Cracks	P, T	T	P, T	None	T
Potholes / Patches	P	None	None	P, T	T
Ruts	P, T	P, T	T	P, T	P, T
Fatigue Cracking	P	P, T	P	P	P, T
Predominate Distress for Test Sections	Transverse Cracking	Fatigue Cracking	Transverse and Longitudinal Cracking	Transverse Cracking	Ruts and Fatigue Cracking

NOTE: P – distress observed during MDT inspection of the entire project; T – distress observed during MSU inspection of the test site.

TABLE 6 MDT Rating Scheme for Stripping Damage in Cores

Core Rating	Description
0 (no core)	Asphalt is mostly gone from all sizes of aggregate or the core has disintegrated.
1 (severely stripped)	Most of the aggregate is so clean, the colors of the rock are decipherable.
2 (stripping)	In addition to moisture damage, some large aggregate is not coated.
3 (moisture damaged)	Loss of sheen; dull appearance; some smaller aggregate (minus No. 60 sieve) is uncoated.
4 (good core)	The face is shiny and black. All aggregate particles are coated.

Rocky Canyon and Lincoln Road–Sieben (intermediate), and Bearmouth–Drummond (best).

In addition to using the cores for stripping damage ratings, a few cores were used to obtain estimates of voids and binder content as indicated in Table 7. With the few replicates used in this part of the study, it can be stated only that no substantial oddities or differences were found among the test sites.

Rehabilitation Scenarios

At each site, rehabilitation construction began with milling operations. In the control sections, milling depths ranged from 6.4 to 12.7 cm (2.5 to 5 in.), as indicated in Table 8. Milling was deep enough to remove the existing OGFC and the existing overlay. With the exception of the Tarkio East site, milling in the control section was deep enough to penetrate into the asphalt concrete that was placed as part of the original pavement. In the test sections, milling was used only to remove the OGFC.

Rocky Canyon was the only site that involved stabilization of material before placement of the overlay. After milling of the control section at Rocky Canyon, 24 cm (9.5 in.) of the remaining material was pulverized and stabilized with portland cement. This 24 cm of material included about 8.9 cm (3.5 in.) of asphalt concrete and about 15.2 cm (6 in.) of underlying aggregate base. The test section did not involve any stabilization.

Overlay thicknesses in control sections ranged from 8.9 to 20 cm (3.5 to 8.0 in.), as indicated in Table 8. Overlay thicknesses in test sections ranged from 5.1 to 12.7 cm (2.0 to 5.0 in.) (Table 8). All top lifts of asphalt concrete were modified with polymers. The Bearmouth–Drummond, Lincoln Road–Sieben, and Tarkio East projects all used hot recycling for the lower overlay lifts in the control sections. All asphalt concrete mixtures were MDT Grade D except for the top lift at Custer County Line

TABLE 7 Evaluation of Cores Removed Before Rehabilitation

Characteristic	Bearmouth-Drummond (westbound)	Bearmouth-Drummond (eastbound)	Rocky Canyon	Lincoln Road-Sieben	Custer County Line West	Tarkio-East
Core Stripping Ratings[a]						
Original Surface						
- Driving Lane	2.2 (2-3)	2.0 (2)	1.2 (1-2)	1.8 (1-2)	0.5 (0-2)	1.0 (1-2)
- Passing Lane	2.0 (2)	2.3 (2-3)	1.3 (1-2)	1.7 (1-2)	1.6 (0-3)	0.5 (0-2)
Overlay						
- Driving Lane	1.7 (1-2)	1.2 (0-2)	1.0 (1)	1.3 (1-2)	1.0 (1)	0.6 (0-2)
- Passing Lane	1.8 (1-2)	1.8 (1-2)	1.0 (1)	1.7 (1-2)	0.6 (0-2)	0.2 (0-2)
Number of Cores Evaluated	14	14	12	12	9	32
Additional Core Tests[b]						
Voids Total Mix (%)						
- Original Surface	3.6	3.6	6.1	7.2	3.3	4.0
- Overlay	5.3	6.0	6.6	5.7	7.1	5.4
Binder Content[c] (%)	6.0	5.5	6.1	6.2	5.9	5.5

[a] Mean (range).

[b] Only one test completed for each characteristic.

[c] Bulk mixture containing both the original mixture and the overlay.

TABLE 8 Details of Rehabilitation Construction

Distress	Bearmouth-Drummond	Rocky Canyon	Lincoln Road-Sieben	Custer County Line West	Tarkio-East
Control Section					
Cold Mill,[a] ft (in.)	0.30 (3.5)	0.40 (5.0)	0.25 (3.0)	0.25 (3.0)	0.20 (2.5)
Improved Existing Material[b]		0.80 ft CTPB			
New Material (First Lift)	0.15 ft PMS (hot recycle)	0.40 ft PMS (polymer-mod.)	0.15 ft PMS (hot recycle)	0.25 ft PMS	0.15 ft PMS (hot recycle)
New Material (Top Lift)	0.15 ft PMS (polymer-mod.)		0.15 ft PMS (polymer-mod.)	0.40 ft PMS (polymer-mod.)	0.20 ft PMS (polymer-mod.)
Surface Treatment[c]	Seal & Cover	Seal & Cover	Seal & Cover	Seal & Cover	Seal & Cover
Change in Pavement Thickness, ft (in.)	0.00 (0.0)	0.00 (0.0)	+0.05 (0.5)	+0.40 (5.0)	+0.15 (2.0)
Test Section					
Cold Mill,[d] ft (in.)	0.05 (0.5)	0.05 (0.5)	0.05 (0.5)	0.05 (0.5)	0.05 (0.5)
Overlay	0.15 ft PMS (polymer-mod.)	0.30 ft PMS (polymer-mod.)	0.15 ft PMS (polymer-mod.)	0.40 ft PMS (polymer-mod.)	0.20 ft PMS (polymer-mod.)
Surface Treatment[c]	Seal & Cover	Seal & Cover	Seal & Cover	Seal & Cover	Seal & Cover
Change in Pavement Thickness, ft (in.)	+0.10 (1.0)	+0.25 (3.0)	+0.10 (1.0)	+0.35 (4.0)	+0.15 (2.0)

NOTE: All asphalt concrete mixtures are Grade D, except for the surface layer at Custer County Line West, which is Grade S. 1 ft = 0.3 m; 1 in. = 2.54 cm.

PMS – plant-mix surface

CTPB – cement-treated pulverized base

[a] Deep enough to penetrate past the existing overlay and into the original plant mix surface.

[b] Cement-stabilized the remaining plant-mix surface and part of the gravel base.

[c] Grade 4A aggregate.

[d] To remove the open-graded friction course.

West, which was MDT Grade S (Superpave). This Grade S lift extended across both the control item and the test item. All test and control sections were topped with a chip seal ("seal and cover") with a 0.95-cm (0.375-in.) maximum-size aggregate.

The control section at Bearmouth–Drummond did not involve an increase in pavement thickness above subgrade relative to the original pavement structure. The MDT design personnel did not believe an increase in structural capacity was necessary at this site. The final thickness of the control section at Rocky Canyon was the same as the original structure, but the structural capacity was increased through stabilization. The control sections at Lincoln Road–Sieben, Custer County Line West, and Tarkio East involved increases in thickness above a subgrade of 1.27 cm (0.5 in.), 12.7 cm (5 in.), and 5.1 cm (2 in.), respectively (see Table 8).

The structural capacities of the test sections at all sites were increased relative to the original pavement structures. Milling was deep enough to remove only the OGFC, so all overlay lift thicknesses were greater than the depth of removed material. Increases in total thickness above subgrade for the test sections ranged from 2.54 to 10.2 cm (1 to 4 in.), as indicated in Table 8.

PAVEMENT PERFORMANCE MONITORING

The test sections at each site have been monitored annually for changes in structural capacity, roughness, and visual distress. Structural capacity has been monitored with both a Road Rater and a Jils falling-weight deflectometer (FWD). (The switch to the FWD was part of a statewide shift to this device by the MDT pavement management system.) Roughness was monitored with a South Dakota profilometer. Distress monitoring has involved visual inspections of the road surfaces and, beginning in 1999, a Rainhart transverse profilograph.

Structural Capacity

The MDT transitioned from using a Road Rater to using a FWD in 1998. Structural evaluations performed in 1997 or earlier involved a Road Rater. Both Road Rater and FWD testing have been done every 127 cm (50 ft) within the test sections. Most tests are performed in the outer wheelpath of the traveling lane. Every fourth test, however, is performed in the outer wheelpath of the passing lane. Thus far, differentiating tests by lane for the purpose of analyzing results has not been deemed necessary.

During Road Rater and FWD testing, the applied force and pavement surface deflections were measured. Surface deflections were measured at the following horizontal offset distances from the load: 0 cm (0 in.), 20.3 cm (8 in.), 30.5 cm (12 in.), 45.7 cm (18 in.) (FWD only), 60.9 cm (24 in.), 91.4 cm (36 in.), and 121.9 cm (48 in.). Currently, the MDT retains only peak loads and peak deflections for analysis purposes. The peak deflections can be used to produce a deflection basin. The deflection basin, in combination with the known load and assumed layer thicknesses, can be used to estimate the elastic moduli of pavement layers.

Additional methods exist for using deflection basin data to characterize pavement materials. For example, an overall pavement response stiffness can be obtained by simply dividing the applied load by the deflection under the load (offset = 0 cm). The curvature of the deflection basin has also been used to deduce material characteristics. Although these simplistic data analysis methods provide less information than the results of backcalculation, they require no assumptions in terms of the number of layers or layer thicknesses. Therefore, the simplistic analysis methods have advantages when thicknesses are unknown or when the number of layers cannot be limited to a manageable amount. The simplistic analysis methods may have advantages when pavement structures that have experienced several cycles of rehabilitation are being analyzed.

Roughness and Rut Depth

Roughness monitoring was performed with a South Dakota profilometer, which is an inertial profiler. The South Dakota profilometer consists of a truck equipped with accelerometers and lasers. Pavement roughness measurements are obtained at speeds between 32 and 105 km/h (20 and 65 mph) (typically at 105 km/h). The accelerometers provide an inertial reference and the lasers are used to measure the distance between the inertial reference and the pavement surface.

Roughness has been reported as international roughness index (IRI) values, which have units of inches/mile (inches of vertical deviations per mile of road). As a pavement's roughness increases, its IRI increases. The MDT ranks the conditions of paved surfaces in terms of IRI as indicated in Table 9.

TABLE 9 MDT Ranking of Pavement Roughness

Condition of Paved Surface	International Roughness Index (inches/mile)
Excellent	< 16
Good	16 to 75
Fair	76 to 150
Poor	151 to 225
Very Poor	> 225

NOTE: 1 in. = 2.54 cm; 1 mi = 1.6 km.

The South Dakota profilometer uses two lasers for measuring pavement surface deviations in order to calculate IRI. These two lasers are attached so that they project into the two wheelpaths. The South Dakota profilometer has a third laser on the front bumper in order to permit calculations of rut depth. The third laser is attached so that it projects in the middle of the lane, centered between the two wheelpaths. As the vehicle travels along the road, 20 to 30 measurements are obtained by each laser per 0.3-m length of pavement. The differences between the lengths measured by the lasers are used to estimate an average rut depth:

$$\text{average rut depth} = \frac{(h_1 - h_2) + (h_3 - h_2)}{2}$$

where

h_1 and h_3 = distances to the pavement surface in the wheelpaths, and
h_2 = distance to the pavement surface at midlane.

To supplement the data collected by the South Dakota profilometer, a Rainhart transverse profilograph is being used to measure rut depths during the final two evaluation years (1999 and 2000). The Rainhart device consists of a solid metal beam upon which a drum with graph paper travels across a single lane of the highway. This produces a hard copy of the transverse profile in a 1:1 ratio in the vertical direction and a 10:1 ratio in the horizontal direction. At most test sites, 10 randomly chosen stations are used for profile measurements in the test sections and 10 are used in the control sections. At the Bearmouth–Drummond site, only 5 stations are used in each test and control section. The locations of the stations from the start of a test or control section are consistent at a single location. However, each site has its own random arrangement.

Measurement of rut depth from profilograph information is accomplished by first drawing a straight line at the highest points about each wheelpath. The maximum vertical depth from this line to the profile is then considered the rut depth. For analysis purposes, the greater of the two wheelpaths is used.

Visual Distress Survey

Visual examinations and the methods for recording distress generally followed the guidelines established by the

TABLE 10 Distress Types Included in Visual Examinations

Distress Type	Unit of Measure	Comments
Bleeding	Percent Length of Affected Area[a]	Discoloration is reported as low severity bleeding even though it may not have substantial effects on pavement performance.
Raveling	Percent Area	Raveling of the surface treatment is differentiated from raveling of the asphalt concrete.
Transverse Cracking	Number and Density (length / area)	Full-width cracks, which extend from shoulder stripe to shoulder stripe, are differentiated from partial-width cracks.
Longitudinal Cracking at Centerline	Percent Length	None.
Longitudinal Cracking in the Wheelpath	Percent Length	None.
Fatigue Cracking	Percent Area	None.
Potholes	Percent Area	None.
Patches	Percent Area	None.

NOTE: Each distress type can have three levels of severity: low-severity, moderate severity, and high severity. Judgment of severity is based on SHRP guidelines (*2*).

[a] Affected area could be one or both wheelpaths, centerline, or edge of lane; localized bleeding was not a problem for the pavements included in this study.

Strategic Highway Research Program (SHRP) (2). Some modifications were implemented to meet the specific needs of this study. For example, units of measure have been adjusted in some cases. The types of distress that were included in the examinations performed for this study are presented in Table 10.

PAVEMENT PERFORMANCE

Pavement evaluations at the test sites have been performed for only 1 or 2 years. None of the pavements has deteriorated so quickly that conclusions are warranted at this time. Therefore, this section of the report serves the purpose of presenting the types of information that have been collected and reduced. Current plans are to continue to collect the same information for the next few years.

Structural Capacity

Pavement layer moduli are backcalculated from Road Rater and FWD tests. Road Rater moduli are substantially different than FWD moduli. Relative to the FWD, the Road Rater appears to estimate lower moduli for surface course layers and appears to estimate higher moduli for base course and subgrade layers. This difference most likely is caused by the different types of loading—that is, vibratory versus impact. For this study, conclusions will be drawn from trends in structural capacity over several years of service. Therefore, to avoid additional data anomalies, future FWD tests are being done in a manner consistent with those performed to date.

Data obtained from all three FWD test loads [2495 kg (5,500 lb), 3629 kg (8,000 lb), and 4536 kg (10,000 lb)] were reduced. The MDT has not yet refined its method for selecting among or combining these data, so all will be retained and included in the analysis for this study.

In addition to reporting mean (average) statistics, this study will provide indications of variability. Variability will become important as differences between the performance of control and test sections have to be judged as significant or not. The variability of backcalculated moduli is commonly high, especially for surface course layers. The coefficients of variation (the standard deviation divided by the mean) of FWD surface moduli within experimental sections were 20 to 60 percent.

Backcalculated moduli will not be the only parameters used to monitor the structural condition of experimental sections. Two additional parameters, structural numbers and the pavement response stiffnesses, are being evaluated. Both of these parameters provide an indication of the structural condition of the overall pavement instead of differentiating between pavement layers. Compared with backcalculated moduli, they tend to be less variable within any particular experimental section. The structural numbers were calculated using layer thicknesses and layer moduli, in accordance with the 1993 AASHTO design guide (3). Pavement response stiffnesses were calculated by dividing peak FWD load by peak deflection at the point of impact.

Roughness and Rut Depth

The experimental pavement sections began their service with roughness values (IRI) of about 40 to 100, which correspond to MDT qualitative rankings of good to fair. The IRI values, soon after construction, were similar for the control and test sections at Rocky Canyon, Lincoln Road–Sieben, and Custer County Line West. At Bearmouth–Drummond and Tarkio East, the IRI values were higher for the test sections than for the control sections. The control sections involve more milling and thicker placements of new material, which should promote a smoother product relative to the thin milling and overlay used for test sections.

The experimental pavement sections began their service with average rut depths of 0.38 cm (0.15 in.) or less. No consistent differences were observed between ruts in the control and test sections. These rut depths were estimated with the South Dakota profilometer. Currently these measurements are being supplemented with the Rainhart transverse profilograph.

The 1999 Rainhart data were analyzed by treating each location as separate smaller experimental sites. With a 95 percent confidence interval, only the Custer County location is offering a difference in performance between the test and control sections. At this site the control section is offering better rutting resistance. Recall that the control sections had stripped material removed before they were overlaid.

Similar to the structural capacity data, variability information is being retained for roughness and rut depth. Variabilities for IRI and rut depth are reported as range and average standard deviation, respectively. The calculation of the IRI range for an experimental section is possible because the South Dakota profilometer presents an IRI for each wheelpath and for each 0.16-km (0.1-mi) length of pavement. The calculation of average standard deviation for rut depths is possible because the South Dakota profilometer presents an average and standard deviation for each 0.16-km length of pavement. These IRI and rut depth calculations are based on 20 to 30 measurements per linear foot of pavement.

Visual Distress Survey

Condition surveys have been performed each year of service for all the test sites. The Tarkio East site has been surveyed only once because of its later construction date. All the sites currently appear to be in good condition. No sites have evidence of fatigue cracking or pothole formation. All the sites have some level of bleeding or transverse cracking.

Bleeding is not necessarily a distress that will lead to performance problems. According to SHRP condition survey procedures (2), low-severity bleeding should be recorded if the surface is discolored by excess asphalt. This can occur without affecting skid resistance. If surface texture is affected, the bleeding is labeled as moderate. Most of the bleeding observed at the test sites was low severity. Tarkio East also had moderate-severity bleeding in the traveling lane wheelpaths.

All transverse cracks at the test sites are currently classified as low severity. According to SHRP condition survey procedures (2), low-severity transverse cracks are either unsealed with a mean width equal to 0.64 cm (0.25 in.) or they are sealed with sealant material in good condition. The Rocky Canyon and Lincoln Road–Sieben site's cracks have been sealed. The Bearmouth–Drummond site and the Lincoln Road–Sieben site have the highest densities of transverse cracks, whereas the Tarkio East site has not yet cracked. Control and test sections have experienced similar transverse cracking at most sites. At Rocky Canyon, however, the control section has cracked more than the test section.

Conclusions and Recommendations

Based on 1 to 2 years of monitoring the test sites, the following conclusions and recommendations appear to be warranted.

- Construction of the experimental sections was successful and will provide informative comparisons between two methods of rehabilitating stripped pavements.
- Because test sections involved a simple overlay, they resulted in an increase in pavement thickness at all test sites. Because control sections involved substantial milling before overlays were placed, final thickness could be controlled. Changes in structural thickness for control sections ranged from 0 to 12.7 cm (0 to 5 in.), depending on anticipated traffic conditions. Consequently, the sites provide for various scenarios under which the two methods of rehabilitation can be compared.
- Because of the different loading conditions provided by the Road Rater and the FWD, the use of results from both types of equipment does not appear to be reasonable for the purposes of this study. This study seeks trends in pavement condition over time, and the pavement layer moduli estimated by the two types of equipment are different. This finding reinforces the importance of maintaining a consistent method of using the FWD throughout the remainder of this project.
- Roughness values (IRI) soon after construction indicate that substantial milling and the placement of new material in multiple lifts provide for smoother pavements relative to simple single-lift overlays. Consequently, the control sections in this study generally began their lives with better smoothness than the test sections.
- The tendency for experimental sections to rut is important to this study. Although the South Dakota profilometer provided an indication of rutting, more detailed rut data were believed to be advantageous. Future site

evaluations are now supplemented with transverse profiles, which are obtained with a Rainhart profiler.

• The predominant visual distress at the test sites has been transverse cracking. The cracks have thus far remained in a low-severity condition. Substantial differences between control and test sections have not yet been observed at the test sites, perhaps with the exception of the control section at Rocky Canyon, which has cracked more than the test section.

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REFERENCES

1. Das, B. M. *Principles of Geotechnical Engineering.* PWS-Kent Publishing Company, Boston, Mass., 1990.
2. *Distress Identification Manual for the Long-Term Pavement Performance Project.* SHRP-P-338. SHRP, National Research Council, Washington, D.C., 1993.
3. *Guide for Design of Pavement Structures.* AASHTO, Washington, D.C., 1993.