# Impact of Design Features on Pavement Response and Performance in Rehabilitated Flexible and Rigid Pavements

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LTPP

# FOREWORD

The primary focus of this research was to determine the effects of design and construction features, such as overlay thickness and mix type, presence of milling, and type of restoration, on pavement response and performance and to establish their importance in the prediction of future performance of rehabilitated pavements. Long-Term Pavement Performance program Specific Pavement Study (SPS)-5 and SPS-6 experiments provided information to obtain a better understanding of the effects of design and construction features on pavement response and performance of rehabilitated flexible and rigid pavements. The research findings provide guidance to identify appropriate features and rehabilitation alternatives for different pavement types and recommendations for improving data collection activities. The analyses results obtained in this study help determine the causes of distress and formulate models for predicting performance of rehabilitated pavements. Additionally, data from SPS-3 and SPS-4 experiments were used to determine the effectiveness and timing of preventive maintenance treatments. The findings suggest that it is possible to determine significant differences between treatment alternatives with respect to pavement performance and treatment timing. Performance of rehabilitated pavement sections from SPS-5 and SPS-6 were also examined using the *Mechanistic Empirical Pavement Design Guide* and compared with the field performance.(1) The results provide useful information about rehabilitated pavement section performance predictions and recommendations for future model improvements.

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16. Abstract

The primary focus of this research was to determine the effects of design and construction features, such as overlay thickness and mix type, presence of milling, and type of restoration, on pavement response and performance and to establish their importance in the prediction of future performances of rehabilitated pavements. Long-Term Pavement Performance program Specific Pavement Study (SPS)-5 and SPS-6 experiments provided information to obtain a better understanding of the effects of design and construction features on pavement response and performance of rehabilitated flexible and rigid pavements. The research findings provided guidance to identify appropriate features and rehabilitation alternatives for different pavement types and recommendations for improving data collection activities. The analyses results obtained in this study helped determine the causes of distress and helped formulate models for predicting performance of rehabilitated pavements. In addition, data from SPS-3 and SPS-4 experiments were used to determine effectiveness and timing of preventive maintenance treatments. The findings suggest that it is possible to determine significant differences between treatment alternatives with respect to pavement performance and treatment timing. Performance of rehabilitated pavement sections from SPS-5 and SPS-6 were also examined using the *Mechanistic Empirical Pavement Design Guide* and compared with the field performance.(1) The results provide useful information about rehabilitated pavement section performance predictions and recommendations for future model improvements.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| in$^2$ | square inches | 645.2 | square millimeters | mm$^2$ |
| ft$^2$ | square feet | 0.093 | square meters | m$^2$ |
| yd$^2$ | square yard | 0.836 | square meters | m$^2$ |
| ac | acres | 0.405 | hectares | ha |
| mi$^2$ | square miles | 2.59 | square kilometers | km$^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| ft$^3$ | cubic feet | 0.028 | cubic meters | m$^3$ |
| yd$^3$ | cubic yards | 0.765 | cubic meters | m$^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in m$^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/m$^2$ | cd/m$^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/in$^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| mm$^2$ | square millimeters | 0.0016 | square inches | in$^2$ |
| m$^2$ | square meters | 10.764 | square feet | ft$^2$ |
| m$^2$ | square meters | 1.195 | square yards | yd$^2$ |
| ha | hectares | 2.47 | acres | ac |
| km$^2$ | square kilometers | 0.386 | square miles | mi$^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| m$^3$ | cubic meters | 35.314 | cubic feet | ft$^3$ |
| m$^3$ | cubic meters | 1.307 | cubic yards | yd$^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/m$^2$ | candela/m$^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/in$^2$ |

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# EXECUTIVE SUMMARY

The main goal of this project was to use Long-Term Pavement Performance (LTPP) Specific Pavement Study (SPS) experiment data to assess the impact of different design, construction, and rehabilitation features on pavement response and performance for specific site conditions. The analysis sought to identify which features could help achieve the best short-term and long-term performance and to evaluate the effectiveness of common maintenance practices used for flexible and rigid pavements.

## PREVENTIVE MAINTENANCE TREATMENTS

The findings of this study are based on the analysis of 81 SPS-3 flexible pavement sites and 34 SPS-4 rigid pavement sites subjected to different preventive maintenance treatments. Most of the flexible pavement sites were monitored for at least 4 years, and approximately 22 percent of the sites were monitored for 10 years or more. Most of the rigid pavement sites were monitored for at least 4 years.

Of all SPS-3 treatments, thin overlay was the only effective alternative to mitigate and delay the progression of roughness; however, it was effective only for pavements in freeze zones, high traffic, or poor condition. It was found that thin overlays could only perform better relative to roughness compared to other treatments if the International Roughness Index (IRI) level was higher than 7.34 ft/mi (1.39 m/km). For lower IRI levels, the sections performed similarly and independent of the treatment, and there was no advantage of applying thin overlays.

Thin overlays slowed the progression of rutting under all circumstances. Chip seal was more effective than slurry seal in wet freeze zones but was only marginally more effective in dry freeze zones. There were no significant differences among slurry seal, crack seal, and the no treatment scenario with respect to rutting, as expected.

Thin overlays and chips seals were more effective than slurry seal and crack seal treatments in mitigating fatigue cracking. Thin overlays performed better than most other treatments if the pavement was in a freeze zone, in a wet climatic region, initially in poor condition as well as subjected to high traffic. For fatigue cracking, thin overlays and chip seals outperformed the other treatments, as well as the control section, when the initial cracking was lower than 232.13 $ft^2$/mi (13.4 $m^2$/km). For higher levels of cracking, every treatment outperformed the control section. Specifically, chip seals performed best, followed by thin overlays.

The data analysis from SPS-4 sites indicated that the joint/crack sealed sections and undersealed sections performed similarly to the control sections. Also, no meaningful differences were found between the two treatments. The analysis was based on a relatively small number of sites that had 4 years of performance history that included recorded surveys with undersealing treatment. While 34 sites were included in the survey measurements for joint/crack sealed sections, only 10 had data for undersealed sections.

## REHABILITATED FLEXIBLE PAVEMENTS

The findings are based on the analysis of 18 SPS-5 rehabilitated flexible pavement sites, with a total of 162 core test sections. Most of the sections were monitored for at least 9 years.

Rehabilitation strategies with milling prior to overlay provided better performance relative to IRI levels for all site conditions. Moreover, strategies with thick overlays provided smoother pavements for all site conditions. Design alternatives with new or recycled asphalt mixes had equivalent performance when used under wet conditions; however, those with recycled asphalt mixes provided smoother pavements when used in dry conditions. Traffic level and freeze conditions did not affect pavement performance relative to roughness.

With respect to rutting, rehabilitation strategies with thin overlays performed better than thick overlays in the short term. The ranking of best strategies was evenly distributed between the two mix types (virgin and recycled asphalt). In the long term, the ranking of best strategies was more evenly distributed for both thick and thin overlays. Rehabilitation strategies with virgin mixes performed better in most of the sites, with the exception of pavements in fair surface condition prior to rehabilitation and under freeze conditions, which corresponded to 33 percent of all sites. Strategies with milling did not improve rutting performance more than alternatives without milling. Surprisingly, the level of traffic did not affect rutting performance for the selected rehabilitation strategies.

Short-term fatigue cracking performance was not significantly affected by any design feature under any site conditions. This finding was expected because overlays are designed to minimize fatigue cracking in the short term. Rehabilitation strategies with thick overlays provided better performance for fatigue cracking for all site conditions that were evaluated. Strategies with milling prior to overlay performed better to mitigate development and propagation of fatigue cracking in all site conditions. In regions with a dry climate, alternatives without milling performed as well as solutions with milling. Strategies with recycled asphalt mixes were better ranked for sites with low traffic when evaluating fatigue cracking.

When comparing the alternatives evaluated and the overall performance for all types of load-associated distress, overlay thickness was the most influential design feature. As expected, thick overlays consistently performed better. The impact of thickness on performance was more evident in the long term (more than 5 years) for most of the distresses. The exception was rutting, for which no evidence was found, suggesting that either thin or thick overlays provided less rutted pavements. The analysis of milling prior to overlay suggests that replacing the distressed portion of the surface layer improved the performance for the majority of distresses commonly observed in flexible pavements. The majority of sites did not show significant differences in performance between sections overlaid with virgin and recycled asphalt mixes. However, when differences existed, they were mostly in favor of virgin mixes.

For evaluation of structural responses, a maximum falling weight deflectometer (FWD) deflection measured under the center of the load was used as a structural response indicator. Rehabilitation strategies with thick overlays provided the lowest structural response independent of site conditions. Strategies with recycled asphalt mix overlays had the smallest structural deflections in freeze regions, while those with virgin mixes presented smaller deflections under no-freeze conditions. Milling prior to overlay did not further impact the structural response. In fact, in no-freeze zones, strategies without milling presented lower deflections. When comparing wet and dry climates, pavement surface conditions, and traffic levels, none had a significant impact on structural responses associated with each rehabilitation alternative.

As expected, rehabilitation strategies with thick overlays had lower maximum deflection values compared to alternatives with thin overlays. There were no differences in pavement response between strategies with virgin and recycled asphalt mix overlays. Strategies with milling prior to overlay did not affect the structural response more than alternatives without milling.

## REHABILITATED RIGID PAVEMENTS

Findings for rehabilitated rigid pavements are based on the analysis of 14 SPS-6 rehabilitated rigid pavement sections, 8 jointed plain concrete pavement (JPCP) sections, and 6 jointed reinforced concrete pavement (JRCP) sections. Most of the sections were monitored for at least 6 years. The results from the analysis are described separately for JPCP and JRCP sites.

With respect to JPCP structures, rehabilitation strategies with hot mix asphalt (HMA) overlays provided significantly smoother pavements than treatments without overlays in both the short term and long term. The best alternative to improve roughness performance was crack/break and seat with an 8-inch (203-mm) overlay. This same alternative and minimum restoration with a 4-inch (102-mm) overlay (without crack/break) had statistically equivalent performances and were found to be the best alternatives for most of the scenarios evaluated when both short-term and long-term roughness performance were considered. Crack/break and seat with a 4-inch (102-mm) overlay was among the worst alternatives to improve pavement performance relative to roughness. Saw and seal provided similar performance to other 4-inch (102-mm) overlays.

Rehabilitation strategies without overlays were the best to mitigate cracking development and propagation. HMA overlays over jointed concrete pavements exhibited more surface cracking than alternatives without overlays. Crack/break and seat the JPCP had no significant effect in reducing the amount of cracking because it performed similarly to the 4-inch (102-mm) overlays over noncracked JPCP (with both minimum and maximum restorations). The three alternatives without overlays, the no treatment scenario, minimum restoration, and maximum restoration, were found to be the best choices to mitigate surface cracking for both short-term and long-term performance. Crack/break and seat with 4-inch (102-mm) overlays was the best alternative among those that involved overlays. The sawed and sealed joints did not deteriorate significantly on these sections, and they effectively controlled reflection cracking.

When evaluating the impact of site conditions, different climate regions and surface conditions did not have a significant impact on roughness and total cracking performance for the rehabilitation strategies included in the SPS-6 JPCP experiment.

Similar to the findings for JPCP, JRCP strategies with HMA overlays improved roughness performance, while strategies without overlays were better at improving total cracking development and propagation. Rehabilitation strategies with overlays performed significantly better when compared to treatments without overlays. Minimum and maximum restorations with overlay were the best strategies to improve short-term performance for roughness. For long-term performance, the best alternative was the crack/break and seat and the 8-inch (203-mm) overlay.

Rehabilitation strategies without overlays were the best when considering total cracking. Saw and seal presented the highest surface cracking among all options evaluated; however, the sawing may have had an impact on the monitoring process because this alternative remained in reasonably good condition over time. Crack/break and seat the JRCP had no significant effect on reducing the amount of cracking because it performed similarly to the 4-inch (102-mm) overlay over noncracked JRCP (with minimum and maximum restoration). Sawing and sealing proved to effectively control reflective cracking.

Deflections at the center of the slab and at the transfer joints were evaluated in this study. JPCP and JRCP structures were evaluated independently. Sections that received HMA overlays were monitored like flexible pavements, and deflections at the center of the lane were used in the analysis. There were limitations due to the amount of data available, particularly after the data were grouped by pavement structure type and surface condition.

The only analysis that provided statistically meaningful results was the evaluation of maximum deflection at the center lane of overlaid JRCP structures. The results of that evaluation suggest that crack/break and seat significantly increased the overall deflections measured on the pavement surface. The remaining treatments provided equivalent maximum deflection magnitudes. This was expected since crack/break and seat was an alternative in which the concrete slab was reduced to smaller pieces, resulting in lower stiffness. This process increased the maximum deflection at the center of the slab.

## FINDINGS FROM MEPDG ANALYSES

The *Mechanistic Empirical Pavement Design Guide* (MEPDG) analysis was used to compare MEPDG-predicted performance of rehabilitated pavement sections with field measured data to verify current calibration for rehabilitated pavement structures.(1)

The roughness models for flexible and rigid pavements provided good estimates for rehabilitated sections with and without HMA overlays, and some bias was identified. The model has a tendency to underpredict roughness for rigid pavement sections with IRI values above 9.50 ft/mi (1.8 m/km). This bias is more characteristic of sections located in dry and freeze regions, and it could be addressed by calibrating the models for local conditions.

The rutting model needs further enhancement to more accurately predict permanent deformation for HMA overlays over flexible and rigid pavements. The model underpredicts rutting of HMA overlays over crack/break and seat restored rigid pavements and overpredicts for HMA overlays with saw and seal and for minimum and maximum restorations prior to overlays.

The cracking models for HMA overlays, particularly the empirical reflection cracking, need further enhancement to provide more accurate estimates for rehabilitated sections. The models for fatigue cracking (new and reflective) and longitudinal cracking were very accurate for estimating consistent and comparable performance with measured values. MEPDG did not predict transverse cracking in any of the SPS-5 or SPS-6 sections, even though some transverse cracking was measured during surveys.

# CHAPTER 1. INTRODUCTION

## BACKGROUND

Rehabilitation represents the majority of pavement design and construction activity in the United States, and the importance of improving the rehabilitation process cannot be overemphasized. It is well known that in addition to site conditions (e.g., traffic level, climatic conditions, subgrade support, drainage, etc.), the performance of rehabilitated pavement sections depends on the condition and design of the existing pavement, including any prerehabilitation measures to improve the existing structure.

Current pavement rehabilitation design procedures are based mainly on the American Association for State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* that uses limited performance models developed from the AASHTO road test in the late 1950s.(2) The recently developed MEPDG reflects the state of the art in pavement design and is considered a significant improvement over the *Guide for Design of Pavement Structures*.(1,2) However, gaps still exist in the knowledge base, particularly for rehabilitated pavements, and the mechanistic design methods still are supported by empirical relationships and judgments made by the designer (e.g., determining the representative response properties of a surface layer that exhibits a moderate level of distress).

One of the most critical aspects of MEPDG analysis for rehabilitated pavements is the characterization of existing pavement conditions prior to rehabilitation. Collection of reliable data is imperative because all major decisions regarding existing pavement problems and feasible rehabilitation alternatives depend on the accuracy and integrity of these data.

More importantly, relatively few of the rehabilitation sections from the LTPP program were included in the calibration of MEPDG compared to what is currently available. Many of the test sections were missing data considered mandatory for the calibration process, and many sections in the SPS experiments exhibited little distress because those projects were less than 5 years old. Most of this missing data are now available on the LTPP database, and most of the SPS projects are at least 10 years old and are starting to exhibit moderate levels of distress. As a result, more data are now available and can be used to evaluate the empirical and subjective relationships. LTPP performance data can also be used to recommend improvements to the MEPDG rehabilitated pavement analysis and design procedures.

Because of continued data collection and improvements over time, LTPP collected information on test sections that included a variety of rehabilitation and preservation strategies. Because of additional data available in the LTPP database, researchers have a better understanding of the effects of design and construction features on pavement response and performance of rehabilitated flexible and rigid pavements. These data were used in the analyses conducted in this study to examine the causes of distress. The information obtained in this study can be used to formulate improved models predicting performance of rehabilitated pavements for eventual use in MEPDG. In addition, the data collected and assembled during the study can be used to improve existing MEPDG calibration and validation. This project also offers a unique opportunity to evaluate MEPDG global calibration factors for rehabilitated pavements.

The results of this research enhance existing knowledge related to rehabilitation design in three primary areas: (1) the relationship between pavement design and construction features and pavement response and performance, (2) guidance for identifying appropriate rehabilitation treatments and features for different pavement types, and (3) recommendations for improving LTPP data collection activities and future MEPDG model improvements. In addition, preventive maintenance alternatives were evaluated in this study, and guidance on selecting effective preventive maintenance treatments was developed based on findings from the SPS-3 and SPS-4 experiments.

## PROJECT OBJECTIVES

The objectives of this project were to use SPS experiment data to determine the following for specific site conditions:

- The impact of the different design, construction, and rehabilitation features on pavement response.
- The contributions of these features to achieve different levels of pavement performance.
- The effectiveness of specific maintenance options for new flexible and rigid pavements.

More specifically, these objectives translate into practical conclusions to respond to the following questions:

- Which design/treatment alternative generally performs better for each type of existing pavement?
- Which design/treatment alternative performs better in the short term (5 years for SPS-5 and SPS-6)?
- Which design/treatment alternative performs better in the long term (10 years for SPS-5 and SPS-6)?
- Which design/treatment alternative performs better in each climatic region?
- Which design/treatment alternative performs better for low and high traffic volumes?
- Does preconstruction activity affect design/treatment alternative performance?
- Are MEPDG distress and roughness predictions biased for different traffic levels, climatic conditions, or pavement types?

Practical findings obtained from this study will help highway engineers and managers make improved pavement design, construction, and rehabilitation decisions.

## REPORT ORGANIZATION

This report documents findings from the investigation of the impact of design features on pavement response and performance in rehabilitated flexible and rigid pavements. The information presented in this report is organized into eight chapters and five appendices.

# CHAPTER 2. LITERATURE REVIEW

## SUMMARY OF FINDINGS FROM PREVIOUS STUDIES

The goal of the literature review was to identify available reports on the response and performance of rehabilitated flexible and rigid pavements and to summarize findings relevant to the objectives of the current study.

The Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) have sponsored numerous studies to assess LTPP SPS experiment statuses, construction adequacies, and key data element availability (e.g., traffic, subgrade, materials, monitoring, etc.) and to conduct preliminary analyses of the collected data. This chapter contains a summary of findings from previous investigations related to the effect of key design and construction features and site conditions on performance of flexible and rigid rehabilitated pavements. The literature review findings are presented in table 1 through table 6.

The literature review findings provide information on the following topics:

- Key measures of pavement performance (distresses, roughness, etc.).
- Previously identified design factors affecting structural responses and pavement performance.
- Previously identified construction factors affecting structural responses and pavement performance.
- Previously identified site conditions affecting pavement performance.
- Effects of prerehabilitation pavement conditions and treatments on rehabilitated pavement responses and performance.
- Optimum timing of preventive maintenance treatments.

## Table 1. Rehabilitation of flexible pavements.

| Publication | Major Findings |
|---|---|
| **Current Study Relevance: Performance Measures** | |
| *Performance of Rehabilitated Asphalt Concrete Pavements in the LTPP Experiments—Data Collected Through February 1997(*FHWA-RD-00-029)(3) | • Nonwheel-path longitudinal cracking was the most prevalent distress in the early period (SPS-5).<br>• Fatigue cracking was the least observed distress (SPS-5).<br>• Nonwheel-path longitudinal cracks exceeded wheel-path longitudinal cracks (general pavement study (GPS)-6).<br>• GPS-6 data showed that fatigue cracking and longitudinal cracking in the wheel path are related. Specifically, the longitudinal cracking in the wheel path will propagate or evolve into fatigue cracking with continued traffic loading. |
| *Rehabilitation of Asphalt Concrete Pavements—Initial Evaluation of the SPS-5 Experiment* (FHWA-RD-01-168)(4) | • Four performance indicators were established: fatigue cracking, transverse cracking, rutting, and IRI.<br>• Fatigue cracking occurred most frequently on older sections.<br>• Transverse cracking occurred in all but four of the projects, all of which were less than 7 years old.<br>• Older sections showed moderate severity of transverse cracks even in a no-freeze climate.<br>• Test sections with extensive transverse and fatigue cracking had high IRIs. |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* Web Document 47 (Project 20-50(3/4))(5) | • All SPS-5 overlay treatments reduced long-term roughness relative to the nonoverlaid sections.<br>• The rutting data from the SPS-5 and GPS-6B experiments indicated that on average, about 0.2 inches (6 mm) of rutting developed in the first year after placement of an asphalt overlay of an asphalt pavement. |
| **Design Factors** | |
| *Performance of Rehabilitated Asphalt Concrete Pavements in the LTPP Experiments—Data Collected Through February 1997 (*FHWA-RD-00-029)(3) | • The nominal 5-inch (127-mm) overlays generally showed better performance than the nominal 2-inch (5l-mm) overlays, as expected (SPS-5).<br>• The thicker overlays generally exhibited less cracking distress than the thinner ones but had little effect on the occurrence of rutting and no apparent effect on roughness (SPS-5).<br>• The different type of mixtures (virgin or recycled asphalt concrete (AC)) appeared to have the least effect on performance of any of the factors included in this experiment (SPS-5).<br>• There was no advantage to using virgin versus recycled mixtures in reducing the number of transverse cracks.<br>• Compared to virgin mixes, recycled AC mixtures resisted longitudinal cracking outside the wheel path substantially better in at least five projects.<br>• Thicker pavement performed better (GPS-6).<br>• The thickness of the pavement was conversely correlated with the extent of nonwheel-path longitudinal cracks (GPS-6).<br>• Neither the age nor the condition of the pavement before the overlay seemed to be critical to cracking extent (GPS-6).<br>• Thicker overlays resisted rutting slightly better than thinner ones (GPS-6).<br>• AC mix properties were the most significant factors to limit rutting (GPS-6).<br>• Thicker overlays offered a slight advantage for roughness (GPS-6).<br>• GPS-6A (existing AC overlays on AC pavements) data showed that overlay designs that provided pavement structure consistent with traffic expectations can be expected to perform well for more than 10 years. |

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| *Rehabilitation of Asphalt Concrete Pavements—Initial Evaluation of the SPS-5 Experiment* (FHWA-RD-01-168)(4) | • Overlay thickness did not appear to have a strong effect on the occurrence of longitudinal cracking in the wheel path and rutting (5 years after rehabilitation).<br>• There was no apparent effect of overlay thickness on roughness based on these early observations (5 years after rehabilitation).<br>• Age of overlay was found to be the leading contributing factor to four of the six distresses studied in the SPS-5 experiment (rehabilitation of AC pavements): fatigue cracking, rutting, transverse cracking, and initial pavement smoothness. |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • Overlay thickness and preoverlay roughness level were the two factors that most influenced the performance of asphalt overlays of asphalt pavements in the SPS-5 experiment with respect to roughness and fatigue cracking.<br>• No significant mean differences were detected in long-term roughness, cracking, and rutting between recycled mixes versus virgin mixes.<br>• No significant mean differences were detected in long-term rutting between minimal versus intensive preparation or thin versus thick overlays.<br>• Preoverlay cracking, age, and accumulated traffic loads significantly correlated to the difference in long-term cracking in nonoverlaid versus overlaid sections. |
| *Reducing Flexible Pavement Distress in Colorado Through the Use of PMA Mixtures*(6) | • Projects using modified HMA mixtures were found to have lower amounts of fatigue cracking, transverse cracking, and rutting.<br>• The use of modified HMA mixtures was found to extend the service life of HMA overlays by about 3 years, a 30 percent increase over the 10-year design life. |
| **Construction Factors** | |
| *Performance of Rehabilitated Asphalt Concrete Pavements in the LTPP Experiments—Data Collected Through February 1997* (FHWA-RD-00-029)(3) | • The test sections that had received intense surface preparation (patching and milling) prior to placement of the overlays generally performed better than test sections that had not. Reduced fatigue cracking, reduced longitudinal cracking in the wheel paths, and reduced transverse cracking were observed on intensely prepared sections.<br>• The amount of transverse cracking was dependent on the original pavement condition before overlay placement. The overlays placed on pavements classified in good condition exhibited less transverse cracking than on pavements classified in poor condition.<br>• No substantial difference was noted between longitudinal cracking outside the wheel paths, rutting, and roughness between the test sections with and without milling (SPS-5).<br>• Rutting was not affected by or related to the condition of the original pavement or age of the overlay (GPS-6).<br>• The condition of the original pavement prior to overlay appeared to have little effect on the occurrence of or increase in roughness (GPS-6).<br>• The amount of traffic affected the growth of roughness (GPS-6). |
| *Rehabilitation of Asphalt Concrete Pavements—Initial Evaluation of the SPS-5 Experiment* (FHWA-RD-01-168)(4) | • Fewer or shorter transverse cracks occurred on sections that had been milled.<br>• According to an analysis of variance (ANOVA), milling depth had an important effect on the length of transverse cracks.<br>• The IRI values of the overlay were lower for the overlays placed over pavements in the fair category and when the existing surface was milled before overlay. |

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|---|---|
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • Asphalt pavements overlaid when rougher tended to have somewhat more initial roughness after overlay than asphalt pavements overlaid when smoother.<br>• There was no significant mean difference in long-term roughness between overlays with minimal versus intensive preoverlay preparation.<br>• No significant mean differences were detected in long-term cracking between minimal versus intensive preparation. |
| **Site Factors** | |
| *Rehabilitation of Asphalt Concrete Pavements—Initial Evaluation of the SPS-5 Experiment*(6) | • The age of the overlay and the climatic factors temperature and moisture had a significant effect on fatigue cracking.<br>• More fatigue cracking occurred on test sections in a climate with less precipitation but higher freeze indices.<br>• Longer transverse cracks occurred on the older pavements in areas with higher freeze indices.<br>• Freeze index had an effect on the length of transverse cracks.<br>• The age of the overlay and precipitation had an effect on rut depth. Sections with increased precipitation had larger rut depths.<br>• The age of the overlay, condition of the pavement before overlay placement, and surface preparation or milling depth were important factors relative to the IRI values.<br>• Milling offered no consistent advantage for resisting longitudinal cracking outside the wheel path during the early life of an overlay. |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • Overlay age and average annual precipitation had a significant effect on long-term rutting.<br>• A significant correlation was detected between average annual precipitation and the difference in long-term rutting in 2-inch (51-mm) versus 5-inch (127-mm) overlays. |

## Table 2. Rehabilitation of rigid pavements.

| Publication | Major Findings |
|---|---|
| **Current Study Relevance: Design Factors** | |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • The effectiveness of the rigid pavement rehabilitation treatments in the SPS-6 experiment can be ranked from most to least effective with respect to IRI, rutting, and cracking as follows: (1) 8-inch (203-mm) overlay of cracked/broken and seated pavement, (2) 4-inch (102-mm) overlay of either intact or cracked/broken and seated pavement with or without sawing and sealing of transverse joints and with minimal or intensive preoverlay repair, (3) concrete pavement restoration with diamond grinding, full-depth repair, and joint and crack sealing, and (4) concrete pavement restoration without diamond grinding but with full-depth repair and joint and crack sealing.<br>• Subdrainage retrofitting, undersealing, and/or load transfer restoration techniques did not produce significantly lower long-term roughness levels compared to sections that received only diamond grinding, full-depth repair, and joint and crack sealing. |
| *Rehabilitation of Jointed Portland Cement Concrete Pavements: Initial Evaluation and Analysis* (FHWA-RD-01-169)(7) | • The rehabilitation techniques in exposed Portland cement concrete (PCC) involve restoration techniques other than overlay including full-depth repair, diamond grinding, joint sealing, and addition of retrofitted edge drains.<br>  • If the prerehabilitated section has significant roughness, diamond grinding should be considered or the section will retain its roughness. Full-depth repairs do not remove significant roughness from a jointed concrete pavement by themselves.<br>  • Both routine and premium pavement preparation treatments reduce the amount of transverse cracking immediately after rehabilitation. Routine preparation treatment includes limited patching, crack repair and sealing, and stabilization of joints. Premium preparation treatment includes subsealing, subdrainage, joint repair and sealing, full-depth repairs with restoration of load transfer, diamond grinding, and shoulder rehabilitation.<br>  • Premium pavement preparation with diamond grinding reduces the amount of faulting to zero immediately after rehabilitation.<br>• AC overlay of nonfractured PCC rehabilitation technique involves applying varying degrees of preoverlay repairs and placing an AC overlay.<br>  • The AC overlay of nonfractured PCC reduces the roughness immediately after rehabilitation to a smooth level (5.28 ft/mi (1.0 m/km)).<br>  • The sections with AC overlay of nonfractured PCC exhibit a faster increase in IRI over time than does the fractured PCC.<br>  • The sections with AC overlay of nonfractured PCC exhibit a lower increase in IRI over time than do premium preparation nonoverlaid PCC sections.<br>  • The routine and premium preparation sections with 4-inch (102-mm) AC overlays exhibited no reflective cracking within the first year after construction. |

| **Design Versus Built Variations** | |
|---|---|
| *Rehabilitation of Jointed Portland Cement Concrete Pavements: Initial Evaluation and Analysis* (FHWA-RD-01-169)(7) | • Sites in South Dakota, Arizona, and California did not meet the annual precipitation requirement for the climate they were considered for.<br>• Sites in Tennessee, Oklahoma, and California did not meet the freeze index requirement for the climate they were considered for.<br>• Four sites fell short on the required age criteria.<br>• A total of 45 percent of sites did not have an AC overlay thickness within the designed range. |
| **Performance Measures** | |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • The rutting data from the SPS-6 (rehabilitation of jointed PCC pavements) and GPS-7B (new AC overlays on PCC pavements) experiments indicate that on average, 0.24 inches (6 mm) of rutting developed in the first year after placement of an AC overlay of either an intact or a cracked/broken and seated concrete pavement. This may be due to compaction of the AC overlay by traffic and appears to be independent of the overlay thickness, mixture type, preoverlay preparation, and preoverlay rutting level.<br>• No significant differences were detected in cracking based on 8 years of data as follows:<br>  • Between minimal (i.e., without milling) and intensive (i.e., with milling) preoverlay preparation.<br>  • Between sections with and sections without sawed and sealed joints.<br>  • Between 4-inch (102-mm) overlays with sawed and sealed joints versus those over cracked/broken and seated pavements.<br>  • Between 4-inch (102-mm) and 8-inch (203 mm) overlays of cracked/broken and seated pavements.<br>• In 4-inch (102-mm) AC overlays of intact slabs, no significant differences were detected in roughness based on 6 years of data as follows:<br>  • Between minimal and intensive preoverlay preparation.<br>  • Between sections with and without sawing and sealing of transverse joints.<br>  • Between overlays with sawed and sealed joints and overlays of cracked/broken and seated slabs.<br>  • Among overlays of cracked/broken and seated slabs, the 8-inch (203 mm) overlays had significantly lower long-term roughness than the 4-inch (102-mm) overlays, as expected. |

## Table 3. Preventive maintenance of flexible pavements.

| Publication | Major Findings |
|---|---|
| **Current Study Relevance: Design Factors** | |
| *The LTPP Experiment SPS-3 5-Year Data Analysis* (FHWA-RD-97-102)(8) | • Structural adequacy did not have a significant effect on the performance of SPS-3 treatments.<br>• Thin overlay had a significant effect in rutting and roughness reduction, while other treatment options were either slightly effective or not effective. |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • In the SPS-3 thin overlay sections, pavement age was the only factor studied that was found to be significantly correlated to the rate of rutting.<br>• In the SPS-3 crack sealed and chip sealed sections, average annual precipitation was the only factor studied found to significantly correlate to the rate of rutting. |
| **Analysis Approach** | |
| *The LTPP Experiment SPS-3 5-Year Data Analysis* (FHWA-RD-97-102)(8) | • This report provides multiple regression models to develop prediction models for cracking, rutting, ride quality, friction, and pavement rating score. |
| *Pavement Maintenance Effectiveness* (SHRP-H-358)(9) | • This study developed a damage modeling approach with an index varying between zero and 1. The index is dependent on accumulated traffic/age, expected traffic/age to failure, and the shape of the performance trend. |
| *LTPP Maintenance and Rehabilitation Data Review* (FHWA-RD-01-019)(10) | • This report documents a survival analysis of SPS-3 sites in the Southern LTPP region in 1999 to obtain life expectancy of each treatment, effect of timing, and the benefit of treatment to the life span of the pavement. |
| **Treatment Performance** | |
| *LTPP Maintenance and Rehabilitation Data Review* (FHWA-RD-01-019)(10) | • After 6 years of service, sections that received maintenance when in poor condition had a probability of failure twice as much as sections initially in fair or good condition.<br>• Sections in fair and good condition had about the same probability of failure.<br>• The overall median survival times for thin overlay, slurry seal, and crack seal were 7, 5.5, and 5.1 years, respectively.<br>• A median survival time for chip seal could not be determined because fewer than 50 percent of these sections had failed at the time of the analysis. Chip seals outperformed thin overlay, slurry seal, and crack seal treatments with respect to controlling the reappearance of distress. |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • In terms of roughness, rutting, and fatigue cracking, the most effective of the maintenance treatments was the thin overlay treatment, followed by the chip seal treatment, and then the slurry seal treatment.<br>• The thin overlay treatment was the only one of the four SPS-3 maintenance treatments to produce an initial small reduction in roughness, and the only one of the four to have a significant effect on long-term roughness, relative to the control sections.<br>• For the SPS-3 test sections, the thin AC overlay treatment was the only one of the four treatments (thin AC overlays, chip seals, slurry seals, and crack seals) that showed a significant initial effect on rutting. Thin AC overlays also had the most significant effect on long-term rutting control.<br>• For rougher pavements, there was some evidence that chip seals and slurry seals also had some effect on long-term roughness, rutting, and cracking relative to the control sections.<br>• Crack seals did not have any significance on long-term roughness, rutting, or fatigue cracking. |

| | |
|---|---|
| *Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations National Report* (FHWA-RD-96-208)(11) | • The thin AC overlay treatments performed best after 5 years.<br>• In general, chip seal treatments also performed well. Chip seal performance was best in the Southern region, which has a predominantly wet no-freeze environment.<br>• The crack seal treatment performed very well in wet freeze environments where the wide shallow sealant reservoir was routed. Crack seal performance in the other two regions was not as successful. |
| *LTPP Pavement Maintenance Materials: SHRP Crack Treatment Experiment* (FHWA-RD-99-143)(12) | • The most cost-effective treatments for crack seals are usually those consisting of rubberized asphalt placed in a standard or shallow-recessed band-aid configuration. The standard recessed band-aid method showed the longest estimated service life, followed very closely by the shallow recessed band-aid method.<br>• For long-term crack-seal performance (5 to 8 years) under the condition where 0.1 to 0.2 inches (2.5 to 5.0 mm) of horizontal crack movement occurred, a modified rubberized asphalt sealant should be installed in either a standard or a shallow recessed band-aid configuration. |
| **Design Versus Built Variations** | |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • The review of construction problems and deviations in the SPS-3 experiment illustrated that more than 40 percent of the sites had problems in the application of maintenance treatments, mostly chip seal. |
| **Treatment Timing** | |
| *Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations National Report* (FHWA-RD-96-208 (11) | • The question of timing cannot be resolved completely from the visual observation of the SPS-3 sites, but indications are that earlier application of the preventive maintenance treatments provides greater benefits than later application. |

## Table 4. Preventive maintenance of rigid pavements.

| Publication | Major Findings |
|---|---|
| **Current Study Relevance: Performance Measures** | |
| *LTPP Data Analysis: Relative Performance of Jointed Plain Concrete Pavement with Sealed and Unsealed Joints* (NCHRP Web Document 32 Project 20-50(2))(13) | • Joint spalling was quantified by several measures, including percentage of joints spalled within a pavement section, total length of joint spalling, percentage of total joint length spalled, and percentage of individual joint length spalled. In addition, weighted measures were used that take into account the severity of joint spalling as characterized by low-, medium-, and high-severity joint spalling.<br>• The faulting measure employed in most previous analyses of LTPP concrete pavement performance is average joint faulting, as measured in the outer wheel path. In addition, average absolute faulting was introduced in the study to account for negative faulting (the approach slab edge being lower than the leave slab edge). Absolute average faulting is calculated as the arithmetic average of the absolute values of the individual joint faulting measurements.<br>• An index of weighted sealant damage was developed to quantify overall transverse joint sealant condition as a weighted average of the numbers of joints within the section with low, medium, and high sealant damage ratings. |
| **Treatment Performance** | |
| *LTPP Data Analysis: Relative Performance of Jointed Plain Concrete Pavement with Sealed and Unsealed Joints* (NCHRP Web Document 32 Project 20-50(2))(13) | • Based on 5 years of data collected at the five test sites built in Arizona, Colorado, and Utah (all in the dry region), the effects of sealed and unsealed joints on spalling were similar. |
| *Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations National Report* (FHWA-RD-96-208)(11) | • SPS-4 sealed joint sections performed better than unsealed sections.<br>• Unsealed joints also had significantly more joint spalling than the sealed joint sections.<br>• Unsealed joints in the control sections contained significantly more debris than sealed joint sections. |
| *Concrete Pavement Maintenance Treatment Performance Review: SPS-4 5-Year Data Analysis* (FHWA-RD-97-155)(14) | • No significant differences were identified between the control sections (unsealed) and the sealed-joint or undersealed (slab stabilization) sections. This observation was based on the 32 SPS-4 sites.<br>• Based on 5 years of data collected in Arizona, Colorado, Nevada, and Utah, no significant differences in initial pavement smoothness were identified among the three treatments consisting of sealed, undersealed, and unsealed joints in the SPS-4 experiment.<br>• In the analysis of SPS-4 performance through 1995, no significant differences were detected in IRI or joint faulting between sealed-joint and unsealed-joint sections. |
| *Design and Construction of PCC Pavements, Volume 1: Summary of Design Features and Construction Practices that Influence the Performance of Pavements* (FHWA-RD-98-052)(15) | • Neither presence nor type of sealant was found to be significant in the regression analysis of JPCP joint faulting in the GPS-3 experiment. |
| *Common Characteristics of Good and Poorly Performing Pavements* (FHWA-RD-97-131)(16) | • In statistical analyses of GPS-3 performance data, neither sealant presence or sealant type was found to be a significant variable in the prediction of dowelled or undowelled joint faulting in JPCP. |

| | |
|---|---|
| *LTPP Pavement Maintenance Materials: SPS-4 Supplemental Joint Seal Experiment* (FHWA-RD-99-151)(17) | • A comparison of joint sealant types among the SPS-4 supplemental test sections built in Arizona, Colorado, Nevada, and Utah between 1990 and 1995 showed that silicone seals outperformed the other two treatments for transverse joint seals (compression seals and hot pours). |

## Table 5. Optimal timing of preventive maintenance.

| **Publication** | **Major Findings** |
|---|---|
| **Current Study Relevance: Review of Previous Studies** | |
| *Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (NCHRP Report 523)(18) | • Several studies researched the issue of optimum timing of the preventive maintenance treatments to achieve best maintenance effectiveness. These included earlier studies of SPS-3 and SPS-4 experiments and State transportation department studies in Arizona, Iowa, Montana, Texas, and South Dakota. None of these studies was successful in identifying the optimum timing of preventive maintenance treatments. |
| **Treatment Timing** | |
| *Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (NCHRP Report 523)(18) | • A methodology was developed to determine the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements. The methodology was based on the analysis of pavement performance and costs associated with maintenance treatment. It assessed the effectiveness of a particular preventive maintenance treatment in terms of both the benefit it provided and the cost required to obtain that benefit. The benefit was defined as the quantitative influence on pavement performance as measured by pavement condition factors. Condition indicators may be expressed by such measures as IRI, present serviceability index, or other custom-defined measure of pavement performance. The optimum application of a preventive maintenance treatment occurred at the point at which the benefit per unit cost was greatest. |
| **SPS-3 and SPS-4 Data Applicability** | |
| *Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (NCHRP Report 523)(18) | • One of the case studies conducted under NCHRP Project 14-14 was a review of the data from LTPP SPS-3 and -4 experiments.(19) The conclusion from that case study was that LTPP data at that time could not be used to conduct the analysis of optimal timing. The reasons provided in the report include the counterintuitive performance trends, no improvement in performance as a result of treatment application, and not enough sections with treatments applied at different ages that exhibited the expected trends to support the analysis. |

## Table 6. Data availability for SPS-3, SPS-4, SPS-5, and SPS-6 experiments.

| Publication | Major Findings |
|---|---|
| *Preliminary Evaluation and Analysis of LTPP Faulting Data— Final Report* (FHWA-RD-00-076)(20) | • Data analysis was performed to determine the usefulness of joint faulting and related data in identifying factors that affect joint faulting. As part of this study, an assessment of data availability and data quality was performed for the SPS-4 experiment. Data for a total of 422 jointed concrete pavement sections were available in the LTPP Information Management System (IMS) database at the time of the study. Of these, only 307 sections had records in the faulting data table MON_JPCC_FAULT, for a total of 24,108 records. |
| *Rehabilitation of Asphalt Concrete Pavements: Initial Evaluation of the SPS-5 Experiment* (FHWA-RD-01-168)(4) | • The data availability and completeness were good overall for the SPS-5 experiment with two exceptions: traffic and materials test data. These data deficiencies should be addressed before a comprehensive analysis of the SPS-5 experiment is conducted. Both of these data elements must be collected in order for the SPS-5 experiment to meet the expectations for calibrating and validating mechanistic models. |
| *Rehabilitation of Jointed Portland Cement Concrete Pavements: SPS-6— Initial Evaluation and Analysis* (FHWA-RD-01-169)(7) | • Data availability and completeness for the SPS-6 experiment are good overall, but some data, such as traffic, climatic, and materials data, were not yet available in the IMS database. Three of the 14 sites were still relatively new and, therefore, did not have much data available. It was believed that the information was collected and in the process of being entered into the IMS database. |
| *LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options* (Project 20-50(3/4))(5) | • The data used in this research were the data available at all quality levels in LTPP data release 11.5 dated June 13, 2001.<br>• Efforts to analyze the SPS-3 experiment were hampered by data availability problems and the short times in which the treatments had been in service.<br>• In both the SPS-5 and -6 experiments, the long-term rutting data were so erratic that analysis of long-term trends was problematic. |
| *LTPP Maintenance and Rehabilitation Data Review* (FHWA-RD-01-019)(10) | • This publication provides a review of maintenance and rehabilitation data elements across all the experiments for data completeness and anomalies. The test sections were divided into three categories based on surface type: HMA, jointed concrete pavement, and continuously reinforced concrete pavement. The study was based on the 1999 third quarter LTPP data release. There were a total of 757 type sections, including SPS and GPS, for which maintenance and rehabilitation techniques have been documented in the database. |

# CHAPTER 3. OVERVIEW OF LTPP MAINTENANCE AND REHABILITATION EXPERIMENTS

## INTRODUCTION

Data from LTPP SPS-5 and SPS-6 experiments provided information to gain an understanding of the effects of design and construction features on pavement response and performance of rehabilitated flexible and rigid pavements. In addition, SPS-3 and SPS-4 experiments contain pavement performance data collected over the years for the sections subjected to different preventive maintenance treatments. The data from these experiments were used as primary data source for this study as follows:

- **SPS-3**: Maintenance treatments for flexible pavements.
- **SPS-4**: Maintenance treatments for rigid pavements.
- **SPS-5**: Rehabilitation of AC pavements.
- **SPS-6**: Rehabilitation of jointed concrete pavements.

SPS-3 and SPS-4 experiments were constructed in 1990 to evaluate the effectiveness of and to determine the optimum timing for applying preventive maintenance treatments for flexible and rigid pavements. SPS-5 and SPS-6 experiments provide critical information to support pavement rehabilitation decisions. The primary objective of these experiments was to develop conclusions concerning the effectiveness of rehabilitation techniques and strategies and their contribution to pavement performance and service life.

## SPS-3 EXPERIMENT

### Experimental Design

An experimental design for SPS-3 was developed to help determine the impact of important factors on the pavement performance changes caused by selected preventive maintenance treatments. Major factors included environment, traffic, subgrade type, structural capacity, and condition prior to treatment for the test sections applied to flexible pavements.

At each site, SPS-3 examined the performance of four preventive maintenance treatments on flexible pavement sections: thin overlay, slurry seal, crack seal, and chip seal. The experiment design stipulated that the effectiveness of each of the four treatments be evaluated independently. The effectiveness of combinations of treatments was not considered; therefore, each test site included the following four treated test sections in addition to a control section:

- Thin overlay.
- Slurry seal.

- Crack seal.
- Chip seal.

## SPS-3 Sections

SPS-3 experiments were initiated at 81 sites in the United States and Canada in 1990 and 1991. In many cases, these sites were linked to a GPS section that served as a control section. Most of these GPS control sections were from the GPS-1, GPS-2, and GPS-6 experiments.

The sections with thin overlays were nominally 1.5 inches (38.1 mm) thick and were placed by State and Provincial highway agencies using their own AC mixes. The slurry seals and chip seals were placed by four different contractors, one from each LTPP region. The material specifications were the same for all four regions. Crack sealing was executed by four different crews—one from each LTPP region. The material used for crack sealing was the same for all sites in all regions, but crack sealing application procedures varied.

A summary of SPS-3 sites and conditions is provided in table 7. The climate condition was defined based on the freeze index and average rainfall for each site. Sites with an average annual rainfall greater than 39 inches (1,000 mm) were classified as wet, and those with less than 39 inches (1,000 mm) of rain were catalogued as dry. Similarly, the sites with a freeze index greater than 140 °F (60 °C) were classified as a freezing climate and those with a freeze index less than 140 °F (60 °C) were designated as a no-freeze climate. By March 1, 2006, all SPS-3 sites were deassigned from the experiment, and data collection stopped. The LTPP database contains information for 370 core SPS-3 sections.

**Table 7. SPS-3 categorization.**

| **Condition at Beginning of Experiment** | **Wet** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Freeze** | | | | **No-Freeze** | | | |
| | **Fine Subgrade** | | **Coarse Subgrade** | | **Fine Subgrade** | | **Coarse Subgrade** | |
| | **Low Traffic** | **High Traffic** | **Low Traffic** | **High Traffic** | **Low Traffic** | **High Traffic** | **Low Traffic** | **High Traffic** |
| Good | 21-A300 | | 26-C300 | | | 5-A300 | 47-B300 | |
| | 24-A300 | | 27-A300 | | | 48-F300 | 48-A300 | |
| | 42-B300 | | 29-B300 | | | | 48-I300 | |
| | 17-A300 | | 36-B300 | | | | 28-A300 | |
| Fair | 19-A300 | 18-A300 | | | 47-A300 | 47-C300 | | 1-A300 |
| | 21-B300 | 26-B300 | | | 48-H300 | 40-C300 | | 1-C300 |
| | 26-D300 | | | | | | | 40-B300 |
| | | | | | | | | 48-G300 |
| Poor | | 51-A300 | 17-B300 | 36-A300 | | 48-B300 | 53-C300 | 1-B300 |
| | | 87-A300 | 27-B300 | 42-A300 | | | | 12-B300 |
| | | 87-B300 | 27-D300 | 89-A300 | | | | 12-C300 |
| | | 29-A300 | | 26-A300 | | | | |
| | | | | 27-C300 | | | | |
| **Dry** | | | | | | | | |
| Good | 16-A300 | | | 16-B300 | 48-K300 | | 48-J300 | 48-D300 |
| | | | | 49-C300 | | | 48-A300 | 48-M300 |
| | | | | 16-C300 | | | | |
| | | | | 83-A300 | | | | |
| Fair | 30-A300 | | 56-A300 | 32-B300 | 48-Q300 | | | 4-D300 |
| | 31-A300 | | 6-A300 | 32-C300 | 48-E300 | | | 48-N300 |
| Poor | 20-B300 | 90-A300 | 56-B300 | 53-A300 | | 40-A300 | | 4-A300 |
| | 8-A300 | | 49-A300 | 90-B300 | | | | 4-B300 |
| | 20-A300 | | 49-B300 | | | | | 4-C300 |
| | 8-B300 | | 32-A300 | | | | | 48-L300 |
| | | | 53-B300 | | | | | |

Note: The numbers in each cell represent the State code followed by the site ID. Blank cells indicate that data are not available.

## SPS-4 EXPERIMENT

### Experimental Design

The purpose of the SPS-4 experiment was to assess the effects of selected rigid pavement maintenance treatments, joint/crack sealing, and joint undersealing on performance relative to the performance of untreated control sections. The experiment design stipulated that the effectiveness of each of the two treatments be evaluated independently at each SPS-4 site.

The experimental design for the main SPS-4 experiment incorporated the same primary experimental factors as in the GPS experiments: climatic zone, subgrade type, and traffic level. The original experimental design for SPS-4 included two second-level factors: type of subbase (granular or stabilized) and condition at the time of treatment (good, fair, or poor). The following maintenance treatments were considered:

- Joint and crack sealing.
- Joint undersealing.

Both JPCP and JRCP were included in the study. The treatment sections on joint/crack sealing test sites consisted of one section in which all joints had no sealant and one in which a watertight seal was maintained on all cracks and joints. Undersealing was included as an optional experiment factor and was performed only on the sections in which the need for undersealing was indicated.

As originally designed, the matrix of cells for this experiment could not be filled out because some agencies were unwilling to provide sites for the SPS-4 study. A primary concern was the use of undersealing as a preventive maintenance treatment. Therefore, the SPS-4 study was modified to allow agencies to participate in installation of sections with joint/crack sealing and undersealing, joint/crack sealing only, or undersealing only. As a result, the standard experiment layout included a test section with silicone sealant and a control section with unsealed joints. In addition, separate undersealed test sections were constructed at eight test sites.

The final experiment design for SPS-4 was reduced to the following factors for JPCP:

- **Climatic zone**: Temperature and moisture.
- **Subgrade type**: Fine-grained and coarse-grained.
- **Subbase type**: Granular and stabilized.

For JRCP, only the wet moisture level was considered.

The SPS-4 experiment included 35 sites in the United States and Canada during 1990 and 1991 and 1 site in Colorado in 1995. Table 8 shows SPS-4 experimental factorials using as-built information.

**Table 8. SPS-4 experimental design.**

| Experimental Factors | | | Freeze | | | | No-Freeze | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fine Subgrade | | Coarse Subgrade | | Fine Subgrade | | Coarse Subgrade | |
| Plain | Wet | Dense | | | 19-A400 | 19-B400 | 40-A400 | | | |
| | | Stabilized | 18-A400 | 21-A400 | 39-A400 | 39-B400 | 48-A400 | | | |
| | Dry | Dense | 46-A400 | | 6-B400 | 8-A400 | | | 4-A400 | 6-A400 |
| | | | | | 31-B400 | 32-A400 | | | 48-C400 | |
| | | | | | 49-C400 | 49-D400 | | | | |
| | | | | | 49-E400 | | | | | |
| | | Stabilized | 31-A400 | 31-C400 | | | | | | |
| Reinforced | Wet | Dense | 29-A400 | 29-B400 | | | | | 5-A400 | 5-B400 |
| | | | 42-A400 | 42-C400 | | | | | 48-E400 | |
| | | Stabilized | | | | | 5-C400 | 28-A400 | | |
| | | | | | | | 48-B400 | 48-D400 | | |
| | Dry | Dense | 20-B400 | | | | | | | |
| | | Stabilized | 20-A400 | | | | | | | |

Note: The numbers in each cell represent the State code followed by the site ID. Blank cells indicate that data are not available.

By March 1, 2006, all SPS-4 sites were deassigned from the experiment. The LTPP database contains information for 79 core SPS-4 sections.

## SPS-5 EXPERIMENT

### Experiment Design

The objective of the LTPP SPS-5 experiment was to help develop improved methodologies and strategies for the rehabilitation of flexible pavements. The experiment was designed to evaluate common rehabilitation techniques currently implemented in the United States and Canada. The factors considered in the experiment included the structural and functional condition of the pavement before overlay, the environmental and traffic loading of the test sections, and the various treatment applications.

The SPS-5 experiment provides a means to compare rehabilitated HMA pavement performance using different surface preparation intensities, overlay thicknesses, and overlay mixtures. It also can be used to determine the appropriate timing of rehabilitation and to evaluate the life-cycle cost of different rehabilitation actions.

The experiment was designed to compare the effect of the following variations on performance of rehabilitated pavements:

- **Climatic zone**: Wet versus dry and freeze versus no-freeze.
- **Existing pavement condition**: Fair versus poor.
- **Surface preparation**: Intense versus minimum.

- **Overlay material**: Recycled versus virgin HMA.
- **Overlay thickness**: Thin 2 inches (51 mm) versus thick 5 inches (127 mm).

Variation of surface preparation alternatives, overlay material, and overlay thickness led to eight design combinations at each SPS-5 site (see table 9). One additional section was assigned as a control section and did not receive any overlay, except for routine maintenance, for a total of nine experimental sections. All test sections were designed to be 500 ft (152.4 m) long over a fine-grained subgrade with minimum annual traffic over the test sections of 85,000 equivalent single axle loads (ESALs).

**Table 9. Core sections of SPS-5 experiment.**

| LTPP ID | Overlay Type |
|---|---|
| 0501 | Control: No treatment |
| 0502 | Thin overlay (2 inches): Recycled HMA mix |
| 0503 | Thick overlay (5 inches): Recycled HMA mix |
| 0504 | Thick overlay: Virgin mix |
| 0505 | Thin overlay: Virgin mix |
| 0506 | Thin overlay: Virgin mix with milling |
| 0507 | Thick overlay: Virgin mix with milling |
| 0508 | Thick overlay: Recycled mix with milling |
| 0509 | Thin overlay: Recycled mix with milling |

1 inch = 25.4 mm

### Final Factorial of SPS-5 Experiment

A total of 18 SPS-5 projects were constructed between 1989 and 1998. The as-built status of the SPS-5 design factorial is shown in table 10. All projects are located in the appropriate cells based on the actual environmental data. Additionally, all of the cells have at least two projects except for the wet no-freeze fair condition and the dry freeze poor condition. A total of 210 test sections (162 core test sections plus 48 supplemental sections) were built as part of the SPS-5 experiment.

**Table 10. Constructed SPS-5 sites for the experimental factorial.**

| Pavement Condition | Soil Classification | Climate, Moisture/Temperature | | | |
|---|---|---|---|---|---|
| | | Wet Freeze | Wet No-freeze | Dry Freeze | Dry No-freeze |
| Fair | Coarse/fine | Georgia | | Colorado | |
| | Coarse | New Jersey | | Alberta, Canada<br>Montana | New Mexico |
| | Fine | | | Minnesota | Oklahoma<br>Texas |
| Poor | Coarse/fine | | | Manitoba, Canada | California |
| | Coarse | Maine | Florida<br>Alabama | | Arizona |
| | Fine | Maryland<br>Missouri | Mississippi | | |

Note: Blank cells indicate data are not available.

One major deviation from the original SPS-5 experimental plan was the subgrade soil type. Originally, the subgrade soils for all SPS-5 projects were supposed to be fine-grained soils. Only six of the SPS-5 projects actually had fine-grained soils. Four SPS-5 projects had soils that varied between fine and coarse grained. The subgrade soils for the remaining eight SPS-5 projects were classified as coarse grained.

## SPS-6 EXPERIMENT

### Experimental Design

The goal of the SPS-6 experiment was to develop improved methodologies and strategies for the rehabilitation of concrete pavements. The experiment was designed to investigate the effects of the specific experimental rehabilitation design features on pavement performance.

The factors considered in the experiment were overlay thickness, various restoration activities, and site conditions such as existing pavement condition, subgrade soil, traffic, and climate. The interactions of these factors also were considered.

The SPS-6 experiment included both JPCP and JRCP. The experiment design examined the effects of the following factors:

- **Climatic zone**: Wet versus dry and freeze versus no-freeze.
- **Pavement condition**: Fair versus poor.
- **Type of concrete pavement**: JPCP versus JRCP.
- **Overlay thickness**: 4 inches (102 mm) versus 8 inches (203 mm).

The SPS-6 experimental plans were originally designed to incorporate project sites in all four LTPP climatic regions and on both fine- and coarse-grained subgrades. Every project constructed as part of the SPS-6 experiment had eight core pavement sections that represented eight different rehabilitation alternatives. These rehabilitation alternatives included variations in pavement preparation, restoration, AC overlay thickness, and additional treatments (saw and seal and crack and seat).

Table 11 lists the eight core experiment sections required for an SPS-6 project. Each section varies by a combination of the extent of pavement preparation, other treatments (saw and seal of the AC overlay and crack and seat), and the overlay thickness. It was also required that at least six of these core sections had 500-ft (152-m) nondestructive performance monitoring areas and that two had 1,000-ft (305-m) areas with an additional 49 ft (15 m) on each end for destructive testing. In addition, traffic in the test lane should have exceeded 200,000 ESALs per year.

**Table 11. Core sections of the SPS-6 experiment.**

| Strategic Highway Research Program (SHRP) ID | Overlay Thickness (mm) | PCC Preparation |
|---|---:|---|
| 0601 | — | Routine maintenance (control) |
| 0602 | — | Minimum restoration |
| 0603 | 102 | Minimum restoration |
| 0604 | 102 | Minimum restoration (saw and seal AC over joints) |
| 0605 | — | Maximum restoration |
| 0606 | 102 | Maximum restoration |
| 0607 | 102 | Crack/break and seat |
| 0608 | 203 | Crack/break and seat |

1 inch = 25.4 mm

Note: The dashes indicate that the section did not receive an overlay.

### Final Factorial of SPS-6 Experiment

The SPS-6 experiment contained 14 sites constructed between 1989 and 1998. Table 12 shows the constructed SPS-6 sites in relation to the experiment factorial. A total of 112 core sections and 58 State supplemental sections have been constructed for the SPS-6 experiment.

**Table 12. As-built SPS-6 sites for the experimental factorial.**

| Pavement Type | Pavement Condition | Climate/Moisture/Temperature | | | |
|---|---|---|---|---|---|
| | | Wet Freeze | Wet No-freeze | Dry Freeze | Dry No-freeze |
| JPCP | Fair | Missouri* | Alabama and Tennessee | South Dakota* | |
| | Poor | Indiana* | Arkansas* | Arizona and California | |
| JRCP | Fair | Iowa, Michigan, and Pennsylvania | Oklahoma* | | N/A |
| | Poor | Illinois and Missouri | | | N/A |

* Represents a single additional site that is needed to complete the original design matrix.
N/A indicates data are not available because there were no JRCP sections in that area of the country.
Note: Blank cells indicate that no section was available at the combination of climate and pavement conditions for that particular pavement type.

## OVERVIEW OF THE LTPP DATA RELEVANT TO THIS STUDY

Information in the LTPP database is divided into the following modules:

- **Inventory**: Section location, pavement characteristics, and material characteristics.
- **Materials testing**: Material properties and characteristics from field and laboratory tests.
- **Climatic**: Temperature, humidity, precipitation, cloud cover, and wind statistics.
- **Maintenance**: Activities performed since inclusion in the LTPP program.
- **Rehabilitation**: Major improvements since inclusion in the LTPP program.
- **Traffic**: Annual traffic summary statistics for a study lane since it was opened to traffic.
- **Monitoring**: FWD, profilometer, surface distress, skid, and transverse profile.
- **Dynamic load response**: Only available from the instrumented SPS-1 and SPS-2 test sections in Ohio and North Carolina.

Each of these modules contains tables that provide information on the various design features and performance measurements of a particular pavement section. For the data elements identified, the LTPP data were examined to determine the extent of availability for all the data elements. The most current LTPP data release was used (23d released in January 2009).

Data extracted from the LTPP database were imported to a Microsoft Access® file and stored in relational databases so that they could be manipulated and linked together for different analyses.

## Assessment of SPS-3 Data

Various tables containing data pertinent to the SPS-3 experiment were examined. Table 13 provides a summary of SPS-3 data availability including the location, number of surveys, number of treatments, and the observation period for each section. For example, all sections of the 1-A300 project were surveyed six times except for the control section, which was surveyed five times. The sections receiving thin overlay, slurry seal, and crack seal were treated twice, while chip seal and control section were treated once. The difference between the first and the last survey was 9 years for all sections except for the control section, which was 8 years. There were no data available for the cells left blank. The tables from the LTPP database used for this assessment were as follows:

- **Inventory**: INV_AGE:TRAFFIC_OPEN_DATE.
- **IRI monitoring**: MON_PROFILE_MASTER.
- **AC distress survey monitoring**: MON_DIS_AC_REV.
- **AC rutting survey monitoring**: MON_T_PRF_INDEX_SECTION.

The sample size for the SPS-3 experiment should allow for meaningful conclusions and should not just allow comparisons between treatments but also comparisons for the effectiveness of treatments for different conditions (e.g., environmental conditions).

**Table 13. Data availability for SPS-3 sites.**

| State Code | SHRP ID | Number of Surveys | | | | | Number of Treatments | | | | | Number of Years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal |
| 1 | A300 | 6 | 6 | 6 | 5 | 6 | 2 | 2 | 2 | 1 | 1 | 9 | 9 | 9 | 8 | 9 |
| 1 | B300 | 5 | 5 | 5 | 5 | 5 | 2 | 2 | 1 | 0 | 1 | 7 | 7 | 7 | 7 | 7 |
| 1 | C300 | 8 | 8 | 8 | 8 | 5 | 1 | 1 | 7 | 0 | 3 | 12 | 12 | 12 | 12 | 7 |
| 4 | A300 | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 4 | 4 |
| 4 | B300 | | 1 | 1 | 5 | 1 | | 2 | 1 | 4 | 2 | | 0 | 0 | 9 | 0 |
| 4 | C300 | 4 | 2 | 3 | 3 | 4 | 2 | 2 | 2 | 0 | 1 | 6 | 1 | 3 | 3 | 4 |
| 4 | D300 | 3 | 1 | 2 | 5 | 1 | 1 | 2 | 2 | 2 | 1 | 6 | 0 | 3 | 12 | 0 |
| 5 | A300 | 8 | 8 | | 8 | 8 | 1 | 1 | | 1 | 1 | 13 | 13 | | 13 | 13 |
| 6 | A300 | 6 | 7 | 7 | 7 | 7 | 2 | 3 | 1 | 0 | 1 | 12 | 13 | 13 | 13 | 13 |
| 8 | A300 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 0 | 1 | 3 | 3 | 3 | 3 | 3 |
| 8 | B300 | 2 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 3 | 0 |
| 12 | A300 | 6 | 6 | 6 | 6 | 6 | 1 | 1 | 1 | 0 | 1 | 6 | 6 | 6 | 6 | 6 |
| 12 | B300 | 4 | 4 | 4 | 6 | 4 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 9 | 4 |
| 12 | C300 | 7 | 6 | 6 | 6 | 6 | 1 | 3 | 4 | 7 | 1 | 7 | 6 | 6 | 6 | 6 |
| 16 | A300 | 5 | 5 | 5 | 6 | 5 | 1 | 1 | 1 | 1 | 1 | 14 | 14 | 14 | 14 | 14 |

| State Code | SHRP ID | Number of Surveys | | | | | Number of Treatments | | | | | Number of Years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal |
| 16 | B300 | 6 | 6 | 6 | 7 | 6 | 1 | 1 | 1 | 0 | 1 | 14 | 14 | 14 | 14 | 14 |
| 16 | C300 | 4 | 4 | 4 | 14 | 4 | 1 | 1 | 1 | 0 | 1 | 7 | 7 | 7 | 7 | 7 |
| 17 | A300 | 8 | 8 | 8 | 8 | 8 | 1 | 1 | 2 | 0 | 1 | 14 | 14 | 14 | 14 | 14 |
| 17 | B300 | 8 | 7 | 7 | 7 | 7 | 2 | 1 | 2 | 1 | 1 | 14 | 14 | 14 | 14 | 14 |
| 18 | A300 | 6 | 7 | 6 | 6 | 6 | 1 | 1 | 1 | 0 | 1 | 4 | 5 | 4 | 4 | 4 |
| 19 | A300 | 4 | 4 | 4 | 4 | 4 | 1 | 1 | 1 | 0 | 1 | 3 | 3 | 3 | 3 | 3 |
| 20 | A300 | 6 | 6 | 6 | 5 | 6 | 2 | 2 | 2 | 0 | 2 | 10 | 10 | 10 | 9 | 10 |
| 20 | B300 | 6 | 6 | 6 | 6 | 6 | 1 | 2 | 2 | 0 | 1 | 7 | 7 | 7 | 7 | 7 |
| 21 | A300 | 4 | 4 | 5 | 4 | 4 | 1 | 1 | 1 | 0 | 1 | 3 | 3 | 4 | 2 | 3 |
| 21 | B300 | 6 | 6 | 5 | 4 | 4 | 1 | 1 | 1 | 0 | 1 | 7 | 7 | 4 | 3 | 3 |
| 24 | A300 | 7 | 7 | 7 | 7 | 7 | 1 | 1 | 1 | 0 | 1 | 8 | 8 | 8 | 8 | 8 |
| 26 | A300 | 4 | 5 | 5 | 5 | 4 | 2 | 1 | 1 | 1 | 1 | 4 | 5 | 5 | 5 | 3 |
| 26 | B300 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 1 | 2 | 5 | 5 | 5 | 5 | 5 |
| 26 | C300 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 26 | D300 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 27 | A300 | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 27 | B300 | 4 | 4 | 4 | 4 | 4 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 27 | C300 | 4 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 27 | D300 | 4 | 3 | 1 | 3 | 4 | 2 | 1 | 1 | 0 | 1 | 2 | 4 | 0 | 4 | 5 |
| 28 | A300 | 5 | 5 | 5 | 13 | 5 | 1 | 1 | 2 | 2 | 1 | 8 | 8 | 8 | 11 | 8 |
| 29 | A300 | 8 | 8 | 8 | 8 | 8 | 2 | 2 | 2 | 0 | 1 | 14 | 14 | 14 | 14 | 15 |
| 29 | B300 | 8 | 7 | 7 | 7 | 7 | 1 | 1 | 1 | 0 | 1 | 13 | 13 | 13 | 13 | 13 |
| 30 | A300 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 0 | 1 | 8 | 8 | 8 | 8 | 8 |
| 31 | A300 | 5 | 6 | 6 | 6 | 6 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 32 | A300 | 4 | 3 | 3 | 3 | 4 | 1 | 3 | 3 | 1 | 2 | 6 | 6 | 6 | 6 | 6 |
| 32 | B300 | 3 | 3 | 3 | 3 | 3 | 1 | 2 | 1 | 0 | 1 | 6 | 6 | 6 | 6 | 6 |
| 32 | C300 | 2 | 2 | 2 | 4 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 6 | 1 |
| 36 | A300 | 7 | 7 | 7 | 7 | 7 | 2 | 1 | 1 | 1 | 1 | 7 | 7 | 7 | 7 | 7 |
| 36 | B300 | 6 | 6 | 6 | 6 | 6 | 1 | 1 | 1 | 0 | 1 | 7 | 7 | 7 | 7 | 7 |
| 40 | A300 | | 5 | 5 | 5 | 5 | | 1 | 0 | 0 | 1 | | 6 | 6 | 6 | 6 |
| 40 | B300 | 6 | 6 | 6 | 7 | 6 | 1 | 1 | 2 | 0 | 1 | 8 | 8 | 8 | 13 | 8 |
| 40 | C300 | 4 | 4 | 4 | 2 | 4 | 1 | 3 | 1 | 1 | 1 | 4 | 4 | 4 | 3 | 4 |
| 42 | A300 | 7 | 7 | 7 | 7 | 7 | 1 | 1 | 1 | 1 | 1 | 6 | 6 | 6 | 6 | 6 |
| 42 | B300 | 6 | | 7 | 6 | 7 | 1 | | 4 | 0 | 2 | 8 | | 11 | 11 | 11 |
| 47 | A300 | 3 | 3 | 3 | 10 | 1 | 2 | 2 | 3 | 2 | 1 | 4 | 4 | 4 | 16 | 0 |
| 47 | B300 | 4 | 4 | 4 | 6 | 4 | 1 | 1 | 2 | 0 | 1 | 6 | 6 | 6 | 8 | 6 |
| 47 | C300 | 4 | 4 | 4 | 9 | 4 | 1 | 1 | 2 | 4 | 3 | 4 | 4 | 4 | 15 | 4 |
| 48 | A300 | 7 | 7 | 7 | 7 | | 1 | 1 | 0 | 0 | | 9 | 9 | 9 | 9 | |

| State Code | SHRP ID | Number of Surveys | | | | | Number of Treatments | | | | | Number of Years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal | Thin Overlay | Slurry Seal | Crack Seal | Control Section | Chip Seal |
| 48 | B300 | 9 | 9 | 9 | 8 | 9 | 2 | 2 | 1 | 0 | 3 | 13 | 13 | 13 | 12 | 13 |
| 48 | D300 | 5 | 5 | 4 | 5 | 5 | 2 | 2 | 3 | 3 | 2 | 5 | 5 | 3 | 5 | 5 |
| 48 | E300 | 5 | 4 | 5 | 6 | 4 | 2 | 4 | 3 | 0 | 4 | 4 | 3 | 4 | 4 | 3 |
| 48 | F300 | 7 | 6 | 6 | 5 | 5 | 1 | 2 | 3 | 0 | 3 | 7 | 5 | 5 | 5 | 4 |
| 48 | G300 | 6 | 6 | 6 | 7 | 5 | 1 | 1 | 0 | 0 | 4 | 8 | 8 | 8 | 14 | 6 |
| 48 | H300 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 2 | 0 | 1 | 6 | 6 | 6 | 6 | 6 |
| 48 | I300 | 6 | 7 | 7 | 7 | 7 | 1 | 1 | 0 | 0 | 1 | 8 | 8 | 8 | 8 | 8 |
| 48 | J300 | 9 | 9 | 9 | 9 | 9 | 2 | 2 | 1 | 1 | 2 | 11 | 11 | 11 | 11 | 11 |
| 48 | K300 | 9 | 9 | 9 | 9 | 9 | 2 | 2 | 0 | 0 | 2 | 8 | 8 | 8 | 8 | 8 |
| 48 | L300 | 8 | 8 | 8 | 8 | 8 | 2 | 2 | 1 | 0 | 2 | 12 | 12 | 12 | 12 | 12 |
| 48 | M300 | 8 | 8 | 8 | 8 | 8 | 2 | 2 | 1 | 2 | 1 | 6 | 6 | 6 | 6 | 6 |
| 48 | N300 | 5 | 5 | 5 | 5 | 5 | 1 | 2 | 5 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| 48 | Q300 | 8 | 8 | 8 | 8 | 8 | 1 | 1 | 0 | 0 | 2 | 11 | 11 | 11 | 11 | 11 |
| 49 | A300 | 4 | 4 | 4 | 5 | 4 | 1 | 1 | 1 | 1 | 1 | 7 | 7 | 7 | 13 | 7 |
| 49 | B300 | 6 | 2 | 6 | 5 | 6 | 2 | 1 | 2 | 2 | 2 | 10 | 2 | 10 | 10 | 10 |
| 49 | C300 | 6 | 6 | 6 | 6 | 6 | 1 | 1 | 1 | 0 | 1 | 11 | 11 | 11 | 11 | 11 |
| 51 | A300 | 7 | 7 | 7 | 7 | 7 | 1 | 1 | 1 | 0 | 1 | 7 | 7 | 7 | 7 | 7 |
| 53 | A300 | 2 | 2 | 2 | 7 | 2 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 13 | 3 |
| 53 | B300 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 2 | 0 | 1 | 9 | 9 | 9 | 9 | 9 |
| 53 | C300 | 4 | 4 | 5 | 4 | 5 | 1 | 1 | 2 | 1 | 1 | 6 | 6 | 6 | 6 | 6 |
| 56 | A300 | 3 | 3 | 3 | 20 | 3 | 1 | 1 | 1 | 2 | 1 | 7 | 7 | 7 | 13 | 7 |
| 56 | B300 | 6 | 6 | 6 | 8 | 6 | 1 | 1 | 1 | 2 | 1 | 11 | 11 | 11 | 12 | 11 |
| 83 | A300 | 7 | 7 | 7 | 8 | 7 | 3 | 3 | 4 | 2 | 2 | 14 | 13 | 13 | 14 | 14 |
| 87 | A300 | 4 | 4 | 4 | 4 | 4 | 1 | 1 | 1 | 0 | 1 | 2 | 2 | 2 | 2 | 2 |
| 87 | B300 | 6 | 6 | 6 | 6 | | 1 | 2 | 1 | 0 | | 7 | 7 | 7 | 7 | |
| 89 | A300 | 6 | 6 | 6 | 6 | 6 | 1 | 1 | 1 | 0 | 1 | 5 | 5 | 5 | 5 | 5 |
| 90 | A300 | 5 | 6 | 4 | 6 | 7 | 1 | 2 | 1 | 5 | 2 | 4 | 5 | 3 | 5 | 5 |
| 90 | B300 | 5 | 6 | 6 | 6 | 6 | 1 | 2 | 2 | 2 | 2 | 8 | 9 | 9 | 9 | 9 |

Note: Blank cells indicate data are not available.

## Assessment of SPS-4 Data

Tables containing data relevant to the SPS-4 experiment were examined. Table 14 summarizes data availability for SPS-4 sections, including the location, number of surveys, number of treatments, and the observation period for each section. The sample size for SPS-4 was not as large as the sample size for the SPS-3 experiment. Moreover, the number of sections with undersealing treatment may not lead to statistically significant conclusions for this experiment. In this case, the research team will attempt to analyze the individual sections to draw some conclusions. The LTPP tables used for this assessment were as follows:

- **Inventory**: INV_AGE:TRAFFIC_OPEN_DATE.
- **IRI monitoring**: MON_PROFILE_MASTER, MON_T_PRF_INDEX_SECTION.
- **PCC faulting monitoring**: MON_DIS_JPCC_FAULT_SECT.
- **PCC distress survey monitoring**: MON_DIS_JPCC_REV, MON_DIS_PADIAS42_JPCC.

## Table 14. Data availability for SPS-4 sites.

| State Code | SHRP ID | Number of Surveys | | | Number of Treatments | | | Number of Years | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sealing | Undersealing | Control Section | Sealing | Undersealing | Control Section | Sealing | Undersealing | Control Section |
| 4 | A400 | 4 | | 4 | 1 | | 0 | 7 | | 7 |
| 5 | A400 | 4 | | 3 | 1 | | 0 | 7 | | 7 |
| 5 | B400 | 3 | | 3 | 1 | | 0 | 6 | | 6 |
| 5 | C400 | 3 | | 3 | 1 | | 0 | 6 | | 6 |
| 6 | A400 | 5 | 4 | 5 | 1 | 1 | 0 | 12 | 12 | 12 |
| 6 | B400 | 5 | 5 | 5 | 1 | 1 | 0 | 9 | 9 | 9 |
| 8 | A400 | 4 | | 4 | 1 | | 1 | 7 | | 7 |
| 18 | A400 | 5 | | 5 | 1 | | 1 | 13 | | 13 |
| 19 | A400 | 1 | | 1 | 1 | | 0 | 0 | | 0 |
| 19 | B400 | 2 | | 2 | 1 | | 0 | 5 | | 5 |
| 20 | A400 | 2 | | 2 | 1 | | 0 | 2 | | 2 |
| 20 | B400 | 3 | | 3 | 1 | | 0 | 5 | | 5 |
| 21 | A400 | 3 | | 3 | 6 | | 0 | 7 | | 7 |
| 28 | A400 | 4 | | 4 | 1 | | 0 | 6 | | 6 |
| 29 | A400 | 3 | | 3 | 2 | | 2 | 4 | | 4 |
| 29 | B400 | 4 | | 4 | 1 | | 0 | 13 | | 13 |
| 31 | A400 | 4 | | 4 | 1 | | 0 | 9 | | 9 |
| 31 | B400 | 4 | | 4 | 1 | | 0 | 9 | | 9 |
| 31 | C400 | 4 | | 4 | 2 | | 0 | 9 | | 9 |
| 32 | A400 | 3 | 4 | 3 | 1 | 1 | 0 | 8 | 9 | 8 |
| 39 | A400 | 4 | | 4 | 1 | | 0 | 11 | | 11 |
| 39 | B400 | 3 | | 3 | 1 | | 1 | 4 | | 4 |
| 40 | A400 | 5 | 5 | 5 | 1 | 1 | 0 | 8 | 8 | 8 |
| 42 | A400 | 5 | | 5 | 2 | | 3 | 9 | | 9 |
| 42 | C400 | 6 | | 6 | 2 | | 1 | 12 | | 12 |
| 46 | A400 | 5 | 4 | 4 | 1 | 1 | 1 | 11 | 11 | 11 |
| 48 | A400 | 4 | 4 | 4 | 1 | 1 | 0 | 7 | 7 | 7 |
| 48 | B400 | 8 | 8 | 8 | 1 | 1 | 0 | 11 | 11 | 11 |
| 48 | C400 | 7 | 7 | 7 | 4 | 7 | 4 | 9 | 9 | 9 |
| 48 | D400 | 7 | 7 | 7 | 1 | 1 | 0 | 10 | 10 | 10 |
| 48 | E400 | 7 | 7 | 7 | 1 | 2 | 1 | 10 | 10 | 10 |
| 49 | C400 | 6 | | 6 | 1 | | 0 | 13 | | 13 |
| 49 | D400 | 4 | | 4 | 2 | | 1 | 9 | | 9 |
| 49 | E400 | 6 | | 6 | 1 | | 0 | 14 | | 14 |

Note: Blank cells indicate data are not available.

## Assessment of SPS-5 Data

The availability of SPS-5 experiment data was assessed in different modules of the LTPP database. Available data needed for the analysis of the experiment and the data needed for running MEPDG were extracted from different modules and stored in a new database. The tables from the LTPP database used to gather information are listed below.

Inventory data were as follows:

- **Inventory**: INV_AGE:TRAFFIC_OPEN_DATE.
- **SPS**: SPS5_PMA_CONSTRUCTION:DATE_COMPLETE.

Traffic data were as follows:

- **Traffic**: TRF_MONITOR_LTPP_LN:TRUCKS_LTPP_LN.
- **Traffic**: TRF_MON_EST_ESAL:AADT_TRUCK_COMBO.
- **Traffic**: TRF_MONITOR_LTPP_LN:TRUCKS_LTPP_LN.

Material data were as follows:

- **Material_Test**: TST_L05B: CONSTRUCTION_NO, LAYER_NO, LAYER_TYPE, REPR_THICKNESS.
- **Material_Test**: TST_L05B: MATL_CODE.
- **Inventory**: INV_SUBGRADE:AASHTO_SOIL_CLASS – reference:CODES:AASHTO_SOIL_CLASS.
- **Inventory**:INV_UNBOUND:AASHTO_SOIL_ CLASS – reference:CODES:AASHTO_SOIL_CLASS.

Monitoring data were as follows:

- **IRI**: MON_PROFILE_MASTER.
- **Rutting surveys**: MON_T_PRF_INDEX_SECTION.
- **Cracking surveys**: MON_DIS_AC_REV.

### *Inventory Data*

Table 15 presents relevant data on the SPS-5 sites. The sites were constructed between 1965 and 1982, and they were rehabilitated based on SPS-5 standard specifications between 1989 and 1998.

**Table 15. Original construction, traffic open, and major rehabilitation dates for SPS-5 projects.**

| State Code | Construction Date | Traffic Open Date | Rehabilitation Date |
|---|---|---|---|
| 1 | 06/1976 | 06/1976 | 12/1991 |
| 4 | 07/1968 | 09/1968 | 05/1990 |
| 6 | 06/1966 | 06/1966 | 04/1992 |
| 8 | 10/1974 | 10/1974 | 10/1991 |
| 12 | 04/1971 | 12/1971 | 04/1995 |
| 13 | 06/1978 | 06/1978 | 06/1993 |
| 23 | 11/1972 | 11/1972 | 06/1995 |
| 24 | 11/1971 | 11/1971 | 06/1992 |
| 27 | 07/1969 | 07/1969 | 06/1990 |
| 28 | 09/1973 | 09/1973 | 09/1990 |
| 29 | 10/1981 | 10/1981 | 09/1998 |
| 30 | 09/1982 | 09/1982 | 09/1991 |
| 34 | 11/1968 | 08/1972 | 08/1992 |
| 35 | 06/1965 | 07/1965 | 09/1996 |
| 40 | 07/1973 | 07/1973 | 07/1997 |
| 81 | 06/1977 | 06/1977 | 10/1990 |
| 83 | 09/1971 | 09/1971 | 09/1989 |

### *Traffic Data*

Available traffic data for the SPS-5 experiment were reviewed and analyzed. The TRF_MON_EST_ESAL and TRF_HIST_EST_ESAL tables include the annual traffic counts and estimates of each site for a number of years. Using the data available from these tables, the average annual daily truck traffic (AADTT) at rehabilitation date, growth rate, and growth method were calculated as presented in table 16. These data are needed to run the MEPDG software.

**Table 16. Traffic data for the SPS-5 experiment.**

| State Code | Construction Year | Rehabilitation Year | AADTT at Rehabilitation Date | Growth Rate | Growth Method |
|---|---|---|---|---|---|
| 1 | 1976 | 1991 | 500 | 5.06 | Compound |
| 4 | 1968 | 1990 | 530 | 8.27 | Compound |
| 6 | 1966 | 1992 | 2,478 | 0 | — |
| 8 | 1974 | 1991 | 781 | 12.7 | Linear |
| 12 | 1971 | 1995 | 131 | 14.9 | Linear |
| 13 | 1978 | 1993 | 3,689 | 21.9 | Linear |
| 23 | 1972 | 1995 | 600 | 4.9 | Linear |
| 24 | 1971 | 1992 | 615 | 7.37 | Linear |
| 27 | 1969 | 1990 | 188 | 7.9 | Linear |
| 28 | 1973 | 1990 | 1,155 | 5.65 | Compound |
| 29 | 1981 | 1998 | 630 | 0 | — |
| 30 | 1982 | 1991 | 751 | 3.9 | Linear |
| 34 | 1972 | 1992 | 1,530 | 28.9 | Linear |
| 35 | 1965 | 1996 | 3,483 | 14.4 | Linear |
| 40 | 1973 | 1997 | — | — | — |
| 81 | 1977 | 1990 | 270 | 18.6 | Linear |
| 83 | 1971 | 1989 | 207 | 7.6 | Linear |

— Indicates data are not available.

Some data are missing from the traffic module. For example, the database does not contain any traffic data for Oklahoma (State code 40). The axle distribution data are missing from Georgia (13) and Missouri (29), and monthly adjustment factors are not available for California (6) and Georgia (13).

### *Material Data*

As shown in the sample in table 17, the State code, SHRP ID, layer number, layer type, and material description are obtained from the LTPP database. The construction number reveals if any major rehabilitation was applied to the site. For example, layer 5 was removed and was replaced with two layers of HMA with 1- and 2-inch (25.4- and 51-mm) thicknesses. As a result, the construction number is changed to 2. Construction 1 always refers to the original construction, and construction 2 is the rehabilitation work. Some sections have received several rehabilitation and maintenance treatments.

**Table 17. Sample materials with project information for the SPS-5 experiment.**

| STATE_CODE | SHRP_ID | CONSTRUCTION_NO | LAYER_NO | LAYER_TYPE | Material Description | REPRESENTATIVE_ THICKNESS (inches) |
|---|---|---|---|---|---|---|
| 1 | 506 | 1 | 1 | SS | Coarse-grained soil: silty sand | |
| 1 | 506 | 1 | 2 | GS | Other (specify, if possible) | 5.4 |
| 1 | 506 | 1 | 3 | GB | Crushed gravel | 10.6 |
| 1 | 506 | 1 | 4 | AC | Hot mixed, hot laid AC, dense graded | 2.2 |
| 1 | 506 | 1 | 5 | AC | Hot mixed, hot laid AC, dense graded | 1.5 |
| 1 | 506 | 2 | 5 | AC | Hot mixed, hot laid AC, dense graded | 0 |
| 1 | 506 | 2 | 6 | AC | Hot mixed, hot laid AC, dense graded | 1 |
| 1 | 506 | 2 | 7 | AC | Hot mixed, hot laid AC, dense graded | 2 |

1 inch = 25.4 mm

Note: The blank cell indicates that there is no thickness for subgrade.

### *Monitoring Data*

Different monitoring data were collected from SPS-5 sites. Distress surveys were obtained and summarized from all experiment sections to compare performance.

Table 18 depicts the number of surveys available for each experiment, the number of treatments applied to each experiment, and the number of years the section was under inspection. The table summarizes the data available from the MON_DIS_AC_REV table from the LTPP database. As shown, distress data have been collected for up to 17 years. Some sites have survey data for up to 12 inspections.

**Table 18. Available monitoring (distress) data.**

| State Code | 501 | | | 502 | | | 503 | | | 504 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Surveys | Number of Treatments | Number of Years | Number of Surveys | Number of Treatments | Number of Years | Number of Surveys | Number of Treatments | Number of Years | Number of Surveys | Number of Treatments | Number of Years |
| 1 | 7 | 2 | 12 | 11 | 2 | 15 | 11 | 2 | 15 | 11 | 2 | 15 |
| 4 | 2 | 1 | 4 | 10 | 6 | 11 | 11 | 5 | 11 | 11 | 5 | 11 |
| 6 | 11 | 5 | 14 | 11 | 4 | 14 | 11 | 4 | 14 | 11 | 2 | 14 |
| 8 | 5 | 3 | 8 | 5 | 3 | 8 | 5 | 3 | 8 | 5 | 3 | 8 |
| 12 | 10 | 1 | 15 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 |
| 13 | | | | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 |
| 23 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 |
| 24 | 10 | 2 | 14 | 12 | 3 | 15 | 12 | 3 | 15 | 11 | 3 | 15 |
| 27 | 11 | 3 | 15 | 11 | 4 | 15 | 9 | 4 | 15 | 12 | 4 | 15 |
| 28 | 4 | 1 | 8 | 4 | 2 | 8 | 4 | 2 | 8 | 4 | 2 | 8 |
| 29 | 4 | 1 | 3 | 7 | 2 | 6 | 7 | 2 | 6 | 7 | 2 | 6 |
| 30 | 7 | 3 | 13 | 6 | 3 | 13 | 7 | 3 | 13 | 7 | 3 | 13 |
| 34 | 9 | 2 | 12 | 10 | 2 | 14 | 11 | 2 | 14 | 10 | 2 | 14 |
| 35 | 6 | 7 | 7 | 9 | 2 | 10 | 9 | 2 | 10 | 9 | 3 | 10 |
| 40 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 |
| 81 | 12 | 3 | 15 | 12 | 3 | 15 | 12 | 3 | 15 | 12 | 2 | 15 |
| 83 | 6 | 6 | 9 | 10 | 5 | 17 | 10 | 5 | 17 | 10 | 5 | 17 |

| State Code | 505 | | | 506 | | | 507 | | | 508 | | | 509 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Surveys | Number of Treatments | Number of Years | Number of Surveys | Number of Treatments | Number of years | Number of Surveys | Number of Treatments | Number of years | Number of Surveys | Number of Treatments | Number of Years | Number of Surveys | Number of Treatments | Number of Years |
| 1 | 11 | 2 | 15 | 11 | 2 | 15 | 11 | 2 | 15 | 11 | 2 | 15 | 11 | 2 | 15 |
| 4 | 11 | 6 | 11 | 11 | 6 | 11 | 11 | 4 | 11 | 11 | 5 | 11 | 11 | 6 | 11 |
| 6 | 11 | 4 | 14 | 11 | 4 | 14 | 11 | 2 | 14 | 11 | 3 | 14 | 11 | 3 | 14 |
| 8 | 5 | 3 | 8 | 5 | 3 | 8 | 5 | 3 | 8 | 5 | 3 | 8 | 5 | 3 | 8 |
| 12 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 |
| 13 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 | 10 | 2 | 12 |
| 23 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 |
| 24 | 11 | 3 | 15 | 11 | 2 | 15 | 11 | 2 | 15 | 12 | 3 | 15 | 11 | 2 | 15 |
| 27 | 11 | 5 | 15 | 12 | 5 | 15 | 12 | 5 | 15 | 11 | 4 | 15 | 11 | 4 | 15 |
| 28 | 4 | 2 | 8 | 4 | 2 | 8 | 4 | 2 | 8 | 4 | 2 | 8 | 4 | 2 | 8 |
| 29 | 7 | 2 | 6 | 8 | 2 | 8 | 8 | 2 | 8 | 8 | 2 | 8 | 8 | 2 | 8 |
| 30 | 7 | 3 | 13 | 7 | 3 | 13 | 7 | 3 | 13 | 7 | 3 | 13 | 7 | 3 | 13 |
| 34 | 10 | 2 | 14 | 10 | 2 | 14 | 11 | 2 | 14 | 11 | 2 | 14 | 10 | 2 | 14 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 9 | 2 | 10 | 9 | 3 | 10 | 9 | 3 | 10 | 9 | 3 | 10 | 8 | 3 | 9 |
| 40 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 | 9 | 3 | 9 |
| 81 | 12 | 2 | 15 | 12 | 2 | 15 | 12 | 2 | 15 | 12 | 2 | 15 | 12 | 3 | 15 |
| 83 | 10 | 5 | 17 | 10 | 4 | 17 | 8 | 5 | 17 | 9 | 5 | 17 | 7 | 4 | 17 |

Note: Blank cells indicate data are not available.

Rutting data are recorded in the MON_T_PROF_INDEX_SECTION table from the LTPP database. Table 19 summarizes the number of rut measurements taken at each site. IRI is another monitoring index measured in SPS-5 sites. The IRI measurements are available from the MON_PROFILE_MASTER table from the LTPP database. The number of IRI measurements taken at each site is presented in table 19. For the sites where there is a considerable difference in available data for each experiment within the site, a range of available surveys is specified.

**Table 19. Number of rutting and IRI surveys conducted at SPS-5 sites.**

| State Code | Rutting | IRI |
|---|---|---|
| 1 | 13 | 11 |
| 4 | 17 | 14 |
| 6 | 18 | 15 |
| 8 | 8 | 10 |
| 12 | 13 | 9 |
| 13 | 14 | 9 |
| 23 | 13 | 10 |
| 24 | 17 | 15–19 |
| 27 | 12–18 | 14 |
| 28 | 6 | 6 |
| 29 | 10–12 | 5 |
| 30 | 12 | 16 |
| 34 | 18 | 17–20 |
| 35 | 12 | 7 |
| 40 | 13 | 9 |
| 81 | 14 | 17 |
| 83 | 13 | 15 |

## Assessment of SPS-6 Data

### *Inventory Data*

The SPS-6 experiment was conducted in 14 States throughout the United States. The sites were originally constructed between 1962 and 1978, and they were rehabilitated according to SPS-6 specifications between 1989 and 1998.

Table 20 shows the States included in the study and their corresponding historic dates. The LTPP tables used to gather the information are as follows:

Inventory data include the following:

- **Inventory**: INV_AGE:TRAFFIC_OPEN_DATE.
- **SPS**: SPS6_PMA_CONSTRUCTION:DATE_COMPLETE.

Traffic data include the following:

- **Traffic**: TRF_MONITOR_LTPP_LN:TRUCKS_LTPP_LN.
- **Traffic**: TRF_MON_EST_ESAL:AADT_TRUCK_COMBO.
- **Traffic**: TRF_MONITOR_LTPP_LN:TRUCKS_LTPP_LN.

Material data include the following:

- **Material_Test**: TST_L05B: CONSTRUCTION_NO, LAYER_NO, LAYER_TYPE, REPR_THICKNESS.
- **Material_Test**: TST_L05B: MATL_CODE.
- **Inventory**: INV_SUBGRADE:AASHTO_SOIL_CLASS – reference:CODES:AASHTO_SOIL_CLASS.
- **Inventory**: INV_UNBOUND:AASHTO_SOIL_ CLASS – reference:CODES:AASHTO_SOIL_CLASS.

Monitoring data include the following:

- **IRI**: MON_PROFILE_MASTER.
- **Rutting survey**: MON_T_PRF_INDEX_SECTION (for sections with AC overlay).
- **Faulting surveys**: MON_DIS_JPCC_FAULT_SECT.
- **PCC distress surveys**: MON_DIS_JPCC_REV, MON_DIS_PADIAS42_JPCC.

**Table 20. Original construction, traffic open, and major rehabilitation dates for SPS-6 sites.**

| State Code | Construction Date | Traffic Open Date | Rehab Date |
|---|---|---|---|
| 1 | 05/1966 | 06/1966 | 06/1998 |
| 4 | 09/1966 | 01/1967 | 10/1990 |
| 5 | 12/1978 | 01/1979 | 12/1996 |
| 6 | 08/1977 | 11/1977 | 09/1992 |
| 17 | 06/1964 | 04/1965 | 06/1990 |
| 18 | 01/1972 | 01/1974 | 08/1990 |
| 19 | 11/1965 | 11/1965 | 09/1989 |
| 26 | 06/1958 | 06/1958 | 05/1990 |
| 29 | 07/1975 | 10/1975 | 08/1992 |
| 29A | 07/1969 | 08/1969 | 09/1998 |
| 40 | 11/1962 | 01/1963 | 08/1992 |
| 42 | 09/1968 | 09/1968 | 10/1992 |
| 46 | 04/1973 | 10/1973 | 09/1992 |
| 47 | 06/1964 | 07/1964 | 05/1996 |

### *Traffic Data*

Similar to the SPS-5 experiment, available traffic data for the SPS-6 experiment were obtained from the TRF_MON_EST_ESAL and TRF_HIST_EST_ESAL tables, including the annual traffic counts and estimates of each site for a number of years. Using the data available from these tables, the AADTT at rehabilitation date was obtained. The growth model with a better fit and the growth rate are presented in table 21.

**Table 21. SPS-6 traffic growth.**

| State | Construction Year | Rehab Year | AADTT at Rehab Date | Growth Rate | Growth Method |
|---|---|---|---|---|---|
| 1 | 66 | 98 | N/A | | |
| 4 | 66 | 90 | 38 | 14.47 | Compound |
| 5A | 78 | 96 | N/A | | |
| 6 | 77 | 92 | 1,436 | 0 | No growth |
| 17 | 64 | 90 | 391 | 11.25 | Linear |
| 18 | 72 | 90 | 110 | 59 | Linear |
| 19 | 65 | 89 | 441 | 11.11 | Linear |
| 26 | 58 | 90 | 476 | 1.2 | Linear |
| 29 | 75 | 92 | 637 | 4.35 | Compound |
| 29A | 69 | 98 | 62 | 12.9 | Linear |
| 40 | 62 | 92 | 630 | 2.9 | Compound |
| 42 | 68 | 92 | 1,594 | 2.5 | Linear |
| 46 | 73 | 92 | 121 | 5 | Linear |
| 47 | 64 | 96 | N/A | | |

N/A indicates data are not available.

Note: Blank cells indicate missing traffic data.

Traffic data are missing from Alabama (1), Arkansas (5), and Tennessee (47). The axle distribution data were missing from Missouri (29), Oklahoma (40), and Pennsylvania (42). Also, Missouri (29) is missing axle per truck data from the database.

### *Material Data*

Pavement structure information for SPS-6 sites and the sequence of the changes made to each site over time were extracted from the LTPP database. Table 22 provides a sample table with project information.

**Table 22. Sample materials with project information for the SPS-6 experiment.**

| State Code | SHRP ID | Construction Number | Layer Number | Layer Type | Material Description | Representative Thickness (inches) |
|---|---|---|---|---|---|---|
| 1 | 0606 | 1 | 1 | Subgrade (untreated) | Coarse-grained soil: clayey gravel | |
| 1 | 0606 | 1 | 2 | Unbound (granular) layer | Crushed stone | 6 |
| 1 | 0606 | 1 | 3 | Portland cement concrete layer | PCC (JPCP) | 10.3 |
| 1 | 0606 | 2 | 1 | Subgrade (untreated) | Coarse-grained soil: clayey gravel | |
| 1 | 0606 | 2 | 2 | Unbound (granular) layer | Crushed stone | 6 |
| 1 | 0606 | 2 | 3 | Portland cement concrete layer | PCC (JPCP) | 10.3 |
| 1 | 0606 | 2 | 4 | AC | Hot mixed, hot laid AC, dense graded | 2.2 |
| 1 | 0606 | 2 | 5 | AC | Hot mixed, hot laid AC, dense graded | 1.3 |

1 inch = 25.4 mm

Note: The blank cell indicates that there is no thickness for subgrade.

### *Monitoring Data*

Table 23 summarizes the basic information about the monitoring data collected during the SPS-6 study. Distress surveys were obtained and summarized from all experiment sections to compare performance. The table shows the number of surveys available for each experiment, the number of treatments applied to each experiment, and the number of years the section was inspected.

### Table 23. SPS-6 available monitoring (distress) data.

| State Code | 601 | | | 602 | | | 603 | | | 604 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years |
| 1 | 9 | 1 | 8 | 9 | 1 | 8 | 9 | 1 | 8 | 9 | 1 | 8 |
| 4 | 1 | 0 | 0 | 1 | 1 | 0 | 7 | 3 | 11 | 7 | 2 | 11 |
| 5 | 10 | 6 | 11 | 10 | 4 | 11 | 10 | 1 | 11 | 11 | 1 | 11 |
| 6 | | | | 10 | 6 | 12 | 11 | 4 | 12 | 11 | 5 | 12 |
| 17 | 10 | 6 | 12 | 10 | 8 | 12 | 11 | 4 | 15 | 11 | 5 | 15 |
| 18 | 2 | 0 | 1 | 9 | 4 | 14 | 10 | 4 | 14 | 11 | 3 | 14 |
| 19 | 6 | 6 | 15 | 6 | 9 | 15 | 8 | 6 | 15 | 8 | 5 | 15 |
| 26 | 3 | 0 | 3 | 3 | 1 | 3 | 4 | 1 | 6 | 4 | 1 | 6 |
| 29 | 6 | 7 | 9 | 6 | 9 | 9 | 9 | 2 | 13 | 9 | 2 | 13 |
| 29A | 8 | 3 | 8 | 8 | 2 | 8 | 8 | 2 | 8 | 7 | 2 | 6 |
| 40 | 13 | 5 | 15 | 13 | 2 | 15 | 13 | 3 | 15 | 13 | 3 | 15 |
| 42 | 11 | 2 | 15 | 11 | 1 | 15 | 11 | 2 | 15 | 11 | 2 | 15 |
| 46 | 10 | 7 | 14 | 9 | 3 | 14 | 9 | 3 | 14 | 9 | 3 | 14 |
| 47 | 8 | 3 | 8 | 8 | 4 | 8 | 8 | 1 | 8 | 8 | 1 | 8 |

| State Code | 605 | | | 606 | | | 607 | | | 608 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years |
| 1 | 9 | 1 | 8 | 9 | 1 | 8 | 9 | 5 | 8 | 9 | 1 | 8 |
| 4 | 2 | 1 | 0 | 7 | 2 | 11 | 7 | 3 | 11 | 7 | 3 | 11 |
| 5 | 10 | 4 | 11 | 10 | 1 | 11 | 10 | 1 | 11 | 10 | 1 | 11 |
| 6 | 8 | 7 | 12 | 11 | 4 | 12 | 11 | 4 | 12 | 11 | 3 | 12 |
| 17 | 10 | 7 | 12 | 11 | 9 | 15 | 11 | 6 | 15 | 11 | 3 | 15 |
| 18 | 8 | 4 | 13 | 10 | 4 | 14 | 11 | 4 | 14 | 10 | 4 | 14 |
| 19 | 6 | 10 | 15 | 8 | 4 | 15 | 9 | 5 | 15 | 10 | 4 | 18 |
| 26 | 3 | 1 | 3 | 4 | 1 | 6 | 4 | 1 | 6 | 4 | 1 | 6 |
| 29 | 6 | 9 | 9 | 9 | 1 | 13 | 2 | 2 | 3 | 9 | 3 | 13 |
| 29A | 7 | 2 | 6 | 9 | 2 | 8 | 8 | 2 | 8 | 7 | 1 | 6 |

| State Code | 605 |  |  | 606 |  |  | 607 |  |  | 608 |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years | No. of Surveys | No. of Treatments | No. of Years |
| 40 | 13 | 9 | 15 | 13 | 3 | 15 | 13 | 6 | 13 | 13 | 2 | 15 |
| 42 | 11 | 1 | 15 | 11 | 1 | 15 | 11 | 1 | 15 | 11 | 1 | 15 |
| 46 | 9 | 4 | 14 | 9 | 3 | 14 | 9 | 5 | 14 | 9 | 4 | 14 |
| 47 | 8 | 6 | 8 | 8 | 1 | 8 | 6 | 1 | 6 | 8 | 1 | 8 |

Rut measurements were collected several times from the SPS-6 sites. Table 24 summarizes the number of surveys conducted for each site. The number of surveys available from the database was not the same for all the sections of a site. Therefore, a range is presented for most of the sites. The number of IRI measurements available from the experiment also is provided.

**Table 24. Number of rutting and IRI surveys conducted at SPS-6 sites.**

| State Code | Rutting Surveys | IRI Surveys |
|---:|---:|---:|
| 1 | 11 | 8 |
| 4 | 11 | 3–14 |
| 6 | 7–17 | 11 |
| 17 | 7–18 | 9–12 |
| 18 | 6–17 | 2–17 |
| 19 | 12–16 | 9–12 |
| 26 | 3–8 | 4–9 |
| 29 | 3–16 | 4–11 |
| 40 | 5–14 | 9–10 |
| 42 | 4–14 | 14–16 |
| 46 | 6–16 | 10–11 |
| 47 | 2–11 | 4–7 |
| 5A | 1–12 | 8–10 |
| 29A | 3–11 | 6 |

# CHAPTER 4. ASSESSMENT OF MAINTENANCE ALTERNATIVES

To evaluate the effectiveness of preventive maintenance treatments, the performance of pavement sections with various treatments was compared to the performance of pavement sections with different treatments as well as to the control section. To make these comparisons possible, it was necessary to select parameters that reflected the actual performance of the pavement over the monitoring period of the experiment. Performance indicators were based on pavement distresses collected during the surveys, and this chapter describes the parameter selected for the analysis carried out in this study.

## PERFORMANCE INDICATORS USED IN PREVIOUS STUDIES

Several performance indicators have been utilized in past studies of LTPP experiments. The literature review conducted in this study identified the following list of indicators and the study where they were applied:

- Most recent survey measures of distress.(5)
- Expert task group field reviews of distress.(8)
- Evaluation of distress trends (distress versus time curves).(4,7,8)
- Distress regression models.(8)
- Area under/above condition indicators (rut, cracking, and friction).(18)
- Maximum distress at the latest age/survey.(21)
- Area under the performance curve.(21)
- Area under the performance curve normalized to the latest age.(21)
- Performance index.(21)
- Distress level immediately after rehabilitation/treatment.(7)
- Average distress over the survey period.(4,7)
- Joint deflection.(13)
- Weighted length of joint spalling.(13)
- Weighted sealant damage.(13)
- Average absolute faulting. (13)
- Mean area under the pavement profile.(5)

## PERFORMANCE INDICATOR IMPLEMENTED IN THIS STUDY

Several parameters were evaluated, and the indicator selected for this study was the weighted distress (WD) or average distress value over the total survey period, as calculated using the following equation presented in figure 1:

$$WD = \frac{\sum_{i=0}^{n-1} (D_i + D_{i+1}) \times P_{i+1} \big/ 2}{\sum_{i=0}^{n} P_{i+1}}$$

**Figure 1. Equation. Weighted distress.**

Where:

WD = Weighted distress average value over the total survey period.
$D_i$ = Distress value measured at the $i$th survey.
$P_{i+1}$ = Period (in years) between survey $i$ and survey $i + 1$ ($i = 0$ is the initial distress level immediately after the treatment).
$n$ = Total number of surveys for the section.

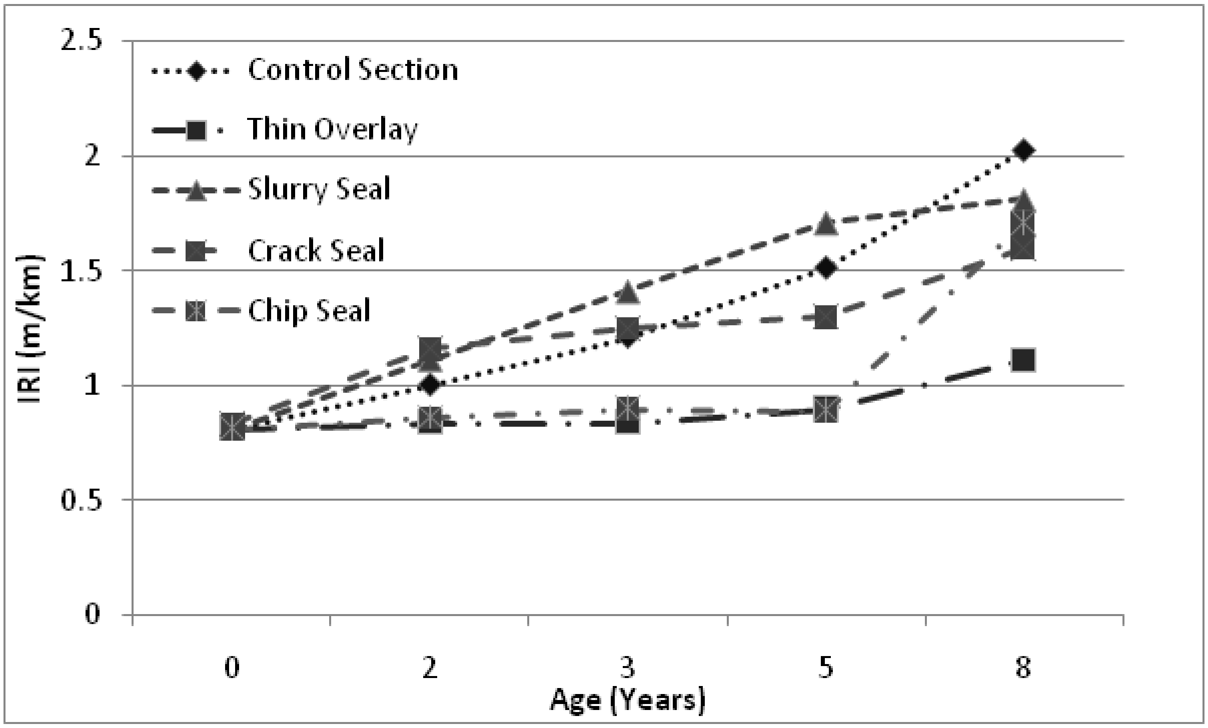
The weighted average represents the total normalized area (per year) under the distress versus time curve. As such, it is a measure of pavement performance relative to the specific distress over the entire monitoring period. The normalization to total time the section was in service provides a means for comparing survey periods that may be different, which allowed the comparison of performance for both the short term and long term.

A hypothetic example of the calculations is provided below. Table 25 and figure 2 contain IRI measurements for a site surveyed for 8 years. The sections were surveyed five times. WD-IRI represents the weighted average value of IRI measured for five surveys conducted in different years. In an 8-year analysis period, thin overlay outperformed other treatments with a WD-IRI value of 4.80 ft/mi (0.91 m/km). Slurry seal presented the worst performance, with a WD-IRI of 7.66 ft/mi (1.45 m/km) over the 8-year period. It can be noted that sections had similar IRI when the experiment was initiated.

**Table 25. Example demonstrating WD-IRI concept.**

| Time (years) | Control Section | | Thin Overlay | | Slurry Seal | | Crack Seal | | Chip Seal | |
|---|---|---|---|---|---|---|---|---|---|---|
| | IRI (m/km) | WD | IRI (m/km) | WD | IRI (m/km) | WD | IRI (m/km) | WD | IRI (m/km) | WD |
| 0 | 0.81 | 0.00 | 0.81 | 0.00 | 0.81 | 0.00 | 0.83 | 0.00 | 0.81 | 0.00 |
| 2 | 1.00 | 0.91 | 0.84 | 0.83 | 1.11 | 0.96 | 1.16 | 1.00 | 0.86 | 0.84 |
| 3 | 1.21 | 0.97 | 0.84 | 0.83 | 1.41 | 1.06 | 1.25 | 1.07 | 0.90 | 0.85 |
| 5 | 1.51 | 1.13 | 0.90 | 0.85 | 1.71 | 1.26 | 1.30 | 1.15 | 0.89 | 0.87 |
| 8 | 2.02 | 1.37 | 1.11 | 0.91 | 1.81 | 1.45 | 1.60 | 1.26 | 1.71 | 1.03 |

1 ft = 0.305 m
1 mi = 1.61 km



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 2. Graph. Example of IRI trends to calculate WD-IRI.**

## STATISTICAL ANALYSIS APPROACH

The statistical test selected for the analysis was the Friedman test, a nonparametric test (distribution-free) used to compare paired observations on a subject. It is also called a nonparametric randomized block analysis of variance. Unlike the parametric repeated measures ANOVA or paired *t*-test, this test makes no assumptions about the distribution of the data (e.g., normality). In addition, unlike the *t*-test, the Friedman test can be used for multiple comparisons, as is the case for the SPS-3 and SPS-4 experiments with four and two different types of treatments, respectively, in addition to the control section. The Friedman test, like many nonparametric tests, uses the ranks of data rather than their raw values. The test statistic for the Friedman test is a chi-square with $n$ - 1 degrees of freedom, where $n$ is the number of repeated measures.

The performance of pavement sections with preventive maintenance treatments was compared to the performance of similar pavements without the treatment (control sections) as well as between the different treatment types. The Friedman test was applied for all design categories and for each distress. The values used were the WDs normalized for the analysis period. The results indicated whether a statistically significant difference existed between any pair of treatments.

Table 26 provides an example of Friedman test results of the SPS-3 experiment for wet climates. A total of 41 sites were located in wet climatic regions with fatigue cracking measurements available for all treatments with 4 degrees of freedom. Based on the test results, thin overlay and chip seal sections had the lowest sum of ranks, and slurry seal and control sections had the highest sum of ranks. A lower sum of ranks indicated better performance because distresses were generally lower over the monitoring period. Analysis results indicated that the difference in performance of thin overlay and chip seal sections compared to slurry seal and the control sections was significant. Only chip seal performed significantly better than crack seal. The difference between other treatments was not significant. The Friedman test value was 49.12 with $p < 0.0001$.

**Table 26. Friedman results of fatigue cracking for treatments in wet climates.**

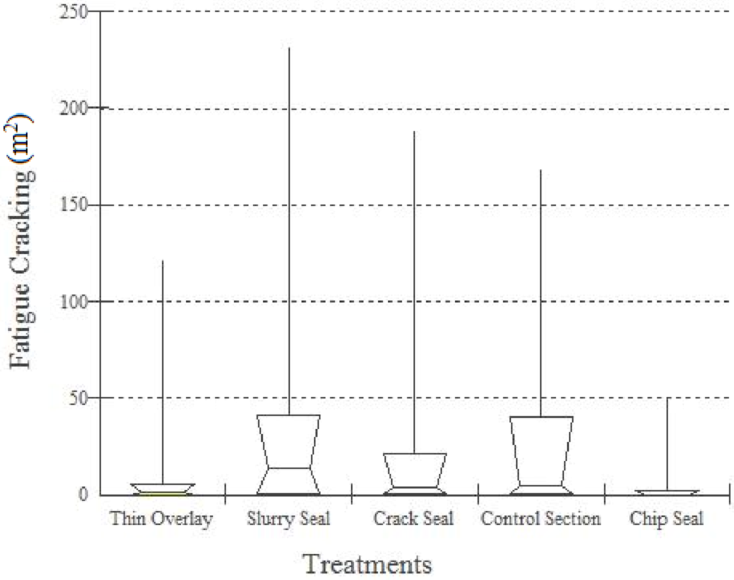
<table>
<tr><th></th><th>Thin Overlay</th><th>Slurry Seal</th><th>Crack Seal</th><th>Control Section</th><th>Chip Seal</th></tr>
<tr><td>Sum of ranks</td><td>99.50</td><td>156.50</td><td>137.50</td><td>148.50</td><td>73.00</td></tr>
<tr><td>Median</td><td>2.30</td><td>20.40</td><td>5.80</td><td>12.70</td><td>0.00</td></tr>
<tr><td>Average of ranks</td><td>2.43</td><td>3.82</td><td>3.35</td><td>3.62</td><td>1.78</td></tr>
<tr><td>Standard deviation</td><td>22.64</td><td>54.15</td><td>63.26</td><td>103.31</td><td>8.04</td></tr>
<tr><th colspan="2">Comparisons</th><th>Difference</th><th colspan="3"><i>p</i>-Value</th></tr>
<tr><td colspan="2">Thin overlay versus slurry seal</td><td>57</td><td colspan="3">< 0.05</td></tr>
<tr><td colspan="2">Thin overlay versus crack seal</td><td>38</td><td colspan="3">not significant</td></tr>
<tr><td colspan="2">Thin overlay versus control section</td><td>49</td><td colspan="3">< 0.05</td></tr>
<tr><td colspan="2">Thin overlay versus chip seal</td><td>26.5</td><td colspan="3">not significant</td></tr>
<tr><td colspan="2">Slurry seal versus crack seal</td><td>19</td><td colspan="3">not significant</td></tr>
<tr><td colspan="2">Slurry seal versus control section</td><td>8</td><td colspan="3">not significant</td></tr>
<tr><td colspan="2">Slurry seal versus chip seal</td><td>83.5</td><td colspan="3">< 0.05</td></tr>
<tr><td colspan="2">Crack seal versus control section</td><td>11</td><td colspan="3">not significant</td></tr>
<tr><td colspan="2">Crack seal versus chip seal</td><td>64.5</td><td colspan="3">< 0.05</td></tr>
<tr><td colspan="2">Control section versus chip seal</td><td>75.5</td><td colspan="3">< 0.05</td></tr>
</table>

## FLEXIBLE PAVEMENTS MAINTENANCE

The effectiveness of treatments in prolonging flexible pavement life was evaluated using two load-associated distresses (fatigue cracking and rutting) and ride quality as measured in surveys conducted for the SPS-3 experiment. Performance was evaluated as the deterioration measured by fatigue cracking, rutting, and IRI.

Figure 3 through figure 5 illustrate box-whisker plots of WD index for fatigue cracking (WD-fatigue), rutting (WD-rutting), and IRI (WD-IRI). The boundaries of the box present lower and upper quartiles, and the middle line is the median. The whisker marks the minimum and maximum limits of WD. Only surveys providing distress measurements for all treatments were used to draw the graphs, and some outliers were excluded.

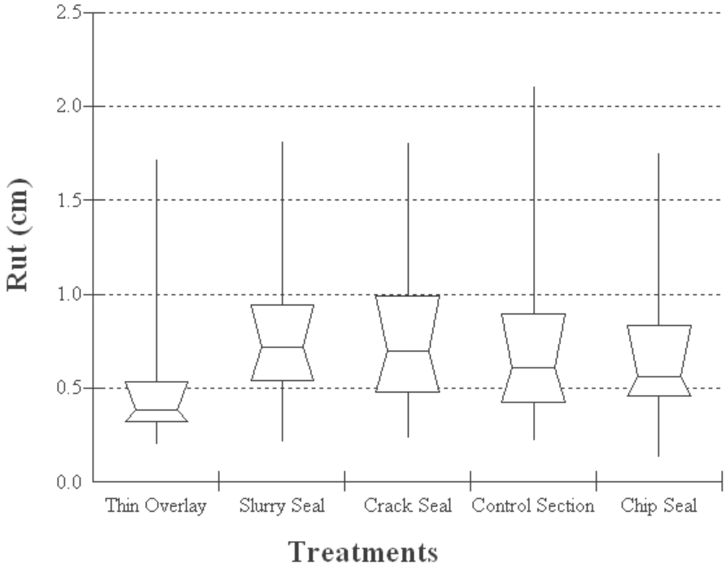
As shown in figure 3, thin overlay and chip seal sections exhibited lower fatigue cracking levels compared to slurry seal, crack seal, and the control section. Chip seal also presented the smallest minimum/maximum range. Sections that were treated with crack seal had lower WD-fatigue compared to slurry seal and the control section. The slurry seal alternative seemed to be less effective in mitigating the progression of fatigue cracking over the monitored period.



1 ft$^2$ = 0.093 m$^2$

**Figure 3. Graph. Box-whisker plot for WD-fatigue of SPS-3 sections.**

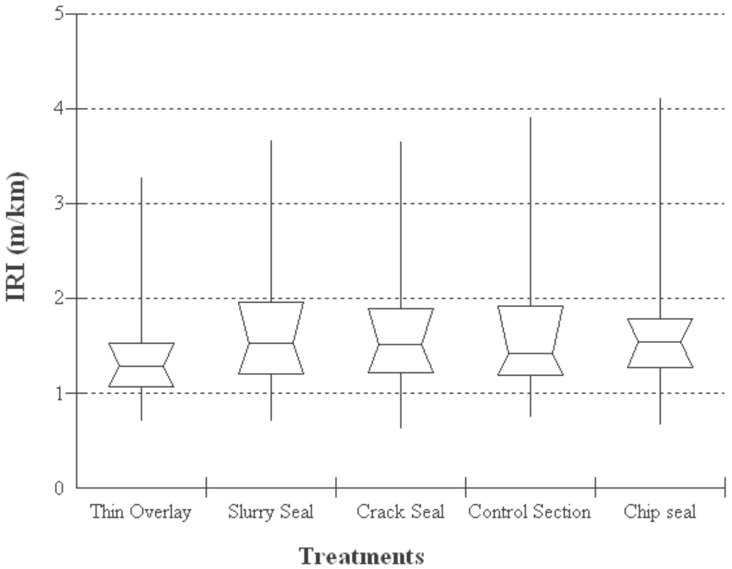
Rutting levels presented considerable differences between sections that were treated with thin overlay and other sections (see figure 4). Thin overlay was effective in reducing rutting immediately after the treatment, and, as a consequence, those sections presented a lower level of rutting over the analysis period. Although chip seal marginally outperformed the rest of the treatments, it provided little advantage over the remaining treatments.



1 inch = 2.54 cm

**Figure 4. Graph. Box-whisker plot for WD-rutting of SPS-3 sections.**

A similar conclusion was found in terms of IRI performance (see figure 5). As expected, thin overlay was the most effective maintenance option in mitigating IRI over the years. This type of treatment was the most effective in reducing initial roughness immediately after treatment rather than providing a significant structural improvement of the pavement section.



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 5. Graph. Box-whisker plot for WD-IRI of SPS-3 sections.**

Although the box-whisker plots showed some indication of which treatments performed best, the Friedman test was applied to the WD indexes to identify if the differences were statistically significant. Results from the test runs for all design categories are summarized in table 27.

.

**Table 27. Summary of flexible pavement performance results based on Friedman test.**

| Condition | | | Fatigue Cracking | | | | Rutting | | | | IRI | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **TH** | **SL** | **CR** | **CO** | **TH** | **SL** | **CR** | **CO** | **TH** | **SL** | **CR** | **CO** |
| **Temperature** | **Freeze** | **SL** | TH | | | | TH | | | | TH | | | |
| | | **CR** | | | | | TH | | | | TH | | | |
| | | **CO** | TH | | | | TH | | | | | | | |
| | | **CH** | | CH | CH | CH | TH | CH | | | TH | | | |
| | **No-freeze** | **SL** | | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | TH | | | | | | | |
| | | **CH** | | CH | CH | CH | TH | | | | | | | |
| **Precipitation** | **Wet** | **SL** | TH | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | TH | | | | TH | | | | | | | |
| | | **CH** | | CH | CH | CH | TH | | | | | | | |
| | **Dry** | **SL** | | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | TH | | | | | | | |
| | | **CH** | | CH | CH | CH | | CH | | | | | | |
| **Subgrade** | **Coarse** | **SL** | TH | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | TH | | | | | | | |
| | | **CH** | | CH | CH | CH | TH | | | | TH | | | |
| | **Fine** | **SL** | | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | TH | | | | TH | | | |
| | | **CH** | | CH | CH | CH | TH | | | | | | | |
| **Traffic** | **High** | **SL** | TH | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | TH | | | |
| | | **CO** | TH | | | | TH | | | | TH | | | |
| | | **CH** | | CH | CH | CH | TH | | | | TH | | | |
| | **Low** | **SL** | | | | | TH | | | CO | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | | CO | | | | | | |
| | | **CH** | | CH | CH | CH | TH | | | | | | | |
| **Pavement Condition** | **Poor** | **SL** | TH | | | | TH | | | | TH | | | |
| | | **CR** | TH | | | | TH | | | | TH | | | |
| | | **CO** | TH | | | | TH | | | | TH | | | |
| | | **CH** | | CH | CH | CH | TH | | | | | | | |
| | **Fair** | **SL** | | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | TH | | | | | | | |
| | | **CH** | | CH | | | TH | | | | | | | |
| | **Good** | **SL** | | | | | TH | | | | | | | |
| | | **CR** | | | | | TH | | | | | | | |
| | | **CO** | | | | | | | | | | | | |
| | | **CH** | | | | CH | | | | | | | | |

TH = thin overlay, SL = slurry seal, CR = crack seal, CO = control, and CH = chip seal.
Note: Blank cells indicate that there is no significant difference between the two treatments being compared.

To compare the treatments, design conditions from the left side of the table and a distress from the top of the table should be selected. Then, one of the treatments from the third column and another one from the top are selected for comparison. If the intersecting cell is empty, there is no significant difference between the two treatments. Otherwise, the cell is filled with the treatment that performed better. For example, the first cell on the left is filled with "TH," indicating that thin overlay is significantly superior to slurry seal with respect to fatigue cracking in freezing climates.

The main objective of the SPS-3 experiment was to provide data to identify the effects of major design factors on the performance of maintenance alternatives. Specifically, the experiment was intended to identify whether different climate conditions, subgrade material, traffic level, or initial pavement condition affect the choice of a preferred treatment. Therefore, the results from different design factors were compared for each type of distress and summarized in the following sections.

### Fatigue Cracking

Temperature had a significant effect when comparing thin overlay with slurry seal and the control section. Thin overlays outperformed both treatments in freeze zones; however, temperature did not have an additional impact on the performance of other alternatives since chip seal outperformed slurry seal, crack seal, and the control section in both freeze and no-freeze zones. The same conclusion is valid for precipitation. Thin overlay outperformed slurry seal and the control section only in wet regions. There were no other significant differences in the performance of other treatments with respect to precipitation.

Subgrade type affected the performance of thin overlays relative to other treatments. Thin overlay generally performed better than slurry seal when the subgrade was comprised of coarse material. Traffic affected the performance of the thin overlay when compared to slurry seal and the control section. Under higher traffic levels, the performance of thin overlays prevailed over both the control and slurry seal sections; however, differences between thin overlays and chip seal or crack seal were not statistically significant.

The performance of maintenance treatments with respect to the initial pavement condition was evaluated to identify the importance of timing. Timing of treatment application impacted pavement performance. When the pavement was in poor condition, thin overlay performed better than slurry seal, crack seal, and the control section. Chip seal also outperformed crack seal, with a significant statistical difference under such conditions. It is important to note that the comparisons were based on fatigue cracking surveys. In this case, chip seals in general may only mask the cracks and mislead survey measurements rather than actually correct the distress to improve performance.

### Rutting

Generally, thin overlays performed better for rutting when compared to other treatment alternatives and the control section. Temperature was one of the factors that affected performance when comparing chip seal and slurry seal sections. In freezing zones, chip seal outperformed slurry seal. In addition to temperature, only precipitation was statistically influential in rutting when comparing chip seals with thin overlays and slurry seals. Under wet conditions, thin overlays outperformed chip seal, and under dry conditions, chip seal performed better than slurry seal.

Under higher traffic levels, thin overlays performed better than the control section; however, in low traffic, the differences were not statistically significant. Surprisingly, slurry seal performed worse than the control section under low traffic level conditions with respect to rutting. No other design factor affected the performance of the pavement sections in a statistically significant way with respect to rutting.

### IRI

Temperature condition was an important factor in defining maintenance activities concerning surface smoothness. Thin overlays performed significantly better than slurry seals, crack seals, and chip seals in freezing zones. In no-freeze zones, there were no significant differences among treatments and the control section with respect to IRI. Precipitation did not affect performance among the flexible pavement treatments evaluated. There was no significant difference among treatments under dry and wet conditions.

In pavements with coarse subgrade, thin overlay was superior to chip seal. In pavements with fine subgrade, thin overlays outperformed the control section only. The comparison of the treatments did not show significant differences in any other combination.

Traffic also affected the performance of maintenance treatments when roughness was considered. Thin overlays outperformed crack seals, chip seals, and the control section in roads under higher traffic levels. In low traffic roads, there were no significant differences among the treatments or the control section.

Pavement initial condition affected the performance of the treatments. Thin overlays performed better than crack seals, chip seals, and the control section if the condition of the pavement was poor. There was no significance difference identified when the pavement condition was good.

Table 28 summarizes the results of the statistical analysis for each distress type evaluated. All four treatments were considered. When pavement performance for the treatment was statistically significant compared to the control section, the treatment code was depicted in the cell. If no statistical significance was identified between the treatments and the control section, the cell was left empty. In some cases, two treatments significantly outperformed others, shown as "2d choice" in the table. For example, in freeze zones and with respect to fatigue cracking, chip seal is presented as the first choice and thin overlay is shown as the second choice.

**Table 28. Preferred flexible pavement treatments.**

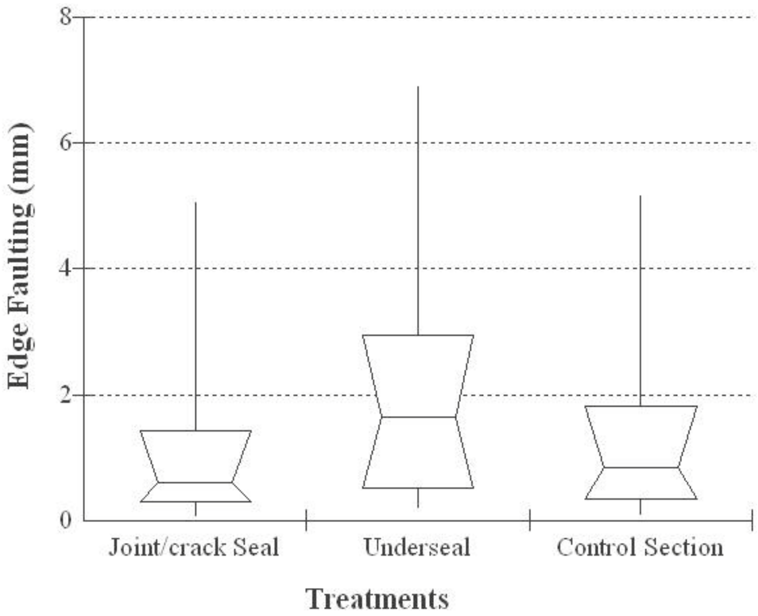
| Distress | Preferred Treatment | Temperature | | Precipitation | | Subgrade | | Traffic | | Pavement Condition | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Freeze | No-freeze | Dry | Wet | Fine | Coarse | Low | High | Good | Fair | Poor |
| Fatigue Cracking | 1st choice | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | TH |
| | 2d choice | TH | — | — | TH | — | TH | — | TH | — | — | CH |
| Rutting | 1st choice | TH | TH | TH | TH | TH | TH | TH | TH | TH | TH | TH |
| | 2d choice | CH | — | CH | — | — | — | — | — | — | — | — |
| Roughness | 1st choice | TH | None | None | None | TH | TH | None | TH | None | None | TH |

CH = chip seal and TH = thin overlay.
— Indicates that no data are available.
Note: None means that neither treatment alternative performed significantly better than the control section. CH is not included as an option for roughness because it was never the preferred treatment method.

## RIGID PAVEMENTS MAINTENANCE

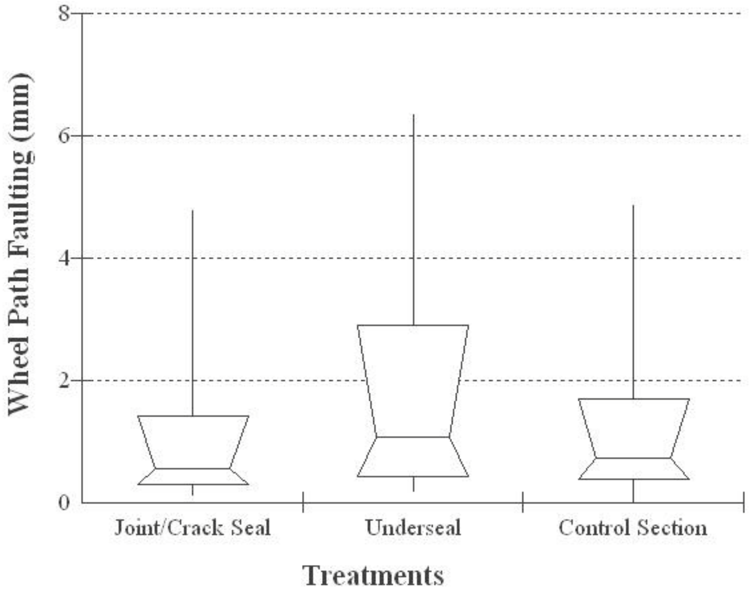
The effectiveness of the treatments in prolonging the pavement life of rigid pavements was evaluated using three types of distresses and the ride quality measurements available for the SPS-4 experiment. Edge faulting, wheel-path faulting, longitudinal cracking, and roughness measurements were chosen as the basis for the performance assessments. Figure 6 through figure 9 illustrate box-whisker plots of WD for these performance indicators.

As shown in figure 6 and figure 7, the experiment showed similar trends for both edge faulting and wheel-path faulting. Joint/crack sealing performed better by showing lower averages and minimum/maximum ranges as compared to the undersealing treatment and the control section. Undersealing treatments resulted in the highest WDs and greater performance variability with respect to edge faulting and wheel-path faulting.



1 inch = 25.4 mm

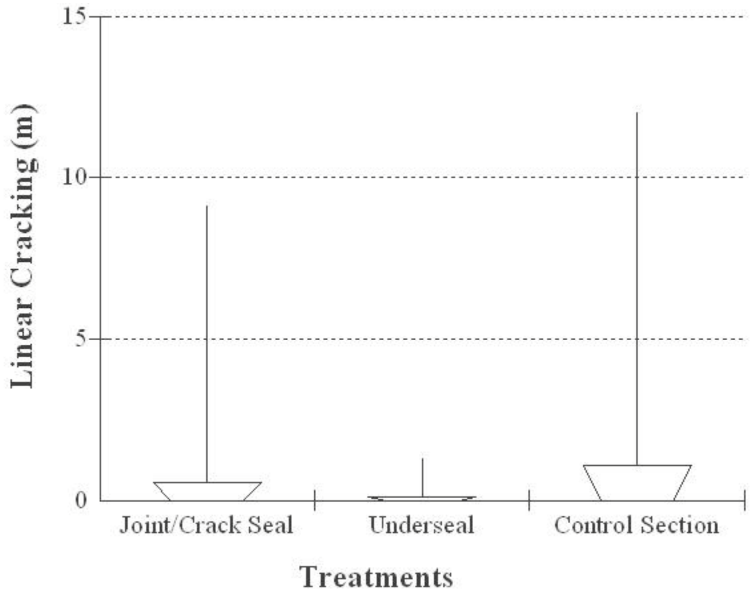
Figure 6. Graph. Box-whisker plot for WD-edge faulting of SPS-4 sections.



1 inch = 25.4 mm

Figure 7. Graph. Box-whisker plot for WD-wheel-path faulting of SPS-4 sections.

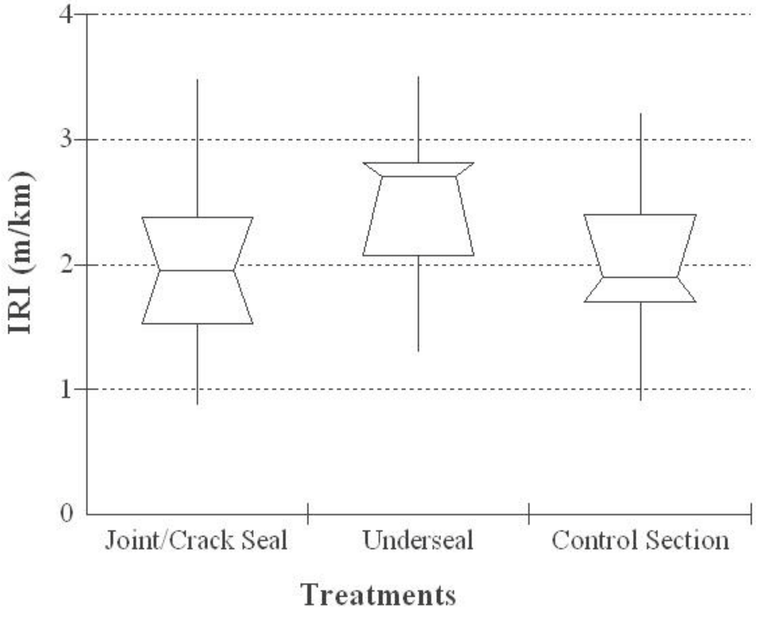
With respect to limiting the propagation of linear cracking, undersealing treatment performed better than the joint/crack sealing and the control section (see figure 8). Joint/crack seal was also better than the control section. Both treatments showed smaller variability as compared to the control section.



1 ft = 0.305 m

**Figure 8. Graph. Box-whisker plot for WD-linear cracking of SPS-4 sections.**

The performance of sections treated by joint/crack sealing was close to that for the control section with respect to IRI (see figure 9). However, the control sections presented lower variability in roughness performance. Sections that were undersealed performed worse than the sealed and control sections.



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 9. Graph. Box-whisker plot for WD-IRI of SPS-4 sections.**

Although the box charts showed indications that joint/crack sealing may be a more effective treatment, the differences were not significant when running the consolidated analysis using the

Friedman test. The analysis also was extended to evaluate the impact of specific site conditions. The SPS-4 test sites were grouped according to precipitation, temperature, structure, base material, and subgrade type. Only 10 sites contained measurements from sections treated by undersealing as compared to 34 sites for joint/crack sealed and control sections. As such, the Friedman test was performed in two stages. In the first stage, only the 10 sites with reported measurements for all 3 sections were considered. In the second stage, the undersealing treatment was excluded from the analysis. As a result, the existence of statistical differences between the crack/joint sealing and control sections was investigated using the data from 34 sites.

The results from both analyses showed no statistically significant differences in performance between the treatments and the control section, indicating that benefits from joint/crack sealing and undersealing may be relatively small; however, the sample size for sections with undersealing was small, which may affect the meaningfulness of the results.

## MAINTENANCE TREATMENT APPLICATION TIMING

Timing of treatment application is an important factor in achieving the best treatment performance. Optimum timing of treatment application can maximize treatment benefits through improved pavement performance while minimizing the overall costs of maintaining the pavement. Performance of preventive maintenance treatments depends on the condition of the pavement at the time of treatment. Different types of treatments are likely to be most effective when applied at certain times in pavement life, providing a cost-effective solution to prolonging pavement life.

The LTPP database was used to obtain information on treatment dates, pretreatment pavement conditions, and post-treatment pavement condition changes over time. The analysis in this section of the report provides an indication for appropriate timing of different maintenance alternatives.

The effects of initial pavement conditions on pavement performance for different treatment alternatives were evaluated by comparing the performances of two groups of pavements: sites with a WD lower than the median distress and sites with a WD higher than the median distress. The performance of the treated sections was evaluated in each group using the Friedman test to investigate the existence of statistically significant differences.

### Flexible Pavement Maintenance Application Timing

#### *IRI*

Figure 10 presents the average rankings of the sites for different treatments. The figure illustrates the average ranking for all sites, including sites initially in poor condition and those initially in fair conditions. As explained earlier, a lower number for ranks indicates better performance. As such, thin overlay had better performance when all sites were included and when the sites were initially in poor conditions. However, the performance of the control section was statistically similar to all treatments with respect to IRI when the sites were initially in better conditions.

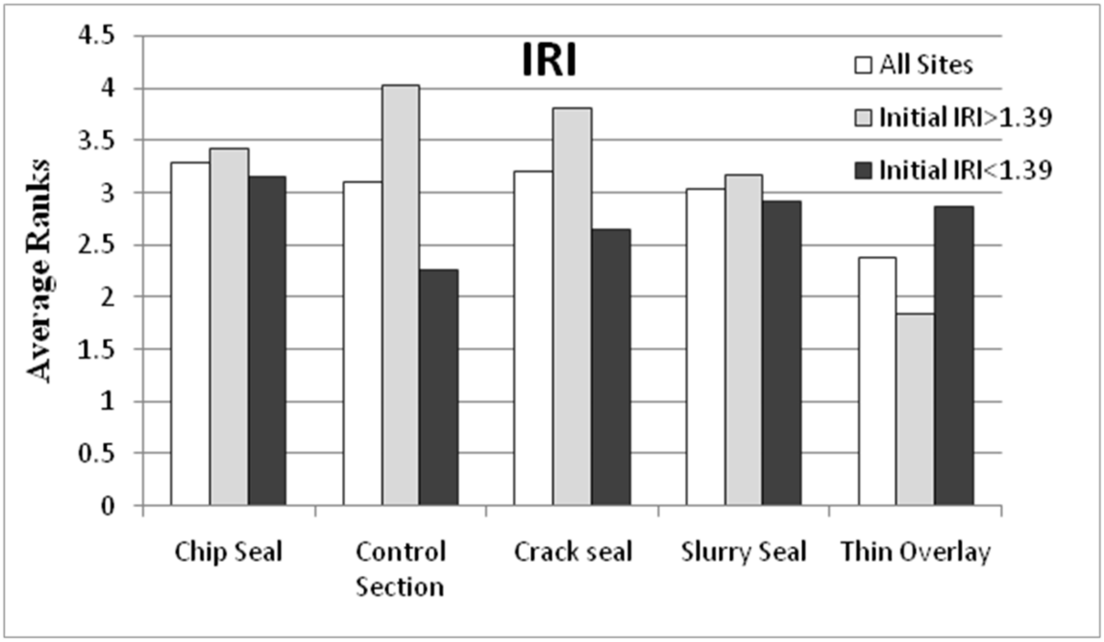


Figure 10. Graph. Average rank of SPS-3 sites with respect to IRI.

Table 29 presents the Friedman test results based on application timing. As shown in the table, the median roughness of the SPS-3 sites was 7.34 ft/mi (1.39 m/km). When considering all the sites collectively for the analysis, thin overlay significantly outperformed the control section, crack seal, and chip seal sections. However, when the analysis was run for those sites with IRIs higher than 7.34 ft/mi (1.39 m/km) (higher levels of roughness), the thin overlay treatment significantly outperformed other treatment types and the control section. No statistically significant differences were observed in the performance of treatments when the existing pavement sections had IRI levels lower than 7.34 ft/mi (1.39 m/km). It was concluded that treatments had little effect on the IRI performance if the pavement had a low initial IRI. Conversely, for sections with higher IRIs prior to the treatment, only thin overlays provided significant improvements to IRI performance over the service life of pavements.

**Table 29. Friedman test results for SPS-3 sites with respect to IRI.**

| All Initial Conditions | $IRI_{initial}$ > 1.39 m/km | $IRI_{initial}$ < 1.39 m/km |
|---|---|---|
| Thin overlay outperformed the control section | Thin overlay outperformed the control section | — |
| — | Thin overlay outperformed slurry seal | — |
| Thin overlay outperformed crack seal | Thin overlay outperformed crack seal | — |
| Thin overlay outperformed chip seal | Thin overlay outperformed chip seal | — |

1 ft = 0.305 m
1 mi = 1.61 km
— Indicates that the Friedman test was not significant for the specific condition.

### *Rutting*

Figure 11 presents the average performance rankings of treatment types related to rutting. The sites were separated in two groups using the median (0.25 inches (6.4 mm)) for initial rutting of all sites. Using the median helped maximize the power of the comparisons using two groups with the same sample size. Thin overlay had better performance whether the sites were in fair or poor conditions. For both groups (low and high levels of initial rutting), the performance of the sites that were treated by crack sealing and slurry sealing was not any better than the control section that received no treatment. However, the average ranking remained consistent with respect to the application timing. There was not a significant difference in performance of the sites with thin overlays with either low or high levels of initial rutting. This was also true for other treatments.

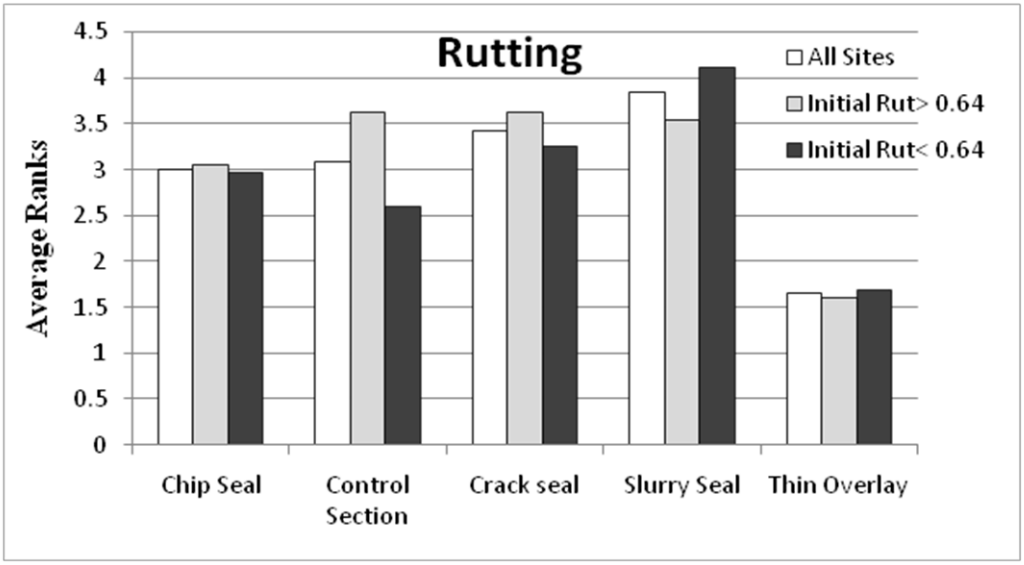


**Figure 11. Graph. Average rank of SPS-3 sites with respect to rutting.**

Table 30 presents the Friedman test results based on application timing for rutting. Thin overlay significantly outperformed slurry seal, crack seal, and chip seal for both levels of rutting. Surprisingly, when the pavements had initial rutting lower than 0.25 inches (6.4 mm), the differences in rankings between the control section and the thin overlay were not statistically significant. Also, chip seal was significantly better than the slurry seal when the sites had initial rutting lower than 0.25 inches (6.4 mm); however, the differences were not identified when the pavement sections had higher levels of rutting prior to the treatments.

**Table 30. Friedman test results of SPS-3 sites with respect to rutting.**

| Any Initial Condition | Rutting$_{initial}$ > 0.25 inches | Rutting$_{initial}$ < 0.25 inches |
|---|---|---|
| Thin overlay outperformed the control section | Thin overlay outperformed the control section | — |
| Control section outperformed slurry seal | — | Control section outperformed slurry seal |
| Thin overlay outperformed slurry seal | Thin overlay outperformed slurry seal | Thin overlay outperformed slurry seal |
| Thin overlay outperformed crack seal | Thin overlay outperformed crack seal | Thin overlay outperformed crack seal |
| Thin overlay outperformed chip seal | Thin overlay outperformed chip seal | Thin overlay outperformed chip seal |
| Chip seal outperformed slurry seal | — | Chip seal outperformed slurry seal |

1 inch = 25.4 mm

— Indicates that the Friedman test was not significant for the specific condition.

### *Cracking*

Figure 12 presents the average performance rankings of sections with different maintenance treatments and varying levels of fatigue cracking prior to receiving those treatments. Similar to the previous analyses, the sites were grouped according to the median level of cracking prior to treatment for all sites. Chip seal had better cracking performance whether the sections had initial lower or higher levels of cracking. The cracking performance of sections that were treated with crack sealing, slurry sealing, and thin overlay was poorer than the control section when the sites had a level of cracking lower than 21.96 ft$^2$ (2.04 m$^2$). All treatments performed relatively better than the control section when the pavement had cracking higher than 21.96 ft$^2$ (2.04 m$^2$).

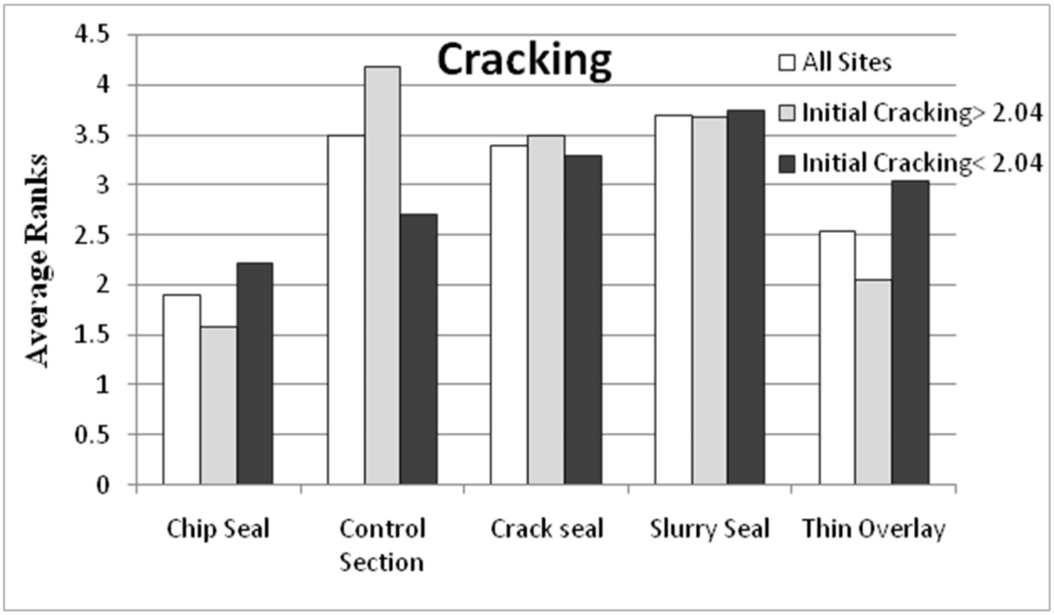


**Figure 12. Graph. Average rank of SPS-3 sites with respect to cracking based on application timing.**

Table 31 presents the Friedman test results based on application timing for cracking. The median level of existing cracking prior to the application of maintenance treatments for all of the sites in initial condition was 21.96 $ft^2$ (2.04 $m^2$). Thin overlay and chip seal significantly outperformed slurry seal, crack seal, and the control section when the existing pavement had more than 21.96 $ft^2$ (2.04 $m^2$) of cracking. Chip seal outperformed slurry seal and crack seal for pavements that had an initial level of cracking lower than 21.96 $ft^2$ (2.04 $m^2$). Under this condition, the control section performed better than slurry seal.

**Table 31. Friedman test results for SPS-3 sites with respect to cracking based on application timing.**

| Any Initial Condition | $\text{Cracking}_{\text{initial}} > 21.96\ ft^2$ | $\text{Cracking}_{\text{initial}} < 21.96\ ft^2$ |
|---|---|---|
| Thin overlay outperformed the control section | Thin overlay outperformed the control section | — |
| Chip seal outperformed the control section | Chip seal outperformed the control section | — |
| Thin overlay outperformed slurry seal | Thin overlay outperformed slurry seal | — |
| Thin overlay outperformed crack seal | Thin overlay outperformed crack seal | — |
| Chip seal outperformed slurry seal | Chip seal outperformed slurry seal | Chip seal outperformed slurry seal |
| Chip seal outperformed crack seal | Chip seal outperformed crack seal | Chip seal outperformed crack seal |
| — | — | Control section outperformed slurry seal |

1 $ft^2$ = 0.093 $m^2$

— Indicates that the Friedman test was not significant for the specific condition.

### Rigid Pavement Maintenance Application Timing

The same analysis was conducted for rigid pavement sites in the SPS-4 experiment. The number of sites with undersealing treatments and reported distress measurements were limited to 10 or less. As a result, this treatment was excluded from further analysis to achieve meaningful conclusions due to the small sample size.

A Friedman test was applied to joint/crack sealed sections and the control sections to investigate significant differences in performance with respect to the application timing. Roughness, edge faulting, wheel-path faulting, and longitudinal cracking distress measurements were considered. No statistically significant differences were identified between the joint/crack sealing and control sections for any of the measured distresses under fair or poor initial pavement conditions.

## CONCLUSIONS

Based on the analysis of SPS-3 sites, the following conclusions were made:

- Thin overlays and chips seals were more effective than slurry seal and crack seal treatments in mitigating fatigue cracking.

- As expected, thin overlay was the most effective option with respect to rutting. Chip seal was more effective than slurry seal in freeze zones and in wet regions. There were no significant differences between slurry seal, crack seal, and the no treatment scenario with respect to rutting.

- As expected, thin overlay was the most effective treatment with respect to IRI.

- With respect to fatigue cracking, thin overlay performed better than most other treatments if the pavement was in a freeze zone, in a wet climatic region, subject to high traffic conditions, or initially in poor condition.

- When the pavement was in a freeze zone, subject to high traffic, or in an initially poor condition, thin overlay was the best choice with respect to IRI.

- Thin overlays were more effective in wet regions compared to other treatments only with respect to fatigue cracking.

- Chip seal performance compared to other treatments was not affected by most design factors with respect to fatigue cracking. Specifically, chip seal performed better than slurry seal, crack seal, and the control section in freeze and no-freeze zones, in wet and dry climatic conditions, with fine and coarse subgrade materials, and under high and low traffic loads. Although chip seal was better than the mentioned treatments in initially poor condition pavements, it outperformed only slurry seal in initially fair condition pavements and outperformed only the control section in initially good condition pavements.

- Design factors had little or no influence on treatments with respect to rutting. Chip seal was only marginally more effective in the freeze zones and in dry climates.

The study of SPS-4 sites showed that the performance of the joint/crack sealed sections and undersealed sections was not significantly different than that of the control sections. No meaningful difference between the two treatments was found. The strength of the analysis was weakened by the number of sites that included recorded surveys with undersealing treatments. While there were 34 sites included in the survey measurements for joint/crack sealed sections, only 10 sites had recorded data for undersealed sections.

# CHAPTER 5. REHABILITATED FLEXIBLE PAVEMENT ANALYSIS AND FINDINGS

## INTRODUCTION

This chapter describes the analysis of rehabilitation alternatives for flexible pavements. The LTPP SPS-5 experiment was the main source of information for this study. The objective of the SPS-5 experiment, “Rehabilitation of Asphalt Concrete Pavements,” was to help develop improved methodologies and strategies for the rehabilitation of flexible pavements. Specifically, the experiment evaluated common rehabilitation techniques implemented in the United States and Canada, and it evaluated the effects of climate, structural condition, and material variations on performance of rehabilitated flexible pavements. The design factorial is documented in *Rehabilitation of Asphalt Concrete Pavements—Initial Evaluation of the SPS-5 Experiment*, and included the following evaluation parameters:(4)

- **Climate**: Wet versus dry and freeze versus non-freeze.
- **Existing pavement condition**: Fair versus poor.
- **Surface preparation**: Milling versus no milling.
- **Overlay material**: Recycled versus virgin HMA.
- **Overlay thickness**: Thin (2 inches (51 mm)) versus thick (5 inches (127 mm)).

Variation of surface preparation alternatives, overlay material, and overlay thickness led to eight combinations at each SPS-5 project site (see table 32). In addition, one section was assigned as the control and did not receive any overlay, except for routine maintenance, creating nine experimental sections at each SPS-5 project site. As a result, each individual SPS-5 project provided a means for directly comparing rehabilitated HMA pavement performance using different surface preparation intensity, overlay thickness, and type of overlay mixture.

The initial SPS-5 sampling matrix was supposed to include only one subgrade type (fine-grained soil) with a minimum annual traffic of over 85,000 ESALs. Other factors considered in the sampling matrix included structural and functional condition of the pavement before overlay and climate. A total of 18 SPS-5 projects were constructed between 1989 and 1998. Table 33 presents the site location of each experiment according to their experimental design classification and as-built data. As shown, there were at least two projects for each condition except for the wet no-freeze fair condition cell and the dry freeze poor condition cell. A total of 162 test sections were built as part of the core SPS-5 experiment.

**Table 32. Core sections of the SPS-5 experiment.**

| SHRP ID | Overlay Type |
|---|---|
| 0501 | Control: No treatment |
| 0502 | Thin overlay (1.99 inches (51 mm)): Recycled HMA mix |
| 0503 | Thick overlay (4.95 inches (127 mm)): Recycled HMA mix |
| 0504 | Thick overlay: Virgin mix |
| 0505 | Thin overlay: Virgin mix |
| 0506 | Thin overlay: Virgin mix with milling |
| 0507 | Thick overlay: Virgin mix with milling |
| 0508 | Thick overlay: Recycled mix with milling |
| 0509 | Thin overlay: Recycled mix with milling |

**Table 33. Constructed SPS-5 sites for the experimental factorial.**

| Pavement Condition | Soil Classification | Climate, Moisture Temperature | | | |
|---|---|---|---|---|---|
| | | Wet Freeze | Wet No-freeze | Dry Freeze | Dry No-freeze |
| Fair | Coarse/fine | Georgia | | Colorado | |
| | Coarse | New Jersey | | Alberta, Canada | New Mexico |
| | | | | Montana | |
| | Fine | | | Minnesota | Oklahoma |
| | | | | | Texas |
| Poor | Coarse/fine | | | Manitoba, Canada | California |
| | Coarse | Maine | Florida | | Arizona |
| | | | Alabama | | |
| | Fine | Maryland | Mississippi | | |
| | | Missouri | | | |

Note: Blank cells indicate data are not available.

One major deviation from the original SPS-5 experimental plan was the subgrade soil type. Originally, the subgrade soils for all SPS-5 projects were supposed to be fine-grained soils; however, only five of the SPS-5 projects actually had fine-grained soils. Four SPS-5 projects had soils that varied between fine- and coarse-grained soils. The subgrade soils for the remaining eight SPS-5 projects were classified as coarse-grained soils.

Additionally, one major deviation from the original SPS-5 sampling matrix was subgrade soil type. Originally, the subgrade soils for all SPS-5 projects were supposed to be fine-grained soils. However, only six of the SPS-5 projects actually had fine-grained soils. Four SPS-5 projects had soils that varied between fine- and coarse-grained soils, while the remaining eight projects were classified as coarse-grained soils. Another deviation from the experimental plan for only a few of the SPS-5 projects was that no control section was left in place. For example, section 0501 for the Colorado project included the placement of a thin overlay during rehabilitation.

## DATA ANALYSES

The impact of design features and site conditions on performance and response can be evaluated by looking at the trends in the survey data over time. Statistical tests can be used to verify if there are differences in these trends and if they can be associated with any of the design features in the experiment. Moreover, it is important to establish if any information on performance or response is reproduced in other sites or if they are associated with a particular site characteristic (e.g., climate, traffic, etc.). The best approach to achieve this objective is to consider every site and section available to statistically compare performance and response.

The SPS-5 experimental designed was balanced between design features intended for investigation. With few exceptions, out of 9 sections in each one of the 18 sites, there was 1 control section and 8 sections that combined equally thin and thick overlays with virgin and reclaimed asphalt pavement (RAP) mixes and milling and not milling prior to overlay. This provided an opportunity for a gradual statistical analysis in which information was gained by sequentially analyzing the data from each site first and complemented with a consolidated analysis. The consolidated analysis involved evaluating all sites and sections simultaneously in search of general trends and conclusions about pavement performance and its dependency on design features and site conditions. Figure 13 illustrates the statistical analysis process.

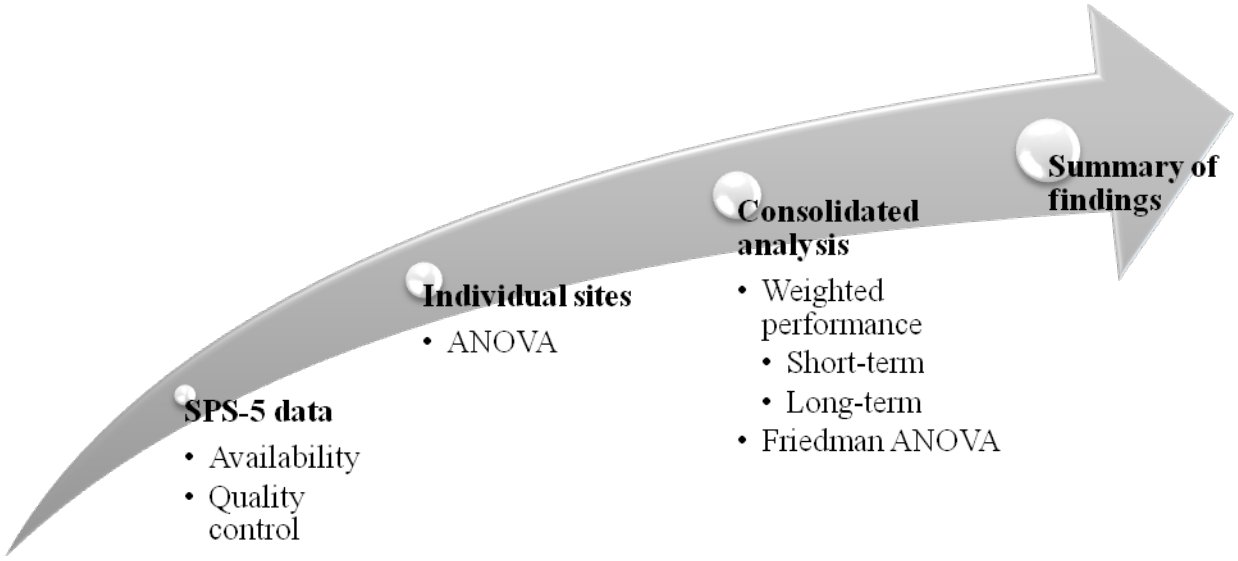


**Figure 13. Illustration. Statistical analysis flow chart.**

### Statistical Approach and Tests

The approach consisted of analyzing each site individually to initially check its construction history to address possible problems during that phase. ANOVA was then used for repeated measures. ANOVA can be used to explain if different trends in performance exist because of a particular choice of design feature (e.g., milling versus no milling). The repeated measures are the surveys conducted throughout the duration of the experiment. Each section that is part of one site has the same site conditions and traffic volume. The surveys were performed within a short period for sections, which made ANOVA with repeated measures the best option for the statistical analysis of individual sites.

The consolidated analysis was performed using the Friedman test. This is a nonparametric test (distribution-free) used to compare repeated observations on similar subjects. Unlike the more common parametric repeated measures such as ANOVA or a paired *t*-test, the Friedman test makes no assumptions about the distribution of the data (e.g., normality), and it can be used for multiple comparisons. The Friedman test uses the ranks of the data rather than their raw values to calculate the statistic. The test statistic for the Friedman test is a chi-square with $n - 1$ degrees of freedom, where $n$ is the number of repeated measures (i.e., the number of sections in each site of the experiment). Statistical significance was defined at 95 percent ($p \leq 0.05$ for the chi-square test).

The Friedman test also permits the evaluation of paired statistical significance between two rehabilitation strategies. In some instances, the result of one analysis may indicate that significant differences exist between the rankings of sections (i.e., the performances of these sections are statistically different). However, there might be groups within the sorted ranking with similar performance. The paired statistical analysis feature is important to identify groups of strategies with equivalent performance.

### Performance Measures

The analysis of individual sites used distress and response data collected throughout the experiment duration. The data were checked for consistency and reasonableness prior to use in the analysis. Roughness, rutting, and fatigue, longitudinal, and transverse cracking were selected as indicative of performance and maximum deflection as indicative of response.

As described in the previous chapter, the consolidated analysis used WD as a performance measure of various distresses and the pavement response. It is calculated using the equation in figure 14.

$$WD = \frac{\sum_{i=0}^{n-1} (D_i + D_{i+1}) \times P_{i+1} \big/ 2}{\sum_{i=0}^{n} P_{i+1}}$$

**Figure 14. Equation. Weighted distress.**

The weighted average, in reality, represents the total normalized area (per year) under the distress versus time curve. As such, it is a measure of pavement performance relative to the specific distress over the entire monitoring period. The normalization to total time the section was in service provides means for comparing survey periods that may be different, which allowed the comparison of performance for both short term and long term.

The WD parameter is related to pavement performance over the whole analysis period. This concept is comparable to performance originally defined as the area under the serviceability curve.(2) The effect of variability from measurements by different surveyors is reduced when using this procedure and provided a parameter that could be used to compare sections with different survey periods. The WD performance measure proved a viable alternative to access the performance of different sections with individual in situ conditions and in-service ages. WD values were computed for the short term to evaluate performance in less than or equal to 5 years after rehabilitation was executed. Additionally, WD values were computed for the long term to compare performance for a period greater than 5 years.

## EFFECT OF DESIGN, CONSTRUCTION FEATURES, AND SITE CONDITIONS ON PERFORMANCE OF REHABILITATED FLEXIBLE PAVEMENTS

The first task was to analyze the impact of design features on performance for each site separately. The objective of this initial step was to identify trends in performance that could be associated with each design feature in the experiment (thin versus thick overlay, RAP versus virgin mix, and milling versus no milling). ANOVA with repeated measures was the statistical test used for this task. This statistical analysis took advantage of the fact that all sections at each SPS-5 site had the same underlying pavement structure, traffic, and climate. The distress surveys and profile measurements were taken on the same day in all sections within each site. The survey dates were used as the repeated measures for the ANOVA.

The following section provides a complete example of the ANOVA tests used for the individual evaluation of SPS-5 sites. Each site in the experiment was evaluated following this sequential approach.

### Example of Repeated Measures of ANOVA for Evaluation of SPS-5 Sites

#### *Site Description and Data Availability*

This site was assigned to LTPP in 1987, marking the initial data collection for the LTPP database. It is located at I-8 eastbound 17 mi (27.37 km) west of the I-10/I-8 interchange in Pinal County, AZ. The subgrade is a silty gravel soil with sand. The base course is a 14-inch (355-mm) soil aggregate mixture. The surface course is 5 inches (127 mm) of HMA. Traffic data are available since 1994, and AADTT for the LTPP lane is approximately 800 trucks. The average growth rate during the period is 8.5 percent. FHWA class 9 trucks account for 80 percent of the total truck traffic.

Data were available for all nine sections of this LTPP site. After being extracted from the LTPP database, performance data were evaluated for completeness and reasonableness. If any outliers were identified, they were removed from the analysis and recorded for reporting. In some instances, there were surveys performed on different days to cover all test sections in one specific date. When this happened, the missing survey was complemented with an interpolation of distresses measured during the previous and next survey dates. The reason for this was the need for equal numbers of surveys required to run ANOVA analysis with repeated measures.

All eight sections were rehabilitated in April 1990 following the selected SPS-5 experimental design. Section 0501 was used as the control section and was left without any rehabilitation. Data collection started after the rehabilitation and continued for 16 years until 2006. Data collection for the control section ended in 1993 probably as a result of the need to rehabilitate this section.

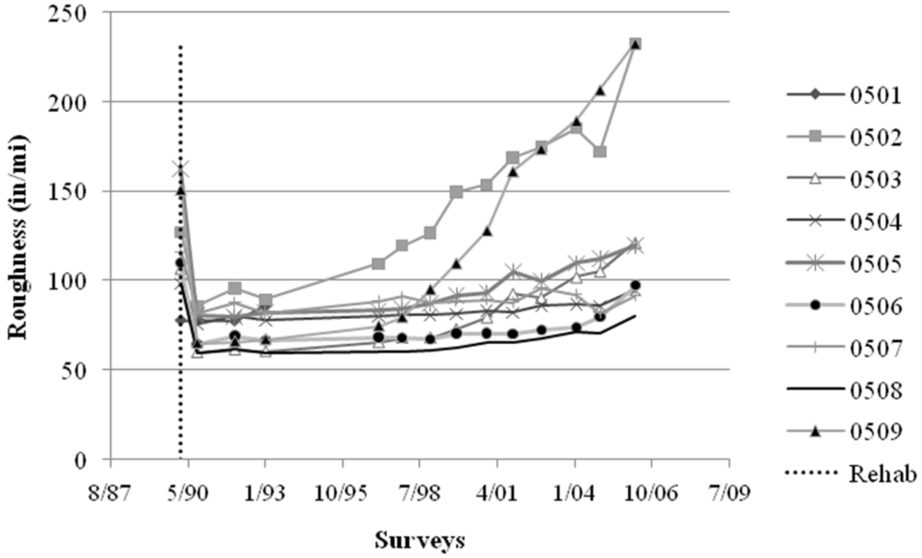
### Analysis Approach

The analysis was performed for each type of distress previously described as well as for the maximum deflection. ANOVA with repeated measures was indicated in this case because the evaluation was carried out through a series of performance measurements taken throughout the duration of the experiment. The number of measurements in each section must be equal, and the experiment factorial must be balanced. The core sections of the SPS-5 experiment were balanced within each one of the three design features (overlay thickness, mix type, and surface preparation) and were independent. Without the control section, the eight remaining core sections provided an equal combination of all options in the design features. Therefore, the control section was not used for the statistical analysis of individual sites.

Repeated measures ANOVA is a technique used to test the equality of means. The null hypothesis has no differences between population means. The *F*-test in ANOVA evaluates the significance of the differences between means. A large *F*-value yields a correspondingly small *p*-value. The *p*-value is the observed significance level, or probability, of a type I error (alpha), which shows that the difference between population means exists when in fact there is no difference. In this study, an acceptable level of significance and probability of a type I error was defined as 0.05. The null hypothesis was rejected if the *p*-value was less than 0.05.

### Analysis of Performance

Roughness was measured by the IRI. Figure 15 presents an example showing IRI values for all sections in the site. The vertical dotted line indicates the year the sections were rehabilitated, as the measured roughness drops from the first to the second measurement. When the data were tested with the repeated measures ANOVA, they were grouped by different design features in the experiment.



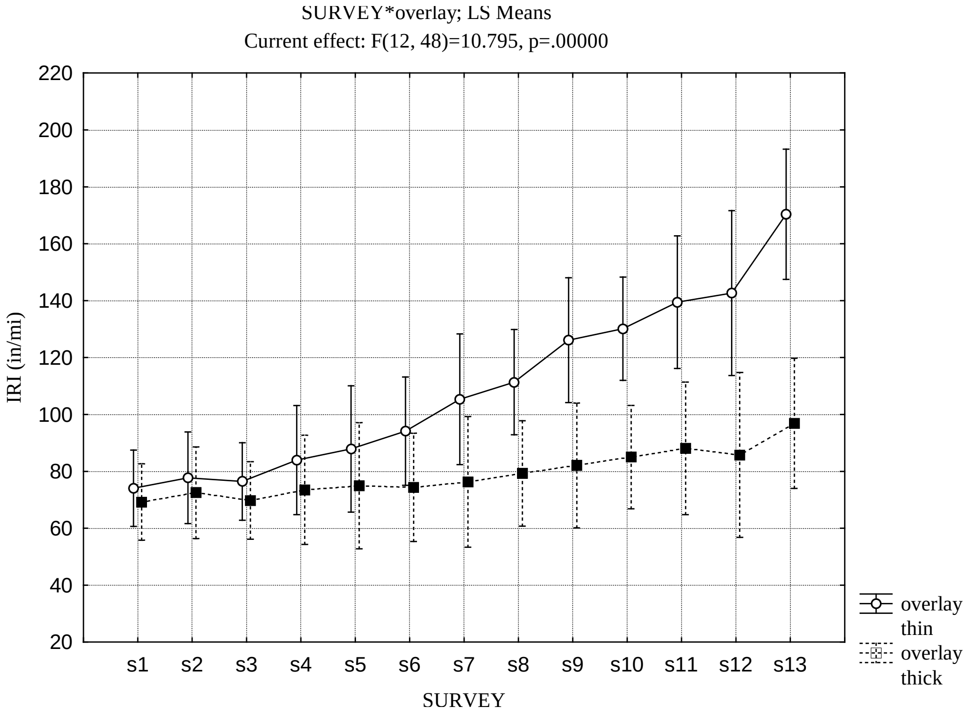
1 inch = 25.4 mm
1 mi = 1.61 km

**Figure 15. Graph. Roughness from an SPS-5 site in Arizona.**

Figure 16 shows IRI over time for both thin and thick overlay sections. The marks are the average IRI for all sections grouped by overlay thickness. The bars represent the range of values with one standard deviation from the average. The *p*-value in the top of the chart is zero and indicates that there is a significant statistical difference in IRI values over time between sections with thin and thick overlays. The plot also indicates that sections with thick overlay performed better than those with thin overlays, as expected.

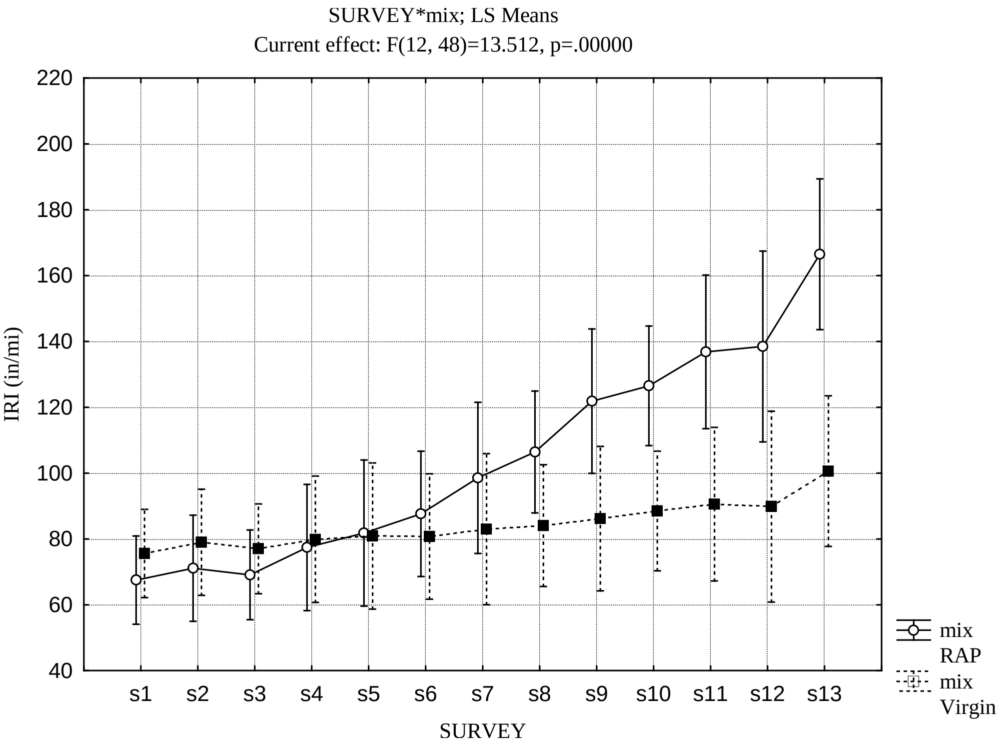
Statistically significant differences were also found when comparing sections overlaid with virgin versus recycled mixtures. Figure 17 shows IRI values over time for both mixture types, and the *p*-value was close to zero. The plot indicates that sections overlaid with virgin mix had better performance than those with recycled asphalt mix. It is interesting to note that soon after rehabilitation, IRI average values were not different between the two types of sections. The great significant difference in performance was more evident later in the pavements' service life.

Surface preparation prior to overlay did not have an impact on roughness performance. Figure 18 shows IRI values over time for sections that were milled versus not milled prior to receiving the overlay. The *p*-value was close to 1.0 and indicated that both distributions were statistically similar.



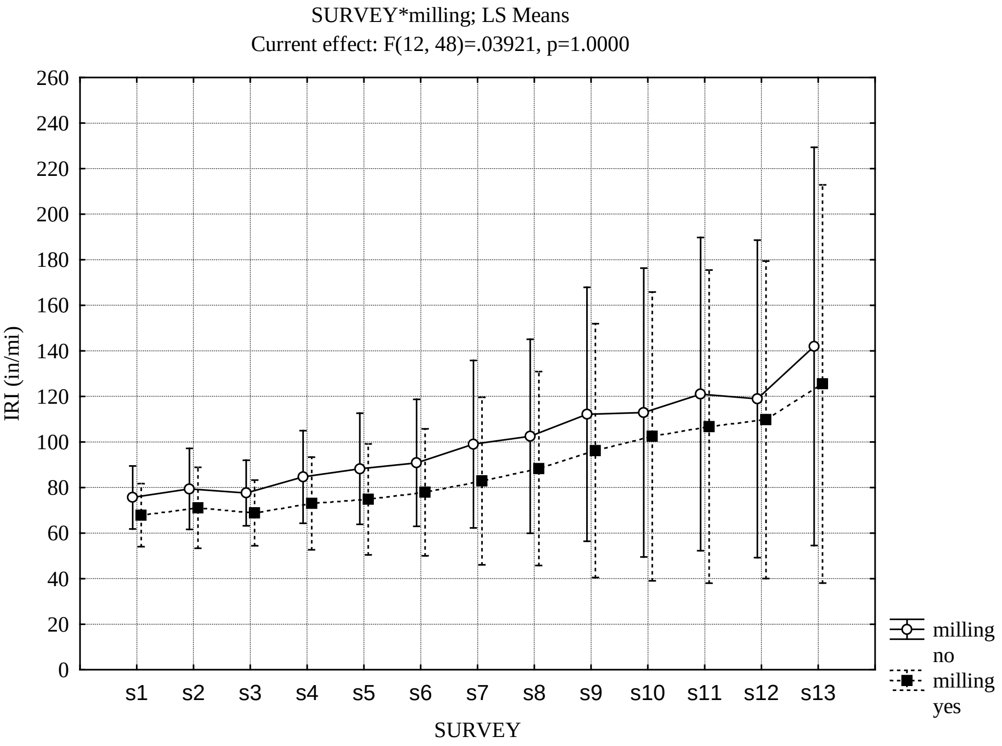
1 inch = 25.4 mm
1 mi = 1.61 km

**Figure 16. Graph. IRI versus overlay thickness (distribution) for an SPS-5 site in Arizona.**



1 inch = 25.4 mm
1 mi = 1.61 km

**Figure 17. Graph. IRI versus mix type (distribution) for an SPS-5 site in Arizona.**



1 inch = 25.4 mm
1 mi = 1.61 km

Figure 18. Graph. IRI versus milling (distribution) for an SPS-5 site in Arizona.

The analysis of pavement performance associated with roughness described previously was repeated for rutting, fatigue, longitudinal cracking, and transverse cracking. The results are summarized in table 34. If a statistically significant difference in performance existed, it is marked with a “Y,” and the corresponding design feature with the best performance was indicated. When no difference was justified statistically, it is marked with an “N” in the table. In this case, a qualitative assessment was made of which design feature provided the best performance. Blank cells indicate that no design feature had predominant performance. For example, the first line (roughness) in table 34 indicates statistical differences in performance when evaluating the effect of overlay thickness. In this case, for both short-term and long-term performances, the performance for thick overlays (5-inch (127-mm)) was found to be better than thin overlays (2-inch (51-mm)).

**Table 34. Summary of statistical analysis results for SPS-5 site in Arizona.**

| | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Best Performance | | | Best Performance | | | Best Performance | |
| Distress | Statistical Difference | Short | Long | Statistical Difference | Short | Long | Statistical Difference | Short | Long |
| Roughness | Y<br>($p = 0$) | Thick | Thick | Y<br>($p = 0$) | | Virgin | N | Mill | Mill |
| Rutting | Y<br>($p = 0.004$) | Thin | Thick | Y<br>($p = 0.0004$) | Virgin | Virgin | N | No mill | |
| Fatigue | N | Thick | Thick | N | | | Y<br>($p = 0.005$) | Mill | Mill |
| Transverse | N | | | N | Virgin | Virgin | N | | |
| Longitudinal | N | | Thin | Y<br>($p = 0.01$) | Virgin | Virgin | N | | |

Note: Blank cells indicate that no design feature had predominant performance.

### Summary of Findings

The repeated measures ANOVA results for this SPS-5 site suggest the following:

- Thick overlays provided smoother pavements after rehabilitation when compared to thin overlays.
- Rehabilitation alternatives with virgin mix overlays were smoother over the long term (5 years or more after rehabilitation) than sections overlaid with recycled asphalt mixes. There was no statistical difference for short-term performance.
- Thin overlays provided better rutting performance for the short term, but thick overlays were statistically better for the long term.
- Virgin mix overlays demonstrated better rutting performance than recycled asphalt mix overlays.
- Milling the existing surface prior to overlay improved fatigue cracking performance when compared to sections that were not milled.
- Neither of the design features investigated had a significant impact on transverse cracking performance.
- Virgin mix overlays provided better longitudinal cracking performance than recycled asphalt mix overlays.

### Conclusions from the Individual Analyses of SPS-5 Sites

The example presented in the previous section illustrates the approach taken to individually evaluate each site in the SPS-5 experiment. The summary tables for each site containing the results of the statistical analysis on performance for roughness, rutting, fatigue cracking, longitudinal cracking, and transverse cracking are presented in appendix A of this report.

The individual analysis of each site provided good qualitative information about the impact of design features on the performance of rehabilitated flexible pavement sections. The differences in performance are best visualized when compiled in plots that explore each design feature investigated in the SPS-5 experiment. These plots and key findings from the individual analyses of SPS-5 sites are presented in this section.

The compilation of results was created by identifying the number of sites in which various design features provided different performance throughout the site's service life. For example, if sections with thick overlays performed better than thin overlaid sections in one site, thick overlay was marked for the site. The process was repeated for all sites and distresses. The plots presented in this section summarize the percentage of sites in which differences in performance were identified. The number of sites with statistically justified differences from the ANOVA repeated measures test was also noted.

Results for roughness are provided in figure 19, suggesting that thick overlays provided the best performance in more than 50 percent of the sites. No differences in short-term performance were found in the majority of sites when comparing the two mix types. When long-term performance was evaluated, virgin mixes were found to perform better than recycled mixes, but no differences were found in 44 percent of sites. Milling improved performance in the majority of sites; however, one-third of sites had no differences in performance between milled and nonmilled sections.

The results in figure 19 were obtained from statistical analysis and engineering judgment when statistically significant differences were not found (*p*-values higher than 0.05) but differences in trends were clearly visible. The choice to consider both statistically-based and engineering judgment-based results was justified by the expansion of data analysis the two approaches provided combined. In the analysis of thickness, five sites (28 percent of all SPS-5 sites) had statistically significant differences in roughness performance. Four sites (22 percent) had statistically significant differences in the analysis of mix type, and three sites (17 percent) had statistically significant differences in the analysis of milling.

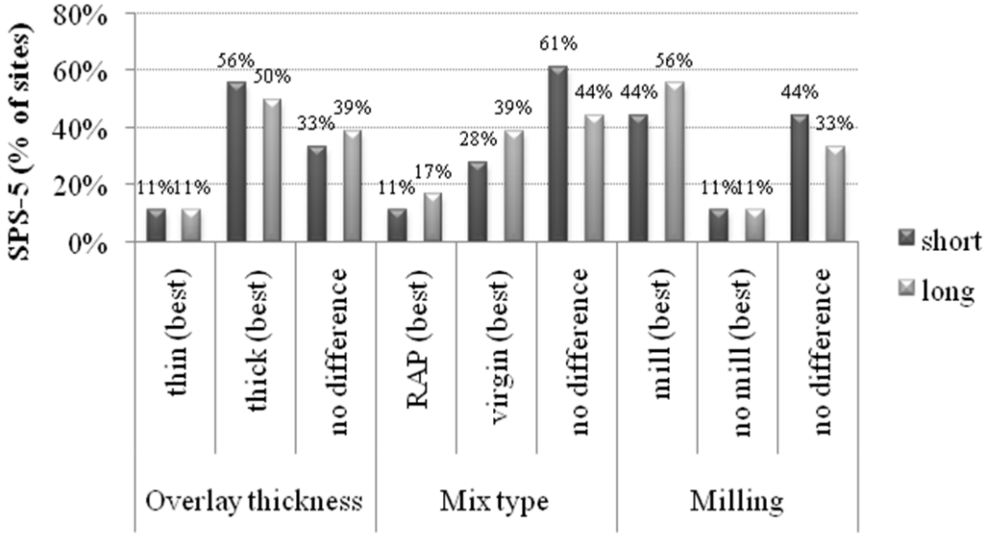


**Figure 19. Graph. Summary of SPS-5 sites by best-performing design feature for roughness according to repeated measures ANOVA results.**

Results for rutting are provided in figure 20, suggesting that the overlay thickness did not impact performance in the majority of sites. Mix type was also a design feature in which the impact on performance was not observed in the majority of sites. It is important to note that when differences were found, they were observed more in favor of sections overlaid with virgin mixes. The results also suggested that milling did not have an impact on rutting performance, and the majority of sites had milled and nonmilled sections performing similarly.

The results in figure 20 were obtained from statistical analysis and engineering judgment. Statistical significant differences were not found (*p*-values greater than 0.05), but differences in trends were clearly visible. In the analysis of thickness, five sites (28 percent of all SPS-5 sites) had statistically significant differences in rutting performance. Four sites (22 percent) had statistically significant differences in the analysis of mix type, and only two sites (12 percent) had statistically significant differences in the analysis of milling.

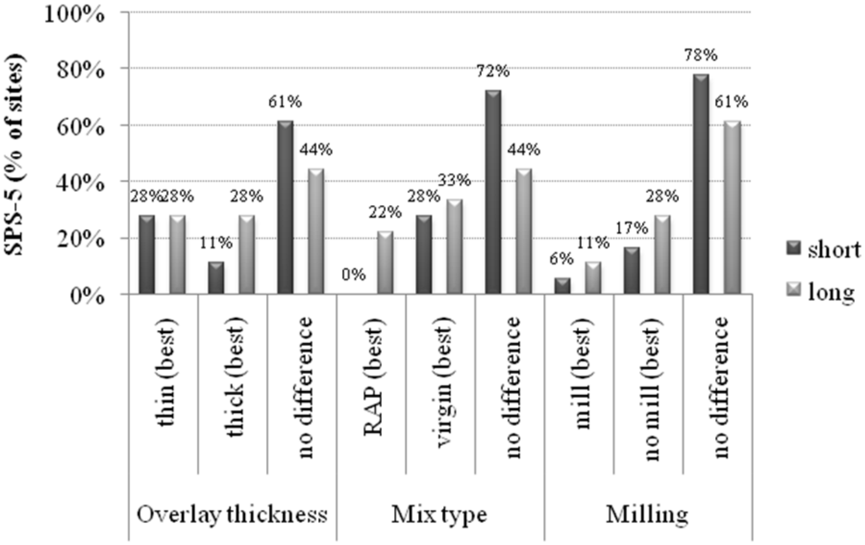


**Figure 20. Graph. Summary of SPS-5 sites by best-performing design feature for rutting according to repeated measures ANOVA results.**

Results for fatigue cracking are summarized in figure 21. None of the design features evaluated had an impact on short-term fatigue cracking performance. Sections with thick overlays had better long-term performances than thin overlays, although there were still 44 percent of sites in which no differences were found. Sections with virgin mix overlay had better long-term performances in half of the sites. Surprisingly, milled and nonmilled sections had equivalent long-term performances in the majority of sites.

The results in figure 21 were obtained from statistical analysis and engineering judgment. Statistically significant differences were not found (*p*-values higher than 0.05), but differences in trends were clearly visible. In the thickness analysis, four sites (22 percent of all SPS-5 sites) had statistically significant differences in fatigue cracking performance. Five sites (28 percent) had statistically significant differences in the analysis of mix type, and two sites (12 percent) had statistically significant differences in the analysis of milling.

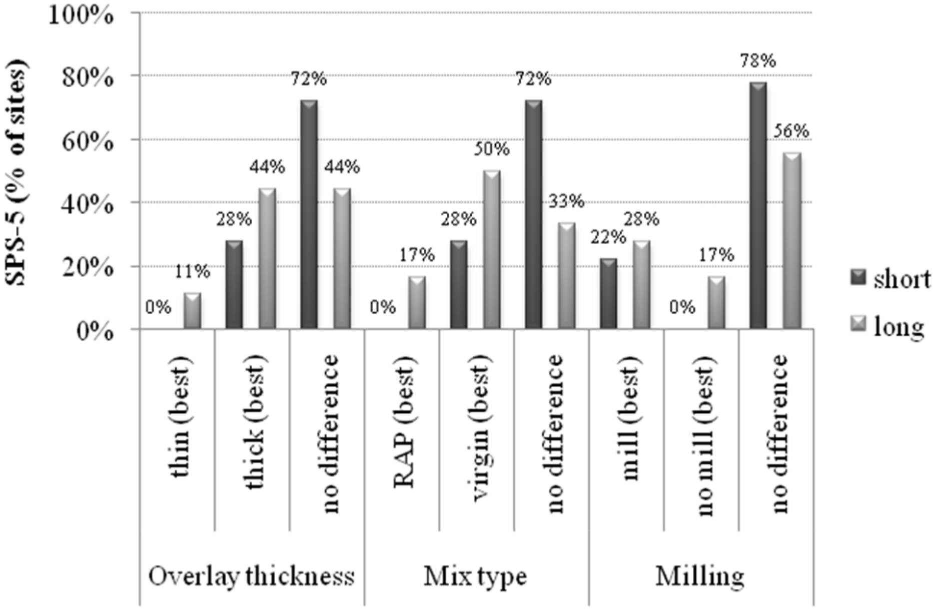


**Figure 21. Graph. Summary of SPS-5 sites by best-performing design feature for fatigue cracking according to repeated measures ANOVA results.**

Results for transverse cracking in figure 22 suggest that none of the design features evaluated in the SPS-5 experiment had any impact on performance in the majority of sites. It is worth noting that thick overlays had better transverse cracking long-term performance in 22 percent of sites, and milling prior to overlay had better transverse cracking long-term performance in 39 percent of sites.

The results in figure 22 were obtained from statistical analysis and engineering judgment. Statistically significant differences were not found (*p*-values greater than 0.05), but differences in trends were visible. In the thickness analysis, five sites (28 percent of all SPS-5 sites) had statistically significant differences in transverse cracking performance. Five sites (28 percent) had statistically significant differences in the analysis of mix type, and three sites (18 percent) had statistically significant differences in the analysis of milling.

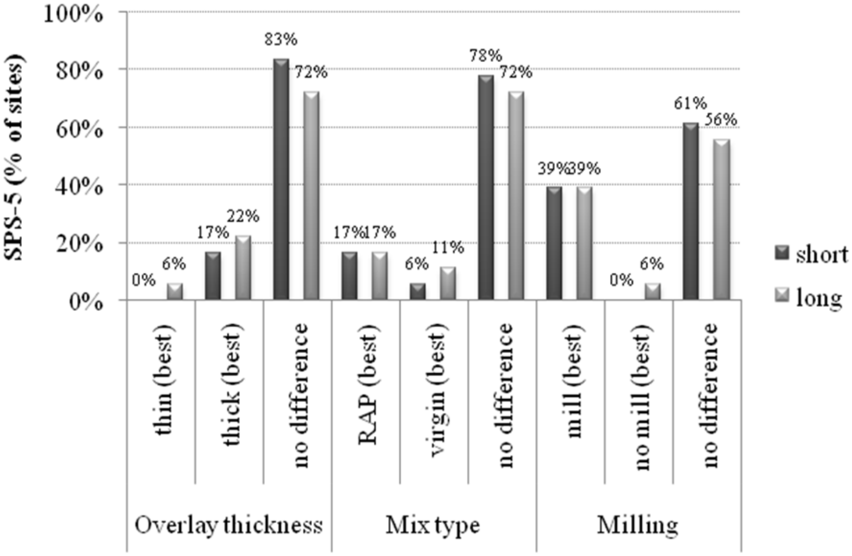


**Figure 22. Graph. Summary of SPS-5 sites by best-performing design feature for transverse cracking according to repeated measures ANOVA results.**

Results for longitudinal cracking are provided in figure 23 and suggest that for the majority of sites, none of the design features evaluated in the SPS-5 experiment had an impact on performance. It is worth noting that thin overlays had better longitudinal cracking long-term performance in 22 percent of sites, and milling prior to overlay had better longitudinal cracking long-term performance in 39 percent of sites.

The results in figure 23 were obtained from statistical analysis and engineering judgment. Statistically significant differences were not found (*p*-values greater than 0.05), but differences in trends were visible. In the thickness analysis, three sites (18 percent of all SPS-5 sites) had statistically significant differences in longitudinal cracking performance. Three sites (18 percent) had statistically significant differences in the mix type analysis, and four sites (22 percent) had statistically significant differences in the milling analysis.

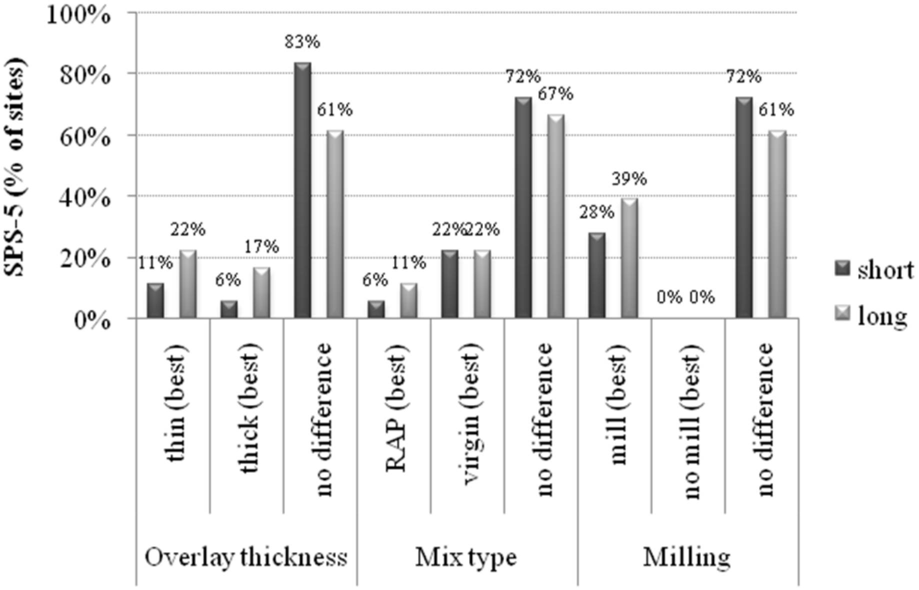


**Figure 23. Graph. Summary of SPS-5 sites by best-performing design feature for longitudinal cracking according to repeated measures ANOVA results.**

The key findings from the assessment of individual sites are listed below.

Roughness results were as follows:

- Thick overlays provided smother pavements in the majority of SPS-5 sites, as expected.
- There were no differences in short-term performance between virgin mix and recycled asphalt overlays for the majority of sites. Although this number dropped when long-term performance was evaluated, it was still higher than the number of sites in which one mix had better performance than the other. When differences were identified, virgin mix overlays performed better in twice as many sites as RAP overlays.
- Milling improved roughness performance, particularly in the long term.

Rutting results were as follows:

- There were no differences in performance between thin and thick overlays.
- Virgin mixes and mixes containing up to 30 percent RAP presented equivalent performance in the majority of sites. When differences were noted, virgin mixes performed better in a slightly higher number of sites.
- Milling did not improve rutting performance.

Fatigue cracking results were as follows:

- There were no differences in short-term performance between thin and thick overlays. However, thick overlays provided better long-term performance.
- Virgin mixes and mixes containing RAP performed equivalently in the majority of sites in the short term. When differences were noted, virgin mixes performed better in half of the SPS-5 sites.
- Milling did not improve fatigue cracking performance, and the number of sites with statistically significant differences was small.

Transverse cracking results were as follows:

- There were no differences in performance between thin and thick overlays in the short term. However, thick overlays provided better long-term performance.
- Virgin mixes and mixes containing RAP performed equivalently in the majority of sites in the short term and long term.
- Milling improved transverse cracking performance; however, in the majority of sites, no differences were noted.

Longitudinal cracking results were as follows:

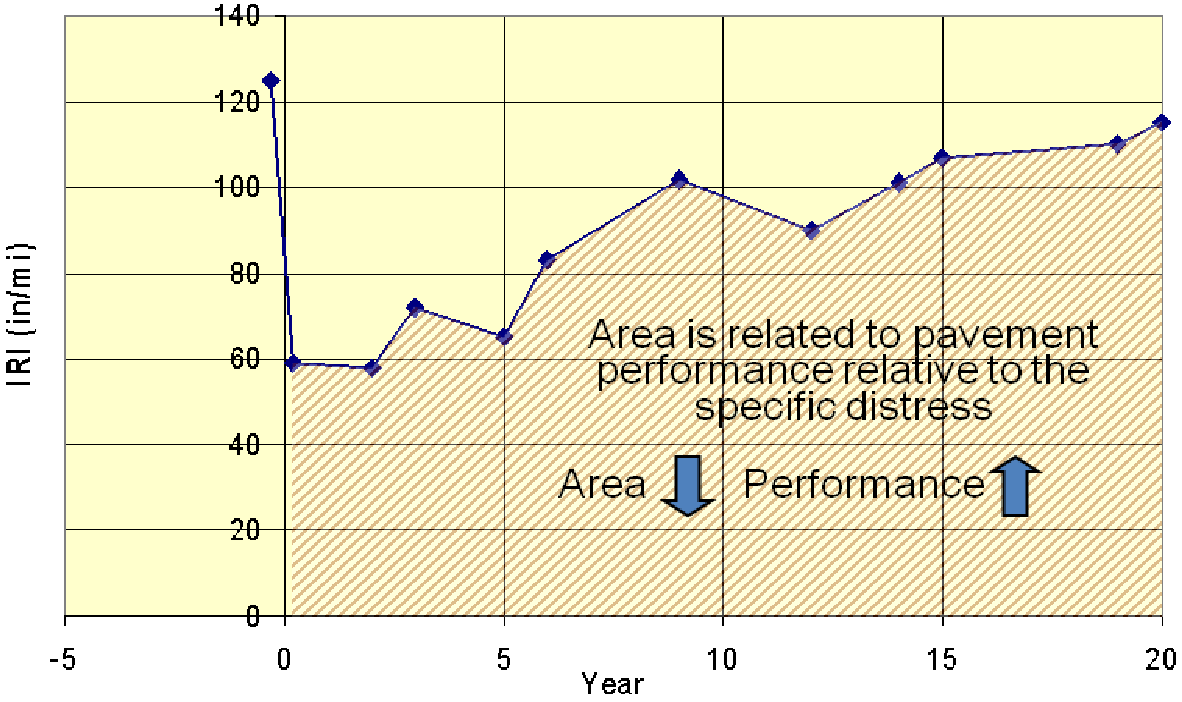
- Performance was not significantly affected by any of the design features.
- The majority of sites had equivalent performance on all three design features (overlay thickness, mix type, and milling).

### Consolidated Analysis

The consolidated analysis involved compiling all sites in the SPS-5 experiment and simultaneously evaluating the impact of design features and site conditions for short-term and long-term performance. WD was the parameter selected for the comparisons, and it allowed the analysis to be carried across different conditions observed in each site of the experiment (more specifically, the different periods of monitoring data).

After the data were processed and verified for quality and existing outliers were corrected after LTPP analysis or removed, WD was computed for short-term and long-term performance. For simplicity, only the values for long-term performance are shown in table 35 through table 39. The remaining results are available in appendix A of this report. The Friedman test used the distress-associated WD to create a ranking of performance from the lowest value of WD (best performance) to the highest value (worst performance) for each site in the dataset. Ranking statistics for each type of section were then used to calculate the Friedman chi-square value used to determine if statistical differences existed among the performance rankings of the sections.

The WD-distress represents the overall performance of the section. It is better understood as an index computed based on the entire performance at a given period, as illustrated in figure 24. Therefore, it is intended for comparative analyses. The higher the WD value, the more distressed the pavement section is compared to sections with lower WD values.



1 inch = 25.4 mm
1 mi = 1.61 km

**Figure 24. Graph. Example of WD-distress values in comparative performance analysis for IRI trend after rehab.**

## Table 35. Long-term average WD-IRI values for SPS-5 sites.

| Section | Experimental Design | | | Sites (State Codes)/Average WD-IRI Values (m/km) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mill** | **Mix** | **Thickness (mm)** | **1** | **4** | **6** | **8** | **12** | **13** | **23** | **24** | **27** | **28** | **29** | **30** | **34** | **35** | **40** | **48** | **81** | **83** |
| 0501 | No | None | | | 80 | 108 | 70 | | | 92 | 97 | 193 | 88 | 130 | | 134 | 39 | 113 | | 127 | 98 |
| 0502 | No | RAP | 51 | 55 | 134 | 130 | 65 | 49 | 40 | 42 | 80 | 90 | 96 | 72 | 74 | 70 | 44 | 86 | 82 | 93 | 104 |
| 0503 | No | RAP | 127 | 53 | 77 | 75 | 50 | 49 | 40 | 54 | 71 | 87 | 114 | 62 | 62 | 45 | 33 | 66 | 76 | 89 | 69 |
| 0504 | No | Virgin | 127 | 57 | 82 | 74 | 56 | 42 | 40 | 56 | 86 | 95 | 87 | 71 | 48 | 51 | 37 | 70 | 93 | 101 | 71 |
| 0505 | No | Virgin | 51 | 58 | 92 | 102 | 55 | 36 | 40 | 45 | 90 | 101 | 110 | 69 | 57 | 57 | 39 | 64 | 95 | 83 | 107 |
| 0506 | Yes | Virgin | 51 | 48 | 71 | 81 | 87 | 32 | 36 | 52 | 59 | 92 | 101 | 69 | 56 | 51 | 37 | 66 | 90 | 72 | 117 |
| 0507 | Yes | Virgin | 127 | 56 | 88 | 73 | 65 | 37 | 39 | 55 | 63 | 72 | 83 | 83 | 61 | 52 | 42 | 62 | 83 | 93 | 59 |
| 0508 | Yes | RAP | 127 | 65 | 64 | 64 | 52 | 46 | 49 | 48 | 53 | 80 | 92 | 62 | 48 | 48 | 35 | 61 | 74 | 78 | 63 |
| 0509 | Yes | RAP | 51 | 55 | 115 | 142 | 62 | 37 | 40 | 60 | 76 | 87 | 108 | 84 | 62 | 49 | 37 | 64 | 78 | 94 | 84 |

1 inch = 25.4 mm
1 ft = 0.305 m
1 mi = 1.61 km
Note: Higher WD values indicate rougher pavement over time. The blank cells indicate data are not available

## Table 36. Long-term average WD-rutting values for SPS-5 sites.

| Section | Experimental Design | | | Sites (State Codes)/Average WD-Rutting Values (mm) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mill** | **Mix** | **Thickness (mm)** | **1** | **4** | **6** | **8** | **12** | **13** | **23** | **24** | **27** | **28** | **29** | **30** | **34** | **35** | **40** | **48** | **81** | **83** |
| 0501 | No | None | | | 0.36 | 0.15 | 0.33 | | | 0.56 | 0.36 | 0.27 | 0.55 | 0.33 | | 0.31 | 0.14 | 0.41 | | 0.36 | 0.36 |
| 0502 | No | RAP | 51 | 0.10 | 0.19 | 0.16 | 0.13 | 0.16 | 0.13 | 0.27 | 0.17 | 0.10 | 0.36 | 0.14 | 0.17 | 0.11 | 0.12 | 0.11 | 0.23 | 0.25 | 0.14 |
| 0503 | No | RAP | 127 | 0.13 | 0.15 | 0.10 | 0.11 | 0.17 | 0.13 | 0.27 | 0.25 | 0.08 | 0.43 | 0.19 | 0.12 | 0.09 | 0.15 | 0.17 | 0.16 | 0.33 | 0.17 |
| 0504 | No | Virgin | 127 | 0.14 | 0.11 | 0.16 | 0.09 | 0.15 | 0.14 | 0.31 | 0.21 | 0.07 | 0.60 | 0.12 | 0.17 | 0.11 | 0.15 | 0.12 | 0.21 | 0.28 | 0.13 |
| 0505 | No | Virgin | 51 | 0.12 | 0.12 | 0.15 | 0.12 | 0.13 | 0.12 | 0.25 | 0.15 | 0.09 | 0.33 | 0.12 | 0.13 | 0.10 | 0.12 | 0.16 | 0.18 | 0.18 | 0.16 |
| 0506 | Yes | Virgin | 51 | 0.09 | 0.11 | 0.12 | 0.14 | 0.11 | 0.12 | 0.35 | 0.12 | 0.09 | 0.36 | 0.12 | 0.20 | 0.13 | 0.15 | 0.15 | 0.25 | 0.25 | 0.18 |
| 0507 | Yes | Virgin | 127 | 0.13 | 0.21 | 0.20 | 0.17 | 0.14 | 0.13 | 0.33 | 0.22 | 0.09 | 0.59 | 0.08 | 0.17 | 0.12 | 0.18 | 0.15 | 0.25 | 0.22 | 0.21 |
| 0508 | Yes | RAP | 127 | 0.21 | 0.14 | 0.11 | 0.13 | 0.16 | 0.12 | 0.32 | 0.19 | 0.08 | 0.56 | 0.17 | 0.11 | 0.10 | 0.16 | 0.11 | 0.18 | 0.23 | 0.22 |
| 0509 | Yes | RAP | 51 | 0.13 | 0.16 | 0.13 | 0.09 | 0.13 | 0.13 | 0.30 | 0.43 | 0.11 | 0.33 | 0.11 | 0.17 | 0.13 | 0.15 | 0.09 | 0.16 | 0.26 | 0.15 |

1 inch = 25.4 mm
Note: Higher WD values indicate the pavement is more rutted over time. The blank cells indicate data are not available.

## Table 37. Long-term average WD-fatigue cracking values for SPS-5 sites.

| Section | Experimental Design | | | Sites (State Codes)/Average WD-Fatigue Cracking Values ($m^2$) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mill | Mix | Thickness (mm) | 1 | 4 | 6 | 8 | 12 | 13 | 23 | 24 | 27 | 28 | 29 | 30 | 34 | 35 | 40 | 48 | 81 | 83 |
| 0501 | No | None | | 2,305 | 692 | | | 13 | 810 | 1 | 51 | 1,927 | | 2,475 | 11 | 0 | | 46 | 377 | 2,305 | 692 |
| 0502 | No | RAP | 51 | 2,566 | 966 | 38 | 0 | 0 | 25 | 0 | 458 | 0 | 1,263 | 463 | 1 | 1 | 3 | 1,480 | 916 | 2,566 | 966 |
| 0503 | No | RAP | 127 | 513 | 137 | 1 | 0 | 0 | 5 | 0 | 46 | 0 | 993 | 151 | 0 | 10 | 8 | 1,052 | 734 | 513 | 137 |
| 0504 | No | Virgin | 127 | 475 | 111 | 0 | 0 | 0 | 96 | 0 | 4 | 2 | 0 | 178 | 2 | 1 | 0 | 384 | 544 | 475 | 111 |
| 0505 | No | Virgin | 51 | 1,467 | 674 | 1 | 0 | 0 | 183 | 0 | 94 | 0 | 16 | 165 | 1 | 4 | 0 | 700 | 681 | 1,467 | 674 |
| 0506 | Yes | Virgin | 51 | 474 | 1,261 | 0 | 0 | 0 | 9 | 0 | 198 | 3 | 1 | 7 | 6 | 1 | 0 | 765 | 822 | 474 | 1261 |
| 0507 | Yes | Virgin | 127 | 528 | 840 | 0 | 1 | 0 | 0 | 0 | 0 | 108 | 0 | 45 | 4 | 1 | 5 | 273 | 489 | 528 | 840 |
| 0508 | Yes | RAP | 127 | 85 | 180 | 0 | 0 | 0 | 84 | 0 | 258 | 0 | 725 | 47 | 0 | 1 | 8 | 399 | 498 | 85 | 180 |
| 0509 | Yes | RAP | 51 | 2,204 | 16 | 0 | 1 | 0 | 0 | 0 | 705 | 2 | 1,511 | 650 | 2 | 0 | 29 | 1,272 | 1068 | 2,204 | 16 |

1 ft = 0.305 m

1 inch = 25.4 mm

Note: Higher WD values indicate increased cracking in the pavement over time. The blank cells indicate data are not available.

## Table 38. Long-term average WD-transverse cracking values for SPS-5 sites.

| Section | Experimental Design | | | Sites (State Codes)/Average WD-Transverse Cracking Values (m) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mill | Mix | Thickness (mm) | 1 | 4 | 6 | 8 | 12 | 13 | 23 | 24 | 27 | 28 | 29 | 30 | 34 | 35 | 40 | 48 | 81 | 83 |
| 0501 | No | None | | | 0 | 154 | 63 | | | 38 | 140 | 245 | 201 | 32 | | 270 | 33 | 91 | | 30 | 32 |
| 0502 | No | RAP | 51 | 110 | 87 | 153 | 69 | 5 | 0 | 0 | 134 | 262 | 96 | 0 | 26 | 199 | 47 | 62 | 220 | 96 | 188 |
| 0503 | No | RAP | 127 | 4 | 339 | 194 | 11 | 0 | 0 | 0 | 54 | 196 | 136 | 0 | 14 | 69 | 44 | 24 | 98 | 88 | 151 |
| 0504 | No | Virgin | 127 | 0 | 40 | 83 | 43 | 0 | 0 | 0 | 32 | 200 | 3 | 0 | 35 | 50 | 3 | 5 | 4 | 61 | 250 |
| 0505 | No | Virgin | 51 | 54 | 216 | 197 | 64 | 8 | 0 | 0 | 152 | 327 | 50 | 0 | 57 | 155 | 56 | 52 | 186 | 288 | 81 |
| 0506 | Yes | Virgin | 51 | 1 | 50 | 152 | 90 | 2 | 0 | 0 | 129 | 294 | 65 | 1 | 51 | 9 | 2 | 33 | 4 | 130 | 39 |
| 0507 | Yes | Virgin | 127 | 1 | 2 | 100 | 10 | 0 | 0 | 0 | 4 | 149 | 1 | 4 | 10 | 11 | 0 | 0 | 2 | 143 | 208 |
| 0508 | Yes | RAP | 127 | 1 | 207 | 257 | 9 | 0 | 0 | 0 | 59 | 217 | 80 | 0 | 10 | 51 | 2 | 0 | 73 | 54 | 225 |
| 0509 | Yes | RAP | 51 | 13 | 339 | 209 | 40 | 0 | 0 | 0 | 5 | 230 | 32 | 1 | 0 | 47 | 9 | 30 | 155 | 19 | 110 |

1 ft = 0.305 m

1 inch = 25.4 mm

Note: Higher WD values indicate increased cracking in the pavement over time. The blank cells indicate data are not available.

## Table 39. Long-term average WD-longitudinal cracking values for SPS-5 sites.

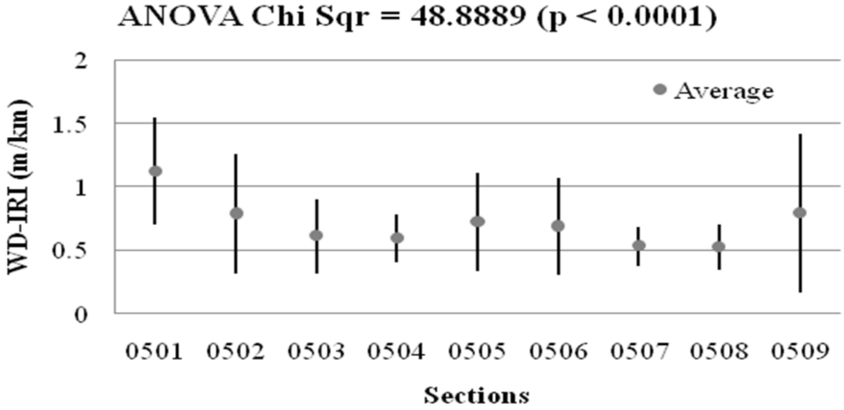
| Section | Experimental Design | | | Sites (State Codes)/Average WD-Longitudinal Cracking Values (m) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mill** | **Mix** | **Thickness (mm)** | **1** | **4** | **6** | **8** | **12** | **13** | **23** | **24** | **27** | **28** | **29** | **30** | **34** | **35** | **40** | **48** | **81** | **83** |
| 0501 | No | None | | | 0 | 364 | 842 | | | 1,039 | 939 | 894 | 239 | 563 | | 670 | 380 | 53 | | 170 | 250 |
| 0502 | No | RAP | 51 | 95 | 47 | 268 | 722 | 2 | 304 | 277 | 795 | 843 | 209 | 52 | 377 | 862 | 405 | 252 | 797 | 575 | 741 |
| 0503 | No | RAP | 127 | 143 | 337 | 430 | 552 | 2 | 209 | 292 | 624 | 549 | 101 | 96 | 186 | 949 | 508 | 113 | 646 | 579 | 848 |
| 0504 | No | Virgin | 127 | 86 | 26 | 362 | 715 | 9 | 132 | 302 | 429 | 677 | 52 | 33 | 176 | 827 | 103 | 83 | 80 | 704 | 669 |
| 0505 | No | Virgin | 51 | 92 | 130 | 342 | 996 | 27 | 293 | 277 | 486 | 894 | 47 | 465 | 270 | 585 | 268 | 28 | 797 | 319 | 932 |
| 0506 | Yes | Virgin | 51 | 0 | 78 | 485 | 673 | 0 | 144 | 214 | 627 | 737 | 52 | 88 | 205 | 599 | 158 | 36 | 337 | 84 | 574 |
| 0507 | Yes | Virgin | 127 | 19 | 3 | 459 | 410 | 0 | 129 | 277 | 651 | 649 | 17 | 74 | 89 | 753 | 60 | 65 | 19 | 456 | 578 |
| 0508 | Yes | RAP | 127 | 69 | 285 | 497 | 152 | 73 | 135 | 218 | 745 | 369 | 170 | 116 | 266 | 926 | 559 | 0 | 631 | 578 | 921 |
| 0509 | Yes | RAP | 51 | 100 | 329 | 492 | 152 | 8 | 206 | 138 | 99 | 572 | 146 | 54 | 322 | 826 | 411 | 48 | 639 | 544 | 392 |

1 ft = 0.305 m

1 inch = 25.4 mm

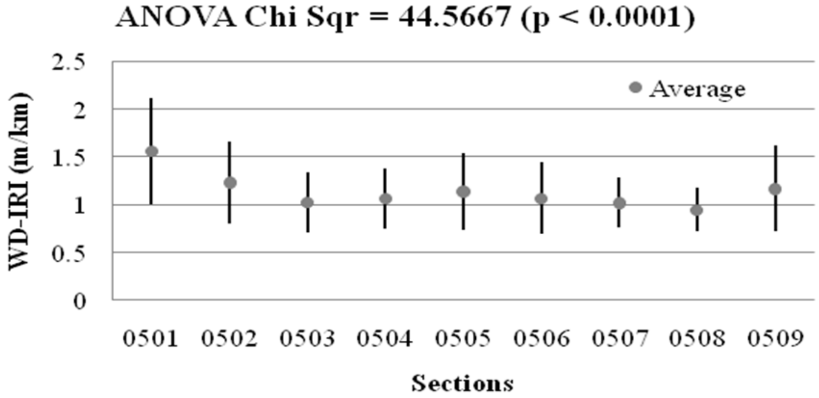
Note: Higher WD values indicate increased cracking in the pavement over time. The blank cells indicate data are not available.

As noted earlier, the Friedman null hypothesis states that there are no differences between the ranking of sections (i.e., all sections have similar performances). The null hypothesis is rejected if the *p*-value is lower than 0.05, which represents a 95 percent confidence level that at least two sections have statistically different rankings. Examples of Friedman test outputs are provided in figure 25 and figure 26. In the figures, the average WD value for IRI found for each rehabilitation strategy among all sites was analyzed. The vertical bars represent the interval between the mean value ±1 standard deviation as an illustration of the variability of the measurements. The results in figure 25 indicate that for short-term roughness performance, there were at least two sections with statistically different performance ($p < 0.0001$, ANOVA chi-square = 48.8889). A similar result was found for long-term performance, as shown in figure 26 ($p < 0.0001$, ANOVA chi-square = 44.5667).



1 ft = 0.305 m
1 mi = 1.61 km

Figure 25. Graph. WD-IRI short-term values in SPS-5 sites.



1 ft = 0.305 m
1 mi = 1.61 km

Figure 26. Graph. WD-IRI long-term values in SPS-5 sites.

When the result of the Friedman test indicated the existence of at least two strategies with statistically different rankings, the next step was to identify which sections were different and to build the rankings of best-performing strategies based on the statistical analysis. Table 40 and table 41 provide the *p*-values for each Friedman test paired analysis for short-term and long-term roughness performance rankings.

**Table 40. Friedman test paired analysis of rehabilitation strategies for short-term roughness performance ranking for SPS-5 sites.**

| Paired Analysis | *p*-Value |
|---|---:|
| 0501 and 0502 | — |
| 0501 and 0503 | < 0.05 |
| 0501 and 0504 | < 0.05 |
| 0501 and 0505 | — |
| 0501 and 0506 | < 0.05 |
| 0501 and 0507 | < 0.05 |
| 0501 and 0508 | < 0.05 |
| 0501 and 0509 | < 0.05 |
| 0502 and 0503 | — |
| 0502 and 0504 | — |
| 0502 and 0505 | — |
| 0502 and 0506 | — |
| 0502 and 0507 | < 0.05 |
| 0502 and 0508 | < 0.05 |
| 0502 and 0509 | — |
| 0503 and 0504 | — |
| 0503 and 0505 | — |
| 0503 and 0506 | — |
| 0503 and 0507 | — |
| 0503 and 0508 | — |
| 0503 and 0509 | — |
| 0504 and 0505 | — |
| 0504 and 0506 | — |
| 0504 and 0507 | — |
| 0504 and 0508 | — |
| 0504 and 0509 | — |
| 0505 and 0506 | — |
| 0505 and 0507 | — |
| 0505 and 0508 | < 0.05 |
| 0505 and 0509 | — |
| 0506 and 0507 | — |
| 0506 and 0508 | — |
| 0506 and 0509 | — |
| 0507 and 0508 | — |
| 0507 and 0509 | — |
| 0508 and 0509 | — |

— Indicates pair analysis with no statistical significance.

**Table 41. Friedman test paired analysis of rehabilitation strategies for long-term roughness performance ranking for SPS-5 sites.**

| Paired Analysis | *p*-Value |
|---|---:|
| 0501 and 0502 | — |
| 0501 and 0503 | < 0.05 |
| 0501 and 0504 | — |
| 0501 and 0505 | — |
| 0501 and 0506 | < 0.05 |
| 0501 and 0507 | < 0.05 |
| 0501 and 0508 | < 0.05 |
| 0501 and 0509 | — |
| 0502 and 0503 | — |
| 0502 and 0504 | — |
| 0502 and 0505 | — |
| 0502 and 0506 | — |
| 0502 and 0507 | — |
| 0502 and 0508 | < 0.05 |
| 0502 and 0509 | — |
| 0503 and 0504 | — |
| 0503 and 0505 | — |
| 0503 and 0506 | — |
| 0503 and 0507 | — |
| 0503 and 0508 | — |
| 0503 and 0509 | — |
| 0504 and 0505 | — |
| 0504 and 0506 | — |
| 0504 and 0507 | — |
| 0504 and 0508 | — |
| 0504 and 0509 | — |
| 0505 and 0506 | — |
| 0505 and 0507 | — |
| 0505 and 0508 | — |
| 0505 and 0509 | — |
| 0506 and 0507 | — |
| 0506 and 0508 | — |
| 0506 and 0509 | — |
| 0507 and 0508 | — |
| 0507 and 0509 | — |
| 0508 and 0509 | — |

— Indicates pair analysis with no statistical significance.

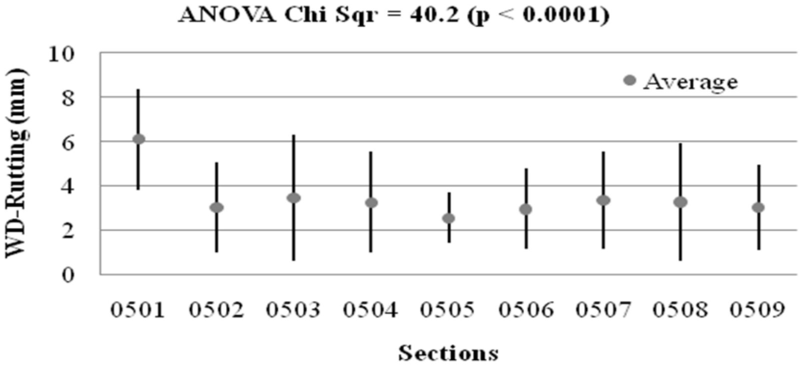
The paired analysis results were used to create a practical ranking of roughness performance based on the statistical differences that were identified. The tables were intended to help users select the best alternatives given the specific conditions that they may want to evaluate. Based on the results presented in table 40 and table 41, the final ranking for evaluating roughness performance was created for the short term and long term (see table 42). Sections were ordered from best to worst performance, and sections with equivalent performance were grouped under the same rank.

**Table 42. Ranking of rehabilitation strategies for roughness, SPS-5 sites.**

| **Statistical Relevance (Y/N)** | **Roughness** | | | |
|---|---|---|---|---|
| | **Short-Term** | | **Long-Term** | |
| | Y | ($p < 0.0001$) | Y | ($p < 0.0001$) |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| | 1 | Mill, thick, RAP | 1 | Mill, thick, RAP |
| | 2 | Mill, thick, virgin | 2 | No mill, thick, RAP |
| | 3 | No mill, thick, RAP | 2 | Mill, thin, virgin |
| | 3 | No mill, thick, virgin | 2 | Mill, thick, virgin |
| | 3 | Mill, thin, virgin | 5 | No mill, thick, virgin |
| | 3 | Mill, thin, RAP | 5 | Mill, thin, RAP |
| | 3 | No mill, thin, virgin | 5 | No mill, thin, virgin |
| | 8 | No mill, thin, RAP | 8 | No mill, thin, RAP |
| | 9 | Control | 9 | Control |

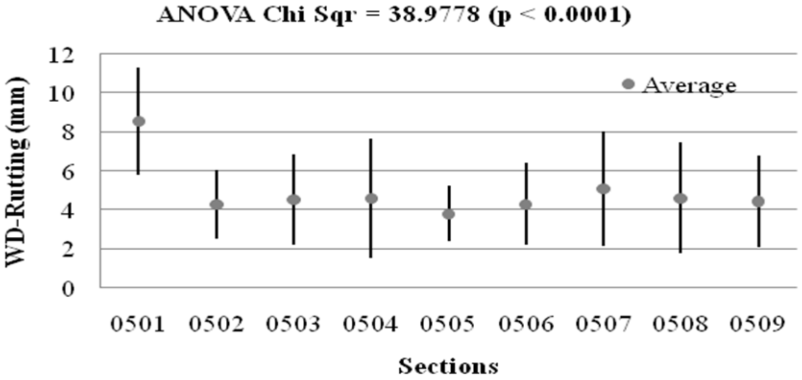
The results in table 42 suggest that rehabilitations with milling and thick recycled overlays provided smoother pavements in both the short-term and long-term performance. Strategies with milling and virgin thick overlay were the second best for short-term performance. For long-term roughness performance, three strategies had equivalent second best performances. A broader analysis of both rankings suggests that thick overlays provided better performance over the short term and long term. Overall, differences between performance of recycled asphalt and virgin overlays were difficult to identify, suggesting that roughness performance was not significantly affected by the overlay mix type. Both rankings also suggested that strategies with milling were more likely to provide better short-term and long-term roughness performance. These results agree with the conclusions drawn from the analysis of individual sites.

The same approach described for the analysis of roughness was applied to all distresses (rutting, fatigue, transverse, and longitudinal cracking). Figure 27 and figure 28 describe the Friedman test for rutting. Based on the same test statistics, the ranking of best-performing rehabilitation strategies for rutting was created (see table 43). The results suggest that thin overlays performed better at early stages for short-term performance (see figure 27, $p < 0.0001$, ANOVA chi-square = 40.2), while no significant differences were identified for long-term performance (see figure 28, $p < 0.0001$, ANOVA chi-square = 38.9778). The top rankings also were equally distributed among sections overlaid with virgin and RAP mixes and among sections previously milled and not milled. These findings agree with the observations from the analysis of individual sites.



1 inch = 25.4 mm

Figure 27. Graph. WD-rutting short-term values for SPS-5 sites.



1 inch = 25.4 mm

Figure 28. Graph. WD-rutting long-term values for SPS-5 sites.

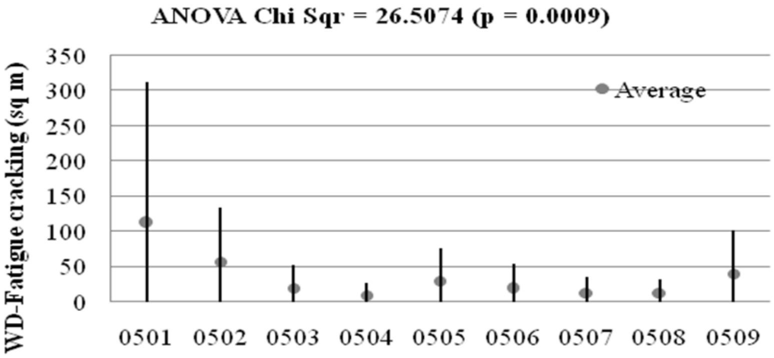
**Table 43. Ranking of rehabilitation strategies for rutting for SPS-5 sites.**

| **Statistical Relevance (Y/N)** | **Rutting** | | | |
|---|---|---|---|---|
| | **Short-Term** | | **Long-Term** | |
| | Y | ($p < 0.0001$) | Y | ($p < 0.0001$) |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| | 1 | No mill, thin, virgin | 1 | No mill, thin, virgin |
| | 1 | No mill, thin, RAP | 1 | Mill, thick, RAP |
| | 1 | Mill, thin, RAP | 1 | No mill, thin, RAP |
| | 1 | Mill, thick, RAP | 1 | Mill, thin, virgin |
| | 1 | Mill, thin, virgin | 1 | No mill, thick, RAP |
| | 1 | No mill, thick, RAP | 1 | Mill, thin, RAP |
| | 1 | No mill, thick, virgin | 1 | No mill, thick, virgin |
| | 8 | Mill, thick, virgin | 8 | Mill, thick, virgin |
| | 9 | Control | 9 | Control |

Design features were found to have an impact on only long-term performance associated with fatigue, longitudinal, and transverse cracking. Figure 29 through figure 31 present descriptive statistics for performance rankings among all sites. Based on the Friedman test, the ranking of best-performing rehabilitation strategies for cracking was created (see table 44 through table 46). Figure 29 ($p = 0.0009$, ANOVA chi-square = 26.5074) and table 44 suggest that thick overlays performed better in the long term for fatigue cracking. As expected, it was evident from the figure that the no treatment control alternative performed the poorest in regards to fatigue cracking. The ranking of alternatives was more equally distributed when comparing mix types; however, out of the top three alternatives, two were virgin mix overlays. Overall, mix type had limited influence on long-term fatigue cracking performance. The results also suggested that milling prior to overlay improved performance. Two of the top three alternatives included milling prior to the overlay.

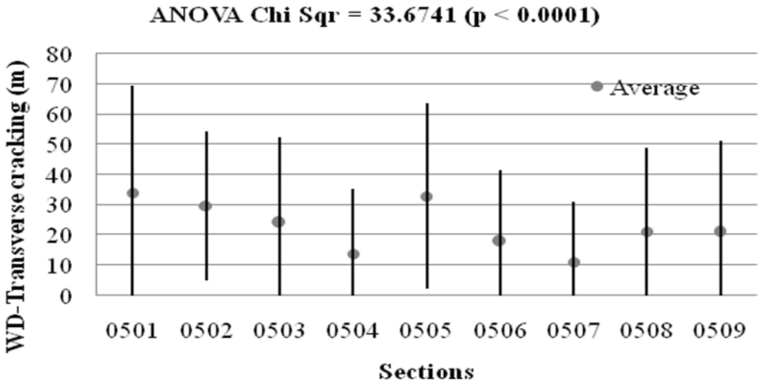
The results described in figure 30 ($p < 0.0001$, ANOVA chi-square = 33.6741) and table 45 suggested that thick overlays were better to mitigate transverse cracking. The two best-ranked sections had virgin mix overlays, but overall the performances of virgin and RAP mix overlays were similar. Sections that were milled prior to overlay consistently performed better than nonmilled ones.

The results for longitudinal cracking in figure 31 ($p = 0.0011$, ANOVA chi-square = 25.8407) and table 46 suggested that none of the design features had a significant influence on performance. Although the best alternative was milling and overlaying with a thick virgin mix, the remaining alternatives that ranked second consisted of different combinations of design features with no clear trend to which one provided better performance associated with longitudinal cracking.



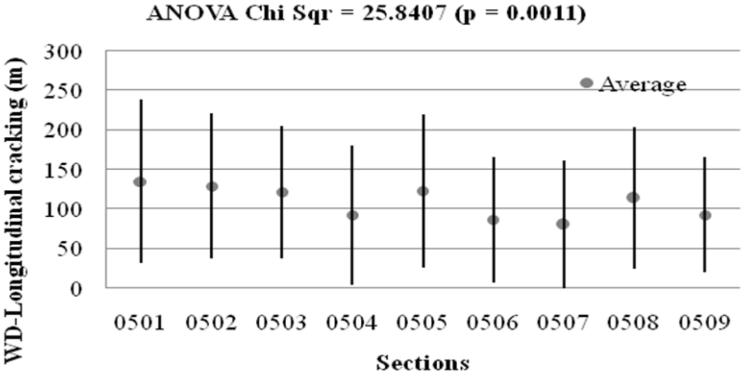
1 ft$^2$ = 0.093 m$^2$

**Figure 29. Graph. Fatigue cracking WD values for long-term performance of SPS-5 sites.**



1 ft = 0.305 m

**Figure 30. Graph. Transverse cracking WD values for long-term performance of SPS-5 sites.**



1 ft = 0.305 m

**Figure 31. Graph. Longitudinal cracking WD values for long-term performance of SPS-5 sites.**

**Table 44. Ranking of rehabilitation strategies for fatigue cracking at SPS-5 sites.**

| Statistical Relevance (Y/N) | Long-Term | |
|---|---|---|
| | Y | $p = 0.0009$ |
| Ranking (if relevant) | **Ranking** | **Strategy** |
| | 1 | No mill, thick, virgin |
| | 1 | Mill, thick, RAP |
| | 1 | Mill, thick, virgin |
| | 4 | Mill, thin, virgin |
| | 4 | No mill, thick, RAP |
| | 4 | No mill, thin, virgin |
| | 4 | Mill, thin, RAP |
| | 4 | No mill, thin, RAP |
| | 9 | Control |

**Table 45. Ranking of rehabilitation strategies for transverse cracking at SPS-5 sites.**

| Statistical Relevance (Y/N) | Long-Term | |
|---|---|---|
| | Y | $p < 0.0001$ |
| Ranking (if relevant) | **Ranking** | **Strategy** |
| | 1 | Mill, thick, virgin |
| | 2 | No mill, thick, virgin |
| | 3 | Mill, thick, RAP |
| | 3 | Mill, thin, RAP |
| | 3 | Mill, thin, virgin |
| | 3 | No mill, thick, RAP |
| | 7 | No mill, thin, RAP |
| | 8 | No mill, thin, virgin |
| | 8 | Control |

**Table 46. Ranking of rehabilitation strategies for longitudinal cracking at SPS-5 sites.**

| Statistical Relevance (Y/N) | Long-Term | |
|---|---|---|
| | Y | $p = 0.0011$ |
| Ranking (if relevant) | **Ranking** | **Strategy** |
| | 1 | Mill, thick, virgin |
| | 2 | Mill, thin, virgin |
| | 2 | No mill, thick, virgin |
| | 2 | Mill, thin, RAP |
| | 2 | No mill, thin, virgin |
| | 2 | Mill, thick, RAP |
| | 7 | No mill, thick, RAP |
| | 7 | Control |
| | 7 | No mill, thin, RAP |

The results obtained in the consolidated analysis agreed for the most part with the results found in the individual site analysis. Overlay thickness was the most influential design feature. Thick overlays consistently performed better, as expected. The impact of thickness on performance was more evident in the long term (more than 5 years) rather than the short term for most of the distresses used as performance measures. The exception was rutting, for which no evidence was found suggesting that either thin or thick overlays provided less rutted pavements.

The majority of sites did not show significant differences in performance between sections overlaid with virgin and RAP mixes. However, when differences existed, they were mostly in favor of virgin mixes.

The analysis of milling prior to overlay suggested that replacing the distressed portion of the surface layer improved the performance for the majority of distresses commonly observed in flexible pavements.

### Influence of Site Condition

The influence of site condition was determined by three variables: (1) pavement surface condition prior to rehabilitation, (2) climate, and (3) traffic levels. These three conditions were determined for each site, and the Friedman test was repeated by grouping the sites according to each of the following variables:

- **Pavement condition**: Fair versus poor.
- **Climate condition**: Wet versus dry and freeze versus no-freeze.
- **Traffic**: Low versus high.

The designation of fair versus poor was assigned by the owner agency nominating the SPS-5 project. These ratings were purely subjective and not based on the actual level of existing distresses prior to rehabilitation. They were used only to ensure a range of surface conditions of the original pavement before rehabilitation. However, the assessment of distresses prior to overlay indicated that, on average, fair pavements had IRI values of 9.50 ft/mi (1.8 m/km) with 0.39 inches (10 mm) or less of rutting and up to 1,237.86 $ft^2$ (115 $m^2$) of fatigue cracking per section. Poor pavements had roughness of 8.71 ft/mi (1.65 m/km) with 0.59 inches (15 mm) of rutting and up to 1,937.52 $ft^2$ (180 $m^2$) of fatigue cracking per section.

Climate condition was defined based on the freeze index and average rainfall for each site. Sites with an average annual rainfall greater than 39 inches (1,000 mm) were classified as wet, and sites with less than 39 inches (1,000 mm) of rain were classified as dry. Similarly, sites with a freeze index greater than 140 °F (60 °C) were classified as a freezing climate, and sites with less than 140 °F (60 °C) were designated as a no-freeze climate. These classifications are part of the LTPP experiment definition.

The classification of traffic was defined based on volume and commercial vehicle distribution. These characteristics were simple to evaluate and, at the same time, most influential on pavement performance predictions estimated with MEPDG. The combination of criteria generated two groups of sites: low traffic and high traffic. Table 47 describes the characteristics of both groups used in this study. Georgia and Texas did not have any traffic information.

**Table 47. Criteria for evaluating traffic characteristics of SPS-5 sites.**

| Traffic Characteristics | Low Traffic | High Traffic |
|---|---|---|
| AADTT | 340–950 | 750–2,750 |
| Vehicle class 5 (percent in volume) | 25–75 | 5–20 |
| Vehicle class 9 (percent in volume) | 10–50 | 40–85 |
| SPS-5 sites | Alabama, Florida, Maine, Maryland, Minnesota, Missouri, and Oklahoma | Arizona, California, Colorado, Mississippi, Montana, New Jersey, New Mexico, Alberta, and Manitoba |

The analysis followed the same steps presented in the previous section. Rankings of rehabilitation strategies were developed for each group of sites using descriptive statistics and the paired analyses from the Friedman test when statistical differences in performance were found. The results are summarized in the tables presented in appendix C.

Table 48 and table 49 provide examples of how the data were summarized. These tables show the ranking of best-performing sections based on long-term performance for roughness and rutting in sections with fair and poor surface conditions prior to rehabilitation.

The examples illustrate the impact of site conditions on performance of rehabilitated flexible pavements. They suggest that rehabilitation strategies with milling and virgin mix overlays were better to improve roughness performance in pavements with poor surface condition. If surface condition was fair, RAP mixes provided a slight advantage in terms of roughness performance.

According to the ranking for rutting performance, rehabilitation strategies with milling and thin overlays with virgin mixes were the best alternatives when pavements had poor surface condition before the overlay. When surface conditions were fair, the impact of design features was not as significant. In fact, rehabilitation strategies with milling prior to overlay were among the worst ranked for rutting performance.

**Table 48. Summary of rankings for long-term roughness and rutting performance of SPS-5 sites in fair surface condition prior to overlay.**

| Statistical Relevance (Y/N) | Distress | | | |
|---|---|---|---|---|
| | Roughness | | Rutting | |
| | Y | $p = 0.0001$ | Y | $p = 0.0044$ |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| | 1 (Best) | Mill, thick, RAP | 1 (Best) | Mill, thick, RAP |
| | 2 | No mill, thick, RAP | 1 | No mill, thin, virgin |
| | 2 | Mill, thin, virgin | 1 | No mill, thick, RAP |
| | 2 | Mill, thin, RAP | 4 | No mill, thick, virgin |
| | 5 | Mill, thick, virgin | 4 | No mill, thin, RAP |
| | 5 | No mill, thick, virgin | 4 | Mill, thin, RAP |
| | 5 | No mill, thin, virgin | 4 | Mill, thin, virgin |
| | 8 | No mill, thin, RAP | 4 | Mill, thick, virgin |
| | 9 (Worst) | Control | 9 (Worst) | Control |

**Table 49. Summary of rankings for long-term roughness and rutting performance of SPS-5 sites in poor surface condition prior to overlay.**

| Statistical Relevance (Y/N) | Distress | | | |
|---|---|---|---|---|
| | Roughness | | Rutting | |
| | Y | $p = 0.019$ | Y | $p = 0.0015$ |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| | 1 | Mill, thick, RAP | 1 | No mill, thin, virgin |
| | 2 | Mill, thin, virgin | 1 | Mill, thin, virgin |
| | 2 | Mill, thick, virgin | 3 | Mill, thin, RAP |
| | 2 | No mill, thick, RAP | 3 | No mill, thin, RAP |
| | 2 | No mill, thick, virgin | 3 | No mill, thick, virgin |
| | 2 | No mill, thin, virgin | 3 | No mill, thick, RAP |
| | 2 | No mill, thin, RAP | 3 | Mill, thick, RAP |
| | 2 | Mill, thin, RAP | 3 | Mill, thick, virgin |
| | 9 | None | 9 | None |

A detailed assessment of the combined results for each of the analyses performed was assembled in tables for better visualization and interpretation of results. These tables were created for each distress and performance period (short-term and long-term performance) with the exception of fatigue and longitudinal cracking, which only presented statistically significant differences for long-term performance data . Table 50 and table 51 present the results for short-term and long-term roughness performance.

Table 52 and table 53 summarize the results for rutting. Table 54 shows the results for long-term fatigue cracking, and table 55 and table 56 present the results for short-term and long-term transverse cracking performance. Finally, table 57 summarizes the results for long-term longitudinal cracking. The best alternatives with statistical relevance are shown in each cell. The number before the treatment indicates its ranking among all alternatives.

The summary of best-performing strategies can be used as a practical guide to help select the best rehabilitation option based on performance. For example, if the section is located in a wet freeze region, and the pavement is in fair surface condition with low traffic levels, based on long-term roughness performance, three alternatives in table 51 provide equivalent best performance (mill, thick, and RAP; mill, thin, and virgin; and no mill, thick, and RAP). This performance-based selection can be further improved by evaluating material availability, costs, and other relevant issues.

These summary tables provide clear information for choosing the best rehabilitation treatment based on distress type and site condition. Moreover, the influence of different site conditions can be determined by observing the best treatments for each condition.

**Table 50. Summary based on short-term roughness performance of SPS-5 pavement structures.**

| Climate | | Traffic/Surface Condition | | | |
|---|---|---|---|---|---|
| | | High | | Low | |
| | | Poor | Fair | Poor | Fair |
| Wet | Freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 2: Mill, thick, RAP | 2: Mill, thick, RAP | 2: Mill thick, RAP | 2: Mill, thick, RAP |
| | | 3: No mill, thick, RAP | 3: No mill, thick, RAP | 3: No mill, thick, RAP | 2: No mill, thick, RAP |
| | | 4: Mill, thin, virgin | 4: Mill, thin, RAP | 4: Mill, thin, virgin | 4: Mill, thin, RAP |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 2: Mill, thick, RAP | 2: Mill thick, RAP | 2: Mill, thick, RAP | 2: Mill, thick, RAP |
| | | 3: Mill, thin, virgin | 3: No mill, thick, RAP | 3: No mill, thick, RAP | 3: No mill, thick, RAP |
| | | 3: No mill, thick, RAP | 4: Mill, thin, RAP | 4: Mill, thin, virgin | 4: Mill, thin, RAP |
| Dry | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 3: No mill, thick, RAP | 3: No mill, thick RAP | 3: No mill, thick, RAP | 3: No mill, thick, RAP |
| | | — | 4: Mill, thin, RAP | — | 4: Mill, thin, RAP |
| | No-freeze | 1: Mill, thick RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: Mill, thick, virgin | 1: Mill thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | — | 3: Mill thin, RAP | 3: No mill, thick, RAP | 3: No mill, thick, RAP |
| | | — | 3: No mill, thick, RAP | — | 4: Mill, thin, RAP |

— Indicates that no preferred treatment was statistically found.

## Table 51. Summary based on long-term roughness performance of SPS-5 pavement structures.

| **Climate** | | **Traffic Surface/Condition** | | | |
|---|---|---|---|---|---|
| | | **High** | | **Low** | |
| | | **Poor** | **Fair** | **Poor** | **Fair** |
| Wet | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: Mill, thick, virgin | 1: Mill, thin, virgin | 1: Mill, thick, virgin | 1: Mill, thin, virgin |
| | | 1: Mill, thin, virgin | 1: No mill, thick, RAP | 1: Mill, thin, virgin | 1: No mill, thick, RAP |
| | | 1: No mill, thick, RAP | 4: Mill, thick, virgin | 1: No mill, thick, RAP | 4: Mill, thick, virgin |
| | No-freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: Mill, thick, virgin | 1: Mill, thin, virgin | 1: Mill, thick, virgin | 1: Mill, thin, virgin |
| | | 1: Mill, thin, virgin | 1: No mill, thick, RAP | 1: Mill, thin, virgin | 1: No mill, thick, RAP |
| | | 1: No mill, thick, RAP | 4: Mill, thick, virgin | 1: No mill, thick, RAP | 4: Mill, thick, virgin |
| Dry | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 1: No mill, thick, RAP |
| | | 3: Mill, thick, virgin | 3: Mill, thin, virgin | 3: Mill, thick, virgin | 3: Mill, thin, virgin |
| | | 3: Mill, thin, virgin | 4: Mill, thick, virgin | 3: Mill, thin, virgin | 4: Mill, thick, virgin |
| | No-freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 1: No mill, thick, RAP |
| | | 3: Mill, thick, virgin | 3: Mill, thin, virgin | 3:Mill, thick, virgin | 3: Mill, thin, virgin |
| | | 3: Mill, thin, virgin | 4: Mill, thick, virgin | 3: Mill, thin, virgin | 4: Mill, thick, virgin |

**Table 52. Summary based on short-term rutting performance of SPS-5 pavement structures.**

| Climate | | Traffic Surface/Condition | | | |
|---|---|---|---|---|---|
| | | **High** | | **Low** | |
| | | **Poor** | **Fair** | **Poor** | **Fair** |
| Wet | Freeze | 1: No mill, thin, virgin | 1:No mill, thin, RAP | 1: No mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: No mill, thin, RAP | 1: No mill, thin, virgin | 2: Mill, thin, virgin | 2: No mill, thin, RAP |
| | | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: No mill, thin, RAP | 3: Mill, thick, RAP |
| | | 3: Mill, thin, virgin | 4: Mill, thin, RAP | 4: Mill, thick, RAP | 3: Mill, thin, RAP |
| | No-freeze | 1: No mill, thin, virgin | 1: No mill, thin, virgin | 1: Mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: Mill, thin, virgin | 2: No mill, thin, RAP | 1: No mill, thin, virgin | 2: Mill, thin, virgin |
| | | 3: No mill, thin, RAP | 3: Mill, thick, RAP | 3: Mill, thin, RAP | 3: Mill, thin, RAP |
| | | 4: Mill, thick, RAP | 3: Mill, thin, RAP | 3: No mill, thin, RAP | 3: No mill, thin, RAP |
| Dry | Freeze | 1: No mill, thin, virgin | 1: Mill, thick, RAP | 1: No mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: Mill, thick, RAP | 1: No mill, thin, RAP | 2: Mill, thick, RAP | 2: Mill, thick, RAP |
| | | 2: No mill, thin, RAP | 1: No mill, thin, virgin | 2: Mill, thin, RAP | 2: Mill, thin, RAP |
| | | 4: Mill, thin, RAP | 4: Mill, thin, RAP | 2: Mill, thin, virgin | 2: No mill, thick, RAP |
| | No-freeze | 1: No mill, thin, virgin | 1: No mill, thin, virgin | 1: No mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: Mill, thick, RAP | 2: Mill, thick, RAP | 2: Mill, thin, virgin | 2: Mill, thin, RAP |
| | | 2: Mill, thin, RAP | 2: Mill, thin, RAP | 3: Mill, thin, RAP | 3: Mill, thick, RAP |
| | | 2: Mill, thin, virgin | 2: No mill, thin, RAP | 4: Mill, thick, RAP | 3: Mill, thin, virgin |

**Table 53. Summary based on long-term rutting performance of SPS-5 pavement structures.**

| Climate | | Traffic/Surface Condition | | | |
|---|---|---|---|---|---|
| | | High | | Low | |
| | | Poor | Fair | Poor | Fair |
| Wet | Freeze | 1: No mill, thin, virgin | 1: No mill, thin, virgin | 1: No mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: Mill, thin, virgin | 2: Mill, thick, RAP | 2: Mill, thin, virgin | 2: Mill, thick, RAP |
| | | 3: Mill, thick, RAP | 2: No mill, thick, RAP | 3: Mill, thick, RAP | 2: Mill, thin, virgin |
| | | 3: No mill, thick, RAP | 4: Mill, thin, virgin | 3: No mill, thick, RAP | 2: No mill, thick, RAP |
| | No-freeze | 1: Mill, thin, virgin | 1: No mill, thin, virgin | 1: Mill, thin, virgin | 1: No mill, thin, virgin |
| | | 1: No mill, thin, virgin | 2: Mill, thin, virgin | 1: No mill, thin, virgin | 2: Mill, thin, virgin |
| | | 3: Mill, thin, RAP | 3: Mill, thick, RAP | 3: Mill, thin, RAP | 3: Mill, thick, RAP |
| | | 4: Mill, thick, RAP | 3: Mill, thin, RAP | 4: Mill, thick, RAP | 3: Mill, thin, RAP |
| Dry | Freeze | 1: No mill, thin, virgin | 1: Mill, thick, RAP | 1: No mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: Mill, thick, RAP | 1: No mill, thin, virgin | 2: Mill, thick, RAP | 2: Mill, thick, RAP |
| | | 2: No mill, thick, virgin | 3: No mill, thick, RAP | 2: Mill, thin, virgin | 3: No mill, thick, RAP |
| | | 4: Mill, thin, virgin | 3: No mill, thick, virgin | 2: No mill, thick, virgin | 3: No mill, thick, virgin |
| | No-freeze | 1: No mill, thin, virgin | 1:No mill, thin, virgin | 1: No mill, thin, virgin | 1: No mill, thin, virgin |
| | | 2: Mill, thin, virgin | 2: Mill, thick, RAP | 2: Mill, thin, virgin | 2: Mill, thick, RAP |
| | | 3: Mill, thick, RAP | 3: Mill, thin, RAP | 3: Mill, thick, RAP | 2: Mill, thin, virgin |
| | | 3: Mill, thin, RAP | 3: Mill, thin, virgin | 3: Mill, thin, RAP | 4: Mill, thin, RAP |

**Table 54. Summary based on long-term fatigue cracking performance of SPS-5 pavement structures.**

| Climate | | Traffic Surface/Condition | | | |
|---|---|---|---|---|---|
| | | **High** | | **Low** | |
| | | **Poor** | **Fair** | **Poor** | **Fair** |
| Wet | Freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 2: Mill, thick, RAP | 2: Mill, thick, RAP | 2: Mill, thick, RAP | 2: Mill, thick, RAP |
| | | 2: No mill, thick, virgin | 2: No mill, thick, virgin | 2: Mill, thin, virgin | 2: Mill, thin, virgin |
| | | 4: Mill, thin, virgin | 4: Mill, thin, virgin | 2: No mill, thick, RAP | 2: No mill, thick, RAP |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 2: Mill, thick, RAP | 2: Mill, thick, RAP | 2: Mill, thick, RAP | 2: Mill, thick, RAP |
| | | 2: No mill, thick, virgin | 2: No mill, thick, virgin | 2: Mill, thin, virgin | 2: Mill, thin, virgin |
| | | 4: Mill, thin, virgin | 4: Mill, thin, virgin | 2: No mill, thick, RAP | 2: No mill, thick, RAP |
| Dry | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin |
| | | — | — | — | — |
| | No-freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, RAP |
| | | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin |
| | | 4: Mill, thin, RAP | 4: Mill, thin, RAP | 4: Mill, thin, RAP | 4: Mill, thin, RAP |

— Indicates that no preferred treatment was statistically found.

**Table 55. Summary based on short-term transverse cracking performance of SPS-5 pavement structures.**

| | | Traffic/Surface Condition | | | |
|---|---|---|---|---|---|
| | | High | | Low | |
| Climate | | Poor | Fair | Poor | Fair |
| Wet | Freeze | — | — | — | — |
| | | — | — | — | — |
| | | — | — | — | — |
| | | — | — | — | — |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin |
| | | — | — | — | — |
| | | — | — | — | — |
| Dry | Freeze | — | — | — | — |
| | | — | — | — | — |
| | | — | — | — | — |
| | | — | — | — | — |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: No mill, thick, virgin |
| | | — | — | — | — |
| | | — | — | — | — |

— Indicates that no preferred treatment was statistically found.

### Table 56. Summary based on long-term transverse cracking performance of SPS-5 pavement structures.

| Climate | | Traffic/Surface Condition | | | |
|---|---|---|---|---|---|
| | | **High** | | **Low** | |
| | | **Poor** | **Fair** | **Poor** | **Fair** |
| Wet | Freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 2: No mill, thick, virgin | 1: No mill, thick, virgin | 2: No mill, thick, virgin |
| | | — | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP |
| | | — | — | 3: No mill, thick, RAP | 4: No mill, thick, RAP |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 2: No mill, thick, virgin | 1: No mill, thick, virgin | 2: No mill, thick, virgin |
| | | — | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP |
| | | — | — | 3: No mill, thick, RAP | 4: No mill, thick, RAP |
| Dry | Freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 2: Mill, thick, RAP | 1: No mill, thick, virgin | 2: Mill, thick, RAP |
| | | 3: Mill, thick, RAP | 2: No mill, thick, virgin | 3: Mill, thick, RAP | 2: No mill, thick, virgin |
| | | 3: Mill, thin, RAP | 4: Mill, thin, RAP | 3: No mill, thick, RAP | 4: No mill, thick, RAP |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: No mill, thick, virgin | 2: No mill, thick, virgin | 1: No mill, thick, virgin | 2: No mill, thick, virgin |
| | | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP |
| | | 3: Mill, thin, RAP | 4: Mill, thin, RAP | 3: No mill, thick, RAP | 4: No mill, thick, RAP |

— Indicates that no preferred treatment was statistically found.

**Table 57. Summary based on long-term longitudinal cracking performance of SPS-5 pavement structures.**

| Climate | | Traffic/Surface Condition | | | |
|---|---|---|---|---|---|
| | | High | | Low | |
| | | Poor | Fair | Poor | Fair |
| Wet | Freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: Mill, thin, virgin | 1: Mill, thin, virgin | 1: Mill, thin, virgin | 1: Mill, thin, virgin |
| | | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP |
| | | 3: Mill, thin, RAP | 3: Mill, thin, RAP | 3: Mill, thin, RAP | 3: Mill, thin, RAP |
| | No-freeze | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 1: Mill, thin, virgin | 1: Mill, thin, virgin | 1: Mill, thin, virgin | 1: Mill, thin, virgin |
| | | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP | 3: Mill, thick, RAP |
| | | 3: Mill, thin, RAP | 3: Mill, thin, RAP | 3: Mill, thin, RAP | 3: Mill, thin, RAP |
| Dry | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, virgin | 1: Mill, thick, RAP | 1: Mill, thick, virgin |
| | | 1: Mill, thick, virgin | 1: Mill, thin, virgin | 1: Mill, thick, virgin | 1: Mill, thin, virgin |
| | | 1: Mill, thin, RAP | 3: Mill, thick, RAP | 1: Mill, thin, RAP | 3: Mill, thick, RAP |
| | | 1: Mill, thin, virgin | 3: Mill, thin, RAP | 1: Mill, thin, virgin | 3: Mill, thin, RAP |
| | No-freeze | 1: Mill, thick, RAP | 1: Mill, thick, virgin | 1: Mill, thick, RAP | 1: Mill, thick, virgin |
| | | 1: Mill, thick, virgin | 1: Mill, thin, virgin | 1: Mill, thick, virgin | 1: Mill, thin, virgin |
| | | 1: Mill, thin, RAP | 3: Mill, thick, RAP | 1: Mill, thin, RAP | 3: Mill, thick, RAP |
| | | 1: Mill, thin, virgin | 3: Mill, thin, RAP | 1: Mill, thin, virgin | 3: Mill, thin, RAP |

The summary tables show only alternatives in which statistically significant differences in performance were identified with the Friedman test analysis. They were created by considering the best alternatives from each analysis performed in the dataset. These selected rehabilitation alternatives were then grouped for each combination of site conditions.

According to the summary tables, the following conclusions were made when roughness performance was considered:

- Rehabilitation strategies with milling prior to overlay provided better roughness performance for all site conditions.
- Strategies with thick overlays provided smoother pavements for all site conditions, as expected.
- Strategies with virgin or RAP mixes had equivalent performances when used under wet conditions.
- Strategies with RAP mixes ranked better when used in dry conditions.
- Traffic level and freeze conditions did not impact roughness performance ranking.

The analysis of rutting indicated the following:

- Rehabilitation strategies with thin overlays performed better than thick overlays in the short term. In the long term, the ranking of best strategies was more evenly distributed for both thick and thin overlays.
- The ranking of best strategies was evenly distributed among the two mix types in the short term. In the long term, rehabilitation strategies with virgin mixes were in the top ranking of performance more frequently, with the exception of fair pavement surface under freeze conditions, which corresponded to 33 percent of all sites.
- Strategies with milling did not improve rutting performance more than alternatives without milling.
- The level of traffic did not impact the rutting performance of selected rehabilitation strategies.

The analysis of fatigue cracking indicated the following:

- Short-term fatigue cracking performance was not significantly affected by any design features under any site conditions.
- Rehabilitation strategies with thick overlays provided better performance for fatigue cracking under all site conditions that were evaluated.
- Strategies with milling prior to overlay performed better to mitigate development and propagation of fatigue cracking in all site conditions.

- Alternatives without milling performed as well as solutions with milling in regions with dry climates.

- Strategies with RAP mixes were better ranked for sites with low traffic.

The analysis of transverse cracking indicated the following:

- There were no differences identified in short-term performance among the rehabilitation strategies in freezing zones.

- Among the sites located in no-freeze zones, the remaining site conditions did not have any impact on short-term performance.

- Strategies with virgin mixes and thick overlays ranked best for long-term transverse cracking performance.

- Strategies with RAP mixes performed better than virgin mixes when the site had low traffic and when it had high traffic and dry climate.

- Milling prior to overlay did not improve performance more than alternatives without milling.

The analysis of longitudinal cracking indicated the following:

- Rehabilitation strategies with milling prior to overlay were consistently better for improving performance than alternatives without milling.

- Strategies with virgin mixes were consistently better than alternatives with RAP in sites located in wet climates.

- There was no difference in ranking between strategies with virgin and RAP mixes in dry conditions.

- Overlay thickness was not a significant factor affecting performance associated with longitudinal cracking.

The summary tables presented in this section, along with a complete set of tables with descriptive statistics for all the analyses conducted, are provided in appendix C.

## EFFECT OF DESIGN AND CONTRUCTION FEATURES AND SITE CONDITIONS ON RESPONSE OF REHABILITATED FLEXIBLE PAVEMENTS

The study to evaluate the impact of design features and site conditions on response of rehabilitated flexible pavements followed the same approach used in the analysis of performance. FWD deflection data are available in the LTPP database and used as the response measure of the pavement structure. Deflections in the wheel path of the LTPP lane were used as indicators of structural response.

The same analysis sequence applied to the study of performance was applied to the study of response. The first task was to evaluate individual sites and how the pavement structural responses were affected by each rehabilitation strategy and its design features. Since the analysis was carried out for each site separately, the deflection values were not adjusted for temperature, and the FWD survey was assumed to take place under similar conditions for all sections of a given site. There were small variations in surface temperature throughout the day, but they were considered minor and unlikely to significantly affect the total pavement stiffness. The variation of deflections over time and over the seasons throughout the year was used as input for the repeated ANOVA.

### Individual Analysis of SPS-5 Sites

Summary tables containing the results of the statistical analysis for pavement response for each site are presented in appendix A.

A compilation of results was created by identifying the number of sites in which design features had provided differences in response throughout the site's service life. For example, if sections with thick overlays had lower deflection measurements than thin overlay sections in one site, the thick overlay was marked for this site, and the process was repeated for all sites. Figure 32 summarizes the percentage of sites in which differences in response were identified.

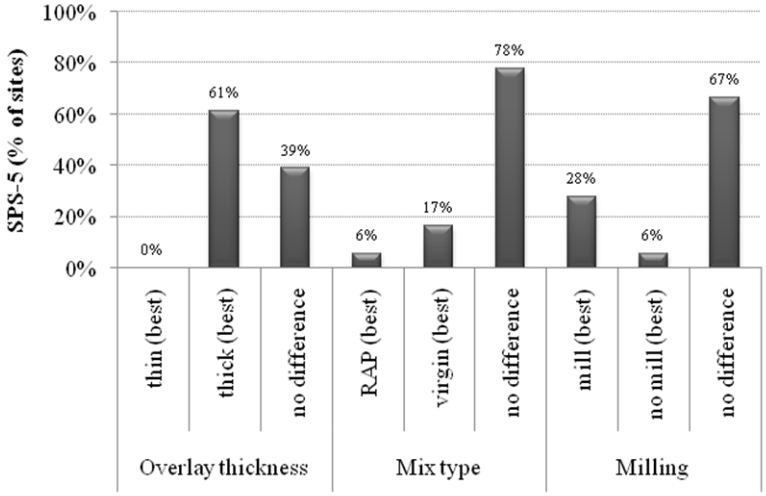


**Figure 32. Graph. Percentage of SPS-5 sections with lower maximum deflection based on repeated measures ANOVA results.**

The key findings from the assessment of individual sites were as follows:

- As expected, rehabilitation strategies with thick overlays had lower maximum deflection values compared to alternatives with thin overlays.
- There were no differences in pavement response between strategies using virgin and RAP mix overlays.

- Strategies with milling prior to overlay did not affect the structural response more than alternatives without milling.

## Consolidated Analysis

The consolidated analysis involved the simultaneous analysis of all sites in the SPS-5 experiment using the Friedman test. A follow-up analysis was performed by grouping the data by site condition to evaluate the impact of design features and site conditions for short-term and long-term performance. WD was the parameter used for this analysis.

After the data were processed and verified for quality, WD was computed for each section in each SPS-5 site. The values are shown in table 58. The Friedman test used WD to create the ranking of performance from the lowest to the highest value for each site in the dataset. Ranking statistics for each type of section were then used to calculate the chi-square value, and this parameter was used to determine if statistical differences existed among the performance rankings of the sections.

The Friedman test output for maximum deflection in the wheel path is provided in figure 33, and it presents the average and standard deviation values for the WD maximum deflection for each type of rehabilitation strategy among all sites analyzed. The results indicate that there were at least two sections with statistically different structural responses ($p < 0.0001$, ANOVA chi-square = 78.737). Therefore, the ranking of sections (i.e., rehabilitation strategies) for structural response can be created using Friedman paired analyses. The results of the paired analyses were used to define a practical ranking for structural response (see table 59).

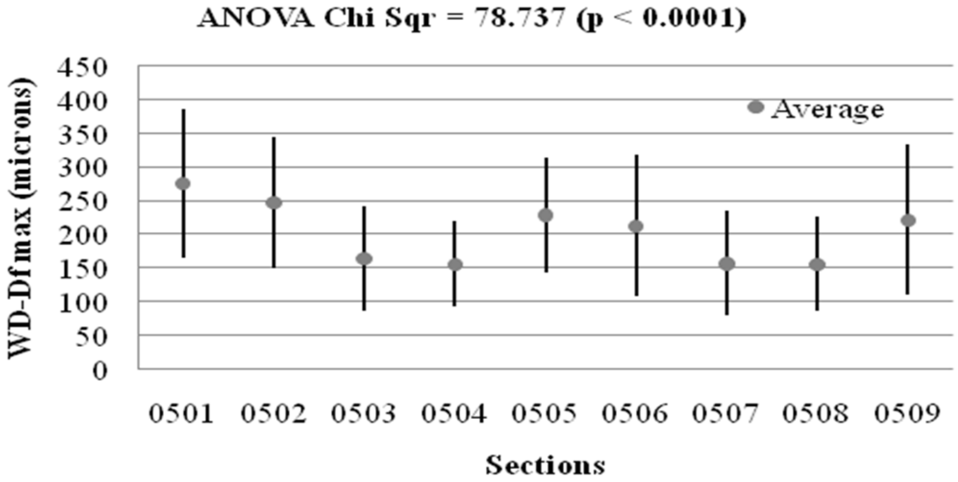
### Table 58. WD-deflection values at the center of the load for SPS-5 sites.

| Section | Experiment Design | | | Sites (State Codes)/Average Deflection WD Values (microns) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mill | Mix | Thickness (mm) | 1 | 4 | 6 | 8 | 12 | 13 | 23 | 24 | 27 | 28 | 29 | 30 | 34 | 35 | 40 | 48 | 81 | 83 |
| 0501 | No | None | | | 374 | 271 | 249 | | | 174 | 164 | 323 | 202 | 285 | | 198 | 333 | 213 | | 394 | 374 |
| 0502 | No | RAP | 51 | 264 | 292 | 319 | 260 | 190 | 102 | 134 | 218 | 250 | 270 | 207 | 465 | 214 | 241 | 168 | 139 | 465 | 257 |
| 0503 | No | RAP | 127 | 115 | 196 | 151 | 197 | 144 | 62 | 107 | 157 | 189 | 209 | 112 | 383 | 33 | 139 | 158 | 149 | 272 | 182 |
| 0504 | No | Virgin | 127 | 130 | 77 | 131 | 155 | 134 | 69 | 106 | 164 | 197 | 143 | 109 | 317 | 104 | 175 | 203 | 148 | 272 | 186 |
| 0505 | No | Virgin | 51 | 286 | 256 | 348 | 275 | 186 | 85 | 132 | 265 | 261 | 198 | 139 | 389 | 131 | 271 | 205 | 112 | 273 | 304 |
| 0506 | Yes | Virgin | 51 | 156 | 112 | 271 | 319 | 182 | 75 | 141 | 161 | 243 | 209 | 144 | 420 | 37 | 294 | 259 | 134 | 384 | 293 |
| 0507 | Yes | Virgin | 127 | 168 | 56 | 167 | 288 | 125 | 63 | 106 | 162 | 177 | 126 | 116 | 292 | 36 | 222 | 145 | 110 | 292 | 180 |
| 0508 | Yes | RAP | 127 | 162 | 99 | 164 | 205 | 128 | 58 | 108 | 168 | 177 | 179 | 84 | 321 | 30 | 157 | 232 | 122 | 217 | 207 |
| 0509 | Yes | RAP | 51 | 179 | 202 | 330 | 240 | 166 | 90 | 145 | 190 | 255 | 212 | 153 | 540 | 35 | 217 | 245 | 138 | 324 | 320 |

1 µm = 0.039 mil

1 inch = 25.4 mm

Note: Higher WD values indicate higher maximum deflection for FWD measurements for pavements. Blank cells indicate data are not available.



1µm = 0.039 mil

**Figure 33. Graph. Maximum deflection (wheel path of LTPP lane) WD values at SPS-5 sites.**

**Table 59. Ranking of rehabilitation strategies for structural response at SPS-5 sites.**

| **Statistical Relevance (Y/N)** | **Deflection** | |
|---|---|---|
| | Y | $p < 0.0001$ |
| Ranking (if relevant) | **Ranking** | **Strategy** |
| | 1 (Lowest) | Mill, thick, virgin |
| | 2 | Mill, thick, RAP |
| | 2 | No mill, thick, RAP |
| | 2 | No mill, thick, virgin |
| | 5 | Mill, thin, virgin |
| | 6 | No mill, thin, virgin |
| | 6 | Mill, thin, RAP |
| | 6 | No mill, thin, RAP |
| | 6 | None |

The results in table 59 and figure 29 support the findings from the analysis of individual sites that suggest that thick overlays provided lower maximum deflections compared to alternatives with thin overlays. The ranking also shows that there were no significant differences in response for strategies using either virgin or RAP mix overlays, and they are intertwined in the ranking. The results further suggest that milling prior to overlay may reduce the level of pavement response, as strategies with this design feature were ranked among those with lower deflections for FWD measurements.

## Influence of Site Condition

Similar to the pavement performance analysis, the influence of site conditions was determined by three variables: (1) pavement surface condition prior to rehabilitation, (2) climate, and (3) traffic levels. The analysis followed the same steps described in the previous section. Rankings of rehabilitation strategies were developed for each group of sites using descriptive statistics and the paired analyses from the Friedman test when statistical differences in performance were found in the first step. The results were summarized in tables and are presented in appendix C.

After a careful assessment of the results from the analyses performed for each group, summary tables including all possible combinations of site conditions were assembled. Table 60 presents the results, and the alternatives with lower deflections with statistical relevance are shown in each cell. The number before the treatment indicates its ranking among all alternatives.

Table 60 can be used as a practical guide to help select rehabilitations strategies that provide low deflection values. For example, if the section is located in a wet freeze region and the pavement is in fair surface condition with low traffic levels, an alternative with a thick RAP overlay without milling is indicated. However, if the same section is in poor condition, the alternative indicated is one with milling and a thick virgin overlay.

These summary tables provide clear information to identify the rehabilitation treatment with the lowest and highest pavement responses based on site conditions, and the influence of different site condition can be determined by observing the ranking of treatments for each condition.

### Table 60. Summary based on structural response (maximum deflection in the wheel path of the LTPP lane) of SPS-5 pavement structures.

| Climate | | Traffic/Surface Condition | | | |
|---|---|---|---|---|---|
| | | High | | Low | |
| | | Poor | Fair | Poor | Fair |
| Wet | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, virgin | 1: No mill, thick, RAP |
| | | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 2: Mill, thick, RAP |
| | | 1: No mill, thick, virgin | 3: No mill, thick, virgin | 1: No mill, thick, virgin | 2: Mill, thick, virgin |
| | | 4: Mill, thick, virgin | 4: Mill, thick, virgin | 4: Mill, thick, RAP | 2: No mill, thick, virgin |
| | No-freeze | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 2: Mill, thick, virgin | 2: Mill, thick, RAP | 1: No mill, thick, virgin | 1: No mill, thick, virgin |
| | | 3: Mill, thick, RAP | 2: Mill, thick, virgin | 3: No mill, thick, RAP | 3: No mill, thick, RAP |
| | | 3: No mill, thick, RAP | 2: No mill, thick, RAP | 4: Mill, thick, RAP | 4: Mill, thick, RAP |
| Dry | Freeze | 1: Mill, thick, RAP | 1: Mill, thick, RAP | 1: Mill, thick, virgin | 1: No mill, thick, RAP |
| | | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 1: No mill, thick, RAP | 2: Mill, thick, RAP |
| | | 1: No mill, thick, virgin | 3: No mill, thick, virgin | 1: No mill, thick, virgin | 2: Mill, thick, virgin |
| | | 4: Mill, thick, virgin | 4: Mill, thick, virgin | 4: Mill, thick, RAP | 2: No mill, thick, virgin |
| | No-freeze | 1: No mill, thick, virgin | 1: No mill, thick, virgin | 1: Mill, thick, virgin | 1: Mill, thick, virgin |
| | | 2: Mill, thick, virgin | 2: Mill, thick, RAP | 1: No mill, thick, virgin | 1: No mill, thick, virgin |
| | | 3: Mill, thick, RAP | 2: Mill, thick, virgin | 3: No mill, thick, RAP | 3: No mill, thick, RAP |
| | | 3: No mill, thick, RAP | 2: No mill, thick, RAP | 4: Mill, thick, RAP | 4: Mill, thick, RAP |

Table 60 shows only alternatives in which statistically significant differences in WD-maximum deflection were found. The table was created by considering the alternatives with the lowest responses for each analysis performed with the dataset. These selected rehabilitation alternatives were then grouped for each combination of site conditions. According to the summary table, the following conclusions were made with respect to structural response:

- Rehabilitation strategies with thick overlays provided the lowest structural response independent of site conditions.
- Strategies with RAP mix overlays had the lowest structural response in freeze regions, while those with virgin mixes presented lower deflections under no-freeze conditions.
- Milling prior to overlay did not further impact structural response. In no-freeze zones, strategies without milling presented lower deflections.
- When comparing wet and dry pavement surface condition and traffic level, neither had a significant impact on structural responses associated with each rehabilitation alternative.

The summary table presented in this section, along with a complete set of tables with descriptive statistics for all the analyses performed, is provided in appendix C.

## RELATIONHIP BETWEEN STRUCTURAL RESPONES IMMEDIATELY AFTER REHABILITATION AND FUTURE PERFORMANCE

There have been many attempts to find direct relationships or models to predict performance based on the structural response of the pavement to loading immediately after construction or rehabilitation. These relationships are not completely straightforward, and deriving them accurately using mechanistic theory can be difficult. The objective of this study was to identify trends in the relationship between response measured after the rehabilitation and the observed performance in subsequent years of the pavement's service life. If these trends can be identified, they will provide important information and guidance on what to expect for a pavement's performance as a result of rehabilitation strategies that yield to a certain level of structural response.

This study concentrated on evaluating FWD maximum deflections measured under the center of the load against the average pavement performance during the service life of SPS-5 sites. WD was once again used as the performance measure. Each response was evaluated against all distresses previously used in this study. Only long-term performance was used for this analysis, indicating performance data of 5 years or more.

The SPS-5 experiment had sites across the United States under different climatic zones, subgrade types, and traffic loads. Consequently, the results from this study could be impacted by in situ conditions. The alternative to circumvent this problem was to normalize the data in each site by a common factor. The rehabilitation strategy selected as the normalization factor had a thin virgin mix overlay without milling, and it was selected because the control section was not available or was eliminated from the surveys for some of the SPS-5 sites. Response and performance measured for thin virgin mix overlaid sections were used to normalize the data of the remaining sections in each site. Normalized values were computed according to the equation in figure 34.

$$Parameter_{Normalized} = \frac{Parameter_{section}}{Parameter_{0602}}$$

**Figure 34. Equation. Parameter subscript normalized.**

The relationship between performance and deflection was verified using Pearson's linear coefficient, $r$. The $t$-Student's test was used to test the null hypothesis stating that no correlation existed between performance and deflection ($r = 0$). A potential relationship between performance and deflection was confirmed if the null hypothesis was rejected with 95 percent confidence ($p \leq 0.05$).

The trend between roughness and maximum deflection is shown in figure 35. It suggests that roughness, measured by IRI, is poorly related to the deflection values measured after the rehabilitation of the pavement structure ($p = 0.029$).

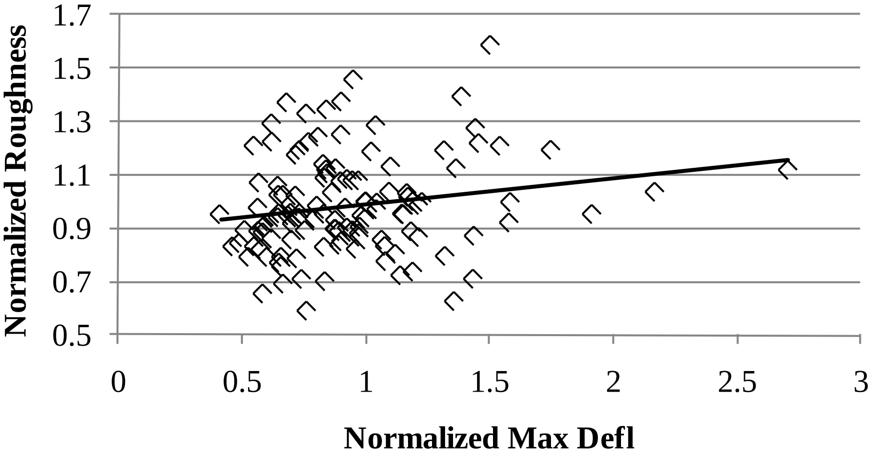


**Figure 35. Graph. Normalized long-term WD-roughness versus normalized maximum deflection measured after rehabilitation in SPS-5 sites.**

Similarly, the results in figure 36 suggest that maximum deflection after the pavement's rehabilitation cannot provide good qualitative information about the rutting performance predictions ($p = 0.296$). This observation may be contrary to what is expected. Rutting is a load-related distress, and because deflection measures the pavement's response to load applications, it seems intuitive that a positive trend might exist. However, instant deflections as measured by FWD tests were more likely to capture instantaneous elastic response of the pavement structure. Rutting is a plastic deformation more likely to occur in unbound aggregate layers and AC at warm temperatures. In rehabilitated flexible pavements, most of the permanent deformation occurred in the overlay. As temperature increases, AC behaves less like a time-dependent elastic material and more like a time-dependent plastic material. The instantaneous FWD deflections cannot be associated with the material's behavior impacting rutting performance.

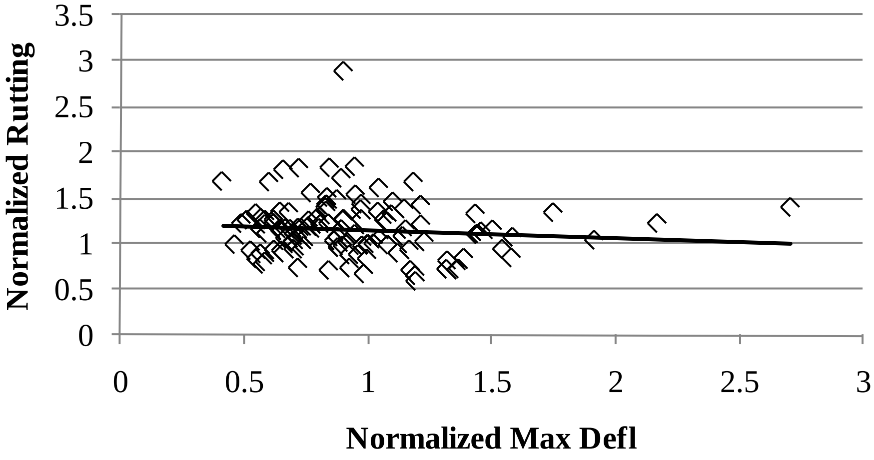


**Figure 36. Graph. Normalized long-term WD-rutting versus normalized maximum deflection measured after rehabilitation in SPS-5 sections.**

Contrary to expectations, the data in figure 37 indicate that no statistically significant trend was found between fatigue cracking performance and maximum deflection (*p* = 0.565). Conversely, the data in figure 38 suggest that higher values of transverse cracking are expected when the pavement has higher deflections (*p* = 0.001). The trend in figure 39 suggests that longitudinal cracking is not related to deflections measured under the center of the load on FWD tests but just marginally (*p* = 0.058).

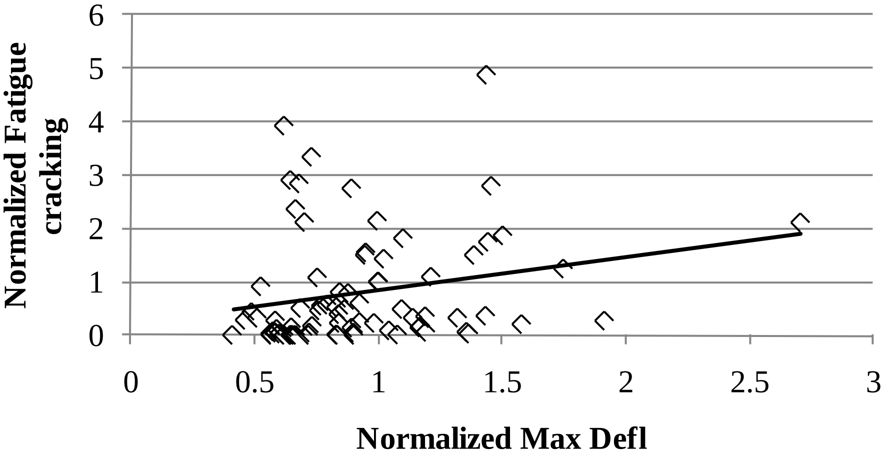


**Figure 37. Graph. Normalized long-term WD-fatigue cracking versus normalized maximum deflection measured after rehabilitation in SPS-5 sections.**

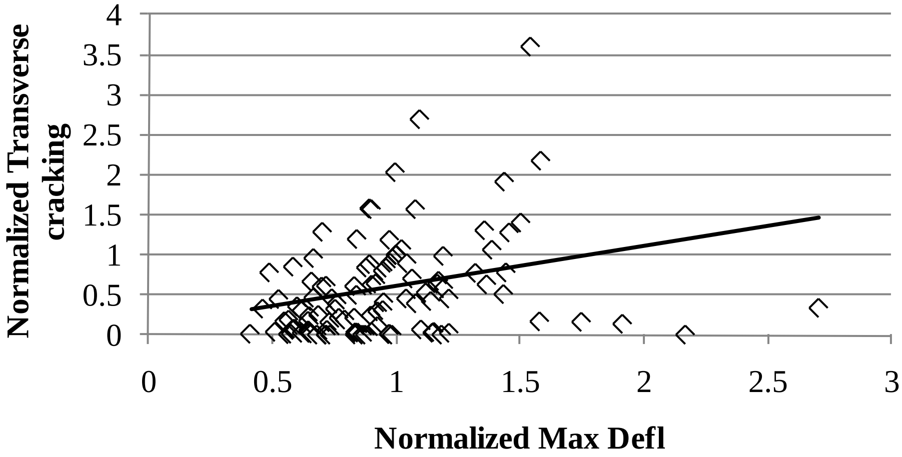


**Figure 38. Graph. Normalized long-term WD-transverse cracking versus normalized maximum deflection measured after rehabilitation in SPS-5 sections.**

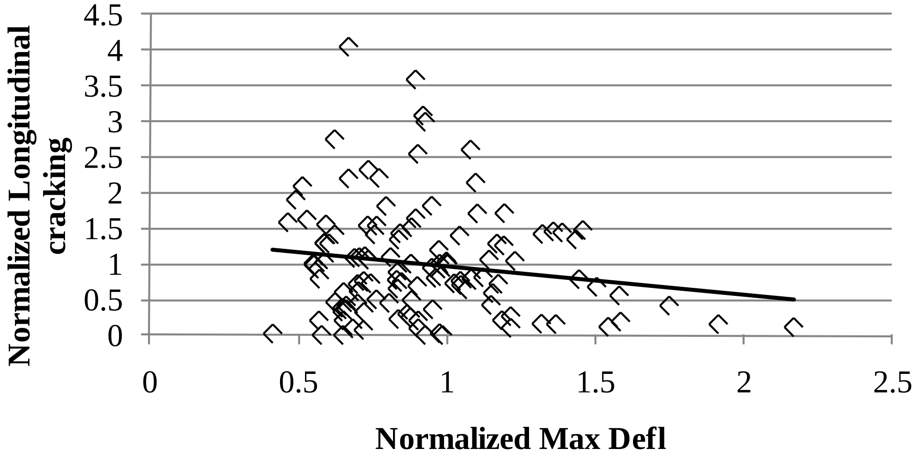


**Figure 39. Graph. Normalized long-term WD-longitudinal cracking versus normalized maximum deflection measured after rehabilitation in SPS-5 sections.**

Some of the distresses had clear trends with responses that agreed with the conventional wisdom and expectations of relationships between performance and response. However, none of the trends were strong enough to suggest a direct correlation between performance and response as measured by maximum deflection. These plots only suggested that deflection could be used to infer qualitative assessments of future performance of some distresses but not to quantitatively predict performance.

# CHAPTER 6. REHABILITATED RIGID PAVEMENT ANALYSIS AND FINDINGS

## INTRODUCTION

This chapter describes the rehabilitation of rigid pavements. Data from the SPS-6 sites were used to assess the impact of rehabilitation effort with and without HMA overlay on performance and response of JPCP and JRCP. The impact of design features (i.e., different rehabilitation procedures and the presence or absence of an HMA overlay) on performance and response was statistically evaluated for major distresses commonly recorded in the LTPP database for rigid pavements and reported in the MEPDG.

## STATISTICAL ANALYSIS APPROACH

The core sections of the SPS-6 experiment consisted of independent rehabilitation strategies. The experiment did not evenly combine all restoration and overlay options. Additionally, it was unbalanced for statistical purposes. As a result, ANOVA of individual sites was not possible. Therefore, the statistical analysis of SPS-6 was performed by simultaneously considering all of the sites in the experiment using the Friedman test.

The Friedman test is a nonparametric test (distribution-free) used to compare repeated observations on the same subjects. Unlike the more common parametric repeated measures ANOVA or paired *t*-test, the Friedman test makes no assumptions about the distribution of the data (e.g., normality). In addition, it can be used for multiple comparisons, as is the case of the SPS-6 experiment which had multiple rehabilitation alternatives. The Friedman test uses the ranks of the data rather than their raw values to calculate the statistic. The test statistic for the Friedman test is a chi-square with $n - 1$ degrees of freedom, where $n$ is the number of repeated measures (i.e., the number of sections in each site of the experiment). Statistical significance was defined at 95 percent ($p \leq 0.05$ for the chi-square test).

The Friedman test also permits the evaluation of paired statistical significance between two rehabilitation strategies. In some instances, the result of one analysis may indicate that significant differences exist between the rankings of sections (i.e., the performances of these sections are statistically different). However, there might be groups within the sorted ranking with similar performances. The paired statistical analysis feature is important to identify groups of strategies with equivalent performance.

### Performance Measures

The WD average (i.e., the unit area under the distress performance curve) over the survey period was selected as a performance measure of various distresses and roughness. It was calculated as described in the previous chapter.

Different distresses were used to evaluate the performance of rehabilitated rigid pavements. The decision was based on the importance and frequency of occurrence, but most notably, it was based on distresses that were visible during the surveys (i.e., present in the surface layer). The SPS-6 experiment consisted of rigid pavement sections that had been rehabilitated with or without HMA overlay. The core sections of the experiment are described in table 61. Sections that were rehabilitated through an HMA overlay were monitored after rehabilitation, and typical flexible pavement distresses (e.g., rutting, fatigue cracking, transverse cracking, etc.) were recorded throughout the service life of the experiment. Sections that were rehabilitated and did not receive an HMA overlay were monitored, and typical rigid pavement distress surveys (e.g., faulting, slab cracking, etc.) were recorded.

This particular characteristic of SPS-6 sites required multiple analyses in which individual sections were grouped based on their surface layer type and, consequently, their monitoring distresses. Roughness was measured in all sections, and it was chosen as the performance measure associated with all sections independent of their surface type as an indication of functional performance of the rehabilitation strategies. Different cracking performance measurements were taken according to the surface layer type. The sum of all cracking area was also an important performance measure used to evaluate all sections simultaneously, especially for decisionmaking on crack preventive maintenance. Therefore, roughness and total cracking were used to simultaneously compare the performance of all rehabilitation strategies.

**Table 61. Core sections of the SPS-6 experiment.**

| SHRP ID | Overlay Thickness (mm) | PCC Preparation | Code |
|---|---:|---|---|
| 0601 | — | Routine maintenance (control) | — |
| 0602 | — | Minimum restoration | min-no |
| 0603 | 102 | Minimum restoration | min-ov |
| 0604 | 102 | Saw and seal AC over joints | ss-ov |
| 0605 | — | Maximum restoration | max-no |
| 0606 | 102 | Maximum restoration | max-ov |
| 0607 | 102 | Crack/break and seat | cb-4 inches |
| 0608 | 203 | Crack/break and seat | cb-8 inches |

1 inch = 25.4 mm
— Indicates that the section did not have an overlay and/or code.

There were four sections in each SPS-6 site with distinct restoration treatments executed prior to or just after the 4-inch (102-mm) overlays. The restoration treatments were minimum and maximum restoration, saw and seal over joints, and crack/break and seat. The impact of these treatments on performance was analyzed by grouping these sections into a new dataset, excluding all others. Roughness and typical flexible pavement distresses were used as performance measures. Sections with different restoration treatments but without overlays were used to evaluate the performance of these treatments when they were the main component of the rehabilitation strategy. The no treatment control section was also analyzed in this group dataset, and roughness and distresses typical of rigid pavement were used as performance measures. Table 62 summarizes all datasets and provides the purpose of the study and the distresses and responses used in each analysis.

The analysis of the SPS-6 sites was intended to assess the impact of rehabilitation strategies on performance and response as well as the influence of climate and pavement surface conditions prior to rehabilitation. Therefore, each dataset defined in table 62 was analyzed in four ways:

(1) all sites in the study, (2) sites grouped by wet/dry condition, (3) sites grouped by freeze/no-freeze condition, and (4) sites grouped by fair/poor condition prior to rehabilitation. By comparing results from different conditions, it was possible to investigate the influence of climate conditions and pavement deterioration prior to rehabilitation on performance. Separate analyses were conducted for JPCP and JRCP.

In addition to performance measures, mechanistic responses were analyzed. Sections with HMA overlays were evaluated using maximum deflection measured at the center of the lane, while sections without overlays were analyzed using the load transfer efficiency between joints and the maximum deflection at the center of the slab.

**Table 62. Description of independent studies and performance measures used in the analyses.**

| Study Type/Dataset | Purpose | Distress |
|---|---|---|
| All rehabilitation strategies and all sections | To compare performance of all rehabilitation options | Roughness |
| | | Total cracking |
| PCC restoration prior to overlay: sections 0603, 0604, 0606, and 0607 | To evaluate the impact of different preoverlay treatments on performance | Roughness |
| | | Rutting |
| | | Fatigue cracking |
| | | Longitudinal cracking |
| | | Transverse cracking |
| | | Maximum deflection |
| PCC restoration: sections 0601, 0602, and 0605 | To evaluate the impact on performance of PCC restoration without HMA overlay | Roughness |
| | | PCC faulting |
| | | Slab corner breaks |
| | | Durability |
| | | Longitudinal slab cracking |
| | | Transverse slab cracking |
| | | Load transfer efficiency (LTE) |
| | | Maximum deflection |

## EFFECT OF DESIGN AND CONSTRUCTION FEATURES AND SITE CONDITIONS ON PERFORMANCE OF REHABILITATED RIGID PAVEMENTS

There were 14 sites in the SPS-6 experiment. Eight of them were JPCP, and six were JRCP. The sites and their characteristics in the experimental factorial are presented in table 63. Their behavior was different, and the level of distresses typically varied. The analysis of the impact of different rehabilitation strategies on performance was performed separately for JPCP and JRCP sites.

**Table 63. SPS-6 sites for the experimental factorial.**

| Pavement Type | Pavement Condition | Climate, Moisture/Temperature | | | |
|---|---|---|---|---|---|
| | | Wet Freeze | Wet No-freeze | Dry Freeze | Dry No-freeze |
| JPCP | Fair | Missouri (29) | Alabama (1) and Tennessee (47) | South Dakota (46) | |
| | Poor | Indiana (18) | Arakansas (5) | Arizona (4) and California (6) | |
| JRCP | Fair | Iowa (19),<br>Michigan (26), and<br>Pennsylvania (42) | Oklahoma (40) | | |
| | Poor | Illinois (17) and<br>Missouri (29) | | | |

Note: State codes are provided in parentheses. Blank cells indicate that there are no sites with those sets of conditions.

## JPCP

This section describes the results of the study on JPCP sites in the SPS-6 experiment. JPCP sites were located throughout the United States and had a balanced distribution between climate and pavement condition. Only the dry, no-freeze climatic zone did not have a representative site. Four out of eight sites were reported to have fair pavement conditions prior to rehabilitation. Five sites were located in wet regions, and five were located in freeze regions. Traffic was similar in all sites in terms of daily truck volume and class distributions.

### *Analysis of All Rehabilitation Strategies*

Roughness and total cracking were used to evaluate all rehabilitation alternatives simultaneously. Roughness was the only performance indicator measured in all sections within each site. The surveys were independent from surface type and were performed systematically during the experiment. The surveys provided a uniform way of comparing the impact of all of the rehabilitation strategies used in the experiment. In addition to roughness, total cracking was used as an indicator of performance. In this case, the measurements were not obtained directly. Cracking was measured depending on the surface layer type after the rehabilitation strategy was completed.

After the data were processed and verified for quality and existing outliers were removed, WD was computed for short-term and long-term performance (see table 64 and table 65). The Friedman test used the calculated WD to create a ranking of performance, from lowest WD (best performance) to highest (worst performance) for each site in the dataset. Descriptive statistics of the ranking (i.e., average, standard deviation, sum of rankings, etc.) for each type of section were used to calculate the chi-square value to determine if statistical differences existed among the performance rankings.

## Table 64. Short-term average WD-IRI values for SPS-6 sites with JPCP.

| Section | Experiment Design | | Sites (State Codes)/Average IRI WD Values (m/km) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Restoration** | **Overlay (mm)** | **1** | **4** | **5** | **6** | **18** | **29** | **46** | **47** |
| 0601 | No | no | 1.57 | 1.64 | 2.02 | | 1.83 | 1.50 | 0.40 | 1.49 |
| 0602 | Minimum | no | 0.69 | 2.43 | 2.01 | 1.89 | 1.02 | 0.69 | 0.47 | 0.86 |
| 0603 | Minimum | 102 | 0.74 | 1.29 | 0.48 | 0.96 | 0.68 | 0.67 | 0.89 | 0.43 |
| 0604 | Saw and seal | 102 | 0.64 | 0.99 | 0.50 | 0.91 | 0.75 | 0.78 | 0.83 | 0.79 |
| 0605 | Maximum | no | 0.69 | 1.51 | 0.97 | 1.95 | 1.18 | 0.73 | 0.41 | 0.89 |
| 0606 | Maximum | 102 | 0.85 | 1.04 | 0.54 | 1.02 | 0.72 | 0.60 | 0.71 | 0.45 |
| 0607 | Crack/break and seat | 102 | 1.07 | 1.56 | 0.55 | 0.86 | 0.78 | 0.72 | 0.90 | 0.90 |
| 0608 | Crack/break and seat | 203 | 0.47 | 0.93 | 0.45 | 0.83 | 0.54 | 0.46 | 0.66 | 0.40 |

1 ft = 0.305 m

1 mi = 1.61 km

1 inch = 25.4 mm

Note: Higher WD values indicate rougher pavement over time. The blank cell indicates data are not available.

**Table 65. Long-term average WD-IRI values for SPS-6 sites with JPCP.**

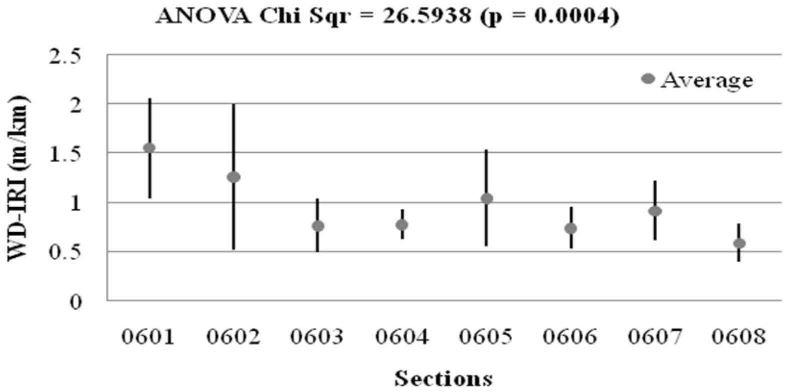
| Section | Experiment Design | | Sites (State Codes)/Average IRI WD Values (m/km) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Restoration | Overlay (mm) | 1 | 4 | 5 | 6 | 18 | 29 | 46 | 47 |
| 0601 | No | no | 3.09 | 2.48 | 3.15 | | 2.72 | 3.15 | 3.03 | 1.86 |
| 0602 | Minimum | no | 1.30 | 3.65 | 2.18 | 2.24 | 2.21 | 1.31 | 1.56 | 1.19 |
| 0603 | Minimum | 102 | 1.32 | 1.74 | 0.94 | 1.39 | 1.07 | 1.26 | 1.36 | 0.78 |
| 0604 | Saw and seal | 102 | 1.23 | 1.20 | 0.97 | 1.55 | 1.19 | 1.41 | 1.50 | 0.98 |
| 0605 | Maximum | no | 1.25 | 1.81 | 1.38 | 1.90 | 2.14 | 1.28 | 1.28 | 1.19 |
| 0606 | Maximum | 102 | 1.48 | 1.37 | 1.01 | 1.84 | 1.13 | 1.13 | 1.25 | 0.80 |
| 0607 | Crack/break and seat | 102 | 2.43 | 1.43 | 1.07 | 1.58 | 1.09 | 1.46 | 1.38 | 1.19 |
| 0608 | Crack/break and seat | 203 | 0.93 | 1.14 | 0.90 | 1.09 | 1.00 | 0.95 | 1.11 | 0.78 |

1 ft = 0.305 m
1 mi = 1.61 km
1 inch = 25.4 mm
Note: The blank cell indicates data are not available.

The Friedman null hypothesis stated that there was no difference between the section rankings (i.e., all sections had identical performances). The null hypothesis was rejected if the *p*-value was lower than 0.05, which represents a 95 percent confidence that at least two sections have statistically different rankings. Examples of Friedman test outputs are provided in figure 40 and figure 41. In the figures, the average WD value for IRI found for each rehabilitation strategy among all sites was analyzed. The vertical bars represent the interval between the mean value ±1 standard deviation as an illustration of the variability of the measurements. The results indicate that for short-term roughness performance, there were at least two sections with statistically different performances (see figure 40, $p = 0.0004$, ANOVA chi-square = 26.5938). A similar result was found for long-term performance in figure 41 ($p < 0.0001$, ANOVA chi-square = 40.2188).

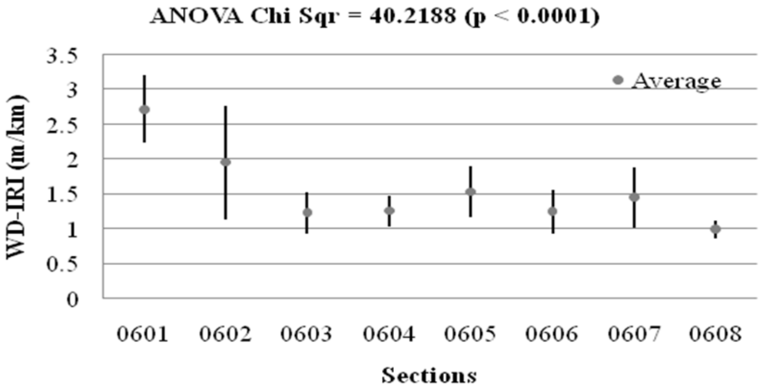
When the result from the Friedman test indicated the existence of at least two strategies with statistically different rankings, the next steps were to identify those sections and build the rankings of best-performing strategies based on the statistical analysis. The paired analyses from the Friedman test were used for this purpose. The significance (*p*-value) of these paired analyses indicated the presence or absense of statistical differences between their rankings. Table 66 and table 67 provide the statistical *p*-values for each paired analysis for short-term and long-term roughness rankings.

The paired analysis results were used to create a practical ranking of roughness performance based on the statistical significance. Based on results presented in table 66 and table 67, the final ranking of evaluating roughness performance was created for the short term and the long term and are described in table 68 and table 69, respectively. Sections were ordered from best to worst performance, and sections with equivalent performance were grouped under the same rank.



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 40. Graph. WD-IRI short-term values for JPCP in SPS-6 sections.**



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 41. Graph. WD-IRI long-term values for JPCP in SPS-6 sections.**

**Table 66. Friedman test paired analysis of rehabilitation strategies by IRI short-term performance ranking for SPS-6 sites with JPCP.**

| Paired Analysis | *p*-Value |
|---|---:|
| 0601 and 0602 | — |
| 0601 and 0603 | — |
| 0601 and 0604 | — |
| 0601 and 0605 | — |
| 0601 and 0606 | — |
| 0601 and 0607 | — |
| 0601 and 0608 | < 0.05 |
| 0602 and 0603 | — |
| 0602 and 0604 | — |
| 0602 and 0605 | — |
| 0602 and 0606 | — |
| 0602 and 0607 | — |
| 0602 and 0608 | < 0.05 |
| 0603 and 0604 | — |
| 0603 and 0605 | — |
| 0603 and 0606 | — |
| 0603 and 0607 | — |
| 0603 and 0608 | — |
| 0604 and 0605 | — |
| 0604 and 0606 | — |
| 0604 and 0607 | — |
| 0604 and 0608 | — |
| 0605 and 0606 | — |
| 0605 and 0607 | — |
| 0605 and 0608 | < 0.05 |
| 0606 and 0607 | — |
| 0606 and 0608 | — |
| 0607 and 0608 | < 0.05 |

— Indicates a pair analysis with no statistical significance.

**Table 67. Friedman test paired analysis of rehabilitation strategies by IRI long-term performance ranking for SPS-6 sites with JPCP.**

| Paired Analysis | *p*-Value |
|---|---:|
| 0601 and 0602 | — |
| 0601 and 0603 | < 0.05 |
| 0601 and 0604 | < 0.05 |
| 0601 and 0605 | — |
| 0601 and 0606 | < 0.05 |
| 0601 and 0607 | — |
| 0601 and 0608 | < 0.05 |
| 0602 and 0603 | — |
| 0602 and 0604 | — |
| 0602 and 0605 | — |
| 0602 and 0606 | — |
| 0602 and 0607 | — |
| 0602 and 0608 | < 0.05 |
| 0603 and 0604 | — |
| 0603 and 0605 | — |
| 0603 and 0606 | — |
| 0603 and 0607 | — |
| 0603 and 0608 | — |
| 0604 and 0605 | — |
| 0604 and 0606 | — |
| 0604 and 0607 | — |
| 0604 and 0608 | — |
| 0605 and 0606 | — |
| 0605 and 0607 | — |
| 0605 and 0608 | < 0.05 |
| 0606 and 0607 | — |
| 0606 and 0608 | — |
| 0607 and 0608 | < 0.05 |

— Indicates a pair analysis with no statistical significance.

**Table 68. Ranking of rehabilitation strategies for short-term roughness performance of SPS-6 sites with JPCP.**

| Section | Ranking | Restoration | Overlay (mm) |
|---|---|---|---|
| 0608 | 1 | Crack/break and seat | 203 |
| 0603 | 2 | Minimum | 102 |
| 0604 | 2 | Saw and seal | 102 |
| 0606 | 2 | Maximum | 102 |
| 0602 | 5 | Minimum | No |
| 0605 | 5 | Maximum | No |
| 0607 | 5 | Crack/break and seat | 102 |
| 0601 | 5 | Control | No |

1 inch = 25.4 mm

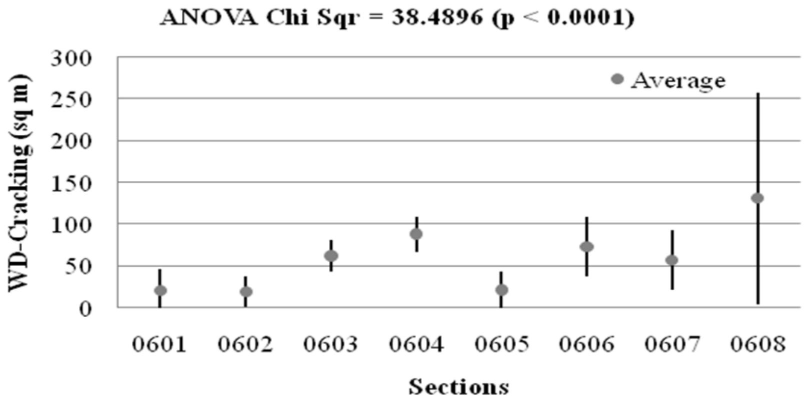
**Table 69. Ranking of rehabilitation strategies for long-term roughness performance of SPS-6 sites with JPCP.**

| Section | Ranking | Restoration | Overlay (mm) |
|---|---|---|---|
| 0608 | 1 | Crack/break and seat | 203 |
| 0603 | 2 | Minimum | 102 |
| 0606 | 2 | Maximum | 102 |
| 0604 | 2 | Saw and seal | 102 |
| 0605 | 5 | Maximum | No |
| 0607 | 5 | Crack/break and seat | 102 |
| 0602 | 5 | Minimum | No |
| 0601 | 8 | Control | No |

1 inch = 25.4 mm

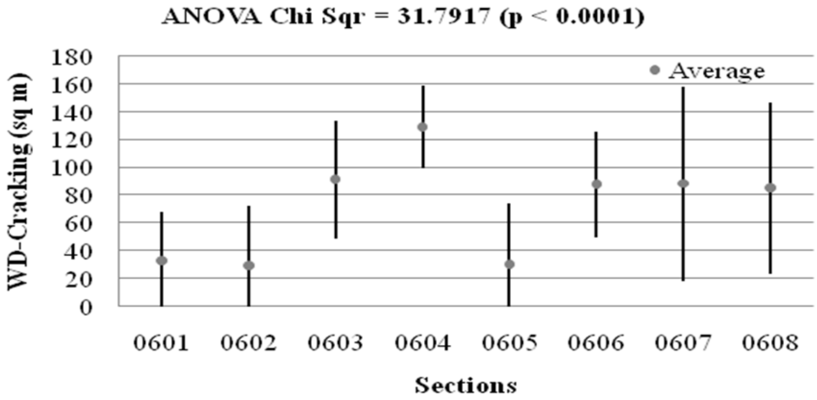
Results from table 68 and table 69 suggest that the rehabilitation alternative for section 0608 (crack/break and seat with an 8-inch (203-mm) overlay) was the best performing treatment for roughness in both the short term and long term. The statistical analysis also suggests that there was practically no difference in performance between sections overlaid with 4-inch (102-mm) HMA regardless of the restoration treatment performed prior to the overlay, except the alternative crack/break and seat with a 4-inch (102-mm) overlay, which was the poorer alternative with overlays. Roughness performance for this rehabilitation alternative was equivalent to not having an overlay after restoration.

The same approach described for the analysis of roughness was applied to total cracking, which was computed as the sum of fatigue, longitudinal, and transverse cracking measured in sections overlaid with HMA and the sum of transverse and longitudinal slab cracking measured in sections without HMA overlays. Figure 42 ($p < 0.0001$, ANOVA chi-square = 38.4896) and figure 43 ($p < 0.0001$, ANOVA chi-square = 31.7919) describe the Friedman ANOVA test for this type of distress. Based on the same test statistics, the ranking of best performing rehabilitation strategies for total cracking was created.



1 ft = 0.305 m

**Figure 42. Graph. Average short-term WD-cracking for JPCP at SPS-6 sites.**



1 ft = 0.305 m

**Figure 43. Graph. Average long-term WD-cracking for JPCP at SPS-6 sites.**

table 70 show a compilation of the rankings for roughness and total cracking performances for short-term performance, and table 71 presents the results for long-term performance.

**Table 70. Summary of rankings for short-term performance of JPCP structures at SPS-6 sites.**

| Statistical Relevance (Y/N) | Distress | | | | | |
|---|---|---|---|---|---|---|
| | Roughness | | | Total Cracking | | |
| | Y | $p = 0.0004$ | | Y | $p = 0.0004$ | |
| | **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| Ranking (if relevant) | 1 | Crack/break and seat | 203 | 1 | Minimum | None |
| | 2 | Minimum | 102 | 2 | Maximum | None |
| | 2 | Saw and seal | 102 | 2 | None | None |
| | 2 | Maximum | 102 | 4 | Crack/break and seat | 102 |
| | 5 | Minimum | None | 5 | Minimum | 102 |
| | 5 | Maximum | None | 5 | Crack/break and seat | 203 |
| | 5 | Crack/break and seat | 102 | 5 | Maximum | 102 |
| | 5 | Control | | 8 | Saw and seal | 102 |

1 inch = 25.4 mm

Note: The blank cell indicates that there was no overlay for the control.

**Table 71. Summary of rankings for long-term performance of JPCP structures at SPS-6 sites.**

| Statistical Relevance (Y/N) | Distress | | | | | |
|---|---|---|---|---|---|---|
| | Roughness | | | Total Cracking | | |
| | Y | $p < 0.0001$ | | Y | $p < 0.0001$ | |
| | **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| Ranking (if relevant) | 1 | Crack/break and seat | 203 | 1 | None | None |
| | 2 | Minimum | 102 | 1 | Minimum | None |
| | 2 | Maximum | 102 | 1 | Maximum | None |
| | 2 | Saw and seal | 102 | 4 | Crack/break and seat | 203 |
| | 5 | Maximum | None | 4 | Crack/break and seat | 102 |
| | 5 | Crack/break and seat | 102 | 4 | Maximum | 102 |
| | 5 | Minimum | None | 4 | Minimum | 102 |
| | 8 | Control | | 8 | Saw/seal | 102 |

1 inch = 25.4 mm

Note: The blank cell indicates that there was no overlay for the control.

The impact of rehabilitation strategies on roughness and total cracking performance was investigated for all sections in the JPCP sites of the SPS-6 experiment. Results from the statistical analysis suggest that rehabilitation treatments with HMA overlay provided smoother pavement sections. The best alternatives to mitigate the progression of total cracking were those without overlays. This result was influenced by the fact that, when combining all cracking from HMA overlays on PCC (including saw and seal joints), reflective cracking at joints was surveyed as longitudinal and transverse cracks, which significantly increased the amount of cracking observed in HMA overlaid sections. The main conclusions from table 70 and table 71 are as follows:

- Rehabilitation strategies with overlays were significantly smoother than treatments without overlays.
- The best alternative to improve roughness performance was to use the thicker overlay alternative (crack/break and seat with 7.9-inch (203-mm) overlay).
- Crack/break and seat with a 4-inch (102-mm) overlay was among the worst alternatives to improve roughness performance.
- Rehabilitation strategies without overlays were the best to mitigate crack development and propagation.
- Saw and seal was rated as the worst alternative to prevent cracking; however, the design goal of this alternative was control of reflection cracks. This alternative provided similar smoothness to other 4-inch (102-mm) overlays.
- Crack/break and seat of JPCP had no significant effect on reducing the amount of cracking, and it performed similarly to the 4-inch (102-mm) overlay over noncracked JPCP (with both minimum and maximum restorations).

### Influence of Site Conditions

The influence of site conditions was determined by two variables: pavement surface condition prior to rehabilitation (fair versus poor) and climate (wet versus dry and freeze versus no-freeze). These conditions were determined for each site, and the Friedman test was applied to each group.

Additionally, traffic was investigated, and AADTT volumes were computed from 2000 to 2007. No significant variation in daily truck traffic was found among the sites in the SPS-6 experiment. All sites had AADTT values close to 800 trucks except for Missouri (1,700 average daily trucks) and South Dakota (292 daily trucks). Therefore, there were not enough sites with significant variations in traffic level that resulted in meaningful statistical results.

The analysis followed the same steps described in the previous section. Rehabilitation strategy rankings were developed for each group of sites using the paired analyses from the Friedman test if statistical differences in performance were found.

Table 72 and table 73 provide the rankings for roughness and total cracking for long-term performance in sections with poor and fair surface conditions prior to rehabilitation. For both tables, four sites were used in the analysis of poor surface condition. Despite grouping the data according to similar characteristics in respect to surface condition, the strategy rankings remained unaltered from the ranking considering all sites. One result was that the maximum restoration effort provided a smoother pavement in the long term than the minimum effort when neither received a HMA overlay.

**Table 72. Summary of rankings for long-term performance of JPCP structures at SPS-6 sites in poor surface condition prior to rehabilitation.**

| **Statistical Relevance (Y/N)** | **Distress** | | | | | |
|---|---|---|---|---|---|---|
| | **Roughness** | | | **Total Cracking** | | |
| | Y | *p* = 0.0007 | | N | | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 203 | | | |
| | 2 | Minimum | 102 | | | |
| | 2 | Saw/seal | 102 | | | |
| | 2 | Maximum | 102 | | | |
| | 2 | Crack/break and seat | 102 | | | |
| | 2 | Maximum | None | | | |
| | 7 | Minimum | None | | | |
| | 7 | Control | | | | |

1 inch = 25.4 mm

Note: Blank cells indicate that no data are available because cracking did not have statistical relevance.

**Table 73. Summary of rankings for long-term performance of JPCP structures at SPS-6 sites in fair surface condition prior to rehabilitation.**

| **Statistical Relevance (Y/N)** | **Distress** | | | | | |
|---|---|---|---|---|---|---|
| | **Roughness** | | | **Total Cracking** | | |
| | Y | *p* = 0.0052 | | Y | *p* = 0.0009 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 203 | 1 | Maximum | None |
| | 2 | Maximum | 102 | 1 | Minimum | None |
| | 2 | Minimum | 102 | 3 | Control | |
| | 2 | Maximum | None | 3 | Crack/break and seat | 203 |
| | 2 | Saw/seal | 102 | 3 | Crack/break and seat | 102 |
| | 2 | Minimum | None | 3 | Minimum | 102 |
| | 2 | Crack/break and seat | 102 | 3 | Maximum | 102 |
| | 8 | None | None | 8 | Saw/seal | 102 |

1 inch = 25.4 mm

Note: The blank cell indicates that there was no overlay for the control.

The influence of other site conditions was evaluated, and tables containing the statistical results and rankings are presented in appendix D.

After a careful assessment of the results from all the analyses performed, summary tables were assembled for better visualization and interpretation of results. These tables were created for each distress and analysis period (short-term and long-term performance). Table 74 and table 75 present the results for short-term and long-term roughness, while table 76 and table 77 describe the results for short-term and long-term total cracking. The best alternatives with statistical relevance are shown in each cell. The number before the treatment indicates its ranking among all the alternatives.

These summary tables provide information for selecting the best rehabilitation alternative among those evaluated in this study based on distress type and site conditions. Moreover, the influence of different site conditions can be determined by observing the best treatments for each condition. The analysis of sites in different climate regions and with different surface conditions resulted in rankings that are similar to each other. Therefore, the study suggests that site conditions did not have a significant impact on roughness and total cracking performance for the rehabilitation strategies included in the SPS-6 JPCP experiment.

**Table 74. Summary of short-term roughness performance of JPCP structures.**

| Climate | | Surface Condition | | | |
|---|---|---|---|---|---|
| | | **Poor** | **Overlay (mm)** | **Fair** | **Overlay (mm)** |
| Wet | Freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1:Minimum | 102 | 1: Minimum | 102 |
| | | 3: Maximum | 102 | 3: Maximum | 102 |
| | | 3: Saw/seal | 102 | 3: Saw/seal | 102 |
| | No-freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3:Maximum | 102 | 3: Maximum | 102 |
| | | 3: Saw/seal | 102 | 3: Saw/seal | 102 |
| Dry | Freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 1: Saw/seal | 102 | 1: Saw/seal | 102 |
| | No-freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 1: Saw/seal | 102 | 1: Saw/seal | 102 |

1 inch = 25.4 mm

**Table 75. Summary of long-term roughness performance of JPCP structures.**

| Climate | | Surface Condition | | | |
|---|---|---|---|---|---|
| | | Poor | Overlay (mm) | Fair | Overlay (mm) |
| Wet | Freeze | 1 : Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3:Maximum | 102 | 3: Maximum | 102 |
| | | 3:Saw/seal | 102 | 3: Saw/seal | 102 |
| | No-freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3: Saw/seal | 102 | 3: Saw/seal | 102 |
| | | 4: Maximum | 102 | 4: Maximum | 102 |
| Dry | Freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 1: Saw/seal | 102 | 1: Saw/seal | 102 |
| | No-freeze | 1: Crack/break and seat | 203 | 1: Crack/break and seat | 203 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 1: Saw/seal | 102 | 1: Saw/seal | 102 |
| | | 4: Maximum | 102 | 4: Maximum | 102 |

1 inch = 25.4 mm

**Table 76. Summary of short-term total cracking performance of JPCP structures.**

| Climate | | Surface Condition | | | |
|---|---|---|---|---|---|
| | | Poor | Overlay (mm) | Fair | Overlay (mm) |
| Wet | Freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 3: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |
| | No-freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 3: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |
| Dry | Freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 1: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |
| | No-freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 1: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |

1 inch = 25.4 mm

Note: Blank cells indicate that there was no overlay for the control.

**Table 77. Summary for long-term total cracking performance of JPCP structures.**

| | | Surface Condition | | | |
|---|---|---|---|---|---|
| Climate | | Poor | Overlay (mm) | Fair | Overlay (mm) |
| Wet | Freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 1: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |
| | No-freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 1: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |
| Dry | Freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 1: Control | | 3: Control | |
| | | 4: Crack/break and seat | 102 | 4: Crack/break and seat | 102 |
| | No-freeze | 1: Maximum | None | 1: Maximum | None |
| | | 1: Minimum | None | 1: Minimum | None |
| | | 1: Control | | 3: Control | |
| | | 4: Crack/beak and seat | 102 | 4: Crack/break and seat | 102 |

1 inch = 25.4 mm
Note: Blank cells indicate that there was no overlay for the control.

The summary tables show only alternatives in which statistically significant differences in performance were found. The tables were developed to identify the best alternatives for each type of analysis performed. The selected rehabilitation alternatives were then grouped for each combination of site conditions. Although these may be the best performance alternatives, they may not be the lowest cost alternatives, and selection of a rehabilitation alternative must also consider the cost.

From the summary tables, the following conclusion was made: crack/break and seat with 8-inch (203-mm) overlays and minimum restoration with 4-inch (102-mm) overlays were statistically equivalent and were found to be the best alternatives for most of the scenarios evaluated when short-term and long-term roughness performance was considered. Additionally, these alternative would be the highest cost alternative.

The analysis of total cracking indicated the following:

- The three alternatives without overlays (no treatment control scenario, minimum restoration, and maximum restoration) were found to be the best choices for short-term and long-term performance.

- Crack/break and seat with 4-inch (102-mm) overlays was the best alternative among options involving overlays.

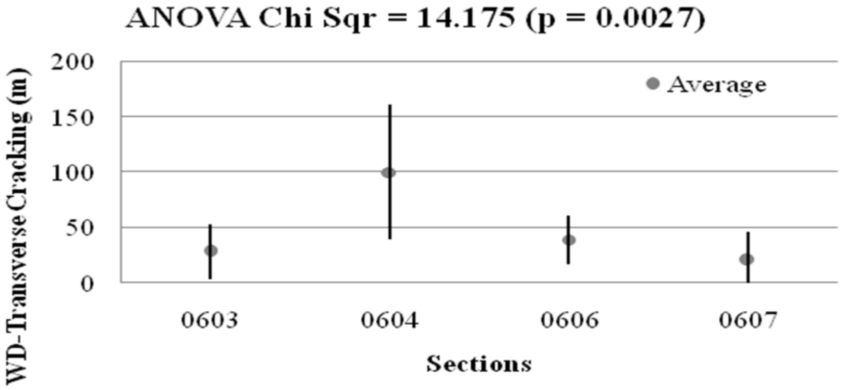
The sawed and sealed joints did not deteriorate significantly on these sections, and they became an effective control of reflection cracking. If they were removed from total cracking, the saw and sealed sections would have shown similar performance to other HMA overlays.

### *PCC Restoration Prior to Overlay*

Different restoration treatments were applied prior to the installation of a 4-inch (102-mm) overlay in four sections as part of the rehabilitation strategy. The impact on performance of these PCC restoration treatments was evaluated by analyzing a subset of the data that included only four sections: 0603, 0604, 0606, and 0607 (see table 62). The same approach used in the analysis of the entire dataset and described in the previous section was applied in this investigation.

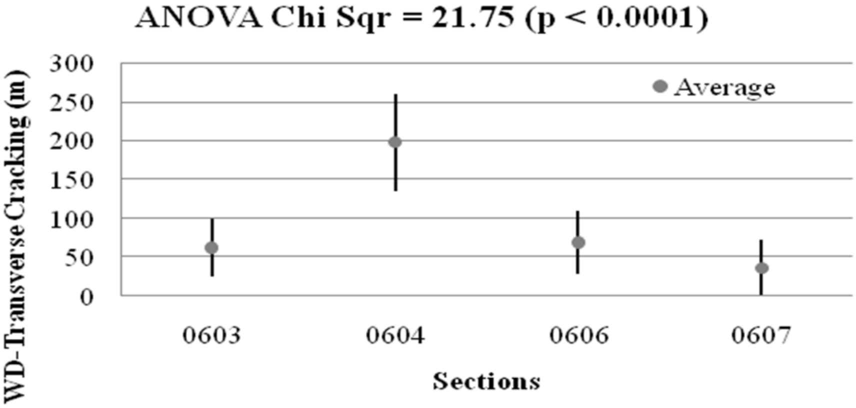
The surface layer after the rehabilitation that was completed was HMA, and the monitoring program to survey these sections was typically used for flexible pavements. Rutting, fatigue, and longitudinal and transverse cracking were used as performance measures. The subset of data was too small to provide results with statistical significance for the majority of distresses observed. Within the availability of data, only short-term and long-term transverse cracking performance was found to be statistically significant, and the results provided insight on expected performance.

Figure 44 ($p = 0.0027$, ANOVA chi-square = 14.175) and figure 45 ($p < 0.0001$, ANOVA chi-square = 21.75) present the average transverse cracking values computed as WD for both short-term and long-term performance. The vertical bars represent the variability among all sites represented by 1 standard deviation from the average. Both plots indicate that saw and seal after overlay (section 0604) was the least effective treatment to prevent transverse cracking, while crack/break and seat (section 0607) was the most effective. It could be argued that the sawed and sealed joints should be excluded from the analysis. This would result in saw and seal being similar to or better than any other overlay. The complete rankings of best-performing rehabilitation treatments with overlay are provided in table 78 and table 79 for short-term and long-term performance.



1 ft = 0.305 m

**Figure 44. Graph. Average short-term WD-transverse cracking values for JPCP at SPS-6 sites.**



1 ft = 0.305 m

**Figure 45. Graph. Average long-term WD-transverse cracking values for JPCP at SPS-6 sites.**

**Table 78. Summary of rankings for short-term performance of JPCP composite structures at SPS-6 sites.**

| Transverse Cracking | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | *p* = 0.0027 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 102 |
| | 2 | Minimum | 102 |
| | 2 | Maximum | 102 |
| | 4 | Saw/seal | 102 |

1 inch = 25.4 mm

**Table 79. Summary of rankings for long-term performance of JPCP composite structures at SPS-6 sites.**

| **Transverse Cracking** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | $p < 0.0001$ | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 102 |
| | 2 | Minimum | 102 |
| | 3 | Maximum | 102 |
| | 4 | Saw/seal | 102 |

1 inch = 25.4 mm

The impact of PCC restoration treatments on performance of overlaid sections was investigated in the JPCP sites of the SPS-6 experiment. Transverse cracking was the only distress for which statistical differences were found between the four treatments. The conclusions from this study were as follows:

- The best alternative to limit the development and propagation of transverse cracking among all options with 4-inch (102-mm) overlays was crack/break and seat.

- Minimum and maximum restorations had an equivalent impact on short-term transverse cracking performance.

## Influence of Site Conditions

The analysis of impact of site conditions had additional constraints on data availability. Statistical differences in performance were identified for short-term roughness and short-term and long-term transverse cracking only. The results are presented in summary tables in appendix D.

Summary tables combine the results for all site conditions and provide a better visualization and interpretation of the outcome. They present the alternatives in which statistical significant differences in performance were found in the analysis. Blank cells indicate no statistical differences in performance of the selected alternatives. The rankings of best alternatives are shown in each cell. The number before the alternative indicates its ranking among all eight alternatives. When one or more alternatives were found to perform better than other sections but no difference was found between the selected ones, the same ranking was assigned to the group of alternatives. Table 80 presents the best restoration treatments prior to overlay for short-term roughness performance.

**Table 80. Performance for short-term roughness of overlaid JPCP structures.**

| Climate | | Surface Condition | | | |
|---|---|---|---|---|---|
| | | Poor | Overlay (mm) | Fair | Overlay (mm) |
| Wet | Freeze | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 1: Saw/seal | 102 | 1: Saw/seal | 102 |
| | No-freeze | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 1: Saw/seal | 102 | 1: Saw/seal | 102 |
| Dry | Freeze | | | | |
| | | | | | |
| | | | | | |
| | No-freeze | | | | |
| | | | | | |
| | | | | | |

1 inch = 25.4 mm

Note: Blank cells indicate that all alternatives have statistically equal performances.

Table 81and table 82 present the results for short-term and long-term transverse cracking performance.

**Table 81. Performance for short-term transverse cracking of overlaid JPCP structures.**

| Climate | | Surface Condition | | | |
|---|---|---|---|---|---|
| | | Poor | Overlay (mm) | Fair | Overlay (mm) |
| Wet | Freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | No-freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| Dry | Freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | No-freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Maximum | 102 | 1: Maximum | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |

1 inch = 25.4 mm

**Table 82. Performance for long-term transverse cracking of overlaid JPCP structures.**

| Climate | | Surface Condition | | | |
|---|---|---|---|---|---|
| | | Poor | Overlay (mm) | Fair | Overlay (mm) |
| Wet | Freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3: Maximum | 102 | 3: Maximum | 102 |
| | No-freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3:Maximum | 102 | 3: Maximum | 102 |
| Dry | Freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3: Maximum | 102 | 3: Maximum | 102 |
| | No-freeze | 1: Crack/break and seat | 102 | 1: Crack/break and seat | 102 |
| | | 1: Minimum | 102 | 1: Minimum | 102 |
| | | 3: Maximum | 102 | 3: Maximum | 102 |

1 inch = 25.4 mm

The summary tables only present alternatives for which statistically significant differences in performance were found. The tables were created by considering the best alternatives for each analysis performed in the dataset. These selected rehabilitation alternatives were then grouped for each combination of site conditions.

Based on the summary tables, the following conclusions were made:

- Statistical differences in performance of overlaid sections were observed only for transverse cracking and short-term roughness when individual site characteristics were considered.

- There was no impact on performance due to variations in surface condition prior to rehabilitation or the climatic region where the LTPP site was located.

- Minimum, maximum, and saw and seal restorations provided the best short-term roughness performance, but there was no difference between the rehabilitation alternatives for long-term performance.

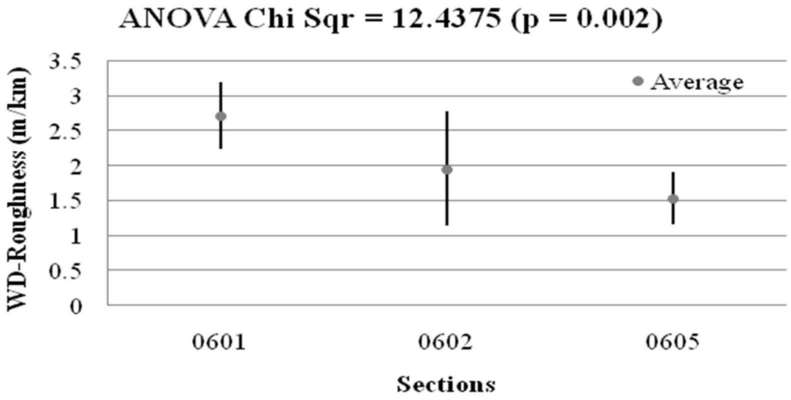
- Crack/break and seat and minimum restoration were the best alternatives to mitigate the development and propagation of transverse cracking for long-term performance.

### *PCC Restoration*

Three sections in each SPS-6 site did not receive overlays as part of their rehabilitation strategies, and they were used to evaluate the impact of PCC restoration on performance. These sections were 0601 (control), 0602 (minimum restoration), and 0605 (maximum restoration). The same approach using the Friedman test was applied. Distresses that were common to rigid pavements were used as performance measures.

The small number of sections available for this study significantly reduced the power of the analysis and the chances of finding statistical differences among the treatment alternatives that were evaluated. No statistical differences in performance were found for short-term performance. The only performance indicator that showed statistical differences between the treatments was long-term roughness. Average WD values for long-term roughness are provided in figure 46 along with the variability of measures in the vertical bars representing one standard deviation from the average ($p = 0.002$, ANOVA chi-square = 12.4375). The ranking of best-performing alternatives is presented in table 83. Longitudinal slab cracking provides an example of performance data that were statistically equivalent (see figure 47 ($p = 0.0582$, ANOVA chi-square = 5.6875)). From the long-term roughness analysis, the findings supported by the statistical analysis can be summarized as follows:

- The maximum restoration treatment produced the smoothest pavement over the long term. The weighted roughness for section 0605 was the lowest.
- The minimum restoration treatment produced the next smoothest pavement over the long term.
- The control section was the roughest pavement over the long-term, as expected, while the weighted roughness for section 0601 was the highest.



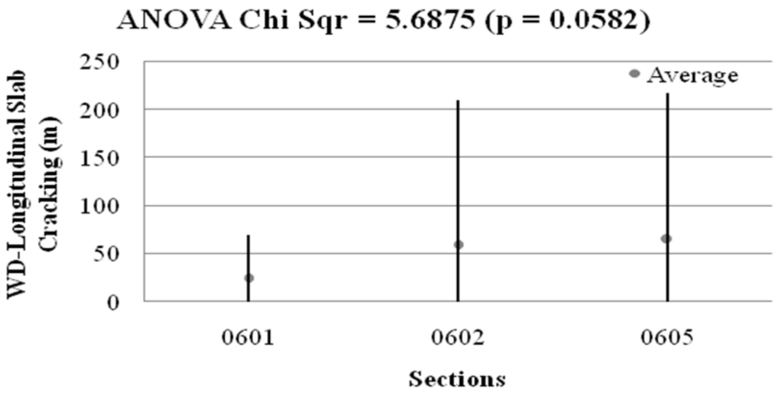
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 46. Graph. Long-term WD-roughness for JPCP at SPS-6 site.**

**Table 83. Rankings for long-term performance of JPCP structures at SPS-6 sites.**

| **Roughness** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | $p$ = 0.002 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Maximum | None |
| | 2 | Minimum | None |
| | 3 | Control | None |

1 inch = 25.4 mm



1 ft = 0.305 m

**Figure 47. Graph. Long-term WD-longitudinal cracking for JPCP at SPS-6 sites.**

An attempt was made to evaluate the impact of site conditions on performance, but the results were not statistically significant. In part, this study remains mostly inconclusive, particularly due to the small sample size and consequent minimal power of the statistical analysis. Additional sections with rehabilitation treatments without overlays would provide a more robust characterization of performance differences among the rehabilitation treatments evaluated in this study.

### *Summary of Findings for JPCP Sites*

When all sections in each site were evaluated simultaneously for roughness and total cracking performance, the following findings were observed:

- Rehabilitation strategies with overlays were significantly smoother than treatments without overlays.
- The best alternative to improve roughness performance was the thicker overlay alternative crack/break and seat with 8-inch (203-mm) overlays.
- Conversely, crack/break and seat with 4-inch (102-mm) overlays was among the worst alternatives to improve roughness performance.

- Rehabilitation strategies without overlays were the best to mitigate cracking development and propagation.

- Saw and seal was rated as the worst alternative to prevent cracking; however, control of reflection cracks was the design goal of this alternative, which was difficult to measure directly. This alternative provided similar smoothness to other 4-inch (102-mm) overlays.

- Crack/break and seat of JPCP had no significant effect in reducing the amount of cracking, and it performed similarly to the 4-inch (102-mm) overlay over noncracked JPCP (with both minimum and maximum restorations).

The results of independent evaluation of sections with HMA overlays suggested the following:

- Based on the available data, only short-term and long-term transverse cracking exhibited statistically meaningful results.

- The best alternative to limit the development and propagation of transverse cracking among all options with 4-inch (102-mm) overlays was crack/break and seat.

- Minimum and maximum restorations had equivalent impacts on short-term transverse cracking performance.

The analysis of rehabilitation treatments without HMA overlays suggested the following:

- Based on the available data, only long-term roughness exhibited statistically meaningful results.

- The maximum restoration treatment produced the smoothest pavement over the long term.

- The minimum restoration treatment produced the next smoothest pavement over the long term.

- The control section was the roughest pavement over the long term, as expected.

## JRCP

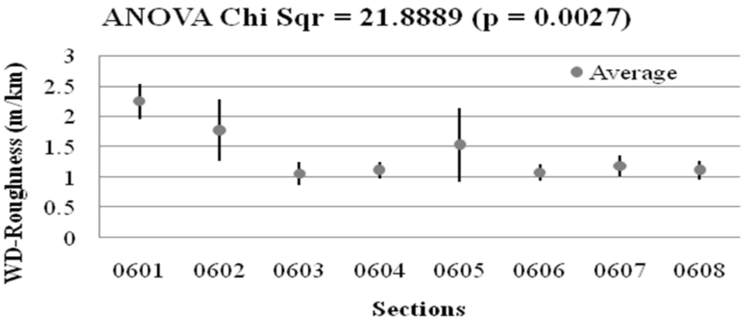
This section describes the analysis results for JRCP sites in the SPS-6 experiment. There were six sites with JRCP structures in the experiment (see table 63). Similar to the study of JPCP sites, the analysis of SPS-6 sites with JRCP structures was originally intended to consider the impact of rehabilitation strategies on performance as well as the influence of climate and pavement surface conditions prior to rehabilitation. Unfortunately, the number of sites evaluated for each climatic region and surface condition was too small for any meaningful statistical analysis. Therefore, only the analysis considering all sites simultaneously was conducted. The study was divided in three parts: (1) all rehabilitation strategies, (2) PCC restoration prior to overlay, and (3) PCC restoration without overlay.

### *Analysis of All Rehabilitation Strategies*

Roughness and total cracking were used to characterize performance and simultaneously evaluate all alternatives. Roughness was the only performance indicator measured for all sections within each site. The surveys were independent from surface type and were performed systematically during the experiment. They provided a uniform way of comparing the impact of different rehabilitation strategies used in the experiment. In addition to roughness, total cracking was used as an indicator of performance for the analysis of all sections. In this case, the measurements were not obtained directly. Cracking was measured depending on the surface layer type after the rehabilitation strategy was completed. For this study, total cracking was computed as the sum of fatigue, longitudinal cracking, and transverse cracking measured in sections overlaid with HMA and the sum of transverse and longitudinal slab cracking measured in sections without HMA overlays.

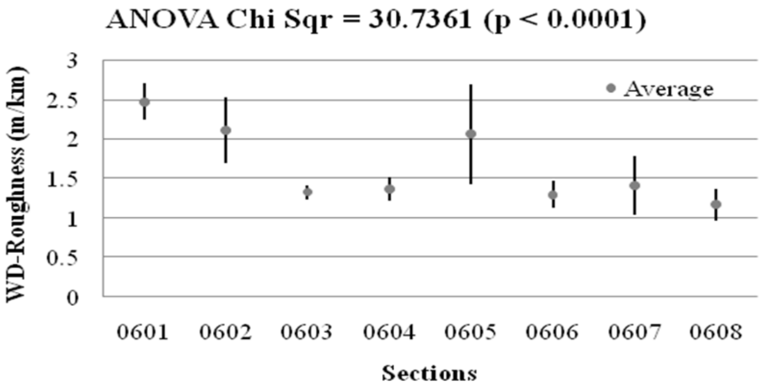
The same analysis approach described in previous sections using WD and the Friedman test was used to evaluate the impact of rehabilitation strategies of JRCP structures. After the data were processed and verified for quality, WD was computed for short-term and long-term performance. The Friedman test used WD to create a ranking of performance from the lowest value of WD (best performance) to the highest value (worst performance) for each site in the dataset. WD results for the entire set were then used in to determine the chi-square statistics to evaluate if differences existed among the performance rankings of the sections.

Roughness and long-term total cracking performances were statistically different among the rehabilitation strategies investigated. The results of the statistical analysis are presented in figure 48 ($p = 0.0027$, ANOVA chi-square = 21.8889), figure 49 ($p < 0.0001$, ANOVA chi-square = 30.7361), and figure 50 ($p = 0.0047$, ANOVA chi-square = 20.4444). Similar to the results for the JPCP sites, the results suggested that rehabilitation strategies with HMA overlays improved roughness performance, while strategies without overlays were better for improving total cracking development and propagation. The complete ranking of best-performing rehabilitation treatments with overlays is provided in table 84 for short-term performance and in table 85 for long-term performance.



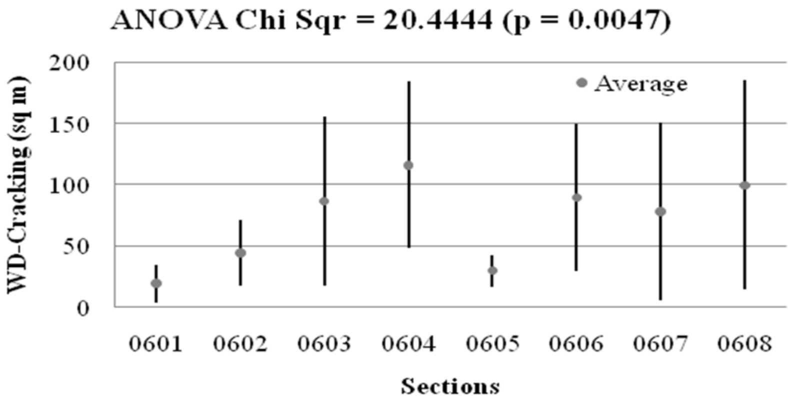
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 48. Graph. Short-term WD-roughness values for JRCP at SPS-6 sites.**



1 ft = 0.305 m
1 mi = 1.61 km

Figure 49. Graph. Long-term WD-roughness values for JRCP at SPS-6 sites.



1 $ft^2$ = 0.093 $m^2$

Figure 50. Graph. Long-term WD-total cracking values for JRCP at SPS-6 sites.

**Table 84. Rankings for short-term performance of JRCP structures at SPS-6 sites.**

| Distress | | | | | | |
|---|---|---|---|---|---|---|
| **Statistical Relevance (Y/N)** | **Roughness** | | | **Total Cracking** | | |
| | Y | $p = 0.0027$ | | N | | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Minimum | 102 | | | |
| | 1 | Maximum | 102 | | | |
| | 3 | Crack/break and seat | 203 | | | |
| | 3 | Saw/seal | 102 | | | |
| | 3 | Crack/ break and seat | 102 | | | |
| | 3 | Maximum | None | | | |
| | 3 | Minimum | None | | | |
| | 8 | Control | | | | |

1 inch = 24.5 mm

Note: The blank cells indicate that no differences were found in short-term total cracking performance among all treatments.

**Table 85. Rankings for long-term performance of JRCP structures at SPS-6 sites.**

| Distress | | | | | | |
|---|---|---|---|---|---|---|
| **Statistical Relevance (Y/N)** | **Roughness** | | | **Total Cracking** | | |
| | Y | $p < 0.0001$ | | Y | $p = 0.0047$ | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 203 | 1 | None | |
| | 2 | Maximum | 102 | 1 | Maximum | None |
| | 2 | Minimum | 102 | 3 | Minimum | None |
| | 4 | Crack/break and seat | 102 | 3 | Crack/break and seat | 102 |
| | 4 | Saw/seal | 102 | 3 | Minimum | 102 |
| | 6 | Maximum | None | 3 | Maximum | 102 |
| | 6 | Minimum | None | 3 | Crack/break and seat | 203 |
| | 8 | None | None | 8 | Saw/seal | 102 |

1 inch = 24.5 mm

Note: The blank cell indicates that there was no overlay for the control.

The results from table 84 and table 85 suggest that rehabilitation strategies with overlays were better for improving roughness performance for both short-term and long-term performance when compared to strategies without overlays. No difference was found in short-term total cracking performance among all treatments, while the control section (no treatment) and maximum restoration without overlays were identified as the best strategies in the long term.

The impact of rehabilitation strategies on roughness and total cracking performance was investigated for all sections in the JRCP sites. Results from the statistical analysis suggest that rehabilitation treatments with HMA overlays provided smoother pavement sections, as expected. The best alternatives to mitigate the progression of total cracking were the ones without overlays. This result was probably influenced by the fact that, when combining all cracking from HMA overlays on PCC, reflective cracking at joints were surveyed as longitudinal and transverse cracks. Additionally, for nonoverlaid sections, the joints were not counted as cracks, which significantly increased the amount of cracking observed during the surveys of HMA overlaid sections. The main conclusions from table 84 and table 85 were as follows:

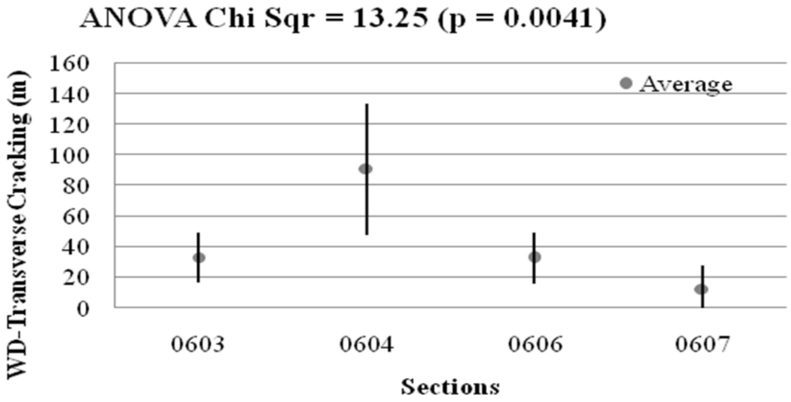
- Rehabilitation strategies with overlays had significantly better roughness performance than treatments without overlays.
- Minimum and maximum restorations with overlays were the best strategies to improve short-term performance for roughness.
- The best alternative for long-term performance was the thick overlay alternative crack/break and seat with 8-inch (203-mm) overlays.
- Rehabilitation strategies without overlays were the best treatments when considering total cracking.
- Saw and seal was the worst treatment to prevent cracking among all of the options that were evaluated.
- Crack/break and seat of JRCP had no significant effect on reducing the amount of cracking, and it performed similarly to the 4-inch (102-mm) overlay over noncracked JRCP (with minimum and maximum restoration).

The sawed and sealed joints did not deteriorate significantly on these sections, and they became an effective control of reflection cracking. If they were removed from total cracking, the saw and sealed sections would have shown similar performance to other HMA overlays.

### *PCC Restoration Prior to Overlay*

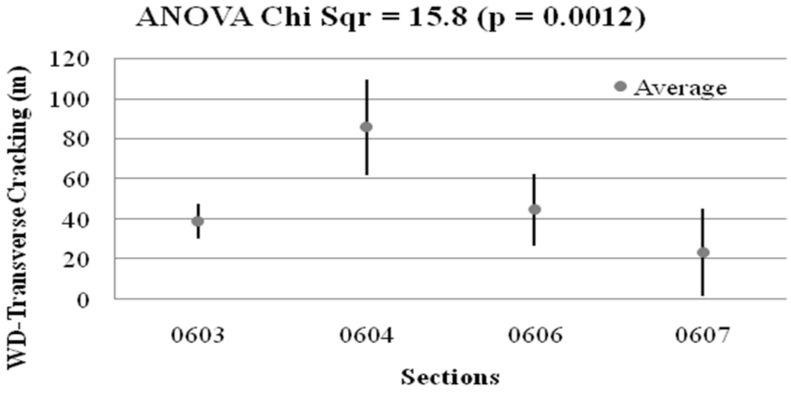
The impact on performance of PCC restoration prior to overlaying the structure with HMA was evaluated by analyzing a subset of the data that included sections 0603, 0604, 0606, and 0607 (see table 62). The sample size was too small to identify statistical differences for the majority of distresses evaluated. Only short-term and long-term transverse cracking performances were found to be statistically different when comparing the rehabilitation alternatives.

Figure 51 ($p = 0.0041$, ANOVA chi-square = 13.25) and figure 52 ($p = 0.0012$, ANOVA chi-square = 15.8) summarize the average WD results with associated standard deviations for short-term and long-term values. Both figures indicate that saw and seal prior to overlay (section 0604) was the worst treatment to prevent transverse cracking when the sawed joints were considered cracks, while crack/break and seat (section 0607) was the best treatment. The complete rankings of best-performing rehabilitation treatments with overlays are provided in table 86 for short-term performance and in table 87 for long-term performance.



1 ft = 0.305 m

Figure 51. Graph. Average short-term WD-transverse cracking values for JRCP at SPS-6 sites.



1 ft = 0.305 m

Figure 52. Graph. Average long-term WD-transverse cracking values for JRCP at SPS-6 sites.

**Table 86. Rankings for short-term performance of JRCP composite structures at SPS-6 sites.**

| **Transverse Cracking** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | *p* = 0.0041 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 102 |
| | 2 | Maximum | 102 |
| | 2 | Minimum | 102 |
| | 4 | Saw/seal | 102 |

1 inch = 25.4 mm

**Table 87. Rankings for long-term performance of JRCP composite structures at SPS-6 sites.**

| **Transverse Cracking** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | *p* = 0.0012 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Crack/break and seat | 102 |
| | 1 | Minimum | 102 |
| | 3 | Maximum | 102 |
| | 4 | Saw/seal | 102 |

1 inch = 25.4 mm

The impact of PCC restoration treatments on performance of overlaid sections was investigated for JRCP sites of the SPS-6 experiment. Transverse cracking was the only distress for which statistical differences were found between the four treatments. The conclusions from this study were as follows:

- Crack/break and seat was the best alternative for short-term performance.
- Minimum and maximum restorations had equivalent impacts on short-term performance.
- The best alternatives to limit the development and propagation of transverse cracking in the long term were crack/break and seat and minimum restoration.
- Saw and seal prior to overlay was the worst treatment among all options evaluated in the SPS-6 experiment.

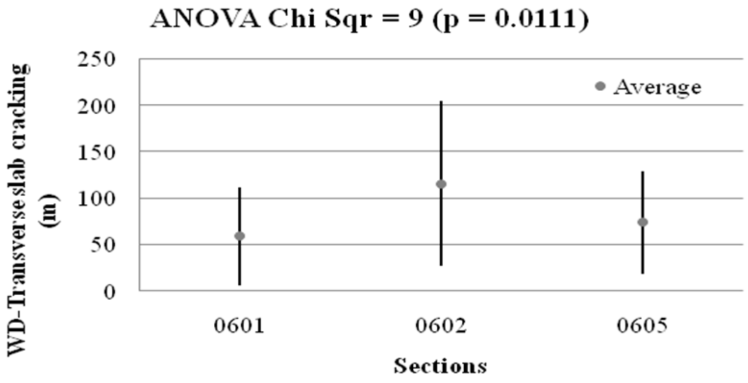
The sawed and sealed joints did not significantly deteriorate on these sections, and they became an effective control of reflection cracking. If they were removed from total cracking, the sawed and sealed sections would have shown similar performance to other HMA overlays.

***PCC Restoration***

Three sections in each SPS-6 site did not receive overlays as part of their rehabilitation strategies, and they were used to evaluate the impact of PCC restoration on performance. The sections included 0601 (control), 0602 (minimum restoration), and 0605 (maximum restoration). Distresses common to rigid pavements were used as performance measures.

The only performance indicator that showed statistical differences between the treatments was short-term transverse slab cracking. Average WD values for short-term transverse slab cracking are provided in figure 53 ($p$ = 0.0111, ANOVA chi-square = 9) along with the variability of measures in the vertical bars represented by one standard deviation from the average. From this figure, the ranking of best-performing alternatives was created and is presented in table 88.

The maximum restoration treatment and the control section had statistically equivalent performances for short-term transverse slab cracking. The minimum restoration treatment provided the worst transverse slab cracking performance. The small number of sites limited the statistical findings.



1 inch = 25.4 mm

**Figure 53. Graph. Short-term average WD-transverse cracking values for JRCP at SPS-6 sites.**

**Table 88. Rankings for short-term performance of JRCP structures at SPS-6 sites.**

| **Transverse Cracking** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | $p$ = 0.0111 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 | Maximum | None |
| | 1 | None | None |
| | 3 | Minimum | None |

1 inch = 25.4 mm

### *Summary of Findings for JRCP Sites*

When all sections in each site were evaluated simultaneously for roughness and total cracking performance, the following were observed:

- Rehabilitation strategies with overlays had significantly better roughness performance than treatments without overlays.
- Minimum and maximum restorations with overlays were the best strategies to improve short-term performance for roughness.
- The best alternative for long-term performance was the thick overlay alternative crack/break and seat with 8-inch (203-mm) overlays.
- Rehabilitation strategies without overlays were the best treatments when considering total cracking.
- Saw and seal was the worst treatment to prevent cracking among all options evaluated.
- Crack/break and seat of JRCP had no significant effect on reducing the amount of cracking, and it performed similarly to the 4-inch (102-mm) overlay over noncracked JRCP (with minimum and maximum restoration).

The results of independent evaluation of sections with HMA overlays suggested the following:

- Crack/break and seat was the best alternative for short-term performance.
- Minimum and maximum restorations had equivalent impacts on short-term performance.
- The best alternatives to limit the development and propagation of transverse cracking on the long-term were crack/break and seat and minimum restoration.
- Saw and seal prior to overlay was the worst treatment among all options evaluated in the SPS-6 experiment.

The sawed and sealed joints did not deteriorate significantly on these sections, and they became an effective control of reflection cracking. If reflective cracking could be removed from total cracking, the saw and sealed sections would have shown similar performance to other treatments.

The findings from this statistical analysis of sections without HMA overlay were as follows:

- The maximum restoration treatment and the control section had statistically equivalent performances for short-term transverse slab cracking.
- The minimum restoration treatment provided the worst transverse slab cracking performance.
- The small number of sites limited the statistical findings in this study.

## EFFECT OF DESIGN AND CONSTRUCTION FEATURES AND SITE CONDITIONS ON RESPONSE OF REHABILITATED RIGID PAVEMENTS

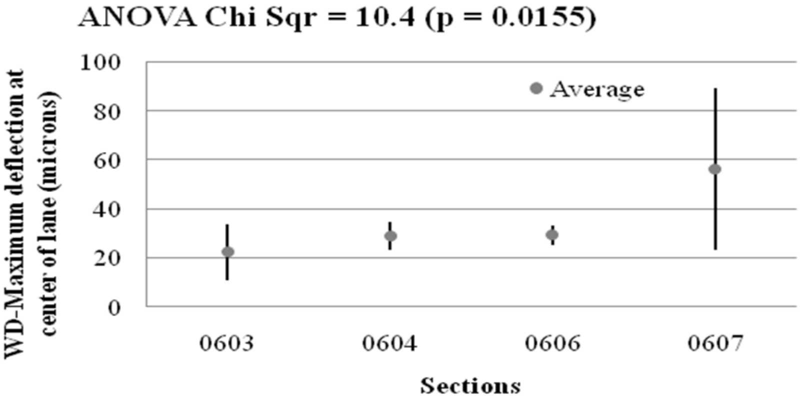
The study to evaluate the impact of design features and site conditions on response of rehabilitated rigid pavements followed the same approach used in the study of performance. FWD deflections obtained from the LTPP database were used as the response measure of the pavement structure. The main difficulty was to determine which deflection measure to use. Sections with concrete slabs at the surface were evaluated as typical rigid pavements. Deflections at the center of the slab and at the transfer joints were used in this study. Sections that received an HMA overlay were monitored like flexible pavements, and deflections at the center of the lane were used.

Two separate analyses were developed to address both deflection measurement patterns. The first analysis was performed by selecting only sections with a concrete slab surface. The analysis investigated the impact of rehabilitation strategies on deflections at the center of the slab and LTE between slabs. The second analysis evaluated the impact of PCC treatments prior to overlay on maximum deflection measured at the center of the lane after being overlaid.

JPCP and JRCP structures were evaluated independently. Sections 0601, 0603, and 0605 were used to evaluate the maximum deflection at the center of the slab and LTE, while sections 0603, 0604, 0606, and 0607 were used to evaluate maximum deflection at the center of the lane in the composite pavement structures. There were limitations due to the amount of data available, especially after the data were grouped by pavement structure type and surface. The statistical power of the analysis was limited because of the small sample size (eight sites), and no statistical differences were found in the pavement response of JPCP structures.

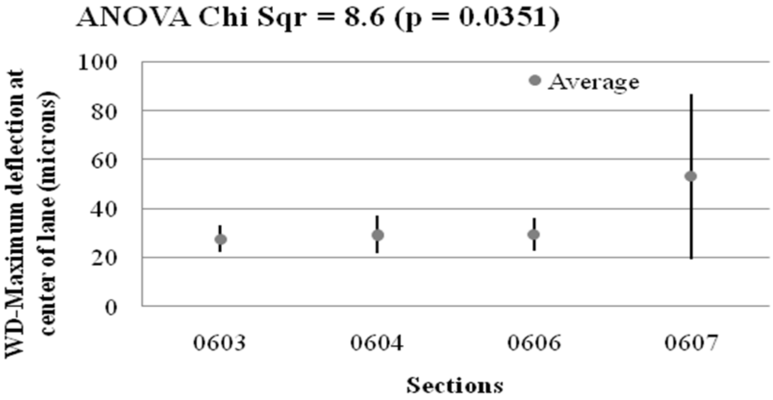
The only analysis that provided some statistically meaningful results was the evaluation of maximum deflection at the center lane of overlaid JRCP structures. Figure 54 ($p = 0.0155$, ANOVA chi-square = 10.4) and figure 55 ($p = 0.0351$, ANOVA chi-square = 8.6) provide the Friedman test results for short-term and long-term maximum deflection, respectively. The vertical bars represent the 68 percent interval, indicating the level of variability given by one standard deviation from the average WD value for maximum deflections.

Table 89 and table 90 present the ranking of rehabilitation strategies based on measurements of maximum deflection at the center of the lane.



1 µm = 0.039 mil

**Figure 54. Graph. Maximum deflection (center of lane) short-term WD values for JRCP at SPS-6 sites.**



1 µm = 0.039 mil

**Figure 55. Graph. Maximum deflection (center of lane) long-term WD values for JRCP at SPS-6 sites.**

**Table 89. Rankings for short-term maximum deflection at the center of the lane of JRCP composite structures in SPS-6 sections.**

| **Maximum Deflection at Center of Lane** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | *p* = 0.0155 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 (Lowest deflection) | Minimum | 102 |
| | 2 | Saw/seal | 102 |
| | 2 | Maximum | 102 |
| | 4 | Crack/break and seat | 102 |

1 inch = 25.4 mm

**Table 90. Rankings for long-term maximum deflection at the center of the lane of JRCP composite structures in SPS-6 sections.**

| **Maximum Deflection at Center of Lane** | | | |
|---|---|---|---|
| **Statistical Relevance (Y/N)** | Y | *p* = 0.0351 | |
| Ranking (if relevant) | **Ranking** | **Strategy** | **Overlay (mm)** |
| | 1 (Lowest deflection) | Maximum | 102 |
| | 1 | Minimum | 102 |
| | 3 | Saw/seal | 102 |
| | 4 | Crack/break and seat | 102 |

1 inch = 25.4 mm

The results suggest that crack/break and seat significantly increased the overall deflections measured on the pavement surface. The remaining treatments interchangeably provided equivalent maximum deflection magnitudes. These results were expected because crack/break and seat was an alternative in which the concrete was reduced to smaller pieces, resulting in lower stiffness that increased the maximum deflection at the center of the slab.

## RELATIONSHIP BETWEEN STRUCTURAL RESPONSES IMMEDIATELY AFTER REHABILITATION AND FUTURE PERFORMANCE

There have been several attempts to find direct relationships or models to predict performance based on the structural response of the pavement to loading immediately after rehabilitation. These relationships are not as straightforward as expected, and accurately deriving them is difficult. The objective of this study was to identify trends in the relationship between response measured immediately after the rehabilitation and the observed performance in the subsequent years of the pavement's service life. If identified, these trends can provide important information and guidance to infer the expected pavement performance as a result of the rehabilitation strategy.

Different structural responses were evaluated against the average pavement performance represented by specific distress levels over time for rehabilitation alternatives of SPS-6 sites. LTE between slabs and maximum deflection at the center of the slab were used when the surface remained concrete slabs after rehabilitation. Maximum deflection at the center of the lane was used when the surface changed to HMA after rehabilitation. The average WD for the specific distress was used as the performance measure. Each response was evaluated against all distresses used previously in this study. Long term-performance was used, which represented performance data for 5 years or more.

The SPS-6 experiment had sites across the United States in different climatic zones and subgrade types. Consequently, the results from this study could be impacted by in situ conditions. The alternative to circumvent this problem was to normalize the data in each site by a common factor. For this purpose, one section was selected to be the normalization factor. Response and performance measured at this section were used to normalize the data of the remaining sections in each site. After some trial and error, the results provided helpful and qualitative information about the expected performance given the pavement response measured after the rehabilitation work had been completed.

### LTE Versus Performance in JPCP

Section 0602 was selected as the normalization factor for the analysis of sections without overlay. Normalized values were computed according to the equation in figure 56. LTE analysis used deflections at the edge of the slabs forming the transverse joint. An average ratio between deflections at the loaded slab and adjacent slab was used to calculate LTE. Only transverse slab cracking exhibited a clear trend with LTE values. Figure 57 shows normalized transverse slab cracking versus normalized LTE. As the efficiency of the load transfer increases, the amount of transverse slab cracking decreases. This trend suggests that good load transfer joint restoration is important to mitigate the development and propagation of slab cracking.

$$Parameter_{Normalized} = \frac{Parameter_{section}}{Parameter_{0602}}$$

**Figure 56. Equation. Parameter subscript normalized.**

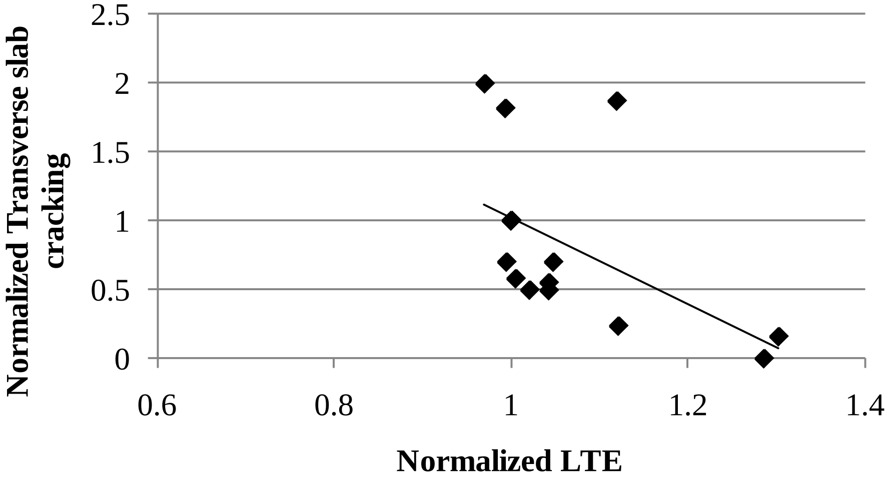


**Figure 57. Graph. Normalized long-term transverse cracking versus normalized LTE measured after rehabilitation of JPCP sites.**

### Maximum Deflection at Center of Slab Versus JPCP Performance

Maximum deflection at the center of the slab was investigated as one possible response that could be associated with future performance. The trend between performance based on roughness and deflection measured at the center of the slab is shown in figure 58, which suggests that higher deflections indicate smoother JPCP over time. This trend is not what would normally be expected, and other correlations for cracking are further examined in the next section.

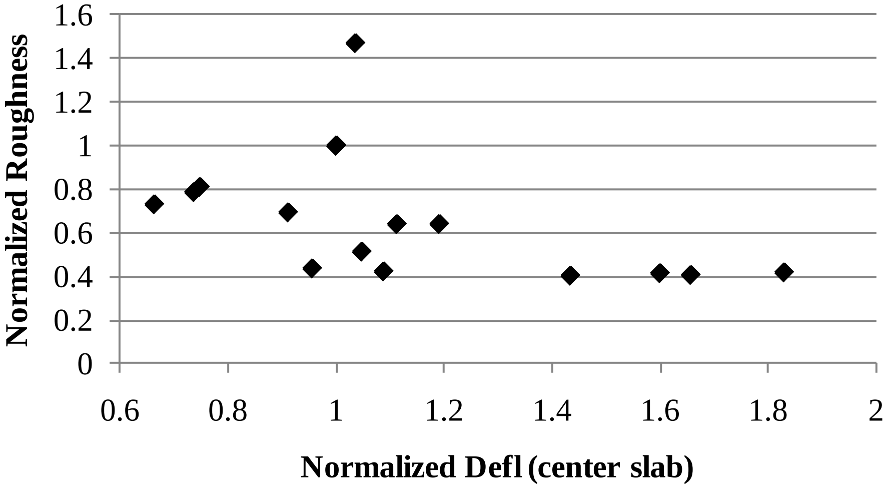


**Figure 58. Graph. Normalized long-term roughness versus normalized deflection at the center of the slab measured immediately after rehabilitation of JPCP sites.**

The level of slab cracking also showed an inverse trend with maximum deflection measured at the center of the slab. The results presented in figure 59 show normalized values for total cracking as a function of normalized deflection. The trend suggests that slabs with higher deflections under FWD loading are less likely to develop cracking. The results shown in figure 60 for longitudinal cracking also suggest the same observation, although no trend was found for transverse cracking (see figure 61). A possible explanation is that stiffer subgrades resulted in higher slab curling and warping stresses, which led to increased slab cracking. This same result was found in MEPDG.(1) While stiffer foundations reduced axle load stresses, they increased curling and warping stresses, which tended to dominate cracking.

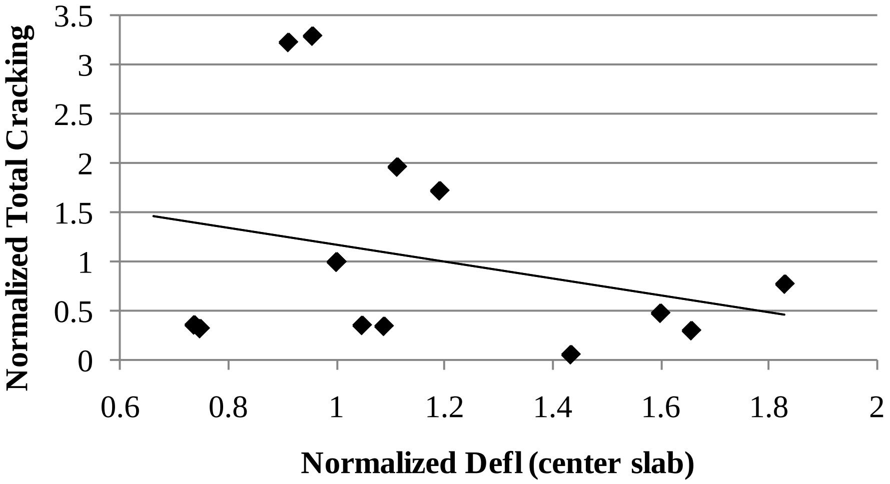


**Figure 59. Graph. Normalized long-term total cracking versus normalized deflection at the center of the slab measured immediately after rehabilitation of JPCP sites.**

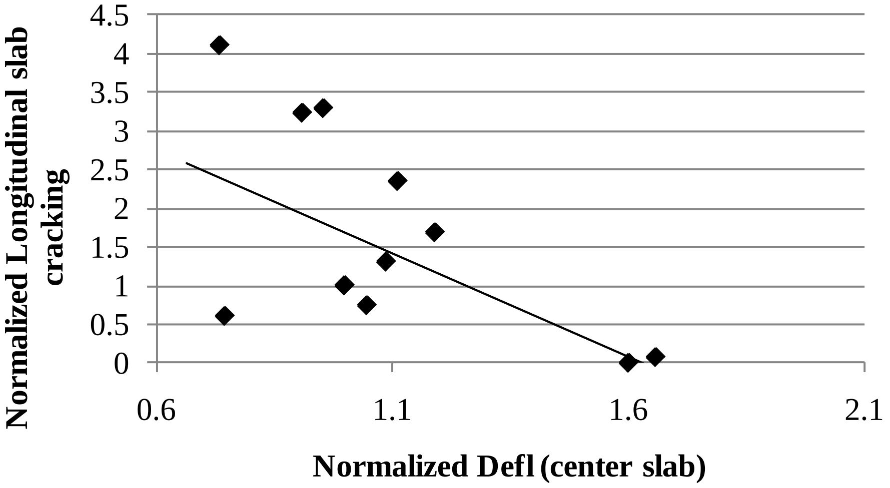


**Figure 60. Graph. Normalized long-term longitudinal slab cracking versus normalized deflection at the center of slab measured after rehabilitation of JPCP sites.**

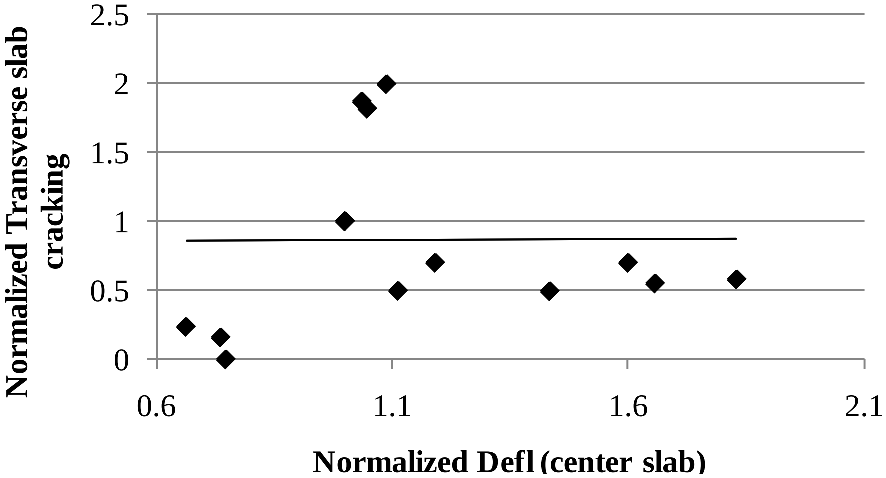


**Figure 61. Graph. Normalized long-term transverse cracking versus normalized deflection at the center of slab measured after rehabilitation of JPCP sites.**

Faulting was also investigated in this study. The trend obtained from the data analyzed is presented in figure 62, suggesting that faulting was inversely proportional to deflection measured at the center of the slab. High deflection values yielded low faulting, although the trend was weak and depended on only one or two points. No logical explanation exists for this result because the opposite result should occur theoretically. However, the small number of data points limited the outcome of the analysis.

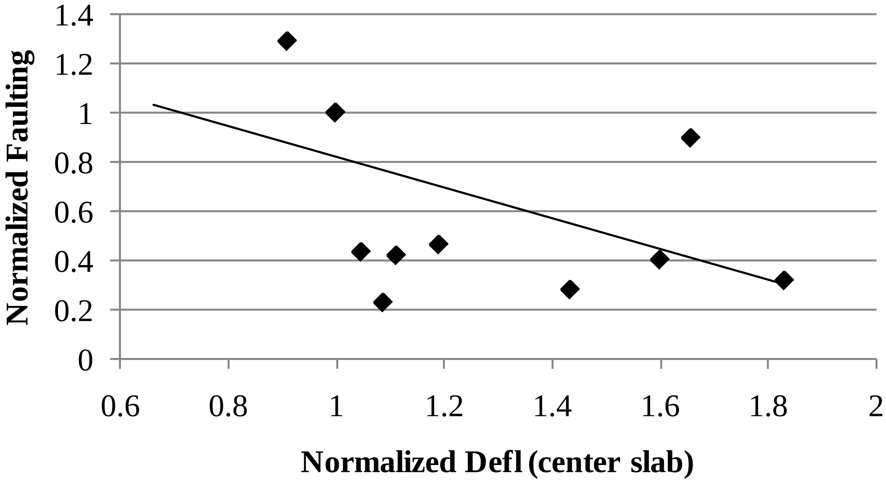


**Figure 62. Graph. Normalized long-term faulting versus normalized deflection at the center of slab measured after rehabilitation of JPCP sites.**

### Maximum Deflection at Center of Lane Versus Performance of Overlaid JPCP

Maximum deflection at the center of the lane was measured in sections that received an overlay as part of the rehabilitation strategy. Sections 0603, 0604, 0606, 0607, and 0608 received different PCC restoration treatments, but all were overlaid as the final step in the rehabilitation process. Section 0603 was chosen for data normalization. Most of the distresses had clear trends with the chosen response. The trends agreed with the conventional understanding and expectations of the relationship between performance and response.

The positive trend between roughness and maximum deflection is shown in figure 63. There was a clear indication in the data, suggesting that overlaid JPCP with high deflections were more likely to be rougher in the long term when compared to sections with low deflection values. Similarly, it was found that overlaid JPCP sections with high center lane deflections were more likely to experience increased rutting compared to sections with low deflection values, as suggested in figure 64. Since most rutting occurred in the HMA layer, the cause for this result was not explainable unless the HMA was so soft that it was contributing to the deflections. Normally, deflections are in the foundation of JPCP.

Fatigue cracking exhibited an expected trend with deflection for overlaid JPCP sections. The trend in figure 65 suggests that high fatigue cracking was expected when deflections values were high. The results in figure 66 suggest that high longitudinal cracking values were observed when maximum deflection at the center of the lane was low. This indicated that the pavement structure was less deformable and more susceptible to surface tensile stresses, which was an important contributor to development and propagation of longitudinal cracking.

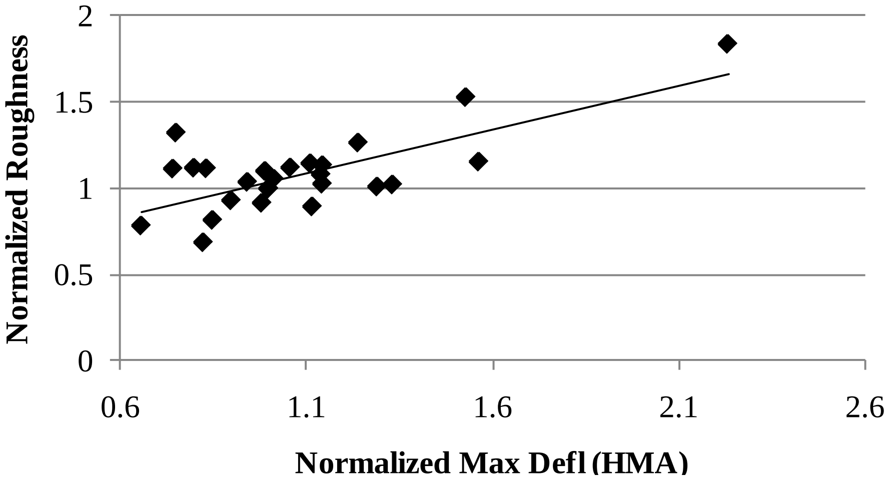


**Figure 63. Graph. Normalized long-term roughness versus normalized deflection at the center of the lane measured after rehabilitation of overlaid JPCP sites.**

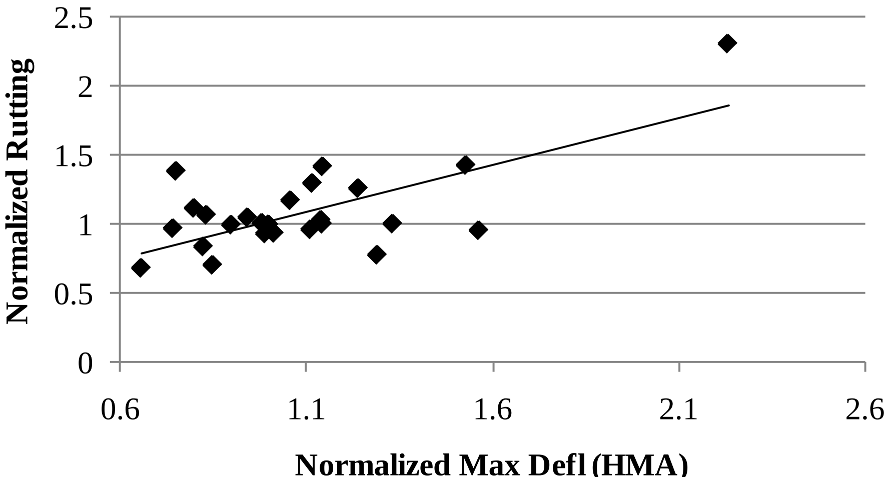


**Figure 64. Graph. Normalized long-term rutting versus normalized deflection at the center of the lane measured after rehabilitation of overlaid JPCP sites.**

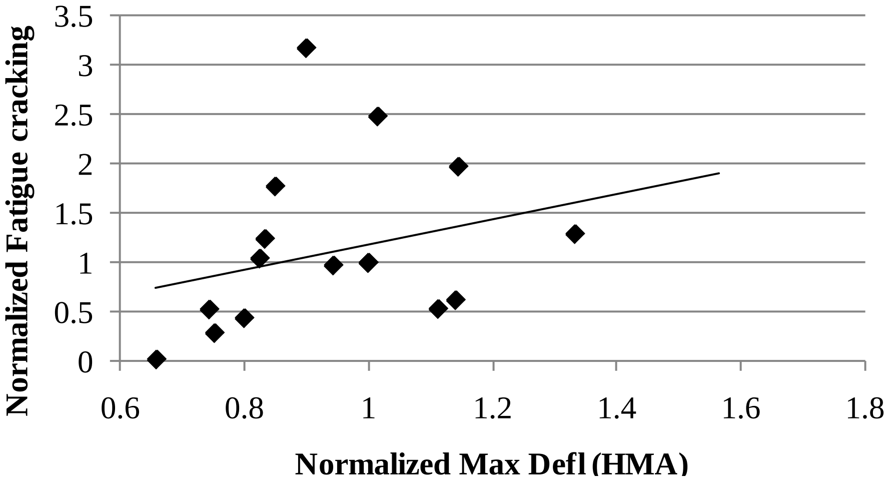


**Figure 65. Graph. Normalized long-term fatigue cracking versus normalized deflection at the center of the lane measured after rehabilitation of overlaid JPCP sites.**

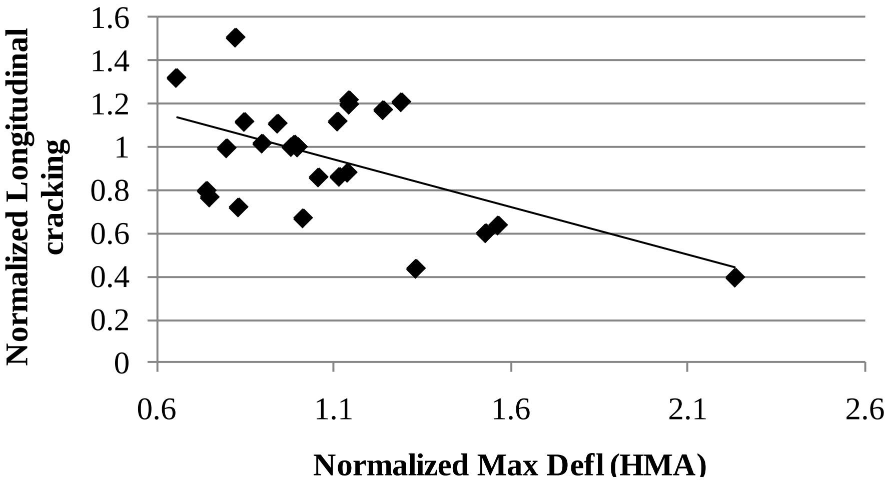


**Figure 66. Graph. Normalized long-term longitudinal cracking versus normalized deflection at the center of the lane measured after rehabilitation of overlaid JPCP sites.**

### Response Versus Performance in JRCP

The investigation of possible trends between response and performance in JRCP structures did not result in any significant conclusions. Different performance measures were analyzed against LTE, maximum deflection at the center of the slab, and maximum deflection at the center of the lane; however, no relevant conclusions were reached.

# CHAPTER 7. ANALYSIS OF REHABILITATED PAVEMENT STRUCTURES USING MEPDG

## INTRODUCTION

One part of this study was to evaluate rehabilitated pavement structures using MEPDG.(1) The objective of the task was to compare MEPDG-predicted performance with field-measured data and verify the current calibration against predictions of rehabilitated pavement structures. Flexible pavement sections from the SPS-5 experiment and rigid/composite pavement sections from the SPS-6 experiment were subject to MEPDG analysis, and the results were compared to actual distress measurements from LTPP surveys. All JPCP sections from both experiments were used in this analysis.

This research also produced a database of rehabilitated sections extracted from the LTPP program that can be used to perform local calibrations. The database is described in appendix E.

## MEPDG OVERVIEW

MEPDG is based on principles of both engineering mechanics and field verification to estimate performance.(1) A mechanistic approach is used to predict pavement responses to traffic loads, and pavement performance is then estimated based on empirical relationships developed from evidence from field data.

### Data Requirements

MEPDG considers three main factors in the analysis of pavement performance: traffic, environment, and pavement structure.(1) Each of these factors is described below.

#### *Traffic*

Traditionally, traffic inputs for pavement design have been single numbers, such as the annual average daily traffic or ESAL concepts. In developing MEPDG, it was recognized that these parameters do not sufficiently characterize the variable effects of axle loads distributions, traffic characteristics (speed, wander, etc.), and axle and tire configuration on pavements.

MEPDG utilizes the traffic spectra, and the anticipated or historical traffic is classified according to axle type (single, tandem, tridem, quad, or special axles) and the distribution of axle weights within each axle type.

#### *Environment*

There are three basic elements required to consider the environmental factors in MEPDG analysis: (1) site-specific environmental data, (2) material-specific data on thermal-related properties, and (3) an algorithm to compute the transmission of heat and moisture within the pavement structure. MEPDG considers the seasonal effects of temperature and moisture on material properties of pavement layers, and consequently, on pavement response and performance.

### *Pavement Structure*

As with any pavement analysis and design procedure, it is necessary to define the materials used in the structure including their properties, thicknesses, and construction characteristics. MEPDG can be used to analyze both new and rehabilitated PCC, HMA, and composite (PCC and HMA) pavements. Measured mechanical properties can be used to characterize the material's behavior to loading and thermal variations.

### *Summary of Data Required for MEPDG Analysis*

Table 91 provides a list of the data required for MEPDG analysis. The current national calibration is defined as level 3 input for material properties. To provide an equivalent level of comparison, the input data for this study were collected as level 3.

**Table 91. Predominant source of data used for preliminary statistical analysis and MEPDG performance models verification.**

| Input Group | | Input Parameter | Data Source |
|---|---|---|---|
| Truck traffic | | Axle load distributions (single, tandem, and tridem) | LTPP |
| | | Truck volume distribution | LTPP |
| | | Lane and directional truck distributions | LTPP |
| | | Tire pressure | MEPDG defaults |
| | | Axle configuration and tire spacing | MEPDG defaults |
| | | Truck wander | MEPDG defaults |
| Climate | | Temperature, wind speed, cloud cover, precipitation, and relative humidity | National Climate Data Center |
| Material properties | Unbound layers and subgrade | Resilient sodulus—subgrade all unbound layers | MEPDG defaults |
| | | Resilient modulus—base/subbase | MEPDG defaults |
| | | Classification and volumetric properties | LTPP |
| | | Moisture-density relationships | LTPP |
| | | Soil-water characteristic relationships | MEPDG defaults |
| | | Saturated hydraulic conductivity | MEPDG defaults |
| | HMA | HMA dynamic modulus | LTPP |
| | | HMA creep compliance and indirect tensile strength | MEPDG defaults |
| | | Volumetric properties | LTPP |
| | | HMA coefficient of thermal expansion | MEPDG defaults |
| | PCC | PCC elastic modulus | LTPP |
| | | PCC flexural strength | LTPP |
| | | PCC coefficient of thermal expansion | LTPP |
| All materials | | Unit weight | LTPP |
| | | Poisson's ratio | MEPDG defaults |
| | | Other thermal properties, conductivity, heat capacity, and surface absorptivity | MEPDG defaults |

Note: MEPDG generates climate files using data from the National Climate Data Center.

## Latest Calibration Efforts

The original calibration for MEPDG was finalized in 2004 and was based on performance data from several projects, mainly from the LTPP program for data collected until 2001. Recently, an effort under NCHRP Projects 1-40A and 1-40D added 4–5 years of new data to improve the national calibration.(21,22) A summary of the efforts carried out to obtain current calibration by pavement type is provided below.

### *Flexible Pavement Calibration*

Data from 49 sections from the GPS-6B and SPS-5 projects were used for the calibration and validation of HMA overlays over existing AC structures. Data from three sections of the SPS-6 experiment were used for the calibration and validation of the HMA overlay over existing fractured slab structures. Data from seven sections from the GPS-7B and SPS-6 projects were used for the calibration and validation of HMA overlay over existing JPCP structures.

### *PCC Rehabilitation Calibration*

Calibration data were obtained from the LTPP database, the American Concrete Pavement Association Longevity and Performance of Diamond-Ground Pavements study, and NCHRP Project 10-41, *Guidelines for the Design of Unbonded PCC Overlays*.(23) Different datasets were used to calibrate restored JPCP.

Data were obtained from the SPS-6 experiment, specifically sections 0601, 0602, and 0605, which corresponded to JPCP sections without overlay in the rehabilitation strategy. The restoration performed on these test sections ranged from the no treatment control section to full depth patching and retrofitting joints with dowels. Specific restoration treatments included the following:

- Crack sealing.
- Transverse joint sealing.
- Full depth transverse joint repair patch.
- Full depth patching of PCC pavement other than at joint.
- Partial depth patching of PCC pavement other than at joint.
- PCC slab replacement.
- AC shoulder restoration.
- AC shoulder replacement.
- Diamond grinding surface (all sections used in verifying faulting).

- Pressure grout subsealing.
- Joint load transfer restoration.

## REHABILITATED FLEXIBLE PAVEMENTS

The performance of the 500-ft (152.5-m) sections in the SPS-5 experiment was estimated using MEPDG software Version 1.003. Load-associated distress trends were compared to LTPP-measured distress values from surveys. Three pavement distress types were evaluated including roughness, rutting, and cracking.

It should be noted that LTPP-measured distress data and MEPDG-predicted performance data do not have the same units of measurement. As a result, MEPDG-predicted performance was converted to match the units used in the LTPP database. Table 92 explains the conversion used in this analysis.

**Table 92. Conversion of MEPDG-predicted performance data to LTPP units.**

| Performance Parameter | LTPP Units for the Parameter | MEPDG Units for the Parameter | Conversion to LTPP Units |
|---|---|---|---|
| Fatigue cracking | $ft^2$ | Percentage of the design lane cracked | (Percentage cracked) × 500_ft×12_ft/100 |
| Longitudinal cracking | ft | ft/mi | (Distress in ft/mile) × 500_ft/5280_ft |
| Transverse cracking | ft | ft/mi | (Distress in ft/mile) × 500_ft/5280_ft |

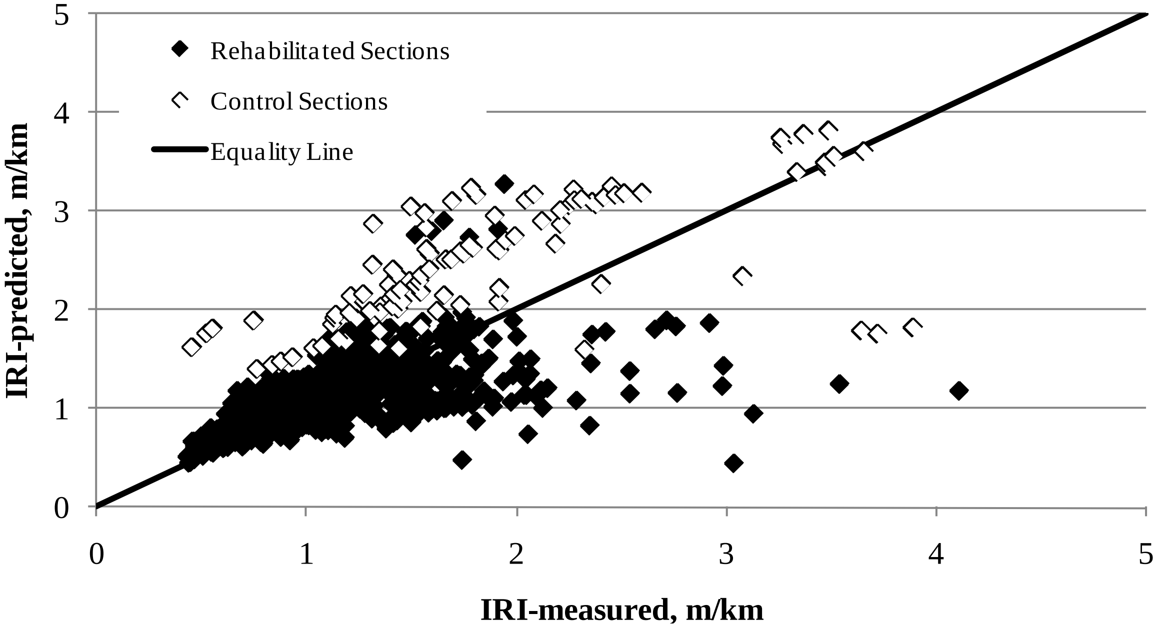
1 ft = 0.305 m
1 $ft^2$ = 0.093 $m^2$
1 mi = 1.61 km
Note: The underscores indicate the format used when entering data into the LTPP database.

Both the LTPP-measured data and the MEPDG-predicted distresses were converted into SI units for plotting. The comparative analyses are presented in the following sections.

### Roughness

Predicted versus measured pavement roughness was evaluated in terms of IRI values. Figure 67 describes predicted versus measured performance for all sections in the SPS-5 experiment. The data were grouped by rehabilitated and control sections (without overlay), and the results were reasonable overall. However, some bias was noted for both sets of data. The results for rehabilitated sections showed a bias for underprediction of IRI, whereas the control sections showed a tendency for bias of overprediction. Because the analysis of the control sections considered the pavement life since its construction and the window monitored for rehabilitated pavements were defined for several years after the initial construction, MEPDG was overpredicting the IRI levels for new flexible pavements during the last portion of the pavement's life.

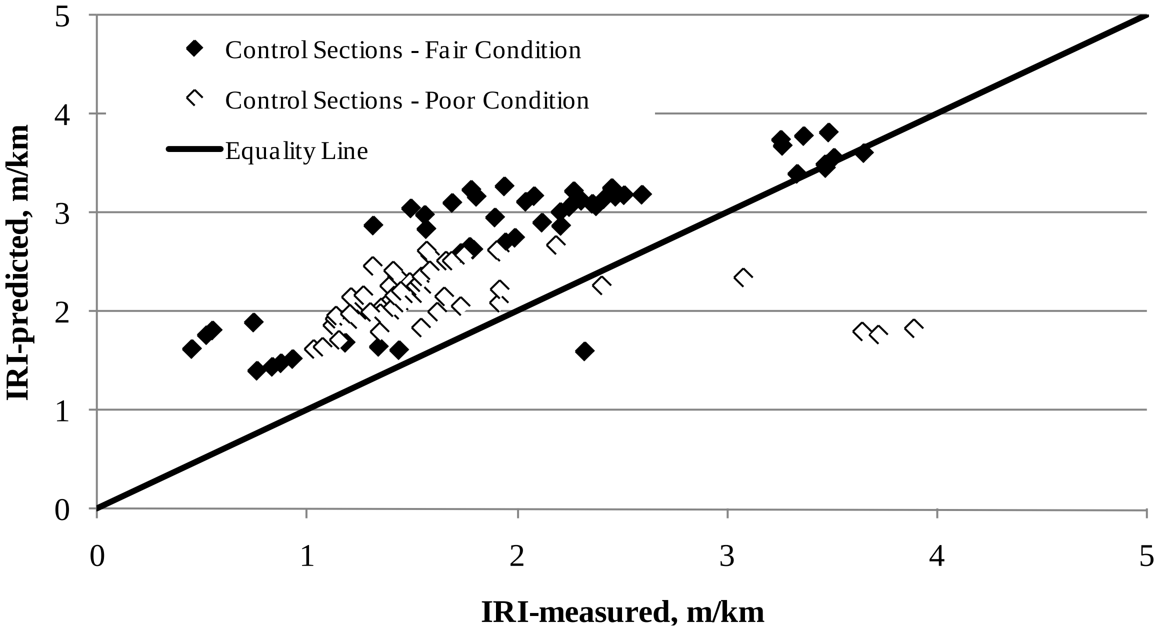
The MEPDG out-of-the-box models were calibrated using only new pavement sections. This exercise involving rehabilitated sections from the SPS-5 experiment indicated that the roughness model could be used to predict IRI values with fairly good accuracy in rehabilitated sections. Local calibration of the current model may further improve accuracy of roughness predictions in rehabilitated sections.



1 ft = 0.305 m
1 mi = 1.61 km

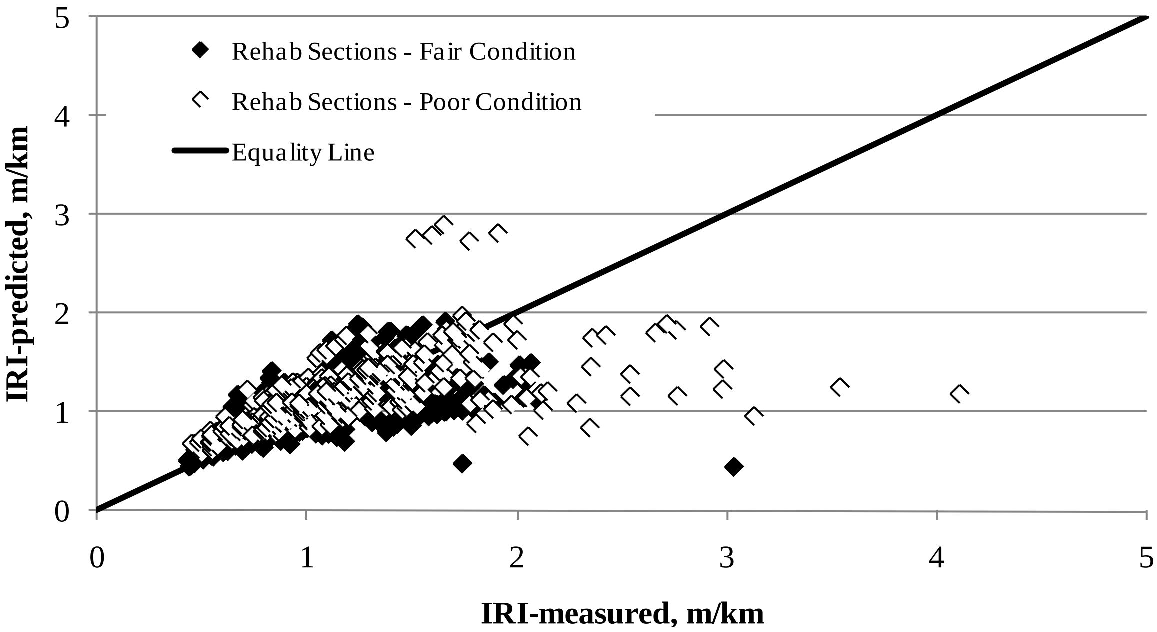
**Figure 67. Graph. LTPP-measured versus MEPDG-predicted IRI for all SPS-5 sections.**

The level of accuracy for the MEPDG roughness model predictions was similar for the control sections with poor and fair pavement conditions prior to the beginning of the experiment (see figure 68). Similar results were found for rehabilitated sections (see figure 69). The difference in this case was that there was a tendency to underpredict rehabilitated sections with poor overall condition and IRI values above 10.56 ft/mi (2 m/km).



1 ft = 0.305 m
1 mi = 1.61 km

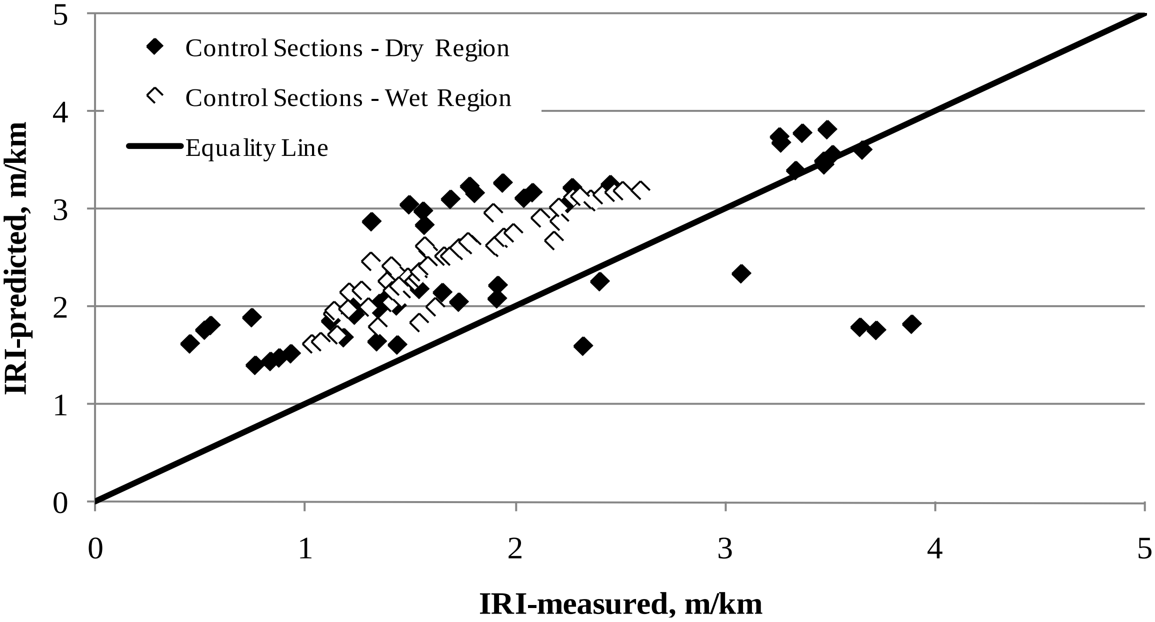
**Figure 68. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 control sections.**



1 ft = 0.305 m
1 mi = 1.61 km

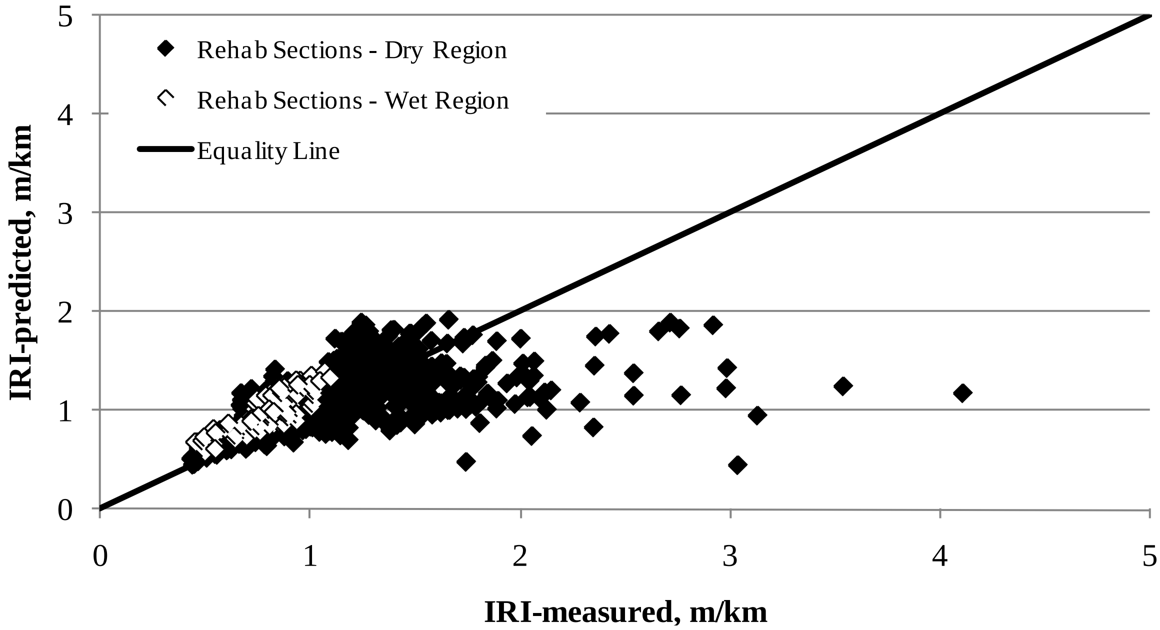
**Figure 69. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 rehabilitated sections.**

Another site factor with a visible impact on the accuracy of the models was the climate condition. Results in figure 70 and figure 71 suggest that despite the small bias for the control sections, the current model did a better job predicting IRI in sections located in wet regions in comparison to dry locations, especially for rehabilitated sections. The other climate variable in the SPS-5 experiment was temperature (freeze versus no-freeze); however, temperature did not influence the accuracy of predictions.



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 70. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 control sections in wet and dry regions.**



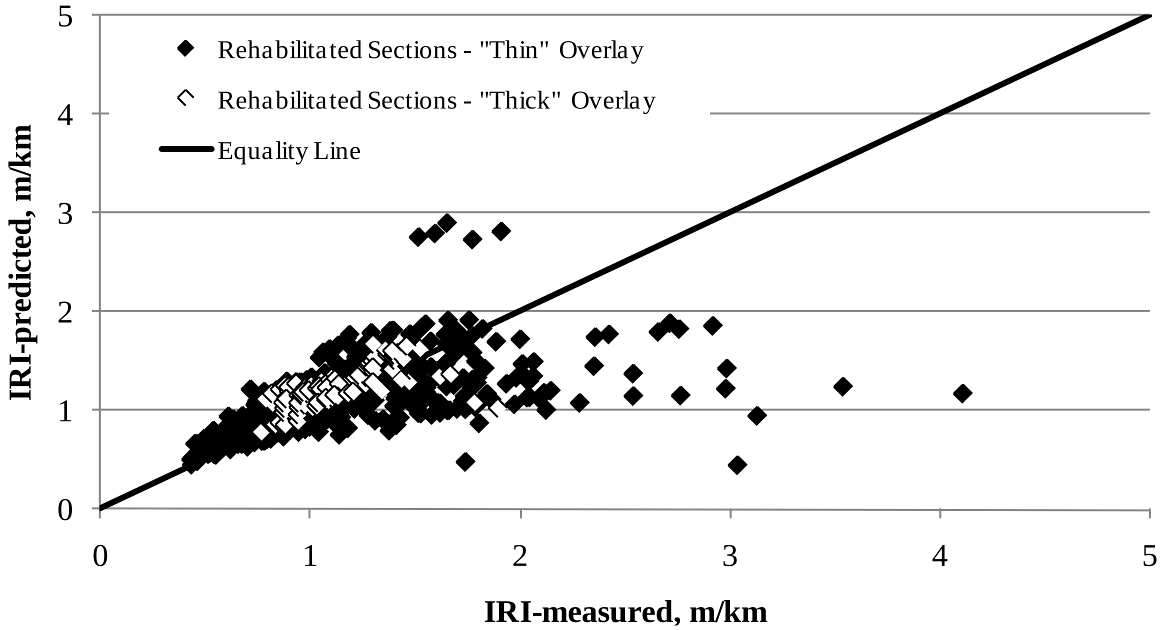
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 71. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 rehabilitated sections in wet and dry regions.**

The influence of design features on the MEPDG performance predictions was also investigated. The results obtained for the rehabilitated sections were grouped by overlay thickness, mix type, and milling. The results of predicted versus measured IRI performance are shown in figure 72 through figure 74.

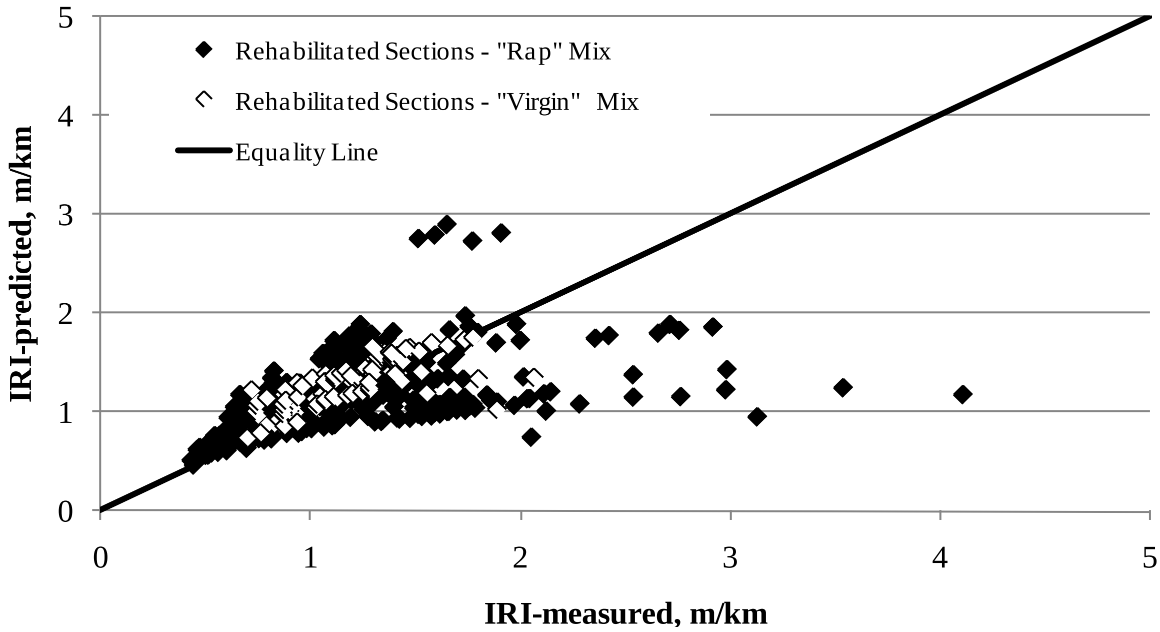
The following observations were made:

- MEPDG did a better job predicting the roughness performance of rehabilitated sections with thick overlays. Thin overlay predictions were more disperse, especially for high IRI values where underprediction was obvious (see figure 72).
- MEPDG did a better job predicting the roughness performance of rehabilitated sections with virgin overlays. RAP mix overlay predictions are more disperse, especially for high IRI values (see figure 73).
- MEPDG predictions of rehabilitated sections with and without milling prior to overlay exhibit the same level of accuracy and bias (see figure 74).



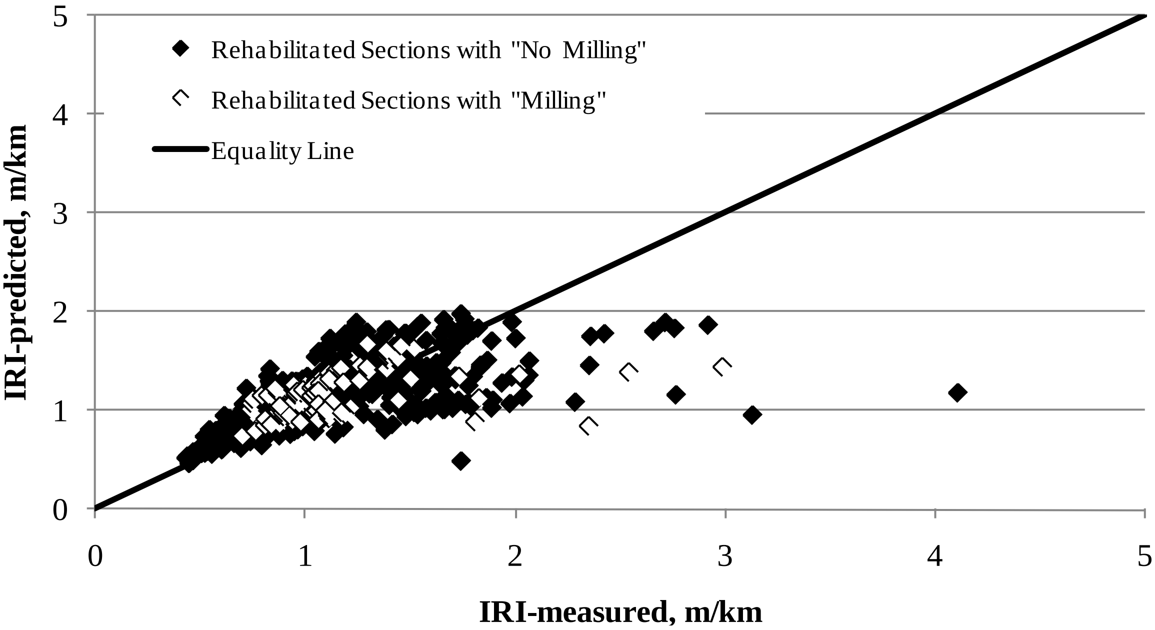
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 72. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 rehabilitated sections grouped by thickness.**



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 73. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 rehabilitated sections grouped by mix type.**



1 ft = 0.305 m
1 mi = 1.61 km

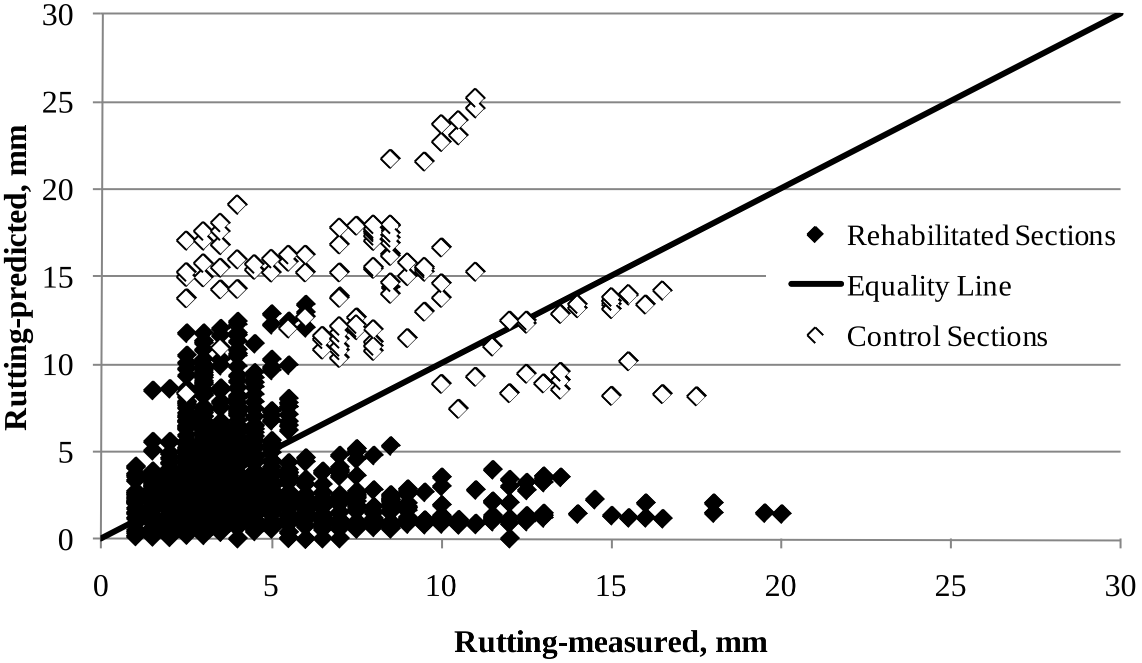
**Figure 74. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-5 rehabilitated sections grouped by milling.**

It is important to note that the group of points with high IRI levels in figure 72 through figure 74 (IRI > 9.50 ft/mi (1.8 m/km)) were sections classified as having poor initial conditions. Results demonstrate that these sections did not perform well and that, in general, MEPDG underpredicted the IRI levels for these sections. Overall, the current MEPDG IRI model predicts performance reasonably well, provided it is calibrated using data from new pavement sections. Local calibration of the model is likely to improve accuracy and reduce bias, especially for rehabilitated sections that were in poor condition prior to rehabilitation.

## Rutting

When comparing actual rutting versus MEPDG-estimated rutting, control sections and rehabilitated sections were evaluated. The goal was to observe the trends when analyzing new pavements and rehabilitated pavements. Control section estimates were obtained by running the MEPDG software for a new section; however, the data screened for the analysis were those gathered during the survey period of the SPS-5 sites.

For most control sections, MEPDG overpredicted rutting, while for rehabilitated sections, there was not an evident bias (see figure 75). Nonetheless, in many cases, the rutting levels were either underpredicted or overpredicted. The control sections were treated as new sections; therefore, the rutting predictions included base and subgarde rutting. For overlays, the only rutting considered in MEPDG was that of the overlay, and no rutting was allowed in the underlying layers. Attempts were made to identify whether there was a consistent reason for underpredictions or overpredictions of rutting (i.e., site conditions or design features of the rehabilitated sections), but no reason was found. The results in figure 75 suggest that the rutting model needs further calibration to reduce bias in predicting the performance of new pavements. Most likely, the lack of sufficient rutting data for each pavement layer during the initial MEPDG calibration and the need to assume individual layer contribution to total rutting led to the results in the figure. A revised model is recommended to improve accuracy in predicting the performance of rehabilitated pavements.



1 inch = 25.4 mm

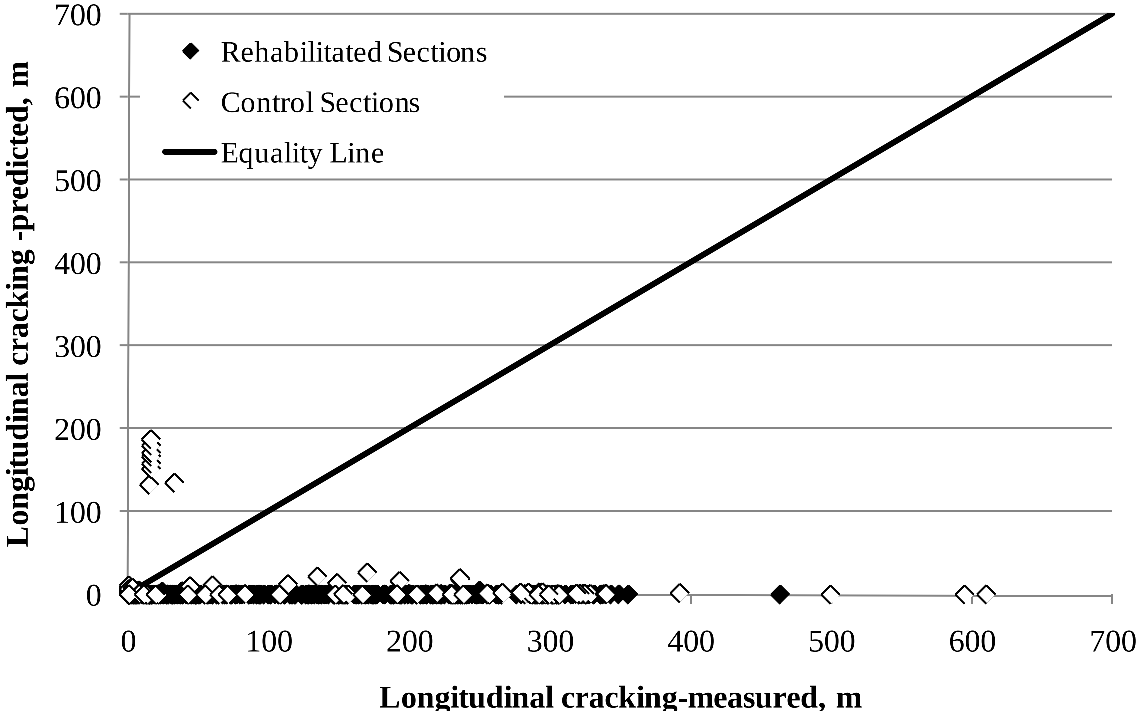
Figure 75. Graph. LTPP measured versus MEPDG predicted rutting for SPS-5 sections.

## Cracking

MEPDG estimates of top-down longitudinal cracking, low temperature transverse cracking, and bottom-up alligator fatigue cracking were computed and compared to actual survey measurements available in the LTPP database for the SPS-5 experiment. Predicted versus measured longitudinal cracking results are shown in figure 76. With the exception of one site, all predictions had zero or near-zero values. MEPDG consistently underpredicts longitudinal cracking for both new and rehabilitated pavements. When comparing transverse cracking, MEPDG does not predict any transverse cracking in any of the analyses that were performed.

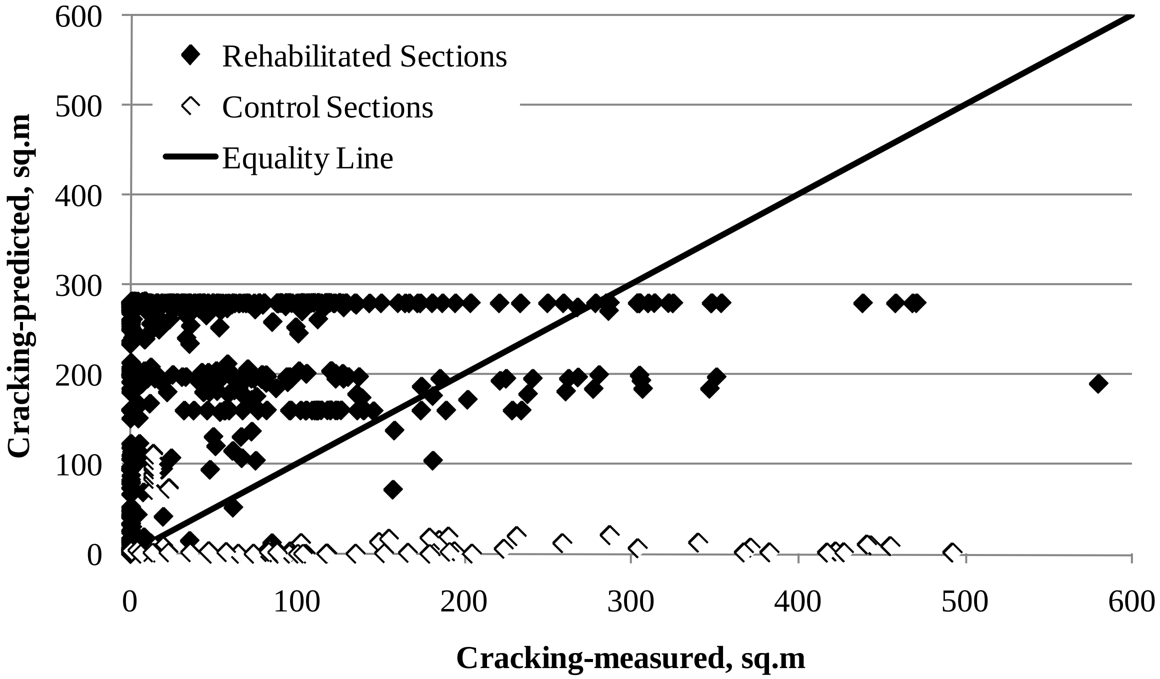
Fatigue cracking was computed as the sum of alligator cracking (developed in the new overlay HMA layer) and reflective cracking (cracking in the old surface propagated upward into the new layer). In MEPDG, these cracking patterns are represented by cracking types FC1 and FC2, respectively. MEPDG predicts fatigue cracking on the surface as a "percentage of the design lane cracked."(1) The MEPDG fatigue cracking outputs were converted into cracked area according to table 92. Predicted fatigue cracking data were plotted against measured data and are presented in figure 77. It can be concluded from the comparative graph that the fatigue cracking model in MEPDG underpredicts the performance of both new and rehabilitated pavements.

The reflective cracking model dominates the total fatigue cracking predictions. If only the fatigue cracking associated with the new overlay layer is plotted against the measured fatigue cracking in the LTPP database, the MEPDG-predicted fatigue cracking is underpredicted (see figure 78). The figure suggests that reflective cracking propagating from the existing layer is the major contributor to the total fatigue cracking predictions. The reflective cracking model needs further improvements to reduce the bias and enhance its accuracy.



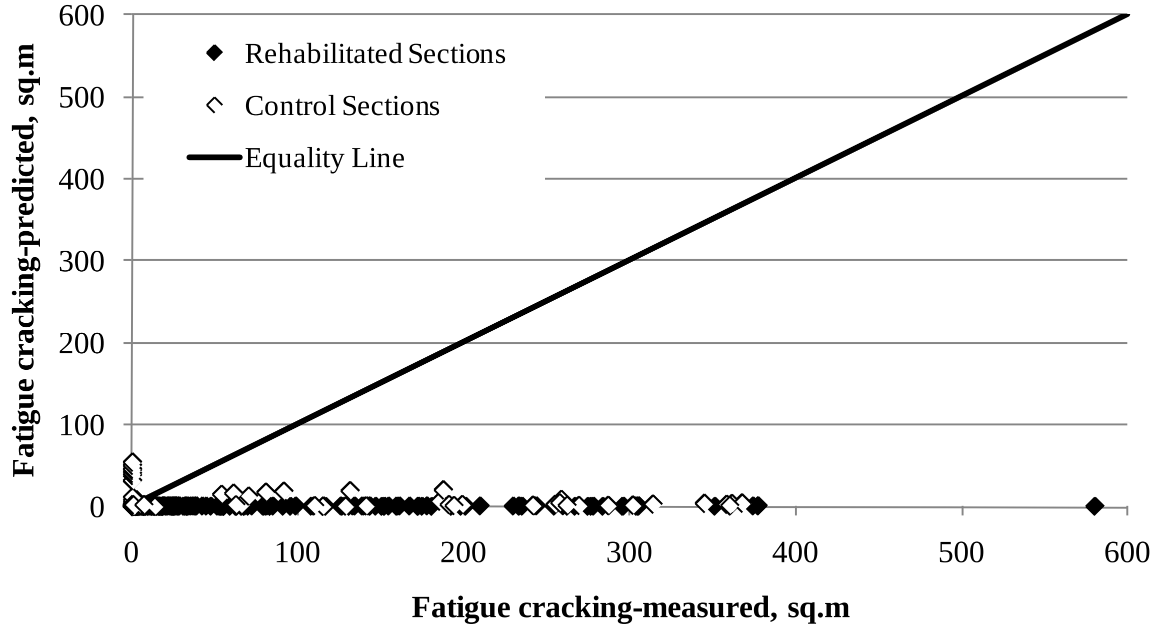
1 ft = 0.305 m

**Figure 76. Graph. LTPP-measured versus MEPDG-predicted longitudinal cracking for SPS-5 sections.**



1 ft$^2$ = 0.093 m$^2$

**Figure 77. Graph. LTPP-measured versus MEPDG-predicted fatigue and reflective cracking for SPS-5 sections.**



1 ft$^2$ = 0.093 m$^2$

**Figure 78. Graph. LTPP-measured versus MEPDG-predicted fatigue cracking for SPS-5 sections.**

## REHABILITATED RIGID PAVEMENTS

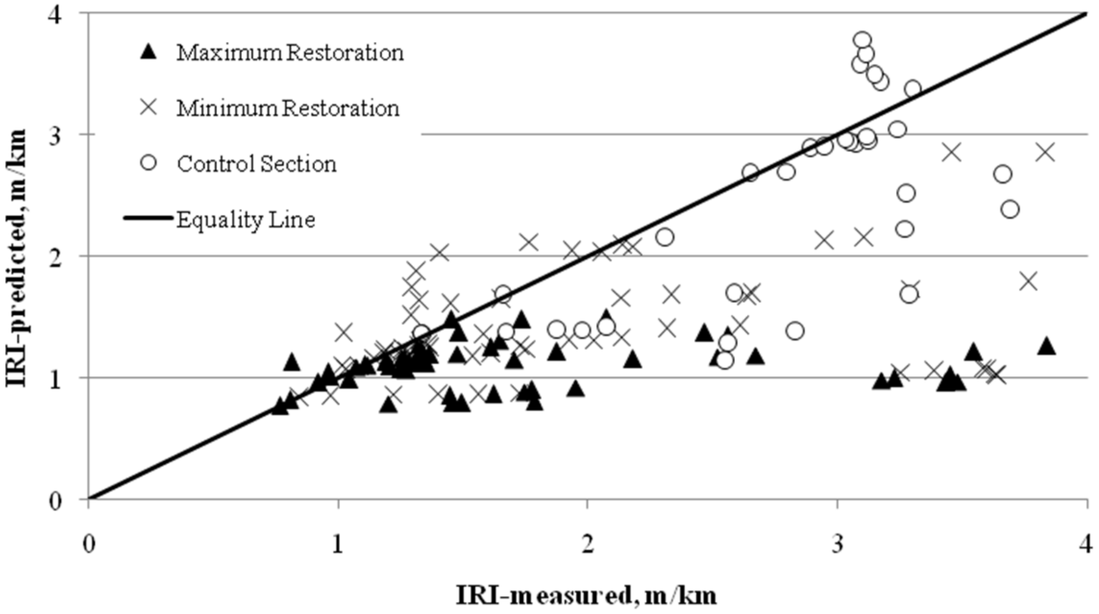
The performance of the 500-ft (152.5-m) sections in the SPS-6 experiment was estimated using MEPDG software Version 1.003. Estimated and actual load-associated distress trends were compared for the following pavement distresses and properties:

- Roughness.
- Rutting.
- Cracking.
- Faulting.
- LTE.

Both the LTPP-measured data and the MEPDG-predicted data were converted into SI units for plotting. The comparative analyses are presented in the following sections.

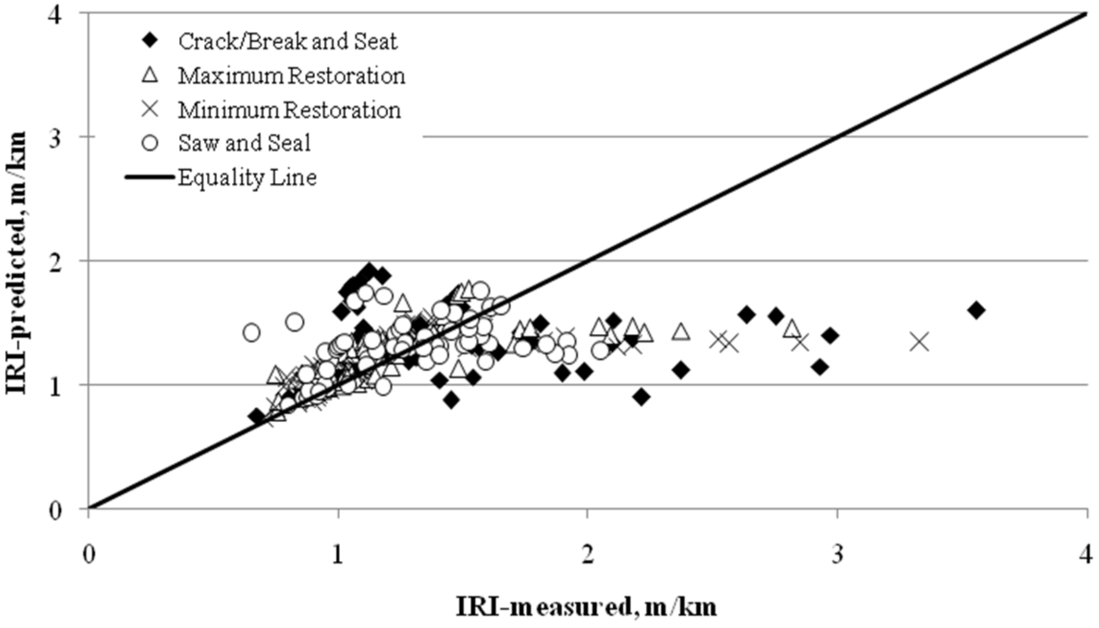
### Roughness

Pavement roughness was evaluated in terms of IRI values. Figure 79 and figure 80 describe predicted versus measured roughness for all sections in the SPS-6 experiment. Figure 79 presents results for all the sections in which the rehabilitation treatment had no overlay. These sections, 0601, 0602, and 0605, received only restoration treatments in the PCC layer or no treatment at all. Figure 80 shows the trends for all sections in which the rehabilitation treatment had overlay (sections 0603, 0604, 0606, 0607, and 0608). Both figures suggest that the IRI model provides fairly good predictions of roughness performance. Sections without overlays were slightly underpredicted, especially for sections with restoration (minimum or maximum). Sections with overlays were predicted more consistently with measured values, especially for IRI values lower than 9.50 ft/mi (1.8 m/km). For IRI values higher than 1.8 m/km, the models consistently underpredicted performance.



1 ft = 0.305 m
1 mi = 1.61 km

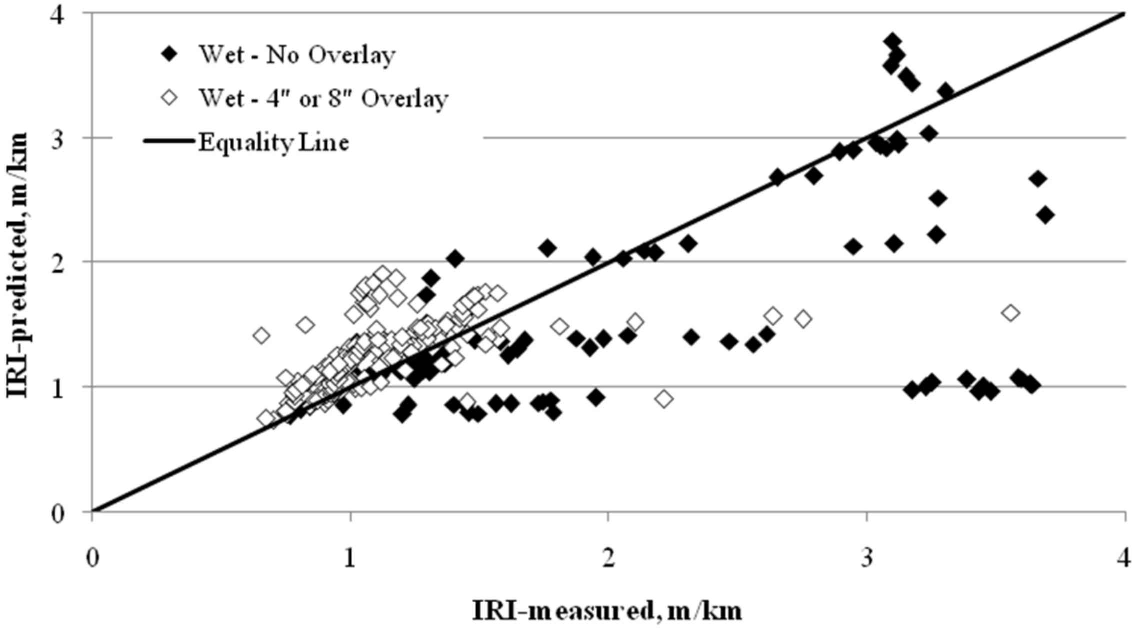
**Figure 79. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-6 sections without overlay.**



1 ft = 0.305 m
1 mi = 1.61 km

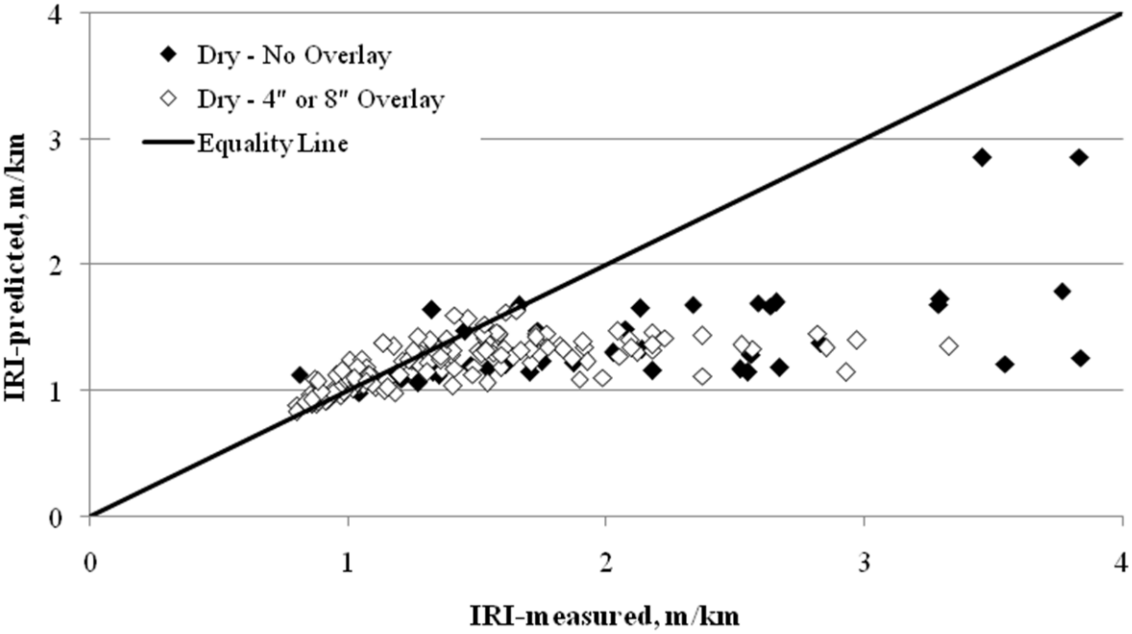
**Figure 80. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-6 sections with overlay.**

Climate condition influenced MEPDG roughness predictions. Figure 81 and figure 82 present predicted versus measured IRI for sites located in wet and dry regions. The results suggest that sites located in wet regions had predictions that were more accurate and less biased than sites located in dry regions; however, there was still underprediction for high IRI levels. MEPDG consistently underpredicts high IRI values (higher than 9.50 ft/mi (1.8 m/km)) in dry regions. Figure 83 and figure 84 show predicted versus measured IRI for sites located in freeze and no-freeze regions. The results suggest that sites located in no-freeze regions have predictions that are more accurate and less biased than sites located in freeze regions. MEPDG consistently underpredicts high IRI values (higher than 9.50 ft/mi (1.8 m/km)) in freeze regions.



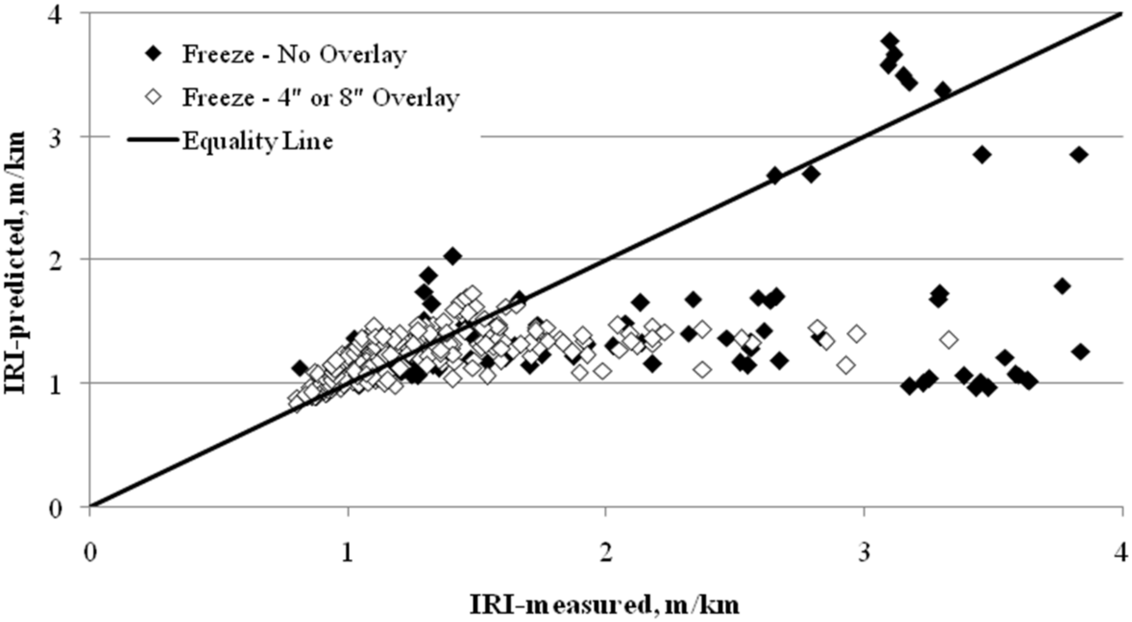
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 81. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-6 sections in wet regions.**



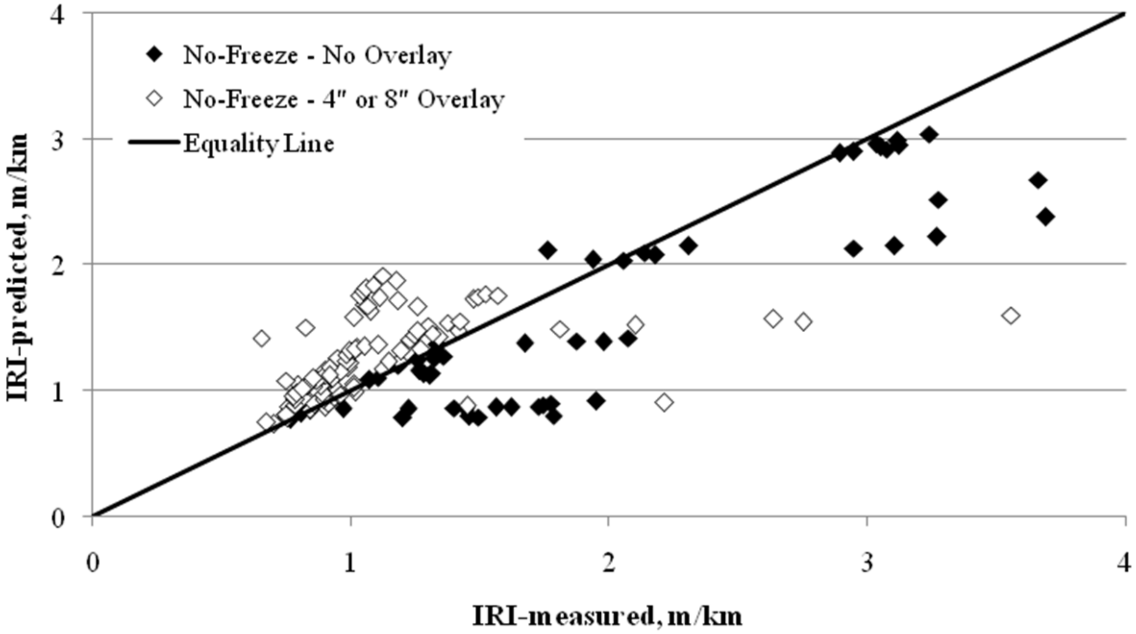
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 82. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-6 sections in dry regions.**



1 ft = 0.305 m
1 mi = 1.61 km

**Figure 83. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-6 sections in freeze regions.**



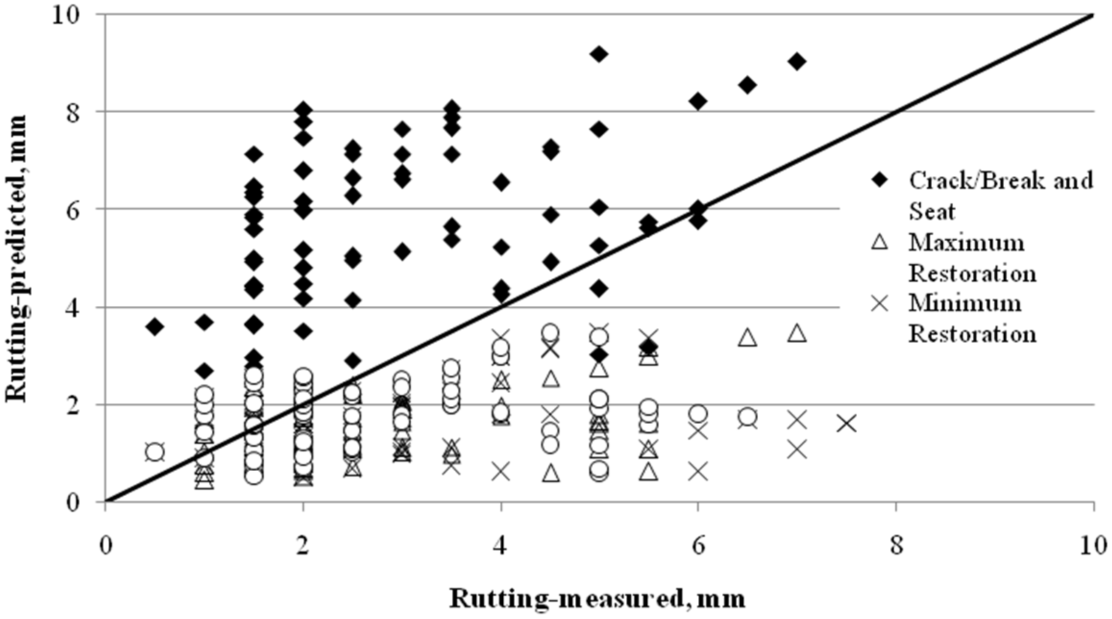
1 ft = 0.305 m
1 mi = 1.61 km

**Figure 84. Graph. LTPP-measured versus MEPDG-predicted IRI for SPS-6 sections in no-freeze regions.**

Despite the variations in the quality of predictions among different site factors, predictions of sections with overlays were consistently better than sections without overlays, including the control section. This was surprising because most of the the MEPDG calibration effort was devoted to new pavement conditions.

## Rutting

Predicted versus measured rutting data are shown in figure 85 for SPS-6 sections with HMA overlays on JPCP. The results suggest that the rutting model was consistently overpredicting for HMA over cracked and seated JPCP . The results also suggest that MEPDG underpredicts for regular HMA over JPCP slab. This is likely caused by the MEPDG assumption for HMA over cracking and seated pavement. The total rutting in all layers is predicted; thus, some overprediction occurred. For HMA over existing JPCP, the rutting output was only in HMA.



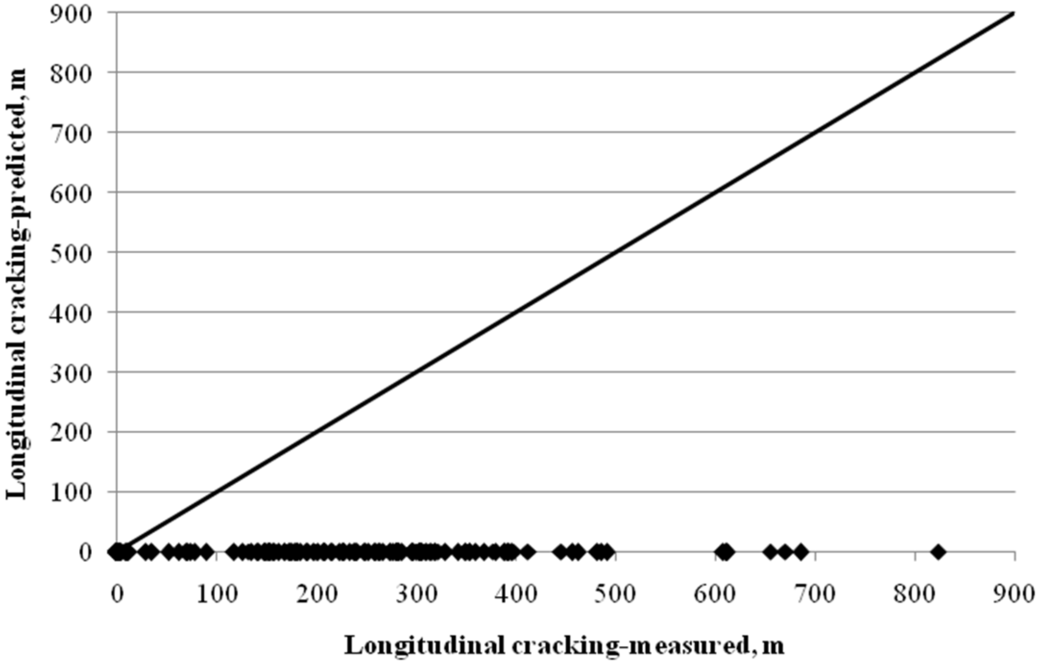
1 inch = 25.4 mm

**Figure 85. Graph. LTPP-measured versus MEPDG-predicted rutting for SPS-6 sections with overlays.**

## Cracking

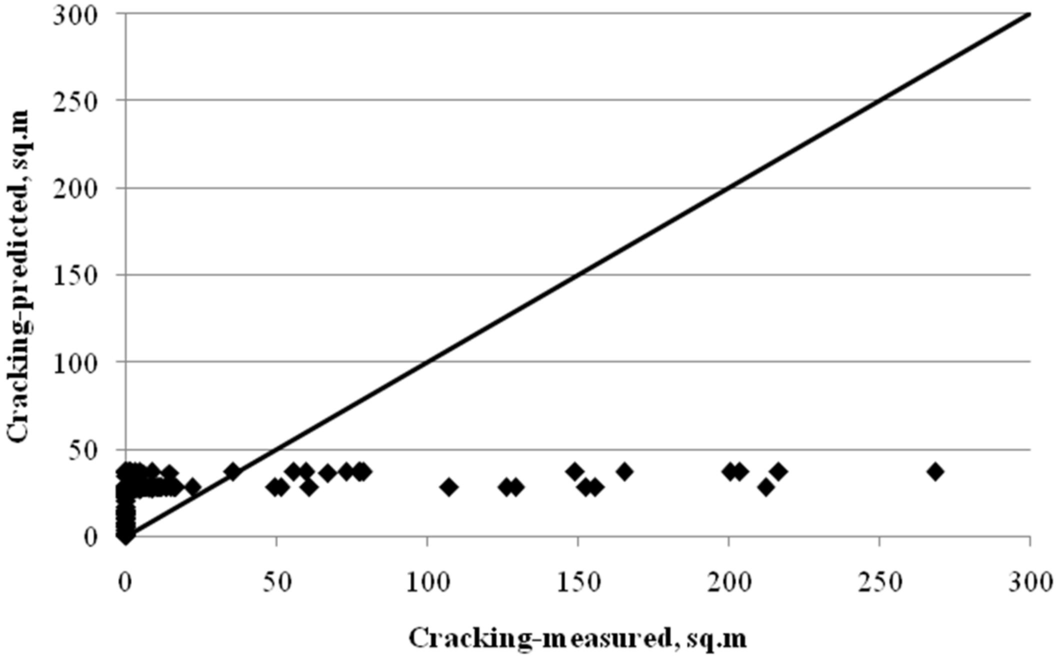
Estimates of longitudinal top-down fatigue cracking and fatigue bottom-up alligator cracking were computed using MEPDG. Predicted versus measured longitudinal fatigue cracking results in wheel paths only are shown in figure 86. The MEPDG software does not predict longitudinal cracking on HMA overlays over JPCP. Total fatigue cracking data (i.e., new cracking originated at the new HMA overlay plus reflective cracking from propagated cracks in the PCC layer) are shown in figure 87. The results suggest that the MEPDG fatigue cracking model may underpredict and overpredict the levels of cracking. Reflective cracking was the only component with predictions higher than zero, as expected.

Several attempts were made to isolate the sections being underpredicted and overpredicted based on climate conditions, pavement condition prior to overlay, or type of treatment, but the results were inconclusive. It was difficult to identify sources of cracking during surveys, and reflective cracking usually was not measured for the LTPP experiments. The confusion on the source of cracking measured in addition to the existing emprical model for reflective cracking incorporated in MEPDG highlights the need for future studies under the LTPP program, particularly to address improvements to the existing model for reflective cracking to be based on reliable data for this type of distress.



1 ft = 0.305 m

Figure 86. Graph. LTPP-measured versus MEPDG-predicted longitudinal cracking for HMA overlaid SPS-6 sections.

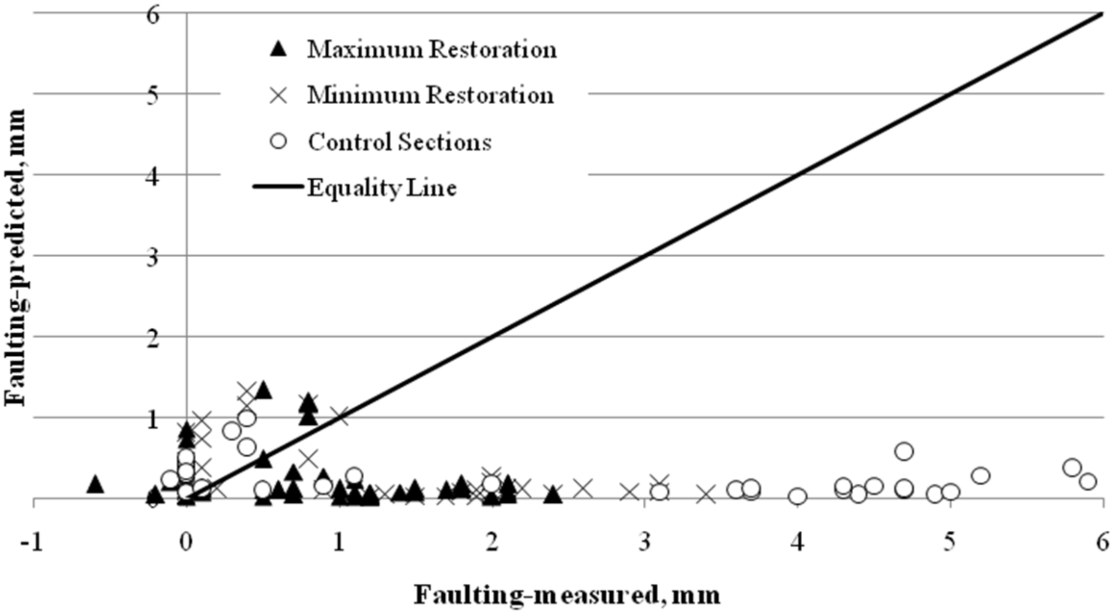


1 ft = 0.305 m

Figure 87. Graph. LTPP-measured versus MEPDG-predicted fatigue and reflective cracking for HMA overlaid SPS-6 sections.

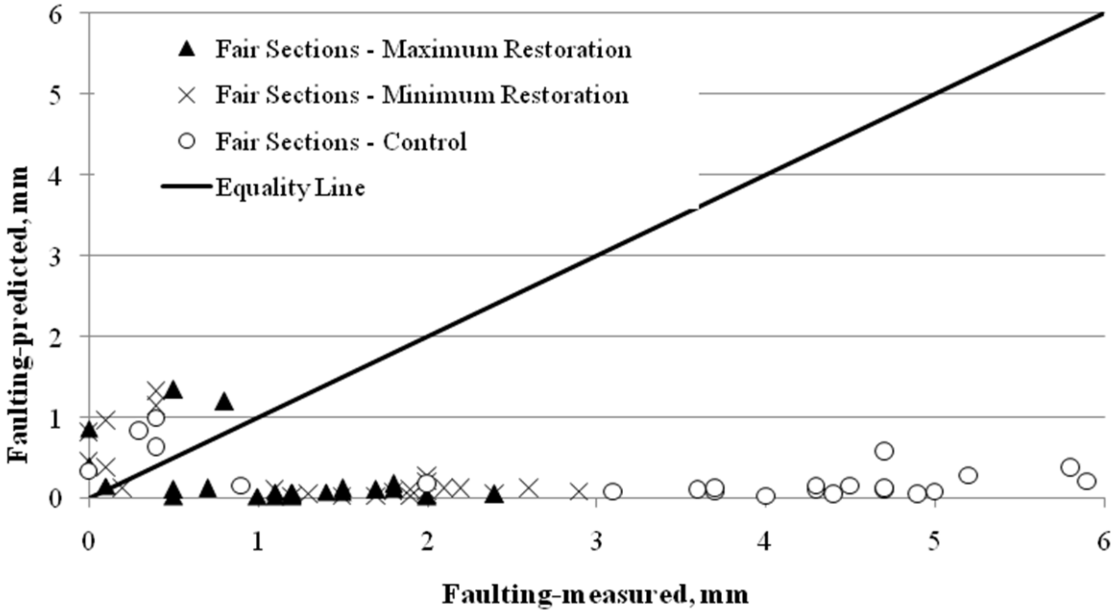
## Faulting

Trends for MEPDG predicted versus measured faulting are shown in figure 88 for SPS-6 sections without overlay. The results suggest that MEPDG underpredicts faulting for the majority of rehabilitated sections. The sites were grouped by climate conditions; however, the results did not provide any information on possible influence of climate conditions. An attempt was made to isolate pavement surface condition prior to rehabilitation. Predicted versus measured faulting for SPS-6 sections grouped by pavement surface condition is shown in figure 89 and figure 90. Faulting in pavements in fair condition prior to rehabilitation was consistently underpredicted, as suggested in figure 89. Predictions were more accurate for sections with pavements in poor condition prior to rehabilitation (see figure 90).



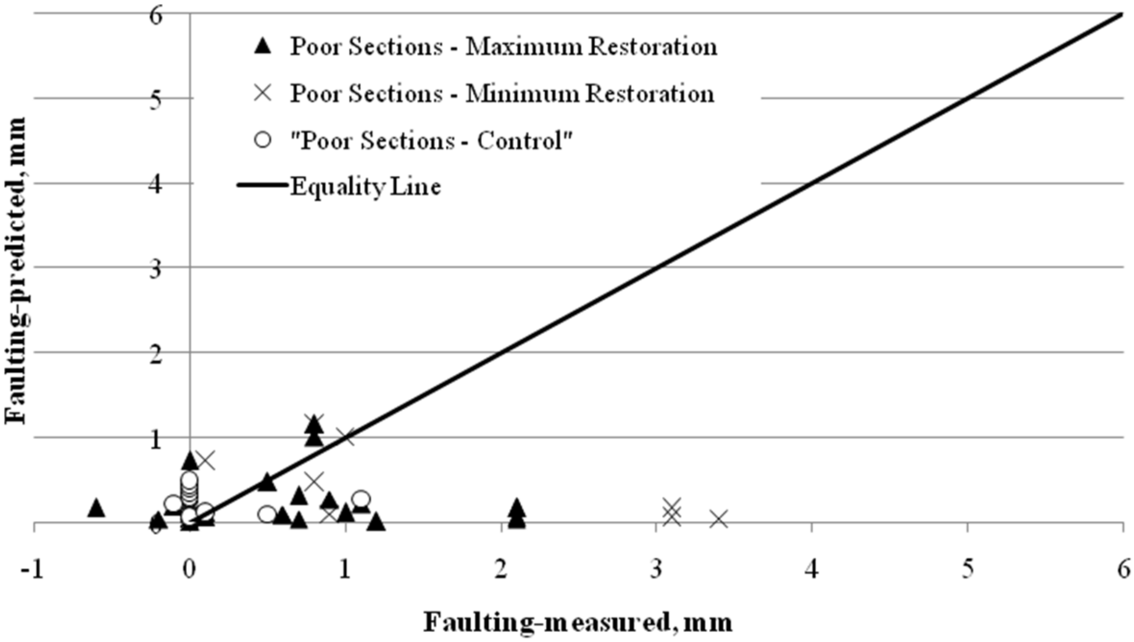
1 inch = 25.4 mm

**Figure 88. Graph. LTPP-measured versus MEPDG-predicted faulting for SPS-6 sections without HMA overlay.**



1 inch = 25.4 mm

**Figure 89. Graph. LTPP-measured versus MEPDG-predicted faulting for SPS-6 sections without HMA overlay with fair pavement condition prior to rehabilitation.**



1 inch = 25.4 mm

**Figure 90. Graph. LTPP-measured versus MEPDG-predicted faulting for SPS-6 sections without HMA overlay with poor pavement condition prior to rehabilitation.**

### Load Transfer Efficiency

LTE was estimated for SPS-6 sections without HMA overlay using MEPDG. Predicted versus measured data from LTPP SPS-6 sections are plotted in figure 91. The results suggest that the LTE model slightly overpredicted LTE for sections without any rehabilitation (control), but estimates were considered reasonable. The results were better for sections that received some maintenance/rehabilitation work (minimum and maximum). Site conditions were investigated, and no further trends were observed.

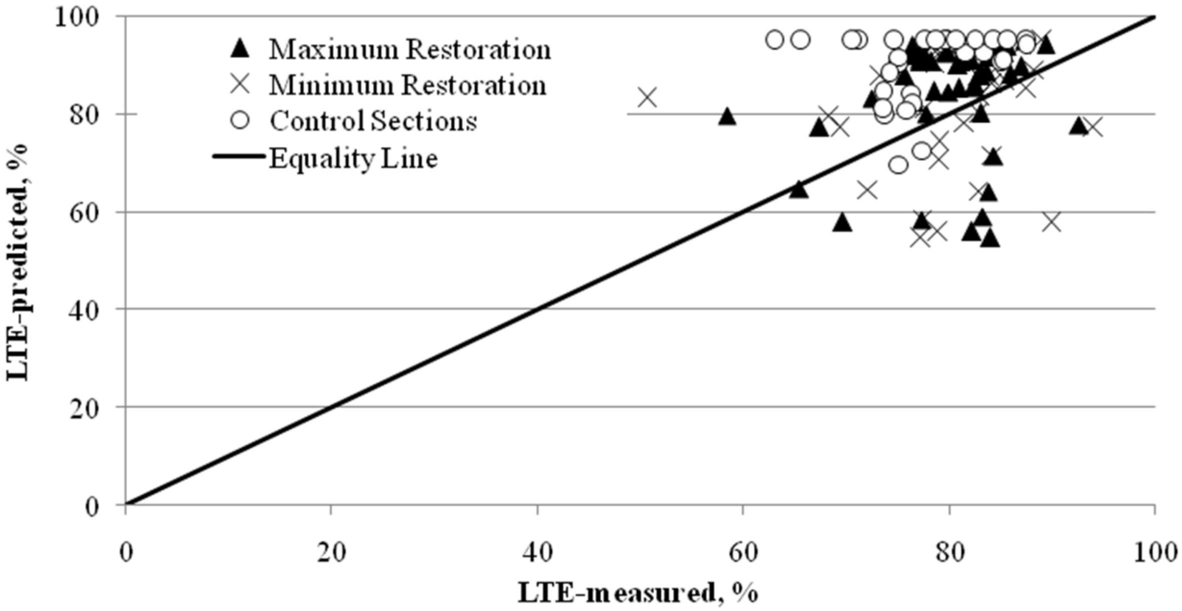


**Figure 91. Graph. LTPP-measured versus MEPDG-predicted LTE for SPS-6 sections without HMA overlay.**

## SUMMARY AND CONCLUSIONS

The MEPDG roughness models for both flexible and rigid pavements provided good predictions of rehabilitated sections with and without HMA overlay. There were some biases in the predictions, which could be addressed with local or a revised general calibration. MEPDG tends to underpredict roughness for rigid pavement sections with IRI values above 9.50 ft/mi (1.8 m/km). This bias was more characteristic of sections located in dry and freeze regions.

The HMA rutting model needs further enhancements to further predict permanent deformation accurately in HMA overlay over flexible and rigid pavements. Interestingly, the rutting model overpredicted performance of HMA overlays over crack/break and seat restored rigid pavements and underpredicted for the rest of restoration treatments (saw and seal and minimum and maximum restorations prior to overlays). MEPDG considers the cracked/broken PCC layer as a new granular base layer. Permanent deformation was predicted for the new layer and the subgrade, which is normally the reason for the overprediction of total rutting identified in this study. The rutting model clearly needs calibration before use with overlaid pavements.

The cracking models for HMA overlays, particularly the empirical reflection cracking, need further enhancements to provide more accurate predictions. The models for fatigue cracking (new and reflective) and longitudinal cracking were not capable of predicting consistent and comparable performance with measured values. MEPDG did not predict transverse cracking in any of the SPS-5 or SPS-6 sections, although some transverse cracking was measured during surveys.

# CHAPTER 8. STUDY FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This chapter provides the findings and conclusions from the analysis of preventive maintenance treatments and performance of different pavement rehabilitation alternatives. Recommendations for future research are provided at the end of the chapter.

## PREVENTIVE MAINTENANCE TREATMENTS

The findings presented in this section are based on the analysis of 81 SPS-3 flexible pavement sites and 34 SPS-4 rigid pavement sections subjected to different preventive maintenance treatments. Most of the flexible pavement sites were monitored for at least 4 years, and about 22 percent of the sites were monitored for 10 years or more. Most of the rigid pavement sites were monitored for at least 4 years.

### Preventive Maintenance Effectiveness for Flexible Pavements

From the analysis of SPS-3 sites, the following effects of preventive maintenance treatments on pavement performance were observed:

**IRI**:

- Of all of the SPS-3 treatments, only thin overlay was effective in mitigating and delaying the progression of roughness; however, this treatment was effective only for pavements in freeze zones, high traffic, or poor condition.

**Rutting**:

- Thin overlay mitigated and slowed the progression of rutting under all circumstances.
- Chip seal was more effective than slurry seal in wet freeze zones but was only marginally more effective in dry freeze zones.
- There were no significant differences between slurry seal, crack seal, and the no treatment control scenario with respect to rutting.

**Fatigue cracking**:

- Thin overlays and chips seals were more effective than slurry seal and crack seal treatments in mitigating fatigue cracking.
- With respect to fatigue cracking, thin overlays performed better than most other treatments if the pavement was in a freeze zone, in a wet climatic region, subject to high traffic, or initially in poor condition.

### Preventive Maintenance Effectiveness for Rigid Pavements

The study of the SPS-4 sites showed that the performance of the joint/crack sealed sections and undersealed sections was not significantly different from the performance of control sections. Additionally, no meaningful difference between the two treatments was found. The analysis was weakened by the small number of sites and only 4 years of performance history that included recorded surveys with undersealing treatment. While 34 sites included the survey measurements for joint/crack sealed sections, only 10 sites had data for undersealed sections.

## REHABILITATED FLEXIBLE PAVEMENTS

The findings presented in this section are based on the analysis of 18 SPS-5 rehabilitated flexible pavement experimental sites with 162 core test sections. Most of the sections were monitored for at least 9 years.

### Evaluation of Rehabilitation Strategies with Respect to Performance

To analyze data from the SPS-5 experiment, a gradual statistical analysis was used in which the data from each site were analyzed first, followed by a consolidated analysis of all sites simultaneously in search for general trends and broader conclusions about pavement performance and its dependency on design features and site conditions. The results obtained in the consolidated analysis mostly agree with the results found in the individual site analyses. A summary of the analysis findings with respect to major pavement performance indicators is provided below.

**IRI**:

- Rehabilitation strategies with milling prior to overlay provided better roughness performance (i.e., smoother) for all site conditions.
- Strategies with thick overlays provided smoother pavements for all site conditions.
- Strategies with virgin or RAP mixes had equivalent performance when used under wet conditions.
- Strategies with RAP mixes provided smoother pavements when used in dry conditions.
- Traffic level and freeze conditions did not impact roughness performance ranking.

**Rutting**:

- Rehabilitation strategies with thin overlays performed better than thick overlays in the short term. In the long term, the ranking of best strategies was more evenly distributed for both thick and thin overlays.
- The ranking of best strategies was evenly distributed among the two mix types (virgin and RAP) in the short term. In the long term, rehabilitation strategies with virgin mixes were in the top ranking of performance more frequently (lowest rutting), with the

exception of fair pavement surface under freeze conditions, which corresponded to 33 percent of all sites.

- Strategies with milling did not improve rutting performance more than alternatives without milling.
- Surprisingly, the level of traffic did not affect rutting performance of the selected rehabilitation strategies.

**Fatigue cracking**:

- Short-term fatigue cracking performance was not affected significantly by any design features under any site conditions, which makes sense because overlays were designed to minimize fatigue cracking in the short term.
- Rehabilitation strategies with thick overlays provided better performance for fatigue cracking under all site conditions evaluated.
- Strategies with milling prior to overlay performed better to mitigate development and propagation of fatigue cracking in all site conditions.
- In regions with a dry climate, alternatives without milling performed as well as solutions with milling.
- Strategies with RAP mixes were better ranked for sites with low traffic.

**Transverse cracking**:

- There were no differences identified in short-term performance among the rehabilitation strategies in freezing zones.
- Among the sites located in no-freeze zones, the remaining site conditions did not have any impact on short-term performance.
- Strategies with virgin mixes and thick overlays ranked best for long-term transverse cracking performance.
- Strategies with RAP mixes performed better than virgin mixes when the site had low traffic and when the site had high traffic and a dry climate.
- Milling prior to overlay did not improve performance more than alternatives without milling.

**Longitudinal cracking (in wheel paths)**:

- Rehabilitation strategies with milling prior to overlay were consistently better for improving performance than alternatives without milling.

- Strategies with virgin mixes were consistently better than alternatives with RAP in sites located in wet climates.

- There was no difference in ranking between strategies with virgin and RAP mixes in dry conditions.

- Overlay thickness was not a significant factor affecting performance associated with longitudinal cracking.

In terms of the effect of design features or construction practices, the following conclusions were made:

**Overlay thickness**:

- Overlay thickness was the most influential design feature. Thick overlays consistently performed better than thin overlays, as expected.

- The impact of thickness on performance was more evident in the long term (more than 5 years) for most of the distresses. The exception was rutting, which had no evidence suggesting that either thin or thick overlays provided less rutting.

**Milling**:

- The analysis of milling prior to overlay suggested that replacing the distressed portion of the surface layer improved the performance for the majority of distresses commonly observed in flexible pavements.

**RAP mixes**:

- The majority of sites did not show significant differences in performance between sections overlaid with virgin and RAP mixes. However, when differences existed, they were mostly in favor of virgin mixes.

### Evaluation of Rehabilitation Strategies with Respect to Structural Responses

For evaluation of structural responses, a maximum FWD deflection measured under the center of the load was used as a structural response indicator. The study concentrated on evaluating FWD maximum deflections against the average pavement performance during the service life of SPS-5 sites. As with the analysis of pavement performance presented above, a gradual statistical analysis was used beginning with the analysis of individual sites, followed by a consolidated analysis of all sites simultaneously. The results from the consolidated analysis supported the findings from the analysis of individual sites. A summary of the analysis findings with respect to structural response is as follows:

- Rehabilitation strategies with thick overlays provided the lowest structural response independent of site conditions.

- Strategies with RAP mix overlays had the lowest structural response in freeze regions, while strategies with virgin mixes presented lower deflections under no-freeze conditions.

- Milling prior to overlay did not affect the structural response. In fact, in no-freeze zones, strategies without milling presented lower deflections.

- When comparing wet and dry climates, pavement surface condition, and traffic level, none had a significant impact on structural responses associated with each rehabilitation alternative.

In terms of the effect of design features or construction practices, the following conclusions were made:

**Overlay thickness**:

- Rehabilitation strategies with thick overlays had lower maximum deflection values compared to alternatives with thin overlays, as expected.

**RAP mixes**:

- There were no differences in pavement response between strategies using virgin and RAP mix overlays.

**Milling**:

- Strategies with milling prior to overlay did not impact the structural response more than alternatives without milling.

### Evaluation of Structural Responses Immediately After Rehabilitation and Future Performance

The objective of this evaluation was to identify trends in the relationship between response measured after the rehabilitation and the observed performance in subsequent years of the pavement's service life. Only long-term performance was used for this analysis, which included performance data of 5 years or more. The following summarizes the analysis findings:

**IRI**:

- The trend between roughness and maximum deflection suggests that roughness, as measured by IRI values, was positively related to the deflection values measured after the rehabilitation of the pavement structure. The higher the deflection after rehabilitation, the higher the IRI over the long term.

**Rutting**:

- The center load FWD deflection after the pavement's rehabilitation did not provide adequate qualitative information about the rutting performance predictions. The instantaneous FWD deflections could not be associated with the material's behavior impacting performance for rutting.

**Fatigue cracking**:

- No statistically significant trend was found between fatigue cracking performance and center load FWD deflection.

**Transverse cracking**:

- Higher values of transverse cracking were found when the pavement had higher center load FWD deflections.

**Longitudinal cracking**:

- No significant correlation was found between longitudinal cracking and center load deflection.

## REHABILITATED RIGID PAVEMENTS

Findings presented in this section are based on the analysis of 14 SPS-6 rehabilitated rigid pavement sites, specifically 8 JPCP and 6 JRCP. Most of the sections were monitored for at least 6 years. The findings from the analysis are described separately for JPCP and JRCP sites.

### Evaluation of JPCP Rehabilitation Strategies with Respect to Performance

The results from the statistical analysis led to the following conclusions with respect to major pavement performance indicators, total cracking and IRI:

**Total cracking**:

- Rehabilitation strategies without overlays were the most effective to mitigate cracking development and propagation. Specifically, HMA overlays over jointed concrete pavements exhibited more total cracking than when the pavement was not overlaid.

- Saw and seal (when counted as an existing crack) showed more total cracking than other alternatives, but the control of reflection cracks (through sawing and sealing) was the design goal for this alternative. The smoothness of sawed and sealed overlays was similar to other overlays of similar thickness.

- Crack/break and seat of JPCP had no significant effect in reducing the amount of cracking, since it performed similarly to the 4-inch (102-mm) overlay over noncracked JPCP (with both minimum and maximum restorations).

- The three alternatives without overlays, no treatment control scenario, minimum restoration, and maximum restoration, were found to be the best choices (i.e., reduced total cracking) for both short-term and long-term performance.

- Crack/break and seat with 4-inch (102-mm) overlays was the best alternative among those which involved overlays to reduce cracking.

- The sawed and sealed joints did not deteriorate significantly on these sections, and they became an effective control of reflection cracking. If they were counted for total cracking, the sawed and sealed sections would have shown similar performance to other HMA overlays.

**IRI**:

- Rehabilitation strategies with HMA overlay were significantly smoother than treatments without overlay for both the short term and long term.

- The best alternative to improve roughness performance was the thicker overlay alternative crack/break and seat with 8-inch (203-mm) overlays. This alternative also has the highest cost.

- Crack/break and seat with 8-inch (203-mm) overlays and minimum restoration with 4-inch (102-mm) overlays (without crack/break and seat) were statistically equivalent and were found to be the best alternatives for most of the scenarios evaluated when both short-term and long-term roughness performance were considered.

- Crack/break and seat with 4-inch (102-mm) overlay was among the worst alternatives to improve roughness performance.

- Saw and seal alternative provided similar smoothness to other 4-inch (102-mm) overlays.

It should be noted that the best performance alternative may not be the lowest cost alternative. Selection of a rehabilitation alternative must also consider the cost and long-term maintenance.

The analysis of impact of site conditions led to the conclusion that different climate regions and surface conditions did not have a significant impact on roughness and total cracking performance for the rehabilitation strategies included in the SPS-6 JPCP experiment.

### *Effect of PCC Restoration Prior to Overlay*

The impact of PCC restoration preoverlay treatments on performance of overlaid sections was investigated in the JPCP sites of the SPS-6 experiment. Transverse cracking was the only distress for which statistical differences were found between the four treatments. The conclusions from this study were as follows:

- The best alternative to limit the development and propagation of transverse cracking among all options with 4-inch (102-mm) overlays was crack/break and seat.

- Minimum and maximum restorations had an equivalent impact on short-term transverse cracking performance.

The analysis of impact of site conditions led to the following additional conclusions:

- Statistical differences in performance of overlaid sections were observed only for transverse cracking and short-term roughness when individual site characteristics were considered.
- The rankings of best treatments prior to overlay remained the same regardless of site characteristics (i.e., surface condition or climate region).
- There was no impact on performance due to variations in surface condition prior to rehabilitation or the climatic region where the LTPP site was located.
- Minimum, maximum, and saw and seal restorations provided the best short-term roughness performance, but there was no difference between the rehabilitation alternatives for long-term performance. Specifically, for the long term, these three restorations showed the same roughness.
- Crack/break and seat and minimum restoration were the best alternatives to mitigate the development and propagation of transverse cracking in the long term.

### *Effect of PCC Restoration Without Overlay*

Three sections in each SPS-6 site did not receive overlays as part of their rehabilitation strategies. These sections were used to evaluate the impact of PCC restoration on performance. The small number of sections available for this study significantly reduced the power of the analysis and the chances of finding statistical differences among the treatment alternatives. No statistical differences in performance were found for short-term performance. The only performance indicator that showed statistical differences between the treatments was long-term roughness. From the analysis of long-term roughness, the findings supported by the statistical analysis were as follows:

- The maximum restoration treatment produced the smoothest pavement over the long term.
- The minimum restoration treatment produced the second smoothest pavement over the long term.
- The no treatment control section, which received no rehabilitation, was the roughest pavement over the long term, as expected.

An attempt was made to evaluate the impact of site conditions on performance; however, the results were not statistically significant.

## Evaluation of JRCP Rehabilitation Strategies with Respect to Performance

Similar to JPCP findings, the results of the JRCP analyses suggested that rehabilitation strategies with HMA overlays improved roughness performance, while strategies without overlays were better at improving total cracking development and propagation. The main conclusions were as follows.

**Total cracking**:

- Rehabilitation strategies without overlays were the best when considering total cracking.
- Saw and seal, when counted as cracking, had the highest total cracking among all options evaluated. However, the sawed and sealed joints remained in reasonably good condition over time.
- Crack/break and seat of JRCP had no significant effect on reducing the amount of cracking since it performed similarly to the 4-inch (102-mm) overlay over noncracked JRCP (with minimum and maximum restoration).

**IRI**:

- Rehabilitation strategies with overlay had significantly better roughness performance (i.e., were smoother) than treatments without overlay.
- Minimum and maximum restorations with overlays were the best strategies to improve short-term performance for roughness.
- For long-term performance, the best alternative was the thick overlay alternative crack/break and seat with 8-inch (203-mm) overlays.

The sawed and sealed joints did not deteriorate significantly on these sections, and they became an effective control of reflection cracking. If they were removed from total cracking, the sawed and sealed sections would have shown similar performance to other HMA overlays.

### *Effect of PCC Restoration Prior to Overlay*

The impact of PCC restoration treatments on the performance of overlaid sections was investigated in JRCP sites of the SPS-6 experiment. Transverse cracking was the only distress for which statistical differences were found between the four treatments. The conclusions from this study were as follows:

- Crack/break and seat was the best alternative for short-term performance.
- Minimum and maximum restorations had an equivalent impact on short-term performance.
- The best alternatives to limit the development and propagation of transverse cracking in the long term were crack/break and seat and minimum restoration.
- Saw and seal prior to overlay when counted as cracks had the highest total cracking among all options evaluated in the SPS-6 experiment.

The sawed and sealed joints did not deteriorate significantly on these sections, and they became an effective control of reflection cracking. If they were removed from total cracking, the saw and sealed sections would have shown similar performance to other HMA overlays.

### *Effect of PCC Restoration Without Overlay*

Three sections in each SPS-6 site did not receive an overlay as part of their rehabilitation strategies. These sections were used to evaluate the impact of PCC restoration on performance. Distresses common to rigid pavements were used as performance measures. The only performance indicator that showed statistical differences between the treatments was short-term transverse reflection slab cracking. The findings from this statistical analysis were as follows:

- The maximum restoration treatment and the control section had statistically equivalent performances for short-term transverse slab cracking.
- The minimum restoration treatment provided the worst transverse slab cracking performance.
- The small number of sites limited the statistical findings in this study.

## Evaluation of Rehabilitation Strategies with Respect to Structural Responses

FWD deflections were used as the response measure of the pavement structure. Deflections at the center of the slab and at the transfer joints were used in this study. JPCP and JRCP structures were evaluated independently. Sections that received an HMA overlay were monitored like flexible pavements, and deflections at the center of the lane were used.

There were limitations due to the amount of data available, especially after the data were grouped by pavement structure type and surface. Because of the small sample size (eight sites), the statistical power of the analysis was low, and no statistical differences were found in the pavement response of JPCP structures.

The only analysis that provided some statistically meaningful results was the evaluation of maximum deflection at the center lane of overlaid JRCP structures. The results suggested that crack/break and seat significantly increased the overall deflections measured on the pavement surface. The remaining treatments interchangeably provided equivalent maximum deflection magnitudes. These results were expected since crack/break and seat was an alternative in which the concrete slab was reduced to smaller pieces resulting in lower stiffness, and this increased the maximum deflection at the center of the slab.

## Evaluation of Structural Responses Immediately After Rehabilitation and Future Performance

The objective of this study was to identify trends in the relationship between response measured immediately after the rehabilitation and the observed performance in the subsequent years of the pavement’s service life. LTE between slabs and maximum deflection at the center of the slab were used when the surface remained concrete slabs after rehabilitation. Maximum deflection at the center of the lane was used when the surface changed to HMA after rehabilitation.

### *LTE Versus Performance in JPCP*

Only transverse slab cracking exhibited a clear trend with LTE values in no overlaid JPCP sections, indicating that as the efficiency of the load transfer increased, the amount of transverse slab cracking decreased. This trend suggested that good load transfer joint restoration was important to mitigate the development and propagation of slab cracking.

### *Maximum Deflection at Center of Slab Versus JPCP Performance*

The trend between performance based on roughness and deflection measured at the center of the slab suggested that the higher the deflection, the smoother the JPCP over time. This trend was not what would normally be expected. The level of slab cracking also showed an inverse trend with maximum deflection measured at the center of the slab. The trend suggested that slabs with higher deflections under FWD loading were less likely to develop cracking. A possible explanation was that stiffer subgrades resulted in higher slab curling and warping stresses, which led to increased slab cracking. This same result was found in MEPDG.(1) While stiffer foundations reduced axle load stresses, they increased curling and warping stresses, which often tended to dominate cracking.

Faulting was also investigated, and the observed trend suggested that faulting was inversely proportional to deflection measured at the center of the slab. High deflection values yielded low faulting, although the trend was weak and depended on only one or two points. There was no logical explanation for this result.

### *Maximum Deflection at Center of Lane Versus Performance of Overlaid JPCP*

For sections that received an overlay as part of the rehabilitation strategy, there was a clear indication that overlaid JPCP with high deflections were more likely to become rougher pavements in the long term compared to sections with low deflection values.

Overlaid JPCP sections with high center lane deflections were more likely to experience higher rutting than sections with low deflection values. Since all rutting occurred in the HMA layer, the cause for this result was not explainable unless the HMA was so soft that it contributed significantly to the total deflection. Normally, nearly all deflection was in the foundation for JPCP.

The fatigue cracking trend suggested that high fatigue cracking was expected when deflection values were high. High longitudinal cracking values were observed when maximum deflections at the center of the lane were low, which indicated that the pavement structure was less deformable and more susceptible to surface tensile stresses, which was an important contributor to the development and propagation of longitudinal cracking.

### *Response Versus Performance in JRCP*

The investigation of possible trends between response and performance in JRCP structures did not result in any meaningful conclusions. Different performance measures were analyzed against LTE, maximum deflection at the center of the slab, and maximum deflection at the center of the lane; however, no relevant conclusion was determined.

## FINDINGS FROM MEPDG ANALYSES

MEPDG analysis was used to compare MEPDG-predicted performance of rehabilitated pavement sections with field-measured data and to verify current calibration against predictions of rehabilitated pavement structures. The following summarizes the findings from the MEPDG analysis.

The findings for the roughness model are as follows:

- The roughness models for flexible pavements and rigid pavements provided good overall predictions of rehabilitated sections with and without HMA overlay.
- There was some bias in the predictions, which could be addressed with local or revised general calibration. The model had a tendency to underpredict roughness for rigid pavement sections with IRI values above 9.50 ft/mi (1.8 m/km). This bias was more characteristic of sections located in dry and freeze regions.

The findings for the rutting model are as follows:

- This model needs further enhancement to more accurately predict permanent deformation in HMA overlay over flexible and rigid pavements before it can be used with overlaid pavements.
- The model overpredicts performance of HMA overlays over crack/break and seat restored rigid pavements
- The model underpredicts performance of HMA overlays for saw and seal and minimum and maximum restorations prior to overlays.
- MEPDG considers the cracked/broken PCC layer as new granular base layer. Permanent deformation is predicted for the new layer and even the subgrade, which is normally the cause of the overprediction of total rutting identified in this study.

The finds for cracking models for HMA overlays are as follows:

- The cracking models for HMA overlays (particularly the empirical reflection cracking) need further enhancement to provide more accurate predictions.
- The models for fatigue cracking (new and reflective) and longitudinal cracking were not capable of predicting consistent and comparable performance with measured values.
- MEPDG did not predict transverse cracking in any of the SPS-5 or SPS-6 sections; however, some transverse cracking was measured during surveys.

## RECOMMENDATIONS FOR FUTURE RESEARCH

The following list provides suggestions for future research to further build on the knowledge gained from this study.

Researchers could monitor or create a new LTPP experiment to examine new and rehabilitated sections, including the following focus areas:

- Monitor rutting for flexible pavements, focusing on trenching and forensic studies to measure the contribution of individual layers to total rutting.
- Develop a means to assess and gather data on reflective cracking to obtain data to calibrate improved models to incorporate in MEPDG.
- Monitor response and performance data to develop or improve MEPDG models.
- Add new rigid pavement sections to the experiment to monitor undersealing of rigid pavements. The sample size used in this analysis was too small to obtain any meaningful conclusions.
- Review LTPP procedures to measure fatigue cracking of rehabilitated sections. There is evidence that cracking for such conditions was mostly associated with the propagation of cracks from the existing pavement prior to the overlay.

Another possible research plan includes future improvements of MEPDG models, including the following:

- Reassess the impact of existing conditions prior to overlay on MEPDG models for IRI. In general, MEPDG underpredicts IRI levels for poor surface conditions and thin overlays, particularly with RAP mixes.
- Use LTPP data to reduce bias on IRI estimates for aged pavements. In general, MEPDG overpredicts IRI for the control sections.
- Revise MEPDG models. MEPDG analysis results for IRI of SPS-6 sections with no overlays presented some bias. In general, the MEPDG models underpredict the IRI level, particularly for sections with maximum restoration. It is recommended to revise the MEPDG models for such conditions to remove bias, particularly for pavements with restoration procedures and pavements located in freeze zones. In general, MEPDG overpredicts rutting for sections rehabilitated with crack/break and seat alternatives. MEPDG models can be improved if the bias is removed with revised models or with improved calibration based on LTPP data for such sections. Except for crack/break and seat, MEPDG estimates for rutting on sections with overlays are underpredicted. The MEPDG models for such conditions should be revised or recalibrated to remove existing bias.

- Improve the MEPDG empirical model for reflective cracking through calibration efforts based on results obtained in this study. Two issues need to be addressed in the future. The first is how fatigue, longitudinal, and transverse cracking may be masked by reflective cracking. It was difficult to separate reflective cracking from other types of cracking during the survey measurements. The attempt to incorporate every type of cracking in the analysis conducted in this study was not very successful, particularly due to the possible confusion when measuring individual types of cracking and due to the poor performance of reflective cracking models in MEPDG. Revised models and procedures to identify reflective cracking during the surveys can help improve MEPDG estimates for cracking of rehabilitated sections of both flexible and rigid pavements.

The recommendations for technology transfer are as follows:

- Develop publications based on findings of this study that can be distributed to the industry to help engineers find the best maintenance treatment or rehabilitation alternatives for their specific conditions.
- Promote use of SPS-5 and SPS-6 data and findings to improve local and general calibration for MEPDG analysis of rehabilitated pavement sections.
- Make MEPDG input data from this project available to users for local calibration of MEPDG models.

# APPENDIX A. SUMMARY STATISTICAL ANALYSIS

## FLEXIBLE PAVEMENTS —SPS-5

The tables in this section describe the statistical results from the ANOVA performed in each site of the SPS-5 experiment. The number found after the State names represents the State code in the LTPP database. If statistical differences were found, they are described as “Y” in the statistical difference column, and the corresponding *p*-value is shown. If no statistical differences were found, they are described as “N.”

**Table 93. Summary of individual statistical analysis results for SPS-5 site in Alabama (1).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | Thin | | N | | | N | | |
| Rutting | N | Thin | Thin | N | | Virgin | N | | No mill |
| Fatigue | N | Thick | Thick | N | Virgin | Virgin | N | Mill | Mill |
| Transverse | Y<br>($p = 0.015$) | Thick | Thick | N | | Virgin | Y<br>($p = 0.00002$) | Mill | Mill |
| Longitudinal | Y<br>($p = 0.003$) | | Thin | N | Virgin | Virgin | Y<br>($p = 0.013$) | Mill | Mill |

Note: Blank cells indicate no difference between design factors.

**Table 94. Summary of individual statistical analysis results for SPS-5 site in Arizona (4).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | Y<br>($p = 0$) | Thick | Thick | Y<br>($p = 0$) | | Virgin | N | Mill | Mill |
| Rutting | Y<br>($p = 0.004$) | Thin | Thick | Y<br>($p = 0.0004$) | Virgin | Virgin | N | No mill | |
| Fatigue | N | Thick | Thick | N | | | Y<br>($p = 0.005$) | Mill | Mill |
| Transverse | N | | | N | Virgin | Virgin | N | | |
| Longitudinal | N | | Thin | Y<br>($p = 0.01$) | Virgin | Virgin | N | | |

Note: Blank cells indicate no difference between design factors.

**Table 95. Summary of individual statistical analysis results for SPS-5 site in California (6).**

| Distress | Overlay Thickness | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | Y<br>($p$ = 0.00001) | Thick | Thick | Y<br>($p$ = 0.0499) | Virgin | Virgin | N | Mill | Mill |
| Rutting | Y<br>($p$ = 0.0025) | | Thick | N | | | N | | |
| Fatigue | Y<br>($p$ = 0.036) | Thick | | N | Virgin | Virgin | Y<br>($p$ = 0.031) | Mill | Mill |
| Transverse | N | | Thick | Y<br>($p$ = 0.0036) | Virgin | Virgin | N | | |
| Longitudinal | N | | | N | | | Y<br>($p$ = 0.011) | No mill | No mill |

Note: Blank cells indicate no difference between design factors.

**Table 96. Summary of individual statistical analysis results for SPS-5 site in Colorado (8).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | | Thick | Y<br>($p$ = 0.027) | | RAP | N | N | |
| Rutting | Y<br>($p$ = 0.034) | | Thick | Y<br>($p$ = 0) | | RAP | N | Y<br>($p$ = 0.034) | |
| Fatigue | N | | Thick | N | | RAP | N | N | |
| Transverse | Y<br>($p$ = 0.01) | | Thick | N | RAP | | N | Y<br>($p$ = 0.01) | |
| Longitudinal | N | | Thick | N | | RAP | N | N | |

Note: Blank cells indicate no difference between design factors.

### Table 97. Summary of individual statistical analysis results for SPS-5 site in Florida (12).

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | Thin | Thin | N | Virgin | Virgin | Y<br>( $p = 0.031$) | Mill | Mill |
| Rutting | N | Thin | Thin | N | Virgin | Virgin | Y<br>($p = 0.02$) | Mill | Mill |
| Fatigue | N | | Thin | N | | Virgin | N | | Mill |
| Transverse | N | | | N | | | N | | |
| Longitudinal | N | | Thick | N | | | Y<br>($p = 0.021$) | | No mill |

Note: Blank cells indicate no difference between design factors.

### Table 98. Summary of individual statistical analysis results for SPS-5 site in Georgia (13).

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | | | N | Virgin | Virgin | N | | |
| Rutting | N | | | N | | | N | | |
| Fatigue | N | | | N | | | N | | |
| Transverse | | | | | | | | | |
| Longitudinal | N | | Thin | N | | | N | | |

Note: Blank cells indicate no difference between design factors.

### Table 99. Summary of individual statistical analysis results for SPS-5 site in Maine (23).

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | | Thin | N | | | N | No mill | No mill |
| Rutting | N | | | N | | | Y<br>($p = 0.005$) | No mill | No mill |
| Fatigue | | | | | | | | | |
| Transverse | | | | | | | | | |
| Longitudinal | N | | | N | | | Y<br>($p = 0.02$) | | mill |

Note: Blank cells indicate no difference between design factors.

**Table 100. Summary of individual statistical analysis results for SPS-5 site in Maryland (24).**

| | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| Distress | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | Thick | x | N | Virgin | x | Y<br>($p = 0.0196$) | Mill | x |
| Rutting | Y<br>($p = 0.0045$) | Thin | x | Y<br>($p = 0$) | Virgin | x | N | | x |
| Fatigue | | | | | | | | | |
| Transverse | | | | | | | | | |
| Longitudinal | | | | | | | | | |

Note: Blank cells indicate no difference between design factors.

**Table 101. Summary of individual statistical analysis results for SPS-5 site in Minnesota (27).**

| | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| Distress | | Short | Long | | Short | Long | | Short | Long |
| Roughness | Y<br>($p = 0.00045$) | Thick | | N | | | N | Mill | Mill |
| Rutting | N | | | Y<br>($p = 0.0095$) | Virgin | | N | | |
| Fatigue | | | | | | | | | |
| Transverse | N | | | N | | RAP | N | | No mill |
| Longitudinal | N | | | N | | | N | | |

Note: Blank cells indicate no difference between design factors.

**Table 102. Summary of individual statistical analysis results for SPS-5 site in Mississipi (28).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | Thick | Thick | N | Virgin | Virgin | N | Mill | Mill |
| Rutting | Y<br>($p = 0.0006$) | Thin | Thin | N | | | N | | |
| Fatigue | Y<br>($p = 0.0217$) | Thick | Thick | Y<br>($p = 0.0066$) | Virgin | Virgin | N | | |
| Transverse | N | | | Y<br>($p = 0.0028$) | | Virgin | N | | |
| Longitudinal | Y<br>($p = 0.0396$) | Thin | Thick | N | Virgin | Virgin | N | | |

Note: Blank cells indicate no difference between design factors.

**Table 103. Summary of individual statistical analysis results for SPS-5 site in Missouri (29).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | Thick | | N | RAP | | N | No mill | |
| Rutting | N | | Thin | Y<br>($p = 0$) | | Virgin | N | | Mill |
| Fatigue | N | | Thin | N | | RAP | N | | No mill |
| Transverse | N | | | N | | | N | | |
| Longitudinal | N | | | N | | | N | | Mill |

Note: Blank cells indicate no difference between design factors.

**Table 104. Summary of individual statistical analysis results for SPS-5 site in Montana (30).**

| | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Best Performance | | | Best Performance | | | Best Performance | |
| **Distress** | **Statistical Difference** | **Short** | **Long** | **Statistical Difference** | **Short** | **Long** | **Statistical Difference** | **Short** | **Long** |
| Roughness | Y<br>($p = 0$) | | Thick | Y<br>($p = 0.0359$) | | Virgin | N | | Mill |
| Rutting | N | Thick | Thick | N | | RAP | N | | |
| Fatigue | N | | Thick | N | Virgin | Virgin | N | | |
| Transverse | N | Thick | Thick | N | RAP | RAP | N | Mill | Mill |
| Longitudinal | N | Thick | Thick | N | RAP | RAP | N | Mill | Mill |

Note: Blank cells indicate no difference between design factors.

**Table 105. Summary of individual statistical analysis results for SPS-5 site in New Jersey (34).**

| | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Best Performance | | | Best Performance | | | Best Performance | |
| **Distress** | **Statistical Difference** | **Short** | **Long** | **Statistical Difference** | **Short** | **Long** | **Statistical Difference** | **Short** | **Long** |
| Roughness | N | Thick | Thick | N | | | Y<br>($p = 0.00097$) | Mill | Mill |
| Rutting | N | Thick | Thick | N | Virgin | Virgin | N | | |
| Fatigue | Y<br>($p = 0.0093$) | | Thick | Y<br>($p = 0.00034$) | | Virgin | N | | |
| Transverse | N | Thick | Thick | Y<br>($p = 0.0081$) | | Virgin | Y<br>($p = 0.019$) | Mill | Mill |
| Longitudinal | N | | | N | Virgin | Virgin | Y<br>($p = 0.0198$) | Mill | |

Note: Blank cells indicate no difference between design factors.

## Table 106. Summary of individual statistical analysis results for SPS-5 site in New Mexico (35).

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | | | N | | | N | | |
| Rutting | Y<br>($p = 0.025$) | | Thin | N | | | N | No mill | No mill |
| Fatigue | N | | | Y<br>($p = 0.003$) | | RAP | N | | No mill |
| Transverse | N | | Thick | N | | | Y<br>($p = 0.00011$) | Mill | Mill |
| Longitudinal | N | | | Y<br>($p = 0.00014$) | Virgin | Virgin | N | | |

Note: Blank cells indicate no difference between design factors.

## Table 107. Summary of individual statistical analysis results for SPS-5 site in Oklahoma (40).

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | Y<br>($p = 0.014$) | Thick | Thick | N | | Virgin | N | Mill | Mill |
| Rutting | N | | | Y<br>($p = 0$) | | RAP | N | | |
| Fatigue | N | | | N | | | N | | |
| Transverse | Y<br>($p = 0.028$) | Thick | Thick | N | | | N | Mill | Mill |
| Longitudinal | N | | | N | | | N | | Mill |

Note: Blank cells indicate no difference between design factors.

**Table 108. Summary of individual statistical analysis results for SPS-5 site in Texas (48).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | Thick | Thick | N | RAP | RAP | N | | Mill |
| Rutting | N | | | N | | RAP | N | | |
| Fatigue | N | | | Y<br>($p = 0.024$) | | Virgin | N | | No mill |
| Transverse | Y<br>($p = 0.0016$) | Thick | Thick | Y<br>($p = 0$) | | Virgin | N | Mill | Mill |
| Longitudinal | Y<br>($p = 0.001$) | Thick | Thick | Y<br>($p = 0$) | Virgin | Virgin | N | Mill | Mill |

Note: Blank cells indicate no difference between design factors.

**Table 109. Summary of individual statistical analysis results for SPS-5 site in Alberta (81).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | N | | | N | | | N | | |
| Rutting | N | | | N | | Virgin | N | | |
| Fatigue | Y<br>($p = 0.003$) | Thick | Thick | Y<br>($p = 0.033$) | Virgin | Virgin | N | Mill | Mill |
| Transverse | N | Thick | | Y<br>($p = 0.0098$) | RAP | RAP | N | Mill | Mill |
| Longitudinal | N | Thin | Thin | N | Virgin | Virgin | N | | |

Note: Blank cells indicate no difference between design factors.

**Table 110. Summary of individual statistical analysis results for SPS-5 site in Manitoba (83).**

| Distress | Overlay Thickness | | | Mix Type | | | Milling | | |
|---|---|---|---|---|---|---|---|---|---|
| | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | | Statistical Difference | Best Performance | |
| | | Short | Long | | Short | Long | | Short | Long |
| Roughness | Y<br>($p = 0$) | Thick | Thick | N | | RAP | Y<br>($p = 0.01$) | | Mill |
| Rutting | N | | | N | | | N | | No mill |
| Fatigue | Y<br>($p = 0.0197$) | | Thick | N | | Virgin | N | | |
| Transverse | Y<br>($p = 0.0107$) | | Thin | N | | | N | | |
| Longitudinal | N | | | N | | | N | Mill | |

Note: Blank cells indicate no difference between design factors.

The following tables provide the WD calculations used in the consolidated analysis with the Friedman test.

### Table 111. Long-term average WD-IRI values for SPS-5 sites.

| Section | Experimental Design | | | Sites (State Codes)/Average WD-IRI values (m/km) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mill | Mix | Thickness (mm) | 1 | 4 | 6 | 8 | 12 | 13 | 23 | 24 | 27 | 28 | 29 | 30 | 34 | 35 | 40 | 48 | 81 | 83 |
| 0501 | No | None | | | 80 | 108 | 70 | | | 92 | 97 | 193 | 88 | 130 | | 134 | 39 | 113 | | 127 | 98 |
| 0502 | No | RAP | 51 | 55 | 134 | 130 | 65 | 49 | 40 | 42 | 80 | 90 | 96 | 72 | 74 | 70 | 44 | 86 | 82 | 93 | 104 |
| 0503 | No | RAP | 127 | 53 | 77 | 75 | 50 | 49 | 40 | 54 | 71 | 87 | 114 | 62 | 62 | 45 | 33 | 66 | 76 | 89 | 69 |
| 0504 | No | Virgin | 127 | 57 | 82 | 74 | 56 | 42 | 40 | 56 | 86 | 95 | 87 | 71 | 48 | 51 | 37 | 70 | 93 | 101 | 71 |
| 0505 | No | Virgin | 51 | 58 | 92 | 102 | 55 | 36 | 40 | 45 | 90 | 101 | 110 | 69 | 57 | 57 | 39 | 64 | 95 | 83 | 107 |
| 0506 | Yes | Virgin | 51 | 48 | 71 | 81 | 87 | 32 | 36 | 52 | 59 | 92 | 101 | 69 | 56 | 51 | 37 | 66 | 90 | 72 | 117 |
| 0507 | Yes | Virgin | 127 | 56 | 88 | 73 | 65 | 37 | 39 | 55 | 63 | 72 | 83 | 83 | 61 | 52 | 42 | 62 | 83 | 93 | 59 |
| 0508 | Yes | RAP | 127 | 65 | 64 | 64 | 52 | 46 | 49 | 48 | 53 | 80 | 92 | 62 | 48 | 48 | 35 | 61 | 74 | 78 | 63 |
| 0509 | Yes | RAP | 51 | 55 | 115 | 142 | 62 | 37 | 40 | 60 | 76 | 87 | 108 | 84 | 62 | 49 | 37 | 64 | 78 | 94 | 84 |

1 ft = 0.305 m

1 mi = 1.61 km

1 inch = 25.4 mm

Note: Higher WD values indicate rougher pavement over time. Blank cells indicate data are not available.

### Table 112. Long-term average WD-rutting values for SPS-5 sites.

| Section | Experimental Design | | | Sites (State Codes)/Average WD-Rutting Values (mm) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mill | Mix | Thickness (mm) | 1 | 4 | 6 | 8 | 12 | 13 | 23 | 24 | 27 | 28 | 29 | 30 | 34 | 35 | 40 | 48 | 81 | 83 |
| 0501 | No | None | | | 0.36 | 0.15 | 0.33 | | | 0.56 | 0.36 | 0.27 | 0.55 | 0.33 | | 0.31 | 0.14 | 0.41 | | 0.36 | 0.36 |
| 0502 | No | RAP | 51 | 0.10 | 0.19 | 0.16 | 0.13 | 0.16 | 0.13 | 0.27 | 0.17 | 0.10 | 0.36 | 0.14 | 0.17 | 0.11 | 0.12 | 0.11 | 0.23 | 0.25 | 0.14 |
| 0503 | No | RAP | 127 | 0.13 | 0.15 | 0.10 | 0.11 | 0.17 | 0.13 | 0.27 | 0.25 | 0.08 | 0.43 | 0.19 | 0.12 | 0.09 | 0.15 | 0.17 | 0.16 | 0.33 | 0.17 |
| 0504 | No | Virgin | 127 | 0.14 | 0.11 | 0.16 | 0.09 | 0.15 | 0.14 | 0.31 | 0.21 | 0.07 | 0.60 | 0.12 | 0.17 | 0.11 | 0.15 | 0.12 | 0.21 | 0.28 | 0.13 |
| 0505 | No | Virgin | 51 | 0.12 | 0.12 | 0.15 | 0.12 | 0.13 | 0.12 | 0.25 | 0.15 | 0.09 | 0.33 | 0.12 | 0.13 | 0.10 | 0.12 | 0.16 | 0.18 | 0.18 | 0.16 |
| 0506 | Yes | Virgin | 51 | 0.09 | 0.11 | 0.12 | 0.14 | 0.11 | 0.12 | 0.35 | 0.12 | 0.09 | 0.36 | 0.12 | 0.20 | 0.13 | 0.15 | 0.15 | 0.25 | 0.25 | 0.18 |
| 0507 | Yes | Virgin | 127 | 0.13 | 0.21 | 0.20 | 0.17 | 0.14 | 0.13 | 0.33 | 0.22 | 0.09 | 0.59 | 0.08 | 0.17 | 0.12 | 0.18 | 0.15 | 0.25 | 0.22 | 0.21 |
| 0508 | Yes | RAP | 127 | 0.21 | 0.14 | 0.11 | 0.13 | 0.16 | 0.12 | 0.32 | 0.19 | 0.08 | 0.56 | 0.17 | 0.11 | 0.10 | 0.16 | 0.11 | 0.18 | 0.23 | 0.22 |
| 0509 | Yes | RAP | 51 | 0.13 | 0.16 | 0.13 | 0.09 | 0.13 | 0.13 | 0.30 | 0.43 | 0.11 | 0.33 | 0.11 | 0.17 | 0.13 | 0.15 | 0.09 | 0.16 | 0.26 | 0.15 |

1 inch = 25.4 mm

Note: Higher WD values indicate increased rutting in pavement over time. Blank cells indicate data are not available.

## Table 113. Long-term average WD-fatigue cracking values for SPS-5 sites.

| | Experimental Design | | | Sites (State Codes)/Average WD-Fatigue Cracking Values ($m^2$) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Section** | **Mill** | **Mix** | **Thickness (mm)** | **1** | **4** | **6** | **8** | **12** | **13** | **23** | **24** | **27** | **28** | **29** | **30** | **34** | **35** | **40** | **48** | **81** | **83** |
| 0501 | No | None | | 2,305 | 692 | | | 13 | 810 | 1 | 51 | 1,927 | | 2,475 | 11 | 0 | | 46 | 377 | 2,305 | 692 |
| 0502 | No | RAP | 51 | 2,566 | 966 | 38 | 0 | 0 | 25 | 0 | 458 | 0 | 1,263 | 463 | 1 | 1 | 3 | 1,480 | 916 | 2,566 | 966 |
| 0503 | No | RAP | 127 | 513 | 137 | 1 | 0 | 0 | 5 | 0 | 46 | 0 | 993 | 151 | 0 | 10 | 8 | 1,052 | 734 | 513 | 137 |
| 0504 | No | Virgin | 127 | 475 | 111 | 0 | 0 | 0 | 96 | 0 | 4 | 2 | 0 | 178 | 2 | 1 | 0 | 384 | 544 | 475 | 111 |
| 0505 | No | Virgin | 51 | 1,467 | 674 | 1 | 0 | 0 | 183 | 0 | 94 | 0 | 16 | 165 | 1 | 4 | 0 | 700 | 681 | 1,467 | 674 |
| 0506 | Yes | Virgin | 51 | 474 | 1,261 | 0 | 0 | 0 | 9 | 0 | 198 | 3 | 1 | 7 | 6 | 1 | 0 | 765 | 822 | 474 | 1,261 |
| 0507 | Yes | Virgin | 127 | 528 | 840 | 0 | 1 | 0 | 0 | 0 | 0 | 108 | 0 | 45 | 4 | 1 | 5 | 273 | 489 | 528 | 840 |
| 0508 | Yes | RAP | 127 | 85 | 180 | 0 | 0 | 0 | 84 | 0 | 258 | 0 | 725 | 47 | 0 | 1 | 8 | 399 | 498 | 85 | 180 |
| 0509 | Yes | RAP | 51 | 2,204 | 16 | 0 | 1 | 0 | 0 | 0 | 705 | 2 | 1,511 | 650 | 2 | 0 | 29 | 1,272 | 1,068 | 2,204 | 16 |

1 $ft^2$ = 0.093 $m^2$

1 inch = 25.4 mm

Note: Higher WD values indicate increased pavement cracking over time. Blank cells indicate data are not available.

## Table 114. Long-term average WD-transverse cracking values for SPS-5 sites.

| | Experimental Design | | | Sites (State Codes)/Average WD-Transverse Cracking Values (m) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Section** | **Mill** | **Mix** | **Thickness (mm)** | **1** | **4** | **6** | **8** | **12** | **13** | **23** | **24** | **27** | **28** | **29** | **30** | **34** | **35** | **40** | **48** | **81** | **83** |
| 0501 | No | None | | | 0 | 154 | 63 | | | 38 | 140 | 245 | 201 | 32 | | 270 | 33 | 91 | | 30 | 32 |
| 0502 | No | RAP | 51 | 110 | 87 | 153 | 69 | 5 | 0 | 0 | 134 | 262 | 96 | 0 | 26 | 199 | 47 | 62 | 220 | 96 | 188 |
| 0503 | No | RAP | 127 | 4 | 339 | 194 | 11 | 0 | 0 | 0 | 54 | 196 | 136 | 0 | 14 | 69 | 44 | 24 | 98 | 88 | 151 |
| 0504 | No | Virgin | 127 | 0 | 40 | 83 | 43 | 0 | 0 | 0 | 32 | 200 | 3 | 0 | 35 | 50 | 3 | 5 | 4 | 61 | 250 |
| 0505 | No | Virgin | 51 | 54 | 216 | 197 | 64 | 8 | 0 | 0 | 152 | 327 | 50 | 0 | 57 | 155 | 56 | 52 | 186 | 288 | 81 |
| 0506 | Yes | Virgin | 51 | 1 | 50 | 152 | 90 | 2 | 0 | 0 | 129 | 294 | 65 | 1 | 51 | 9 | 2 | 33 | 4 | 130 | 39 |
| 0507 | Yes | Virgin | 127 | 1 | 2 | 100 | 10 | 0 | 0 | 0 | 4 | 149 | 1 | 4 | 10 | 11 | 0 | 0 | 2 | 143 | 208 |
| 0508 | Yes | RAP | 127 | 1 | 207 | 257 | 9 | 0 | 0 | 0 | 59 | 217 | 80 | 0 | 10 | 51 | 2 | 0 | 73 | 54 | 225 |
| 0509 | Yes | RAP | 51 | 13 | 339 | 209 | 40 | 0 | 0 | 0 | 5 | 230 | 32 | 1 | 0 | 47 | 9 | 30 | 155 | 19 | 110 |

1 ft = 0.305 m

1 inch = 25.4 mm

Note: Higher WD values indicate increased pavement cracking over time. Blank cells indicate data are not available.

## Table 115. Long-term average WD-longitudinal cracking values for SPS-5 sites.

| Section | Experimental Design |  |  | Sites (State Codes)/Average WD-Longitudinal Cracking Values (m) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Mill | Mix | Thickness (mm) | 1 | 4 | 6 | 8 | 12 | 13 | 23 | 24 | 27 | 28 | 29 | 30 | 34 | 35 | 40 | 48 | 81 | 83 |
| 0501 | No | None |  |  | 0 | 364 | 842 |  |  | 1,039 | 939 | 894 | 239 | 563 |  | 670 | 380 | 53 |  | 170 | 250 |
| 0502 | No | RAP | 51 | 95 | 47 | 268 | 722 | 2 | 304 | 277 | 795 | 843 | 209 | 52 | 377 | 862 | 405 | 252 | 797 | 575 | 741 |
| 0503 | No | RAP | 127 | 143 | 337 | 430 | 552 | 2 | 209 | 292 | 624 | 549 | 101 | 96 | 186 | 949 | 508 | 113 | 646 | 579 | 848 |
| 0504 | No | Virgin | 127 | 86 | 26 | 362 | 715 | 9 | 132 | 302 | 429 | 677 | 52 | 33 | 176 | 827 | 103 | 83 | 80 | 704 | 669 |
| 0505 | No | Virgin | 51 | 92 | 130 | 342 | 996 | 27 | 293 | 277 | 486 | 894 | 47 | 465 | 270 | 585 | 268 | 28 | 797 | 319 | 932 |
| 0506 | Yes | Virgin | 51 | 0 | 78 | 485 | 673 | 0 | 144 | 214 | 627 | 737 | 52 | 88 | 205 | 599 | 158 | 36 | 337 | 84 | 574 |
| 0507 | Yes | Virgin | 127 | 19 | 3 | 459 | 410 | 0 | 129 | 277 | 651 | 649 | 17 | 74 | 89 | 753 | 60 | 65 | 19 | 456 | 578 |
| 0508 | Yes | RAP | 127 | 69 | 285 | 497 | 152 | 73 | 135 | 218 | 745 | 369 | 170 | 116 | 266 | 926 | 559 | 0 | 631 | 578 | 921 |
| 0509 | Yes | RAP | 51 | 100 | 329 | 492 | 152 | 8 | 206 | 138 | 99 | 572 | 146 | 54 | 322 | 826 | 411 | 48 | 639 | 544 | 392 |

1 ft = 0.305 m

1 inch = 25.4 mm

Note: Higher WD values indicate increased pavement cracking over time. Blank cells indicate data were not available.

# APPENDIX B. PRACTICAL GUIDE: SELECTION OF PAVEMENT MAINTENANCE ALTERNATIVES

This appendix is intended to help users select the best pavement maintenance alternatives based on the results of this study and on specific conditions of pavement sections planned for maintenance. The most relevant differences in performance determined in this research are those for flexible pavements under the SPS-3 experiment, which is partially related to the larger sample size and the number of alternatives evaluated in the study. Under the SPS-4 experiment, only the performance of one maintenance alternative, joint/crack seal, could be evaluated. The second treatment, undersealing, had a sample size that was too small to obtain any meaningful results.

## FLEXIBLE PAVEMENTS

Five alternatives were evaluated for flexible pavements: control, thin overlay, slurry seal, crack seal, and chip seal.

The conditions that were evaluated included climate (temperature and moisture), subgrade type (fine grained versus coarse grained), traffic loading (low versus high), and pavement condition (good, fair, or poor).

The best performances among the alternative treatments evaluated were thin overlay and chip seal. Thin overlay was most effective when rutting or roughness were the major existing distresses. Chip seal was the most effective when fatigue cracking was the major existing distress. Table 116 summarizes the best alternatives given specific conditions of the pavement section.

**Table 116. Preferred flexible pavement treatments.**

| | | **Temperature** | | **Precipitation** | | **Subgrade** | | **Traffic** | | **Pavement Condition** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Distress** | **Preferred Treatment** | **Freeze** | **No-freeze** | **Dry** | **Wet** | **Fine** | **Coarse** | **Low** | **High** | **Good** | **Fair** | **Poor** |
| Fatigue Cracking | 1st choice | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | TH |
| | 2d choice | TH | — | — | TH | — | TH | — | TH | — | — | CH |
| Rutting | 1st choice | TH | TH | TH | TH | TH | TH | TH | TH | TH | TH | TH |
| | 2d choice | CH | — | CH | — | — | — | — | — | — | — | — |
| Roughness | 1st choice | TH | None | None | None | TH | TH | None | TH | None | None | TH |

CH = chip seal and TH = thin overlay.

— Indicates that no data are available.

Note: None means that neither treatment alternative performed significantly better than the control section. CH is not included as an option for roughness because it was never the preferred treatment method.

### Example

An engineer is planning the maintenance of a road section placed on a coarse subgrade with a high level of traffic. The section is located in a wet, no-freeze location, and the existing pavement condition is poor with fatigue cracking and roughness being the major existing distresses. In this case, the engineer should concentrate only on the choices to mitigate fatigue cracking and roughness, since these are the major distresses. Table 117 provides the possible options.

**Table 117. Flexible pavement example.**

| Distress | Preferred Treatment | Temperature | Precipitation | Subgrade | Traffic | Pavement Condition |
|---|---|---|---|---|---|---|
| | | No-freeze | Wet | Coarse | High | Poor |
| Fatigue cracking | 1st choice | CH | CH | CH | CH | TH |
| | 2d choice | — | TH | TH | TH | CH |
| Roughness | 1st choice | — | — | TH | TH | TH |

CH = chip seal and TH = thin overlay.
— Indicates that no data are available.

From the table, the choice appears straightforward. Although chip seal is the best choice for fatigue cracking under most conditions, thin overlay is also a good choice for fatigue cracking, particularly if the pavement is in poor condition. Moreover, only thin overlays can help mitigate roughness. If the difference in cost between chip seal and thin overlay is not an issue, the pavement treatment choice is thin overlay.

## RIGID PAVEMENTS

Three alternatives were evaluated for rigid pavements: control, joint/crack seal, and undersealing.

The conditions that were evaluated included climate (temperature and moisture), subgrade type (fine grained versus coarse grained), traffic loading (low versus high), and pavement condition (good, fair, or poor).

There were no differences in performance between the control and the two maintenance alternatives evaluated in this study. However it is important to note that the sample size was small, particularly for the evaluation of undersealing, which only had eight sites.

# APPENDIX C. PRACTICAL GUIDE: FACTORS AFFECTING PERFORMANCE OF REHABILITATED FEXIBLE PAVEMENTS

## INTRODUCTION

This appendix summarizes the research results of the SPS-5 experiment to help engineers select the best rehabilitation alternatives for rigid pavements among those evaluated in the experiment and, from a performance perspective, as a function of specific site conditions and distresses in the existing pavement.

The selection is made based on the best alternative in each group. Despite the practicality of the information, tables in this section should be used with caution, particularly when the sources of distresses are associated with construction, new techniques, or other unusual circumstances not reflected in the SPS-6 experiment.

The design factors and site characteristics investigated in the SPS-5 experiment were as follows:

- **Site conditions**: Climate (wet versus dry and freeze versus no-freeze), pavement condition (fair versus poor), and traffic (low versus high).
- **Design features**: Surface preparation (milling versus no milling), overlay material (virgin versus recycled HMA), and overlay thickness (thin versus thick).

## SELECTION PROCESS

This section summarizes the rehabilitation alternatives that are most likely to provide best performances under a given set of conditions. Within each group, the impact of design features is characterized by ranking the rehabilitation strategies from the best to the worst. Each distress is evaluated independently. Only rankings with statistical significance are shown in the table. If there is no ranking associated with one particular distress, no statistical difference in performance was found, which indicates that none of the design features evaluated had differential impact on performance.

The tables presented in this appendix can be used as a guide to determine which design features may perform better among the options evaluated in this study. An example is described here and summarized in table 118. Table 119 through table 127 can be used to evaluate which design feature will provide better performance measured by the distresses listed in the tables. The selection is made based on the best alternative in each group.

### Selection Process Example

An engineer will select a rehabilitation alternative for the following conditions:

- The existing pavement is in fair condition, and fatigue cracking is the major distress type followed by a medium level of roughness that should be mitigated. The level of rutting is minor, and no transverse or longitudinal cracking is observed.

- The section is located in a no-freeze zone and in wet conditions. The level of traffic is considered high.

The selection process involves gathering the information from each table containing the ranking of alternatives for each specific condition. Using the information in the example, the best alternatives for wet conditions are taken from table 120 and included in table 118. The same process is performed for each of the site conditions, and the information is included in table 118. As a result, the combination of design features presented in the table is likely to provide the best performance to the selected distresses.

**Table 118. Selection of design features to improve performance of rehabilitated flexible pavements.**

| Site Condition | Roughness | | | Rutting | | | Fatigue Cracking | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mill** | **Thickness** | **Mix Type** | **Mill** | **Thickness** | **Mix Type** | **Mill** | **Thickness** | **Mix Type** |
| Wet | Yes | Thin | Virgin | No | Thin | | No | Thick | RAP |
| | | | | Yes | Thin | Virgin | Yes | Thin | Virgin |
| | | | | | | Virgin | Yes | Thick | Virgin |
| No-freeze | — | — | — | Yes | Thin | Virgin | No | Thick | Virgin |
| | | | | No | Thin | Virgin | | | |
| | | | | Yes | Thin | RAP | | | |
| Existing fair pavement | Yes | Thick | RAP | Yes | Thick | RAP | — | — | — |
| | | | | No | Thin | Virgin | | | |
| | | | | No | Thick | RAP | | | |
| High traffic | Yes | Thick | RAP | No | Thin | Virgin | No | Thick | Virgin |
| | | | | | | | Yes | Thick | Virgin |
| | | | | | | | Yes | Thick | RAP |
| Final selection | Yes | Thick | RAP | No | Thin | Virgin | Yes | Thick | Virgin |

— Indicates that no preferred treatment was statistically found.

**Table 119. Summary of performance for all SPS-5 sections.**

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Roughness** | | **Rutting** | | **Fatigue Cracking** | | **Longitudinal Cracking** | | **Transverse Cracking** | | **Deflection** | |
| **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| 1 | Mill, thick, RAP | 1 | No mill, thin, virgin | 1 | No mill, thick, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin |
| 2 | No mill, thick, RAP | 1 | Mill, thick, RAP | 1 | Mill, thick, RAP | 2 | Mill, thin, virgin | 2 | No mill, thick, virgin | 2 | Mill, thick, RAP |
| 2 | Mill, thin, virgin | 1 | No mill, thin, RAP | 1 | Mill, thick, virgin | 2 | No mill, thick, virgin | 3 | Mill, thick, RAP | 2 | No mill, thick, RAP |
| 2 | Mill, thick, virgin | 1 | Mill, thin, virgin | 4 | Mill, thin, virgin | 2 | Mill, thin, RAP | 3 | Mill, thin, RAP | 2 | No mill, thick, virgin |

**Table 120. Summary of performance for SPS-5 sections in wet zones.**

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roughness | | Rutting | | Fatigue Cracking | | Longitudinal Cracking | | Transverse Cracking | | Deflection | |
| Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy |
| 1 | Mill, thin, virgin | 1 | No mill, thin, virgin | 1 | No mill, thick, RAP | 1 | Mill, thin, virgin | 1 | No mill, thick, virgin | 1 | Mill, thick, RAP |
| 2 | Mill, thick, RAP | 1 | Mill, thin, virgin | 1 | Mill, thin, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin |
| 2 | Mill, thick, virgin | 3 | No mill, thin, RAP | 1 | Mill, thick, virgin | 3 | No mill, thick, virgin | 3 | Mill, thin, RAP | 1 | No mill, thick, RAP |
| 2 | No mill, thick, RAP | 3 | No mill, thick, RAP | 4 | No mill, thick, virgin | 3 | Mill, thin, RAP | 3 | Mill, thick, RAP | 1 | No mill, thick, virgin |
| 2 | No mill, thick, virgin | 3 | Mill, thin, RAP | 4 | Mill, thick, RAP | 3 | No mill, thin, virgin | 3 | Mill, thin, virgin | 5 | Mill, thin, virgin |
| 2 | No mill, thin, RAP | 3 | Mill, thick, RAP | 4 | No mill, thin, virgin | 3 | Mill, thick, RAP | 3 | No mill, thick, RAP | 5 | Mill, thin, RAP |
| 2 | No mill, thin, virgin | 3 | Mill, thick, virgin | 4 | Mill, thin, RAP | 3 | No mill, thin, RAP | 3 | No mill, thin, virgin | 5 | No mill, thin, virgin |
| 2 | Mill, thin, RAP | 3 | No mill, thick, virgin | 4 | No mill, thin, RAP | 3 | No mill, thick, RAP | 3 | No mill, thin, RAP | 8 | None |

### Table 121. Summary of performance for SPS-5 sections in dry zones.

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roughness | | Rutting | | Fatigue Cracking | | Longitudinal Cracking | | Transverse Cracking | | Deflection | |
| Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy |
| 1 | Mill, thick, RAP | 1 | No mill, thick, virgin | | | | | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin |
| 2 | No mill, thick, RAP | 1 | No mill, thin, virgin | | | | | 2 | No mill, thick, virgin | 1 | No mill, thick, virgin |
| 3 | Mill, thick, virgin | 1 | Mill, thick, RAP | | | | | 2 | Mill, thick, RAP | 1 | Mill, thick, RAP |
| 3 | No mill, thick, virgin | 4 | Mill, thin, RAP | | | | | 2 | Mill, thin, RAP | 1 | No mill, thick, RAP |
| 3 | Mill, thin, virgin | 4 | No mill, thick, RAP | | | | | 2 | No mill, thick, RAP | 5 | No mill, thin, virgin |

Note: Blank cells indicate that no preferred treatment was found.

### Table 122. Summary of performance for SPS-5 sections in freeze zones.

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Roughness** | | **Rutting** | | **Fatigue Cracking** | | **Longitudinal Cracking** | | **Transverse Cracking** | | **Deflection** | |
| **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| 1 | Mill, thick, RAP | 1 | No mill, thin, virgin | | | | | | | 1 | No mill, thick, RAP |
| 1 | No mill, thick, RAP | 1 | Mill, thick, RAP | | | | | | | 1 | Mill, thick, RAP |
| 1 | Mill, thick, virgin | 1 | No mill, thick, virgin | | | | | | | 3 | No mill, thick, virgin |
| 1 | Mill, thin, virgin | 1 | No mill, thin, RAP | | | | | | | 3 | Mill, thick, virgin |

Note: Blank cells indicate that no preferred treatment was found.

### Table 123. Summary of performance for SPS-5 sections in no-freeze zones.

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Roughness** | | **Rutting** | | **Fatigue Cracking** | | **Longitudinal Cracking** | | **Transverse Cracking** | | **Deflection** | |
| **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| | | 1 | Mill, thin, virgin | 1 | No mill, thick, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin |
| | | 1 | No mill, thin, virgin | 2 | Mill, thin, virgin | 2 | Mill, thin, virgin | 2 | No mill, thick, virgin | 2 | No mill, thick, virgin |
| | | 1 | Mill, thin, RAP | 2 | Mill, thick, virgin | 2 | No mill, thick, virgin | 3 | Mill, thin, virgin | 3 | Mill, thick, RAP |

Note: Blank cells indicate that no preferred treatment was found.

## Table 124. Summary of performance for SPS-5 sections in fair surface condition prior to rehabilitation.

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roughness | | Rutting | | Fatigue Cracking | | Longitudinal Cracking | | Transverse Cracking | | Deflection | |
| Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy |
| 1 | Mill, thick, RAP | 1 | Mill, thick, RAP | | | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin | 1 | Mill, thick, RAP |
| 2 | No mill, thick, RAP | 1 | No mill, thin, virgin | | | 1 | Mill, thin, virgin | 2 | Mill, thick, RAP | 2 | No mill, thick, RAP |
| 2 | Mill, thin, virgin | 1 | No mill, thick, RAP | | | 3 | Mill, thick, RAP | 3 | Mill, thin, RAP | 2 | Mill, thick, virgin |
| 2 | Mill, thin, RAP | 4 | No mill, thick, virgin | | | 3 | No mill, thick, virgin | 3 | No mill, thick, virgin | 2 | No mill, thick, virgin |

Note: Blank cells indicate that no preferred treatment was found.

**Table 125. Summary of performance for SPS-5 sections in poor surface condition prior to rehabilitation.**

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roughness | | Rutting | | Fatigue Cracking | | Longitudinal Cracking | | Transverse Cracking | | Deflection | |
| Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy |
| 1 | mill, thick, RAP | 1 | No mill, thin, virgin | | | | | | | 1 | No mill, thick, virgin |
| 2 | Mill, thin, virgin | 1 | Mill, thin, virgin | | | | | | | 1 | Mill, thick, virgin |
| 2 | Mill, thick, virgin | 3 | Mill, thin, RAP | | | | | | | 3 | No mill, thick, RAP |
| 2 | No mill, thick, RAP | 3 | No mill, thin, RAP | | | | | | | 4 | Mill, thick, RAP |
| 2 | No mill, thick, virgin | 3 | No mill, thick, virgin | | | | | | | 5 | Mill, thin, virgin |
| 2 | No mill, thin, Virgin | 3 | No mill, thick, RAP | | | | | | | 6 | No mill, thin, Virgin |
| 2 | No mill, thin, RAP | 3 | Mill, thick, RAP | | | | | | | 6 | Mill, thin, RAP |
| 2 | Mill, thin, RAP | 3 | Mill, thick, virgin | | | | | | | 8 | No mill, thin, RAP |

Note: Blank cells indicate that no preferred treatment was found.

### Table 126. Summary of performance for SPS-5 sections with low traffic levels.

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roughness | | Rutting | | Fatigue Cracking | | Longitudinal Cracking | | Transverse Cracking | | Deflection | |
| Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy | Ranking | Strategy |
| 1 | Mill, thick, RAP | 1 | No mill, thin, virgin | | | | | 1 | No mill, thick, virgin | 1 | No mill, thick, RAP |
| 1 | Mill, thin, virgin | 1 | Mill, thin, virgin | | | | | 1 | Mill, thick, virgin | 1 | Mill, thick, virgin |
| 1 | Mill, thick, virgin | 3 | No mill, thin, RAP | | | | | 1 | Mill, thick, RAP | 1 | No mill, thick, virgin |
| 1 | No mill, thick, RAP | 3 | No mill, thick, virgin | | | | | 1 | No mill, thick, RAP | 4 | Mill, thick, RAP |

Note: Blank cells indicate that no preferred treatment was found.

**Table 127. Summary of performance for SPS-5 sections with high traffic levels.**

| Distress | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roughness | | Rutting | | Fatigue Cracking | | Longitudinal Cracking | | Transverse Cracking | | Deflection | |
| **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** | **Ranking** | **Strategy** |
| 1 | Mill, thick, RAP | 1 | No mill, thin, virgin | 1 | No mill, thick, virgin | | | | | 1 | No mill, thick, virgin |
| 2 | No mill, thick, RAP | 2 | No mill, thick RAP | 1 | Mill, thick, virgin | | | | | 1 | Mill, thick, RAP |
| 2 | No mill, thick, virgin | 2 | No mill, thin, RAP | 1 | Mill, thick, RAP | | | | | 1 | No mill, thick, RAP |
| 2 | Mill, thick, virgin | 2 | No mill, thick, virgin | 4 | No mill, thick RAP | | | | | 4 | Mill, thick, virgin |
| 2 | Mill, thin, virgin | 2 | Mill, thick RAP | 4 | No mill, thin, virgin | | | | | 5 | Mill, thin, RAP |
| 2 | No mill, thin, virgin | 2 | Mill, thin, RAP | 4 | Mill, thin virgin | | | | | 5 | Mill , thin, virgin |

Note: Blank cells indicate that no preferred treatment was found.

# APPENDIX D. PRACTICAL GUIDE: FACTORS AFFECTING PERFORMANCE OF REHABILITATED RIGID PAVEMENTS

## INTRODUCTION

This appendix summarizes the research results of the SPS-6 experiment to help engineers select the best rehabilitation alternatives for rigid pavements. The selection is based on alternatives evaluated in the SPS-6 experiment and from a performance perspective as a function of specific site conditions and distresses in the existing pavement.

The selection is made based on the best alternative in each group. Despite the practicality of the information, the tables in this section should be used with caution, particularly when the sources of distresses are associated with construction, new techniques, or other unusual circumstances not reflected in the SPS-6 experiment.

The design factors and site characteristics investigated in the SPS-6 experiment were as follows:

- **Site conditions**: Climate (wet versus dry and freeze versus no-freeze) and pavement condition (fair versus poor).
- **Design features**: Surface PCC restoration (minimum, maximum, saw and seal, crack/break, and seat) and overlaid (4 and 8 inches (102 and 203 mm)) versus not overlaid.

## SELECTION PROCESS

This section summarizes the rehabilitation alternatives that are most likely to provide best performances under a given set of conditions. Within each group, the impact of design features is characterized by ranking the rehabilitation strategies from the best to the worst. Each distress is evaluated independently. Only rankings with statistical significance are provided in the tables. If there is no ranking associated with one particular distress, no statistical difference in performance was found, which indicates that none of the design features evaluated had differential impact on performance.

The tables can be used as a guide to determine which rehabilitation design alternatives will perform better among the options evaluated in this study. This selection process is only applicable to JPCP sections. The study described in the main volume of this report suggests that all rehabilitation strategies applied to JRCP sections were equivalent in performance when the sections were grouped by site conditions. The number of JRCP sections available was small and significantly limited the results from a statistical analysis standpoint.

An example is described for JPCP and summarized in table 128. To create this table, information was taken from table 129 through table 134 to evaluate which of the design features evaluated in this study would provide better performance as measured by the level of distresses listed in the tables. The selection is made based on the best alternative for each group.

### Selection Process Example

An engineer will select a rehabilitation alternative for the following conditions:

- The existing pavement is in fair condition, and cracking is the major distress type followed by a medium level of roughness that should be mitigated.
- The section is located in a no-freeze zone and in wet conditions.

The selection process involves gathering the information from each table containing the ranking of alternatives for each specific condition. Using the information in the example, the best alternatives for wet conditions were taken from table 130. The same process was performed for each of the site conditions. As result, the combination of design features presented in table 128 should provide the best alternatives to address existing distresses and have satisfactory performance over the design life of the rehabilitated pavement. Based on the information in the table, the choice should be crack/break and seat with an 8-inch (203-mm) HMA surface layer because the best alternatives for cracking will not mitigate roughness. In addition, crack/break and seat is the second best alternative for total cracking.

**Table 128. Selection of design features to improve performance of rehabilitated rigid pavements (JPCP).**

| Site Condition | Roughness | | Total Cracking | |
|---|---|---|---|---|
| | Restoration | Thickness (mm) | Restoration | Thickness (mm) |
| Wet | Crack/break and seat | 203 | None | None |
| | Minimum restoration | 102 | None | None |
| No-freeze | Crack/break and seat | 203 | None | None |
| Existing fair pavement | Crack/break and seat | 203 | Minimum restoration | None |
| | Crack/break and seat | 203 | Maximum restoration | None |

1 inch = 25.4 mm

**Table 129. Summary of performance for all JPCP SPS-6 sections.**

| Distress | | | | | |
|---|---|---|---|---|---|
| Roughness | | | Total Cracking | | |
| Ranking | Strategy | Overlay (mm) | Ranking | Strategy | Overlay (mm) |
| 1 | Crack/break and seat | 203 | 1 | None[1] | None |
| 2 | Minimum | 102 | 1 | Minimum | None[1] |
| 2 | Maximum | 102 | 1 | Maximum | None[1] |
| 2 | Saw/seal | 102 | 4 | Crack/break and seat | 203 |
| 5 | Maximum | None | 4 | Crack/break and seat | 102 |
| 5 | Crack/break and seat | 102 | 4 | Maximum | 102 |
| 5 | Minimum | None | 4 | Minimum | 102 |
| 8 | None | None | 8 | Saw/seal | 102 |

1 inch = 25.4 mm

[1] Indicates that based on the distress survey data for cracking, the alternatives without overlays were found to perform better; however, the user should apply these results with caution. It is difficult to differentiate fatigue cracking from reflective cracking, and it seems that reflective cracking is measured as fatigue, longitudinal, or transverse cracking. In this situation, for overlaid pavement, reflective cracking from JPCP joints may have been measured as one of the categories of cracking (fatigue, transverse, or longitudinal). For nonoverlaid pavements, the joints are not measured as cracking, causing the differences in performance identified in the statistical analysis.

**Table 130. Summary of performance for JPCP SPS-6 sections in wet zones.**

| Distress | | | | | |
|---|---|---|---|---|---|
| **Roughness** | | | **Total Cracking** | | |
| **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| 1 | Crack/break and seat | 203 | 1 | None[1] | None |
| 1 | Minimum | 102 | 2 | Minimum | None[1] |
| 3 | Maximum | 102 | 2 | Maximum | None[1] |
| 3 | Saw/seal | 102 | 2 | Crack/break and seat | 102 |
| 3 | Maximum | None | 2 | Crack/break and seat | 203 |
| 3 | Crack/break and seat | 102 | 2 | Minimum | 102 |
| 3 | Minimum | None | 2 | Maximum | 102 |
| 8 | None | None | 8 | Saw/seal | 102 |

1 inch = 25.4 mm

[1] Indicates that based on the distress survey data for cracking, the alternatives without overlays were found to perform better; however, the user should apply these results with caution. It is difficult to differentiate fatigue cracking from reflective cracking, and it seems that reflective cracking is measured as fatigue, longitudinal, or transverse cracking. In this situation, for overlaid pavement, reflective cracking from JPCP joints may have been measured as one of the categories of cracking (fatigue, transverse, or longitudinal). For nonoverlaid pavements, the joints are not measured as cracking, causing the differences in performance identified in the statistical analysis.

**Table 131. Summary of performance for JPCP SPS-6 sections in dry zones.**

| Distress | | | | | |
|---|---|---|---|---|---|
| **Roughness** | | | **Total Cracking** | | |
| **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| 1 | Crack/break and seat | 203 | | | |
| 2 | Maximum | 102 | | | |
| 2 | Minimum | 102 | | | |
| 2 | Saw/seal | 102 | | | |
| 2 | Crack/break and seat | 102 | | | |
| 2 | Maximum | None | | | |
| 7 | None | None | | | |
| 7 | Minimum | None | | | |

1 inch = 25.4 mm

Note: Blank cells indicate that no statitstical difference in performance was found.

The performance of all rehabilitation strategies for JPCP SPS-6 sections in freeze zones were equivalent.

**Table 132. Summary of performance for JPCP SPS-6 sections in no-freeze zones.**

| **Distress** | | | | | |
|---|---|---|---|---|---|
| **Roughness** | | | **Total Cracking** | | |
| **Ranking** | **Strategy** | **Overlay (mm)** | **Ranking** | **Strategy** | **Overlay (mm)** |
| 1 | Crack/break and seat | 203 | 1 | None[1] | None |
| 2 | Minimum | 102 | 2 | Minimum | None[1] |
| 2 | Saw/seal | 102 | 2 | Maximum | None[1] |
| 4 | Maximum | 102 | 2 | Crack/break and seat | 203 |
| 4 | Maximum | None | 2 | Crack/break and seat | 102 |
| 4 | Crack/break and seat | 102 | 2 | Maximum | 102 |
| 7 | Minimum | None | 2 | Minimum | 102 |
| 8 | None | None | 8 | Saw/seal | 102 |

1 inch = 25.4mm

[1] Indicates that based on the distress survey data for cracking, the alternatives without overlays were found to perform better; however, the user should apply these results with caution. It is difficult to differentiate fatigue cracking from reflective cracking, and it seems that reflective cracking is measured as fatigue, longitudinal, or transverse cracking. In this situation, for overlaid pavement, reflective cracking from JPCP joints may have been measured as one of the categories of cracking (fatigue, transverse, or longitudinal). For nonoverlaid pavements, the joints are not measured as cracking, causing the differences in performance identified in the statistical analysis.

## Table 133. Summary of performance for JPCP SPS-6 sections in fair surface condition prior to rehabilitation.

| Distress | | | | | |
|---|---|---|---|---|---|
| Roughness | | | Total Cracking | | |
| Ranking | Strategy | Overlay (mm) | Ranking | Strategy | Overlay (mm) |
| 1 | Crack/break and seat | 203 | 1 | Maximum | None[1] |
| 2 | Maximum | 102 | 1 | Minimum | None[1] |
| 2 | Minimum | 102 | 3 | None[1] | None |
| 2 | Maximum | None | 3 | Crack/break and seat | 203 |
| 2 | Saw/seal | 102 | 3 | Crack/break and seat | 102 |
| 2 | Minimum | None | 3 | Minimum | 102 |
| 2 | Crack/break and seat | 102 | 3 | Maximum | 102 |
| 8 | None | None | 8 | Saw/seal | 102 |

1 inch = 25.4 mm

[1] Indicates that based on the distress survey data for cracking, the alternatives without overlays were found to perform better; however, the user should apply these results with caution. It is difficult to differentiate fatigue cracking from reflective cracking, and it seems that reflective cracking is measured as fatigue, longitudinal, or transverse cracking. In this situation, for overlaid pavement, reflective cracking from JPCP joints may have been measured as one of the categories of cracking (fatigue, transverse, or longitudinal). For nonoverlaid pavements, the joints are not measured as cracking, causing the differences in performance identified in the statistical analysis.

## Table 134. Summary of performance for JPCP SPS-6 sections in poor surface condition prior to rehabilitation.

| Distress | | | | | |
|---|---|---|---|---|---|
| Roughness | | | Total Cracking | | |
| Ranking | Strategy | Overlay (mm) | Ranking | Strategy | Overlay (mm) |
| 1 | Crack/break and seat | 203 | | | |
| 2 | Minimum | 102 | | | |
| 2 | Saw/seal | 102 | | | |
| 2 | Maximum | 102 | | | |
| 2 | Crack/break and seat | 102 | | | |
| 2 | Maximum | None | | | |
| 7 | Minimum | None | | | |
| 7 | None | None | | | |

1 inch = 25.4 mm

Note: Blank cells indicate that no significant difference in performance was found.

# APPENDIX E. PERFORMANCE AND INPUT DATABASE FOR MEPDG ANALYSIS

This section is an electronic appendix and explains the electronic file structure and fields in the various tables in the database. Performance data of SPS-5 and SPS-6 experiments were compiled into this database for comparison with MEPDG analysis results. The database also contains the input data used in the MEPDG analyses. The data provided in this database were used during phase 2 of this project. Moreover, it allows for the creation of the input files for all sections in SPS-5 and SPS-6 experiments.

## PERFORMANCE DATA

Performance data for all SPS-5 and SPS-6 sections are stored in the database. These data were used in phase 2 of this project. The performance data tables are labeled “Performance” followed by the distress type. The following lists the tables and respective fields:

**Table name**: Performance_Roughness

- **Fields**:
    - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
    - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
    - **Date**: Survey date.
    - **IRI Mean**: Average of IRI measurements, inch/mi.
    - **IRI Std Dev**: Standard deviation of IRI measurements, inch/mi.
    - **IRI Num**: Number of IRI measurements.

**Table name**: Performance_Rutting

- **Fields**:
    - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
    - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
    - **Date**: Survey date.
    - **Rut Depth Mean**: Average of rutting measurements, inch/mi.

  - **Rut Depth Std Dev**: Standard deviation of rutting measurements, inch/mi.
  - **Rut Depth Num**: Number of rutting measurements.

**Table name**: Performance_Fatigue_cracking

- **Fields**:
  - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
  - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
  - **Date**: Survey date.
  - **Low Severity**: Low severity, ft$^2$.
  - **Moderate Severity**: Moderate severity, ft$^2$.
  - **High Severity**: High severity, ft$^2$.
  - **Total Severity**: Total severity, ft$^2$.

**Table name:** Performance_Longitudinal_cracking

- **Fields**:
  - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
  - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
  - **Date**: Survey date.
  - **Not Sealed Low Severity**: Low severity, ft.
  - **Not Sealed Moderate Severity**: Moderate severity, ft.
  - **Not Sealed High Severity**: High severity, ft.
  - **Not Sealed Total**: Total, ft.
  - **Sealed Low Severity**: Low severity, ft.
  - **Sealed Moderate Severity**: Moderate severity, ft.

- **Sealed High Severity**: High severity, ft.
- **Sealed Total**: Total, ft.
- **Total Low Severity**: Low severity, ft.
- **Total Moderate Severity**: Moderate severity, ft.
- **Total High Severity**: High severity, ft.
- **Total**: Total, feet.

**Table name:** Performance_Transverse_cracking

- **Fields**:
    - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
    - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
    - **Date**: Survey date.
    - **Not Sealed Low Severity**: Low severity, ft.
    - **Not Sealed Moderate Severity**: Moderate severity, ft.
    - **Not Sealed High Severity**: High severity, ft.
    - **Not Sealed Total**: Total, ft.
    - **Sealed Low Severity**: Low severity, ft.
    - **Sealed Moderate Severity**: Moderate severity, ft.
    - **Sealed High Severity**: High severity, ft.
    - **Sealed Total**: Total, ft.
    - **Total Low Severity**: Low severity, ft.
    - **Total Moderate Severity**: Moderate severity, ft.
    - **Total High Severity**: High severity, ft.
    - **Total**: Total, ft.

**Table name:** Performance_Faulting

- **Fields**:
  - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
  - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
  - **Date**: Survey date.
  - **Average**: Average of faulting measurements, inch.
  - **Minimum**: Minimum of faulting measurements, inch.
  - **Maximum**: Maximum of faulting measurements, inch.
  - **Std Dev**: Standard deviation of faulting measurements, inch.

**Table name:** Performance_PCC_slab_cracking

- **Fields**:
  - **STATE_CODE**: Numerical code for state or province. U.S. codes are consistent with Federal information processing standards.
  - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
  - **Date**: Survey date.
  - **Longitudinal Not Sealed Low Severity**: Longitudinal cracking low severity, ft.
  - **Longitudinal Not Sealed Moderate Severity**: Longitudinal cracking moderate severity, ft.
  - **Longitudinal Not Sealed High Severity**: Longitudinal cracking high severity, ft.
  - **Longitudinal Not Sealed Total**: Total longitudinal cracking not sealed, ft.
  - **Longitudinal Sealed Low Severity**: Longitudinal cracking low severity, ft.
  - **Longitudinal Sealed Moderate Severity**: Longitudinal cracking moderate severity, ft.
  - **Longitudinal Sealed High Severity**: Longitudinal cracking high severity, ft.

- **Longitudinal Sealed Total**: Total longitudinal cracking not sealed, ft.
- **Transverse Not Sealed Low Severity**: Transverse cracking low severity, ft.
- **Transverse Not Sealed Moderate Severity**: Transverse cracking moderate severity, ft.
- **Transverse Not Sealed High Severity**: Transverse cracking high severity, ft.
- **Transverse Not Sealed Total**: Total transverse cracking not sealed, ft.
- **Transverse Sealed Low Severity**: Transverse cracking low severity, ft.
- **Transverse Sealed Moderate Severity**: Transverse cracking moderate severity, ft.
- **Transverse Sealed High Severity**: Transverse cracking high severity, ft.
- **Transverse Sealed Total**: Total transverse cracking not sealed, ft.
- **Total Low Severity**: Total longitudinal and transverse cracking low severity, ft.
- **Total Moderate Severity**: Total longitudinal and transverse cracking moderate severity, ft.
- **Total High Severity**: Total longitudinal and transverse cracking high severity, ft.
- **Total**: Total longitudinal and transverse cracking, ft.

## MEPDG INPUT DATA

Data used to create the MEPDG run files are stored in two tables in the database. One table contains the data for SPS-5 sections, and the other contains data for SPS-6 sections. Additional input data could not be placed in the database file and were stored in folders to support the main database.

Traffic data for monthly adjust factors (MAFs) and axle load factors (ALFs) were stored in files already in the format required by MEPDG. These files are located in the folder called "Traffic—Supporting Files." Climate files are also stored in the "Climate—Supporting Files" folder. References to the files stored outside the database are located in the appropriate fields in the MEPDG inputs table in the database.

The following tables and respective fields were populated and stored in the database:

- **Table name:** SPS-5 MEPDG Inputs.
- **Fields**:
  - **STATE_CODE**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
  - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
  - **Design Life**: Number of years of service life in the LTPP program after rehabilitation.
  - **Subgrade Construction Month**: Subgrade construction month.
  - **Pavement Construction Month**: Pavement construction month.
  - **Traffic Open Date**: Date pavement was opened to traffic after rehabilitation.
  - **Traffic_AADTT**: Average annual daily truck traffic.
  - **Traffic_MAF**: Name of file containing the monthly adjusted factors, in MEPDG format.
  - **Traffic_VCD**: Vehicle class distribution, separated by commas (classes 4–13).
  - **Traffic_HD**: Hourly distribution.
  - **Traffic Growth Factor**: Traffic growth factor.
  - **ALF**: Name of file containing the axle load factors in MEPDG format. This file is located in the supporting folders to the database.
  - **Number of Axles Per Truck**: Name of file containing the number of axles per truck, in MEPDG format. This file is located in the supporting folders to the database.
  - **Climate**: Name of file containing the climate data, in MEPDG format. This file is located in the supporting folders to the database.
  - **Structure**: Description of pavement layers and thicknesses.
  - **Pavement Rating**: Pavement rating before rehabilitation.
  - **Rutting**: Pavement rutting before rehabilitation.
  - **Milling Thickness**: Milling thickness before rehabilitation.

  - **HMA_Retained $^3/_4$-inch Sieve**: HMA-retained $^3/_4$–inch (19.05-mm) sieve.
  - **HMA_Retained $^3/_8$-inch Sieve**: HMA-retained $^3/_8$–inch (9.53-mm) sieve.
  - **HMA_Retained #4 Sieve**: HMA-retained #4 sieve.
  - **HMA_% Passing #200 Sieve**: HMA percentage passing #200 sieve.
  - **HMA_Asphalt Binder Type**: HMA asphalt binder type.
  - **HMA_Effective Binder Content**: HMA effective binder content.
  - **HMA_Air Voids**: HMA air voids.
  - **Unbound Material Properties**: Unbound resilient modulus, when available.
- **Table name:** SPS-6 MEPDG Inputs.
- **Fields**:
  - **ID**: Numerical code for State or province. U.S. codes are consistent with Federal information processing standards.
  - **SHRP_ID**: Test section identification number assigned by LTPP program. Must be combined with STATE_CODE to be unique.
  - **Design Life**: Number of years of service life in the LTPP program after rehabilitation
  - **Subgrade Construction Month**: Subgrade construction month.
  - **Pavement Construction Month**: Pavement construction month.
  - **Traffic Open Date**: Date pavement was opened to traffic after rehabilitation.
  - **Traffic_AADTT**: Average annual daily truck traffic.
  - **Traffic_MAF**: Name of file containing the monthly adjusted factors, in MEPDG format.
  - **Traffic_VCD**: Vehicle class distribution, separated by commas (classes 4–13).
  - **Traffic_HD**: Hourly distribution.
  - **Traffic Growth Factor**: Traffic growth factor.
  - **ALF**: Name of file containing the axle load factors in MEPDG format. This file is located in the supporting folders to the database.

- **Number of Axles Per Truck**: Name of file containing the number of axles per truck in MEPDG format. This file is located in the supporting folders to the database.

- **Climate**: Name of file containing the climate data in MEPDG format. This file is located in the supporting folders to the database.

- **Structure**: Description of pavement layers and thicknesses.

- **Joint Spacing (ft)**: Joint spacing, ft.

- **Pavement Rating**: Pavement rating before rehabilitation.

- **Modulus of Rupture (psi)**: PCC modulus of rupture.

- **Elastic Modulus (psi)**: PCC modulus of rupture.

- **% Slabs w/ Transverse Cracks Before**: Percentage slabs with transverse cracking before rehabilitation.

- **% Slabs w/ Transverse Cracks Fixed**: Percentage slabs with transverse cracking fixed during rehabilitation.

- **HMA_Retained $^3/_4$-inch Sieve**: HMA-retained $^3/_4$-inch (19.05-mm) sieve.

- **HMA_Retained $^3/_8$-inch Sieve**: HMA-retained $^3/_8$-inch (9.53-mm) sieve.

- **HMA_Retained #4 Sieve**: HMA-retained #4 sieve.

- **HMA_% Passing #200 Sieve**: HMA percentage passing #200 sieve.

- **HMA_Asphalt Binder Type**: HMA asphalt binder type.

- **HMA_Effective Binder Content**: HMA effective binder content.

- **HMA_Air Voids**: HMA air voids.

- **Unbound Material Properties**: Unbound resilient modulus, when available.

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