Pooled Fund Study TPF-5(332)
LTPP Forensic Evaluations

WA-RD 905.1

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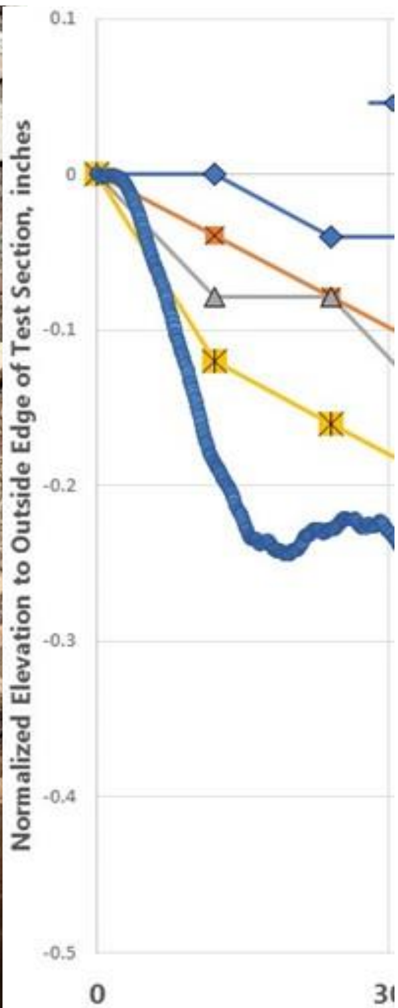
June 2021



Washington State
Department of Transportation

Disclaimer

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Final Report

Pooled Fund Study TPF-5(332)
LTPP Forensic Evaluations
WA-RD 905.1

LTPP Forensic Evaluations

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<tr><td colspan="5">16. Abstract
This report provides a summary of the forensic evaluations conducted on LTPP test sections as they prepared to go out of service. The forensic studies completed evaluated why the pavements performed the way they did through the combination of desktop studies, using readily available data in LTPP InfoPave™, and follow-up investigations which included both field and office activities. In total, 63 test sections at 26 locations were nominated and accepted for investigation. The key findings regarding the performance and identified LTPP data issues for each test site are summarized in this report.</td></tr>
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Final Report
TPF-5(332) LTPP Forensic Evaluations

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Introduction

Long-Term Pavement Performance Program

Program Overview

The Long-Term Pavement Performance (LTPP) program was established in 1987, as part of the Strategic Highway Research Program (SHRP) (FHWA, 2015). In 1992, after the five-year SHRP effort ended, the Federal Highway Administration (FHWA) assumed management and administrative responsibilities to continue LTPP and complete the planned pavement performance monitoring. With the 2020 data collection cycle completed, a dataset reflecting more than three decades of data collection is available. These data are being used in support of the LTPP program mission, which is to promote increased pavement life through (FHWA, 2015):

- Collecting and storing performance data from in-service highways in the United States and Canada, over an extended period, to support analysis and product development.
- Analyzing these data to describe how pavements perform and to explain why they perform as they do.
- Translating these insights into knowledge and usable engineering products related to pavement design, construction, rehabilitation, maintenance, preservation, and management.

The program's goal is to understand how and why pavements perform as they do. As highway agencies transition to a performance-based approach to managing highway investments, this goal is, if anything, more important than ever (FHWA, 2015).

To accomplish the stated mission and goal of the LTPP program, approximately 2,600 test sections on in-service pavements were established throughout North America, as shown in Figure 1 (FHWA, 2015).

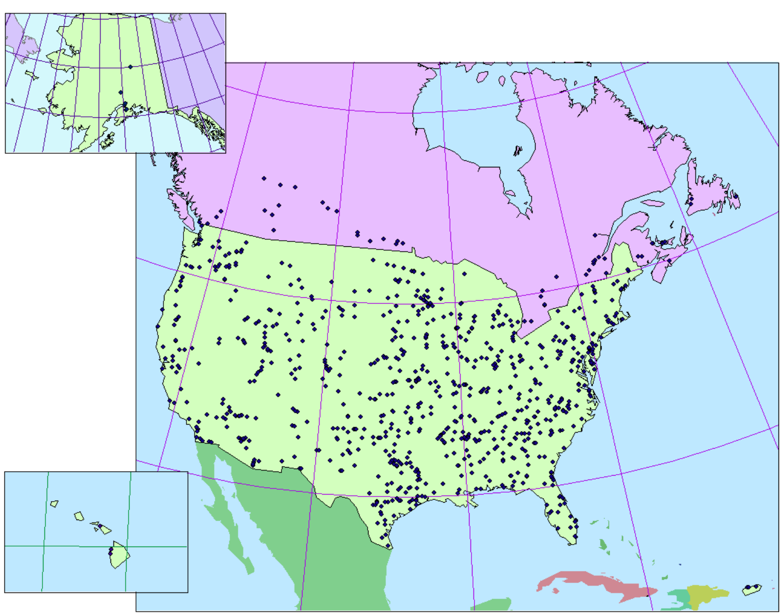

Figure 1. Map. Geographic Distribution of LTPP Test Sections.

The test sections were organized into 18 scientifically designed field experiments within two broad sets of studies: General Pavement Studies (GPS) and Specific Pavement Studies (SPS). Table 1 and Table 2 list the experiments within the GPS and SPS, respectively, including total number of sections per experiment (FHWA, 2015).

Table 1. List of General Pavement Study (GPS) experiments.

Experiment	Experiment Title	Total No. of Sections
GPS-1	Asphalt Concrete (AC) Pavement on Granular Base	106
GPS-2	AC Pavement on Bound Base	65
GPS-3	Jointed Plain Concrete Pavement (JPCP)	113
GPS-4	Jointed Reinforced Concrete Pavement (JRCP)	49
GPS-5	Continuously Reinforced Concrete Pavement (CRCP)	55
GPS-6	AC Overlay of AC Pavement	421
GPS-7	AC Overlay on PCC Pavement	142
GPS-9	Unbonded PCC Overlay on PCC Pavement	25
-	Total Sections:	976

Table 2. List of Specific Pavement Study (SPS) experiments.

Experiment	Experiment Title	Total No. of Sections
SPS-1	Strategic Study of Structural Factors for Flexible Pavements	147
SPS-2	Strategic Study of Structural Factors for Rigid Pavements	207
SPS-3	Preventive Maintenance Effectiveness of Flexible Pavements	445
SPS-4	Preventive Maintenance Effectiveness of Rigid Pavements	220
SPS-5	Rehabilitation of AC Pavements	166
SPS-6	Rehabilitation of Jointed Portland Cement Concrete (JPCC) Pavements	150
SPS-7	Bonded PCC Overlays on Concrete Pavements	39
SPS-8	Study of Environmental Effects in the Absence of Heavy Loads	50
SPS-9P/-9A	Validation and Refinements of SuperPave®Asphalt Specifications and Mix Design Process/SuperPave Asphalt Binder Study	109
SPS-10	Warm Mix Asphalt Overlay of Asphalt Pavement	72
-	Total Sections:	1,605

The GPS are a series of studies on selected existing pavement structures. These studies were restricted to pavements having materials and designs representing good engineering practices and having strategic future importance due to widespread use throughout North America. The SPS are studies of specially constructed, maintained, or rehabilitated pavement sections incorporating a controlled set of experimental design and construction features. The SPS experiments were designed to provide a broader range of pavement factors than those available from pavements designed to meet local conditions. The GPS and SPS were designed to complement and supplement each other.

Figure 2 shows the test sections that remain active in the LTPP program as of the July 2020 LTPP public data release. As shown, the number of test sections has steadily decreased from a high of 2,278 in 1997, 10 years after the LTPP program started, to a current 2020 low of 350, and hence the urgency to perform forensic investigations on test sections before they go out-of-study to capture information that helps explain their performance. Funding constraints have played a major role in the reduction of LTPP test sections—many of them were taken out-of-study while still in good condition.

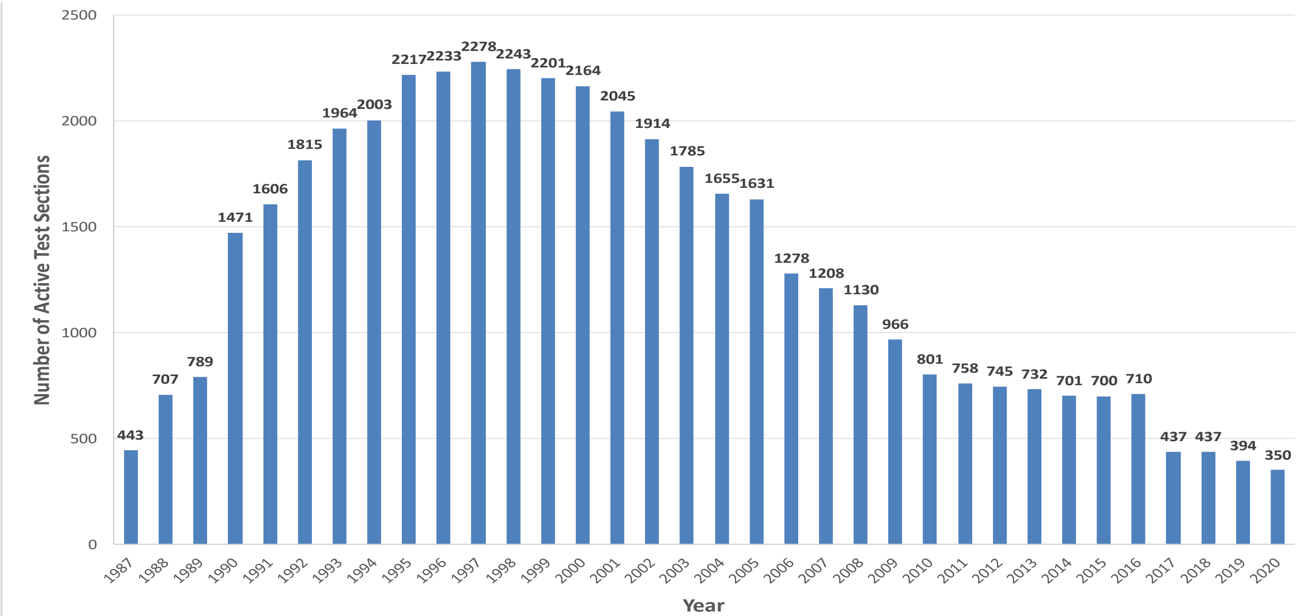

Figure 2. Variation in number of active LTPP test sections over time.

Past LTPP forensic investigations

The concept of performing forensic investigations on LTPP test sections has long been contemplated. They have always been considered of value not only in terms of examining and explaining distress causes and mechanism(s), but also in terms of explaining what worked and why. Therefore, the focus was not just on pavement failures and poor performance, but also on well-performing pavements. However, a formal forensic evaluation plan was never implemented within the program, mostly because of resource constraints.

The earliest formal LTPP forensic investigation was performed in 2000, at a seasonal monitoring program (SMP) test section on route 117 near Groton, Connecticut that was going out-of-study. The investigation was carried out for several reasons, including obtaining missing data, examining SMP instrumentation installed in 1993, obtaining seasonal ground truth moisture measurements, carrying out distress mechanism investigations, and obtaining test section thickness measurements at the SMP FWD test locations. These activities were successfully accomplished and documented in a 2000 technical memorandum and later updated via a report prepared in 2007.

Several more investigations have been carried out since the Connecticut one. Figure 3, for example, shows the trenches that were carried out at the SPS-1 project in Texas to determine the reason for premature rutting of the test sections. A ground penetration radar survey and trenches were performed in addition to typical LTPP monitoring. Based on the collected data, it was determined the rutting was due to AC mix problems, so the surface was milled and replaced.

Figure 3. Photo. Texas SPS-1 trenches.

In addition to the multiple investigations, a framework for LTPP forensic investigations was prepared in April 2004 (FHWA, 2004). This framework, which is not to be confused with a plan, addressed the various stages of an investigation from the nomination of an investigation, to its approval or rejection based on factors such as available test section data, to the preparation and implementation of the investigation plan, and concluding with a technical memorandum or report. The framework was intended to promote consistency and uniformity and to maximize the benefits from the investigations. Unfortunately, the framework was never formally implemented within the LTPP program due to resource constraints. However, it did serve as a major contributor to the National Cooperative Highway Research Program (NCHRP) guidelines for conducting forensic investigations of highway pavement, which are contained in NCHRP Report 747 and are addressed in the next section.

Subsequently, in 2007, FHWA provided the LTPP program with $120,000 to carry out forensic investigations. Two options for using the funds were considered by the program. One was to carry out case studies, possibly focused on key distresses such as rutting or cracking. The other was to conduct a national workshop that included presentations on LTPP and non-LTPP forensic investigations as well as hands-on field work, with the workshop documented in the form of proceedings. In the end, the decision was made to have each of the four LTPP regional support contractors at that time carry out an investigation. They were performed on the following LTPP SPS projects: Arizona SPS-5, Connecticut SPS-9, Ohio SPS-8, and Texas SPS-5. Ultimately, a national workshop sponsored by the LTPP program did take place as part of the project that led to NCHRP Report 747.

NCHRP Forensic Investigation Guidelines

NCHRP Project 01-49 was carried out over a timeframe of 2010 to 2012. Its objective was to develop guidance for conducting forensic investigations of highway pavements—whether to determine failure causes, understand reasons for excellent performance, gather missing data, or other reasons (Rada et al., 2013). This guidance was to include organization and planning of the investigation, sampling and testing requirements, interpretation of results, and decision-making processes. An important element of the guidance was achieving a balance between requirements, priorities, and available resources. Implementation of the guidelines was expected to lead to various benefits, such as (Rada et al., 2013):

- Investigations that are focused on the factors relevant to the questions being asked or issues being raised,
- Enhanced utilization of the collected information,
- More cost-effective investigations,
- Improved understanding of pavement behavior/performance, providing insight into extending pavement life and eliminating premature failures, and
- Improved collection of data to support development of models for pavement evaluation and design.

To accomplish the stated objective, a literature review, survey of highway agencies, and follow-up interviews were carried out, and together with the research team's substantial knowledge, an initial set of guidelines was put together. Those initial guidelines were then tested via six separate case study investigations, and, incorporating findings from those case studies, the final guidelines were established as contained in NCHRP Report 747 and summarized below (Rada et.al. 2013).

Developing a framework, decision tree, or flowchart that attempts to guide the investigator through a step-by-step process to identify the most likely reason(s) for the observed performance (be it poor or exceptional) would have been desirable. However, the investigators believed this approach could reasonably be developed only for investigations in which only one issue contributed to the observed performance (e.g., poor compaction leading to early rutting). The combination of potential investigation objectives and the numerous factors associated with each investigation make it difficult if not impossible (and in some cases, counterproductive) to develop a practical framework that covers all possibilities. Instead, the guidelines start with a general investigation philosophy to help users better understand the forensic investigation guidelines. The philosophy entails the following three fundamental aspects (Rada et al., 2013):

- Understanding pavement performance and the factors that affect it – The success of a forensic investigation requires a clear understanding of how pavements perform and why they perform/behave as they do. Four factors, separately or in combination, define the performance of a pavement: (1) pavement structure, (2) subgrade soil, (3) traffic, and (4) environment.
- Recognizing pavement performance data and information needs – Understanding the performance of a given pavement requires that data and information about each of the factors addressed in the first bullet be collected and analyzed. Three potential sets of data should be pursued in addition to the performance measures of interest: (1) as-designed data and information (performance expectations are established here), (2) as-constructed data and information (actual performance established here), and (3) comparison data and information.
- Avoiding premature or unsupported conclusions about pavement performance – Avoiding quick conclusions and recognizing that whatever the performance issue is, it is highly unlikely to be the result of a single factor. On the other hand, gathering data and information on every possible pavement performance measure and every factor potentially affecting

pavement performance is unnecessary and often beyond the available resources of most agencies.

Having established the philosophy, the NCHRP guidelines then take the user through the following three-phase approach:

1. Preliminary investigation or desktop study,
2. Non-destructive testing, and
3. Destructive and/or laboratory testing.

In the first phase, available information is reviewed to determine what data, if any, is needed to understand the pavement performance. As an aside for this report, a wealth of information is available for each LTPP test section, and therefore carrying out one or both of the remaining phases may not be necessary. If required, however, the information gathered as part of the desktop study is used to develop and implement an investigation plan, preferably starting with the NDT testing (phase two). However, it is also possible to skip NDT testing altogether and go directly to the destructive and laboratory testing phase (phase three).

Within the three-phase approach, the guidelines take the user through the various investigation steps, including (Rada et al., 2013):

- Investigation request and preliminary investigation,
- Initial forensic investigation plan,
- Non-destructive testing,
- Final investigation plan,
- Destructive and laboratory testing,
- Data analysis, hypothesis testing, and final report, and
- Investigation close-out.

The guidelines also address generic issues and provide case studies, example forms, example checklists, and references.

TPF-5(332) Pooled Fund Study

In support of the LTPP program, pooled fund study TPF-5(332) LTPP Forensic Evaluations was established in 2017. The primary objective was to investigate LTPP test sections as they prepare to go out-of-service, capturing data on exactly why the pavements performed as they did; however, a number of test sections that remained active in the LTPP program were investigated. This could entail trenching and coring, measuring lift deflection, and potential lab testing of field samples for materials characteristics as described below. Moreover, the investigations were to be carried out in accordance with the guidelines contained in NCHRP Report 747.

The study was managed by the Washington State Department of Transportation (WSDOT), which issued a solicitation in May 2017 and awarded the contract in December 2017. Other members of the pooled fund study included the California Transportation Department (Caltrans), the Mississippi, New York, and Texas Departments of Transportation (DOTs), and FHWA. Representatives from these organizations, plus Mr. Larry Scofield of the International Grooving and Grinding Association (IGGA), formed the study's Technical Advisory Committee (TAC), which overviewed and guided the study.

While not a part of the study, several other State DOTs actively supported the project by providing traffic control, coring and boring, or information needed for the forensic evaluations. They include the Colorado, Florida, Georgia, Idaho, Iowa, Kansas, Maine, Montana, New Mexico, Ohio, Oklahoma, Pennsylvania, and South Carolina DOTs. The FHWA LTPP program, as well as the LTPP Data Collection Contractor (DCC), also made significant contributions to the study, including coordination of information concerning test sections going out-of-study, coordination of coring activities with the State DOTs, and execution of deflection testing, distress surveys, and longitudinal and transverse profile surveys.

To accomplish the stated objective for the pooled fund study, the following four tasks were established:

1. Project management
2. Test section selection and desktop studies
3. Follow-up investigations
4. Project summary report

Each of these four tasks along with associated activities are detailed next.

Task 1. Project Management

This task included those management and administrative activities required for the successful conduct and completion of the project:

- Project safety plan,
- Project management plan,
- Routine project management activities (regular cost control, preparation and submittal of progress reports to WSDOT, preparation and submittal of invoices to WSDOT, and contract and subcontract administration),
- As needed, other coordination and communications activities with WSDOT and, as directed, with members of the study TAC, and
- Project close-out activities.

Task 2. Test Section Selection

This task addressed the selection and approval of LTPP test sections that were to undergo forensic evaluations as part of the study. Test sections approved for evaluation by WDSOT fell into one of the following two categories:

- LTPP test sections that are being taken out-of-study (not necessarily due to failure). These test sections can be from any of the LTPP experiments, regardless of pavement type. Also, it is highly likely that these test sections represent long-lasting, well-performing pavements (i.e., not failures but successes).

- LTPP test sections that remain active in the program but were of interest for other reasons such as excellent performance, longevity, contrasting pavement condition metrics, and atypical pavement structures.

Higher priority was to be given to the first category of LTPP test sections, but given the numbers and types of test sections remaining after award of the contract, several test sections for forensic evaluation came from the second category. The test section selection and approval process consisted of the following activities:

- Task 2.a Data assessments and recommendations, including:
    - Communications with WSDOT, TAC, LTPP Program, and State Highway Agencies (SHAs) to
        1. Identify candidate test sections for forensic evaluation.
        2. Establish level of support LTPP and SHAs were able/willing to contribute towards evaluations (e.g., traffic control, deflection testing, trenching, etc.).
        3. Coordinate forensic evaluation activities with other LTPP field activities to take advantage of traffic control and/or other support being provided by the State DOTs and LTPP contractors, while minimizing impact on the DOTs.
    - For each test section, submittal of recommendation to WSDOT to proceed or not with preliminary investigation (desktop study per Chapter 3 of NCHRP Report 747) by means of quick review of data in the LTPP database and, as appropriate, discussions with the LTPP DCC. Criteria for making recommendation included the reason test sections were being considered, the level of support by the SHA and the LTPP program, LTPP data availability, and geographical location of the test section.
    - WSDOT decision whether to proceed or not with preliminary investigation.
- Task 2.b Preliminary investigation and evaluation plan or report, including:
    - If approved, conduct preliminary investigation using data stored in the LTPP database. Outcome of the investigation was one of the following:
        1. Draft forensic investigation plan per Chapters 4 through 8 of NCHRP Report 747. The plan included detailed evaluation activities, proposed evaluation team, and evaluation schedule.
        2. Further field investigation of test sections was not required, as available LTPP data adequately explained performance of test section. While further investigation was not required, preparation of a report along with the estimated cost and schedule was required.
    - WSDOT review of recommendation and approval (or not) to proceed with forensic investigation plan. If WSDOT approved to move forward with evaluation, the forensic investigation plan was revised and finalized based on WSDOT input.

The activities under Task 2.a were required for candidate LTPP test sections being considered for forensic evaluation, while the activities under Task 2.b were only required for those test sections that were considered serious candidates for forensic evaluation.

Task 3. Forensic Evaluations

Under this task, LTPP test section evaluations were carried out based upon the investigation plans developed under the previous task. The activities carried out as part of the forensic evaluations included several of the following:

- Non-destructive testing (deflection testing and distress and profile surveys),
- Destructive testing (coring and boring, test pits, and dynamic cone penetrometer (DCP)),
- Data analysis and hypothesis testing, and
- Report preparation.

The above activities were carried in general accordance with the guidelines presented in Chapters 4 through 9 of NCHRP Report 747. The final deliverables for each LTPP test section forensic evaluation were as follows:

- Technical memorandum containing relevant data and information were prepared following Appendix B Case Studies of NCHRP Report 747 as samples.
- Recommended evaluation data and information for input into the LTPP database by the FHWA-LTPP program. It is worth noting that in many instances, reasons were found to update the LTPP pavement performance database (PPDB) and/or InfoPave™ based on the desktop studies and/or follow up investigation findings.

Drafts of the deliverables were provided to WSDOT for review and comment and, in turn, were finalized based on WSDOT input. With WSDOT permission, the final version of the memorandum was provided to the FHWA-LTPP Team.

Task 4. Final Project Report

Under this task, which was performed at the end of the study, this final report summarizing what was done under the project was prepared. A draft of the final report was submitted to WSDOT and the study TAC for review and comment and, based on the input received, the report was revised and finalized. With permission from WSDOT, the final version of the overall project report was provided to the FHWA-LTPP Team for action as appropriate.

At the conclusion of the study on June 30, 2021, forensic investigations (desktop studies with or without follow-up investigations) were completed for 63 test sections at 26 different locations in 23 different States throughout the country.

Report Organization

This final project report has been organized into the following four chapters:

- Introduction – This chapter provides important background information on the LTPP program, NCHRP Report 747, and TPF-5(332), which help the reader better understand what was done in the pooled fund study and why.
- LTPP Test Section – This chapter provides a summary of the LTPP test sections receiving forensic investigations, including their geographical location and distributions based on pavement type, experiment, and investigation purpose.
- Test Section Investigations – This chapter provides information on location, investigation objectives, investigation dates, activities conducted, desktop study, follow-up investigations,

findings, and conclusions and recommendations for each test section that underwent forensic evaluation as part of the pooled fund study.

- Summary, Conclusions and Recommendations – This chapter presents a summary of the major findings and conclusions from the project along with recommendations specific to the LTPP program and more general recommendations relating to forensic investigations.

References are provided at the end of the report, which may be of value to the reader if more detailed information is desired, especially in terms of the background material presented in the Introduction.

LTPP Test Sections

Over a hundred LTPP test sections were identified by the project team, with support from the LTPP program, for possible forensic evaluation. Of those, 63 test sections at 26 locations across 23 States were nominated and accepted for investigation. This chapter provides an overall summary of the 63 LTPP test sections studied in terms of geographical location and distributions based on pavement type, experiment, purpose of investigation, and climate. The next chapter—Test Section Investigations—provides findings from the individual investigations for each project location.

Overview

LTPP test sections were nominated and selected for forensic evaluations based on the performance and available data for each site. The initial focus was to select test sections that were going out-of-study within the States that contributed to the Pooled Fund study. However, as the project progressed, test section nomination and forensic evaluations were expanded to include a diverse set of test sections in terms of experiment type, pavement type, and purpose of investigation, as shown in Table 3. For cases where the test section moved from one experiment type to another one, multiple entries (with the year the experiment type changed) are shown under experiment type column. While the priority continued to be on test sections going out-of-study, other tests sections such as those identified as long-life test sections by the LTPP Program were considered and, in several cases, investigated.

Table 3. Summary of test section.

Study #	State	LTPP ID	Experiment Type	Pavement Type	Purpose of Investigation
1	WA	53-1005	GPS-1 (1988) GPS-6B[1] (1989) GPS-6S[2] (2001)	AC	Pavement Failure, Other
2	AZ	04-0214; 04-0215; 04-0217; 04-0262	SPS-2 (1993)	JPCP	Pavement Failure, Excellent Performance
3	CO	08-0216; 08-0218; 08-0223; 08-0224	SPS-2 (1993)	JPCP	Other
4	KS	20-0201; 20-0203; 20-0206; 20-0212	SPS-2 (1992)	JPCP	Pavement Failure, Excellent Performance
5	OH	39-5003	GPS-5 (1988) GPS-7C[3] (2012)	CRCP with an AC overlay	Other
6	TX	48-1111	GPS-1 (1987) GPS-6B (1999)	AC	Excellent Performance

[1] GPS-6B: AC Overlay Using Conventional Asphalt of AC Pavement-No Milling
[2] GPS-6S: AC Overlay of Milled AC Pavement Using Conventional or Modified Asphalt
[3] GPS-7C: AC Overlay Using Modified Asphalt on PCC Pavement

Study #	State	LTPP ID	Experiment Type	Pavement Type	Purpose of Investigation
7	MS	28_5025	GPS-5 (1987)	CRCP	Other
8	CA	06_7452	GPS-2 (1989) GPS-6B (1999) GPS-6C[4] (2010)	AC	Other
9	FL	12_0502 to 12_0509; 12_0561 to 12_0566; 12_1030	SPS-5 (1987)/ GPS-1 (1987) 12-1030 only GPS-6S (2014)	AC	Other
10	OK	40_AA01 to 40_AA03; 40_AA61 to 40_AA63	SPS-10 (2015)	AC	Performance Comparison, Other
11	NM	35_0801; 35_0802	SPS-8 (1995)	AC	Performance Comparison, Other
12	IA	19_1044	GPS-1 (1987) GPS-6B (2002)	AC	Other
13	MT	30_8129	GPS-1 (1988) GPS-6B (2003)	AC	Other
14	GA	13_7028	GPS-7A[5] (1987) GPS-7S[6] (1998)	JPCP with AC overlay	Provide Missing Data, Other
15	TX	48_1096	GPS-1 (1987) GPS-6B (2001)	AC	Pavement Failure, Provide Missing Data
16	SC	45_1024	GPS-1 (1987)	AC	Excellent Performance, Other
17	ME	23_1028	GPS-1 (1988) GPS-6B (1994)	AC	Other
18	UT	49_7082; 49_7085 49_7086	GPS-3 (1989)	JPCP	Performance Comparison, Other
19	MD	24_1634	GPS-2 (1988) GPS-6C (1998)	AC	Other
20	IN	18_1037	GPS-1 (1987) GPS-6S (1994) GPS-6D[7] (2003)	AC	Poor Performance, Other
21	MN	27_6251	GPS-1 (1987) GPS-6S (1998)	AC	Other
22	PA	42_1597	GPS-1 (1988) GPS-6S (2000)	AC	Other
23	AR	05_0803; 05-0804; 05-0809; 05-0810;	SPS-8 (1996)	AC	Performance Comparison, Other

4 GPS-6C: AC Overlay Using Modified Asphalt of AC Pavement-No Milling
5 GPS-7A: Existing AC Overlay on PCC Pavement
6 GPS-7S: Second AC Overlay, Which Includes Milling or Geotextile Application, on PCC Pavement With Previous AC Overlay
7 GPS-6D: AC Overlay on Previously Overlaid AC Pavement Using Conventional Asphalt

Study #	State	LTPP ID	Experiment Type	Pavement Type	Purpose of Investigation
24	WA	53-0801; 53_0802; 53_A809; 53_A810	SPS-8 (1997)	AC and PCC	Performance Comparison
25	ID	16_1020	GPS-1 (1988) GPS-6C (2011)	AC	Excellent Performance, Other
26	OK	40_4157	GPS-3	JPCP	Excellent Performance, Other

Geographical Location and Climate Region

The LTPP test sections where forensic evaluations took place were well-distributed throughout the continental United States, as depicted in Figure 4. As noted at the start of this chapter, the study covered 63 test sections in 26 locations in 23 states. In Arizona, Colorado, Kansas, Ohio, Mississippi, California, Florida, New Mexico, Iowa, Montana, Georgia, South Carolina, Maine, Utah, Maryland, Indiana, Minnesota, Pennsylvania, Arkansas, and Idaho, one forensic investigation was conducted, while in Washington, Texas, and Oklahoma, two studies were conducted.

Figure 4. Map. Geographical locations of the studied test sections.

Through the investigation of a diverse set of locations within the U.S., multiple climatic conditions and regions were studied. In particular, the recommended test sections covered each of the four major climatic regions defined by LTPP: Wet Freeze, Dry Freeze, Wet No-Freeze, and Dry No-Freeze. As depicted in Figure 5, roughly two thirds of the test sections studied were a part of Wet climates, whereas one third of test sections were classified as being in a Dry climate. There were slightly more investigations involving No-Freeze than Freeze climates; 58% of test sections were a part of a No-Freeze climate while 42% of test sections were located in Freeze climates. When compared to the climate distribution of all test sections in the LTPP program, which is shown in Figure 6, the distribution of the nominated test sections slightly overrepresents the Dry climate (which makes up 20% of all LTPP test sections) and underrepresents Wet climate test sections (which represents 80% of all LTPP test sections). When considering the breakdown of all LTPP test sections in Freeze versus No-Freeze climates, the distribution of the nominated test sections was more aligned with the distribution of all LTPP test sections. Overall, No-Freeze test sections make up 48% of all LTPP test sections (compared to the 58% of nominated test sections) while Freeze sites make up 52% of all test sections (compared to 42% of nominated test sections.

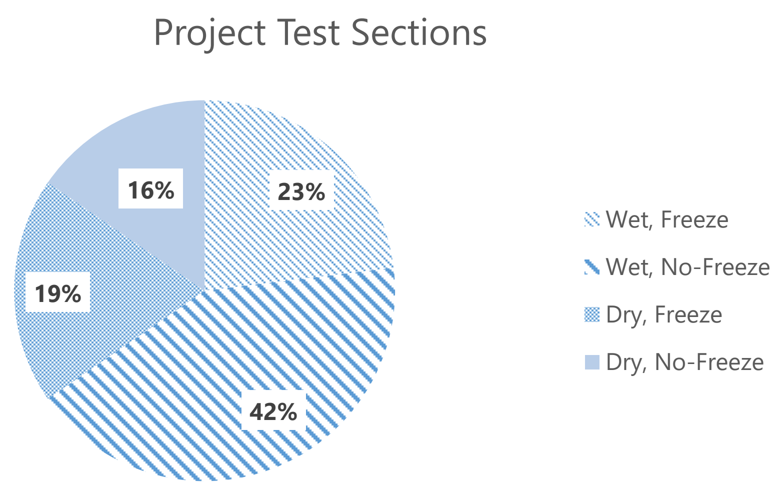

Figure 5. Chart. Distribution of investigations by climate.

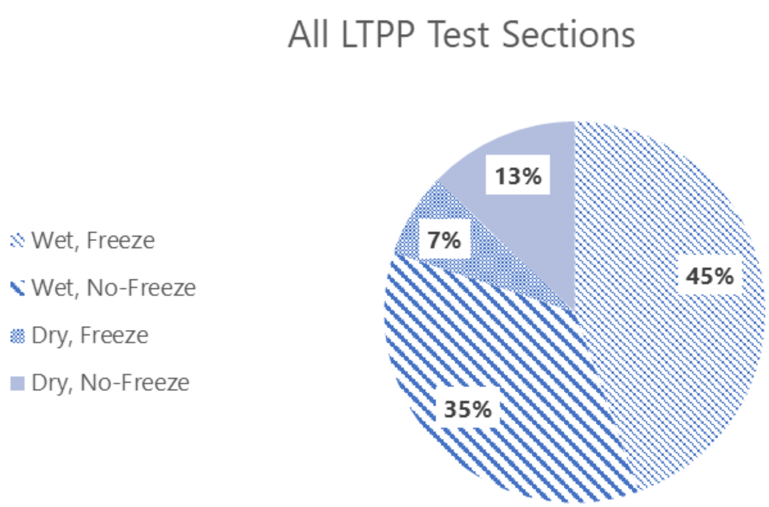

Figure 6. Chart. Distribution of investigations by climate.

The even distribution of test sections based on climatic factors enabled the study of test sections with varying external factors affecting performance. While test sections in Wet, Freeze climates reported freeze-thaw cycles which resulted in high amounts of transverse cracking in some cases, test sections in Dry, No-Freeze climates often reported issues with aging or oxidation.

Distribution of Test Section by Factors

In addition to climate, the evaluated test sections were also well distributed in terms experiment type, pavement type, and the cause for investigation. Figure 7 provides a summary of test sections by experiment type, where the experiment type is defined as the experiment type of the test section at the time of its incorporation in the LTPP program. As shown in the figure, a large proportion of the test sections were a part of the SPS experiments, specifically SPS-8, SPS-2, and SPS-5. However, as the primary focus of the forensic evaluations was on active test sections that were going out-of-study as well long-life test sections, the skew towards SPS experiments, which were often incorporated in the LTPP program more recently than the GPS test sections, was expected. Test sections that were classified as GPS test sections were predominantly GPS-1 sites.

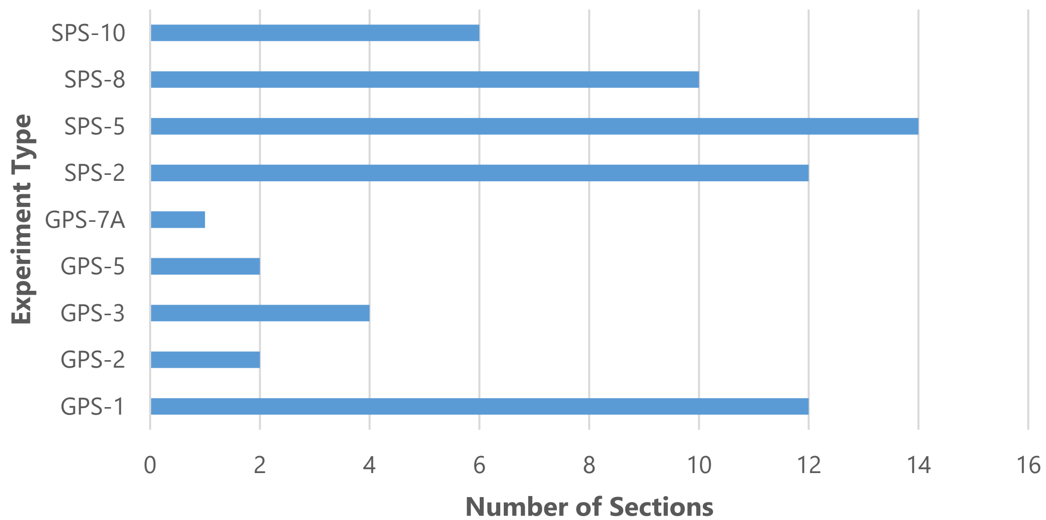

Figure 7. Chart. Summary of test sections by experiment types.

The distribution of the selected test sections based each section's original pavement surface is provided in Figure 8. As depicted in the figure, most of the selected test sections were constructed with an AC surface, whereas sites with PCC surfaces (both CRCP and JPCP) accounted for approximately one third of all selected test sections. This distribution is largely connected to the reason each test section was nominated for investigation.

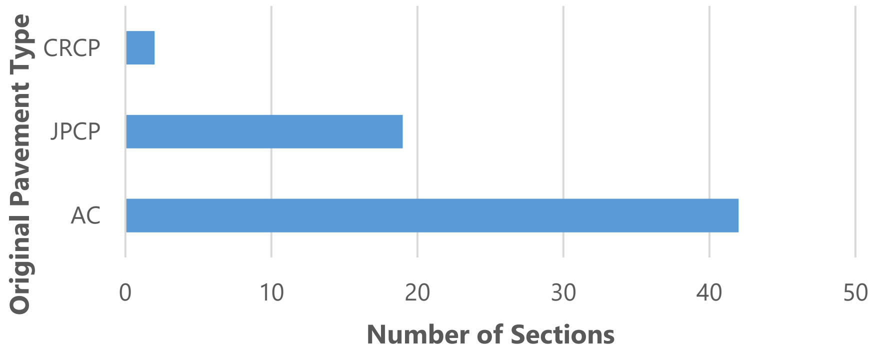

Figure 8. Chart. Summary of test sections by pavement type.

As shown in Figure 9, test sections were nominated for six key reasons: due to reported pavement failure, poor performance of the test section, excellent performance of the test section, to compare the performance of multiple test sections, to provide missing data on the test sections, or "Other." "Other" describes test sections that were nominated based on the performance or data characteristics of that test section. This included investigating specific pavement distresses, analyzing data of test sections included in the Seasonal Monitoring Program (SMP), and identifying the cause(s) for the change in performance over time. While these reasons for investigation can apply to any pavement type, test sections which reported poor performance and pavement failure and were therefore going out-of-study were predominantly AC pavements, which have a shorter lifecycle than PCC pavements, helping to explain the selection of more AC pavements than PCC test sections.

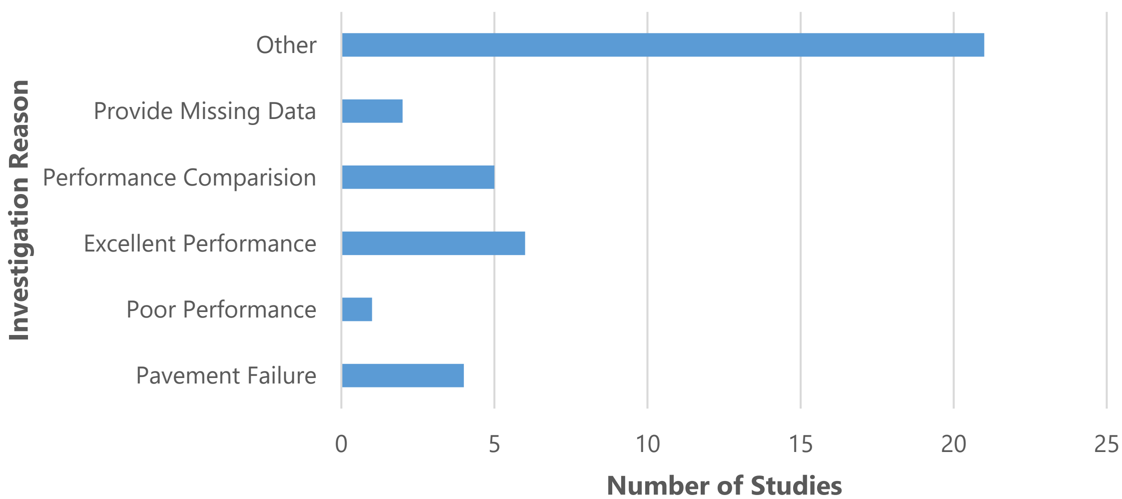

Figure 9. Chart. Summary of forensic studies by investigation reasons.

The test sections were also summarized in terms of the relationship of pavement type, experiment type, and investigation reason by climate as shown in Table 4, Table 5, and Table 6. The distribution of test sections by pavement type and climate shows the majority of AC test sections nominated were in Wet, No-Freeze climates, while PCC test sections were more equally distributed by climate.

Table 4. Number of test sections per pavement type by climate.

Pavement Type	Dry, Freeze Climate	Dry, No-Freeze Climate	Wet, Freeze Climate	Wet, No-Freeze Climate
AC	3	5	4	30
JPCP	7	6	4	2
CRCP	0	0	1	1

Table 5 shows the distribution of test sections by experiment type and climate. While the GPS and SPS-2 experiment types were well-distributed, the SPS-5, SPS-8, and SPS-10 experiments tended to favor No-Freeze climates. Once again, this seems to align with the relationship between the pavement type of test sections. The SPS-5 and SPS-10 experiments are solely focused on AC pavements, while the SPS-8 experiments consider both AC and JPCP pavements. As the AC test sections nominated were predominately located in No-Freeze climates, this finding is aligned with expectation.

Table 5. Number of test sections per experiment type by climate.

Experiment Type	Dry, Freeze Climate	Dry, No-Freeze Climate	Wet, Freeze Climate	Wet, No-Freeze Climate
GPS-1	3	0	4	3
GPS-2	0	1	0	2
GPS-3	3	0	0	1
GPS-5	0	0	1	1
GPS-7A	0	0	0	1
SPS-2	4	4	4	0
SPS-5	0	0	0	15
SPS-8	0	6	0	4
SPS-10	0	0	0	6

Finally, Table 6 shows the distribution of test sections by investigation reason and climate. For the most part, the test sections were well-distributed by investigation reason and climate; however, there was a slight preference for test sections in Wet, No-Freeze climates for all investigation reasons except “Poor Performance.” This is likely related to the fact that most selected test sections were AC pavements and subsequently, most AC pavements were a part of Wet, No-Freeze climates.

Table 6. Number of test sections per investigation reason by climate.

Investigation Reason	Dry, Freeze Climate	Dry, No-Freeze Climate	Wet, Freeze Climate	Wet, No-Freeze Climate
Pavement Failure	1	4	4	1

Investigation Reason	Dry, Freeze Climate	Dry, No-Freeze Climate	Wet, Freeze Climate	Wet, No-Freeze Climate
Poor Performance	0	0	0	1
Excellent Performance	1	5	4	2
Performance Comparison	3	6	0	10
Provide Missing Data	0	0	0	2
Other	10	2	5	32

Timeline

Figure 10 depicts a timeline of the key activities conducted as a part of this study. Milestones for each test section or group of test sections investigated includes the nomination of the test section, the completion of a desktop study, and any follow-up forensic investigations. On average, each investigation study was completed 188 days following its nomination. Only test sections where follow-up investigations were recommended and could be performed show information on the length of time taken to complete the follow-up investigation.

WS TPF	start	end
Washington State Test Section 53-1005	**09/14/18**	**06/19/19**
Nomination	09/14	09/14
Desktop Study	09/14	12/03
Follow-up Investigation	12/03	06/19
Arizona SPS-2 Test Sections	**11/09/18**	**04/23/19**
Nomination	11/09	11/09
Desktop Study	11/15	04/23
Colorado SPS-8 Test Sections	**01/11/19**	**07/09/20**
Nomination	01/11	01/11
Desktop Study	01/23	08/15
Follow-up Investigation	08/15	07/09
Kansas SPS-2 Test Sections	**11/09/18**	**06/20/19**
Nomination	11/09	11/09
Desktop Study	11/15	06/20
Ohio Test Section 39-5003	**06/14/19**	**09/09/19**
Nomination	06/14	06/14
Desktop Study	06/14	09/09
Texas Test Section 48-1111	**06/14/19**	**07/01/20**
Nomination	06/14	06/14
Desktop Study	06/14	08/15
Follow-up Investigation	08/15	07/01
Mississippi Test Section 28-5025	**08/23/19**	**10/21/19**
Nomination	08/23	08/23
Desktop Study	08/23	10/21
California Test Section 06-7452	**08/23/19**	**09/16/20**
Nomination	08/23	08/23
Desktop Study	08/23	10/01
Follow-up Investigation	10/01	09/16
Florida SPS-5 Test Sections and Test Section 12-1030	**08/23/19**	**04/03/20**
Nomination	08/23	08/23
Desktop Study	08/23	04/03
Oklahoma SPS-10 Test Sections	**12/02/19**	**04/09/20**
Nomination	12/02	12/02
Desktop Study	12/02	04/09
New Mexico SPS-8 Test Sections	**12/02/19**	**12/29/20**
Nomination	12/02	12/02
Desktop Study	12/02	02/04
Follow-up Investigation	02/04	12/29
Iowa Test Section 19-1044	**12/02/19**	**04/16/21**
Nomination	12/02	12/02
Desktop Study	12/02	02/27

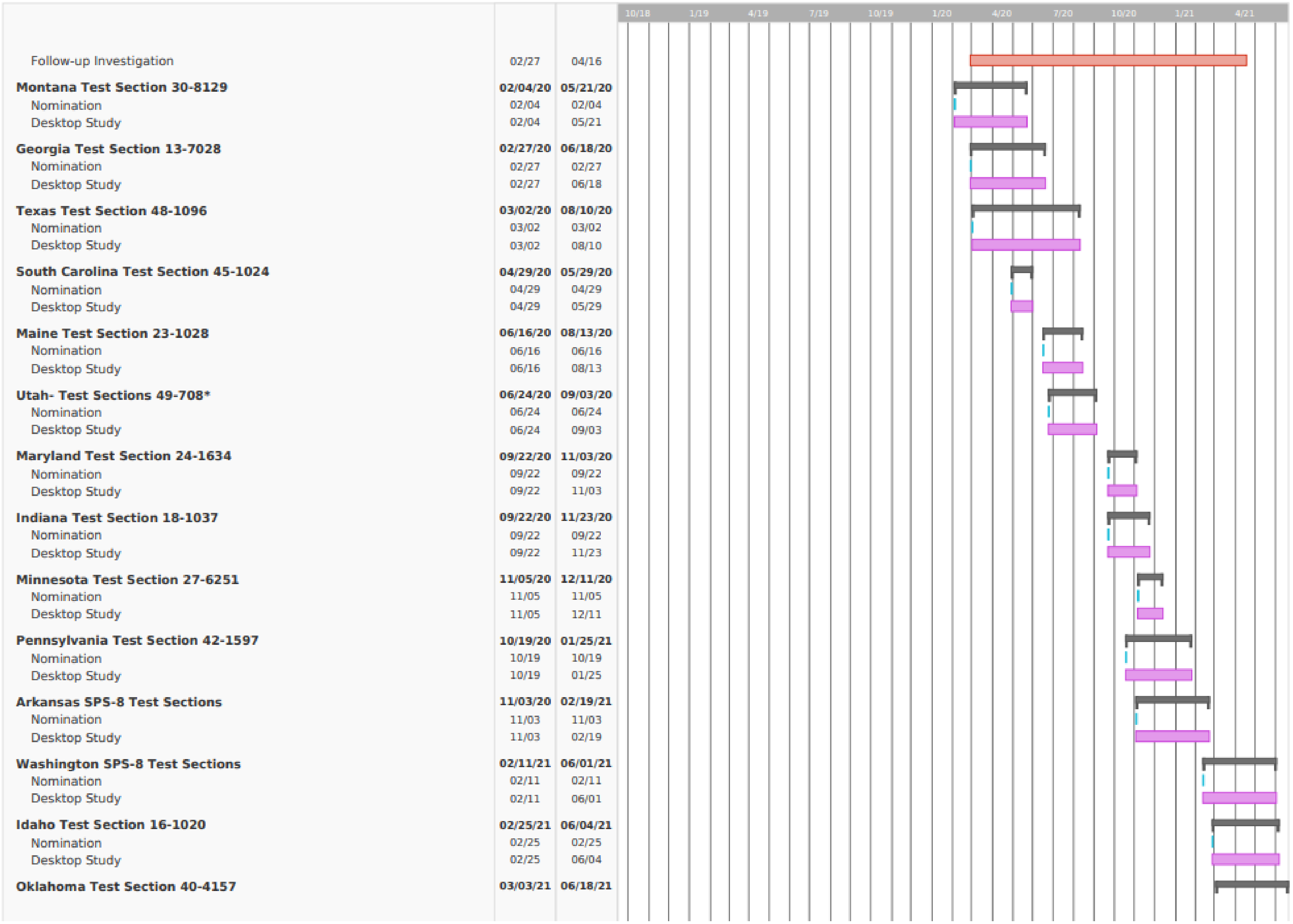

Figure 10. Chart. Timeline of study.

Test Section Investigations

As mentioned in the Introduction, the forensic evaluation of nominated test sites was focused on better understanding the performance of test section(s) through a desktop study and, if necessary, a follow-up investigation. This chapter provides a summary of the key findings from these activities for the 26 nominated and accepted test sites. Specifically, the following sections present an overview of the context, objectives, activities, key findings, conclusions, and recommendations for each forensic investigation conducted. The findings of each study are presented in the order shown in Figure 10.

Washington Test Section 53_1005

Test section 53_1005 is an LTPP site located on I-90 eastbound at milepost 208.6 in Adams County, Washington State. I-90 is a rural interstate highway with two lanes in the direction of traffic. The test section was constructed in 1973 and incorporated into the LTPP program in 1988 as a General Pavement Study (GPS-1) site. The site received four additional treatments between 1989 and 2013—a 2.3-inch dense graded asphalt overlay in 1989 (moving the test section to a GPS-6B experiment), a 2-inch mill and nominal overlay in 2001 (moving the section to a GPS-6S experiment), and patching in 2008 and 2013. In addition to the treatments reported in the LTPP database, during field investigations, it was discovered that a wheel path chip seal occurred on the test section in 2016. Table 7 shows the pavement structure following the 2001 mill and overlay event.

Table 7. Pavement structure from 2001 to date.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	Semi-infinite (SI)	Coarse-Grained Soil: Poorly Graded Gravel with Silt
2	Unbound (granular) subbase	6.5	Crushed Gravel
3	Unbound (granular) base	3.0	Crushed Gravel
4	Asphalt concrete layer	5.9	Hot Mixed, Hot Laid AC, Dense Graded
5	Asphalt concrete layer	3.6	Hot Mixed, Hot Laid AC, Dense Graded
6	Asphalt concrete overlay layer	0.2	Hot Mixed, Hot Laid AC, Dense Graded
7	Asphalt concrete overlay layer	2.1	Hot Mixed, Hot Laid AC, Dense Graded

The test section was scheduled for another mill and overlay in 2019 and was therefore considered a good candidate for nomination, given the opportunity for forensic field evaluations prior to the construction event. Specifically, the objective of the study was to review the test section's history and distress manifestations and make recommendations on the need for forensic field evaluation to explain the performance of the test section over time.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 53_1005 (Elkins et. al, 2019b) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study provided insight on the performance of the section between construction events. During the first pavement performance cycle—between the original construction date and the application of the first overlay in 1989—transverse cracking, related to low temperature cracking, appeared to be the most prevalent distress manifestation in the pavement structure. In the second pavement performance cycle—between the overlay in 1989 and the next overlay in 2001—rutting in the overlay appeared to be the most critical distress reported on test section, reaching over 0.4 in prior to the 2001 overlay. Transverse cracks existing in the pavement structure prior to overlay also appeared to have reflected through this overlay during the second performance cycle. During the third pavement performance cycle on this test section—after the mill and fill construction event in 2001 to present—the pavement structure was generally in good condition. Milling of the initial pavement overlay in 2001 appeared to have reduced the rate of rutting observed during the second performance period and changed its location across the pavement structure.

While many questions surrounding the performance of the test section over time were answered by the desktop study, forensic field evaluations were recommended to be performed at the test site to better understand the observed rutting on the section as well as to confirm the structural capacity of the pavement. As such, follow-up field investigations were performed on April 1, 2019, during which five cores were taken across the width of the pavement at stations 200 and 400 in lieu of trenching, FWD testing was performed, a manual distress survey was performed, and transverse profiles and surface texture measurements were collected.

Examination of the cores did not provide an identifiable trend in the AC layer thickness that could explain what pavement layer the rutting was occurring. The cores showed a consistent linear pattern in the decrease in thickness from the outside lane edge to the inside lane edge. While the wheel path chip seal in 2016 made it difficult to assess, the differences in the transverse profiles of the surface of this pavement appeared to be due to gradual eroding of the pavement surface as depicted in Figure 11. While the depths of the elevation in the wheel path decreased, the depths in mid-path portion of the pavement structure also decreased. This is the type of behavior that would be expected from test sections that are snow-covered for portions of a year and traffic wandering when drivers cannot see the edges of the lane and use of traction control devices is the greatest.

Conclusions and Recommendations

Overall, the desktop study and forensic field evaluations found that the pavement section, while located on a major interstate highway, performed well over its 45 years in service, with just two minor overlay construction events. The findings reinforced Washington State DOT's practice of performing "preservation" and "rehabilitation" construction treatments in advance of the time normal PMS threshold limits are reached. Deviations from this good performance (particularly due to rutting) appeared to be caused by ablative wear in the wheel paths. Sufficient information was available to adequately explain the observed performance of the pavement test section and therefore, no further activities were recommended.

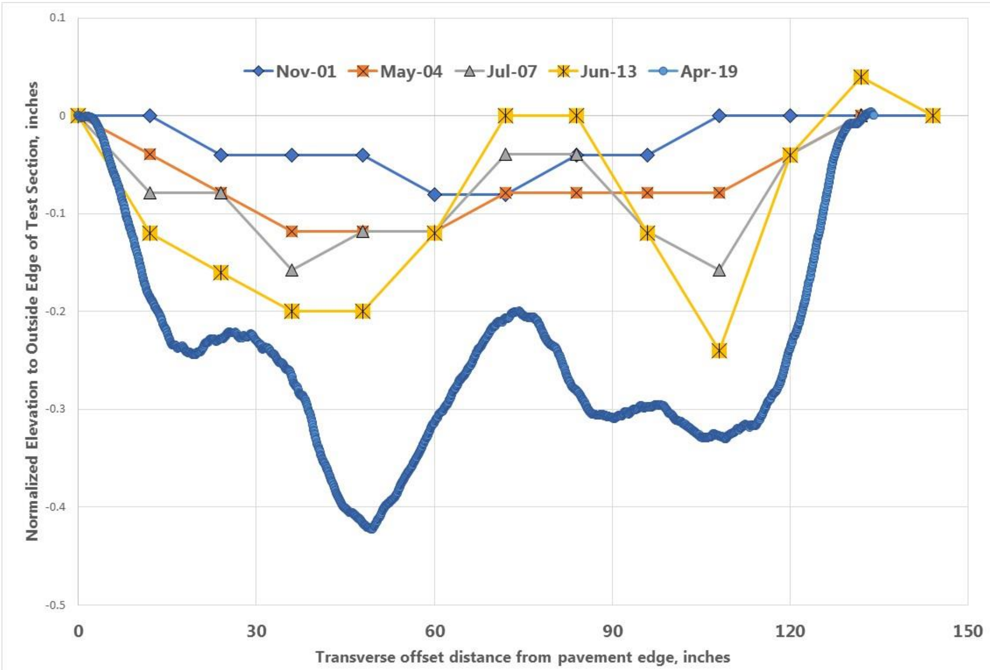

Figure 11. Chart. Historic normalized transverse profile plots at station 0+00.

Arizona SPS-2 Test Sections

Test sections 04_0214, 04_0215, 04_0217, and 04_0262 are located on eastbound Interstate 10, starting at milepost 105.95, in Maricopa County, Arizona. Interstate 10 is a two-lane rural interstate highway in the direction of travel. The four test sections were constructed and accepted into the LTPP Program as part of the SPS-2 experiment in 1993. Each section varies in terms of pavement thickness, structural factors (such as flexural strength), base type, and lane width; Table 8 summarizes the differences in the pavement thicknesses and material types used for each test section. The core SPS-2 sections, test sections 04_0214, 04_0215, and 04_0217, are doweled concrete pavement, while the State supplemental section 04_0262 is undoweled. Additional construction events that occurred on the test sections included partial-depth patching in 2009 and partial-depth patching at the joints in 2016 for test section 04_0217, and partial-depth patching at locations other than the joints in 2009 and partial-depth patching at joints in 2013 for test section 04_0262. All patching that occurred on the test sections was minimal. Given the variability in the properties associated with each of the JPCP test sections, a forensic investigation was recommended to compare the performance of the test sections over time.

Activities and Findings

In pursuit of the stated objectives, a desktop study of the test sections (Regalado et al., 2019) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (longitudinal cracking, transverse cracking, IRI, surface wear, and faulting) history using information available from InfoPave™ (InfoPave™, 2021). The focus of the desktop study was on examining and identifying the cause(s) for the differences in pavement performance over time.

Table 8. Pavement structure for Arizona SPS-2 test sections following CONSTRUCTION_NO (CN) = 1.

Section	Layer No.	Layer Type	Thickness (in.)	Material Code Description
040214	1	Subgrade (untreated)	SI	Coarse-Grained Soil: Silty Sand with Gravel
040214	2	Unbound (granular) base	6.1	Crushed Gravel
040214	3	Portland cement concrete layer	8.3	Portland Cement Concrete (JPCP)
040215	1	Subgrade (untreated)	SI	Coarse-Grained Soil: Silty Sand with Gravel
040215	2	Unbound (granular) base	6.3	Crushed Gravel
040215	3	Portland cement concrete layer	11	Portland Cement Concrete (JPCP)
040217	1	Subgrade (untreated)	SI	Coarse-Grained Soil: Silty Sand with Gravel
040217	2	Bound (treated) base	6.1	Lean Concrete
040217	3	Portland cement concrete layer	8.1	Portland Cement Concrete (JPCP)
040262	1	Subgrade (untreated)	SI	Coarse-Grained Soil: Silty Sand with Gravel
040262	2	Unbound (granular) base	6.1	Crushed Gravel
040262	3	Portland cement concrete layer	8.1	Portland Cement Concrete (JPCP)

Test sections 04_0214 and 04_0215 have performed quite well over time, as depicted in Table 9. As of 2016, test sections 04_0214 and 04_0215 reported "Fair" IRI values based on FHWA definitions, minimal cracking and faulting, low deflections, and load transfer efficiencies (LTE) of 62% and 73%, respectively. However, test section 04_0214 did report significant map cracking. The good performance of these test sections is likely related to their flexural strength (900 psi for test section 04_0214) and PCC thickness (11 inches for test section 04_0215). Test section 04_0217 performed slightly worse when compared to the first two sections; the section had moderate distress development across most categories. The test section reported 699 linear feet of longitudinal cracking, 269 linear feet of transverse cracking (the most of the four sections), and significant map cracking. However, faulting was minimal, rutting was less than 0.2 inches, deflection was very low, and LTE was 53%. Lastly, test section 04_0262 exhibited the most distress development in all categories, except for transverse cracking, and therefore, performed the worst out of the four test sections. As of 2016, the test section reported an IRI of 245 inches/mile (FHWA "poor" category), a deflection of 5 mils, LTE of 22%, 144 feet of longitudinal cracking, the highest joint spalling of the four sections (5 affected joints), rutting of nearly 0.3 inches (FHWA "fair" category), and average faulting over 0.2 inches. Significant map cracking was also noted. The poor performance of test sections 04_0262 and 04_0217 may have been related to the base type used (lean concrete for 04_0217), the PCC thickness (8.1 inches for both sections), the design flexural strength (550 psi for both test sections), and the slab width (14 feet for both test sections). Test section 04_0262 likely performed worse than 04_0217 because the test section was undoweled.

Table 9. Summary of experimental factors and performance as of 2016.

Section	PCC (in.)	Base (6-in.)	Slab Width (ft)	Design Flexural Strength (psi)	IRI	Fault	Trans. Crack.	Rut	Long. Cracks	Significant Map Cracks	LTE
040214	8.3	Crushed gravel	12	900	Fair	Good	Good	Good	Minimal	Yes	Good
040215	11	Crushed gravel	12	550	Fair	Good	Good	Fair	Minimal	No	Fair
040217	8.1	Lean concrete	14	550	Good	Good	Poor	Good	Some	Yes	Fair
040262[1]	8.1	Crushed gravel	14	550	Poor	Poor	Good	Fair	Many	Yes	Poor

[1]*undoweled*

Conclusions and Recommendations

Based on the findings reported, the performance of the test sections could mostly be explained based on PCC thickness, base type, slab widths, and whether the test sections were doweled or undoweled. Specifically, the following conclusions were made based on the desktop study:

- The presence of a lean concrete base had a positive impact on IRI as test section 04_0217 was the only section that maintained "good" IRI throughout the monitoring period.
- Sections with 14-foot slab widths were more prone to longitudinal cracking, and the presence of the lean concrete base (test section 04_0217) had a negative impact on transverse cracking.
- As expected, the undoweled pavement (Section 040262) had the highest IRI (nearly 250 inches/mile), the highest faulting (>0.2 inches), and lowest load transfer efficiency of all four sections.

However, it remained unclear why test sections 04_0217 and 04_0262, with 550-psi flexural strength concrete, exhibited significant map cracking when other 550-psi sections in the experiment did not. This could have been the result of poor curing practice during construction or the onset and progression of alkali-silica reactivity. However, a follow-up investigation would be necessary to ascertain the hypothesis.

Based on the desktop study, a follow-up evaluation of test sections was recommended. Specifically, the desktop study proposed a site visit and field survey, petrographic analysis of extracted cores, deflection testing, and beam cuts from concrete slabs to assess the flexural strength. However, it was found that Arizona DOT was not able to support this effort, and no additional work as part of the forensic evaluation was conducted.

Colorado SPS-2 Test Sections

Test sections 08_0216, 08_0218, 08_0223, and 08_0224 are located on I-76 eastbound at milepost 18.4 in Denver, Colorado. I-76 is a two-lane rural interstate highway in the direction of travel. The test sections were constructed in 1993 as a part of the SPS-2 (Strategic Study of Structural Factors for Rigid Pavements) experiment. Therefore, per the experiment design, the test sections varied in terms of overall layer thicknesses and materials, lane width, and flexural strength, as summarized in Table 10. In terms of other construction events reported at the sites, test section 08_0216 received partial-depth patching at locations other than the joints (in June 2005, July 2010, and September 2016) as well as partial-depth patching at the joints (in July 2010 and September 2016), while test sections 08_0218 and 08_0224 reported only partial-depth patching at the joints (in June 2005, June 2008, June 2014, June 2015, and September 2016 for 08_0218 and in July 2003, July 2014, and September 2016 for 08_0224).

Table 10. Summary of differences in experimental factors for Colorado SPS-2 test sections.

Structure Measurement	08_0216	08_0218	08_0223	08_0224
Unbound (granular) base thickness (in)	5.9	N/A	4.7	3.1
Bound (treated) base thickness (in)	N/A	6.2 (LCB)	4.2 (PATB)	4.6 (PATB)
PCC thickness (in)	11.9	7.6	11.7	11.6
Concrete Mixture 14-day Design Flexural Strength (psi)	900	900	550	900
Slab width (ft)	14	12	12	14

These four test sections were selected for analysis due to the observed differences in diurnal profile testing (performed in June 2013) trends between IRI and temperature. For test section 08_0223, IRI increased with an increase in temperature, whereas the remaining three test sections reported decreasing IRI with increasing temperature. The difference in IRI versus temperature trend appeared to be related to the mix type; all of the SPS-2 test sections in Colorado with decreasing IRI and increasing temperature had a high-strength mix. However, this correlation did not hold true for site 08_0224, which showed no significant change in IRI with increasing temperature, although it did have the high-strength mix. Therefore, the objective of the study was to investigate the role of locked-in surface curvature, temperature, and PCC pavement structure properties that potentially influence changes in IRI over the course of a single day, as shown with existing LTPP diurnal measurements on four JPCC test sections.

Activities and Findings

In pursuit of the stated objectives, a desktop study of the test sections (Regalado et al., 2020) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (patching, longitudinal cracking, transverse cracking, IRI, spalling, faulting, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study provided insight on the observed differences amongst the test sections in terms of the relationship between IRI and temperature based on diurnal testing. The key factor affecting the relationship appeared to be the differences in PCC mixture properties, with the mixes with high cement contents showing decreasing IRI with increasing temperature, whereas the mixes with low cement content had no or increasing IRI with increasing temperature. The difference in cement content between the mixes was significant and resulted in the high-strength mix having a much higher dimensional change due to changes in moisture. Additionally, the available weather data for the sites showed a combination of high daily temperature variation along with a minor precipitation event on the day of diurnal testing, which could have caused variations in both curl and warp during the day. The temperature-related curl would be expected to be similar for all the test sections, whereas the moisture-related changes in warp would be expected to be more significant for the high-strength sections. A further investigation of the role weather played in the IRI-temperature trends observed using diurnal testing data was recommended.

Section 08_0223 was the only site that showed a clear increase in IRI with increasing temperature, whereas the other sections showed no clear trend. Amongst the sections investigated in the desktop study, 08_0223 is also the only test section that showed clear failure of the dowel bars, with a sharp drop in LTE in the 2004–2005 timeframe and an increase in faulting in 2014. It is possible that loss of restraint from the dowel bars allowed the joints to rotate more due to warp and curl and thus increased the roughness observed.

While many questions surrounding the performance of the test sections were answered by the desktop study, forensic field evaluations were recommended to further assess the factors that influence changes in IRI over the time of a single day. Follow-up investigations included a review of the SPS-2 construction report for the test sections and previous research on diurnal testing on SPS-2 sites, a detailed assessment of the weather conditions during the diurnal testing in 2013, and the collection of FWD testing, faulting, and longitudinal profile data in 2019. While FWD testing was recommended to be collected three times throughout the day for all test sections, due to time and weather constraints, testing was limited to test sections 08_0223 and 08_0224. The follow-up study confirmed the behaviors observed in the desktop study with regards to the changes in transverse profile data due to temperature. The time series FWD testing showed that 08_0224 experienced little change in both load transfer and underslab voids with respect to temperature changes. Finally, the follow-up investigation showed test section 08_0223 had an increased load transfer efficiency value and decreased potential for underslab voids with an increase in temperature.

Conclusions and Recommendations

Based on the findings of both the desktop study and the follow-up investigation, the relationship between IRI and temperature from diurnal testing seemed to be most affected by properties of the mix of each test section and moisture conditions which may have led to curl and warp. While the follow-up study provided additional context to the findings of the desktop study, it was recommended that additional cores (once the test sections go out-of-study) and FWD data (mid-panel) be collected. More broadly, additional investigation on the differences between raw profile measurements and faultmeter measurements and the minimum perceptible fault level was also recommended.

Kansas Test Sections 29_02**

Test sections 29_0201, 29_0203, 29_0206, and 29_0212 are LTPP sites located on Interstate 70 westbound starting at milepost 289.3 in Dickinson County, Kansas. Interstate 70 is rural interstate highway with two lanes in the direction of travel. The test sections were constructed between June 1 and July 25, 1992 and were incorporated into the LTPP program as part of the SPS-2 Strategic Study of Structural Factors for Rigid Pavements experiment, which was introduced in the Introduction and is described in more detail in *The Long-Term Pavement Performance Program* (FHWA,2015). A summary of the experimental differences in each of the test sections is provided in Table 11. All test sections on this SPS-2 project were constructed on fill locations with an approximate 6-inch layer of fly ash modified subgrade, which was reported as a silty clay. The construction report indicates the fly ash was added to mitigate the generally wet condition of the subgrade at this site.

Table 11. Summary of test section structures.

Structure Measurement	29_0201	29_0203	29_0206	29_0212
Unreinforced PCC thickness (in)	7.7	11.2	7.7	11.1
PCC Compressive Strength (psi)	600	626	880	928
Slab width (ft)	12	14	14	12
Dowel bar diameters (in)	1.25	1.5	1.25	1.5

The SPS-2 test sections were recommended for forensic analysis based on findings from an SPS-2 Tech Day, where state, academia, and industry personnel performed an on-site visit. During the visit, it was observed that cracking, appearing to mirror the presence of dowel bars, was present in many sections across the transverse joints, particularly on test sections 29_0201 and 29_0206. Therefore, the objective of this study was to better understand the factors contributing to this cracking.

Activities and Findings

In pursuit of the stated objective, a desktop study of the SPS-2 test sections (Elkins et al., 2019a) was conducted, which investigated the pavement structure, construction history, and pavement distress (IRI, faulting, transverse cracking, and longitudinal cracking at joints) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study confirmed the longitudinal cracking at dowel bar locations occurred mostly on test section 20_0201 and to a lesser extent on test section 20_0206—the sections with the thinnest PCC surface layers (7.7 inches). The average minimum depth of coverage of PCC over the top of the dowel bars on these test sections was 2.8 inches, which is less than half the thickness of the PCC layer (which is just outside the construction requirements tolerance). Even if the two test sections had been built to the specified 8-inch PCC thickness, the dowel bars were positioned about 10% higher in the PCC layer than desired. In addition to the thickness and placement of the dowel bars, test section 20_0201 also had lower strength concrete compared to the other test sections. Despite these findings, the FWD load transfer measurements at joints with the most longitudinal cracks over dowel bar locations did not illustrate a significant loss in load transfer as might be expected. As shown in Figure 12, the average Load Transfer Efficiency (LTE), while dipping between 1996 and 2001, remained relatively consistent over time despite the increase in longitudinal cracking at the joints.

The desktop study also aimed to examine the relationship between the magnetic induction tomograph (MIT) measurements of dowel bar alignment with the test section performance related to the joints in the PCC pavement. To do so, the project team developed a dataset of LTPP joint faulting data and information on the number of longitudinal cracks at each transverse joint, as summarized in Figure 13. An assessment of this information revealed variability in the MIT dowel bar data. The data reported ranged from -2.4 to 18.3 inches, which indicates dowel bars were positioned above the PCC pavement surface and below the depth of the PCC layer. The desktop study also found little relationship between the fault height and the number of longitudinal cracks at the transverse joint. The most effective rank ordering of observed longitudinal cracks at the transverse joints appeared to be the computed dowel bar diameter statistic. These findings suggest the current summary statistics derived from the MIT measurements do not satisfactorily explain the performance of doweled joints relative to surface distresses.

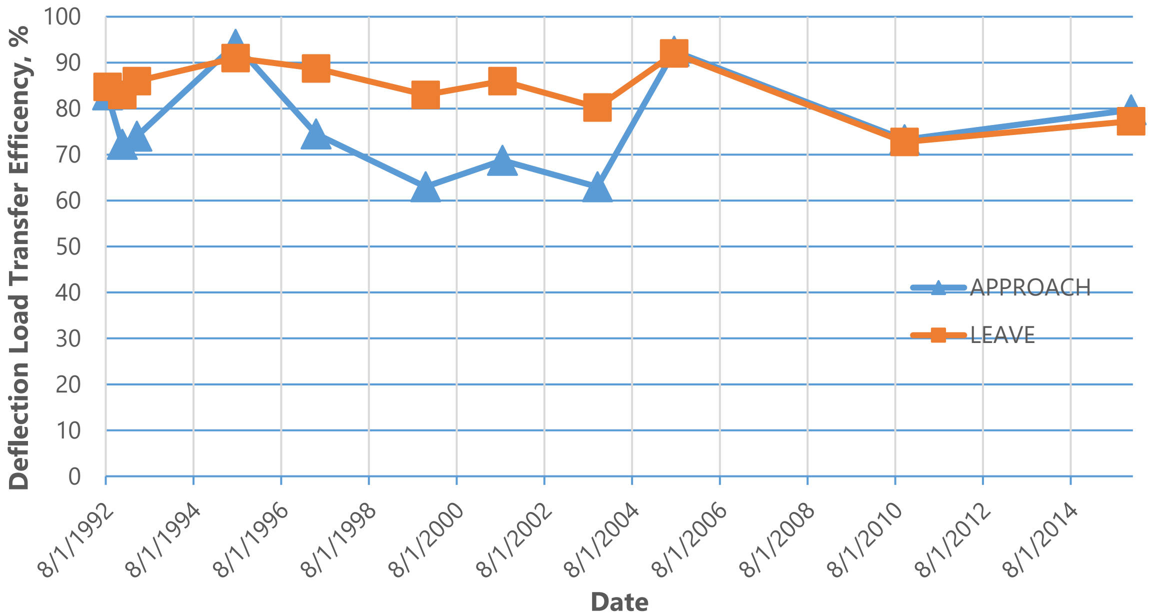

Figure 12. Chart. Time history of average deflection load transfer efficiency at joint 131.1 on section 20_0201 from drop height 4.

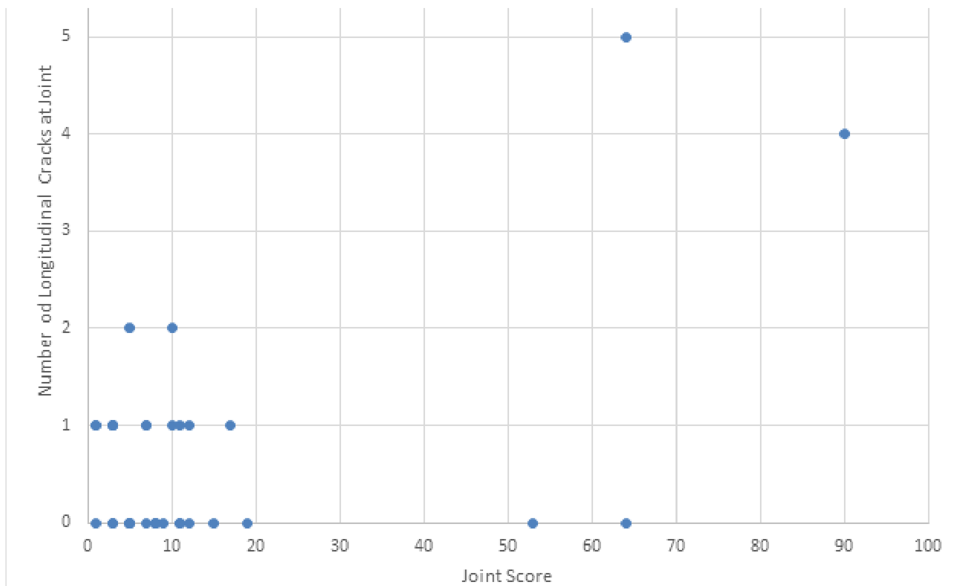

Figure 13. Number of longitudinal joints at transverse joints versus joint score from MIT measurements for test section 20_0201.

Conclusions and Recommendations

The cracking reported along the transverse joints of the pavement section appeared to be related to the thickness of the PCC, placement of the dowel bar in the PCC layer, and the compressive strength of the PCC layer. Due to the variability of the MIT measurements for these test sections, the MIT measurements did not satisfactorily explain the effect of the dowel bar alignment on the performance of the test sections at the joints of the PCC layer. Based on the findings of this study, it was recommended these test sections continue to be monitored over time. This expanded data coverage will allow a more refined explanation of the performance of these experimental test sections. No additional field investigation was recommended prior to when the test sections are taken out-of-study.

Ohio Test Section 39_5003

Test section 39_5003 is an LTPP site located on U.S. 20 eastbound at milepost 11.1 in Lorain County, Ohio. U.S. 20 is a rural principal arterial with two lanes in the direction of traffic. Originally constructed and incorporated into the LTPP program in 1988 as a GPS-5 site, the pavement structure consisted of 9.8 inches of continuously reinforced PCC, 4.8 inches of treated base, and 5.2 inches of unbound (granular) subbase over an untreated subgrade. The site had three treatment events between 1988 and 2012— partial-depth patching in 2008 and 2011 and patching and 3.4-inch AC overlay in 2012, which moved the section to the LTPP GPS-7C experiment. Table 12 shows the pavement structure following the 2012 overlay event.

Table 12. Pavement structure of test section 39_5003 from 2012 to date.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soil: Silty Clay with Sand
2	Unbound (granular) subbase	5.2	Crushed Stone
3	Bound (treated) base	4.8	Hot Mix Asphalt Concrete (HMAC)
4	Portland cement concrete layers	9.8	Portland Cement Concrete (CRCP)
5	AC layer	3.4	Recycled AC, Hot Laid, Central Plant Mix

The test section was selected for a forensic study due to its performance following the 3.4-inch AC overlay in 2012. The proposed investigation aimed to examine the test section history, distress manifestations, and other information to explain the performance of both the original CRCP pavement structure (prior to overlay) and the CRCP pavement structure with AC overlay.

Activities and Findings

In pursuit of the stated objectives, a desktop study (Rada et al., 2019a) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress history (fatigue/alligator cracking, longitudinal cracking, punchouts, patches, transverse cracking, IRI, and rutting) using information available from InfoPave™ (InfoPave™, 2021).

The desktop study confirmed the original CRCP pavement structure performed well over the 24-year period prior to application of the AC overlay in 2012. However, the same could not be said about the performance of the pavement after the AC overlay, specifically in terms of cracking. Two years after the construction event, the AC overlay showed significant amounts of fatigue/alligator, longitudinal (NWP), and transverse cracking, as shown in Table 13. The other performance measures following the overlay showed better pavement condition; IRI improved by 25 (from 64 to 39) inches/miles, rutting improved by 0.1 inches, and the average normalized maximum deflection improved by 0.4 mils after the overlay. Additionally, those values remained low during the next two years of the AC overlay life. The performance of the test section, particularly in terms of alligator cracking, was hypothesized to be a result of a separation between the AC overlay and CRCP layer. However, the deflections values reported on the section did not seem to support this hypothesis—i.e., the referenced layers appeared to be acting monolithically given the low deflections. It was also hypothesized the issue may be materials- or traffic-related; however, additional information needed to be pursued.

While there was sufficient data to adequately explain the performance of the test section prior to the 2012 overlay, it was recommended that a follow-up investigation be conducted to better understand the performance of the section following the overlay. However, the section was found to have been overlaid in 2019 and placed out-of-study. Therefore, additional follow-up activities were not conducted.

Conclusions and Recommendations

The original CRCP test section performed well throughout the first 24 years of the test section's life, but not so after the application of the AC overlay in 2012. The poor performance of the test section following the AC overlay was hypothesized to be related to the debonding of AC and CRCP layers, material issues, and/or traffic levels at the test section. While Ohio DOT provided additional information to help better understand the findings of the desktop study, additional follow-up field activities were needed to assess the validity of these hypotheses. Follow-up investigations were recommended to better understand the performance of the test section following the 2012 overlay. However, as stated previously, the section was found to have been overlaid in 2019 and placed out-of-study. Therefore, additional follow-up activities were not conducted.

Table 13. Pavement condition history on test section 39_5003.

Pavement Condition Metric	Condition Prior to AC Overlay	Condition After AC Overlay	Latest Condition
Longitudinal Cracking Wheel Path	50 ft	0 ft	507 ft in 2014
Transverse Crack Count & Length	177 / 2,100 ft	0 / 0 ft	90 / 490 ft in 2014
Patching	14 ft^2	0 ft^2	0 ft^2 in 2014
Rutting	0.2 inches	0.1 inches	0.1 inches in 2014
IRI	64 inches/mile	39 inches/mile	39 inches/mile in 2016
Normalized Maximum Deflection	2.2 mils	1.8 mils	2.0 mils in 2014

Texas Test Section 48_1111

Test section 48_1111 is an LTPP site located on State Route (SR) 289, eastbound, at milepost 6.4 in Lubbock County, Texas. SR-289 is a rural principal arterial ring road around the city of Lubbock, Texas with two separate lanes in each direction of traffic. The test section was constructed in 1972 and incorporated into the LTPP program in 1987 as GPS-1 site. The test section received two additional treatments between 1987 and 2011—a 2.6-inch dense graded asphalt overlay on top of a 0.1-inch geo-fabric in August 1999, and a chip seal in June 2011. Table 14 shows the pavement structure following the 2011 chip seal event.

Table 14. Pavement structure of test section 48_1111 from 2011 to date.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Coarse-Grained Soil: Clayey Sand
2	Unbound (granular) base	8.4	Soil Aggregate Mixture (Predominantly Coarse-Grained)
3	AC layer	5.7	Hot Mixed, Hot Laid AC, Dense Graded
4	AC layer	1.2	Hot Mixed, Hot Laid AC, Dense Graded
5	AC layer	0.2	Chip Seal
6	AC layer	0.3	Chip Seal
7	Engineering fabric	0.1	Woven Geotextile
8	AC layer	2.6	Hot Mixed, Hot Laid AC, Dense Graded
9	AC layer	0.5	Chip Seal

The test section was selected for an investigation due to its good performance despite its age. The study examined the test section history, distress manifestations, and other information to explain the excellent performance of the test section over time.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 48_1111 (Rada et al., 2020a) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study provided insight on the performance of the section and suspected factors contributing to the section's performance over time. One such finding was the pavement structure exhibited excellent performance even prior to the AC overlay in 1999. Exceptions to this performance observed before the overlay included moderate levels of transverse and NWP longitudinal cracking as well as higher IRI values (although less than 150 in/mi), which seemed to drive the 1999 AC overlay. Another observation made about the test section was the application of the AC overlay and geofabric in 1999 helped to both improve condition metrics and reduce the deterioration rate following the overlay. A third suspected contributing factor over time was the quality and strength of the pavement foundation; the layer modulus backcalculated from FWD measurements exhibited very stiff base and subgrade layers.

To further pursue the reasons for the excellent performance of the test section over time, forensic field evaluations were recommended. As such, follow-up field investigations were performed on

November 14, 2019, including: FWD testing, coring (eight cores in total), longitudinal profiling, and distress measurements (through a visual distress survey). Additionally, the original construction plans and traffic data from TxDOT's Traffic Count Database System (TCDS) for the test site were gathered and reviewed.

As a part of the follow-up study, an analysis of the FWD remaining life, depicted in Figure 14, was conducted. The analysis showed that the average remaining ESALs for each FWD test date, while variable, did not show a decrease over time as would be expected. The remaining ESALs represents the number of ESALs the pavement can withstand before reaching failure. This finding could indicate the paving fabric has played a role in the slowed manifestation of reflective cracks from the underlying AC into the overlay. The remaining ESALs values indicate these reflective cracks should have already occurred.

Additional data collected as a part of the follow-up investigation showed the test section continued to perform well in terms of longitudinal cracking, alligator cracking, and IRI despite the level of degradation found in the original AC layers through the cores. In addition to revealing AC degradation, the cores also showed the total thickness of the AC varied throughout the test section and that cracks below the surface of the geofabric appeared to have reflected to the overlay in six of the eight cores. The bonding between layers also varied from core to core. Through a comparison of the LTPP traffic data (estimated data) and the TxDOT truck traffic counts (measured data), it was found that while the LTPP traffic data showed an estimated average daily truck traffic ranging from around 325 to 400 trucks per day since 2013, the TxDOT truck traffic counts were consistently lower at around 300 trucks per day since 2013. Finally, the IRI of the test section in 2019 indicated the test section was still very smooth, and the IRI had only increased by 13 in/mi over the nearly 20 years since the overlay was placed.

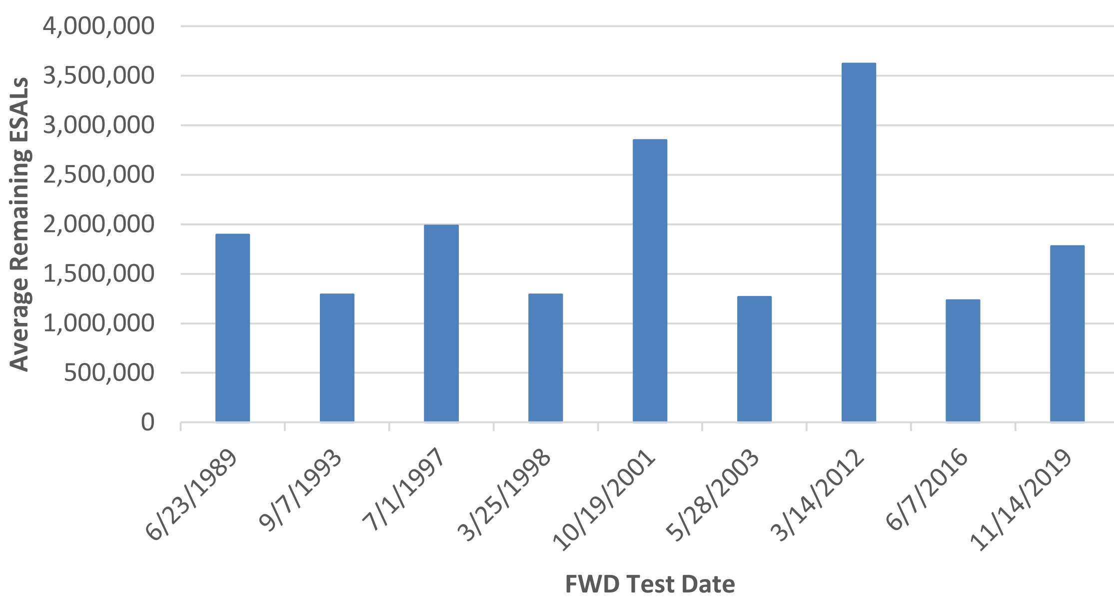

Figure 14. Chart. Average remaining ESALs values over life of test section 48_1111.

Conclusions and Recommendations

Overall, the 1999 overlay of test section 48_1111 performed extremely well likely due to the used of the geotextile fabric and the thickness of the surface layer, among other factors. The degree of contribution of the geotextile fabric to this outcome is uncertain, but it does appear to have been a positive influence on performance. In some locations the bonding between layers was excellent, while bonding layers had deteriorated in others, and the cracking locations were linked to the latter. Pavement smoothness was not impacted significantly regardless of the bonding condition. The pavement design conditions were not radically different than the as-built structure and subsequent traffic loading—acknowledging that LTPP and TxDOT traffic data show some variance—so overdesign of the pavement does not appear to be a reason for the excellent performance. Sufficient information was available to adequately explain the observed performance of the pavement test section and therefore, no further activities were recommended.

Mississippi Test Section 28_5025

LTPP test section 28_5025 is located on U.S. Route 84, westbound, in Lincoln County, Mississippi. U.S. Route 84 is a rural principal arterial with two lanes in the direction of traffic. The initial pavement structure was constructed in 1978 and incorporated into the LTPP program in 1987 as part of the GPS-5 experiment. At the time of incorporation, the test section consisted of 8.2 inches of PCC, 4.3 inches of bound HMAC base, and 6.8 inches of unbound granular subbase on a coarse-grained subgrade. The longitudinal reinforcement within the test section consists of number 5 (5/8 inch) deformed bars with a 6.5 inch spacing in the nominal 8-inch PCC layer; this represents 0.6% longitudinal steel reinforcement. The transverse reinforcement consists of number 4 (0.5 inch) bars spaced 36 inches apart. The average coefficient of thermal expansion (CTE) for the PCC at the test section is 6.05×10^{-6} /°F, which is a typical average value—i.e., not an extreme CTE value. The pavement structure of the test section is summarized in Table 15.

Table 15. Pavement structure for test section 28_5025 from 1987 to present (CN=1).

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Coarse-Grained Soil: Silty Sand
2	Unbound (granular) subbase	6.8	Soil-Aggregate Mixture (Predominantly Coarse-Grained)
3	Bound (treated) base	4.3	HMAC
4	Portland cement concrete layer	8.2	Portland Cement Concrete (CRCP)

The test section is still active after 43 years (1978 to date), and it appears to have performed well when viewed in terms of IRI, rutting, and deflections, but not so in terms of transverse cracking. There were 178 transverse cracks observed during the most recent manual distress survey in 2014. Therefore, the objective of the study was to understand the factors affecting transverse cracking, including the amount of reinforcement used and the influence of climatic conditions.

Activities and Findings

In pursuit of the stated objectives, a desktop study of the test sections (Rada et al., 2019b) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (transverse cracking, IRI, rutting, and pumping, among others) history using information available from InfoPave™ (InfoPave™, 2021). The desktop study focused on understanding the performance of the test section over time, particularly with regards to transverse cracking.

From the desktop study, it was found that, as depicted in Figure 15, the number and length of transverse cracks had increased over time. On this site, the average spacing between transverse cracks in 2014 was approximately 3 feet. While this average spacing approximates the distance between the transverse steel reinforcement, the locations of the transverse cracks did not appear to have a uniform pattern. Older design concepts from the 1970s suggested that transverse crack spacing less than 5 feet might result in increased punchouts. However, other LTPP test sections with crack spacings as short as 2 feet have shown good performance if they were built on supportive layers. This test section has not exhibited any punchouts or corrective maintenance events to address punchouts. The steady increase in the number and length of transverse cracking over time (and hence the short crack spacing) also supported the hypotheses that the increase in deflections and the reduction in moduli of the CRCP layer were directly related to the transverse cracking. However, the load transfer efficiency (LTE) of the transverse joints remained between 88% and 92%, which are considered good values, throughout the life of the test section. This implied that while the structural capacity of the pavement was steadily deteriorating, load transfer at the transverse cracks resulting from the longitudinal steel and aggregate interlock was still performing well.

Other distresses observed on the section included significant pumping. However, the time history of pavement pumping was inconsistent. Pumping peaked in 1999 and by 2014 it was nearly nonexistent. Pavement pumping on CRCP pavements is thought to be due to the eroding of the base structure under the outside edge of the pavement. This eroding leads to punchouts at the lane edge that requires maintenance events to repair. However, this test section had not reported punchouts or patches. In the pictures taken during the manual distress surveys, what was rated as pumping appeared to be water seeping to the pavement surface at the outside pavement edge and not the eroding of the unbound base layers.

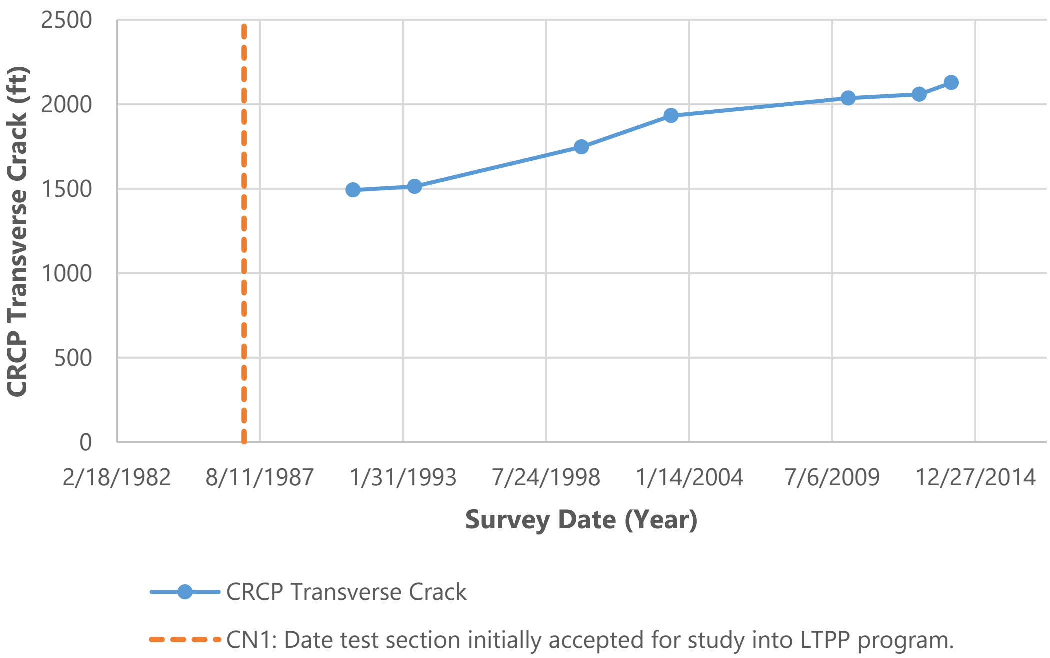

Figure 15. Chart. Time history of transverse cracking length on test section 28_5025.

Conclusions and Recommendations

Overall, the CRCP test section performed well without any maintenance. The two key distresses observed on the test section included high numbers of transverse cracking and pumping. The steady increase in the number and length of transverse cracking over time (and hence the short crack spacing) support the hypothesis that the increase in deflections and the reduction in moduli of the CRCP layer are directly related to the transverse cracking. In the case of pumping, it was postulated that water was pushed to the outside pavement edge of the pavement due to its cross slope and not the traditional pumping mechanism associated with CRCP pavements with unbound base.

While sufficient data were available to explain the performance of test section 28_5025, it was recommended that additional activities be pursued to extend the analysis conducted as part of the desktop study. Recommended follow-up activities included the continual monitoring of test section conditions and the performance of additional FWD testing, backcalculations, and coring on the areas adjacent to the test section. However, due to time constraints, these activities were not able to be conducted as part of this pooled fund study.

California Test Section 06_7452

Test section 06_7452 is located on State Route 29, northbound, at milepost 44.5 in Lake County, California. State Route 29 is a rural minor arterial with two lanes in the direction of traffic. Constructed in 1972, the test section was incorporated into the LTPP program in 1989 as a part of the GPS-2 study. The original pavement structure consisted of 3.9 inches of AC, 6.7 inches of treated base, and 9.8 inches of unbound (granular) subbase over an untreated subgrade. Following its incorporation into the LTPP program, the site received a 4-inch AC overlay in 1999—moving the test section to the GPS-6B study—and a mill and overlay in 2010—moving the test section to the GPS-6C study. Table 16 shows the pavement structure following the last mill and overlay event in 2010.

Table 16. Pavement structure of test section 06_7452 from 2010 to date.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soils: Sandy Lean Clay
2	Unbound (granular) subbase	9.8	Gravel (Uncrushed)
3	Bound (treated) base	6.7	Lean Concrete
4	Asphalt concrete layer	3.4	Hot Mixed, Hot Laid AC, Dense Graded
5	Asphalt concrete layer	0.5	Chip Seal
6	Asphalt concrete layer	2.6	Hot Mixed, Hot Laid AC, Dense Graded
7	Asphalt concrete layer	1.4	Hot Mixed, Hot Laid AC, Dense Graded
8	Asphalt concrete layer	1.2	Hot Mixed, Hot Laid AC, Dense Graded with partial milling

The test section's performance over time has been mixed, with low IRI, rutting, and deflections reported, but high amounts of longitudinal and transverse cracking. Therefore, the focus of the study was to better understand the performance of the test section in terms of cracking over time. Specifically, the investigation aimed to identify the differences in transverse cracking reported prior to the first AC overlay (on average, one transverse crack every 5 feet) and after the overlays (only ten cracks and one crack reported in 2010 and 2015, respectively).

Activities and Findings

In pursuit of the stated objective, a desktop study (Rada et al., 2020b) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress history (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) using information available from InfoPave™ (InfoPave™, 2021).

The desktop study provided insight on the performance of the test section between its construction in 1972 and 2015. Other than the longitudinal and transverse cracking reported at the end of the CN=1 period (1972 to 1999) and the alligator and longitudinal cracking (although only moderate amounts) reported at the end of the CN=2 period (1999 to 2010), the test section appeared to be in good condition throughout its long life. The study explored the reason for the limited transverse cracking on the AC overlays, despite high amounts of cracking prior to the first overlay. It was hypothesized the observed transverse cracking prior to the first overlay was due to the reflection of cracks in the lean concrete base to the AC surface layer. The application of the two AC overlays would have delayed the re-appearance of transverse cracking. However, only 10 transverse cracks were observed at the end of CN=2, when a 4-inch AC overlay was placed, and only one transverse crack was observed in 2015, five years after the second AC overlay.

Through the desktop study, the layer moduli backcalculated from the FWD deflection test data were also assessed. The reported values appeared reasonable. Surprisingly, the values for the unbound granular layers remained stable over the 22 years of deflection testing (1989 to 2011), despite pavement deterioration and variability in climatic conditions.

As an extension of the desktop study, a follow-up investigation on the test section was conducted. As part of the follow-up field activities, a manual distress survey and FWD testing were performed, nine 6-inch cores within the test section were collected, and longitudinal and transverse profiles were collected in February of 2020. Cores obtained on the site showed the lean concrete base layer (LCB) was distressed with multiple cracks that were reflected through the entire AC layer. Additionally, it was found that the LCB moduli values were decreasing over the life of the section, based on backcalculated moduli. This would indicate increased cracking in the LCB layer over time and could result in increased reflective cracking into the AC layer observed in 2020. Another key finding from the inspection of the cores was that the layer structure for CN=3 was incorrect. The LTPP database showed the 2010 treatment as being an overlay adding a 1.3-inch AC layer on top of the existing 1999 AC overlay. However, examination of the cores showed layer 7 had been completely milled off and layer 6 was reduced in thickness from 2.6 inches to 2.1 inches. The correct layer information was provided to the LTPP Program for update in the next LTPP Standard Data Release.

As part of the follow-up study, the distresses, structural capacity, and remaining ESALs on the test section over time were also reviewed. The 2020 manual distress survey notably showed widespread cracking had developed since 2015; however, the rutting and roughness on the site remained minimal. A structural assessment of the test section was conducted and showed the moduli values for the section had remained stable through the life of the pavement with little seasonal variation. Finally, overlay design analyses studied the section’s remaining ESALs before failure. Projecting forward, the analyses indicated the pavement would reach failure between 2022 and 2032.

Conclusions and Recommendations

The performance of test section 06_7452 over almost 50 years and two major rehabilitation events was good when considering IRI, rutting, and deflections, but not in terms of cracking, particularly for transverse cracking prior to 1999 and in 2020. Both the desktop study and follow-up investigation focused on better understanding the causes of observed cracking and why limited amounts of transverse cracking appeared after the overlays. Through the follow-up field investigations, it was found that the pavement structure did show signs of degradation, especially the LCB, and that cracking had begun to reflect to the overlay layers by 2020. Therefore, it appeared the overlays had slowed down the deterioration of the pavement structure as hypothesized, and the overall pavement system is close to reaching the end of its service life. While this project will be placed out-of-study, additional project-related data collected by Caltrans as part of designing either another rehabilitation or a reconstruction would be of interest. Given the degradation of the LCB, treatments similar to the 2010 mill and overlay would not be expected to perform well.

Florida SPS-5 Test Sections

The LTPP SPS-5 test sections 12_0502, 12_0503, 12_0504, 12_0505, 12_0506, 12_0507, 12_0508, 12_0509, 12_0561, 12_0562, 12_0563, 12_0564, 12_0565, and 12_0566 and GPS control section 12_1030 are located on U.S. Route 1, southbound, in Martin County, Florida. Route 1 is a rural principal arterial with two lanes in each direction of traffic. The original pavement structure of this portion of U.S. Route 1 was constructed in 1971 and consisted of a semi-infinite untreated coarse-grained soil with a poorly graded sand subgrade layer, an unbound granular subbase, an unbound granular base layer, a dense graded AC layer, and an open graded surface coarse layer. For each of the SPS-5 test sections, a second construction event took place in April 1995 when the overlays were placed. The existing pavement surface for each was milled and overlaid with hot-mix AC of varying thickness, and the AC shoulder of the test sections was replaced. Table 17 shows the history of the change in the pavement structure due to milling and addition of new pavement layers. The final construction event for the SPS-5 sections (CN=3) took place in July 2014 when the existing pavement was milled and received a 2-inch overlay of hot-mix recycled AC, moving the test sections to the GPS-6S experiment. The control section (12_1030) underwent two construction events after being incorporated into the LTPP program in 1987. In 1993, the AC shoulder was replaced, and in July 2014, the section was milled and overlaid with hot-mix recycled asphalt.

These LTPP sections were recommended for forensic investigation to 1) examine the performance of the 15 test sections at the Florida SPS-5 project site from 1995 to 2014, and 2) assess the effects of unusually high moisture on the performance of the test sections due to extreme rain events, such as hurricanes and tropical storms.

Table 17. Change in pavement structure due to milling an addition of new pavement layers.

SHRP ID	AC Thickness before (in)	AC Mill (in)	AC Overlay (in)	AC Thickness after (in)	Number of AC Overlay Lifts	AC Type
12_0502	3.4	-1.4	2.3	4.3	3	recycled
12_0503	4.0	-1.5	5.5	8.0	3	recycled
12_0504	3.0	-0.8	5.4	7.6	3	virgin
12_0505	3.3	-1.2	2.6	4.7	3	virgin
12_0506	4.4	-2.7	3.5	5.2	3	virgin
12_0507	3.1	-2.6	7.1	7.6	3	virgin
12_0508	3.3	-2.7	7.5	8.1	3	recycled
12_0509	3.7	-3.0	4.5	5.2	3	recycled
12_0561	3.0	-0.9	4.4	6.5	3	recycled
12_0562	2.8	-0.9	4.0	5.9	3	virgin
12_0563	3.2	-2.6	2.7	3.3	3	virgin
12_0564	3.3	-2.7	2.4	3.0	3	recycled
12_0565	3.2	-2.7	6.2	6.7	4	recycled
12_0566	3.3	-3.0	5.9	6.2	4	virgin
12_1030	3.3	0.0	0.0	3.3	0	control

Activities and Findings

In pursuit of the stated objectives, a desktop study of the sections (Elkins et al., 2020b) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). To evaluate the performance of the pavement sections, the initiation and progression of fatigue/alligator cracking, longitudinal cracking, transverse cracking, and IRI were assessed using statistical analyses.

For fatigue/alligator cracking, initiation and propagation models were developed using available data on the test sections. For the initiation model, the effects of overlay total thickness, the area of fatigue/alligator cracking reported prior to the overlay, the total thickness of the AC layers after milling, and whether the AC layers used virgin or recycled aggregates were assessed. The propagation model considered the number of years since crack initiation, the total milling depth, the total thickness of the AC layers after the milling (but prior to the overlay), and the number of years since overlay application until fatigue/alligator cracking showed in the surface. Based on the analysis, it was found that the thickness and materials used in the overlay played a significant role in the initiation of fatigue/alligator cracking, while the pre-existing cracking and the milling depth did not. The total thickness and number of years since the overlay was applied until fatigue/alligator cracking developed had a positive relationship with the propagation of cracking. In other words, the higher the AC thickness after milling (but prior to overlay) or the greater the number of years to fatigue/alligator cracking initiation, the faster the fatigue/alligator cracking growth rate. On the other hand, the deeper the milling depth, the slower the fatigue/alligator cracking growth rate.

Similar analyses were conducted for longitudinal cracking, transverse cracking, and IRI. Key findings included:

- **Longitudinal Cracking**: While non-wheel path (NWP) longitudinal cracking was present following the overlay, none of the SPS-5 treatment factors played a significant role in the initiation or propagation of NWP longitudinal cracking. It was hypothesized that the substantial precipitation that occurred in 1999 (66.4 in), caused in part by Hurricane Irene and Tropical Storm Harvey, may have played a role in the amount of NWP longitudinal cracking reported.
- **Transverse Cracking:** While the cause of the transverse cracking initiation and propagation remains unclear since this site is located in a no-freeze zone, some LTPP studies have indicated that repeated truck wheel loading associated with fatigue type cracking mechanism appears to influence the increase in transverse cracking. The type and thickness of the asphalt overlay selected did not seem to play a clear role in this distress mechanism.
- **IRI:** Following the overlay, higher initial IRI values and lower total AC overlay thickness values resulted in higher deterioration rates in IRI, as expected. Since test sections with AC overlays using virgin mixes had lower initial IRI values, their deterioration rates were lower. Although these effects were statistically significant, their magnitudes were found to be moderate.

The desktop study was also useful in revealing discrepancies between the pavement type reported for the control section (12_1030) in InfoPave™ and what was shown in pictures of the control section. In the initial pavement structure characterization, it appears that what is reported as an open graded surface course on the other SPS-5 test sections at this site, was combined into a single AC structural layer on this control section. Judging by photographs of the control test section, it also had an open graded surface course, but was not noted in the original LTPP core examination that was used to determine layer thicknesses.

Conclusions and Recommendations

Overall, the desktop study provided sufficient information to justify the performance of the test sections. Using information gathered from InfoPave™, a better understanding of the factors that affected the overall performance of the test sections was explored. Based on the information gathered and analyzed in the desktop study, further desktop evaluation of anomalies within section 12_1030 was recommended. The study team developed Data Analysis/Operations Feedback Reports (DAOFRs) and submitted them to LTPP staff to investigate the correction of some of the issues discovered during this study. No follow-up field investigations were recommended.

Oklahoma Test Sections 40_AA**

Test sections 40_AA01, 40_AA02, 40_AA03, 40_AA61, 40_AA62, and 40_AA63 are on State Route 66, westbound, in Canadian County, Oklahoma. State Route 66 is an urban principal arterial with two lanes in the direction of traffic. The six Oklahoma test sections were incorporated into the LTPP program in March 2015 as part of the SPS-10 Warm Mix Asphalt Experiment. The pavement structure for each test section at the time they were incorporated into the LTPP program are summarized in Table 18; this information corresponds to CN=1 in the LTPP database. As the table shows, the total AC thicknesses for the sections varied between 8.8 and 10.8 inches, and each AC layer was comprised of five identified dense graded HMAC layers. The AC thickness was intended to be uniform throughout the test sections, thus the variation in thickness was not part of the experiment design. However, the type of asphalt mix varied from section to section. Test section 40_AA01 was the control section and received a conventional hot-mix asphalt (HMA) overlay, sections 40_AA02, 40_AA03, 40_AA61, and 40_AA62 received Warm Mix Asphalt (WMA) overlays, and section 40_AA63 received a stone-matrix asphalt (SMA) overlay.

Table 18. Pavement structure for CN=1 of Oklahoma SPS-10 test sections 40_AA.**

Layer Number	Layer Type	Material Description	Thickness (in.) for Section 40_AA**					
			01	02	03	61	62	63
1	Subgrade (untreated)	Fine-Grained Soils: Clay	SI	SI	SI	SI	SI	SI
2	Unbound (granular) base	Soil-Aggregate Mixture (Predominantly Fine-Grained)	12.0	12.0	12.0	12.0	12.0	12.0
3 to 7	Asphalt concrete layer	Hot Mixed, Hot Laid AC, Dense Graded	8.8	10.4	9.7	10.1	10.5	10.8

The test sections were selected for forensic investigation to examine the reason cracking, specifically NWP longitudinal cracking, re-appeared a year after a 2-inch overlay was applied to the test sections. The proposed investigation was intended to determine if the cracks that re-appeared following the overlay were reflection cracks, to capture the time before crack initiation, and to compare the performance to-date for the Oklahoma SPS-10 test sections.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test sections 40_AA01, 40_AA02, 40_AA03, 40_AA61, 40_AA62, and 40_AA63 (Elkins et al., 2020a) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, edge cracking, block cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study revealed differences in the distress types reported on each of the test sections following the overlay in 2015. For each test section, all pavement distresses, deflections, and IRI were reduced immediately after the application of the experimental overlay in 2015, as was to be expected. However, the propagation of the distresses following the overlay varied from section to section. Specifically, section 40_AA61, which had virgin asphalt one grade lower than the core experimental test sections and a chemical WMA additive, exhibited the greatest amount of cracking in the overlay. As depicted in Table 19, test section 40_AA61 reported the highest amount of fatigue/alligator cracking and transverse cracking of all the test sections in 2019. On the other hand, the HMA test section (test section 40_AA01) appeared to have slightly better performance than the warm mix sections, given the limited historical distress data available.

Table 19. Summary of 2019 distresses data for Oklahoma SPS-10 test sections 40_AA.**

Section	Fatigue Cracking (sq. ft.)	NWP Longitudinal Cracking (ft)	Transverse Cracking (Count & Length)	Edge Cracking (ft)	Block Cracking (sq. ft.)	IRI (in/mi)	Rutting (in) (2019)	Deflection (mil) (2016)
40_AA01	1.1	502.6	50 (339.9 ft)	470.2	0	56.8	0.04	14.1
40_AA02	1.1	500.0	49 (320.9 ft)	194.6	0	52.9	0.08	15.6
40_AA03	0.0	510.5	58 (395.4 ft)	0.0	0	43.3	0.08	17.8
40_AA61	139.9	500.0	178 (730.4 ft)	408.2	0	54.4	0.12	17.2
40_AA62	0.0	538.4	0 (0 ft)	86.3	0	50.7	0.14	19.4
40_AA63	0.0	500.0	0 (0 ft)	123.0	0	78.4	0.16	25.7

Another finding of the desktop study was that the presence of NWP longitudinal cracking both prior to and following the overlay was due to the longitudinal cold joint between lanes created by the construction process. Therefore, while NWP longitudinal cracking observed prior to the overlay may have been reflected following the overlay, the root cause of the cracking observed was construction-related.

Conclusions and Recommendations

Overall, the desktop study provided information on the reasons for the differences in the performances of the six SPS-10 test sections. The desktop study also found that the test section with the HMA overlay seemed to perform the best following the overlay. While sufficient information was available to adequately explain most of the observed performance of the pavement sections, the desktop study did recommend continuous monitoring of the test sections (including FWD testing), the reassessment of the analysis conducted in the desktop study once the results of the time history laboratory data tests were made available, and the use of ground penetrating radar (GPR) to more accurately characterize the thickness of the pavement layers and identify saturated regions of the unbound base layers.

New Mexico SPS-8 Test Sections

Test sections 35_0801 and 35_0802 are located on the Interstate Highway 10 (I-10) Frontage Road (FR), eastbound, in Grant County, New Mexico. I-10 FR is a remote rural local collector with one lane in each direction of traffic. Both sections are in a Dry-No Freeze climatic zone with an average annual precipitation ranging between 7.3 inches (2003) and 15.4 inches (2011) and an annual average air freezing index ranging between 0 deg F deg days (multiple years) and 83 deg F deg days (2011). The initial pavement structure for both test sections was constructed in 1995 and incorporated into the LTPP program that same year as part of the SPS-8 experiment. The original pavement structures (at CN=1) for each section are detailed in Table 20; no maintenance or rehabilitation has been applied to either test section since the initial construction date.

Table 20. Pavement structure for New Mexico SPS-8 test sections from 1995 to present.

Layer Number	Layer Type	Test section 35_0801		Test section 35_0802	
		Thickness (in.)	Material Code Description	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	Semi-infinite	Coarse-Grained Soil: Clayey Sand	Semi-infinite	Coarse-Grained Soil: Clayey Sand with Gravel
2	Unbound (granular) subbase	9.7	Soil-Aggregate Mixture (Predominantly Coarse-Grained)	12.7	Soil-Aggregate Mixture (Predominantly Coarse-Grained)
3	Asphalt Concrete (AC) layer	4.2	Hot Mixed, Hot Laid AC, Dense Graded	7.0	Hot Mixed, Hot Laid AC, Dense Graded

Despite the test sections being a part of the SPS-8 experiment and therefore reporting low levels of traffic, the test sections both developed fatigue/alligator cracking. Contrary to intuition, more fatigue/alligator cracking was measured on the thicker test section (35_0802). Therefore, a forensic evaluation of these test sections was recommended to investigate the reason(s) for the presence of fatigue/alligator cracking and to compare the overall performance of the two sections, which are subjected to the same traffic and climatic conditions and were constructed with the same materials and on similar subgrade soil.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 53_1005 (Gardner et al., 2020i) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

Through the desktop study, the performance of the pavement sections between the first (~1999) and more recent measurements of the pavement distresses (~2016) were assessed. Most notable from the comparison of the two sections was the higher quantity of fatigue/alligator related cracking reported for the thicker pavement section (section 35_0802), which was almost triple that of the thinner section (35_0801), as depicted in Figure 16. Using the HPMS 2016 percent cracking metric of cracks in the wheel paths, the relative difference between the two sections is much smaller, but still significant. The study team did confirm from the data forms completed during construction of the test sections that the pavement thicknesses contained in the LTPP database are correct.

The increased fatigue-related cracking on the thicker section was hypothesized to be the result of asphalt hardening, stripping, or different drainage conditions between the two test sections. However, follow-up forensic investigations were strongly recommended to better understand the reason these pavement sections are behaving the way they are.

Based on the recommendations of the desktop study, field work—including FWD testing, coring, a manual distress survey, and transverse and longitudinal profiling—and office work—such as a comparison of the New Mexico SPS-8 test sections' performance to other SPS-8 test sections and the further investigation of the traffic reported on the test sections—were conducted. Follow-up field investigations were performed in July 2020 and a summary of key activities was prepared in December 2020.

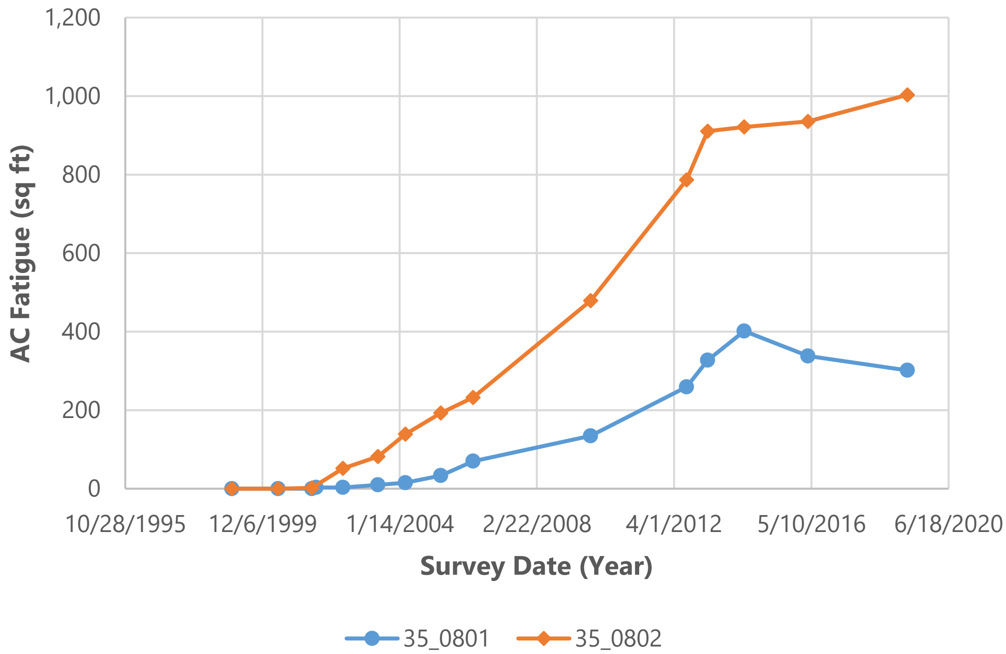

Figure 16. Chart. Total area of alligator cracking over time.

The activities conducted as a follow-up to the desktop study revealed the performance of the test sections was likely related to age hardening or oxidation as stripping; variation in test section thicknesses, and truck traffic were not found to play a clear role in the performance of these test sections. However, additional material testing on the collected cores was recommended to confirm this conclusion.

Conclusions and Recommendations

Overall, the desktop study and forensic field evaluations found the pavement sections did report abnormally high levels of fatigue/alligator cracking despite the low levels of truck traffic reported on these test sections. While test section 35_0802 consisted of a thicker pavement structure, it performed worse than test section 35_0801 in terms of fatigue/alligator cracking, HPMS 2016 Percent Cracking, longitudinal cracking, and transverse cracking. Additional investigation as to the cause of the fatigue/alligator cracking performance on the test sections is still necessary. Material testing of the test sections could not be conducted due to time constraints; therefore, it is recommended that PG grading be performed on the extracted cores. In doing so, information on whether the test sections have oxidized can be inferred.

Iowa Test Section 19_1044

LTPP test section 19_1044 is located on U.S. Route 20, eastbound, in Buchanan County, Iowa. U.S. Route 20 is a rural principal arterial with two lanes in the direction of traffic. The initial pavement was constructed in 1971, and it was incorporated into the LTPP program in 1987 as part of the GPS-1 experiment. The pavement structure at the time of its incorporation into the LTPP program consisted of 16.1 inches of asphalt concrete (split between three layers) and 10 inches of lime treated subbase over a fine-grained subgrade soil. The test section received crack sealing and patching in 1992 (CN=2) and 1995 (CN=3), a fog seal in 1995 (CN=4), and an AC overlay in 2002 (CN=5), at which point the test section was reclassified as a GPS-6B site. Additionally, following an interview with Iowa DOT staff in February of 2021, it was learned that an additional construction event had occurred on the test section. The unreported construction event on the test section was a 1.5-inch mill and 2-inch AC overlay in 1989. This information has been passed on to the FHWA LTPP Team so they may implement the necessary corrective measures. Table 21 summarizes the pavement structure of the test section following the 2002 overlay event.

Table 21. Pavement structure for test section 19_1044 following CN=5.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	114-Fine-Grained Soils: Sandy Lean Clay
2	Bonded (treated) subbase	10.0	338-Lime-Treated Soil
3	Asphalt Concrete (AC) Layer	13.0	1-Hot Mixed, Hot Laid AC, Dense Graded
4	Asphalt Concrete (AC) Layer	2.2	1-Hot Mixed, Hot Laid AC, Dense Graded
5	Asphalt Concrete (AC) Layer	0.9	1-Hot Mixed, Hot Laid AC, Dense Graded
6	Asphalt Concrete (AC) Layer	0.1	73-Fog Seal
7	Asphalt Concrete (AC) Layer	2.0	1-Hot Mixed, Hot Laid AC, Dense Graded
8	Asphalt Concrete (AC) Layer	1.7	1-Hot Mixed, Hot Laid AC, Dense Graded

Prior to the overlay in 2002, the IRI at test section 19_1044 reached to nearly 300 in/mi. However, following the 2002 overlay, the IRI at the test section dropped to 33 in/mi and remained smooth for the next 18 years despite showing significant signs of distress. Therefore, the objective of the study was to investigate the performance of the test section prior to and following the 2002 overlay to better understand the incongruous distress versus IRI trends.

Activities and Findings

In pursuit of the stated objective, a desktop study of test section 19_1044 (Gardner et al., 2021b) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, patching, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The study focused on assessing the performance of the test section in light of the IRI reported over time.

The desktop study provided insight on how the test section performed both prior to and following the AC overlay event in 2002. Specifically, as summarized in Table 22, the distresses observed prior to the 2002 AC overlay were compared to the distresses reported during the 2015 manual distress survey. In most cases, the amount of distress reported prior to the overlay event was similar to or less than the amount of distress reported following the overlay event, as was the case for fatigue/alligator cracking, longitudinal cracking, and rutting. However, for transverse cracking and IRI, the conditions reported prior to the 2002 overlay were worse than the conditions reported 13 years after the overlay. Additionally, the low rate of increase in roughness observed following the AC overlay was incongruous with the distresses recorded on the section following the overlay. The placement of patches at transverse cracks likely caused the high levels of roughness reported on the test section prior to the overlay. Additionally, the desktop study examined the causes of the distresses observed. While much of the performance of the test section was thought to be related the deterioration of the pavement structure over time, it was hypothesized that the performance was also impacted by low temperature winter conditions, patching, and (following the 2002 overlay) the reflection of cracking from the original AC layer to the overlay layer. Additional investigation was recommended to confirm these hypotheses.

Table 22. Summary of test section 19_1044 performance metrics over time.

Attribute	Measurement Prior to 2002 AC Overlay	Measurement After AC Overlay (2007)	Previous Measurement (2015)	Latest Measurement (2020)
Average Fatigue cracking (ft^2)	382.1	0	1,703.9	1,741.6
Average WP Longitudinal Cracking (ft)	0	0	0	0
Average NWP Longitudinal Cracking (ft)	892.2	568.8	1,036.2	1,049.6
Transverse Cracking (ft)	395.6 (47 transverse cracks)	26.2 (3 transverse cracks)	130.9 (32 transverse cracks)	196.1 (57 cracks)
Patching (ft^2)	647.80 (16 patches)	0	0	0
IRI (in/mi)	286.89 (in 2001)	42.7	75.65	81.5
Rutting (in)	0.16	0.16	0.31	Pending

Based on the findings and recommendations from the desktop study, follow-up investigations were conducted. This included a series of follow-up field work—including a manual distress survey, transverse and longitudinal profiling, coring, and FWD testing—and office work—including an interview with Iowa DOT personnel.

The field activities, which took place in June 2020, showed the overall performance of the test section in terms of fatigue/alligator cracking, wheel path (WP) longitudinal cracking, NWP longitudinal cracking, and IRI remained the same or slightly decreased when compared to the data collected in 2015. However, it is important to note the extent of NWP longitudinal cracking and fatigue/alligator cracking was already significant in 2015, so there was limited capacity for growth, as depicted in Figure 17. Through coring, it was found that the transverse cracking observed in the AC overlay layers appeared to have been reflected from the original pavement structure prior to the overlay event. The cores also showed the original AC layers (Layers 3-5) had deteriorated significantly, which helps explain the increase in deflection and cracking reported on the test section over time. The consistency of the IRI values reported on the test section over time was also notable. With high amounts of cracking observed, it was expected that there would be substantial increases in the IRI on the test section. It is hypothesized that this is due to the severity of the cracking observed in the wheel paths being predominantly low.

Through an interview with Iowa staff, it was found that for the most part, the performance of the pavement section over time was aligned with the expected performance of a relatively thick pavement segment. The Iowa DOT hypothesized the lack of milling prior to the 2002 overlay event and the AC mix used at the section played a role in the fatigue/alligator cracking observed on the test section, while the propagation of transverse cracking was likely exacerbated by the expansion of the lime-treated base. The Iowa DOT also noted the rutting on the test section was inconsistent with rutting typically observed on DOT roadways and hypothesized the rutting occurred in the AC surface layers. The performance of the test section in terms of IRI was thought to have been affected by the changing smoothness specifications, use of contractor incentives for smooth pavements, and improved equipment used by the DOT. In addition to these key findings, it was found that an additional construction event had occurred on the test section. This important information was shared with the LTPP Data Collection contractor.

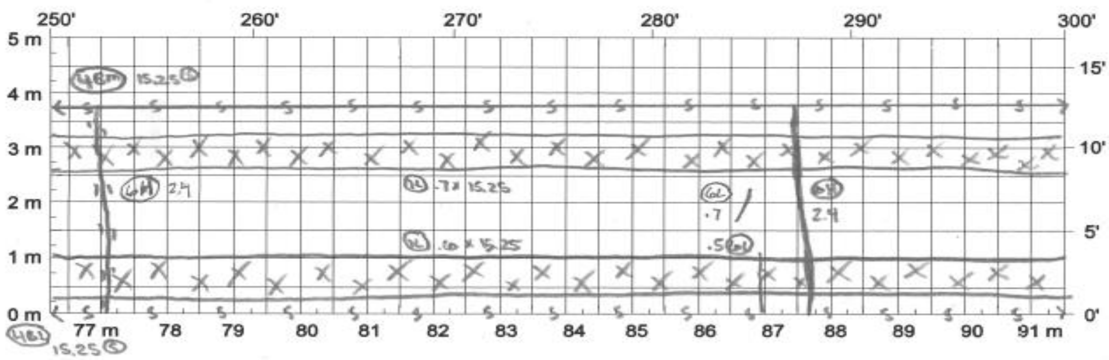

Figure 17. Map. 2015 distress survey of test section between 250 feet to 500 feet.

Conclusions and Recommendations

Prior to the 2002 overlay, the test section's performance seemed to be most affected by low temperatures, the lime-treated base, and AC mix properties, which triggered cracking and patching and resulted in increased roughness levels. Following the 2002 AC overlay, the performance of the test section decreased over time as evidenced by increased levels of cracking and deterioration observed in the collected cores. It was also found that much of the cracking prior to the AC overlay reflected to the AC overlay layer. Despite the amount of cracking observed on the test section following the overlay, the overall roughness of the test section did not increase to the same levels observed prior to the overlay, likely due to the absence of patching and changes in the State's smoothness specifications prior to the 2002 overlay. Through the desktop study and the follow-up investigations, the performance of the test section could be adequately explained. As the field activities conducted on the test section in June 2020 was the closeout testing, the test section is out-of-study.

Montana Test Section 30_8129

Test section 30_8129 is a LTPP site located on U.S. Route 12, eastbound, in Golden Valley County, Montana. U.S. Route 12 is a rural principal arterial with one lane in the direction of traffic. The test section was reconstructed and incorporated into the LTPP program in 1988 as a

General Pavement Study (GPS-1) site and received a shoulder replacement, a 4-inch AC overlay, and a 0.2-inch aggregate seal coat during a second construction event (CN=2) in June 2003, moving it from a GPS-1 to GPS-6B AC Overlay Using Conventional Asphalt of AC Pavement-No Milling study. A final construction event (CN=3) occurred in June 2013; the section received crack sealing and therefore, the overall pavement structure did not change. Table 23 shows the pavement structure following the 2003 construction event.

In addition to being a GPS-1 study, test section 30_8129 was also a part of the Seasonal Monitoring Program (SMP) and was therefore equipped with an on-site weather station and subsurface temperature, moisture, frost detection and water table depth sensors. During the period when SMP data collection was active (1992–1997), the collection of falling weight deflectometer (FWD) measurements and downloading of instrumentation data was performed on a monthly interval, and data collection of distress and profile measurements was conducted quarterly. Given the frequency of data collection and the types of data available at this site, this test section was recommended as an opportunity to 1) make inferences on seasonal load restriction regulations based on the investigation, and 2) explore the development of fatigue/alligator and transverse cracking in relationship to climatic and other variables.

Table 23. Pavement structure for CN=2.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soils: Gravelly Lean Clay with Sand
2	Unbound (granular) base	22.8	Crushed Gravel
3	Asphalt Concrete (AC) Layer	3.0	Hot Mixed, Hot Laid AC, Dense Graded
4	Asphalt Concrete (AC) Layer	0.2	Chip Seal
5	Asphalt Concrete (AC) Layer	4.0	Hot Mixed, Hot Laid AC, Dense Graded
6	Asphalt Concrete (AC) Layer	0.2	Seal Coat

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 30_8129 (Gardner et al., 2020a) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The study focused on using the SMP dataset to better characterize the performance of the test section over time.

Utilizing the frequency of data collection during the SMP analysis period, an assessment of the change in pavement deflection over time with regards to pavement temperature and subgrade moisture content was conducted. As depicted in Figure 18, for the most part, increases and decreases in deflections correspond to increases and decreases in the pavement temperature and subgrade moisture content. Additionally, the largest increases in deflections observed seemed to correspond to spring months, when it is postulated the subgrade is weakest due to the thawing of frost zones.

Based on these findings, a regression analysis was performed to statistically relate variations in deflection to the changes in both the referenced variables and the test section age. Ultimately, the regression analysis yielded the following model to predict pavement deflection (mils) based on pavement temperature (°F), subgrade moisture content (%), and measurement position (0 under the center of load plate or 1 at 48 inches from the center of the load plate). The relationship between the predicted deflection values from the model and the actual deflected values showed a good correlation with a coefficient of determination (R^2) of 0.88. It was recommended this model, given in Figure 19, be further explored as a means of establishing load restrictions during the spring-thaw period.

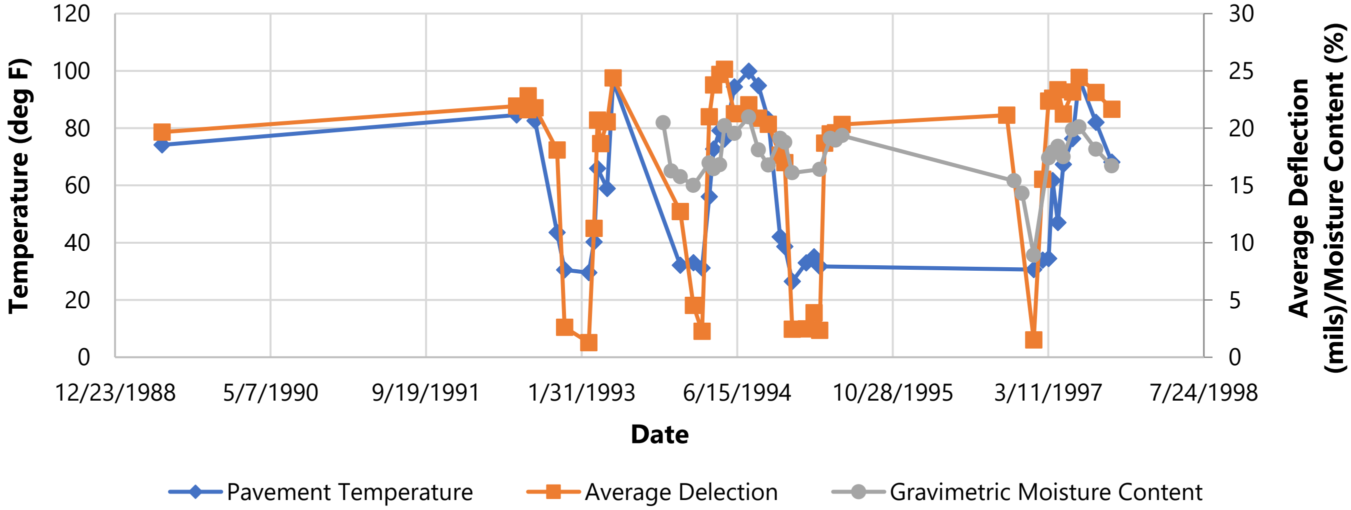

Figure 18. Chart. FWD deflections, average daily pavement temperature 1.85 inches below surface, and gravimetric moisture content 33 inches below surface.

$$\text{Deflection} = 17.95 + 0.15 * \text{Temperature} + 1.29 * \text{Moisture Content} - 15.23 * \text{Position} - 0.15 * \text{Temperature} * \text{Position} - 1.14 * \text{Moisture} * \text{Position}$$

Figure 19. Equation. Deflection predictive model for test section 30_8129.

In addition to studying the role of climatic factors on the reported pavement deflection, the effect of climatic factors on pavement distresses was also explored. While fatigue/alligator cracking, longitudinal cracking, and transverse cracking were reported on the section during the SMP analysis period, the rate of propagation was gradual despite the fluctuation in climatic factors over time.

Conclusions and Recommendations

Based on the analysis conducted, the change in deflection over time appears to be directly related to the seasonal change in pavement temperature and subgrade moisture content over time. For the most part, increases and decreases in deflections correspond to increases and decreases in the pavement temperature and subgrade moisture content; these findings can be useful in developing load restriction regulations. Additionally, it was found that climatic factors did not play the same role for pavement distresses as they did for pavement deflection, as the rate of propagation was gradual and did not seem to vary greatly despite reported changes in climatic factors. Closeout monitoring was recommended for this site, including a pavement distress survey, longitudinal and transverse profile surveys, and deflection testing. Coring, to verify the layer thicknesses and further investigate pavement deformation at the test section, was suggested as well. Finally, it was recommended the use of deflection-based regressions be expanded to other test sections as a means for establishing spring-thaw load restrictions.

Georgia Test Section 13_7028

LTPP test section 13_7028 was a GPS-7A Existing AC Overlay of PCC site located on Interstate 85, northbound, in Franklin County, Georgia. Interstate 85 is a rural interstate principal arterial with two lanes in the direction of traffic. This section of I-85 was initially constructed in 1966 as a JPCP pavement and received an AC overlay in 1986; it was subsequently incorporated into the LTPP program in January 1987. The test section received crack sealing in 1996 and a mill and 2.5-inch overlay in July 1998, moving the test section to the GPS-7S experiment, Existing AC Overlay of PCC (with structural milling of AC overlay). Table 24 summarizes the pavement structure after the mill and overlay event in 1998.

This test section was recommended for forensic investigation in order to: (1) pursue information concerning the JPCP layer, including steel reinforcement, if any, (2) confirm the transverse and NWP longitudinal cracking on the section after the overlay was reflection cracking, (3) investigate why the IRI remained so low despite the presence of cracking (e.g., is it related to the severity level of the cracking? Is it related to steel reinforcement? etc.), and (4) explore and clarify the reason for the small quantity (19 feet) of wheel-path (WP) longitudinal cracking observed in the 2014 and 2016 distress surveys.

Table 24. Pavement structure from 1998 to present.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Coarse-Grained Soil: Clayey Sand
2	Unbound (granular) subbase	3.9	Other
3	Bound (treated) base	3.1	Asphalt Treated Mixture
4	Portland cement concrete Layer	9.1	Portland Cement Concrete (JPCP)
5	Asphalt Concrete (AC) Layer	2.6	Hot Mixed, Hot Laid AC, Dense Graded
6	Asphalt Concrete (AC) Layer	0.1	Slurry Seal[8]
7	Asphalt Concrete (AC) Layer	1.9	Hot Mixed, Hot Laid AC, Dense Graded
8	Asphalt Concrete (AC) Layer	2.5	Hot Mixed, Hot Laid AC, Dense Graded

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 13_7028 (Gardner et al., 2020c) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The desktop study was instrumental in addressing all four of the stated objectives.

[8] While the 0.1-inch layer is identified as a slurry seal in the LTPP database, it is suspected that this layer is a tack coat.

By evaluating data on InfoPave™, it was found that the PCC layer of the test section consisted of sawed transverse joints that were spaced 30 feet apart and were undoweled; no steel reinforcement was used. A lab test of a core taken in 1990 determined the compressive strength, modulus of elasticity, Poisson's ratio, and coefficient of thermal expansion of the PCC layer were 5,980 psi, 3,350,000 psi, 0.16, and 0 in/in/deg F, respectively. The presence of undoweled PCC pavement below the AC layers helped better explain the cause and location of transverse cracking on the test section. A comparison of the distress maps before and after the AC overlay in 1998 showed the transverse and NWP longitudinal cracking appeared in similar locations along the test section (approximately every 30 feet, or at the transverse joints of the PCC layer, and at the edge and along the longitudinal joint of the test section, respectively) as depicted in Figure 20 and Figure 21. This indicated the transverse cracking and NWP longitudinal cracking observed after the application of the overlay in 1998 was likely a reflection of the cracking observed before the overlay.

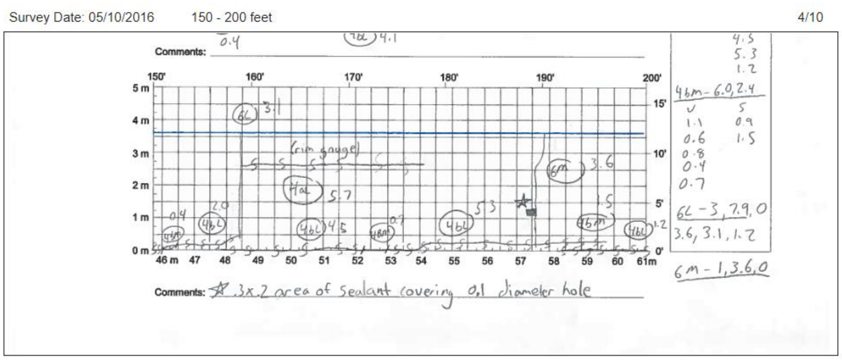

Figure 20. Map. 2016 distress survey map between sta 01+50 and 02+00.

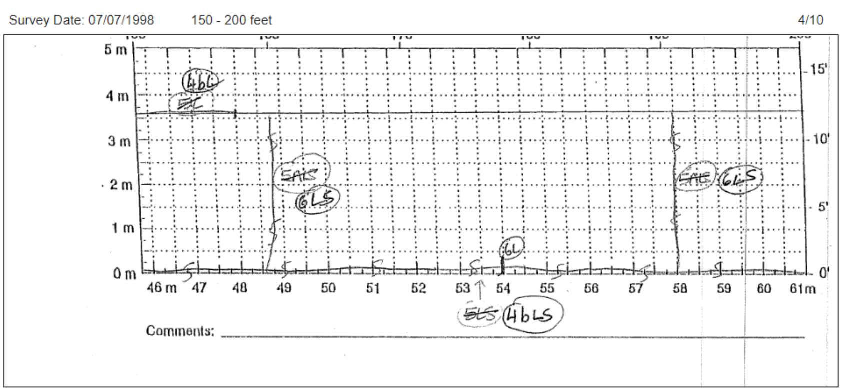

Figure 21. Map. 1998 distress survey map between sta 01+50 and 02+00.

The desktop study also explored the low IRI values on the section despite the presence of cracking and the small amount of wheel path longitudinal cracking reported in 2014 and 2016. Despite the amount of cracking observed on the section before and after the overlay in 1998, the IRI reported on the section remained relatively low. This is likely due to the type of cracking reported on the test section. Prior to and following the overlay, most of the cracking observed on the test section was low severity transverse cracking. It was also hypothesized that the underlying PCC layer contributed significantly to the smoothness of the pavement over time. In terms of the small quantity of longitudinal cracking reported inside the wheel path in 2014 and

2016, the 2014 manual distress survey revealed this "longitudinal cracking" on the WP was a result of a rim gouge rather than a typical distress mechanism. Therefore, no increase in WP longitudinal cracking was reported in 2016.

Conclusions and Recommendations

Overall, the desktop study provided sufficient information to justify the performance of the test section. Using information gathered from InfoPave™, a better understanding of the JPCP layer, the causes of the transverse and NWP longitudinal cracking following the 1998 overlay, the reasons for the low levels of IRI despite the presence of cracking throughout time, and the appearance of a small quantity of WP longitudinal cracking on the test section were explored. Based on the information gathered and analyzed in the desktop study, only closeout monitoring (not including FWD testing) and coring was recommended at this site. The coring will be used to confirm that the test section thicknesses and that the transverse and NWP longitudinal cracking reported is being reflected from the PCC joints.

Texas Test Section 48_1096

LTPP test section 48_1096 is located on U.S. 90, westbound, in Medina County, Texas. U.S. 90 is a rural principal arterial with two lanes in the direction of traffic. It was constructed in 1981 and incorporated in the LTPP program in 1987 as a GPS-1 site. The pavement structure at the time of its incorporation into the LTPP program consisted of 7.1 inches of asphalt concrete (split between three layers), 8.1 inches of unbound granular base, and 6 inches lime-treated bound subbase over a fine-grained (fat clay with sand) subgrade soil. The next significant construction event occurred in 1996, when the test section received a 0.3-inch aggregate seal coat. On May 30, 2001, the test section received an additional 0.3-inch aggregate seal coat (chip seal). Two weeks later (June 15, 2001), the test section received a 2-inch AC overlay and became a part of the GPS-6B experiment. These two construction events were combined and considered collectively as CN=3; the pavement structure of CN=3 is depicted Table 25. While the construction events described are the only events called out in the LTPP pavement history dataset, pictures and the amount of sealed cracking reported in the manual distress surveys indicated crack sealing was applied to the section prior to the March 1995, November 2013, and January 2017 distress surveys.

Since placement of an AC overlay in 2001, the test section has shown a steady increase in wheel path cracking, while at the same time maintaining an acceptable level of pavement roughness. Therefore, the objectives of the study were to examine the rapid rise in wheel path/fatigue-related cracking after the 2001 overlay, provide a history of crack sealing performed on the test section in order to update the contents of the LTPP database, and perform a comparison between pavement design model predictions and observed pavement performance.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 48_1096 (Gardner et al., 2021d) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

Table 25. Pavement structure for test section 48_1096 following CN=3.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soils: Fat Clay with Sand
2	Bound (treated) subbase	6.0	Lime-Treated Soil
3	Unbound (granular) base	8.1	Crushed Stone
4	Asphalt concrete layer	0.0	Fog Seal
5, 6 and 7	Asphalt concrete layer	7.1	Hot Mixed, Hot Laid AC, Dense Graded
8 and 9	Asphalt concrete layer	0.6	Chip Seals
10	Asphalt concrete layer	2.0	Hot Mixed, Hot Laid AC, Dense Graded

One objective of the study was to investigate the initiation and propagation of fatigue/alligator cracking on the section over time. While minimal fatigue/alligator cracking was observed prior to the overlay in 2001, following the overlay, fatigue/alligator cracking increased over time, reaching 336 ft^2 by 2017. The increase observed in fatigue/alligator cracking following the AC overlay was hypothesized to be the result of increased traffic in the early to mid-2000s, precipitation, and aging (perhaps more appropriately, oxidizing) of the AC surface layer, leading to a more brittle material prone to fatigue cracking. The desktop study also focused on better understanding the history of crack sealing performed on the test section. While only three construction events were called out in the LTPP pavement history dataset, pictures of the test section over time and the amount of sealed cracking reported in the manual distress surveys indicated crack sealing was applied to the section prior to the March 1995, November 2013, and January 2017 distress surveys. The crack sealing applied during this time likely included areas of pavement that did not have cracking, and additional investigation was recommended.

Finally, the desktop study compared the actual performance of the test section with the predicted performance using the AASHTO 1972 Interim Guide modified flexible pavement empirical design equation. Based on the reported average moduli for each layer, the number of 18-kip equivalent single axle loads (ESALs) was calculated to be 94.5 million using lab data, 311.6 million using backcalculated moduli from field data, and 17.2 million using corrected field data. Given the truck traffic observed at the test section, it appears that the pavement structure was overdesigned and that the anticipated traffic was overestimated.

To assess some of the hypotheses and findings presented in the desktop study, a follow-up investigation was conducted on the test section. Follow-up activities included manual distress and profile surveys, coring at 14 locations within the test section, and the performance of layer moduli backcalculations for all FWD data between 1990 and 2017. When arriving on site for the 2021 data collection, the LTPP DCC found that the test section had received a seal coat, which had not been reported to the DCC. A follow-up discussion with TxDOT revealed the seal coat was applied to the section in 2017. TxDOT also shared that crack-sealing occurred on test section 48_1096 in 2013, 2014, 2017, and 2021. The results of the manual distress survey also prompted further investigation of the observed wheel path cracking following the 2001 AC overlay. It was also found, using LTPPBind, that the binder was sufficient and therefore wasn't likely a significant factor in terms of the observed cracking.

Coring was also conducted as a part of the follow-up investigation. The cores showed the relative uniformity of pavement layers when compared to the thicknesses reported in the LTPP database. Layer 5 did show two areas that were thicker than reported: (1) in the mid-lane at station 100 and (2) nearly the entire width across at station 400. The cores were all in good condition with no signs of material degradation such as cracking or stripping. The backcalculated AC moduli, which used temperature-adjusted and normalized FWD data, were used to calculate the AC layer coefficient and structural numbers. The results, depicted in Figure 22, showed the AC layer coefficient was high prior to the AC overlay in 2001, but began to drop in 2011 and reached lower values in 2013 before jumping up in 2017. The results show the decreasing layer coefficient was lagging behind the development of fatigue cracking. In terms of the structural number, the results showed the effective structural number remained relatively stable pre-overlay and then hovered around 6 after placement of the overlay. Placement of the overlay has only increased the structural capacity, which would mean the cracking observed on the pavement surface is likely not full-depth structural cracking, but instead top-down cracking caused by a combination of AC oxidation, poor bonding between the overlay and the original AC surface, and the stresses resulting from tire-pavement interactions such as vehicle braking and accelerating.

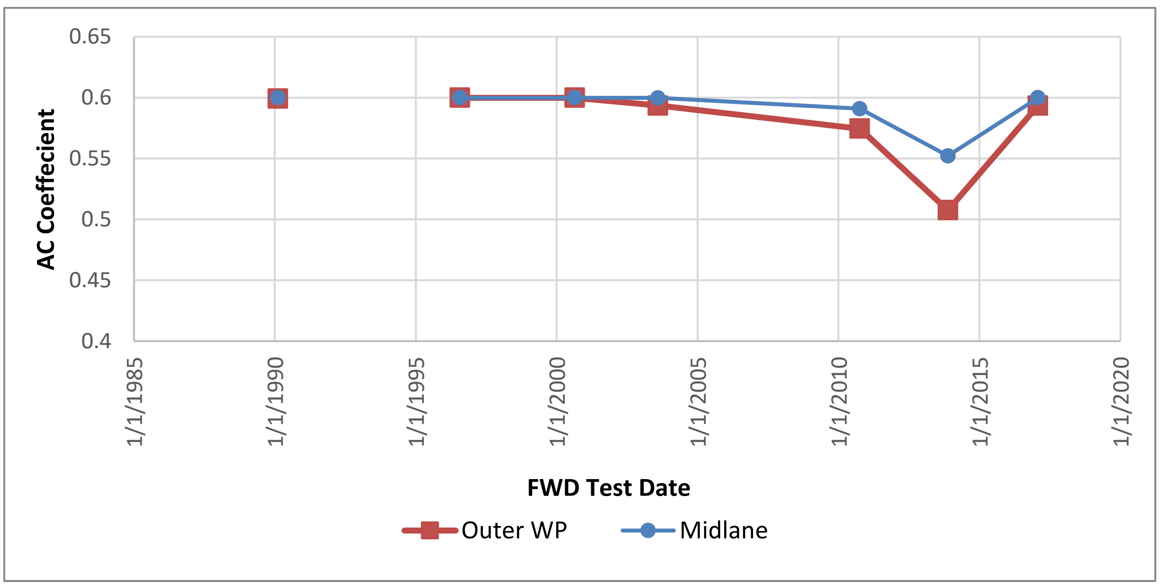

Figure 22. Chart. Average AC layer coefficient.

Conclusions and Recommendations

The analyses conducted provided insight on the test section's the performance over time, particularly with regards to wheel path cracking. In terms of the rapid rise in fatigue/alligator cracking following the AC overlay, the cracking observed was likely related to a combination of AC oxidation, poor bonding between the overlay and the original AC surface, and the stresses resulting from tire-pavement interactions such as vehicle braking and accelerating. The results of the performance prediction using the AASHTO 1972 Interim Guide, as well as the temperature-adjusted backcalculated moduli, indicated the pavement had enough structural capacity to resist the development of structural cracks. This signifies that the surface cracking observed in the overlay is unlikely to be structural cracks and is more likely to be top-down rather than bottom-up cracking. Based on the information gathered and analyzed in the desktop study and follow-up investigation and given the test section is now considered out-of-study, no further activities were recommended.

South Carolina Test Section 45_1024

Test section 45_1024 is a GPS-1 site located on State Route 1623, eastbound, in Lexington County, South Carolina. State Route 1623 is an urban collector with one lane in each direction of traffic. The test section was constructed in 1985 with no additional maintenance or rehabilitation events following the construction date; the pavement structure at the time of its incorporation into the LTPP program in January 1987 is shown in Table 26. Despite the age of the test section and its relatively thin AC layer, the test section is still active and performed well prior to 2015.

Table 26. Pavement structure for CN=1.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Coarse-Grained Soil: Clayey Sand with Gravel
2	Unbound (granular) base	4.8	Soil-Aggregate Mixture (Predominantly Coarse-Grained)
3	Asphalt Concrete (AC) Layer	1.6	Hot Mixed, Hot Laid AC, Dense Graded

In light of the performance reported prior to 2015, this test section was recommended for a forensic desktop study in order to: (1) investigate the long-term performance of the pavement structure in terms of cracking, rutting, and IRI; (2) assess pavement performance in the absence of traffic; (3) explore the initiation and propagation of the various crack types; and (4) identify those factors most responsible for the pavement performance.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 45_1024 (Gardner et al., 2020b) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The study focused on identifying the reason(s) for the good performance of the test section prior to 2015, when relatively low amounts of cracking and lower values of IRI and rutting (92 inches/mile and maximum rutting of 0.2 inches in 2014) were reported. One hypothesized reason for the good pavement performance prior to 2015 was the extremely low truck traffic observed on the test section. The site reported almost no average annual daily truck traffic (AADTT) or annual 18-kip ESALS throughout the history of the section.

The increase in reported pavement distresses following 2015 seemed to be related to an increase in precipitation on the test site in 2015. The increase, depicted in Figure 23, is likely related to a flooding event that occurred in South Carolina in early October of 2015. The flooding, which was caused in part by Hurricane Joaquin, resulted in more than 20 inches of rainfall in nearby Columbia, SC (NOAA, 2016). The high amount of precipitation observed in 2015 is likely the cause of the increased cracking and the sand deposits observed on the test section in 2016. Figure

24 provides a summary of the cracking reported on the pavement section over time with the increase starting in 2016. Despite the substantial increases in cracking along the section during this period, there was no notable increases in IRI or rutting in 2016.

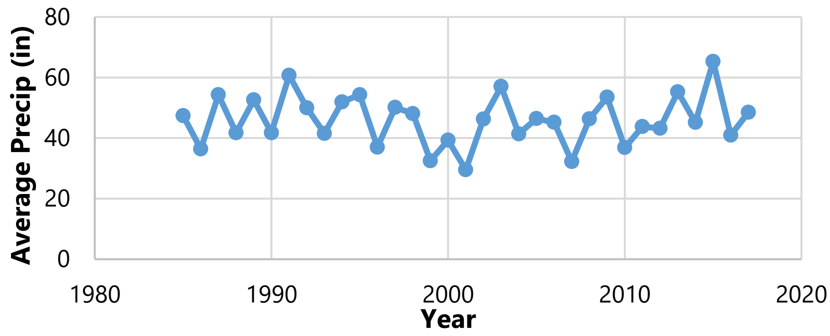

Figure 23. Chart. Average annual precipitation over time.

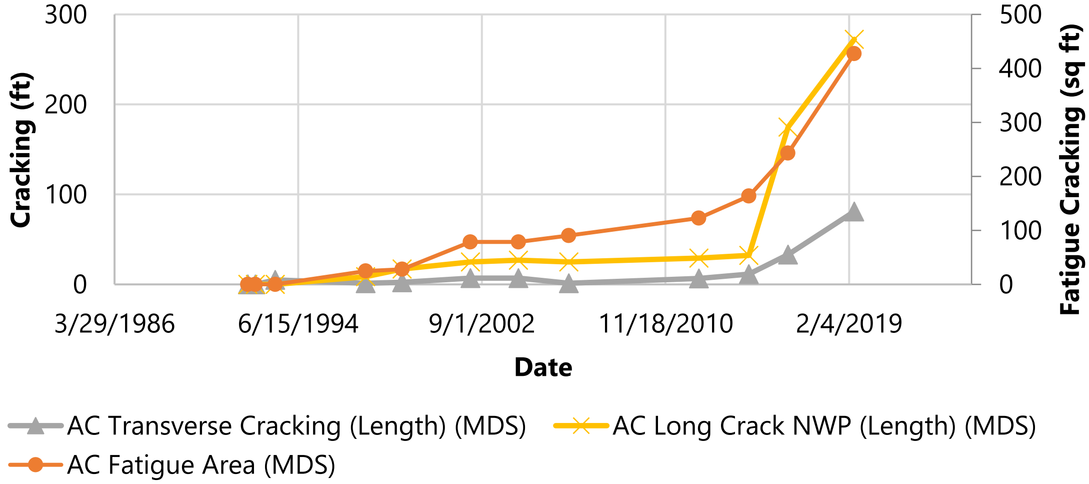

Figure 24. Chart. Time history of length of cracks.

Conclusions and Recommendations

Despite the test site having an unusually thin AC and base layer, the pavement performed well prior to 2015. The site exhibited low levels of cracking and rutting, "Fair" IRI based on FHWA performance definitions, and had consistent FWD deflections. This is likely attributed to the low levels (almost none) of truck traffic observed on the section throughout time. In 2016, following the reported increase in the average annual precipitation (65 inches in 2015), the performance of the pavement began to deteriorate more rapidly. Based on the information presented, continued monitoring and closeout coring was recommended for this site. The coring was recommended to confirm that the test section thicknesses match those reported when the test section was first incorporated into the LTPP program in January 1987. Because the test section has been categorized by LTPP as being a "long life" section, closeout monitoring is not yet planned, and the next round of monitoring is tentatively scheduled for 2021. Given the recent deterioration rates, it is hypothesized this may also serve as the closeout monitoring.

Maine Test Section 23_1028

LTPP test section 23_1028 is located on U.S. 2, eastbound, in Oxford County, Maine. U.S. 2 is a rural principal arterial with one lane in the direction of traffic. The test section was constructed in 1972 and was incorporated into the LTPP program in 1988, as part of the GPS-1 experiment. At the time of incorporation, the test section consisted of 7.1 inches of AC (over two layers) and 18.2 inches of a soil aggregate base, on a poorly graded sand with gravel subgrade. In 1992, the section received full-depth patching (CN=2), and in 1994, 22 years after it was originally constructed, the test section was overlaid with 1.9 inches of AC, moving the test section to the GPS-6B experiment. The pavement structure of the test section following the AC overlay is summarized in Table 27.

The performance of the test section has been mixed as high amounts of NWP longitudinal cracking, transverse cracking, and rutting were reported, but no fatigue/alligator cracking, wheel path longitudinal cracking, block cracking, or patching were measured after the overlay in 1994. While the IRI on the section prior to the 1994 AC overlay was close to 100 inches/mile, it decreased prior to the overlay and has remained below 80 inches/mile as of the last survey in 2016. The primary objective of this study was to determine what was driving the performance of the test section over time.

Table 27. Pavement structure for test section 23_1028 from 1994 to present (CN=3).

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Coarse-Grained Soils: Poorly Graded Sand with Grave
2	Unbound (granular) base	18.2	Soil-Aggregate Mixture (Predominantly Coarse-Grained)
3 and 4	Asphalt concrete layer	7.1	Hot Mixed, Hot Laid AC, Dense Graded
5 and 6	Asphalt concrete layer	1.9	Hot Mixed, Hot Laid AC, Dense Graded

Activities and Findings

In pursuit of the stated objectives, a desktop study of the test sections (Gardner et al., 2020d) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The study focused on understanding the test section performance, specifically prior to and following the overlay event in 1994. In the case of fatigue/alligator cracking and WP longitudinal cracking, cracking was reported prior to the overlay event, but was not observed after the overlay event. For fatigue/alligator cracking, the apparent spike in cracking prior to the overlay, which is depicted in Figure 25, was likely related to the distress collection method rather than a sudden increase in fatigue cracking—i.e., while already present, fatigue cracking was not captured using the automated method used prior to 1994. It was also hypothesized that the cause of the fatigue cracking prior to the overlay in 1994 was a result of the high levels of moisture and the freeze-thaw cycles experienced at the test section. NWP longitudinal cracking and transverse cracking were observed both prior to and following the overlay event. It appeared that NWP longitudinal cracking observed prior to the overlay was reflected onto the new overlay surface. The transverse cracking observed on the section was mostly short cracks near the edges of the lane rather than full width transverse cracks, indicating the observed transverse cracking was not likely low temperature cracking.

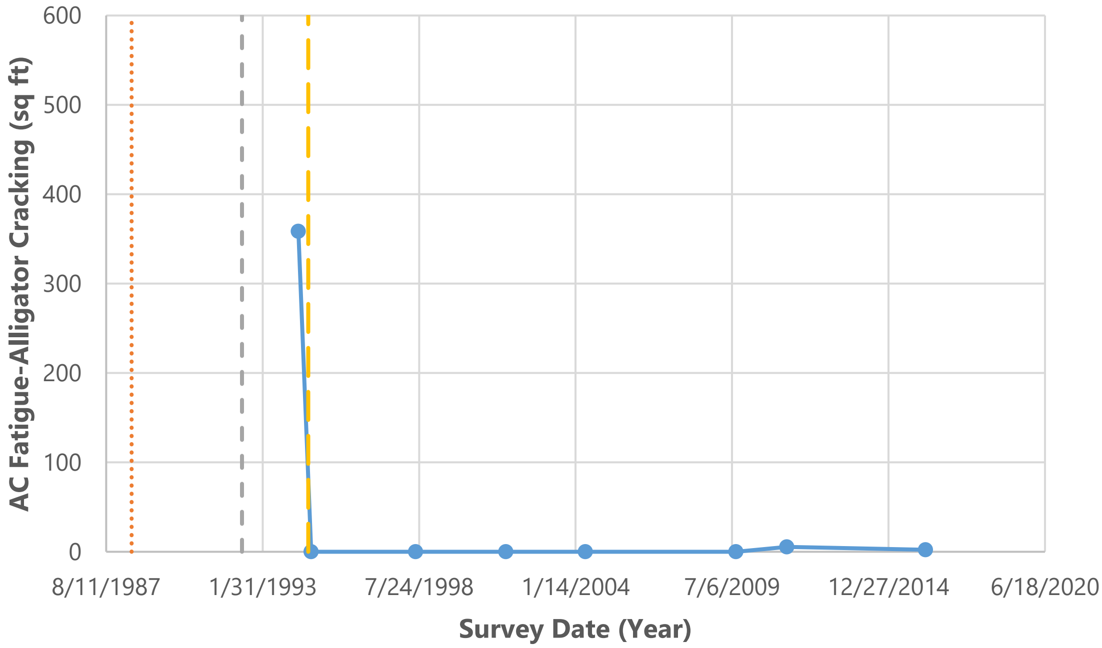

Figure 25. Time history of bottom-up cracking area on test section 23_1028.

In addition to the cracking assessment, using data from cores collected outside the section following the AC overlay, the average thickness of each pavement layer was evaluated. While there was limited variability in the thicknesses reported at each end of the section for most layers, the interlayer (Layer 5) of the overlay was reported to be 0.3 inches on one side of the test section and 3 inches on the other side of the section. Similarly, differences in layer thicknesses were also reported for the backcalculations of layer moduli of the section. The thicknesses used in the backcalculations varied from the reported layer thicknesses of the test section due to a lack of reasonable results (e.g., low RSME) when using the reported layer thicknesses. In both cases, further information on these differences in thicknesses was recommended to be pursued.

Conclusions and Recommendations

Overall, the desktop study was able to provide insight on the performance of the test section both prior to and following the AC overlay. From a review of the distress and coring information collected on the site, it was found that the AC overlay was effective in reducing the amount of fatigue/alligator and WP longitudinal cracking observed on the test section. For NWP longitudinal cracking and transverse cracking, while the overlay reduced the amount of cracking reported in the short-term, both cracking types increased over time following the overlay. In the case of NWP longitudinal cracking, it appeared that some cracking reported prior to the overlay event was reflected to the AC overlay layers. Additionally, the desktop study also revealed that, based on cores collected directly outside the test section, the layer thicknesses outside of the test section outside varied. Based on the desktop study, closeout monitoring and coring were recommended to help confirm some of the hypotheses raised during the study. However, it was found that an ultra-thin wearing course had been applied to the section since the 2016 manual distress survey and therefore, additional follow-up activities could not be pursued.

Utah Test Sections 49_708*

Test sections 49_7082 and 49_7086 are and test section 49_7085 was located near Salt Lake City; test section 49_7082 is located on Interstate 15, northbound, in Box Elder County, Utah, test section 49_7085 was located on U.S. 40, eastbound, in Wasatch County, Utah, and test section 49_7086 is located on State Route 154, southbound, in Salt Lake County, Utah. Each test section was accepted in the LTPP program as a part of the GPS-3 study in 1990 (test 49_7082) or 1991 (test sections 49_7085 and 49_7086). The pavement structures of the test sections were similar. Both test section 49_7082 and 49_7085 consist or consisted of 9.8 inches of Portland Cement Concrete (PCC), 4.2 inches of lean concrete base, 4 inches of crushed gravel unbound granular subbase, 18 inches of unbound soil-aggregate mixture granular subbase, and a clayey gravel with sand subgrade. Test section 49_7086 consists of 10.1 inches of PCC, 5.4 inches of lean concrete base, 16 inches of unbound soil-aggregate mixture granular subbase (over two layers), 0.5-inch non-woven geotextile, 12 inches of crushed gravel unbound granular subbase, 0.1-inch woven geotextile, and a clayey gravel with sand subgrade. While each section reported additional construction events over time, none of the events changed the overall structure of the test sections. Test section 49_7085 was taken out-of-study in 2017, while test sections 49_7082 and 49_7086 are considered long life sections and are therefore still active.

The test sections were selected for forensic investigation, as each undoweled JPCP section was incorporated into the LTPP program between 1990 and 1991 yet were located in areas with varying climatic and traffic characteristics. The investigation was therefore focused on comparing the performance between each test section and identifying factors driving the differences in the performance measures.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test sections 49_7082, 49_7085, and 49_7086 (Gardner et al., 2020g) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (longitudinal cracking, transverse cracking, patching, corner breaks, IRI, faulting, and wheel path surface wear) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study revealed test section 49_7085 performed the worst of the three test sections for most performance metrics, as summarized in Table 28. This seems to be largely attributed to two of the climatic factors reported at this test section (annual precipitation and freezing index), which were notably higher than the other test sections. These factors likely contributed to higher amounts transverse cracking and patching. Test sections 49_7082 and 49_7086 overall reported similar performance. However, the faulting on test section 49_7086 was notably worse than section 49_7082, which resulted in higher IRI on test section 49_7086. It was hypothesized the higher amount of faulting was due to higher temperatures at test section 49_7086, but it could also be related to other factors such as ambient conditions at the time the test section was constructed or temperature conditions at the time faulting and IRI measurements were made (i.e., warping and curling of the slabs, etc.).

Based on this desktop study, it appears that differences in the performance of the three sections was largely driven by environmental factors, while the remaining factors do not appear to have contributed substantially. Test section 49_7085 had the worst performance in terms of longitudinal cracking, transverse patching, corner breaks, and wheelpath surface wear, and this performance appears to be driven by the significantly higher precipitation and freezing index at the site. While test section 49_7086 had the worst faulting and IRI, with higher temperatures apparently driving the higher faulting levels, which in turn affected the IRI values.

Table 28. Summary of performance metrics for test sections 49_7082, 49_7085, and 49_7086.

Performance Metrics	Values for test section 49_7082	Values for test section 49_7085	Values for test section 49_7086
Max. Measured Deflection, mils	4.6	7.7	5.4
Max Longitudinal Cracking Value, ft	0	681	0
Max Transverse Cracking Value (count)	3	47	0
Max Transverse Cracking Value (length, ft)	15	260	0
Max Patching Value (count)	0	20	3
Max Patching Value (area, ft^2)	0	1,944	5
Max Corner Breaks	0	2	0
Max Average IRI Value, in/mile	100	151	228
Max Faulting Value, in	0.10	0.09	0.14
Wheelpath surface wear, in	0.12	0.24	0.2

While the desktop study helped underscore the key differences in the performance of each of the test sections, it also raised questions about the reported data in the LTPP database. Specifically, the desktop study revealed discrepancies 1) between the construction events reported in the LTPP database and the actual work done on test sections 49_7082 and 49_7086 and 2) in the labelling of 49_7086 as a Dry climate site in the LTPP database even though the reported precipitation at this section indicated it was a Wet climate site. To pursue additional information on these issues, a follow-up investigation focused on identifying, correcting, and explaining the construction history and climate classification of the test sections was conducted. Based on the knowledge and documentation of Utah DOT staff, industry, and regional contractors, it was found the actual construction history of test sections 49_7082 and 49_7086 deviated from what was reported in the LTPP database and was updated accordingly. The updated construction history helped better explain the performance of test section 49_7086—particularly with regards to the IRI and faulting observed on the section over time. Additionally, further information on why test section 49_7085 was classified as "Dry," given the precipitation reported on the section, was pursued. It was found that in the current LTPP dataset, climate classifications are based on the location of the section rather than the average annual precipitation or freezing index at the test site. However, starting with the 2021 LTPP data release, an updated climate classification methodology, which will use the average annual precipitation of a test section based on MERRA data, will be implemented. Using the new classification methodology, test section 49_7085 will be classified as being in a "Wet" region.

Conclusions and Recommendations

Overall, the desktop study and follow-up investigation provided information on the reasons for the differences in the performances of the three undoweled JPCP test sections. The desktop study showed that differences in the performances of the three sections was largely driven by environmental factors. Therefore, test section 49_7085, which reported high values for its annual precipitation and freezing index, performed the worst of the three sections. The follow-up investigation helped correct the construction history and climate classification of the test sections, which further explained the performance of each of the test sections over time. Sufficient information was available to adequately explain the observed performance of the pavement test sections. However, as both test section 49_7082 and 49_7086 are considered long life test sections, continuous monitoring of these test section is recommended.

Maryland Test Section 24_1634

LTPP test section 24_1634 was located on State Route 90, eastbound, in Worcester County, Maryland. State Route 90 is a rural principal arterial with one lane in the direction of traffic. The test section was constructed in 1976 and was accepted into the LTPP Program as part of the GPS-2 experiment in November 1988. The site received a shoulder restoration and a 3.2-inch AC overlay in May 1998, moving to the GPS-6C study. Table 29 summarizes the pavement structure following the overlay, which corresponds to CN=2. The test section was found to be milled and overlaid sometime after the last survey date in 2016, and therefore, the site is now considered out-of-study.

Table 29. Pavement structure for test section 24_1634 following CN=2.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soil: Silt
2	Unbound (granular) subbase	13	Soil-Aggregate Mixture (Predominantly Coarse-Grained)
3	Unbound (granular) subbase	4	Fine-grained Soils
4	Bound (treated) base	4.8	Sand Asphalt
5	Asphalt Concrete (AC)	3.5	Hot Mixed, Hot Laid Asphalt Concrete (AC), Dense Graded

Layer Number	Layer Type	Thickness (in.)	Material Code Description
6	Asphalt Concrete (AC)	1.7	Recycled AC, Hot Laid, Central Plant Mix
7	Asphalt Concrete (AC)	1.5	Hot Mixed, Hot Laid AC, Dense Graded

The site was also included in the LTPP Seasonal Monitoring Program (SMP) between 1994 and 1998. As part of the SMP, the section was instrumented with an on-site weather station, along with subsurface temperature, moisture, frost detection, and water table depth sensors. The collection of FWD measurements and the downloading of the climatic information were performed monthly, and collection of longitudinal profile measurements were conducted quarterly. Given the frequency of data collection and the types of data available at this site, a forensics investigation was recommended to examine 1) the reason(s) for high amounts of fatigue/alligator and NWP longitudinal cracking following the AC overlay of the test section, 2) the reason(s) for the extremely low IRI on the pavement section despite the presence of cracking throughout time, and 3) the relationship between the pavement deflection, pavement temperature, and subgrade moisture content using the SMP dataset.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 24_1634 (Gardner et al., 2020e) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The study focused on using this data and the SMP dataset to better characterize the performance of the test section over time.

Utilizing data collected during the SMP analysis period, an assessment of the change in pavement deflection over time with regards to pavement temperature and subgrade moisture content was conducted. As depicted in Figure 26, increases and decreases in deflections under the center load plate typically corresponded to increases and decreases in the pavement temperature and subgrade moisture content. The change in deflection 48 inches from the load plate (Sensor 7) appeared to be related to the change in moisture content over time, but less so to the change in pavement temperature over time.

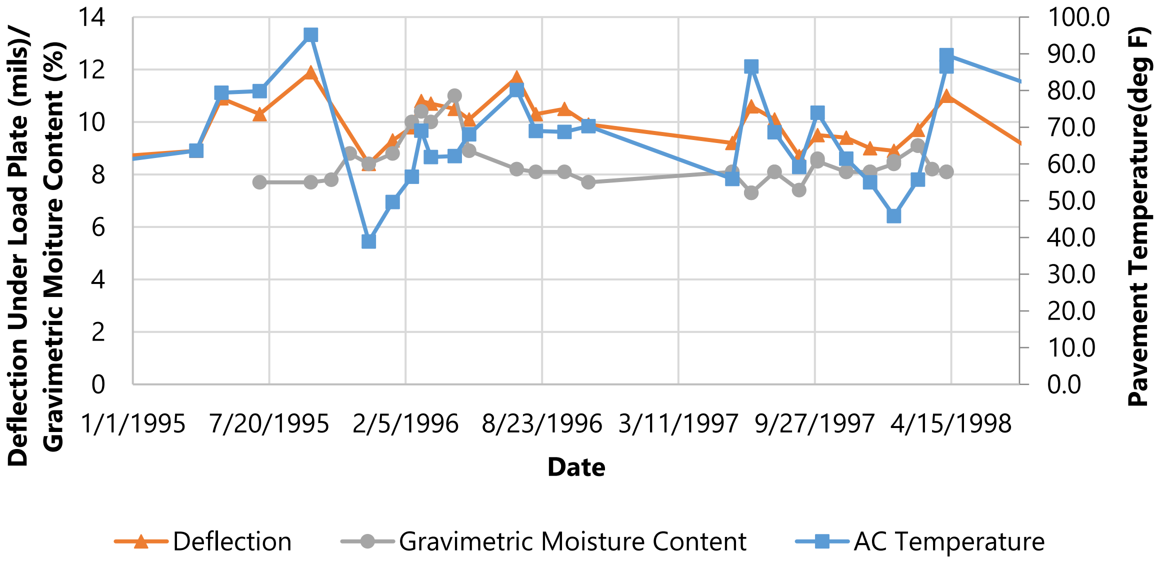

Figure 26. Comparison of FWD deflections, average pavement temperature 0.98 inches below surface, and gravimetric moisture content 26 inches below surface.

Based on these findings, a regression analysis was performed to statistically relate variations in deflection to the changes in both the referenced variables and the test section age. Ultimately, the regression analysis yielded the model shown in Figure 27 to predict pavement deflection (mils) based on pavement temperature (°F), subgrade moisture content (%), and measurement position (0 under the center of load plate or 1 at 48 inches from the center of the load plate). The relationship between the predicted deflection values from the model and the actual deflected values showed a strong correlation, with a coefficient of determination (R^2) of 0.99.

$$\begin{aligned}\text{Deflection} = {} & 10.02 + 0.06 * (\text{Temperature} - 66.13) + 0.37 * (\text{Moisture Content} - 8.53) \\ & - 8.59 * \text{Position} - 0.07 * (\text{Temperature} - 66.13) * \text{Position} - 0.27 \\ & * (\text{Moisture} - 8.53) * \text{Position}\end{aligned}$$

Figure 27. Equation. Deflection predictive model for test section 24_1634.

In addition to studying the role of climatic factors on the reported pavement deflections, the cause(s) of the high amounts of fatigue/alligator and NWP longitudinal cracking and the low amount of IRI on the pavement section despite the presence of cracking throughout time were also explored. The increase in fatigue/alligator and NWP longitudinal cracking following the overlay in 1998 seemed to be related to pavement aging and overall structural degradation. The original structure of the pavement was constructed in 1976 and therefore likely had been experiencing increased cracking due to long-term environmental exposure and traffic loading. Another potential reason for the increase in cracking following the overlay in 1998 was the slightly increased levels of precipitation following the overlay. The low levels of IRI reported seemed to be a result of the severity of cracking observed throughout time. As the severity level of the cracking reported was predominantly low, the impact of the cracking observed on IRI was correspondingly low.

Conclusions and Recommendations

Through the desktop study, the average deflection of the test section during the SMP analysis period was reviewed to associate deflections with climate changes related to seasonal temperature and moisture fluctuations. Statistical analysis revealed a clear relationship between the pavement deflection (mils) and pavement temperature (°F), subgrade moisture content (%), and measurement position (0 under the center of load plate or 1 at 48 inches from the center of the load plate). Additionally, the desktop study was used to assess and hypothesize the reason(s) for the high amounts of fatigue/alligator cracking and NWP longitudinal cracking as well as the low levels of IRI despite the amount of cracking observed on the section throughout time. While the test section was reported as active when it was initially nominated for investigation, this test section was found to have been milled and overlaid when preparing to schedule the field evaluation. For this reason, while coring on this section would have been useful for further analysis, no follow-up field investigations were recommended for this test section.

Indiana Test Section 18_1037

Test section 18_1037 was located on State Route 66, eastbound, in Spencer County, Indiana. State Route 66 is a rural minor arterial with one lane in the direction of traffic. The test section was constructed in 1983 and was accepted into the LTPP Program as part of the GPS-1 experiment in January 1987. The test section subsequently received a mill and a 2.4-inch AC overlay in September 1994 (moving the section to the GPS-6S experiment), a 1.5-inch overlay in May 2003 (moving the section into the GPS-6D experiment), and crack sealing in June 2000 and June 2014. The test section was found to be milled and overlaid sometime after the last survey date in 2016, and therefore, the site has been placed out-of-study. Table 30 shows the pavement structure following the final overlay event in 2003 (CN=4).

Despite the low levels of truck traffic observed on the test section and the additional structural capacity provided by AC overlays in September 1994 and May 2003, the test section reported relatively high levels of rutting from 1987 to present, an increase in cracking (fatigue/alligator and NWP longitudinal) following the second overlay in 2003, and relatively low FWD deflections and IRI. In light of this, the test section was recommended for investigation in order to: 1) explore the cause(s) of the rutting depths observed, particularly prior to the first overlay in 1994, 2) examine the reason(s) for increased cracking following the second overlay in 2003, and 3) further explore the reason(s) for the performance of the pavement in terms of low deflections and IRI.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 18_1037 (Gardner et al., 2020f) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The focus of the desktop study was on examining the causes of the rutting depths, cracking, deflections, and IRI observed over time.

Table 30. Pavement structure for test section 18_1037 following CN=4.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soil: Silt

Layer Number	Layer Type	Thickness (in.)	Material Code Description
2	AC-Asphalt concrete layer	4.3	Hot Mixed, Hot Laid AC, Dense Graded
3	AC-Asphalt concrete layer	7.4	Hot Mixed, Hot Laid AC, Dense Graded
4	AC-Asphalt concrete layer	2.3	Hot Mixed, Hot Laid AC, Dense Graded
5	AC-Asphalt concrete layer	0	Hot Mixed, Hot Laid AC, Dense Graded
6	AC-Asphalt concrete layer	0.7	Hot Mixed, Hot Laid AC, Dense Graded
7	AC-Asphalt concrete layer	1.7	Hot Mixed, Hot Laid AC, Dense Graded
8	AC-Asphalt concrete layer	1.5	Hot Mixed, Hot Laid AC, Dense Graded

Prior to the first overlay in 1994, the rutting on the test section was extremely high, with an average reported rut depth of 0.51 in, despite having a relatively thick pavement structure (14.7 in of AC over 4 layers). Following the mill and overlay in 1994, the average rut depth dropped to 0.04 in. This decrease in rutting following the overlay, while expected to a smaller extent, was notable. Based on the decrease and further assessment of the rutting, it was hypothesized that the rutting observed prior to 1994 was effectively removed during the mill and overlay event in 1994, leading to lower rutting values following this event.

Another objective of the desktop study was to assess the cause(s) of the increase in both fatigue/alligator cracking and NWP longitudinal cracking following the second AC overlay in 2003. As shown in Figure 28, while there was little-to-no fatigue/alligator cracking prior to the mill and overlay in 1994 and the overlay in 2003, starting in 2009, fatigue/alligator cracking propagated at a rate of 82.7 ft^2/year. Similarly, for NWP longitudinal cracking, while cracking was reported prior to the overlay in 2003, the cracking reported after the overlay was greater in length. The increase in the cracking was likely related to a combination of aging/structural deterioration of the pavement section over time and the increased levels of precipitation during this period, particularly in 2011 when 75 inches of precipitation was recorded in the area.

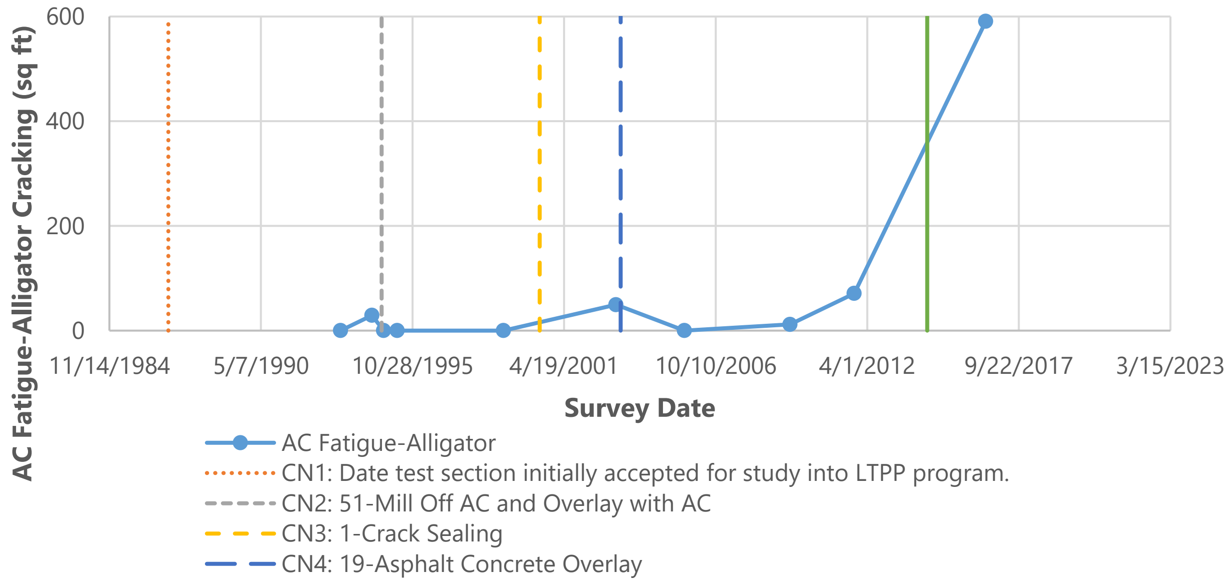

Figure 28. Chart. Time history of fatigue cracking on test section 18_1037.

The deflections and IRI reported on the test section over time were also investigated in the desktop study. The deflections reported on the test section were relatively low, ranging from 3.9 mils (1993) to 6.1 mils (2005), which correlates with the substantial overall thickness of the AC layers. The low levels of IRI reported on the section did not seem to be correlated to the cracking reported on the section throughout time; while there were low IRI values reported on the test section, there was significant cracking observed. This may be related to the severity of the cracking observed on the section—predominantly low and medium—which plays less of a role in the roughness of the test section. Additionally, since the initial IRI of the test section (at the time of its incorporation in the LTPP program in 1987) is unknown, it is also possible the initial roughness or IRI of the test section was not as smooth as the IRI measured after the two overlay events.

Conclusions and Recommendations

The performance of test section 18_1037 was largely affected by the timing of its treatments, overall pavement thickness, and the precipitation reported on the test section. The rutting observed on the test section sharply decreased after the mill and overlay in 1994, likely because the rutting observed prior to that was effectively milled during the construction event. The increase in cracking following the overlay event in 2003 was hypothesized to be related to a combination of aging/structural deterioration and increase in levels of precipitation. Finally, the low deflection and IRI values reported on the section over time seemed to be related to the substantial thickness of the AC layers and the low severity of cracking and initial roughness of the test section when first constructed in 1983, respectively.

While the test section was reported as active when it was initially nominated for investigation, the test section was found to have been milled and overlaid when preparing to schedule the field evaluation. Therefore, no follow-up field investigations were suggested. Instead, it was recommended that the FHWA LTPP Team investigate the differences in the reported layer thickness and the thicknesses used for backcalculations for the section, reasons for the mill and overlay in 1994 and overlay in 2003, and the reason for the slowed increase in IRI after 2003 (as there may have been an unreported M&R event between 2003 and 2008).

Pennsylvania Test Section 42_1597

LTPP test section 42_1597 is located on State Route 49, eastbound, in Tioga County, Pennsylvania. State Route 49 is a rural minor arterial with one lane in the direction of traffic. The test section was constructed in 1980 and was accepted into the LTPP Program as part of the GPS-1 experiment in August 1988. The pavement structure at the time of its incorporation into the LTPP program consisted of 6.5 inches of asphalt concrete (split between two layers) and 16.8 inches of unbound granular base over a fine-grained subgrade soil. The next major construction event occurred in July 2000, when the test section received a shoulder restoration and a 1.5-inch mill and 6.6-inch AC overlay (over three layers with three different mix types), moving the test section to the GPS-6S experiment. An additional construction event in June 2015 (CN=8), a slurry seal, also resulted in a 0.3-inch increase to the pavement structure as shown in Table 31. Other minor construction events that occurred over time on the test section included crack sealing in June 1990 (CN=2), June 1996 (CN=3), May 1999 (CN=5), June 2011 (CN=7), and June 2019 (CN=9) and patching in August 1997 (CN=4). Additionally, it is important to note, while not changing the overall pavement structure, rumble strips were placed in the centerline of the roadway sometime between 2003 and 2007.

Table 31. Pavement structure for test section 42_1597 following CN=8.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Fine-Grained Soils: Gravelly Lean Clay
2	Unbound (granular) base	16.8	Gravel (Uncrushed)
3	AC-Asphalt concrete layer	5	Hot Mixed, Hot Laid AC, Dense Graded
4	AC-Asphalt concrete layer	0	Hot Mixed, Hot Laid AC, Dense Graded
5	AC-Asphalt concrete layer	2.2	Hot Mixed, Hot Laid AC, Dense Graded
6	AC-Asphalt concrete layer	2.5	Hot Mixed, Hot Laid AC, Dense Graded
7	AC-Asphalt concrete layer	1.9	Hot Mixed, Hot Laid AC, Dense Graded
8	AC-Asphalt concrete layer	0.3	Slurry Seal

The overlay event in 2000, which occurred approximately 20 years after the construction of the pavement section, provided an opportunity to assess and compare the condition and performance of the pavement prior to and following the rehabilitation. Therefore, the objectives of the study were to investigate the cause(s) of the fatigue cracking following the mill and overlay in 2000, whether any of the cracking observed prior to the mill and overlay (specifically longitudinal and transverse cracking) was reflected following the mill and overlay, the cause(s) of the high IRI and rutting values (256 in/mi and 0.31 in, respectively, in 2000) prior to the mill and overlay event which did not reoccur following the overlay, and the differences in the initiation and propagation of cracking prior to and following the mill and overlay.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 42_1597 (Gardner et al., 2021c) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021). The study focused on better understanding and comparing the performance of the test section prior to and following the overlay event in 2000.

One distress warranting particular attention over the performance period of the test section was fatigue/alligator cracking; fatigue/alligator cracking on the test section was not significant until after the mill and overlay in 2000. The increase in the fatigue/alligator cracking after the mill and overlay was likely related to a combination of environmental and structural factors. Specifically, it was hypothesized that an increase in precipitation following the overlay, increased loading on the test section over time during thaw periods (when the base layer is weakened), and the bond (or lack thereof) between the AC mixes used for the overlay may have played a role in the increase of fatigue/alligator cracking observed.

NWP longitudinal cracking was predominantly found on the centerline (between the section lane and the lane in the opposite direction) prior to the mill and overlay event in 2000 and on both the centerline and edge of the lane following the 2000 mill and overlay. Given the location of the cracking, it was hypothesized that the propagation of the NWP longitudinal cracking was construction related. Unlike the NWP longitudinal cracking, the location of the transverse cracking before and after the overlay was not consistent as depicted in Figure 29 and Figure 30.

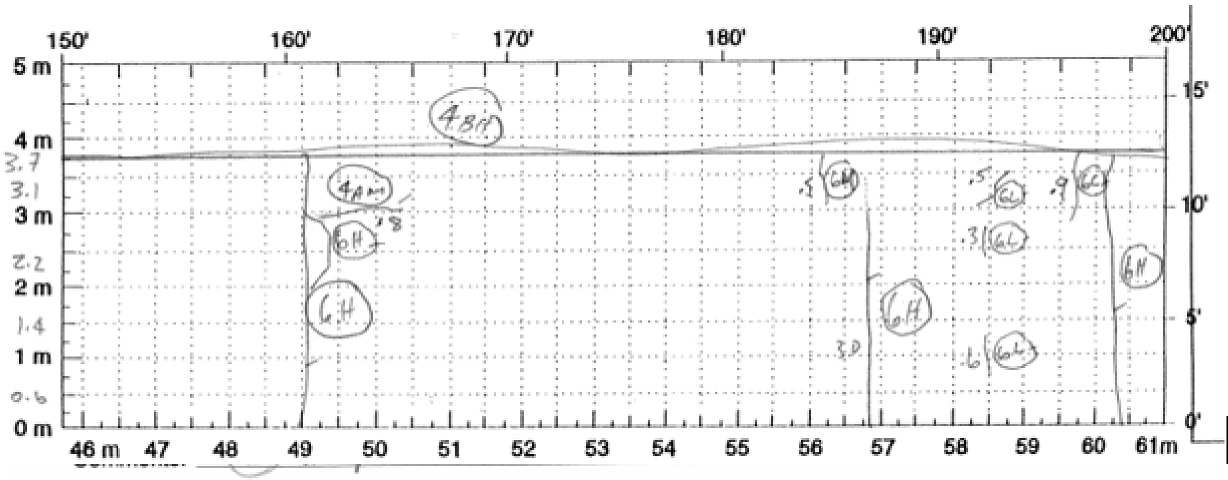

Figure 29. Map. April 2000 distress survey showing transverse cracking before overlay.

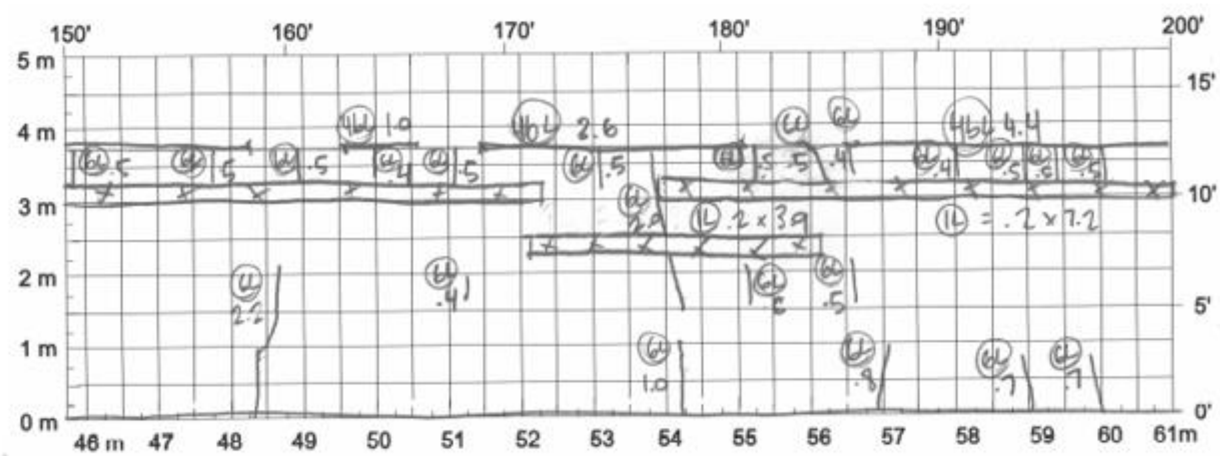

Figure 30. Map. June 2016 distress surveys showing transverse cracking after overlay.

The IRI reported on the section did not correlate to the cracking reported following the mill and overlay; the predominant cracking types that purportedly affect the overall IRI of the test section—fatigue/alligator and transverse cracking—were present in equal or higher quantities following the mill and overlay in 2000 than prior to the overlay event despite the lower average IRI reported following the overlay. This was likely the result of the low-severity cracking reported following overlay and the initial smoothness of the roadway during incorporation into the LTPP program which would affect the deterioration of smoothness prior to the overlay. The rutting reported on the section prior to the mill and overlay in 2000 increased from 0.16 in in 1989 to 0.28 in in 2000, and following the mill and overlay in 2000, the average rut depth dropped before increasing at a rate of 0.01 in/year between 2000 and 2016. It is hypothesized that the majority of the rutting observed prior to 2000 occurred within the top 1.5-inch AC layer (which was removed during the mill and overlay event in 2000, leading to lower rutting values following the overlay).

Based on the findings and recommendations of the desktop memorandum, a follow-up investigation was conducted on the test section. The follow-up investigation focused on assessing the 2020 data collected on the test section and gaining additional insight on the test section via an interview conducted with PennDOT personnel. The key findings from the follow-up investigation supported some of the hypotheses presented in the desktop study. With regards to the fatigue/alligator cracking observed on the test section following the 2000 mill and overlay, PennDOT suggested that it may have been a result of the way in which the AC overlay was constructed. During the time of the overlay, there was no tack coat applied between AC overlay layers (although there was between the original surface and the first overlay layer), which could have resulted in the overlay layers acting independently (and therefore, creating a much weaker pavement structure) and caused the propagation of fatigue/alligator cracking on the test section. Furthermore, the oxidation of the 0.5-inch wearing course could have also contributed to the increase in cracking observed. PennDOT later changed their specifications to use a 0.375-inch wearing course because of this issue. NWP longitudinal cracking may have been caused by two issues: 1) the paver dragging material under the gear box, and 2) the use of notch wedge joints. In response to these issues, PennDOT now uses overband joints and density specifications at the joints.

Conclusions and Recommendations

Through the desktop study and follow-up investigation, the performance of the test section prior to and following to the 2000 mill and overlay event was assessed. The findings, which are summarized above, were supported by the environmental and structural conditions of the test section; a combination of an increase in precipitation, an increase in ESALs, freeze-thaw, the material properties, and construction practices used for the AC layers in the overlay are hypothesized to have affected the performance of the pavement following the mill and overlay event.

Although the test section was considered active at the time it was recommended for a desktop study, closeout monitoring occurred on the test section in September 2020. Therefore, the section is anticipated to officially go out-of-study soon. As such, coring within the section was recommended to confirm the thicknesses of the layers of the test section, to investigate whether any of the cracking observed was reflection cracking, to identify issues with bonding between AC layers, and to investigate the layers contributing to rutting on the test section.

Minnesota Test Section 27_6251

LTPP test section 27_6251 was located on U.S. Route 2, westbound, in Beltrami County, Minnesota. U.S. Route 2 is a rural principal arterial with two lanes in the direction of traffic. The test section was constructed in September 1981 and was accepted into the LTPP Program as part of the GPS-1 experiment in January 1987. The pavement structure at the time of its incorporation into the LTPP program consisted of 7.4 inches of dense-graded asphalt concrete (AC) and 10.2 inches of unbound (granular) base over a coarse-grained subgrade layer. The next construction event occurred in June 1998, when the test section received a 1.6-inch mill and a 3.4-inch AC overlay, moving it to the GPS-6S AC Overlay of Milled AC Pavement Using Conventional or Modified Asphalt study. The pavement structure of the test section following the mill and overlay event is depicted in Table 32. Additional construction events that occurred on the site included crack sealing in both June 2001 and June 2015 (CN=3 and CN=4) and skin patching in June 2016 (CN=5). The test section was found to be milled and overlaid sometime after the last survey date in 2017, and therefore, the site has been placed out-of-study.

Table 32. Pavement structure for CN=2 at test section 27_6251.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	SI	Coarse-Grained Soils: Poorly Graded Sand with Silt
2	Unbound (granular) subbase	10.2	Gravel (Uncrushed)
3	Asphalt concrete layer	5.8	Hot Mixed, Hot Laid AC, Dense Graded
4	Asphalt concrete layer	3.4	Recycled AC, Hot Laid, Central Plant Mix

This site was also included in the LTPP Seasonal Monitoring Program (SMP) between 1993 and 2003. As part of the SMP, the section was instrumented with an on-site weather station, along with subsurface temperature, moisture, frost detection, and water table depth sensors. The collection of FWD measurements and the downloading of the climatic information were performed monthly, and data collection of profile measurements was conducted quarterly. Given the frequency of data collection and the types of data available at this site, a forensics investigation was recommended to examine the relationship between pavement deflection, pavement temperature, and subgrade moisture content, the cause(s) for the reduction in the reported fatigue cracking area between 2015 and 2016, whether any of the NWP longitudinal cracking or transverse cracking observed prior to the mill and overlay was reflected following the mill and overlay, and the reason(s) for the extremely low IRI on the pavement section following the overlay despite the presence of cracking throughout time.

Activities and Findings

In pursuit of the stated objectives, a desktop study of test section 27_6251 (Gardner et al., 2020h) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

From the data collected during the SMP analysis period, an assessment of the change in pavement deflection over time with regards to pavement temperature and subgrade moisture content was conducted. As depicted in Figure 31, the change in deflection under the load plate over time appeared to be directly related to the change in pavement temperature over time. For the most part, increases and decreases in deflections corresponded to increases and decreases in the pavement temperature. The relationship between the change in deflection measured at the farthest sensor from the load plate did not show a clear correlation to either temperature or moisture.

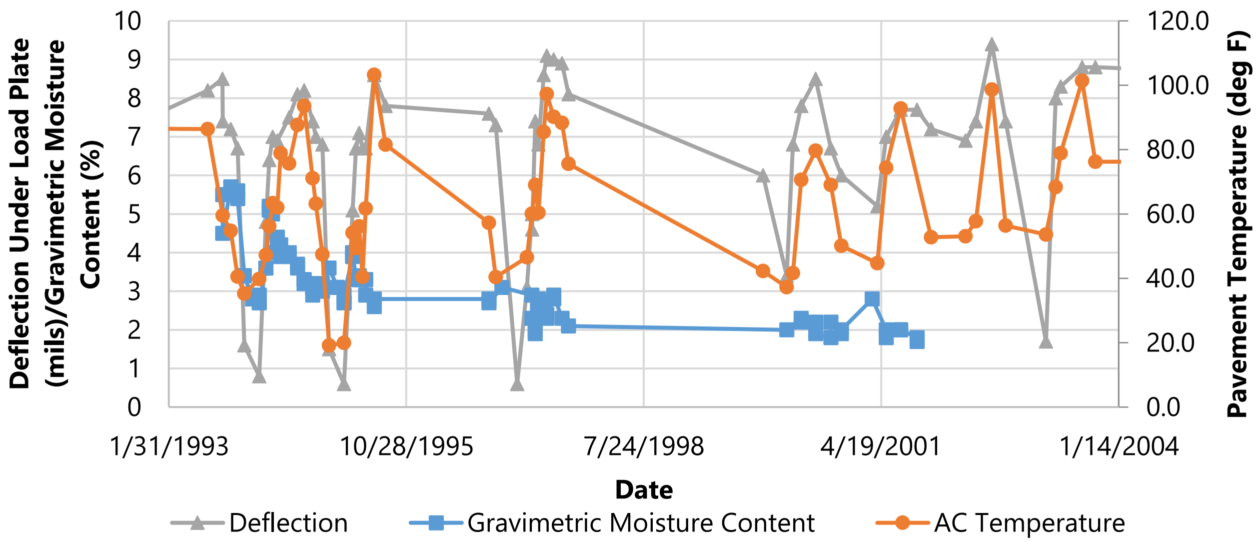

Figure 31. Chart. Comparison of FWD deflections, average pavement temperature 1-inch below surface, and gravimetric moisture content at 24 inches below surface.

As an extension of the investigation, a regression analysis was performed to statistically relate variations in deflection to the changes in both the referenced variables and the test section age. Ultimately, the regression analysis yielded the model shown in Figure 32 to predict pavement deflection (mils) based on pavement temperature (°F), subgrade moisture content (%), and measurement position (0 under the center of load plate or 1 at 60 inches from the center of the load plate). The relationship between the predicted deflection values from the model and the actual deflected values showed a strong correlation, with a coefficient of determination (R^2) of 0.92.

$$\text{Deflection} = 6.78 + 0.087 * (\text{Temperature} - 64.42) + 0.45 * (\text{Moisture} - 3.43) - 5.76 * \text{Position} - 0.084 * (\text{Temperature} - 64.42) * \text{Position} - 0.41 * (\text{Moisture} - 3.43) * \text{Position}$$

Figure 32. Equation. Deflection predictive model for test section 27_6251.

In addition to studying the role of climatic factors on the reported pavement deflections, the cause(s) for the reduction in the reported fatigue cracking area between 2015 and 2016, whether any of the non-wheel path longitudinal cracking or transverse cracking observed prior to the mill and overlay was reflected following the mill and overlay, and the potential reason(s) for the extremely low IRI on the pavement section following the overlay despite the presence of cracking throughout time were explored.

Conclusions and Recommendations

Overall, the desktop study examined the relationship between pavement deflection, pavement temperature, and subgrade moisture content. In addition to studying the role of climatic factors on the reported pavement deflections, the following conclusions were drawn:

- The drop in fatigue/alligator cracking in 2016 was likely due to the combination of the differences in rater opinions between the 2015 and 2017 surveys and the effects of the skin patching that occurred in 2016 (CN=5).

- The NWP longitudinal cracking reported prior to the mill and overlay was predominantly located on the edge of the lane and between the wheel paths. After the overlay, the cracking was predominantly observed on the edge and centerline of the lane. Given the cracking location, it was hypothesized that the propagation of the NWP longitudinal cracking was construction-related (rather than reflection cracking). In terms of transverse cracking, based on the location of the cracking observed prior to and following the overlay event, it was hypothesized that transverse cracking prior to the overlay likely reflected to the overlay surface.
- The IRI reported on the section did not seem to be correlated to the fatigue cracking reported throughout time; while there was low IRI values reported on the test section following the mill and overlay in 1998, there was significant cracking observed. This may be related to the severity of the cracking observed on the section—predominantly low and medium—and the lower amounts of transverse cracking reported after the mill and overlay.

While the test section was reported as active when it was initially nominated for investigation, this test section was found to have been milled and overlaid following the 2017 monitoring. For this reason, no follow-up field investigations were recommended.

Arkansas SPS-8 Test Sections

LTPP test sections 05_0803, 05_0804, 05_0809 and 05_0810 are located on U.S. 65, southbound, in Jefferson County, Arkansas. U.S. 65 is an urban collector with one lane in the direction of traffic. The four test sections were constructed and accepted into the LTPP Program in 1997 as part of the SPS-8 experiment. In Arkansas, these SPS-8 projects consist of two AC test sections—05_0803 and 05_0804—and two jointed plain concrete pavement (JPCP) test sections—05_0809 and 05_0810. At the time of incorporation into the LTPP program, test section 05_0803 consisted of 3.7 inches of dense-graded asphalt concrete (0.3-inch less than the specified design thickness) and 7.3 inches of unbound granular base (1.3 inches greater than the specified design thickness) over a fine-grained subgrade soil, while test section 05_0804 consisted of 7.3 inches of dense-graded asphalt concrete (0.3-inch greater than the specified design thickness) and 12.7 inches of unbound granular base (0.7-inch greater than the specified design thickness) over a fine-grained subgrade soil. Test sections 05_0809 and 05_0810 were constructed as three layers at the time of incorporation into the LTPP program. Test section 05_0809 was constructed as 8.7 inches of Portland Cement Concrete (PCC) (0.7-inch greater than the specified design thickness), 8 inches of unbound granular base (2 inches greater than the specified design thickness) over a fine-grained subgrade soil for test sections) while test section 05_0810 was constructed as 11.5 inches of Portland Cement Concrete (PCC) (0.5-inch greater than the specified design thickness) and 8 inches of unbound granular base (2 inches greater than the specified design thickness) over a fine-grained subgrade soil. Both test sections also received lane-shoulder longitudinal joint sealing in July 2001.

The four test sections provided an opportunity to compare the performance of test sections with similar (low) traffic and environmental conditions and varying pavement structures. The objectives of the desktop study were to investigate 1) the cause(s) for the increase in fatigue cracking in 2019 on the AC test sections (05_0803 and 05_0804), 2) the cause(s) for the spike in longitudinal cracking (both inside and outside the wheel path) in 2014 on the AC test sections (05_0803 and 05_0804), 3) the reason(s) for the spike in transverse cracking reported in 2014 on both AC test sections (05_0803 and 05_0804) and the subsequent decrease in transverse cracking reported on test section 05_0804 in 2019, and 4) the differences in the reported faulting of the JPCP test sections (05_0809 and 05_0810) over time.

Activities and Findings

In pursuit of the stated objectives, a desktop study of the test sections (Gardner et al., 2021a) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, faulting, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study provided insight on the causes of the increase in fatigue, longitudinal, and transverse cracking observed on the AC test sections (05_0803 and 05_0804) over time. Between 2014 and 2019, the amount of fatigue cracking exhibited at the test sections increased at an abnormally high level for a low-traffic roadway. Some of the increase in fatigue/alligator cracking was related to other cracking types in the wheel path evolving into fatigue/alligator cracking starting in 2019; most of the additional fatigue cracking observed in 2019 was located in areas where wheel path longitudinal cracking and transverse cracking already existed, as depicted in Figure 33 and Figure 34. Hypothesized causes for the increase in fatigue/alligator cracking along the test sections included the high levels of precipitation due to a flooding event in 2019, aging/oxidation of the AC layers, and construction or material inconsistencies. The increase and subsequent drop in NWP and WP longitudinal cracking and transverse cracking on the AC test sections was related to the fatigue/alligator cracking observed on the test sections as discussed previously.

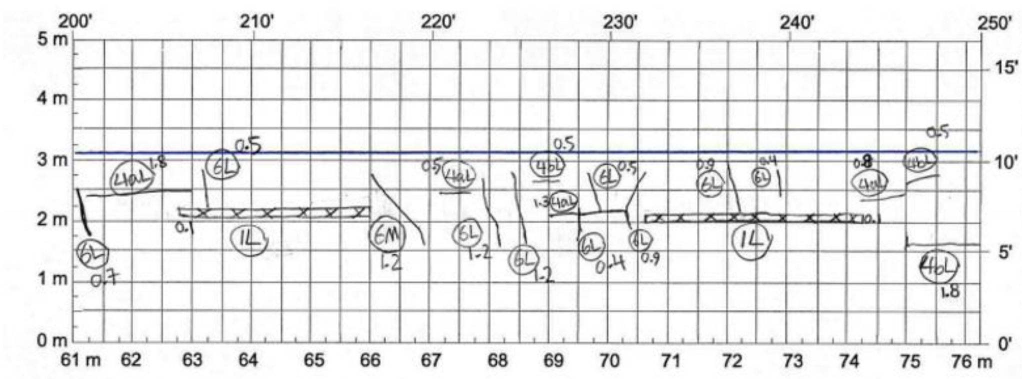

Figure 33. Map. Fatigue cracking propagation on test section 05_0803 in 2014.

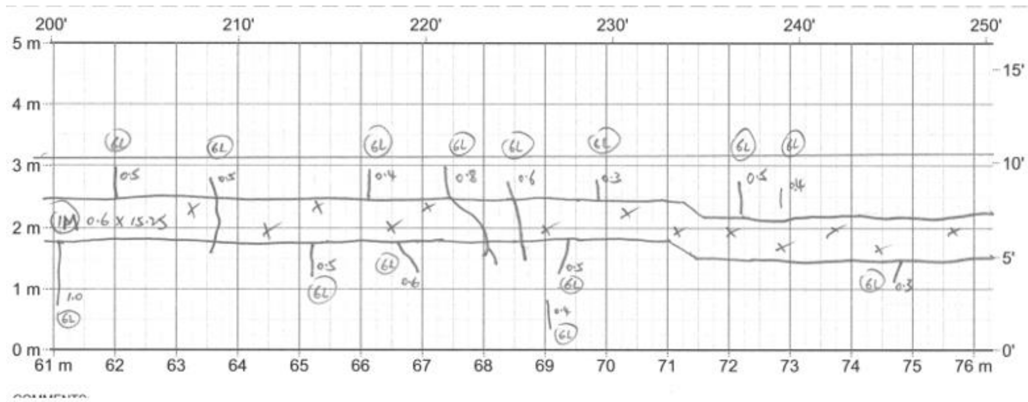

Figure 34. Map. Fatigue cracking propagation on test section 05_0803 in 2019.

The desktop study also focused on better understanding the performance of the JPCP test sections (05_0809 and 05_0810) in terms of faulting and the performance of all test sections based on IRI. While there was some fluctuation over time, the amount of faulting on both JPCP test sections was sufficiently low. Each section remained in the "Good" category throughout the monitoring period (to date). In terms of IRI, the two AC test sections reported lower IRI measurements than the JPCP test sections, as shown in Figure 35; this is likely because the IRI of the JPCP test sections was affected by the modest faulting and joints along the sites.

Conclusions and Recommendations

Based on the findings of the desktop study, the performance of the SPS-8 test sections could be adequately explained. The AC test sections, which reported high levels of fatigue cracking and spikes in longitudinal and transverse cracking, seemed to be most affected by the increase in fatigue cracking reported between the two most recent surveys, as well as by high levels of precipitation due to a flooding event in 2019, aging/oxidation of the AC layers, and construction or material inconsistencies. The JPCP test sections performed fairly well over time with no cracking reported during the analysis period. While the two AC test sections reported lower IRI measurements than the JPCP test sections, the IRI of the JPCP test sections was likely affected by the faulting and joints along the site. Based on the findings of the desktop study, it was recommended that additional information be pursued to better explain the performance of the test sections over time. Specifically, additional FWD testing, coring, continued monitoring, and a discussion with Arkansas DOT staff familiar with the test sections was suggested. These recommendations will be further pursued once the test sections have reached the end of their service life.

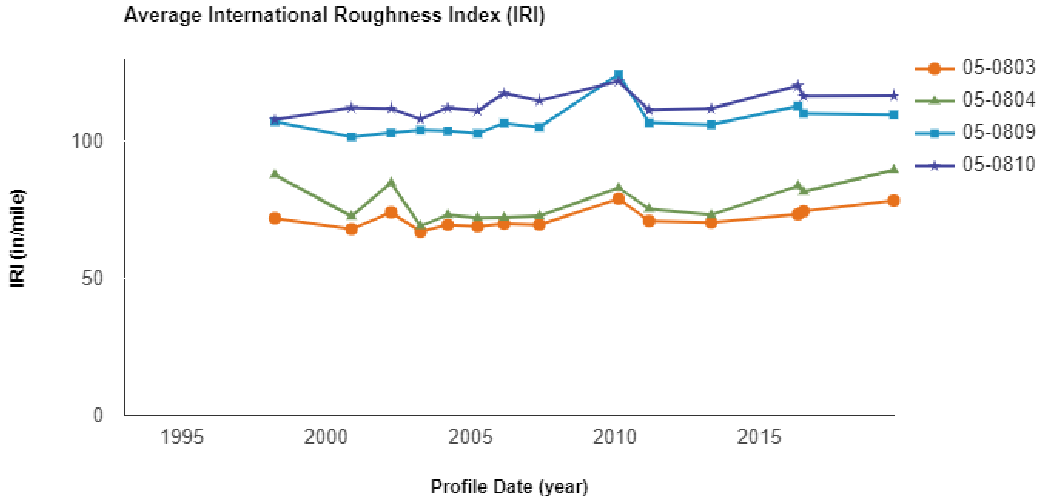

Figure 35. Chart. Time history of pavement roughness on Arkansas SPS-8 test sections.

Washington State SPS-8 Test Sections

LTPP test sections 53_0801 and 53_0802 are located on North Touchet Rd, northbound, in Columbia County, Washington State, while test sections 53_A809 and 53_A810 are located on Smith Springs Rd, eastbound, in Walla Walla County. All four test sections are located on rural local collectors and were constructed as part of the SPS-8 Study of Environmental Effects in the Absence of Heavy Loads experiment. This experiment was developed to better understand the effect of varying pavement structures (in terms of surface and base thicknesses, specifically) in the absence of heavy loading. At the time of construction in 1995, test section 53_0801 consisted of 3.7 inches of dense-graded asphalt concrete and 8 inches of unbound granular base over 38.4 inches of unbound subbase and a fine-grained subgrade soil. Test section 53_0802, also constructed in 1995, consisted of 6.8 inches of dense-graded asphalt concrete and 11.7 inches of unbound granular base over 38.4 inches of granular subbase and a coarse-grained subgrade soil. Both test sections were crack sealed in 2000 (CN=2), 2003 (CN=3), and in June and October of 2015 (CN=6 and CN=7 for 53_0801 and CN=5 and CN=6 for 53_0802). Test section 53_0801 also received 0.3-inch chip seal in 2005 (CN=4) and a 0.1-inch fog seal in 2011 (CN=5) while test section 53_0802 only received a 0.3-inch chip seal in 2005 (CN=4). Test sections 53_A809 and 53_A810 were both constructed in 2000 as four layers: 8.5 and 10.9 inches of Portland Cement Concrete (PCC) and 4.5 and 4.7 inches of unbound granular base over an unbound granular subbase and fine-grained subgrade soil for test sections 05_A809 and 05_A810, respectively. Neither section reported any additional construction events following their incorporation into the LTPP program.

Although the pavement structures vary in terms of layer material types and thicknesses, they are exposed to similar truck traffic (very little, in line with the SPS-8 experiment design) and climatic conditions. Because of this, these test sections provided an opportunity to assess the effects of varying layer material types and thicknesses on the performance of pavements subjected to similar climatic conditions in the absence of heavy loads. The objectives of the study were to assess and compare the performance of the test sections with a focus on the differences in pavement deflections, IRI, and pavement surface distresses over time (recognizing the AC and PCC pavement test sections were independent projects constructed five years apart).

Activities and Findings

In pursuit of the stated objectives, a desktop study of Washington State SPS-8 test sections (Gardner et al., 2021e) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, faulting for test sections 53_A809 and 53_A810 and rutting for test sections 53_0801 and 53_0802) history using information available from InfoPave™ (InfoPave™, 2021). Additionally, the project team was also able to engage County engineers familiar with the test sections, which was helpful to the overall investigation.

One of the key areas of investigation was the fatigue/alligator cracking observed on test section 53_0802. Despite test section 53_0802 being the thicker of the two AC test sections, fatigue/alligator cracking was only reported on test section 53_0802. Between 2008 and 2020, the fatigue/alligator cracking observed increased from 14 ft^2 to 156 ft^2 at an average rate of 11.8 ft^2/year, as observed in Figure 36. One potential reason for the differences in the fatigue/alligator cracking observed on the AC test sections was the difference in construction of the two test sections. It was noted in the construction report for the test sections that the AC surface of test section 53_0802 was constructed in multiple lifts. However, between the first and second lift, the contractor did not allow time for the first lift to cool before the second lift was applied. Instead, an emulsified tack coat was added. It is therefore suspected that a lack of bonding between these two lifts may have resulted in the fatigue/alligator cracking observed on test section 53_0802.

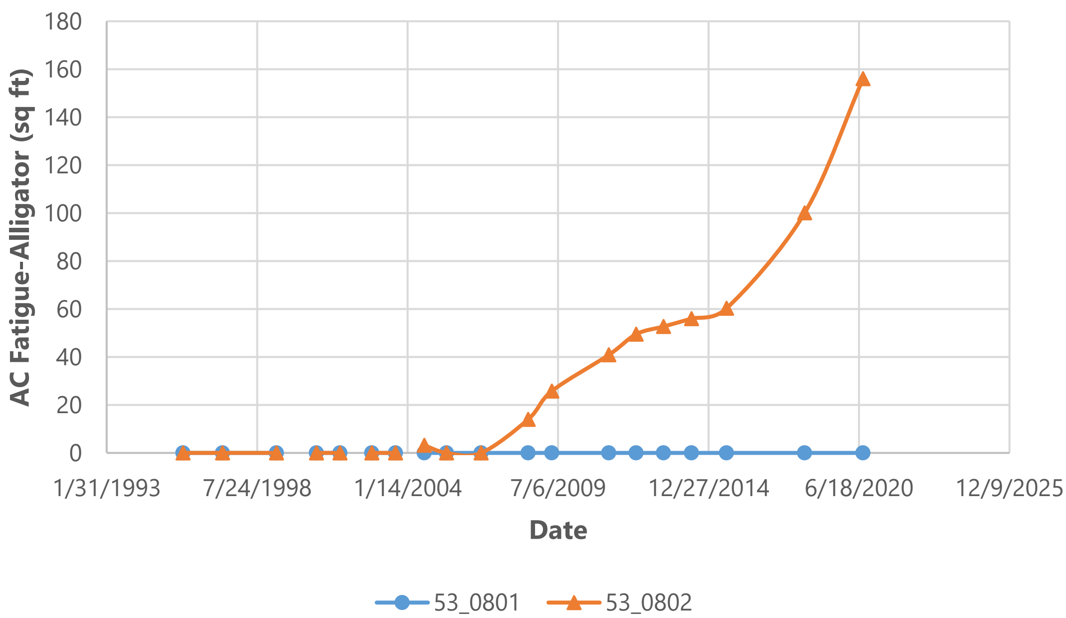

Figure 36. Chart. Time history of fatigue cracking on test sections 53_0801 and 53_0802.

The desktop study also investigated the difference in the number of transverse cracks reported on the AC test sections (53_0801 and 53_0802). Test section 53_0801 reported 110 feet (11 cracks) of transverse cracking in 2020 while test section 53_0802 reported 176 feet of cracking (55 cracks) in 2020. For test section 53_0801, the observed transverse cracking was a mix of both full-width (across the entire lane) and partial-width cracks while for test 53_0802, the reported cracking was predominantly partial-width cracks, some in which crack sealing was applied but failed. While the reported transverse cracking on both sections remained minimal, it is hypothesized that it was thermal-induced cracking related to freeze-thaw cycles.

Finally, the desktop study compared the performance of the test section in terms of IRI. Despite the differences in the pavement types (PCC vs AC), all four test sections performed similarly in terms of IRI. It was notable that while the PCC test sections did not report any cracking and reported only minimal faulting, the smoothness of the PCC sections was comparable to the AC test sections. This was likely related to curl and warp on the PCC test sections.

Conclusions and Recommendations

Through the desktop study, the four Washington State test sections were able to be compared. All four test sections generally performed well over time. However, test sections 53_0801 and 53_0802 did report NWP longitudinal cracking, transverse cracking, and in the case of test section 53_0802, fatigue/alligator cracking. The observed distresses, while minimal, were hypothesized to be related to a lack of bonding between the AC layers (fatigue/alligator cracking), the construction joints of the test sections (NWP longitudinal cracking), and thermal factors or freeze-thaw cycles (transverse cracking). It was recommended the desktop study be extended to further investigate the trends observed on the test sections. Performance monitoring, FWD testing, and coring were recommended follow-up activities.

Idaho Test Section 16_1020

LTPP test section 16_1020 is located on U.S. Route 93, northbound, in Jerome County, Idaho. U.S. Route 93 is a rural principal arterial with one lane in the direction of traffic. The test section was constructed in 1986 and was accepted into the LTPP Program as part of the GPS-1 experiment in July 1988. At the time of its incorporation into the LTPP program, the test section consisted of 0.2 inches of chip seal, 3.6 inches asphalt concrete, 12.3 inches of aggregate base, and 8.2 inches of subbase over a fine-grained subgrade soil, as summarized in Table 33. The next significant construction events occurred in June 2011, when the test section received a 2.4-inch AC overlay, moving the test section to the GPS-6C experiment, and in July 2013, when the test section received a 0.2-inch chip seal. Other minor construction events that occurred on the test section included crack sealing in April 1993 and patching in August 2008. While the Idaho Transportation Department (ITD) does have work planned on a nearby area of U.S. 93, it was confirmed that this test section was not included in the planned work and is not scheduled to be rehabilitated or reconstructed in the immediate future.

Overall, the test section has performed well over time with respect to cracking, IRI, and average deflection under the center load plate. However, the level of rutting reported on the test section prior to the overlay was notable, reaching 0.35 inches in 2011. Between 1990 (the first year where rutting data was available) and 2011, the average rut depth only increased by 0.15 inches; more than half of the observed rutting occurred prior to 1990. Accordingly, the objectives of the study were to examine the key reason(s) for the relatively good performance of the test section and the key cause(s) of rutting at this test section.

Table 33. Pavement structure for 16_1020 (CN=1)

Layer Number	Layer Type	Thickness (in.)	Material Code Description

1	Subgrade (untreated)	93.0	Fine-grained soils: silt
2	Unbound granular subbase	8.2	Soil-aggregate mixture
3	Unbound granular base	12.3	Crushed gravel
4	Asphalt concrete layer	3.6	Hot mixed, hot laid AC, dense graded
5	Asphalt concrete layer	0.2	Chip seal

Activities and Findings

In pursuit of the stated objectives, a desktop study of Idaho test section 16_1020 (Gardner et al., 2021f) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (fatigue/alligator cracking, longitudinal cracking, transverse cracking, IRI, and rutting) history using information available from InfoPave™ (InfoPave™, 2021).

The desktop study primarily focused on what contributed to the test section's overall good performance. As noted previously, the test section reported minimal cracking over time. In 2020, 34 years after the test section was constructed and nine years after the AC overlay, 79 ft^2 of fatigue/alligator cracking, 0 feet of longitudinal cracking, and 9 feet (3 cracks) of transverse cracking were reported. Additionally, the IRI on the test section remained below 55 in/mi throughout the entire analysis period, and the average deflection under the center load plate was relatively constant throughout time. It was hypothesized that the good performance of the test section is related to the pavement design and the lack of extreme environmental conditions.

Another key objective of the desktop study was to investigate was the key cause(s) of rutting observed on the test section. The rutting on the section prior to 2011 increased from 0.2 in in 1989 to 0.35 in in 2011. Following the overlay in 2011, the average rut depth dropped to 0.04 in. The average rut depth began to slightly increase following the overlay, at a rate of less than 0.01 in/year between 2011 and 2020, as depicted in Figure 37. Using the transverse profiles of the test section at multiple locations, an analysis of the predominant layer in which plastic deformation occurs was assessed using the method developed in NCHRP Project 01-34a. Based on the analysis conducted for each of the transverse profiles of the test section for the collection dates between September 1989 and June 2013, the predominant layer contributing to rutting was the surface layer. It was hypothesized that the rutting observed prior to 1990 may have been related to the AC thickness, annual pavement temperature, the binder used, and to a lesser extent, the increase in agricultural and constructed-related traffic along the roadway. Additionally, while there may have been some studded tires used on this road, studded tire and chain abrasion in the winter months were not considered by ITD as significantly impacting rut measurements.

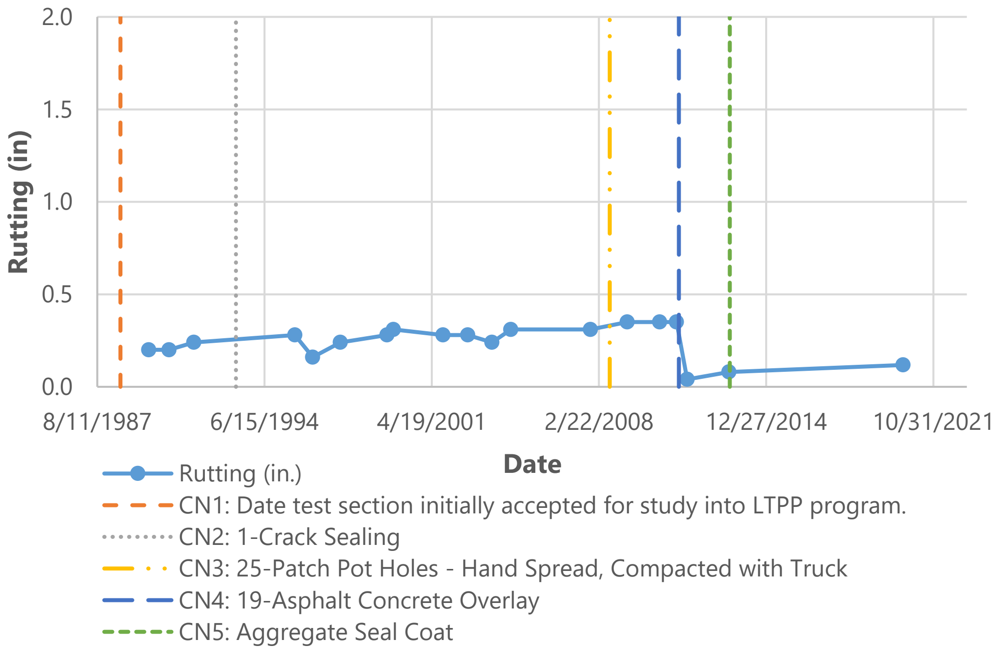

Figure 37. Chart. Time history of average rut depth on test section 16_1020.

Finally, while not a key objective of the study, the investigation helped identify discrepancies between the LTPP reported traffic data and the actual traffic observed on the test section. This reported data, which was calculated using a linear growth function (2004–2008 and 2010–2017), was not included in the analysis because it appeared to substantially underestimate the traffic experienced on this test section over time. Based on an interview with ITD staff familiar with this test section, traffic on the test section has increased significantly since the early 2000s due to an increase in agricultural- and construction-related truck traffic in the area. The discrepancy between the non-monitored traffic reported (which was approximately ¼ of the actual AADTT) in the LTPP database and the monitored traffic counts was a significant finding of the study and will be submitted as a DAOFR to be further addressed by the LTPP program. Overall, despite the sharp increase in traffic loading on this test section, the test section performed well.

Conclusions and Recommendations

The desktop study conducted on test section 16_1020 provided insight on the overall good performance in terms of cracking, IRI, and deflections and poor performance with regards to the rutting observed on the test section prior to the overlay. Through an analysis of available data and an interview with ITD, the performance of the test section was hypothesized to be predominantly affected by the pavement design, the lack of extreme environmental conditions, and the binder used for the AC surface layer. Although the test section was considered active at the time it was nominated for a desktop study, closeout monitoring occurred on the test section in August 2020. It was recommended that coring and the analysis of Traffic Speed Deflectometer (TSD) data collected in 2020 be conducted as a follow-up to this investigation.

Oklahoma Test Section 40_4157

LTPP test section 40_4157 is located on U.S. Route 69, northbound, in Mayes County, Oklahoma. U.S. Route 69 is a rural principal arterial with two lanes in the direction of traffic.

The test section was constructed in March 1986 and was accepted into the LTPP Program as part of the GPS-3 experiment in January 1987. At the time of its incorporation into the LTPP program, the test section consisted of 9.1 inches of JPCP and 3.8 inches of hot-mix AC treated base over 42.0 inches of unbound silty sand subgrade soil. The original structure remained largely unchanged following the original construction; however, the test section did receive joint load transfer restoration (CN=2), a surface grind (CN=3), transverse joint sealing, and longitudinal joint sealing (CN=4) in September 2012. The surface grind resulted in the PCC surface layer being reduced from 9.1 inches to 8.9 inches, as shown in Table 34.

Table 34. Pavement structure for 40_4157 (CN=3).

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)	42	Coarse-Grained Soil: Silty Sand
2	Bound treated base	3.8	HMAC
3	Portland cement concrete layer	8.9	Portland Cement Concrete (JPCP)

Prior to the 2012 construction event, the test section performed well in terms of distress (no cracking or patching), deflections, IRI, and faulting. However, joint load transfer efficiency (LTE) remained in the 20% to 60% range for most years until the 2012 joint load transfer restoration, surface diamond grinding, and joint sealing. As such, the objectives of the study were to examine and identify those factors that contributed to the excellent performance of the test section, study the history of joint LTE of the test section prior to the application of the 2012 treatments and identify those factors contributing to the low joint LTE values, and study the effects of the treatments applied in 2012 on the performance of the test section, with a particular focus on IRI and faulting.

Activities and Findings

In pursuit of the stated objectives, a desktop study of Oklahoma test section 40_4157 (Gardner et al., 2021g) was conducted, which investigated the pavement structure and construction history, climate history, traffic loading history, and pavement distress (durability cracking (D cracking), joint seal damage, spalling, faulting, and IRI) history using information available from InfoPave™ (InfoPave™, 2021).

Through the desktop study, an analysis of the LTE prior to and following the 2012 construction events was conducted. As depicted in Figure 38, except for values reported in 1990 and 2003, the test section generally reported poor load transfer efficiency prior to 2012. However, after further investigation, the reported LTE values appeared to be strongly related to the daily air temperature (MERRA). During the warmer months of the year, it is likely that slabs expanded, and the resulting locked joints provided sufficient load transfer of the joints. In colder months, the load transfer was poor, which typically results in faulting, pumping, and—if left untreated—corner breaks. The only measurement after the dowel bar retrofit showed a substantially improved load transfer, although this also aligned with the temperature/LTE trend observed prior to the construction event.

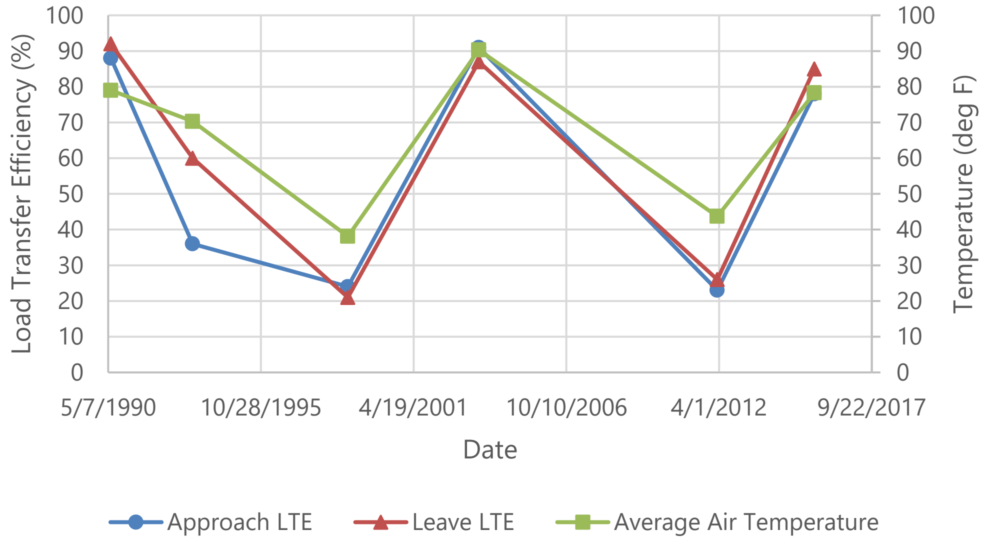

Figure 38. Load Transfer Efficiency on test section 40_4157 over time.

The desktop study also examined the faulting and IRI of the test section prior to and following the construction events in 2012. Faulting measurements on the test section were slightly higher prior to the construction activities in 2012; however, all measurements were consistently less than 0.1 inches throughout the analysis period. Following this work, the faulting on the section was essentially zero, which is to be expected with the combination of dowel bar retrofits and surface grinding conducted. Similarly, the roughness measurements were consistently "Good" prior to the 2012 construction activities based on FHWA performance definitions. Following the dowel bar retrofit and surface grinding, the IRI dropped substantially (from around 80 in/mi to below 45 in/mi). It was hypothesized that approximately half of the measured roughness during CN=1 could be attributed to faulting.

Finally, while not an objective of the desktop study, the project team identified an issue with the reported traffic plots being displayed as a part of the LTPP InfoPave™ Section Summary Report module. The plot produced, when compared with the data in the TRF_TREND table for the test section, was found to have to have been reporting the wrong traffic data. Upon further investigation, the issue was found to have been widespread and the traffic reported for other test sections were also found to be incorrect for this plot. The LTPP program was notified about this issue with InfoPave™.

Conclusions and Recommendations

Overall, the test section performed well in terms of distress (no cracking or patching), deflections, and faulting. The excellent performance of the test section was hypothesized to be attributed to the pavement design of the test section, which includes a thick PCC layer over an asphaltic base layer, as well as the lack of freezing observed on the site. However, additional information on the predicted traffic loads and construction practices used at the test section would be helpful in further understanding the excellent performance of the test section. While the test section is part of LTPP's long life test sections, additional investigation of the test section was recommended to better understand its excellent performance. Recommended activities include coring (once the test section goes out-of-study), FWD testing at the joints, continued analysis of the performance trends over time, an interview with Oklahoma DOT staff, and a comparison of the test section's performance to other LTPP JPCP test sections.

Summary, Conclusions and Recommendations

At the test section and site level, the forensic evaluations conducted as a part of this project provided insight on the performance of test sections when considering external factors and in comparison to other test sections. As illuminated in the previous chapter, the forensic evaluation of the nominated test sites led to valuable insight for individual State DOTs and more generally, for test sections with varying climates and traffic. From the desktop studies, the causes of individual distresses and conditions that led to the initiation of these distresses were hypothesized. Through field work conducted as a part of the follow-up investigations, the likely reason for propagation of cracking could be determined using collected cores.

However, more generally, the pooled fund project was also crucial in identifying and helping to improve the value of the LTPP database. As the LTPP database provides researchers and practitioners with information valuable for pavement research and for informing decision-making policies, the accuracy and timeliness of the LTPP data is critical. While the LTPP program provides the most up-to-date information available to data users on an annual basis, issues with existing data do still occur. Table 35 summarizes the key issues identified through the project which led to changes to the LTPP database. These identified issues, which will be confirmed and documented through the creation of individual Data Analysis/Operations Feedback Reports, demonstrate the value of forensic evaluations to the larger community. Moving forward, the hope is that State DOTs will utilize the data available from the LTPP program to conduct their own forensic investigations.

Table 35. Summary of identified issues from forensic studies.

State	Test Section(s)	Identified Issues
CO	08_0224	A patch applied in 2014 was not recorded in the manual distress survey. The patch has been added to the manual distress survey (MDS) and the LTPP pavement performance database (PPDB).
WA	53_1005	The laser transverse profile measurement in 2019 shows differences in the profile from the historic transverse profiles measured in the past. This could be due to the increased number of measurements in 2019, which were approximately 0.08 inches apart. The LTPP program is currently assessing this issue.
OH	39_5003	Test section was found to be milled and overlaid in the Summer of 2019, but LTPP not informed.
CA	06_7452	2020 core measurements showed the layer structure for CN=3 was incorrect. The LTPP database showed the 2010 treatment as being an overlay adding a 1.3-inch AC layer on top of the existing 1999 AC overlay. However, examination of the cores showed layer L7 had been completely milled off and layer L6 was reduced in thickness from 2.6 inches to 2.1 inches.
FL	12_1030	Judging by photographs of the control test section, it also had an open graded surface course, but was not noted in the original LTPP core examination that was used to determine layer thicknesses.

State	Test Section(s)	Identified Issues
IA	19_1044	It was learned that an additional construction event had occurred on the test section. The unreported construction event on the test section was a 1.5-inch mill and 2-inch AC overlay in 1989.
IA	19_1044	Crack sealing appeared in the photographs taken of the section in 2007, the first year the section was assessed following the overlay event, despite not being reported in the LTPP database. The application of crack sealing between 2002 and 2007 was supported by the distress survey conducted on the section in 2007.
TX	48_1096	Pictures of the test section over time and the amount of sealed cracking reported in the manual distress surveys indicated crack sealing was applied to the section prior to the March 1995, November 2013, and January 2017 distress surveys. However, this information was not reflected in the LTPP construction history.
TX	48_1096	The LTPP Data Collection Contractor (DCC) noted upon arriving to the test section that a surface seal coat had been applied to the test section, which was not reported to the DCC. An image of the site in 2017 and Google Streetview imagery from 2018 are shown in Figure 21. According to the LTPP Directive GO-67, the application of the seal coat meant the section would have to be removed from study.
SC	45_1024	The patching observed on the site was over a core hole approximately 84 meters from sta. 0+00. The coring (which was subsequently patched) at this location was in violation of the standing LTPP policy that pavement in the test section should not be disturbed.
ME	23_1028	The test section was found to have been treated with ultra-thin wearing course prior to closeout monitoring.
UT	49_7082, 49_7085, 49_7086	Climate classifications were based on the location of the section rather than the average annual precipitation or freezing index at the test site. While test section 49_7085 reported high levels of precipitation each year, the test section was classified as being a part of a “Dry” region.
UT	49_7082	Further investigation revealed additional work was carried out on test section 49_7082 in June 2013 that was not captured in the LTPP database. In addition to the grinding and joint load transfer reported on the section during CN=2, transverse joint sealing and lane-shoulder longitudinal joint sealing also took place.

State	Test Section(s)	Identified Issues
UT	49_7086	For CN=3, it was found that partial depth patching at locations other than the joints did not occur on the test section in November 2010. Instead, the test section received transverse joint sealing, full depth transverse joint repair, and partial depth patching at the joints in addition to the grinding originally reported on the test section during CN=3. InfoPave™ also reported a fourth construction event (CN=4) on the test section, which included joint sealing and grinding in June 2013. However, based on knowledge and documentation provided by Utah DOT staff, this construction did not occur and therefore was removed from the LTPP database.
MD	24_1634	The test section was found to have been milled and overlaid in the Summer of 2019.
IN	18_1037	The test section was found to have been milled and overlaid in the Summer of 2019.
AR	05_0803, 05_0804, 05_0809, 05_0810	The reported traffic data for the Arkansas SPS-8 test sections (05_0803, 05_0804, 05_0809, and 05_0810) in 2005 and 2006 was incorrect; the classification data reported in February 2005 for the test sections corresponds to data for a site with the 6-digit identifier of 350215 and weight data in April 2006 for a site with the 6-digit identifier 160058. However, the 6-digit identifier for these test sections is 350512. Therefore, the data reported in 2005 and 2006 for the SPS-8 test sections needed to be removed and the corresponding tables related to this data needed to be updated.
MN	27_6251	Differences between NWP longitudinal cracking reported in manual distress surveys and distress information reported in InfoPave™ were found.
MN	27_6251	The test section was found to have been milled and overlaid sometime after the 2017 monitoring.
ID	16_1020	Data reported using a linear growth function (2004–2008 and 2010–2017), was not included in the analysis because it appeared to substantially underestimate the traffic experienced on this test section over time. Based on an interview with ITD staff familiar with this test section, traffic on the test section has increased significantly since the early 2000s due to an increase in agricultural- and construction-related truck traffic in the area. The discrepancy between the non-monitored traffic reported (which was approximately ¼ of the actual AADTT) in the LTPP database and the monitored traffic counts was a significant finding of the study and will be submitted as a DAOFR to be further addressed by the LTPP program.

State	Test Section(s)	Identified Issues
OK	40_4157	The project team identified an issue with the reported traffic plots being displayed as a part of the LTPP InfoPave™ Section Summary Report module. The plot produced, when compared with the data in the TRF_TREND table for the test section, was found to have to have been reporting the wrong traffic data. Upon further investigation, the issue was found to have been widespread and the traffic reported for other test sections were also found to be incorrect for this plot. The LTPP program was notified about this issue with InfoPave™.
OK	40_4157	Two joints were recorded as being sealed in 2013, and only one was recorded as being sealed in 2015.

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