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Best practices and promising technologies that can be used now to enhance concrete paving

Performance Experience and Lessons Learned from the SPS 2 Test Sections of the Long Term Pavement Performance Program (LTPP)

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ROAD MAP TRACK 6

PROJECT TITLE
Performance Experience and Lessons Learned from the SPS 2 test sections of the Long Term Pavement Performance Program (LTPP)

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Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The December 2018 MAP Brief provides information relevant to Track 6 of the CP Road Map: Concrete Pavement Construction, Reconstruction, and Overlays.

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefDecember2018.pdf.

Introduction

Would you like to know how well pavements are performing across the United States and Canada? The Long Term Pavement Performance (LTPP) Program is where you would start looking for answers. The LTPP program is a large research project that includes two fundamental classes of studies and several smaller studies to investigate specific pavement-related details that are critical to pavement performance. The fundamental classes of study are the General Pavement Study (GPS) and the Specific Pavement Studies (SPS). The combined GPS and SPS programs consist of over 2,500 test sections located on in-service highways in North America.

This MAP Brief is intended to summarize the performance and lessons learned from the SPS 2 test sections, which represents the nation's largest study of concrete pavement performance. It will also explain the transportation pooled funded project that has been established to use the SPS-2 test sections to optimize future pavement preservation strategies.

LTPP Background

LTPP was established as part of the original Strategic Highway Research Program (SHRP) to determine how and why in-service pavements perform the way they do, and was transitioned to Federal Highway Administration (FHWA) management in 1992. Operating continuously since the 1990s, LTPP is the world's most comprehensive study of in-service pavements. The Program has evolved considerably over this time, and now all relevant data collected are available via the InfoPave™ data portal (https://infopave.fhwa.dot.gov/). These data include not only research quality performance measurements collected at regular intervals, but also detailed traffic loading, materials, and climatic data that facilitate modeling and model development.

The LTPP data was the primary data source used in developing the AASHTOWare PavementME Design software and continues to be used to improve the programs ability to predict field performance. Thanks to this leadership, plus critical support from the State and Provincial Highway Agencies (SHAs) and countless volunteers in both academia and industry, LTPP is helping answer the important question: How can we optimize our investment in our pavements?

While many LTPP test sections were in active service at the time LTPP began—General Pavement Studies (GPS)—additional studies were designed to examine maintenance and rehabilitation strategies, and others looked at the impacts of design features on new construction. These experiments were designated as Specific Pavement Studies (SPS). Both rigid and flexible test sections are included in LTPP, and the following comprise the rigid pavement experiments:

- GPS-3—Jointed Plain Concrete Pavements
- GPS-4—Jointed Reinforced Concrete Pavements
- GPS-5—Continuously Reinforced Concrete Pavements
- GPS-8—Unbonded Portland Cement Concrete Overlay of Portland Cement Concrete Pavements
- SPS-2—Strategic Study of Structural Factors for Rigid Pavements
- SPS-4—Preventive Maintenance Effectiveness of Rigid Pavements
- SPS-6—Rehabilitation of Jointed Portland Cement Concrete Pavements
- SPS-8—Study of Environmental Effects in the Absence of Heavy Loads (both AC and PCC Pavements

SPS-2 Test Sections

The SPS-2 experiment was designed to study the construction features, flexural strength, lane width, PCC thickness, base type, and drainage as shown in Table 1. Table 1 also shows the environmental factors. Traffic wasn't a variable, but there was a minimum level of loading to be accepted.

Recognizing the cost implications of building a full factorial design at a location (24 test sections at a site), it was decided that each SPS-2 project would have 12 test sections and similar environmental projects would be linked. This plan worked for some combinations, while others have gaps. Fourteen projects in all were built between 1992 and 2000. Figure 1 presents the locations of each SPS-2 project and dates each was opened to traffic.

Detailed construction records were collected for each SPS-2 project, and all construction reports can be found on the InfoPave™ website (https://infopave.fhwa.dot.gov/). Measured materials test results, traffic loading, climatic conditions, and pavement performance measurements are also available on InfoPave™. The latter includes time series measurements of longitudinal profile, pavement distress, faulting, and deflection testing conducted mid-panel, pavement edge, and joints using an FWD.

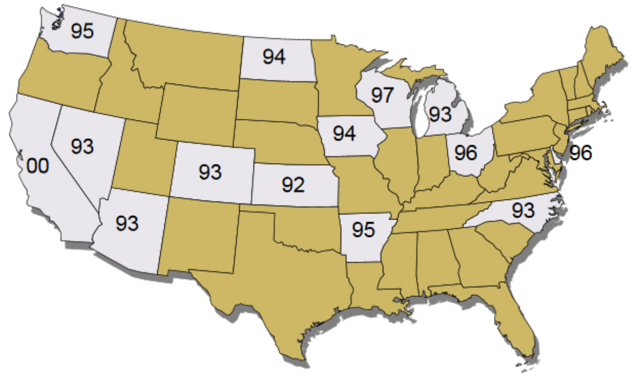

Figure 1. Location of LTPP SPS-2 sites and years constructed (figure courtesy of Larry Scofield)

SPS-2 Pavement Preservation Pooled Fund TPF 5[291]

Given the age of the SPS-2 projects, and the relatively good condition of most test sections, this experiment was identified in the early 2010s as an excellent candidate to consider for a study of pavement preservation. The specific focus was examining optimal timing for routine application of pavement preservation treatments to extend pavement life at the lowest cost.

Table 1. Experimental factors considered in the original SPS-2 experiment

Type of experimental factor	Variables affected	Experimental factor	Number of levels	Levels
Environmental	Site-specific	Traffic	0	N/A
		Climate	4	Wet-Freeze
				Wet-No Freeze
				Dry-Freeze
				Dry-No Freeze
		Subgrade	2	Fine
				Coarse
Structural	Base/ Subbase	Base type	3	Dense-graded untreated unbound aggregate (DGAB)
				Lean concrete (LCB)
				Open-graded permeable asphalt drainage layer (PATB)
		Drainage type	2	Open-graded permeable asphalt drainage layer (PATB)
				No drainage layer
	Pavement surface	PCC thickness	2	8 inch
				11 inch
		PCC flexural strength	2	550 psi
				900 psi
		Lane width	2	12 ft
				14 ft

Another element of interest was functional improvements resulting from pavement preservation. Recognizing the opportunity to leverage existing LTPP activities, a pooled fund study—with Washington State DOT as the Lead State—was developed and funded too address these two levels of interest. Arizona, California, Colorado, Georgia, Kansas, and North Carolina also contributed to the pooled fund.

Pooled fund activities began late in 2015. Tests sections were developed to accomplish the proposed research, with a detailed report compiled documenting the status of every SPS-2 test section. The pool fund panel was provided with options for implementing a pavement preservation experiment. A significant challenge in this regard was that no two test sections on a given project were identical, and with each test section being 500 feet in length, breaking down a test section into sub-sections was impractical.

In order to compare tests sections, the panel approved a plan to study the ability of the AASHTOWare PavementME Design software to compare predicted pavement condition against actual pavement performance. The desired outcome was for the predicted and actual performance after 20+ years to be sufficiently close. Having the software accurately model the present condition of the test sections could allow for work to be performed on an active section and provide the ability to compare the software's predicted performance going forward on untreated sections against actual performance after applying preservation treatments.

Predicted vs. Actual SPS-2 Test Section Performance

Considering the fact that the Pavement ME Design software was developed using primarily LTPP data and the LTPP database contains the vast majority of required software inputs, the 205 SPS-2 test sections were ideal for comparing predicted versus actual pavement performance. The results for each of the design criteria are summarized below:

Transverse Cracking: Of the 205 test sections, the software predicted low levels of cracking on 189 (92%) tests sections and 16 (8%) tests sections at high levels. See Figure 2.

Predicted vs. Measured Transverse Cracking on SPS-2 Test Sections: See Figure 3 and Table 2.

Types I- 132 (64%) test sections predicted low levels of cracking matched measured low levels

Types II- 57 (29%) test sections predicted low levels of cracking but measured high levels

Type III- 9 (4%) tests sections predicted high levels of cracking but measured low levels

Typed IV- 7 (3%) tests sections predicted high levels of cracking matched measured high levels

As can be seen, for the majority of the test sections the software predicted low levels of cracking and that is also what was measured (Type I). However, there were a significant number of sections where higher than predicted cracking was measured (Type II). Much smaller in number were test sections with less measured cracking than predicted (Type III) and test sections where cracking occurred and the amount was correctly predicted (Type IV).

Given the differences in predicted vs. actual values, the Technical Advisory Committee (TAC) decided the software was not sufficiently accurate to be utilized as the control in predicting future performance of the untreated test sections. The TAC is currently evaluating other options for evaluating preservation treatment performance improvements.

In examining the analysis results, some general trends were observed in each of the categories defined earlier (Table 3 on page 4). Overall, the AASHTOWare PavementME Design software was observed to over-predict the influence of pavement strength and traffic loading on SPS-2 test sections. The software also predicted better than observed performance on many of the test sections constructed on lean concrete base (LCB).

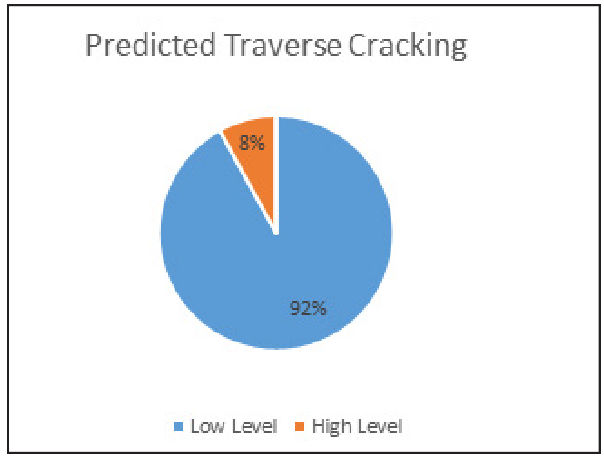

Figure 2. Predicted transverse cracking on SPS-2 test sections

Predicted Slabs Cracked	Measured Slabs Cracked	
	LOW	HIGH
LOW	Type I	Type II
HIGH	Type III	Type IV

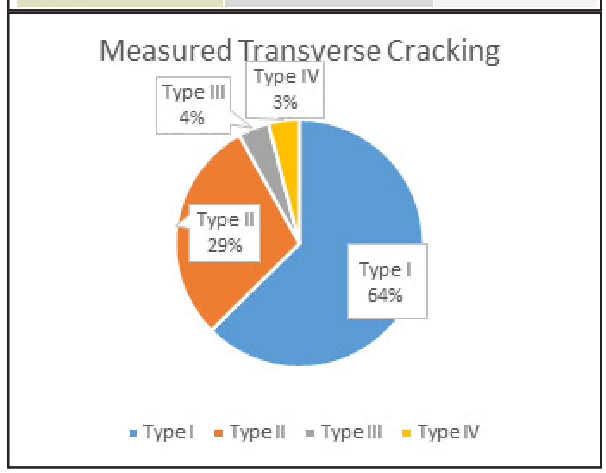

Figure 3. Definition of type of cracked slabs and measured transverse cracking on SPS-2 test sections (Note the predicted and measured cracks refers to the number of cracks not the severity)

Faulting and Longitudinal Roughness

The AASHTOWare PavementME Design software was also utilized to determine if it could accurately compare the measured vs. actual performance for faulting and longitudinal roughness. The results have not been assessed to the same degree as the transverse cracking presented above, but some trends were quite clear. Given that all but a small number of transverse joints were doweled (any sections with undoweled joints were all supplemental test sections), the amounts of measured and predicted faulting were extremely low. Most of the undoweled joints have also exhibited very little faulting. With regard to longitudinal profiles, the initial roughness of a test section is the best predictor of roughness over time. LTPP is studying the impacts of curl and warp on roughness

Table 2. Predicted vs. measured transverse cracking by SPS-2 project. The Type II and Type III test sections represent where the software does not accurately predict measured performance

State	Number of Test Sections			
	Type I	Type II	Type III	Type IV
Arizona	10	5	4	-
Arkansas	5	2	3	2
California	3	5	1	3
Colorado	9	4	-	-
Delaware	13	1	-	-
Iowa	12	1	-	-
Kansas	9	2	1	1
Michigan	7	6	-	-
Nevada	2	10	-	-
North Carolina	12	2	-	-
North Dakota	16	2	-	-
Ohio	5	13	-	1
Washington	9	4	-	-
Wisconsin	20	-	-	-

Table 3. Trends in comparing predicted vs. measured SPS-2 test section performance

Type I Sections (Measured as predicted) • Lower traffic loads • Thicker PCC sections • 34% with PATB and 24% with LCB	**Type III Sections (Measured lower than predicted)** • Heavier traffic loads • PCC with lower strength and/or more elastic • No LCB sections
Type II Sections (Measured higher than predicted) • 28% with PATB and 47% with LCB • PCC with higher strength and/or less elastic	**Type IV Sections (Measured as predicted)** Most design factors near average values

separately, and there is evidence of strong correlations provided enough profile measurements are collected to capture different temperature conditions.

For states where local calibration efforts had been performed on the software, very few differences were observed in the ability to accurately predict performance compared to the results using national inputs values. This is something for State Highway Agencies (SHAs) to consider when deciding to make the significant investment required for local calibration.

SPS-2 Tech Days

Another important activity authorized by the pooled fund, in partnership with the SHAs and industry, was to schedule a series of SPS-2 Tech Days. These Tech Days involve both classroom and field elements at locations near existing SPS-2 test sections and encourage agency, industry, academia, and consultant participation. To date, six Tech Days have been completed in 2018: Arizona, Colorado, Washington, Iowa, Kansas, and North Dakota. Attendance has been outstanding, ranging from 30-70 participants per location.

During the classroom portion, a number of presentations are given, with audience interaction being strongly encouraged. The presentations introduce the audience to LTPP and the SPS-2 experiment and cover performance on both the national and project-specific levels. Perhaps one of the most important outcomes from the Tech Days is the exchange of information regarding pavement preservation between the "old timers" and the new engineers. This was not the original intent of the Tech Days when started, but early on has been recognized as one of the most important aspects.

When going to the field, each participant is given a test section layout that depicts the order of the test sections along with the section-specific experimental factors. Bus transportation to the site is provided by the local ACPA chapter, with on-site traffic control provided by the SHA. Once on site, the participants walk the project and are encouraged to provide recommendations by test section for appropriate pavement preservation treatments. Also during the site visits, excellent dialogue between all participants occurs. For example, on the Arizona SPS-2, both the contractor's pavement superintendent and Arizona DOT's lead inspector reminisced about challenges during construction and observed how well (in most cases) the sections were performing, along with a few areas where significant distress had developed.

In surveying participants at the end of each Tech Day, the overwhelming response has been the event was extremely valuable. Participants provided the following reasons they found the event valuable:

- Having the rare opportunity to know exactly what was built and to be able to observe the resulting performance after 25+ years
- Seeing how well many of the test sections are performing
- Observing sections that aren't performing as well and discussing with others the possible reasons why
- Learning more about the LTPP program and the types of resources that are available through LTPP
- Understanding agency and contractor practices better and noting how they have evolved over the years

General observations by the SHAs have included the following:

Arizona (See Figure 4)

- Substantial surface cracking is present on most of the 900 psi test sections, with the cracking in the truck lane wheelpaths being more pronounced than in the passing lane.
- The 550 psi mixes showed substantial paste wear in the wheelpaths.
- The LCB sections have the most cracking, with the thin PCC sections on aggregate base also having significant cracking.
- The PATB and thick PCC section on aggregate base look very good, as do most of the Arizona supplemental test sections.

Figure 4. Arizona SPS-2 field visit

- With the shoulders not being tied, there was both horizontal and longitudinal movement of the truck lane with regards to the shoulder.
- The silicone joint sealant was predominantly in very good condition.
- Many of the supplemental test sections without dowels had significant faulting.

Colorado

- The 550 and 900 psi pavement sections were visibly different to the eye, with surface cracking visible on most 900 psi pavements and the paste being worn off (particularly in the wheel paths) on the 550 PSI pavements.
- There was some spalling of transverse joints.
- One of the LCB sections had cracked to the point of failure.
- Silicone sealant was missing in most joints.
- The standard state section has performed extremely well.

Iowa

- There was none of the surface cracking observed on most other projects on the 900 PSI sections, nor any significant paste wear on the 550 PSI sections.
- The interface between the truck lane and the AC shoulder was in poor condition, with some substantial settlement in areas.
- The depth of tining varied between sections, with no obvious cause (suggested that it may be due to the time between finishing paving and starting the tining).
- Grinding had been performed on several of the sections, along with some patching, and otherwise most sections were in excellent condition.

Kansas (See Figures 5 and 6)

- The 550 and 900 psi pavement sections were visibly different to the eye, with surface cracking visible on most 900 psi pavements and the paste being worn off (particularly in the wheel paths) on the 550 PSI pavements.
- Several sections had small longitudinal cracks along transverse joints that looked to align with the locations of the dowel bars—primarily on the 8" 900 psi sections.
- Grinding had been performed in several sections, and some sections (mostly on LCB base) had substantial cracking and patching.
- The passing lane exhibited more spalling of transverse joints than the truck lane.
- Both spalling and corner breaks were present in a few sections.

Figure 5. Kansas SPS-2 field visit, 900 psi surface cracking

Figure 6. Kansas Section 0209 (8 in. PCCP on 4 in. PATB and 4 in. DGAB, 550 psi mix, 12 ft. shoulder)

North Dakota (See Figures 7 and 8)

- Very few of the 900 psi pavement sections had visible surface cracking (other than over the dowels), and the minor surface cracking was mid-panel.
- The 550 psi mixes showed substantial paste wear in the wheelpaths.
- Cracking over the dowels on many test sections, similar to those in Kansas—reported by the agency to have occurred shortly after construction and not further deteriorated thereafter.
- CPR was performed in 2009 and 2016, so there were areas that previously had substantial cracking and/or spalling where the panels were replaced.
- The interface between the truck lane and the AC shoulder was in poor condition, and had been replaced twice since original construction.
- Grinding had been performed on several sections.

Washington (See Figure 9)

- The 550 and 900 psi pavement sections were visibly different to the eye, with surface cracking visible on most 900 psi pavements and the paste being worn off (particularly in the wheel paths) on the 550 PSI pavements.
- The interface between the truck lane and the AC shoulder was in poor condition.
- Most sites are in excellent condition, including the standard state section.
- Joint sealing was done with a hot pour sealant.
- The most substantial distress was in the first test section that was paved—likely due to construction issues more than loading or environmental influences.

Performance Commonalities Observed and Conclusions

While there is certainly more to be learned from the 2/3rds of SPS-2 sections still active and performing well, several trends have emerged in looking at the performance to date. These include the following:

- Roughness progression was very minimal on most sections, so initial smoothness correlated directly with smoothness over time.
- Sections constructed on PATB were smoother than sections constructed on LCB or untreated base.
- Widened slabs exhibited less faulting than conventional width slabs, but the overall level of faulting was ex-

Figure 7. North Dakota SPS-2 field visit, cracking over dowels

Figure 8. Closeup on North Dakota SPS-2

Figure 9. Washington SPS-2 field visit

tremely low for all doweled test sections, and would not be noticed by the driving public.

- The thin widened slabs had a propensity to have longitudinal cracking mid-panel—this was much less common in the conventional width slabs and the thicker widened slabs.
- Sections on untreated base showed more faulting than sections on LCB or PATB.
- Thinner sections developed more transverse cracks than thicker slabs (thinner sections on the widened lane showed the most transverse cracking).
- Sections on PATB showed the lowest cracking (both longitudinal and transverse), with sections on LCB having the highest cracking (again, both longitudinal and transverse).
- Map cracking was commonly present on the 900 psi test sections, while surface wear of the concrete paste was more prevalent on the 550 psi test sections.
- Because the experiment design called for all untied shoulders, no conclusions were drawn related to tied vs. untied shoulders. However, many participants across the various Tech Days observed that tied shoulders would have further improved test section performance.

Detailed investigations into the reasons for the above trends have not yet been completed. A prevalent point of discussion across all of the Tech Days was the comparatively worse performance of sections constructed on LCB sections. A common suggestion was that while there was not supposed to be a bond between the LCB and PCC, the methods used to separate the layers (typically a double coat of bond breaker) was not effective.

Looking ahead, the highest value to the pavement community will come from not only monitoring these sections as long as possible but also in applying appropriate preventive maintenance and replacing with new sections as appropriate.

In addition, work continues in scheduling Tech Days for those agencies with active SPS-2 projects. Information regarding scheduling is found both on InfoPave™ and on ACPA's web site (http://www.acpa.org/sps-2-tech-day-event-on-concrete-pavement-preservation/). Be on the lookout for one near you!