U.S. Department of Transportation
Federal Highway Administration

KEY FINDINGS

from LTPP Analysis

2000-2003

Contents

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2000-2003

The Long-Term Pavement Performance (LTPP) program, established in 1987, is a comprehensive 20-year study of in-service pavements using a series of rigorous long-term field experiments to monitor more than 2,400 asphalt and portland cement concrete (PCC) pavement test sections across the United States and Canada. The program's primary goal is to understand why some pavements outperform others. Knowledge of the factors contributing to good pavement performance is key to building and maintaining a cost-effective highway system.

LTPP has addressed topics ranging from traffic loading to pavement design, maintenance, and rehabilitation. Findings illustrate not only the immediate value of the LTPP database, but also its potential for improving pavement technology.

This document highlights some key findings from LTPP analysis studies completed between 2000 and 2003. A number of analysis projects have been conducted since the publication of the first volume in 2000, *Key Findings from LTPP Analysis 1990–1999*. In all, approximately 50 documents were reviewed, including LTPP research reports and National Cooperative Highway Research Program (NCHRP) projects using LTPP data. Most of these documents are available at the LTPP or NCHRP Web site. The goal of this report is to provide LTPP partners with information that can help them in their efforts to design, build, and maintain cost-effective and long-lasting pavements, by providing sections on:

- Site conditions.
- Structural features.
- Material characterization.
- Initial roughness.
- Pavement maintenance.
- Pavement rehabilitation.
- Local calibration of the *2002 Pavement Design Guide*.

LTPP PROGRAM

The LTPP program incorporates two major studies—the Specific Pavement Studies (SPS) and the General Pavement Studies (GPS). The primary goal of SPS experiments is to conduct detailed analysis of specific performance factors of newly constructed pavements and overlays. In contrast, the primary goal of GPS experiments is to analyze performance factors of existing pavements and overlays.

SPS Experiments: Analyses of newly constructed pavements and overlays:

SPS-1	*Study of Structural Factors for Flexible Pavements*
SPS-2	*Study of Structural Factors for Rigid Pavements*
SPS-3	*Preventive Maintenance Effectiveness of Flexible Pavements*
SPS-4	*Preventive Maintenance Effectiveness of Rigid Pavements*
SPS-5	*Rehabilitation of Asphalt Concrete (AC) Pavements*
SPS-6	*Rehabilitation of Jointed PCC Pavements*
SPS-7	*Bonded PCC Overlays of Concrete Pavements*
SPS-8	*Study of Environmental Effects in the Absence of Heavy Loads*
SPS-9	*Validation of Superpave® Asphalt Specifications and Mix Design*

GPS Experiments: Analyses of existing pavements and overlays:

GPS-1	*AC on Granular Base*
GPS-2	*AC on Bound Base*
GPS-3	*Jointed Plain Concrete Pavements (JPCP)*
GPS-4	*Jointed Reinforced Concrete Pavements (JRCP)*
GPS-5	*Continuously Reinforced Concrete Pavements (CRCP)*
GPS-6A	*Existing AC Overlays on AC Pavements*
GPS-6B	*New AC Overlays on AC Pavements*
GPS-7A	*Existing AC Overlays on PCC Pavements*
GPS-7B	*New AC Overlays on PCC Pavements*
GPS-9	*Unbound PCC Overlays of PCC Pavements*

SITE CONDITIONS

Pavement projects start out with a given set of site conditions, including traffic, climate, and subgrade/foundation. LTPP data analyses have shown that each of these site conditions affects pavement performance. While these conditions cannot be controlled, they always should be considered. In critical situations, the pavement design features should be selected to mitigate the adverse effects of site conditions on performance. The following key findings from several LTPP site conditions analyses are grouped into three areas: traffic, climate, and subgrade/foundation.

TRAFFIC

1

Report No. FHWA-RD-00-054
Information on cumulative truck axle loads plays an important role in pavement design and performance analysis. It is especially crucial for mechanistic design methods and load-related distress prediction models. A comprehensive traffic load spectra projection methodology was developed using a corridor-assignment model and evaluated at 12 LTPP test sections. Initial results indicate that the proposed methodology can provide feasible traffic load projections.

2

Report No. FHWA-RD-00-054
The new traffic load projection methodology provides a way to predict annual axle load spectra. These are the frequency distributions of axle weight of a given axle type into weight ranges for:

- All in-service years of a roadway segment.
- Single, tandem, and tridem axles.
- All trucks combined (Federal Highway Administration (FHWA) vehicle classes 4 through 13).

The cumulative axle load spectra can be obtained by summing the annual axle load spectra to the year of interest.

3

Report No. FHWA-RD-03-094
Annual axle load spectra projected by the traffic load projection methodology for all in-service years up to 1998 were concluded to be reasonable (i.e., falling into expected ranges) for the majority (558, or 63 percent) of the 890 LTPP traffic sites. The traffic load spectra projected for the remaining 332 (37 percent) of traffic sites were considered unreliable because of inadequate or missing data collected at those sites.

4

Report No. FHWA-RD-03-094
The LTPP *Pavement Loading Guide* (PLG) was developed to overcome the difficulty of estimating traffic loads for the remaining 332 (37 percent) of the 890 LTPP sites. The document contains guidelines for the development of the PLG along with two examples using the PLG to obtain traffic load projections for LTPP sites without site-specific truck class and/or axle load data.

5

Report No. NCHRP 20-50(5)
In pavement design, the vehicle class distribution and the axle load spectrum cannot be assumed using a default or single load distribution for either the roadway functional class or a region.

6

Report No. NCHRP 20-50(5)
To make predictions that can be used with confidence, research quality traffic survey data of at least 5 years is recommended, which should include accurately measured vehicle classes, number of axle loads, and load configurations for a given roadway segment.

7

General Traffic Pattern Findings

Report No. FHWA-RD-03-094

Based on the 558 LTPP traffic sites with reasonable axle load projection results, general traffic pattern findings obtained are summarized as follows:

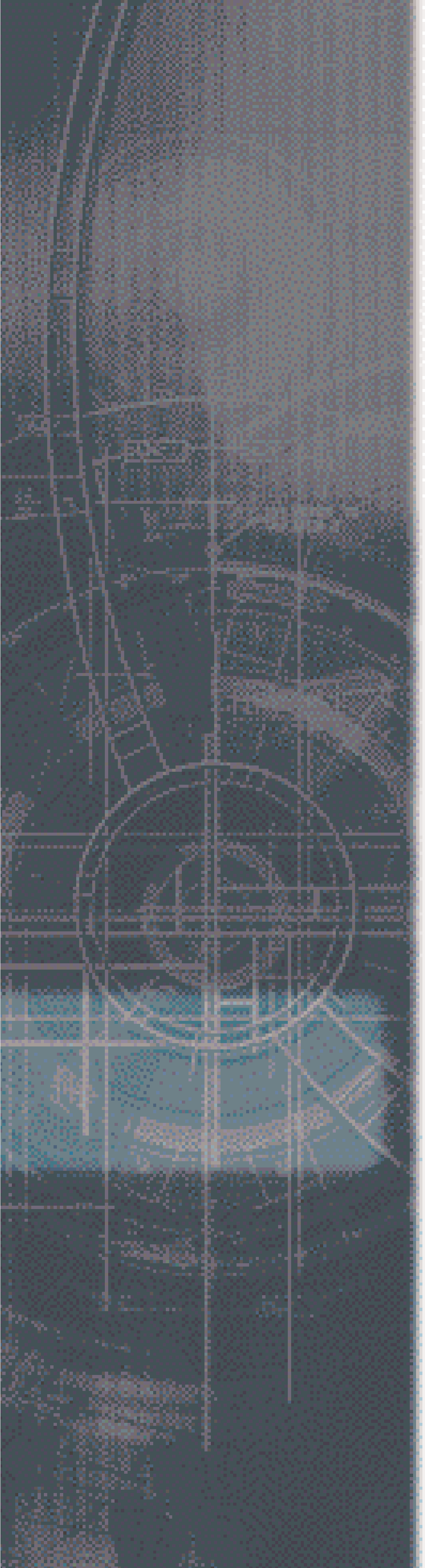
- The leading 4 traffic load contributors are 5-axle single trailer trucks (FHWA vehicle class 9), 2-axle-6-tire single unit trucks (class 5), 3-axle single unit trucks (class 6), and 4-axle or fewer single trailer trucks (class 8). These four vehicle classes comprise 90 percent of the vehicles projected.
- The projected percentages of all vehicles contributed by 5-axle single trailer trucks and 2-axle-6-tire single unit trucks are listed, respectively, for four roadway functional classes:
  - For urban principal interstates: 50 percent and 25 percent, respectively.
  - For urban principal freeways and expressways: 45 percent and 20 percent, respectively.
  - For rural principal interstates: 65 percent and 10 percent, respectively.
  - For rural principal freeways and expressways: 50 percent and 20 percent, respectively.
- The minimum average daily traffic truck volume ranges from 30 trucks per day for a site located on a rural minor arterial highway to 6,310 trucks per day on a site located on an urban interstate highway. Between 1994 and 1998, the projected mean annual growth rate in truck volumes was:
  - For urban freeways and expressways: 6.5 percent.
  - For rural interstates: 4.6 percent.
  - For rural minor arterial highways: 3 percent.

8

Vehicle Characteristics

Report No. FHWA-RD-00-054

- As of 1998, the nearly exclusive use of radial truck tires was observed at all LTPP sites. By comparison, 74 percent of all truck tires were radials in 1988.
- The use of air suspension in trucks has increased. As of 1998, about 80 percent of all new truck tractors and about 60 to 70 percent of all new semi-trailers were equipped with air suspension.
- Compared to bias ply tires, radial tires operate at higher tire pressures and, thus, generate more sharply defined imprints on pavements, which represent more concentrated loads.
- Compared to the traditional spring-leaf suspension, air suspensions are considered to generate lower dynamic pavement loads. However, air suspensions result in a common high dynamic load frequency regardless of load magnitude. The spatial concentration of traffic loads leads to accelerated localized pavement damage.



CLIMATE

1 Climatic Effects on Pavement Performance

Report No. FHWA-RD-01-167

- In the SPS-2 experiment, the highest transverse cracking was observed in the slabs built in the dry no-freeze climates, followed by the wet-freeze climates, and then by the dry-freeze climates. The slabs built in the wet no-freeze climates have the lowest transverse cracking. The data support similar findings from earlier studies that, in drier climates (the western United States) where high thermal gradients exist, it is important to design for resistance to transverse cracking (shorter joint spacing minimizes the adverse effect of climate).

- The largest longitudinal cracking lengths of SPS-2 sections occurred in the dry no-freeze climates, followed by the dry-freeze climates, and then by the wet-freeze climates. The lowest longitudinal cracking lengths were observed in those sections built in the wet no-freeze climates.

2 Estimating Climatic Parameters Using Virtual Weather Stations Data

Report No. FHWA-RD-03-092

- The daily, monthly, and yearly LTPP Virtual Weather Station (VWS) climatic estimates obtained by a newly developed model were found to be reasonably accurate for locations across North America. The climatic conditions (including air temperature, precipitation, humidity, freezing index, and wind speed) for 880 SPS and GPS pavement sections are estimated using data from as many as 5 nearby national weather stations. These VWS estimates are compared to onsite data for the same time period measured by the Seasonal Monitoring Program (SMP) at 63 GPS and SPS sections and by Automatic Weather Stations at 35 SPS test sections. Results of this comparison have verified that the model for developing VWS estimates can be a useful tool to predict climatic conditions.

- The LTPP VWS climatic estimates also were found to compare well to the National Climatic Data Center's (NCDC) measurements. These data were collected from 1994 through 1996 for the NCDC Cooperative Program; they covered 8,000 weather stations scattered over 5,347 NCDC sites throughout the United States.

- A difference in elevation between a project site and the nearby weather station(s) of more than 250 meters (m) (825 feet (ft)) significantly affects the climatic estimates. In this case, temperatures must be corrected to reduce the bias of the estimate. A model was developed for correcting the maximum temperature for elevation difference.

- Within a range of 60 kilometers (km) (37.5 miles), the distance of the contributing weather stations from a project site does not affect the VWS estimates at any project site.

3

Variability of Climatic Parameters

FHWA-RD-03-092

Significant year-to-year variability was observed in climatic data, an important factor for pavement design procedures. The year-to-year variability of annual precipitation is 21 percent; and of the freezing index, 34 percent. On average, the year-to-year variability of monthly temperature data is 6 percent.

SUBGRADE/FOUNDATION

1

Environmental Effects in the Absence of Heavy Load

Report No. FHWA-RD-02-087

It is very important to study the effects of environmental factors such as climate and subgrade on the performance of flexible and rigid pavement with a reduced number of heavy axle loads. The SPS-8 experiment is designed to emphasize the effects of site-related factors (temperature, precipitation, and subgrade) and structural factors (pavement type and layer thickness) on flexible and rigid pavements with no more than 10,000 18-kip equivalent single-axle loads (ESALs) per year in the study lane. The SPS-8 experiment can be considered as an extension of SPS-1 (new flexible pavements) and SPS-2 (new rigid pavements) with limited traffic effects.

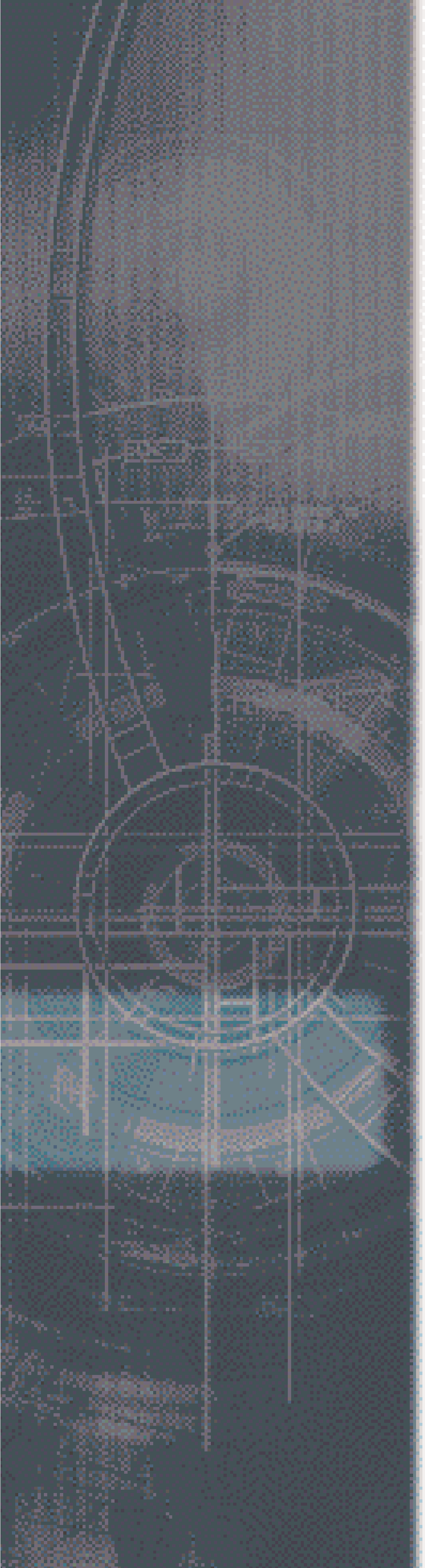
- Temperature and Precipitation

  For SPS-8 AC sections, the most prevalent early distress is longitudinal cracking outside the wheel path. The distress is most commonly observed for sections built in the wet-freeze climates and for sections on an active subgrade (frost-susceptible or swelling soils due to freeze-thaw cycles). Fatigue, longitudinal cracking in the wheel path, and transverse cracking are present on just a few sections. The mean rut depths for all AC sections are below 6 millimeters (mm) (0.24 inches).

- Subgrade

  - Pavements (flexible or rigid) constructed on active subgrade have the highest mean initial International Roughness Index (IRI) values and slopes (the smoothness rate of change over time), followed by pavements constructed on fine subgrade, and coarse subgrade. The data support a similar finding from previous studies that a good working platform (specifically, stabilized base and granular subgrade or embankment) contributed to a smoother pavement construction.

  - Initial IRI values for the SPS-8 test sections show that flexible pavements were constructed to be smoother than the rigid pavements. The analysis of IRI slopes indicates that the subgrade is the most important factor for flexible sections, while precipitation appears to be the most important factor for rigid sections.



- Pavement Type and Layer Thickness
  - The SPS-8 flexible pavements with thin (102-mm (4-inch)) AC surface layers were found to be smoother than the sections with thick (178-mm (7-inch)) AC layers. Similarly, the SPS-8 rigid pavements with thin (203-mm (8-inch)) concrete slabs were constructed to be smoother than the sections with thick (279-mm (11-inch)) concrete slabs. This seems to contradict the general idea that thicker surface layers can generate smoother pavements. Further investigations should be conducted.
  - A few of the SPS-8 PCC sections have very limited transverse cracking and joint faulting. The mean joint faulting on all PCC sections is insignificant, i.e., below 0.4 mm (0.02 inches). However, these observations are based on 8 years of data (the oldest SPS-8 test section was 8 years old as of June 2001), which is early in terms of pavement life.
- Comparisons of SPS-1, -2, and -8 Test Sections
  - As expected, traffic loading is much heavier on SPS-1 and SPS-2 than on SPS-8 sites. As of June 2001, the estimated accumulated ESALs on SPS-1 sites was about 1.46 million, compared to 0.043 million ESALs on SPS-8 AC sites. Similarly, SPS-2 sites had accumulated 4.77 million ESALs, compared to 0.23 million ESALs on SPS-8 PCC sections.
  - The average IRI slopes (the smoothness rate of change over time) for both SPS-1 and SPS-2 sections are much higher than for the corresponding SPS-8 sections. The variability of mean IRI slopes is higher for PCC than for AC sections.
  - Overall, the much more heavily loaded SPS-1 and SPS-2 sections exhibit higher amounts of load-related distresses. Such distresses include AC rutting, AC fatigue cracking, JPCP joint faulting, and JPCP transverse cracking. However, the non-load-related distresses including AC transverse cracking and non-wheel path longitudinal cracking are similar for SPS-1, SPS-2, and SPS-8.

2

Moisture Contents

Report No. FHWA-RD-99-115

The Time Domain Reflectometry (TDR) technique measures the dielectric constant of soils in the LTPP SMP. This constant can be used to compute the in-situ moisture content of unbound base and subgrade materials. This study was intended to develop procedures to produce good estimates of in-situ gravimetric moisture content using the TDR traces in the LTPP database.

- In-situ gravimetric moisture content of unbound base and subgrade materials can be determined using a two-step procedure:
  - Volumetric moisture content of unbound base and subgrade materials is determined using four proposed models based on LTPP TDR traces and necessary material properties.
  - In-situ gravimetric moisture content is then determined using two newly developed methods based on volumetric moisture content.
- The two-step procedure was further developed into a user-interactive computer program, MOISTER. The program is used to determine moisture content of unbound base and subgrade materials.

3

Frost Penetration

Report No. FHWA-RD-99-088

The bulk resistivity of a soil increases dramatically when the soil freezes. The electrical resistivity technique is used to measure the electrical resistance, which is the voltage drop divided by the current passing through a pavement depth, which is based on Ohm's law. Together with soil temperature measurements, the electrical resistivity (i.e., geometry-adjusted resistance) is used to estimate the depth of frost penetration beneath a pavement section.

- A user-interactive computer program, FROST, was developed to facilitate the determination of frost penetration depth within a pavement structure by interpreting the electrical resistivity and soil temperature data collected at the SMP sections.
- The moisture content of a soil determined by MOISTER (FHWA-RD-99-115) based on the TDR data can be used to confirm the freezing events as determined by FROST. The rationale is that the moisture content computed by TDR data does not include the frozen water (ice content). Hence, when a soil freezes, its TDR-computed moisture content drops because its unfrozen moisture content decreases.

STRUCTURAL FEATURES

Producing an effective pavement design is a complex process. The obvious decisions—asphalt or concrete, and how thick—are critical, but there are other equally important decisions regarding other structural features that can assist with a pavement design. The following are key findings from several LTPP analyses on the effects of structural features on pavement performance. These findings are grouped into two areas: rigid and flexible pavements.

RIGID PAVEMENTS

1

Slab Thickness
Report No. FHWA-RD-01-167
In the SPS-2 experiment:

- Thinner slabs (203 mm (8 inches)) develop more transverse cracking than do thicker slabs (279 mm (11 inches)). These data support a similar finding from earlier studies that slab thickness has a strong effect on transverse cracking.
- Thinner slabs (203 mm (8 inches)) have more longitudinal cracks than do thicker slabs (279 mm (11 inches)). Sections with a thinner slab and widened slab show the highest level of longitudinal cracking.
- Thinner slabs (203 mm (8 inches)) with lower (3.8 megapascals (MPa) (550 poundforce per square inch (psi)) 14-day strengths were found to be smoother than thicker slabs (279 mm (11 inches)) with higher (6.2 MPa (900 psi)) 14-day strengths.

2

Slab Widening
Report Nos. FHWA-RD-00-076 and FHWA-RD-01-167
For jointed concrete pavements (JCP) with nondoweled joints, the PCC slabs originally built wider by 0.6 m (2 ft) (i.e., 4.26 m (14 ft) in total) as compared to conventional-width (3.66 m (12 ft)) slabs appear smoother and show reduced joint faulting. The reduction in joint faulting is achieved by moving wheel loads further away from the corner of the slab, reducing the frequency of traffic encroachment to the slab corner or pavement edge. This confirms a similar finding from a previous study.

3

Base
Report No. FHWA-RD-01-167

- In the SPS-2 experiment, the sections with permeable asphalt-treated base developed the fewest transverse and longitudinal cracks, whereas the sections with lean concrete base developed the most transverse and longitudinal cracks over the first 10 years of pavement life. This confirms a similar finding from previous studies.
- In the SPS-2 experiment, those sections built over a permeable asphalt-treated base with edge drains or aggregate base were found to be smoother than those over lean concrete base.

4

Subgrade
Report No. FHWA-RD-01-167
The SPS-2 JCP without dowels built over fine-grained subgrades are rougher after construction than those built over coarse-grained subgrades. Stiffer foundation appears to be a key factor.

❺ Subdrainage

Report No. NCHRP Project 1-34B

- Based on 7 years (on average) of SPS-2 data, for JCP with dowels, both permeable bases and edge drains were not found to reduce joint faulting significantly.

Report No. NCHRP Project 1-34C

In the SPS-2 experiment:

- For IRI, transverse cracking, and longitudinal cracking with all other factors matched:
  - Pavement sections with undrained dense-graded aggregate bases tend to perform more poorly than those with drained permeable asphalt-treated bases.
  - Pavement sections with undrained lean concrete bases tend to perform more poorly than those with drained permeable asphalt-treated bases.
- The faulting levels were too low for analysis.

❻ Joint Faulting

Report No. FHWA-RD-00-076

- Based on the faulting data collected from 307 test sections in the SPS-2, SPS-4, SPS-6, SPS-8, GPS-3, GPS-4, and GPS-9 experiments, the presence of dowels was found to be the most effective of the design features examined in controlling joint faulting. When doweled joints are used, the effects of design features such as subdrainage, tied-concrete shoulders, and joint spacing are not as significant. The analysis supports a similar finding from a previous study that JCP with dowels had 50 percent less joint faulting than those without dowels.
- Widened lanes showed significant reduction in joint faulting for both doweled and nondoweled joints.
- Effective subdrainage designs reduce faulting for all types of pavements and designs, especially for nondoweled sections.
- For nondoweled JPCP, the following design features were found to significantly reduce faulting:
  - Use of widened lanes.
  - Effective subdrainage system.
  - Stabilized base/subbase.
  - Shorter joint spacing.
- The analysis results confirm similar findings from previous studies reviewed in the *Key Findings from LTPP Analysis 1990–1999* brochure.

- The use of load transfer devices (circular steel dowels) has the greatest effect on the amount of joint faulting for all concrete pavements. Sections with dowels having larger diameters (e.g., 38 mm (1.5 inches)) exhibited much less faulting. The use of properly sized dowel bars reduces joint faulting of JPCP by more than a factor of two.
- The nondoweled JPCP sections located in the colder and wetter climates exhibit the worst faulting among all sections examined. This also confirms a similar finding from previous studies.
- In the SPS-2 experiment:
  - Doweled joint faulting occurred mostly in the dry-freeze climates, followed by the dry no-freeze climates, and the wet-freeze climates. Sections in the wet no-freeze climates have the least faulting.
  - Sections with an unbound aggregate base have the highest doweled joint faulting level. Sections with a lean concrete base and permeable asphalt-treated base have the lowest doweled joint faulting.
  - Widened (4.27 m (14 ft)) slab sections have less faulting than conventional-width (3.66 m (12 ft)) slabs.

Report No. FHWA-RD-01-167

- The data support similar findings from other studies.

Load Transfer Efficiency

7 Load transfer efficiency (LTE) of cracks and joints profoundly affects the performance of concrete pavements.

Report No. FHWA-RD-02-088

- Poor correlation was found between LTE and design parameters such as PCC thickness, PCC strength, steel content, joint spacing, and joint orientation.

Report No. FHWA-RD-96-198

- The presence of properly sized dowels at the joint will eliminate corner breaks and transverse cracking near the joint as well as minimize joint faulting.

Report No. NCHRP 20-50(5)

- For pavement engineers to incorporate variations in LTE into design, NCHRP Project 20-50(5), *Variations in Pavement Design Inputs*, outlines recommendations for LTE variability for three types of concrete pavements: JCP with no dowels at joints, JCP with doweled joints, and CRCP (LTE at transverse cracks).
  - JCP with nondoweled joints:

    The variability of the average LTE of a given section measured over time is inversely correlated to the average LTE. As the average section LTE increases, the variability decreases.

The average joint spacing, base type, and outside shoulder type (PCC or AC) show no effect on the variability of the average LTE measured over time.

The average LTE of pavements with subsurface drainage systems has higher variability measured over time than that of pavements without subsurface drainage systems.

The average LTE of pavements with a granular subgrade has higher variability than pavements with a silty clay subgrade.

The amount of annual precipitation, the number of annual freeze-thaw cycles, and the average mean annual temperature do not have any effect on the variability of the average LTE measurements over time. However, the variability of the average LTE seems to decrease as the annual freezing index increases.

There is no direct relationship between pavement age and the variability of LTE measurements over time.

- JCP with doweled joints:

The variability of the average LTE measured over time is inversely correlated to the average LTE. As the average LTE increases, the variability decreases.

The average joint spacing and base type do not show any effect on the variability of the average LTE measured over time.

The average LTE of pavements with a concrete shoulder has higher variability than that of pavements with an asphalt shoulder.

The average LTE of pavements with subsurface drainage systems has lower variability than that of pavements without subsurface drainage systems.

The amount of annual precipitation, the number of annual freeze-thaw cycles, and the average mean annual temperature do not show any effect on the variability of the average LTE measured over time. However, the variability of the average LTE seems to decrease as the annual freezing index increases.

There is no direct relationship between pavement age and the variability of LTE measurements over time.

- CRCP:

  No apparent relationship was found between the variability of the mean transverse crack LTE measured over time and the mean crack LTE. Ranges of both crack LTE and its variability are very small. This is expected because the transverse cracks are strongly reinforced and changes in crack width and LTE are minimal.

  The average crack spacing of the CRCP slabs, base type, slab stiffness, and outside shoulder type does not have any effect on the variability of the average LTE measured over time.

  The average crack LTE of CRCP with subsurface drainage systems has lower variability than those of pavements without subsurface drainage systems.

  The amount of annual precipitation does not show any effect on the variability of the average crack LTE. However, the variability of the average LTE seems to decrease as the annual freezing index increases.

  No direct relationship between pavement age and the variability of crack LTE was observed. This is expected because an increase in variation would indicate a deterioration of transverse cracks in CRCP, which would lead to rapid failure.

8 **Joint Spacing**

Report No. FHWA-RD-00-076

- For JRCP sections in good condition, the average joint spacing is about 13 m (43 ft). For JRCP sections in poor/normal condition, the spacing is approximately 18 m (59 ft). The LTPP data shows that the joint spacing of sections in good condition is significantly shorter. This confirms a similar finding from previous studies reviewed in the *Key Findings from LTPP Analysis 1990–1999* brochure.

Report No. FHWA-RD-96-198

- Thermal gradients, moisture gradients, and built-in construction curling are important considerations in overall slab support. These considerations should be used along with traffic loadings and slab thickness in the selection of appropriate joint spacing for JCP with nondoweled joints.

9

Joint Type

Report No. FHWA-RD-00-076

- Large-diameter dowel bars reduce joint faulting more than do small-diameter dowel bars. For example, pavements with 38-mm (1.5-inch) diameter dowels have very little faulting regardless of other design features.
- Results show that doweled joints do not need to be skewed to control faulting and provide reinforcement. Skewed joints are primarily introduced to minimize the impact slab curling and joint faulting have on vehicles. This provides reinforcement to the same finding from a previous study.

10

CRCP

Report No. NCHRP 20-50(8/13)

CRCP has the potential to provide long-term, smooth, and low-maintenance service life, as evidenced by many well-performing sections in the GPS-5 experiment (existing CRCP).

- Steel content was concluded to be the most important factor in CRCP performance. This is consistent with previous findings.
- The CRCP sections in the GPS-5 experiment have shown little change in roughness over the monitored period, and many of the pavements are very old.
- The parameters with higher parameter values found to contribute to higher levels of roughness in CRCP include:
    - For both wet-freeze and wet no-freeze weather zones: the PCC elastic modulus and the ratio between the PCC elastic modulus and tensile strength.
    - For the wet-freeze weather zone: the content of fines in the subgrade, the moisture content in the subgrade, and the number of wet days per year.
    - For the wet no-freeze weather zone: the number of days per year greater than 32 °C (90 °F).
- The parameters with higher parameter values found to contribute to lower levels of roughness in CRCP pavements include:
    - For both wet-freeze and wet no-freeze weather zones: the PCC water-cement ratio.
    - For the wet-freeze weather zone: none of the factors studied was found to contribute to lower levels of roughness.
    - For the wet no-freeze weather zone: the number of wet days per year.

11

Variability of PCC Pavement Design Parameters
Report No. NCHRP 20-50(5)
To help pavement engineers incorporate the variability of PCC pavement parameters into design, NCHRP Project 20-50(5), *Variations in Pavement Design Inputs*, presents variability recommendations for four key laboratory concrete strengths and four backcalculated PCC pavement design parameters, respectively.

- Variability of concrete strengths (laboratory):
  - Compressive strength data variability: For the GPS sections, the variability of the 7-day and 28-day strengths was found to be similar. For the SPS test sections, it was found that the variability was also independent of test age (7 days, 21 days, and 1 year) and specimen type (cylinders versus cores).
  - Flexural strength data variability: For both the GPS and SPS sections, the variability of flexural strength appears to be independent of age at time of testing.
  - Split-tensile strength data variability: Only SPS-2 data were available for analysis. The variability of split-tensile strength data was found to be independent of age at testing.
  - Modulus of elasticity data variability: Only SPS-2 data were available for analysis. The variability of concrete modulus of elasticity was found to be independent of age at time of testing.
  - The recommended magnitudes of acceptable variability for the above four laboratory concrete strength measurements are available in the report for pavement design consideration.
- Variability of backcalculated moduli data for PCC pavements:
  - The variability associated with four backcalculated parameters for PCC pavements was found to be relatively low and consistent from one testing time to another over a period of several years. The four backcalculated parameters investigated were:

    Modulus of subgrade reaction.

    Concrete modulus of elasticity-dense liquid foundation.

    Subgrade modulus of elasticity-elastic solid foundation.

    Concrete modulus of elasticity-elastic solid foundation.
  - The recommended magnitudes of variability for the above four backcalculated PCC pavement design parameters are available in the report for design consideration.

1

Layer Thickness

Report No. FHWA-RD-01-166

- The SPS-1 test sections with thick (178-mm (7-inch)) AC surface layers appear to be smoother and develop less fatigue cracking than those sections with thin (102-mm (4-inch)) surface layers. This confirms a similar finding from earlier studies.
- In the SPS-1 experiment, AC surface thickness and the age of the project appear to influence the amount of fatigue cracking that occurs. The test sections that are younger and have thicker AC surface layers have the least fatigue cracking.

Report No. NCHRP 20-50(5)

- For pavement designers to predict that a given layer thickness will be constructed at least as thick as was assumed in design, several layer thickness adjustment recommendations are available in NCHRP Project 20-50(5), *Variations in Pavement Design Inputs*, for the following layer materials falling within qualified thickness ranges:
  - Unbound granular base layers from 100 to 360 mm (4 to 14 inches).
  - Treated (with either portland, asphalt, or lime cement in small quantities) base layers from 100 to 150 mm (4 to 6 inches) and 180 to 250 mm (7 to 10 inches).
  - Asphalt-bound layers (surface AC and asphalt-treated base) from 100 to 180 mm (4 to 7 inches) and 200 to 300 mm (8 to 12 inches).
  - AC overlays from 50 to 130 mm (2 to 5 inches) over existing AC.
  - AC overlays around 100 mm (4 inches) over existing PCC.

2

Base

Report No. FHWA-RD-01-166

In the SPS-1 experiment:

- Hot-mix asphalt (HMA) pavements with unbound aggregate base layers show greater rut depths than those sections with asphalt-treated base layers. This suggests that a portion of the rutting measured at the surface is a result of permanent deformations in the unbound aggregate base layer, which is consistent with a previous finding from analysis of the GPS test sections.
- The HMA pavements with unbound aggregate layers have slightly more fatigue cracking and higher IRI values than those sections with asphalt-treated base layers.

- The test sections with coarse-grained soils, asphalt-treated base layers, permeable base layers, thicker bases, and thicker HMA layers were found to be smoother.
- The test sections with permeable asphalt-treated base layers exhibit more fatigue cracking than those without permeable base layers.

Report No. NCHRP 20-50(8/13)
GPS-2 (AC pavements on stabilized base):

- For the asphalt-treated bases in the GPS-2 projects, a higher rate of increase of IRI is noted for sections with high AC void ratios (percentage of air voids per unit AC volume).
- For the cement-treated bases in the GPS-2 projects, a higher rate of increase of IRI is observed for sections in warmer climates.

3

Subgrade
Report No. FHWA-RD-01-166
In the SPS-1 experiment:

- HMA pavements built over coarse-grained subgrade soils are smoother than pavements built over fine-grained subgrade soils. This is consistent with the finding in the SPS-2 JPCP: A stiffer foundation contributes to smoother pavements.
- HMA pavements built over coarse-grained subgrade soils and in a no-freeze climate are smoother and stay smoother over a longer period of time than do those built over fine-grained subgrade soils in a freeze climate.
- HMA pavements built over fine-grained subgrades and in a wet-freeze climate are substantially rougher than those built in other climates.
- HMA pavements built over fine-grained subgrade soils have more fatigue cracking than those projects built over coarse-grained subgrade soils.
- Subgrade soil type and, to a lesser degree, age are important to the amount of transverse cracking measured at each site. More transverse cracking has occurred on the HMA pavements built on fine-grained soils than on pavements built on coarse-grained soils.

4

Subdrainage
Report No. NCHRP Project 1-34B

- Based on 7 years (on average) of SPS-1 data, those HMA sections built on permeable bases without edge drains were found to perform better than those with edge drains.

Report No. NCHRP Project 1-34C
In the SPS-1 experiment:

- In terms of IRI and cracking with all other design features matched, from poor to good performance: undrained dense-graded aggregate bases, drained permeable asphalt-treated bases, and undrained dense-graded asphalt-treated bases.
- In terms of rutting, the results for the above three subdrainage designs are inconclusive, thus far.

5 **Variability of AC Pavement Design Parameters**
Report No. NCHRP 20-50(5)
To help pavement engineers incorporate the variability of AC pavement parameters into design, NCHRP Project 20-50(5), *Variations in Pavement Design Inputs*, presents variability recommendations for backcalculated surface AC layer and for subgrade modulus of elasticity.

- The variability of the backcalculated AC modulus is independent of the falling weight deflectometer (FWD) drop height.
- The data analysis indicates that the variability of the backcalculated subgrade modulus is not related to the environmental zone in which the pavements are located.
- AC layers, as well as granular base layers, have less variability in backcalculated moduli than other underlying layers.
- The variability associated with AC layer backcalculated modulus is primarily dependent on the season in which the FWD measurements are taken. Layers underlying the AC layer in AC-surfaced pavements display no discernable patterns in relation to the season.

GUIDE TO PAVEMENT LAYER THICKNESS DATA

Report Nos. FHWA-RD-03-040 and FHWA-RD-03-041
A users guide has been developed to provide guidance for selecting layer material and thickness data from the LTPP database. The LTPP database contains extensive information for pavement layer material type and thickness (as-designed versus as-constructed) for both rigid and flexible pavements. Such information is very important for many types of analyses including backcalculation of layer moduli, mechanistic analysis of pavement structures, and performance modeling. Layer thickness variability and the comparisons of thickness design versus constructed values for various pavement layer types are also available in the users guide.

MATERIAL CHARACTERIZATION

The knowledge of pavement layer material properties is important for modeling pavement behaviors. The following are summaries from several LTPP material studies.

BACKCALCULATION OF PAVEMENT LAYER MATERIAL PROPERTIES

Pavement material properties such as stiffness (modulus of elasticity) can be backcalculated from FWD layer-deflection data by three approaches: the slab on elastic solid (ES) foundation, the slab on dense liquid (DL) foundation, and the elastic layer procedures. While the ES and DL approaches are used for rigid pavements only, the elastic layer approach can be used for both rigid and flexible pavements.

The LTPP program conducted two studies to demonstrate how the LTPP deflection data can be used for backcalculation of pavement layer material properties. In the first study, the ES and DL approaches were used; the elastic layer approach was used in the second study for backcalculation of pavement material properties. The following findings are obtained from the two studies.

1

Backcalculation of Rigid Pavement Layer Parameters
Report No. FHWA-RD-00-086
The layer material properties for rigid pavements are backcalculated using FWD deflection data from the LTPP database by the ES and DL foundation approaches.

- For the SPS and GPS test sections studied:
  - PCC moduli:

    The majority of the backcalculated PCC moduli using either the ES or DL subgrade approach fall in the range of 25,000 to 55,000 MPa (3,625 to 7,977 ksi). It seems that the two backcalculation approaches can generate acceptable PCC moduli.

    The PCC moduli obtained by the ES approach are consistently lower than the DL approach. This is expected because an ES foundation provides significant shear load redistribution while the DL approach provides no shear load redistribution.
  - Base moduli:

    For treated base materials, the backcalculated base moduli were found to be within reasonable ranges using either the ES or DL approach. The backcalculated base moduli obtained by the ES approach appear to be higher than the DL approach.

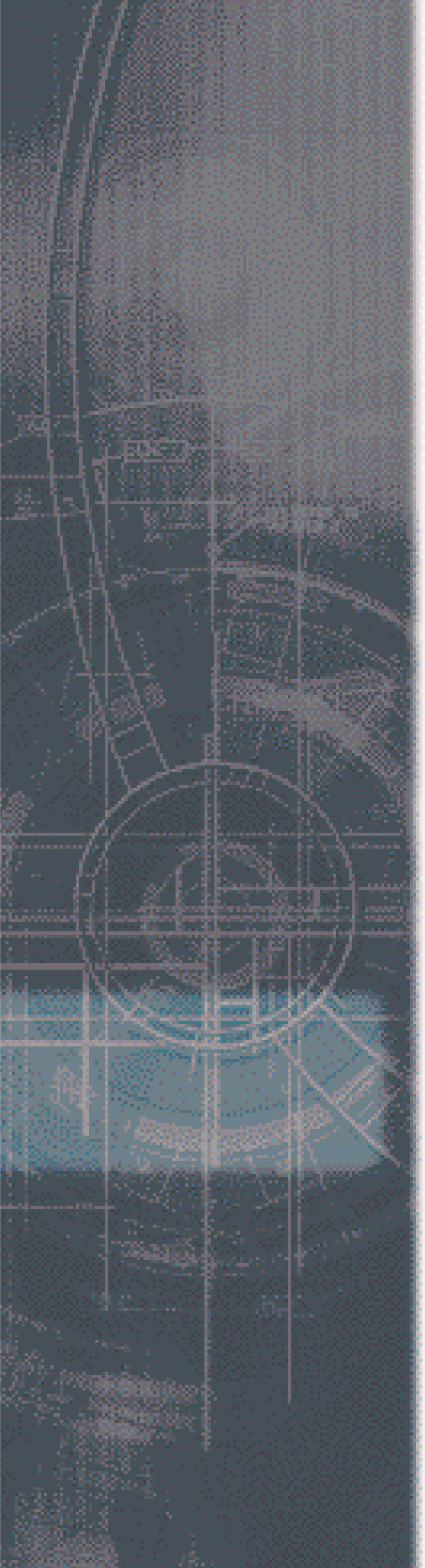
    For untreated base materials, the backcalculated base moduli obtained by the ES approach are usually lower than the DL approach. Base moduli backcalculated using either the ES or DL approach fall in reasonable ranges.

- For the SMP test sections studied, both backcalculated moduli of elasticity of the subgrade using the ES approach and moduli of subgrade reaction (k-value) using the DL approach fall in reasonable ranges, as do backcalculated radii of relative stiffness.
- For the SPS, GPS, and SMP test sections studied, the backcalculation results using either the ES or DL model do not depend on FWD load level. This supports a similar finding obtained from earlier studies.
- Slab curling due to temperature increase during the day increases the variability in the backcalculation results. Conducting FWD basin testing early in the morning when temperature gradients are low will reduce variability in backcalculated parameters.
- Poor correlation was found between backcalculated and laboratory elastic moduli of concrete.

2

Backcalculation of Flexible and Rigid Pavement Layer Parameters
Report No. FHWA-RD-01-113
Layer properties of flexible and rigid pavements are backcalculated from FWD deflection measurements in the LTPP database using an elastic layer approach.

- The backcalculated elastic layer moduli obtained in this study were found to be consistent with earlier studies.
    - Seasonal effects: Moduli of AC surface layers, base layers, and subgrade increase for the winter months and decrease in the summer months.
    - Temperature effects: Moduli of AC surface layers increase as mid-depth pavement temperature decreases.
    - Time effects: Moduli of the AC and PCC surface layers increase with respect to pavement age. This is due to hardening and curing.
- No significant difference in the computed layer moduli (Young's) was found between the wheel path and non-wheel path deflection measurements.



FWD DATA FOR QUALITY CONTROL/QUALITY ASSURANCE MEASURE

Report No. NCHRP 20-50(9)

The feasibility of using FWD data as a quality control and quality assurance measure during the construction of pavement structures has been an interesting topic. The key findings of NCHRP Project 20-50(9) are presented below.

- In general, FWD test results provide data that can be used with confidence to estimate material properties—mainly stiffnesses or moduli—and their variations at each layer interface during new or reconstructed pavement construction. These values generally follow a similar deflection pattern from layer to layer with respect to stationing. Moreover, these FWD data are moderately well correlated to other measures (e.g., material densities) of pavement quality.
- The correlations between the FWD-derived unbound material parameters (e.g., stiffness) and many of the traditional unbound material parameters were found to be fair to good. Similarly, the correlation between the FWD-derived bound layer parameters and some other available bound layer parameters also were found to be good.

Initial Roughness

Pavement roughness greatly affects ride quality, safety, and vehicle operating costs. The following are key findings from several LTPP studies to enhance understanding of how and why roughness occurs in pavements.

FINDINGS FROM SPECIFIC PAVEMENT STUDIES

1

Report No. NCHRP 20-50(8/13)

- Increase in IRI in the SPS-1 (new AC pavements) projects is attributed to pavement distresses such as transverse cracking, longitudinal cracking in the wheel path, fatigue cracking, and rutting.
- In the SPS-2 (new PCC pavements) projects, no clear relationship between IRI changes and pavement distress was found.
- Generally, for the SPS-6 (rehabilitation of PCC pavements) projects, diamond-ground sections that have higher values of IRI before overlay are showing a higher rate of increase of IRI.

2

Report No. NCHRP 20-50(3/4)

- In the SPS-3 experiment (maintenance of flexible pavements), the thin (38-mm (1.5-inch)) AC overlay treatment has a small but significant effect in initial reduction of roughness. It is the only one of the four treatments studied (thin AC overlays, chip seals, slurry seals, and crack seals) to have a significant effect on long-term pavement roughness.
- Based on the SPS-5 (rehabilitation of AC pavements) data and the GPS-6B (new AC overlays on AC pavements) data, initial post-treatment asphalt overlay IRI depends on pre-treatment asphalt pavement IRI. Higher pre-treatment asphalt pavement IRI results in higher post-treatment asphalt pavement IRI.

3

Report No. FHWA-RD-00-029

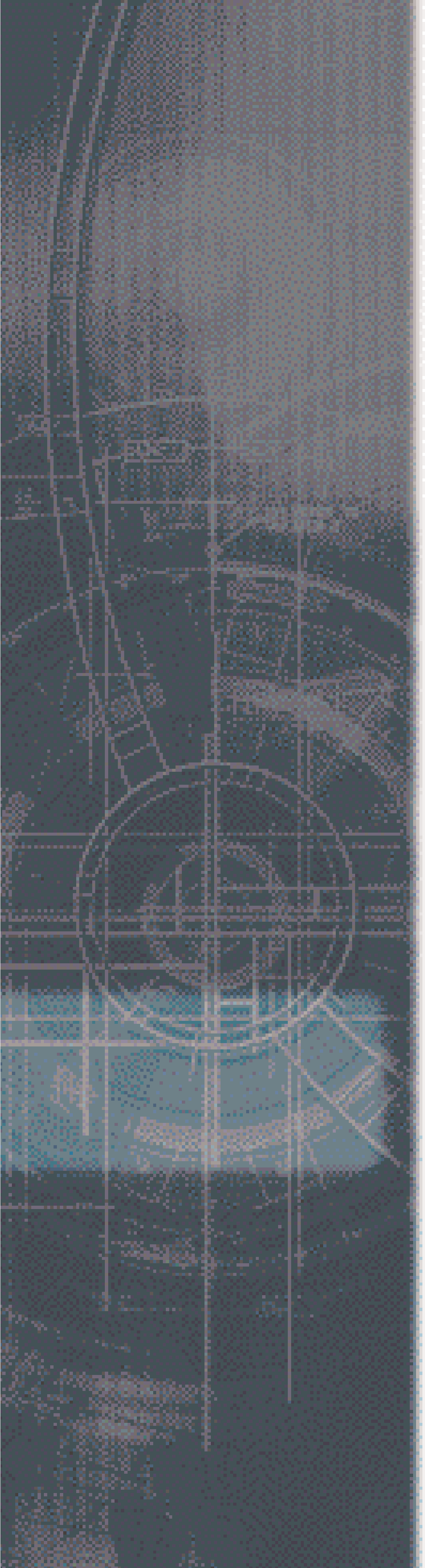
- Based on 8 years of data collected in the SPS-5 experiment (rehabilitation of AC pavements) in the United States and Canada, the long-term control of roughness generally can be attained with thin (51-mm (2-inch)) and thick (127-mm (5-inch)) AC overlays. However, the success of each project depends on various factors such as surface preparation, traffic loads, climatic regions, and pavement conditions before the overlay is placed.

FINDINGS FROM GENERAL PAVEMENT STUDIES

1

Report No. NCHRP 20-50(8/13)

- In the GPS-1 experiment (AC pavements on granular base), the strongest relationships between the rate of increase of IRI over time and an evaluated parameter exist for the following parameters: percentage of base material passing No. 200 sieve, freezing index, and plasticity index of subgrade. Higher parameter values induce higher rates of IRI increase.
- In the GPS-2 experiment (AC pavements on stabilized base), those sections built over asphalt-treated bases with high AC void ratios (percentage of air voids per unit AC volume) have a higher rate of increase of IRI. Also, those sections built over cement-treated bases in warmer climates have a higher rate of increase of IRI.
- Among the doweled pavements in the GPS-3 experiment (JPCP), those pavements with dowels have less joint faulting, which results in lower IRI values than those pavements without dowels. Higher IRI values are associated with a high number of wet days.
- In the GPS-4 experiment (JRCP), pavements with low cement content (less than 300 kg/cubic meter (505 lbm/cubic yard)) or high water-cement ratios (greater than 0.50) have higher IRI values.
- In the GPS-5 experiment (CRCP), 90 percent of CRCP sections are located in the wet climatic region (freeze and no-freeze). In the region, higher levels of roughness are associated with those sections with higher PCC elastic moduli and higher ratios between PCC elastic moduli and tensile strength.
- In the GPS-6 experiment (AC overlay of AC pavements), the IRI rate of increase on overlaid pavements is related to the IRI prior to overlay.
- In the GPS-7 (AC overlay of PCC pavements) experiment, initial results indicate that high rates of IRI increase were observed for overlays on PCC sections that have high PCC elastic modulus.



2 Base and Subgrade

Report No. FHWA-RD-01-166

- HMA pavements with unbound aggregate layers have slightly more fatigue cracking and higher IRI values than do those with asphalt-treated base layers.

Report No. FHWA-RD-01-167

- Jointed plain concrete pavements constructed on coarse-grained subgrade soils are smoother than pavements constructed on fine-grained subgrade soils. This confirms a similar finding from a previous study.

3 Climate

Report No. NCHRP 20-50(8/13)

- Flexible and rigid pavements in areas that have a high freezing index or a high number of freeze-thaw cycles have higher IRI values when other contributors to roughness are ruled out.

- In hot climates, higher IRI values are noted for AC sections in areas that have a higher number of days above 32 °C (90 °F).

4 Miscellaneous Findings

Report No. NCHRP 20-50(8/13)

- Placing overlays on pavements (flexible or rigid) that have an IRI of less than 2.0 m/km (10.6 ft/mile) appear to be an effective rehabilitation strategy in extending the life of the pavement. However, the section should have sufficient structural capacity to carry the anticipated traffic volume.

Report No. FHWA-RD-02-057

- Using LTPP profile data, the basis for roughness computations, 54 models were developed to assist highway agencies in transitioning smoothness specification limits from profile index (PI) (5, 2.5, and 0 mm (0.2, 0.1, 0 inches)) to IRI or to $PI_{0.0}$. Depending on the current situation and an agency's need, appropriate models can be chosen from the 54 models for transition.

Pavement Maintenance

Accomplishing necessary maintenance with minimal disruption to traffic is important from the standpoints of customer satisfaction, the safety of both those doing the work and the traveling public, and overall productivity. The following are key findings from several LTPP pavement maintenance studies. These findings are grouped into two areas: maintenance of rigid pavements and maintenance of flexible pavements.

MAINTENANCE OF RIGID PAVEMENTS

1

Treatment Performance

Report No. FHWA-RD-97-155

- There are no significant differences (either in spalling or in any other performance measure) between the control sections (unsealed) and the sealed-joint or undersealed (slab stabilization) sections. This observation is based on the 32 test sites constructed for the SPS-4 experiment (rigid pavement maintenance) in the United States and Canada between 1990 and 1995.

- Based on 5 years of data collected in Arizona, Colorado, Nevada, and Utah, differences in initial pavement smoothness among the three treatments consisting of sealed, undersealed, and unsealed joints in the SPS-4 experiment are not significant. Neither does faulting analysis indicate significant differences among the three treatments.

Report Nos. FHWA-RD-97-155 and NCHRP 20-50(2)

- Based on 5 years of data collected at the five test sites built in Arizona, Colorado, and Utah (all in the dry region), the effects of sealed and unsealed joints on spalling are similar.

Report No. FHWA-RD-99-151

- Predominant among the SPS-4 State supplemental test sections built in Arizona, Colorado, Nevada, and Utah between 1990 and 1995 was a comparison of joint sealant types: silicone seals, compression seals, and hot pours. Silicone seals appeared to outperform the other two treatments for transverse joint seals.

Report No. FHWA-RD-99-153

- When comparing saw-and-patch and chip-and-patch procedures in 28 test sites in four climatic regions, the annual cost for chip-and-patch is lower than for saw-and-patch. There are other considerations, in addition to cost, that make the chip-and-patch procedure preferable to saw-and-patch.

MAINTENANCE OF FLEXIBLE PAVEMENTS

1

Treatment Performance

Report No. NCHRP 20-50(3/4)

- In terms of roughness, rutting, and fatigue cracking, the most effective of the four maintenance treatments investigated in the SPS-3 experiment (flexible pavement maintenance) is the thin (38-mm (1.5-inch)) AC overlay treatment, followed by the chip seal treatment, the slurry seal treatment, and then the crack seal treatment.
- For the SPS-3 test sections, the thin (38-mm (1.5-inch)) AC overlay treatment is the only one of the four treatments (thin AC overlays, chip seals, slurry seals, and crack seals) under investigation that has shown a significant initial effect on rutting. Thin AC overlays also have the most significant effect on long-term rutting control.
- In the SPS-3 thin overlay sections, age of pavement was the only one of the factors studied (traffic, climate, stiffness, thickness) found to be significantly correlated to the rate of rutting.
- In the SPS-3 crack sealed and chip sealed sections, average annual precipitation was the only one of the factors studied found to be significantly correlated to the rate of rutting.

2

Pothole Repair Treatment Performance and Repair Methods

Report No. FHWA-RD-99-168

- The two main elements of quality pothole patching in flexible pavements are material selection and repair procedures. For every combination of these two factors, the cost-effectiveness of the overall patching operation will be affected by material, labor, and equipment costs.

Report No. FHWA-RD-98-073

- Although pothole patches are intended to be temporary repairs, using the best materials available can provide patches that remain in service for several years and that reduce the need for re-patching.

Report No. FHWA-RD-99-143

- The most cost-effective treatments for crack seals are usually those consisting of rubberized asphalt placed in a standard or shallow-recessed band-aid configuration. The standard recessed band-aid method showed the longest estimated service life, followed very closely by the shallow recessed band-aid method.
- For long-term crack-seal performance (5 to 8 years) under the condition where a 2.5 to 5.0 mm (0.1 to 0.2 inches) of horizontal crack movement occurred, a modified rubberized asphalt sealant should be installed in either a standard or shallow recessed band-aid configuration.

Pavement Rehabilitation

With a large portion of the national highway system at or beyond its original design life, pavement rehabilitation has come to the forefront as a key activity for highway agencies. The magnitude of the challenges faced by agencies as they pursue the rehabilitation of our highway system is tremendous. LTPP analysis has begun to provide some of the many answers that highway agencies need as they address this challenge. The following are key findings from several LTPP analyses of pavement rehabilitation.

REHABILITATION OF RIGID PAVEMENTS

1

Findings of the SPS-6 Experiment

The primary objective of the SPS-6 experiment (rehabilitation of jointed PCC pavements) is to examine the effects of different rehabilitation techniques on JPCP or JRCP. Based on pavement preparation, the rehabilitation techniques investigated can be separated into three pavement categories: exposed PCC, AC overlay of non-fractured PCC, and AC overlay of fractured PCC. Within each category, direct comparisons of performance based on distress are described below.

Report No. FHWA-RD-01-169

- Exposed PCC: The rehabilitation techniques in this category involve the restoration techniques other than overlay, including full-depth repair, diamond grinding, joint sealing, and addition of retrofitted edge drains.
  - If the pre-rehabilitated section has significant roughness, a diamond grinding should be fully considered or the section will retain its roughness. Full-depth repairs do not remove significant roughness from a JPCP or JRCP by themselves.
  - Both routine and premium pavement preparation treatments reduce the amount of transverse cracking immediately after rehabilitation. Routine preparation treatment includes limited patching, crack repair and sealing, and stabilization of joints. Premium preparation treatment includes subsealing, subdrainage, joint repair and sealing, full-depth repairs with restoration of load transfer, diamond grinding, and shoulder rehabilitation.
  - Premium pavement preparation with diamond grinding reduces the amount of faulting to zero immediately after rehabilitation.
- AC overlay of non-fractured PCC: This rehabilitation technique involves applying varying degrees of pre-overlay repairs and placing an AC overlay.
  - The AC overlay of non-fractured PCC reduces the roughness immediately after rehabilitation to a smooth level (1.0 m/km (5.3 ft/mile)).
  - The sections with AC overlay of non-fractured PCC exhibit a faster increase in IRI over time than does the fractured PCC.
  - The sections with AC overlay of non-fractured PCC exhibit a lower increase in IRI over time than do premium preparation PCC sections.
  - The routine and premium preparation sections with 102-mm (4-inch) AC overlays exhibited no reflective cracking within the first year after construction.

- AC overlay of fractured PCC: This rehabilitation technique includes AC overlays placed on crack/break and seated PCC or rubberized PCC.
  - The AC overlay of fractured PCC has a low IRI immediately after rehabilitation.
  - The AC overlay of fractured PCC has the lowest rate of increasing IRI after rehabilitation than any of the other rehabilitation alternatives investigated in this experiment.
  - Both crack/break and seat rehabilitation techniques with 102-mm (4-inch) and 203-mm (8-inch) AC overlay develop low amounts of fatigue cracking over time.

Report No. NCHRP 20-50(3/4)

- The rigid pavement rehabilitation treatments in the SPS-6 experiment (rehabilitation of jointed PCC pavements) can be ranked from most to least effective with respect to IRI, rutting, and cracking in the following order:
  - 203-mm (8-inch) overlay of cracked/broken and seated pavement.
  - 102-mm (4-inch) overlay of either intact or cracked/broken and seated pavement, with or without sawing and sealing of transverse joints, and with either minimal or intensive pre-overlay repair.
  - Concrete pavement restoration with diamond grinding, full-depth repair, and joint and crack sealing.
  - Concrete pavement restoration without diamond grinding, but with full-depth repair, and joint and crack sealing.
- Of the SPS-6 test sections that received diamond grinding, most also received full-depth repair, joint resealing, and crack sealing. In addition to those four techniques, some sections also received subdrainage retrofitting, undersealing, and/or load transfer restoration. The last three techniques do not appear to have produced significantly lower long-term roughness levels, compared to sections that received only diamond grinding, full-depth repair, and joint and crack sealing.

Findings of the SPS-6 and GPS-7B Experiments

Report No. NCHRP 20-50(3/4)

- The rutting data from the SPS-6 (rehabilitation of jointed PCC pavements) and GPS-7B (new AC overlays on PCC pavements) experiments indicate that, on average, 6 mm (0.24 inches) of rutting develops in the first year after placement of an AC overlay of either an intact or a cracked/broken and seated concrete pavement. This may be due to compaction of the AC overlay by traffic, and appears to be independent of the overlay thickness, mixture type, pre-overlay preparation, and pre-overlay rutting level.
- No significant differences were detected in cracking based on 8 years of data:
  - Between minimal (i.e., without milling) and intensive (i.e., with milling) pre-overlay preparation.
  - Between sections with versus without sawed and sealed joints.
  - Between 102-mm (4-inch) overlays with sawed-and-sealed joints versus those over cracked/broken and seated pavements.
  - Between 102-mm (4-inch) versus 203 mm (8-inch) overlays of cracked/broken and seated pavements.
- In 102-mm (4-inch) AC overlays of intact slabs, no significant differences were detected in roughness based on 6 years of data:
  - Between minimal and intensive pre-overlay preparation.
  - Between sections with versus without sawing and sealing of transverse joints.
  - Between overlays with sawed and sealed joints versus overlays of cracked/broken and seated slabs.
  - As expected, among overlays of cracked/broken and seated slabs, the 203-mm (8-inch) overlays have significantly lower long-term roughness than the 102-mm (4-inch) overlays.

REHABILITATION OF FLEXIBLE PAVEMENTS

1

Findings of the SPS-5 Experiment

The performance of the rehabilitation techniques in the SPS-5 experiment (rehabilitation of AC pavements) is presented in four categories: the AC overlay thickness, the age of overlay, milling with overlays, and the overlay mixture type (with or without recycled asphalt pavement).

- AC overlay thickness.

  Report No. NCHRP 20-50(3/4)

  - Overlay thickness and pre-overlay roughness level are the two factors that most influenced the performance of asphalt overlays of asphalt pavements in the SPS-5 experiment with respect to roughness, rutting, and fatigue cracking.

  Report No. FHWA-RD-01-168

  - Overlay thickness does not appear to have a strong effect on the occurrence of longitudinal cracking in the wheel path and rutting. There is no apparent effect on roughness based on these early observations (5 years after rehabilitation).

  Report No. FHWA-RD-00-029

  - Compared to thinner (51-mm (2-inch)) overlays, thicker (127-mm (5-inch)) overlays consistently have less longitudinal cracking outside the wheel path.

- Age of AC overlay.

  Report No. FHWA-RD-01-168

  - Age of overlay was found to be the leading contributing factor to four of the six distresses studied in the SPS-5 experiment (rehabilitation of AC pavements): fatigue cracking, rutting, transverse cracking, and initial pavement smoothness.

  - Age of the overlay and the climatic factors (temperature and precipitation) have a significant effect on the fatigue cracking at each project. The thickness of the overlay was less significant than these two factors based on these early observations (5 years after rehabilitation).

  - Age of the overlay and precipitation were found to have an important effect on the rut depths. However, increased precipitation may not be the sole factor related to increased rut depths.

  - Age of the overlay, pavement condition before overlay, and milling were found to be important relative to pavement smoothness.

- Milling with overlays.

  Report No. FHWA-RD-00-029

  - The data consistently show fewer transverse cracks on milled surfaces, compared to unmilled surfaces, before overlay placement. This seems logical, because removal of the top material from the original AC layer should reduce the effects of the cracks in the original pavement on the overlay.

  - The amount of transverse cracking is dependent on the original pavement condition before overlay placement. The overlays placed on pavements classified in good condition exhibit less transverse cracking than on pavements classified in poor condition.

  Report No. FHWA-RD-01-168

  - The data show that milling offers no consistent advantage for resisting longitudinal cracking outside the wheel path during the early life of an overlay. Milling has little effect in the short run.

- Overlay mixture type (with or without recycled asphalt pavement).

  Report No. FHWA-RD-00-029

  - There is no advantage to using one mixture type over the other (virgin versus recycled mixtures) in reducing the number of transverse cracks.

  - Compared to virgin mixes, recycled AC mixtures resisted longitudinal cracking outside the wheel path substantially better in at least five projects constructed.

2 Findings of the GPS-6 Experiment

Report No. FHWA-RD-00-029

- The GPS-6 (including GPS-6A: existing AC overlays on AC pavements and GPS-6B: new AC overlays on AC pavements) data show that fatigue cracking and longitudinal cracking in the wheel path are related. Specifically, the longitudinal cracking in the wheel path will eventually propagate or evolve into fatigue cracking with continued traffic loading.

- GPS-6A (existing AC overlays on AC pavements) data show that overlay designs that provide pavement structure consistent with traffic expectations can be expected to perform well for more than 10 years.

3

Findings of the SPS-5 and GPS-6B Experiments
Report No. NCHRP 20-50(3/4)

- Similar to the results from the SPS-6 (rehabilitation of jointed PCC pavements) and GPS-7B (new AC overlays on PCC pavements) experiments, the rutting data from the SPS-5 (rehabilitation of AC pavements) and GPS-6B (new AC overlays on AC pavements) experiments indicate that, on average, about 6 mm (0.24 inches) of rutting develops in the first year after placement of an AC overlay of an AC pavement. This may be due to compaction of the AC overlay by traffic and appears to be independent of the overlay thickness, mixture type, pre-overlay preparation, and pre-overlay rutting level.
- No significant differences were detected in rutting based on 10 years of data between:
  - Virgin versus recycled mixtures.
  - Minimal versus intensive pre-overlay preparation.
  - Thin (51-mm (2-inch)) versus thick (127-mm (5-inch)) AC overlays.

Local Calibration of the *2002 Pavement Design Guide*

As the States and Provinces start to implement the 2002 ***Pavement Design Guide****, it will be critical to perform local calibration and validation of the global mechanistic-empirical models developed based on the LTPP data. The locally calibrated/validated models will play a key role in how State and Provincial agencies will be designing and rehabilitating the pavements in their regions in the future.*

Local calibration can be carried out by identifying a set of representative pavements, developing the distress, materials, traffic, and climatic database for these pavements, and verifying the *2002 Pavement Design Guide* against these local pavements. This process will identify whether or not any local calibration needs to be performed. In summary, if a State or Province plans to do local calibration, the calibration will be done with a set of different pavements other than the LTPP sections that were considered in the global models. In that case, the State or Province will need to develop a database for design inputs, such as local material properties, and the State or Province must either do this independently or pool resources with other States or Provinces that have similar conditions.

The following example demonstrates how the LTPP data was used to develop and calibrate the design input libraries and the mechanistic-empirical models of the *2002 Pavement Design Guide*. The local development and calibration process can be performed similarly.

Report No. NCHRP Project 1-37A

- During the development stage, LTPP data were used extensively for a variety of critical items:
  - Establishing national default vehicle class distributions.
  - Establishing national default axle load distributions for single, tandem, and tridem axles.
  - Establishing other default inputs such as axle spacing, number of axles per truck class, and 24-hour percentages of truck traffic.
  - Developing materials-aging models.
  - Characterizing pavement material properties.
  - Verifying joint opening/closing models.
  - Verifying/validating Enhanced Integrated Climatic Models using the SMP data, especially the in-situ moisture contents and frost depth data.

- During the calibration stage, LTPP data were used to calibrate the following models:
  - IRI prediction models for flexible pavements, AC overlays of flexible pavements, and AC overlays of rigid pavements.
  - IRI prediction models for JPCP and CRCP.
  - Fatigue-cracking models (both top down and bottom up) for flexible pavements and AC overlays.
  - Rutting models for flexible pavements and AC overlays.
  - Thermal cracking models for AC pavements.
  - Transverse fatigue-cracking models for JPCP (both top down and bottom up), JPCP unbonded overlays, and restored JPCP.
  - Joint faulting models of new JPCP, unbonded JPCP overlays, and restored JPCP.
  - Punchout model of new CRCP and CRCP unbonded overlays.

SELECTED LTPP REPORTS

FHWA-RD-96-198
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