

SUMMARY OF

CRCP Long-Term Performance



PERFORMANCE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT IN THE LTPP PROGRAM—

Identifying design and construction factors that lead to high-performance CRCP

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INTRODUCTION

Since the 1960s, thousands of miles of continuously reinforced concrete pavement (CRCP) have been built in the U.S. These pavements have typically provided 20 or more years of service life without requiring major rehabilitation.

CRCP is a portland cement concrete pavement with continuous longitudinal steel reinforcement and no intermediate expansion or contraction joints. CRCP is designed to develop a transverse cracking pattern, with cracks generally spaced at about 0.6 to 1.8 meters (2.0 to 5.9 feet).

The cracking pattern is governed by environmental conditions at time of construction, amount of steel reinforcement, and concrete strength. The longitudinal reinforcement restrains the opening of the cracks and provides high load transfer across them.

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As a result, CRCP, when properly designed and constructed, maintains a relatively low state of stress under load, providing excellent performance. The CRCP riding quality is typically very good and will remain good as long as there is structural continuity of the transverse cracks.

The LTPP GPS-5 data used in the study reported here were obtained from DataPave Version 2.0, FHWA, released September 1999.

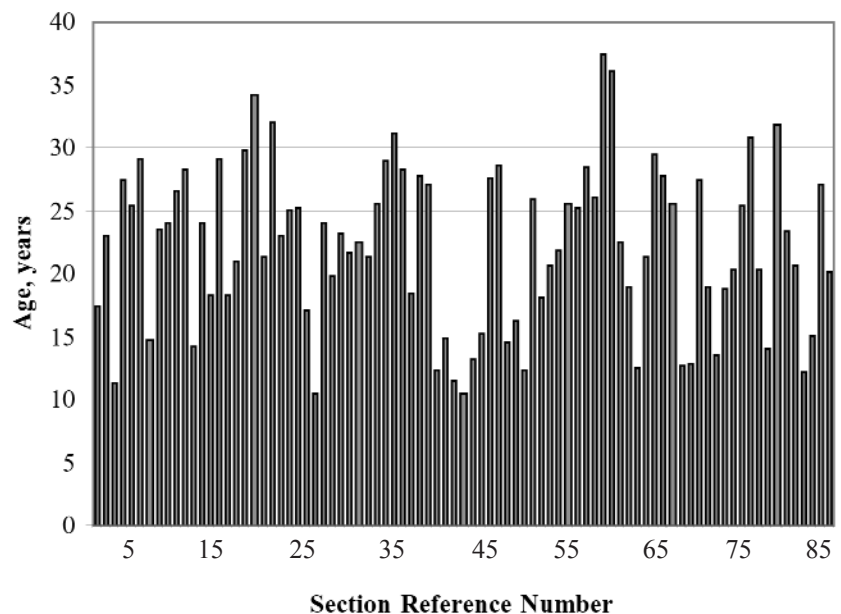
Federal Highway Administration's (FHWA's) Long Term Pavement Performance Program (LTPP)

In 1987, FHWA began the Long Term Pavement Performance program, a series of rigorous long-term field experiments monitoring more than 2,400 pavement test sections on active highways across the U.S. and Canada.

The primary objective of the program is to investigate the impacts of different designs, loads, environmental factors, and maintenance practices on pavement performance, and, therefore, to increase pavement life by instituting improved designs.

As part of the program, existing design methods are being evaluated, improvements in design and rehabilitation methods are being developed, and factors affecting pavement distress and performance are being investigated.

Figure 1
AGE OF CRCP SECTIONS



GPS-5 Test Section Characteristics

The General Pavement Study-5 (GPS-5) consists of 85 CRCP test sections located in 29 different states and four climatic regions, as shown in **Table 1**.

As of September 1999, 13 sections had been overlaid and were removed from the GPS-5 study. For the overlaid sections, only data for the period prior to overlay were used.

Four major types of data were collected under the LTPP program: test section inventory, climatic conditions, traffic loading, and monitoring.

Inventory

The design and condition characteristics of importance in the LTPP program include the age of the pavement, the original design parameters, the base and subgrade materials, and the shoulder type.

Age

The age of the test sections were from 11 to 38 years, with 55 sections over 20 years of age, as shown in **Figure 1** (left). (For overlaid sections, actual age at time of overlay is shown.)

Slab Design

CRCP design procedures have evolved over time. Slab thickness is typically based on design procedures for jointed concrete pavements, with many agencies using slightly smaller CRCP thicknesses than those of comparable jointed concrete pavements. The design of the continuous longitudinal steel reinforcement is based on meeting crack spacing, crack width, and concrete strength criteria.

Out of the 85 sections, 46 had 203-millimeter-thick (8-inch-thick)

Table 1

GENERAL PAVEMENT STUDY – GPS-5 TEST SECTIONS

State	# of Sections	Section Reference No.'s. (for this study)	Climatic Region (a)
Alabama	2	1-2	WNF
Arizona	1	3	DNF
Arkansas	2	4-5	WNF
California	1	6	DNF
Connecticut	1	7	WF
Delaware	2	8-9	WF
Georgia	1	10	WNF
Idaho	1	11	WNF
Illinois	8	12-19	WF
Indiana	3	20-22	WF
Iowa	3	23-25	WF
Maryland	1	26	WF
Michigan	1	27	WF
Minnesota	1	28	WF
Mississippi	5	28-33	WNF
Missouri	1	34	WF
Nebraska	1	35	WF
North Carolina	3	36-38	WF/WNF
North Dakota	1	39	WF
Ohio	2	40-41	WF
Oklahoma	3	42-44	WF/WNF
Oregon	6	45-50	WNF/DF
Pennsylvania	3	51-53	WF
South Carolina	3	54-56	WNF
South Dakota	3	57-59	WF/DF
Texas	19	60-78	WNF/DNF/WF
Virginia	4	79-82	WNF
West Virginia	1	83	WF
Wisconsin	2	84-85	WF

(a) WF = Wet-Freeze Region
WNF = Wet-Nonfreeze Region

DF = Dry-Freeze Region
DNF = Dry-Nonfreeze Region

slabs and 18 had 229-millimeter-thick (9-inch-thick) slabs. Only five sections had slab thickness greater than 270 millimeters (10.6 inches).

Most (61) sections contain 0.62 percent or less longitudinal reinforcement. Only 13 sections had steel amounts equal to or less than 0.51 percent, and only nine sections had steel amounts equal to 0.7 percent or greater. (Steel amount is calculated as percent steel area of total pavement

cross-section area.)

Design depth to longitudinal reinforcement was between 75 and 127 millimeters (3 and 5 inches).

Design spacing of longitudinal reinforcement was between 147 and 229 millimeters (5.8 and 9 inches).

Where used, design spacing of transverse reinforcement was between 610 and 1,524 millimeters (24 and 60 inches).

Base and Subgrade Materials

Base material, characterized by material type, is presented in [Table 2](#). Dense-graded asphalt, cement-aggregate mixture, and gravel represent over three-quarters of the base material types in the GPS-5 sections. Subgrade soil types are presented in [Table 3](#).

Shoulder Type

Forty percent of the GPS-5 sections have concrete shoulders and sixty percent have asphaltic concrete shoulders. A majority of the concrete shoulders are jointed plain concrete with a few jointed reinforced concrete shoulders.

Climatic

Climatic data gathered and analyzed by the LTPP program include climatic region, average annual freezing index, average annual precipitation, and average mean annual temperature. The GPS-5 sections are distributed throughout the U.S. and are subjected to a range of environmental conditions.

Traffic

The cumulative 80-kN (18 kips) equivalent single-axle load (ESAL) was used to characterize traffic loading. The cumulative ESALs for each test section was determined by summing the estimated annual ESALs over the years the section was in service to the date of the latest distress survey.

If ESAL values were missing for a few years, regression analysis was performed to estimate the annual total ESALs for these years. A summary of the cumulative ESAL data is given in [Figure 2](#) (far right, top).

Table 2

BASE MATERIAL TYPES

Material Type	No. of Sections	Percent Distribution
Cement-Aggregate Mixture	19	22
Cement Treated Subgrade Soil	2	2
Dense Graded Asphalt Cement	33	39
Gravel	17	20
Lean Concrete	2	2
Lime Treated Subgrade Soil	1	1
Open Graded Asphalt Cement	3	4
Soil Cement	8	10

Table 3

SUBGRADE TYPES

AASHTO Classification	No. of Sections	Percent Distribution
A-1-a (gravel and sand)	1	1
A-1-b (gravel and sand)	2	2
A-2-4 (silty/clayey gravel and sand)	14	16
A-2-5 (silty/clayey gravel and sand)	2	2
A-2-6 (silty/clayey gravel and sand)	3	4
A-2-7 (silty/clayey gravel and sand)	3	4
A-3 (fine sand)	5	6
A-4 (silty soil)	14	16
A-5 (elastic silt)	6	7
A-6 (lean clay)	12	14
A-7-5 (plastic clay)	4	5
A-7-6 (plastic clay)	4	5
Not Documented	15	18

AASHTO - American Association of State Highway and Transportation Officials

Because of the potential for the estimated traffic data to be somewhat unreliable, the estimated traffic data presented should be used with care. The LTPP program is currently developing more reliable traffic data for each test section using site-specific weigh-in-motion and automatic vehicle classification data.

Monitoring Pavement Performance

The GPS-5 pavement performance data available include an assessment of high-severity transverse cracking, average transverse crack spacing, total punchouts and patches, International Roughness Index (IRI), and pavement

deflection. Two types of distress surveys were performed in the LTPP program: manual surveys and photographic surveys using the PADIAS (Pavement Distress Analysis System).

High-Severity Transverse Cracking

Both the manual and PADIAS surveys indicate a very small percentage of high-severity transverse cracking, ranging from 0.33 and 0.20 percent, respectively, based on total number of cracks.

Average Transverse Crack Spacing

The average transverse crack spacing, calculated by dividing the length of the section (152 meters, or 500 feet) by the total number of cracks, is shown in Figure 3. Based on the manual survey data, the average crack spacing for the GPS-5 sections ranged from 0.33 to 2.06 meters (1.1 to 6.8 feet), with an average value of 1.13 meters (3.7 feet).

Punchouts and Patches

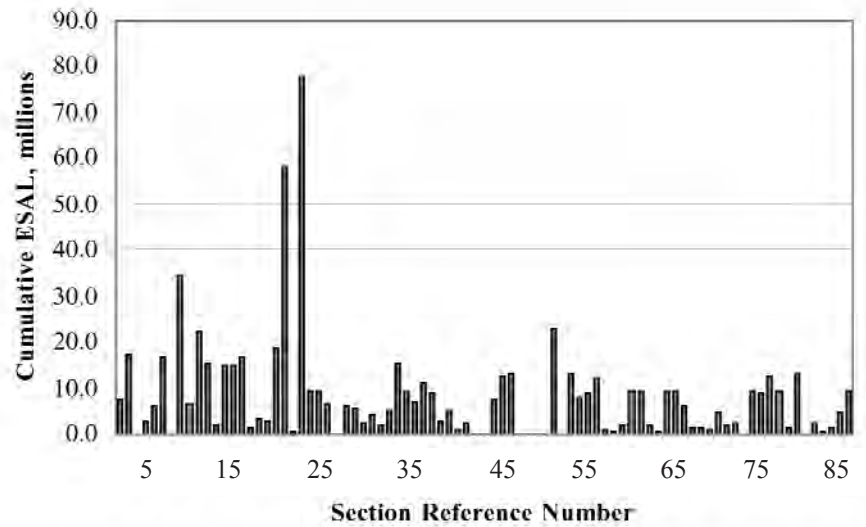
Punchout distress, a major concern for CRCP, is defined as the area enclosed by two closely spaced (usually less than 0.6 meters, or 2 feet) transverse cracks, a short longitudinal crack, and the edge of the pavement or a longitudinal joint.

Punchout distress is typically related to crack spacing, pavement thickness, poor foundation support, and/or heavy truck loading. Punchouts are typically repaired using full-depth concrete patches.

The total number of localized failures for any individual test section was determined by adding the total number of punchouts and patches across all severity levels. In general, localized failures such as punchouts and

Figure 2

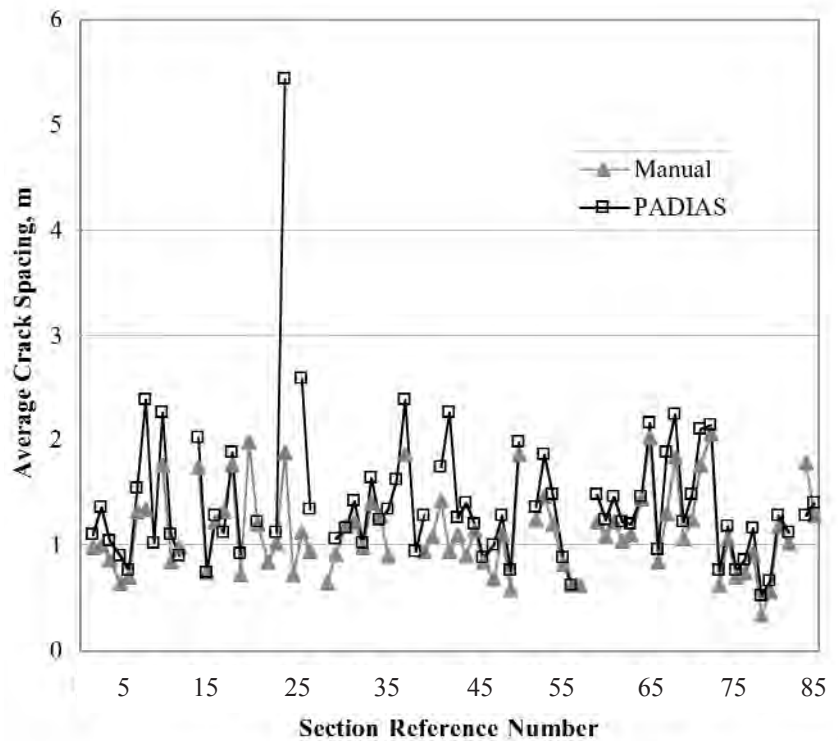
CUMULATIVE EQUIVALENT SINGLE AXLE LOADS



Note: Traffic data not available for 12 sections.

Figure 3

AVERAGE CRACK SPACING



Note: Generally, PADIAS surveys gave larger crack spacing, indicating that photographic procedures could not identify all low-severity transverse cracking, resulting in larger estimated crack spacing.

patches have not been a serious problem for the GPS-5 sections. Only four sections exhibited localized failures, their totals being 16, 18, 22, and 39 failures.

It is believed that these high numbers of failures are due to problems of interpretation of the distress data. For example, 39 localized failures over a length of 152 meters (500 feet) would equate to a rate of about 256 localized failures per kilometer (412 failures per mile).

Apparently, the presence of longitudinal cracking resulted in those segments being classified as having punchouts. It is highly unlikely that any transportation agency would permit such a high amount of localized failures to remain on a public highway.

Overall, it appears that the GPS-5 CRCP test sections have performed very well.

Profile (Smoothness) Data

The International Roughness Index (IRI) is one index used to characterize pavement ride in the LTPP program. As shown in **Figure 4**, IRI values for the GPS-5 sections ranged from about 0.7 to 2.8 meters/kilometer (3.7 to 14.8 feet/mile), with almost 80 percent having IRI values of less than 2.0 meters/kilometer (10.6 feet/mile).

Considering the ages of the sections in the GPS-5 study, the CRCP sections are exhibiting good ride quality.

Time series analyses were performed for CRCP sections located in four different states—Illinois, Mississippi, Oregon, and Texas—with five or more CRCP sections. The time series analyses are presented in **Figure 5** (far right, top).

Table 4

AVERAGE LTE AND CV

	Load Applied at Approach Side			Load Applied at Leave Side			Combined Data		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Average LTE, %	91	100	77	92	101	78	91	100	77
Coefficient of Variation, %	3	12	1	3	13	1	3	13	1

LTE – load transfer efficiency

Note: The coefficient of variation (CV) in LTE is very small, indicating very consistent LTE distribution.

Cores taken from CRCP show tight cracks, which indicate high LTE and aggregate interlock.

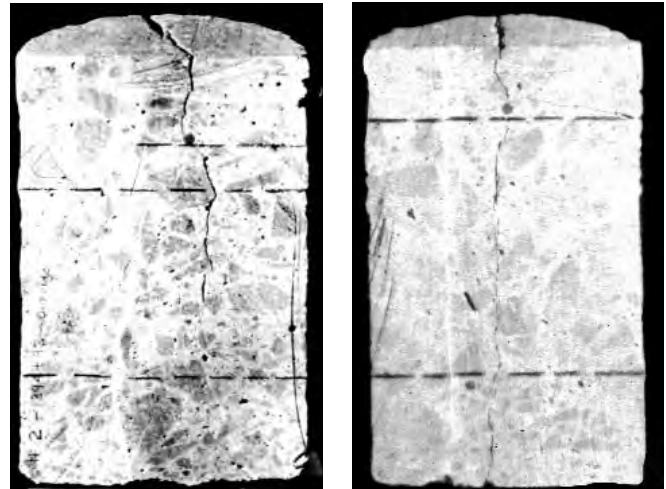
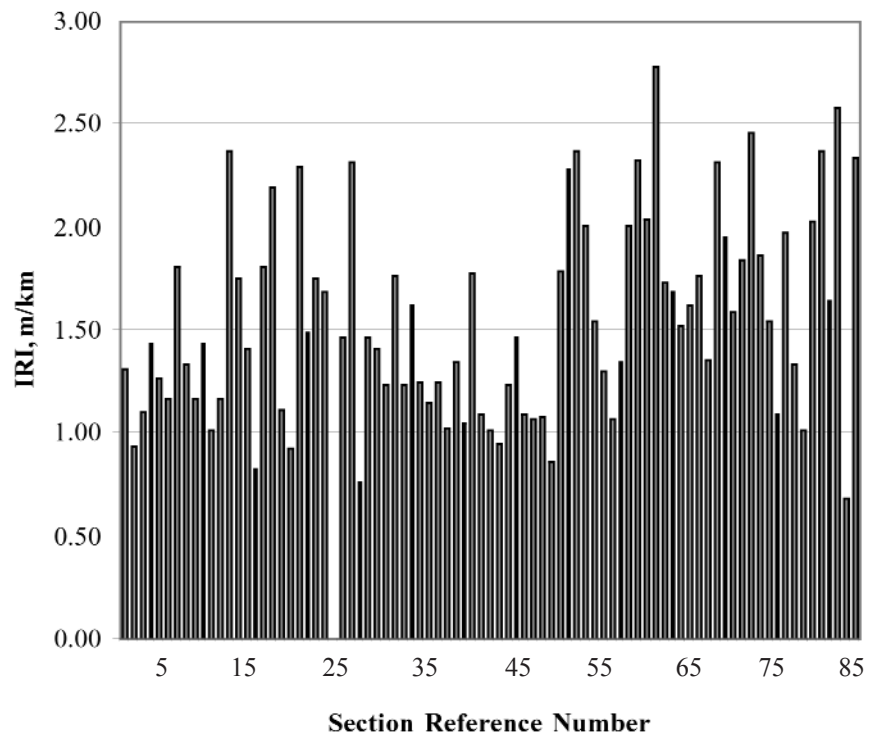


Figure 4

INTERNATIONAL ROUGHNESS INDEX



Although there is some variability, the IRI remained relatively constant over time for most sections. Sections of different ages showed the same IRI pattern. It is therefore reasonable to conclude that CRCP generally maintains its initial IRI over a long period of time.

Pavement Deflection

Deflection testing is performed regularly at the LTPP sections using a falling weight deflectometer at interior locations and at cracks. The deflection data were analyzed to determine load transfer efficiency (LTE) at cracks. Testing is typically conducted at about 20 crack locations at both the approach and leave sides of the cracks.

The statistics for the LTE data are given in **Table 4** (left) and the distribution of the LTE values is given in **Figure 6** (right, bottom).

CRCP test sections exhibit very good LTE, with most cracks exhibiting 90 percent or greater LTE, irrespective of temperature or time of testing. Within each section, the variation in LTE is very small, indicating very consistent LTE distribution, irrespective of the crack spacing pattern.

There did not appear to be any effect from base type or shoulder type on load transfer efficiency development. The coefficient of variation tended to be lower for sections exhibiting higher load transfer efficiencies. The load transfer efficiency values remain high even as pavements get older and are subjected to increasing traffic loadings.

Figure 5
IRI VERSUS TIME

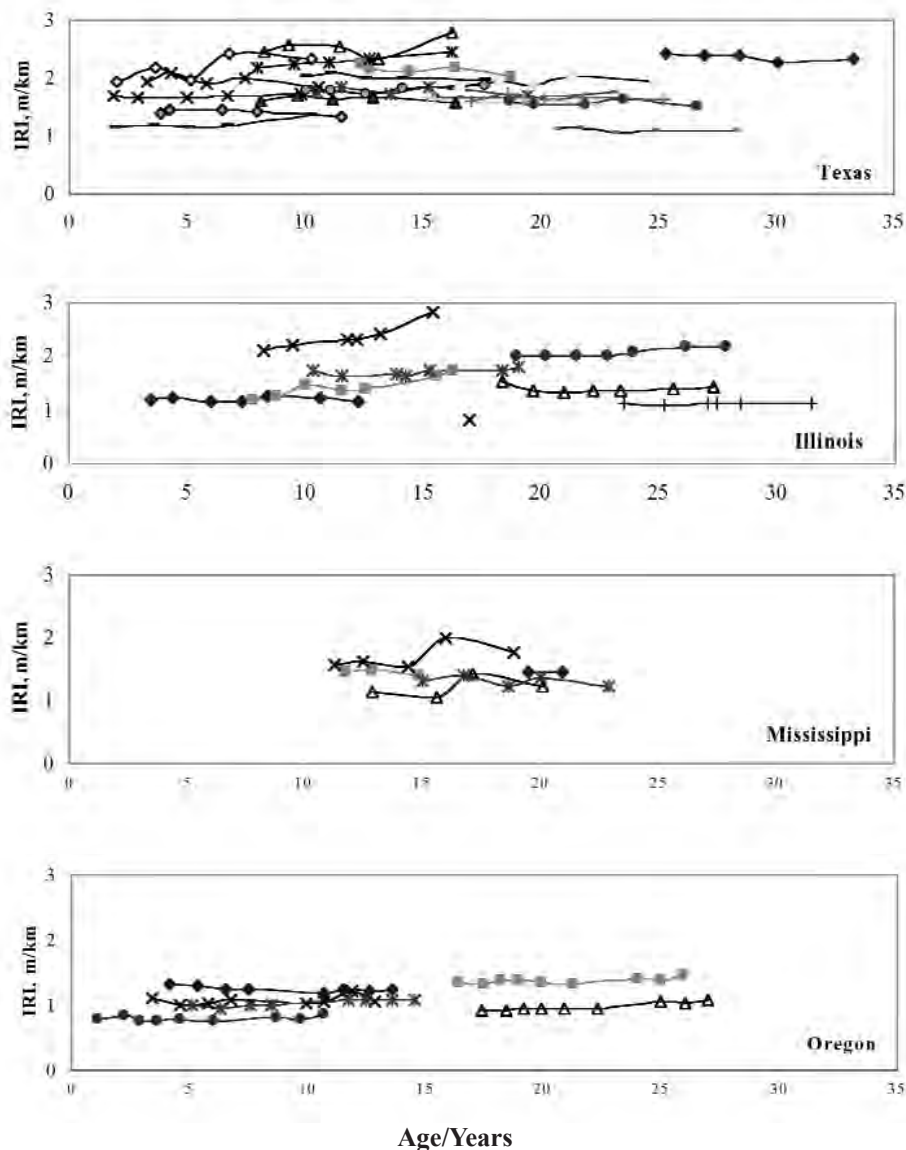
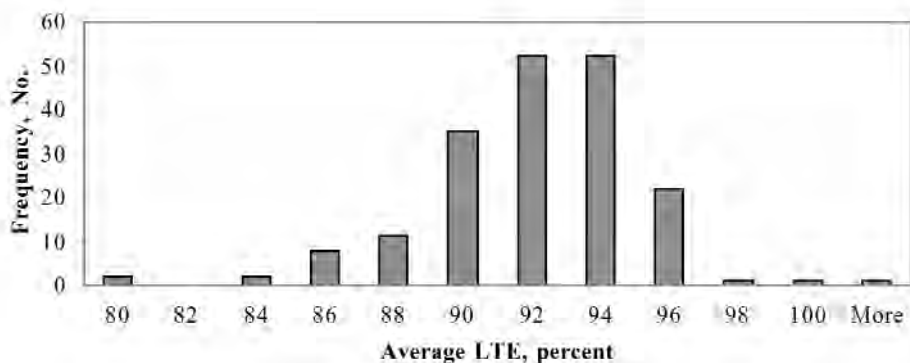


Figure 6
DISTRIBUTION OF AVERAGE LOAD TRANSFER EFFICIENCY



Characteristics of Exceptionally Well-Performing CRCP

In general, all of the GPS-5 CRCP sections have performed well over long periods of time.

However, 13 sections have shown exceptional performance, as defined for the purpose of this analysis, as follows: they have been in service for 20 years or more; have an IRI ranking of less than 1.5 meters/kilometer (7.9 feet/mile); and have no high-severity cracking, punchouts, or patches. The sections are located in Alabama, Arkansas, California, Illinois (2), Nebraska, North Carolina, Oregon (2), South Carolina, South Dakota, and Virginia. A summary of the characteristics of the exceptionally well-performing sections is presented in [Table 5](#).

The following general observations are made:

- All sections were built with concrete with compressive strength well above 27.6 MPa (4,000 psi), which is a commonly specified 28-day concrete strength for pavements.
- Most of the sections (12 out of 13) used a treated base layer.
- Three-quarters of the sections had a longitudinal reinforcement amount of 0.59 percent or higher.
- Seventy-five percent of the pavements had average crack spacing less than 0.90 meters (3 feet). The generally recommended crack spacing is between 0.6 and 1.8 meters (2 and 5.9 feet).
- Seventy-five percent of the pavements had average IRIs less than 1.31 meters/kilometer (6.9 feet/mile). The time series analysis of the IRI for these thirteen well-performing CRCP sections showed that the IRI remained relatively constant over long periods of time.

Because reliable traffic data were not yet available at the time of this study, it was not possible to perform in-depth analyses of the effect of various design features on CRCP performance. It is expected that such analyses will be possible in the near future when accurate traffic data become available.

CONCLUSIONS

As a result of invaluable data collected in the FHWA's Long Term Pavement Performance program, exceptionally well-performing CRCP sections appear to have the following characteristics:

- **Higher concrete strength with higher concrete modulus of elasticity**
- **Stiffer base layer (treated base)**
- **Smaller crack spacing**
- **Amount of longitudinal steel reinforcement greater than 0.59 percent**
- **Ninety percent or greater load transfer efficiency at crack locations.**

CRCP designed and constructed to have these characteristics should provide many years of long-term: smoothness, durability, cost savings and load-carrying capacity.

Table 5

CHARACTERISTICS OF WELL-PERFORMING CRCP SECTIONS

Characteristic	Minimum	Maximum	Average
Concrete Compressive Strength, MPa	39.5	60.6	50.2
Concrete Elastic Modulus, GPa	21.4	42.9	29.2
Base Thickness, mm	51	122	122
Longitudinal Reinforcement, %	0.51	0.75	0.61
Depth to Longitudinal Reinf., mm	64	114	91
Average Crack Spacing, m	0.33	1.29	0.81
Average IRI, m/km	0.93	1.47	1.21
Average LTE, %	77	100	92

Note: Conversion of above values to inch-pound units omitted for clarity.