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PAVEMENT PERFORMANCE ANALYSIS OF THE ILLINOIS INTERSTATE HIGHWAY SYSTEM

By

Mark E. Dwiggins
Michael I. Darter
James P. Hall
Craig L. Flowers
James B. DuBose

Research Report 517-03

A Report of the Findings of:

Development and Field Testing of an Illinois Pavement Feedback System

Project IHR-517
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Conducted by the

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16. Abstract

The Illinois Interstate highway system was mostly constructed between 1957 and 1980 and consists primarily of continuously reinforced concrete pavement (CRCP) and jointed reinforced concrete pavement (JRCP). Extensive pavement design, traffic and performance data were obtained from 3228 one-directional miles of Interstate highway. Truck traffic has increased tremendously since 1957. The mean yearly 18-kip ESAL (one-direction, outer lane) application rate averages over all pavements has increased from about 300,000 to 1,200,000 over this time period. The annual compound growth rate of accumulated ESAL has been over 8 percent, far more than expected.

Survival curves showing the percent of construction sections overlaid as a function of age and ESALs were developed for each pavement type and design. The average life span until 50 percent of the sections were rehabilitated was 21 years, after carrying about triple their design ESALs over that time period. The thickness of CRCP had a major effect on the number of ESALs carried.

Durability cracking ("D" cracking) of PCC aggregates severely affects CRCP performance, shortening the average life by five years or more. The average life of JRCP was not shortened significantly by "D" cracking (although a few sections developed severe "D" cracking which shorted their life considerable).

The average 8 in CRCP carried about the same 18-kip ESAL as the average 10 in JRCP, however, non "D" cracked 8 in CRCP carried more ESALs than than 10 in JRCP.

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List of Reports

Research Report 517-1, "An Illinois Pavement Feedback System: Feasibility and System Requirements," by Ron J. Roman, Mark B. Snyder and Michael I. Darter, presents results of investigative study and the system requirements study for an Illinois Pavement Feedback System, FHWA-IL-UI-209, 1985.

Research Report 517-2, "Logical and Physical Design of the Illinois Pavement Feedback System," by Mark E. Dwiggins, James P. Hall, Michael I. Darter, Craig L. Flowers and James B. DuBose, summarizes two years of designing the Illinois Pavement Feedback System and provides some results, FHWA-IL-UI-219, 1988.

Research Report 517-3, "Pavement Performance Analysis of the Illinois Interstate Highway System," by Mark E. Dwiggins, Michael I. Darter, James P. Hall and James B. DuBose, describes performance of pavement designs used on the Illinois Interstate system, FHWA-IL-UI-220, 1989.

Research Report 517-4, "Analysis of the Traffic Loadings on Interstate Highways in Illinois," by Michael I. Darter, Ricardo A. Salsilli, Mark E. Dwiggins, Thomas Fitch and Alan Lundberg, describes the compilation of annual traffic volumes and classifications and the estimation of equivalent single axle loads (ESAL's) for each pavement section and shows the dramatic growth of ESALs over the past 30 years, FHWA-IL-UI-222, 1989.

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INTRODUCTION

The Interstate highway system in the State of Illinois ranks third behind California and Texas in size (1940 miles) and includes four intercontintal routes and two major north-south routes.(1,5) The Interstate system in Illinois is particularly important for commercial trucking. In 1987, more than 52 percent of all goods shipped by highway moved on the Interstate system, and 64 percent of all truck travel was on Interstate highways (5). Keeping the Interstate highway pavement system in good condition is absolutely vital to the health of the states' economy.

Ilinoi Department Of Transportation (IDOT) management requested that a joint University of Illinois and IDOT research team objectively analyze Interstate highway pavement performance using data collected by the Illinois Pavement Feedback/Management System (IPFS). Results from the study would be particularly useful for design and planning purposes. A direct comparision of the performance of continuously reinforced concrete pavement (CRCP) and jointed reinforced concrete pavement (JRCP) was also of interest.

Figure 1 shows a breakdown of the pavement types included in this study. The analysis included 3228 miles of one-directional roadway. Several newer Interstate highways and those of the Illinois Toll Road were not included. Ten-inch JRCP and eight-inch CRCP are "equivalent" designs according to IDOT's previous pavement design procedure, and together constitute 69 percent of the Interstate pavements as shown in Figure 1.

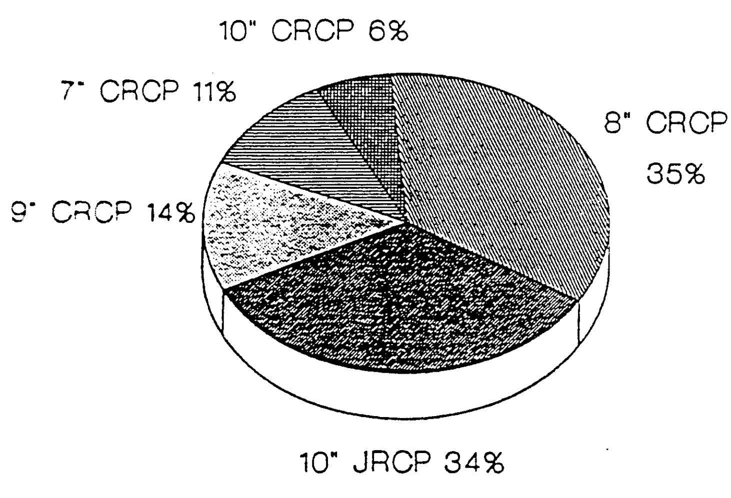

Figure 1. Illinois Interstate pavement types (3228 total one-directional mileage).

BACKGROUND INFORMATION

Design

The JRCP design included 100 ft joint spacing and a 10 in thick slab. The base course was mostly a dense graded aggregate. Reinforcement was welded wire fabric with a longitudinal steel content of 0.17 square inches per foot width of slab. The joints contained non-coated steel dowel bars having a diameter of 1.25 in. Many of the joints locked up due to corrosion of the steel dowels, causing transverse cracks to open and the steel to rupture. The joints were not regularly resealed after construction.

The CRCP design included 7, 8, 9, and 10 in thick slabs, having either deformed reinforcement bars (typical) or deformed welded wire fabric of about 0.58 to 0.72 percent area. The bases consisted of mostly bituminous stabilized granular materials, but also included a few untreated granular and cement treated granular bases.

Longitudinal drain pipes were not included in the original designs, although these were retrofit on several projects over the years. The subgrade soils were generally fine-grained silts and clays. Poor subdrainage conditions existed on practically all projects, and pumping/erosion and loss of support was common. The shoulders were asphalt concrete surfaced with various base types.

About 40 percent of these pavements suffered from a concrete durability problems called "D" cracking, which caused a disintegration of the concrete near joints and cracks.

Age

Age distribution of all Interstate pavements is shown in a histogram in Figure 2. The height of the bars indicates the total length of two-lane miles for each of the age groups. The cross-hatched bars indicate the length that had been rehabilitated through 1987.

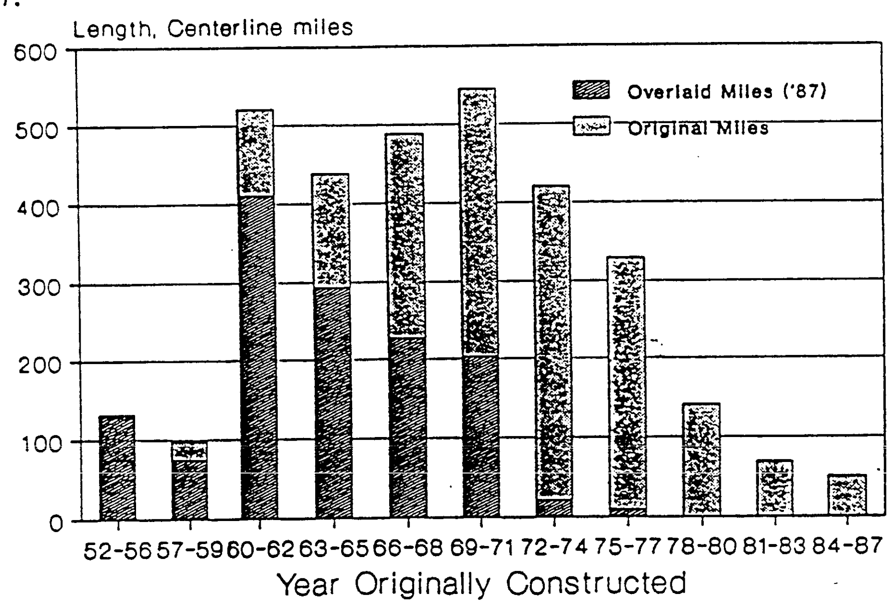

Figure 2. Age distribution of all pavements.

Traffic

Interstate pavements are designed to carry a specified number of traffic loads without deteriorating to a point that a major rehabilitation, such as an asphalt overlay, is required. Pavements deteriorate due to both traffic loadings and aging. Aging actually represents cycles of freeze/thaw, hot/cold and wet/dry. It is important that the designer predict the traffic loads the pavement will be subjected to during the future design life.

The standard AASHTO 18-kip Equivalent Single Axle Loads (ESALs) was used to approximately quantify mixed traffic loading in the design lane, typically the outer truck lane of a highway facility. For example, one average tractor semi-trailer combination is equivalent to 1.91 18-kip ESALs; one average single unit vehicle such as a dump truck or a bus is equivalent to 0.39 ESALs; and one passenger car does the same damage as 0.0004 ESALs in the 1987 IDOT Design Manual (2).

ESALs were estimated for each section on the Interstate highway system using standard traffic volume and classification counts. The average truck factors for each year beginning in the late 1950's were obtained from the IDOT design manual which were generally based upon FHWA W-4 loadometer tables. (Note: it is believed that these truck factors may be up to 50 percent lower than actual data as indicated by weigh-in-motion monitoring in various states.) Reference 4 provides details of the traffic analysis.

Annual ESAL applications have increased dramatically since the Interstate highway system was first begun. Figure 3 shows average annual ESAL applications

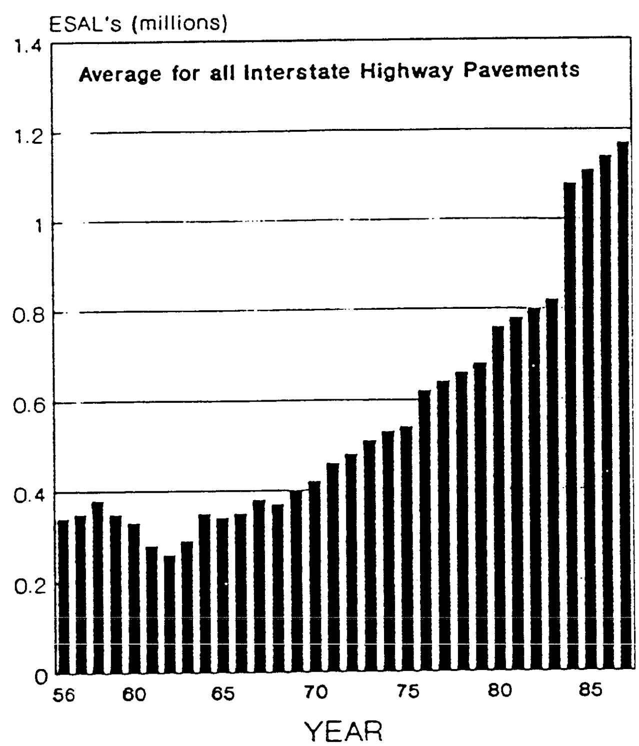

Figure 3. Average annual ESALs by year in the outer traffic lane.

in Illinois for the past 30 years. The average ESAL application rate in the outside lane has increased from about 300,000 to 1,000,000 per year over this time period. The average compound annual growth rate of accumulated ESALs over these years is over 8 percent, which was not anticipated by the designers. For example, as will be shown later, the design 20 year accumulated ESALs for 8-inch CRCP and 10-inch JRCP are only 4.8 million compared to an actual average of about 12 million over 20 years.

ESAL numbers can be put into perspective by comparing rates at different locations. ESAL applications on the outer lane in one direction on I-72 near Champaign was 300,000 in 1986. In comparison, ESALs on I-94 along the Dan Ryan Expressway in Chicago, considered one of the busiest highways in the world, were over 5,000,000 in 1986 in one truck lane.

Figure 4 shows the the distribution of accumulated outer lane ESALs. Most of these sections were designed for less than 5 million ESALs. The histogram shows that the vast majority of them were subjected to far more than 5 million.

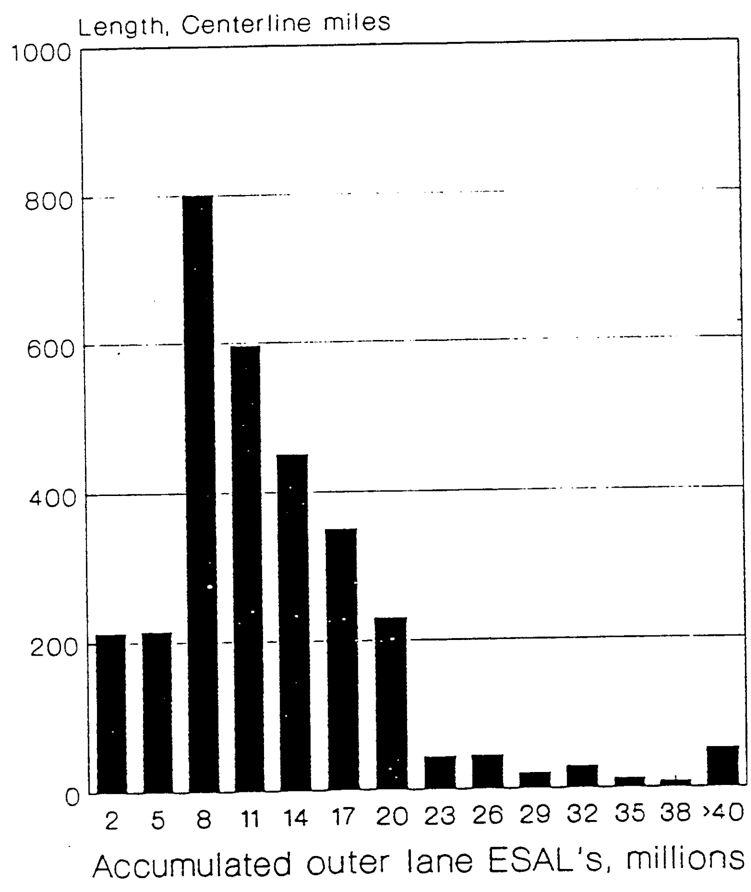

Figure 4. Accumulated ESAL distribution of Interstate pavements.

CURRENT STATUS OF INTERSTATE HIGHWAY PAVEMENTS

Pavement life is defined herein as the point at which the pavement has deteriorated to a state such that a major rehabilitation is required. The condition of JRCP at this point typically includes extensive joint deterioration (spalling and faulting) and/or transverse crack deterioration (spalling and faulting). The condition of CRCP at the point of rehabilitation includes extensive punchouts or transverse cracks with ruptured steel. When "D" cracking has occurred, extensive spalled out areas in the wheel paths are typical. The most typical rehabilitation used is an asphalt concrete overlay along with full-depth repairs and subdrainage.

Pavement life can be discussed in terms of age in years and traffic (ESAL) loadings applied. The 1987 overall status of the Interstate highway pavements is shown in Figure 5. The average original pavement age of all sections in 1987 was 19 years. The average traffic loading had been 16 million 18-kip ESALs. Forty percent of these pavements had been overlaid by 1987.

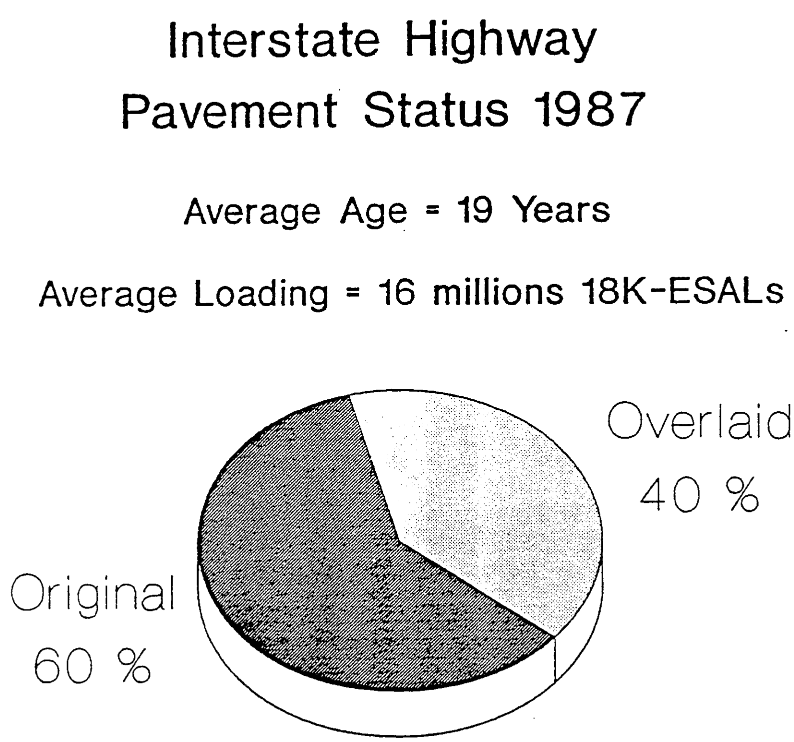

Figure 5. 1987 status of all Illinois Interstate pavements.

SURVIVAL ANALYSIS PROCEDURE AND RESULTS

Indicators of the useful life of a pavement that is common to both CRCP and JRCP are **age** and **ESAL applications** carried prior to the first major rehabilitation.

An estimate of the distribution of age/ESALs to first overlay was made using a survival curve analysis called the product limit or Kaplan-Meier method found in the SAS statistical analysis software (3). The survival distribution estimates the percent construction sections overlaid versus age and accumulated ESALs.

A survival curve for all pavements combined in terms of age is shown in Figure 6. The plot shows the percent of all the pavements overlaid as age increases. For example, approximately 43 percent of all sections were overlaid by the time they reached the age of 20 years. The average life span of all sections when 50 percent were overlaid is 21 years.

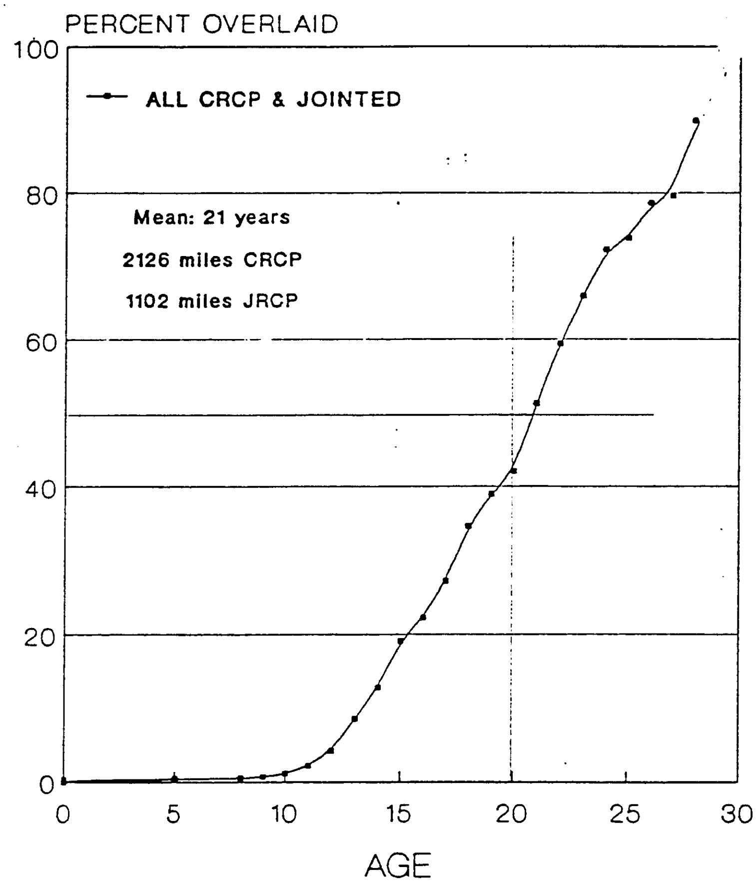

Figure 6. Survival curve by age for all pavements.

A similar survival curve for all pavements in terms of ESALs is shown in Figure 7. This plot shows that about 50 percent of the sections had been overlaid by the time that 14 million ESALs were applied. A large percentage of the sections (80) were designed for less than 5 million ESALs. When this number of ESALs were applied, only about 5 percent of the sections were overlaid. This indicates a design reliability of approximately 95 percent.

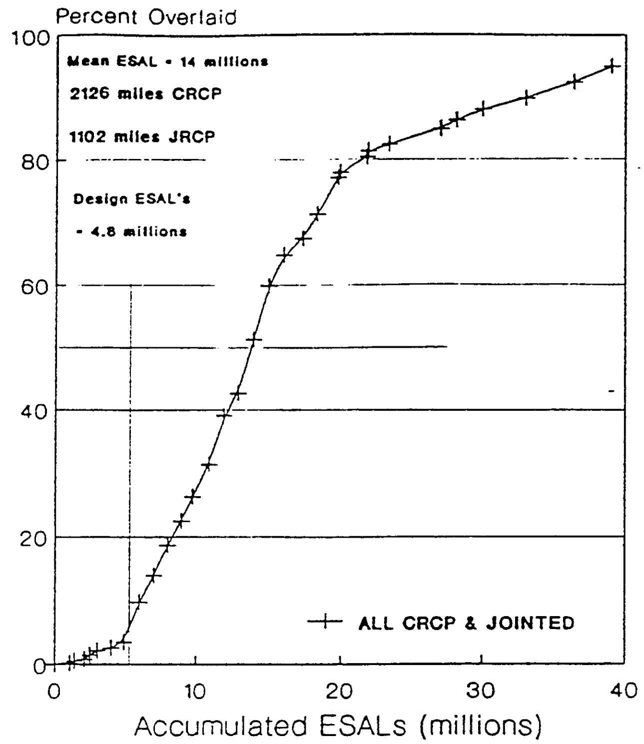

Figure 7. Survival curve by ESAL for all pavements.

Survival curves comparing 8 in CRCP and 10 in JRCP are shown in Figure 8. They are fairly similar, indicating practically equivalent performance overall.

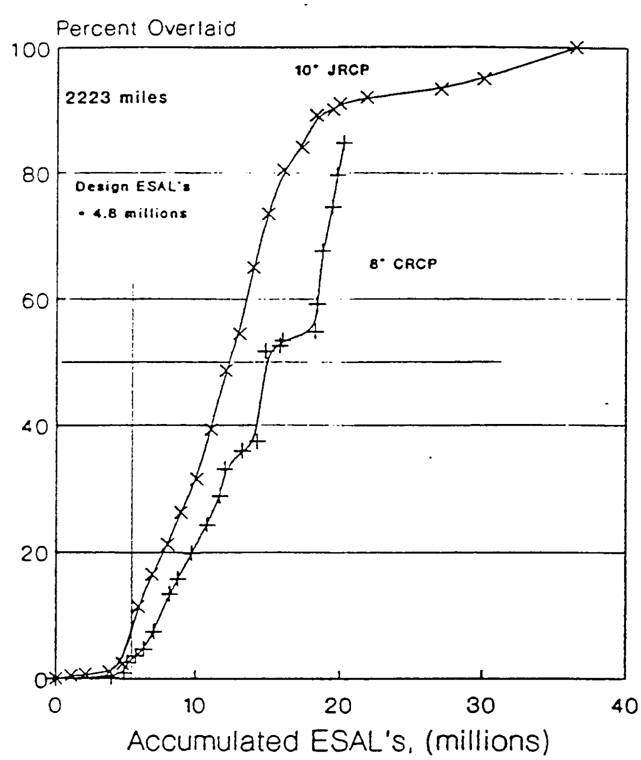

Figure 8. Performance comparison of 8 in CRCP and 10 in JRCP.

Survival curves in terms of ESALs for 7 to 10 in CRCP and 10 in JRCP are shown together for comparison in Figure 9. These results show an expected trend, that the thicker CRCP slabs carried more traffic than thinner slabs (e.g., 7 in = 8 million ESALs, 8 in = 15 million, 10 in = 27 million). The traffic carried by 10 in CRCP has been very high. For example, portions of the Stevenson expressway (I-55) carried 39 million ESALs before it was overlayed, and the local truck lanes of the Dan Ryan expressway have carried over 60 million ESALs in 18 years, and have still not been overlayed.

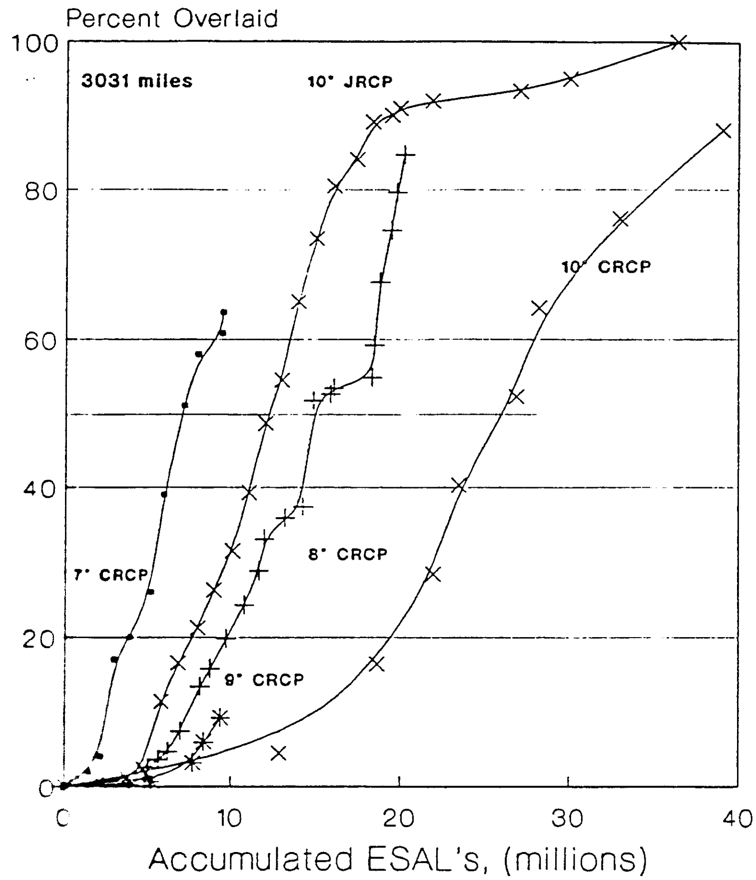

Figure 9. Survival curves by ESAL for 7, 8, 9, and 10 in CRCP, and 10 in JRCP.

A summary of pavement life for each design type that has shown deterioration is presented in Figure 10. For example, a typical 7 in CRCP has carried 8 million ESALs at a mean life of 17 years. This pavement was designed for approximately 2 million ESALs. Each pavement design has exceeded its design traffic by a factor of about 3 when 50 percent of the sections were rehabilitated. These results show that on average the actual traffic carried exceeds design traffic by a factor of 2.7 to 4.0 over the 20 year design period.

Pavement Type	Mean Life ** (yrs)	Mean ESAL's *** (millions)	ESAL Design * Ratio
7" CRCP	17	8	4.0
8" CRCP	20	15	3.1
10" JOINTED	22	13	2.7

* ESAL's Actually Applied/Design ESAL's

** Mean Age of pavements when 50% had been overlaid

*** Mean ESAL's applied when 50% had been overlaid

Figure 10. Comparison of actual traffic with design traffic.

DURABILITY CRACKING ("D" CRACKING)

"D" cracking deterioration begins at the joints and cracks and progresses into the slab. "D" cracking occurs when more porous aggregate in the Portland cement concrete is exposed to frequent water saturation and cycles of freezing and thawing. As the saturated aggregate freezes, the ice expands creating intense pressures which crack the aggregate and eventually the matrix. The integrity of the concrete is then lost and eventually pieces break loose and spall away under traffic.

The effect of "D" cracking with age in JRCP and CRCP is shown in Figures 11 and 12. CRCP has shrinkage cracks every three to ten feet that apparently allows water to infiltrate and begin the deterioration process. If severe "D" cracking progresses two feet from each crack, then that means virtually the entire pavement is D-cracked. "D" cracking progresses rapidly in some CRCP sections and eventually spalling at transverse cracks in the wheel path occurs, resulting in a severe roughness problem that requires constant maintenance. In JRCP, "D" cracking is limited to the 100 foot contraction joints, centerline, edge, and transverse cracks which are far fewer than in CRCP.

The results show that "D" cracking drastically affects the performance of CRCP and greatly shortens its life. There is a five year average life difference between 8 in CRCP pavements constructed with "D" cracking susceptible aggregates and 8 in CRCP pavements constructed with sound aggregate as shown in Figure 12. Conversely, there is little difference in JRCP life between "D" cracked and sound pavements as seen in Figure 11. However, there have been JRCP with severe "D"

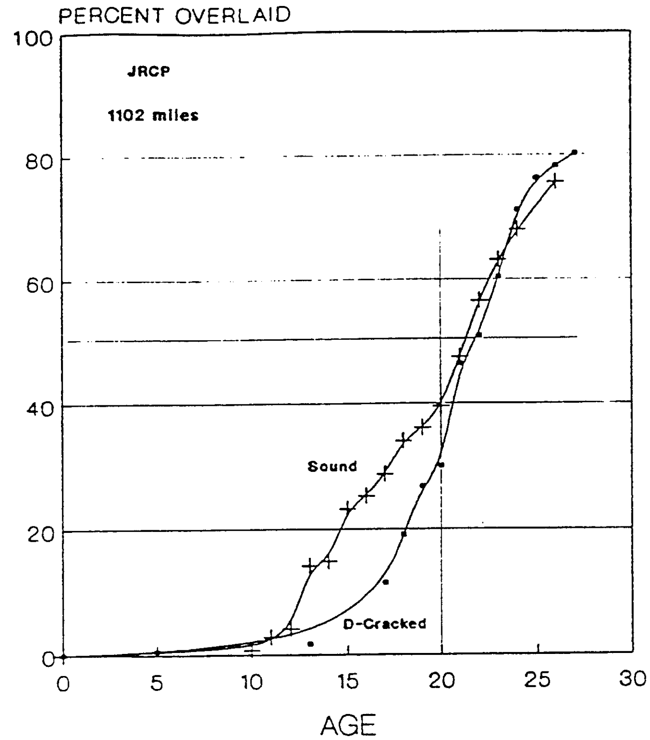

Figure 11. Performance comparison of "D" cracked and sound 10 in JRCP

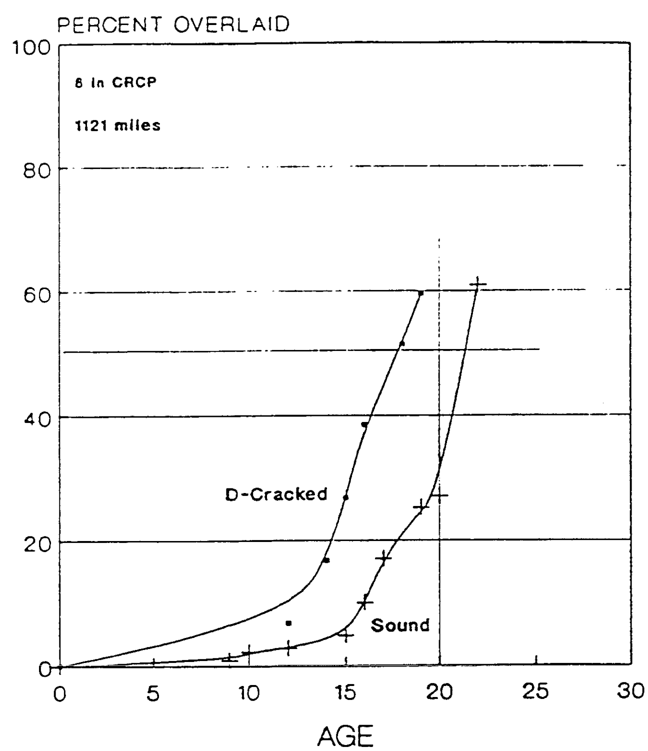

Figure 12. Performance comparison of "D" cracked and sound 8 inch CRCP.

cracking aggregates that greatly reduced their life. IDOT has taken steps to prevent the use of aggregates that are highly susceptible to D-cracking.

A comparison of Figures 11 and 12 indicate that an 8-inch CRCP constructed with sound aggregates survived (for age) on average approximately the same as a 10-inch JRCP with sound aggregates. Figure 9 shows that the 8 in CRCP carried 3 million more ESALs until rehabilitation was needed than the 10 in JRCP.

Some of the survival curves do not extend out to the extreme age/ESAL limits of some existing pavements types. The curves extend only as far as the greatest age/ESAL for which an overlay was performed. For example, the estimated survival of non "D" cracked (sound) 7 in CRCP is shown through 9 years in Figure 13. Nine years was the greatest age at which an overlay was performed, but there are several original 7-inch CRCP pavements that range up to 20 years in age. They are represented in the survival plots as a flat line because no non-"D" cracked 7-inch CRCP between 9 and 20 years old has been overlaid.

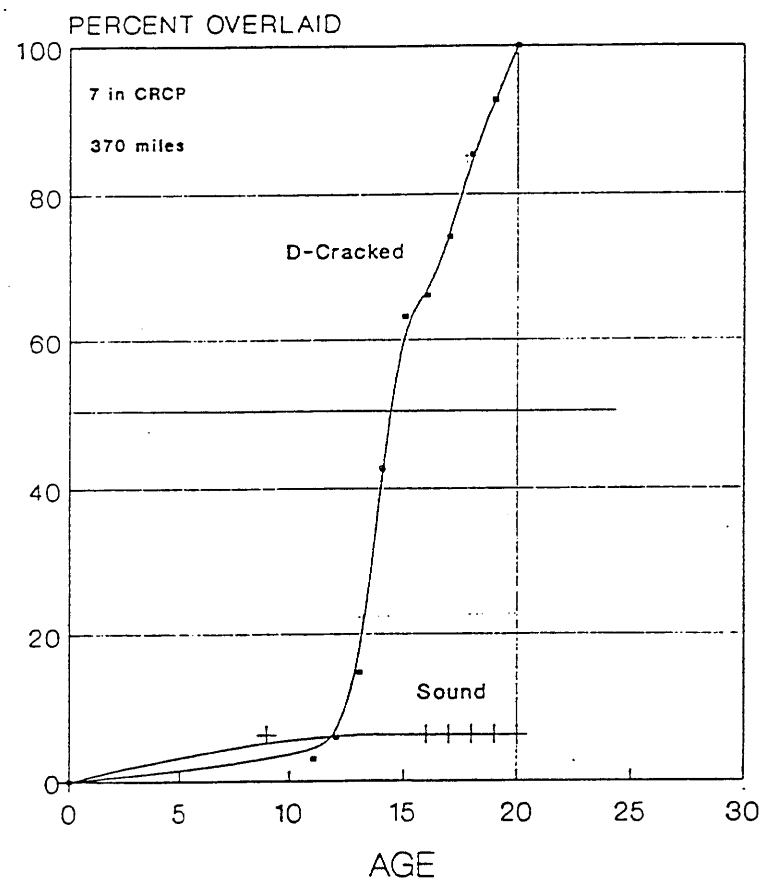

Figure 13. Performance comparison of "D" cracked and sound 7 inch CRCP.

All of the 9 in CRCP that has been overlaid to date exhibited "D" cracking as shown in Figure 14. Thus, these survival curves are very conservative in estimating pavement life. As time passes, these curves will be revised to reflect more accurately the survival of these non-"D" cracked pavements.

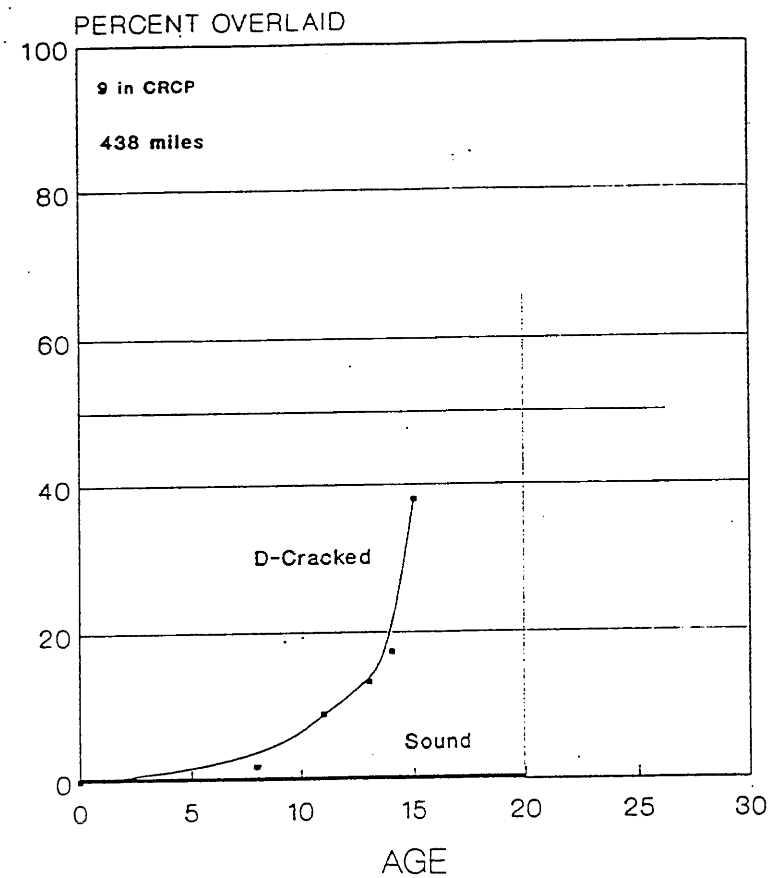

Figure 14. Performance comparison of "D" cracked and sound 9 inch CRCP.

CONCLUSIONS

The JRCP and CRCP Interstate highway pavements in Illinois have performed remarkably well. On average, they are withstanding three times the design traffic loadings before rehabilitation is applied. When the design traffic was applied to these pavements, only about 4 percent had been overlayed.

The average ESAL application rate in the outside lane has increased from 300,000 per year to 1,000,000 per year over the past 30 years. An annual compounded growth rate of accumulated ESALs has been 8 to 9 percent over the past 30 years. Even with the greatly increased traffic loadings, the average life span of the pavements is 21 years.

The 7 in CRCP carried 8 million ESALs, the 8 in CRCP 15 million, the 9 in CRCP probably over 20 million, and the 10 in CRCP 27 million ESALs until 50 percent are overlaid (all of the 9 in CRCP overlaid thus far were "D" cracked). The 10 in JRCP carried 13 million ESALs until 50 percent of the sections were overlaid.

The overall performance of 8-inch CRCP was approximately equal (in terms of ESALs to first rehabilitation) to that of 10-inch JRCP, which was the design intent. D-cracking, however, severely affects performance of CRCP. Eight-inch CRCP constructed with a "D" cracking susceptible aggregate showed approximately a 5 year shorter life than with a non "D" cracked aggregate. The difference was greater for 7 and 9 in CRCP.

The research for this study was conducted by a joint IDOT and University of Illinois research team working on the Illinois Pavement Feedback/Management System project. The data needed for this research came from a new centralized data base being compiled on this project from various IDOT pavement sources. This study is an example of the special pavement studies that can now be performed with the ready availability of detailed pavement management data.

The results of this study is that the Illinois concrete pavements are performing far better than they were designed to perform in terms of ESALs. At the design ESALs, only 5 percent had been overlaid as shown on the survival curve plot for all pavements. Conversely, there is a 95 percent probability that a pavement will reach its design ESALs prior to overlay. The pavements on the average, carried three times their design ESALs before rehabilitation.

Analysis of this data will be used for many purposes, such as a source to predict future pavement performance. Analyses of the data are continuing.

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