

PAVEMENT PERFORMANCE ANALYSIS OF THE ILLINOIS INTERSTATE HIGHWAY SYSTEM

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ABSTRACT

The Illinois Interstate highway system consists primarily of CRCP and JRCR. These pavements were constructed mostly between 1957 and 1980. Extensive pavement design, traffic and performance data were obtained from 3400 one-directional miles of Interstate highway. The average ESALs application rate has increased by an annual compounded growth rate of 7 percent, far more than expected.

Survival curves showing the percent of total length 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 23 years, after carrying about triple the design ESALs over that time period.

Durability cracking ("D" cracking) of PCC aggregates severely affects CRCP performance, shortening the average life by five years or more. The average life of JRCR was shortened only by about one year by "D" cracking. Overall, 8 in CRCP performed equally as well as 10 in JRCR, however, non "D" cracked 8 in CRCP performed better than 10 in JRCR.

Overall, even though there have been a variety of specific design, materials and construction problems, the Illinois CRCP and JRCR have performed very well in carrying far more than their design traffic.

INTRODUCTION

The Illinois Department Of Transportation (IDOT) manages 1700 centerline miles of Interstate highway pavement (1). 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 System (IPFS). Particularly, they wanted to analyze the performance of two major pavement design types, continuously reinforced concrete pavement (CRCP) and jointed reinforced concrete pavement (JRCR).

Figure 1 shows a breakdown of the pavement types included on the Interstate highway system. Ten-inch JRCR and 8-inch CRCP are equivalent designs according to IDOT's pavement design procedure and together constitute 71 percent of the Interstate pavements as shown in Figure 1. The "Other 7%" category includes mainly 10 in CRCP.

The analysis was limited to downstate Interstate highway pavements because insufficient ESAL data were available for the approximately 200 miles in Cook county (Chicago) and the surrounding four counties comprising District One.

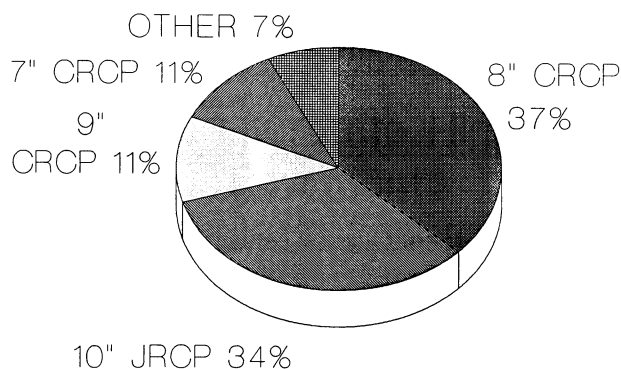


Figure 1. Illinois Interstate pavement types.

BACKGROUND INFORMATION

Design

The JRCR 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 0.70 percent area. The bases included 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 pavement suffered from 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 portion of the length of each age group that is overlaid is indicated in the bottom part of each bar.

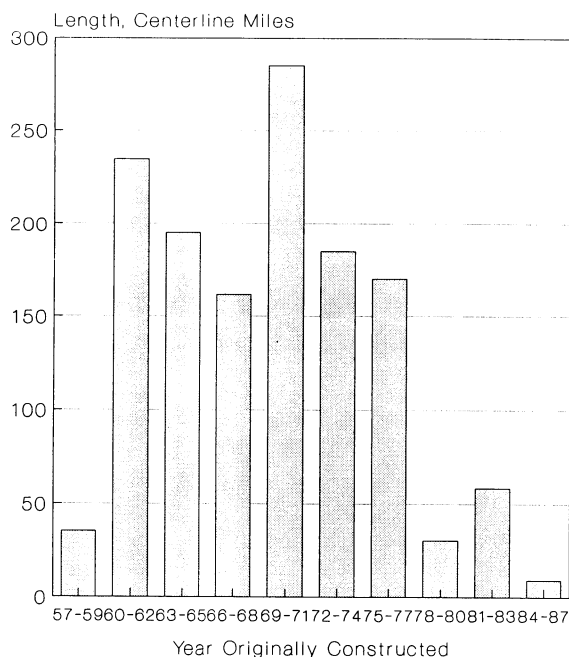


Figure 2. Age distribution of all pavements.

Traffic

Interstate pavements are designed to carry 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 age, which actually represents cycles of freeze/thaw, hot/cold, wet/dry. Therefore, a designer must predict the traffic loads the pavement will be subjected to during the design life.

The standard AASHTO 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. The number of equivalent 18-kip single axle loads are identified as ESALs. For example, one tractor semi-trailer combination is equivalent to 1.91 18-kip ESALs; one 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 well known that these truck factors may be up to 50 percent lower than actual data as indicated by weigh-in-motion monitoring in various states.)

Annual ESAL applications have increased dramatically since the Interstate highway system was first begun. Figure 3 shows average annual ESAL applications in downstate Illinois for each year since 1959. The average ESAL application

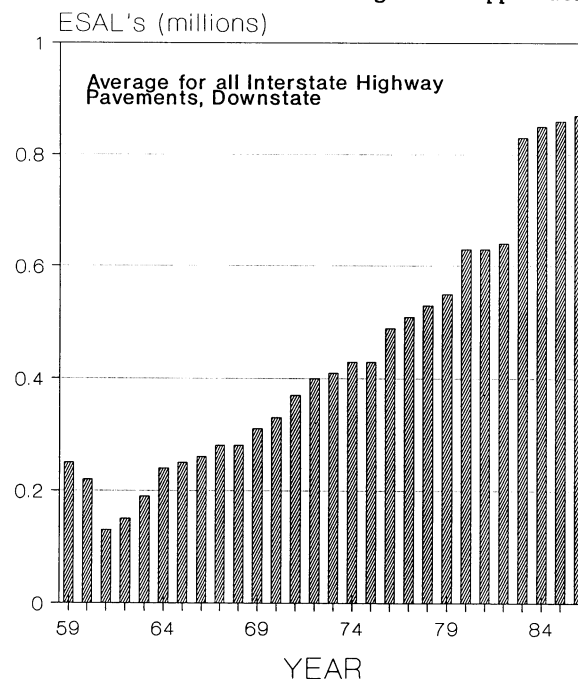


Figure 3. Average annual ESALs by year in the outer traffic lane (downstate).

rate in the outside lane has increased from 150,000 per year in 1961 to 900,000 per year in 1987. The average compound growth rate of ESALs over these years is approximately 7 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 13 million for 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-57 just north of Champaign were 900,000 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 for all down state sections (not Chicago area). 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.

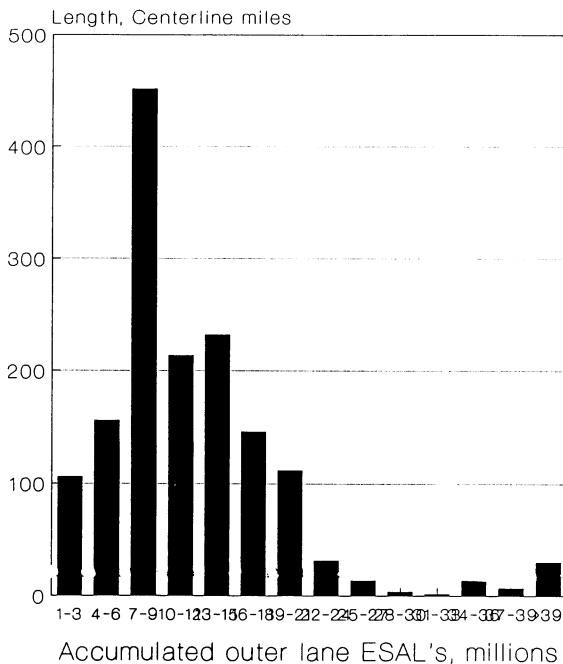


Figure 4. Accumulated ESAL distribution of downstate Interstate pavements.

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 is typical. The most typical rehabilitation used in Illinois 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 current 1987 overall status of the Interstate highway pavements are shown in Figure 5. The average pavement age of all sections in 1987 was 20 years (which was also the design life). The average traffic loading has been 10 million 18-kip ESALs. Thirty-eight percent of these pavements have been overlaid in 1987.

Average Age = 20 Years
Average Loading = 10 million 18K-ESAL's

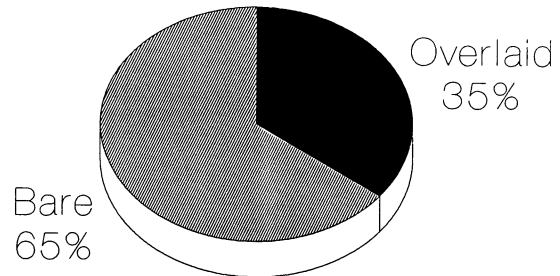


Figure 5. 1987 status of downstate Interstate Pavements.

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 prior to the first major rehabilitation.

An estimate of the distribution of age/ESALs to first overlay was made using the product limit or Kaplan-Meier method found in the SAS statistical analysis software (3). The survival distribution estimates of percent length of pavement overlaid versus age and accumulated ESALs were then plotted as survival curves.

A survival curve for all pavements combined in terms of age is shown in Figure 6. The plot shows the percent length of all the pavements overlaid as age increases. For example, 38 percent of all sections were overlaid when they reached the standard design age of 20 years. The average life span of all sections when 50 percent sections were overlaid is approximately 23 years.

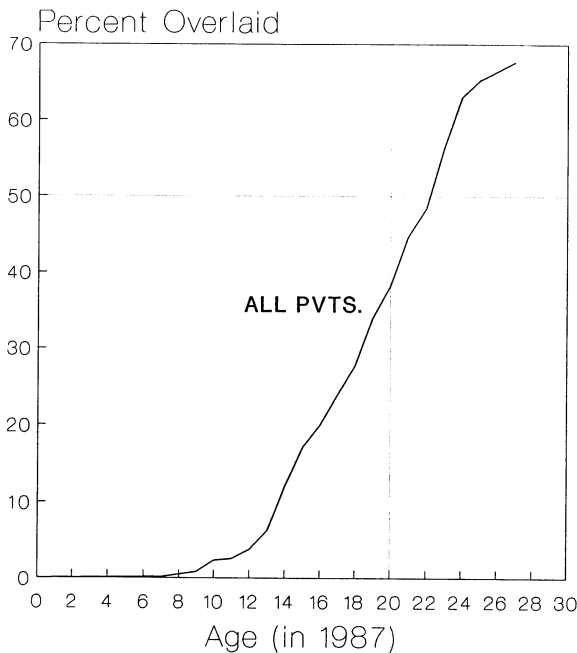


Figure 6. Survival curve by age for all pavements.

A similar survival curve for all pavements in terms of ESALs is shown in Figure 7. This plot shows that when 13 million ESALs had been applied, about 50 percent of the sections had been overlaid. A large percentage of the sections (82) were designed for less than 5 million ESALs. When this number of ESALs were applied, only about 6 percent of the sections were overlaid. This indicates a design reliability of about 94 percent overall.

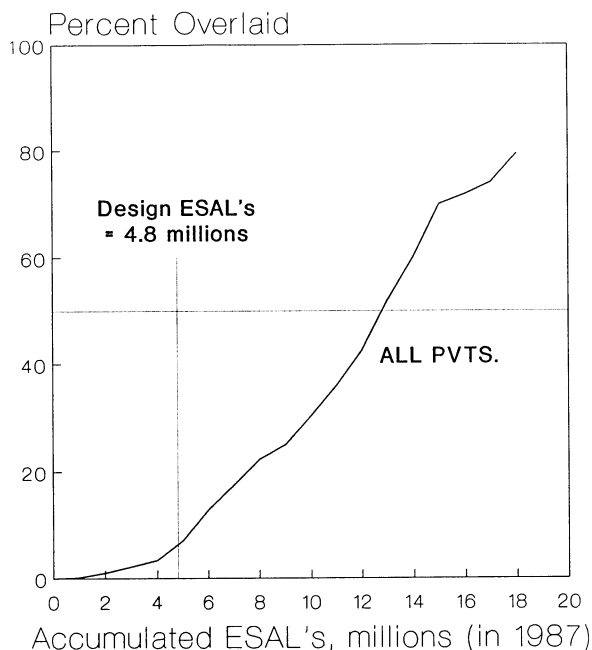


Figure 7. Survival curve by ESAL for all pavements.

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

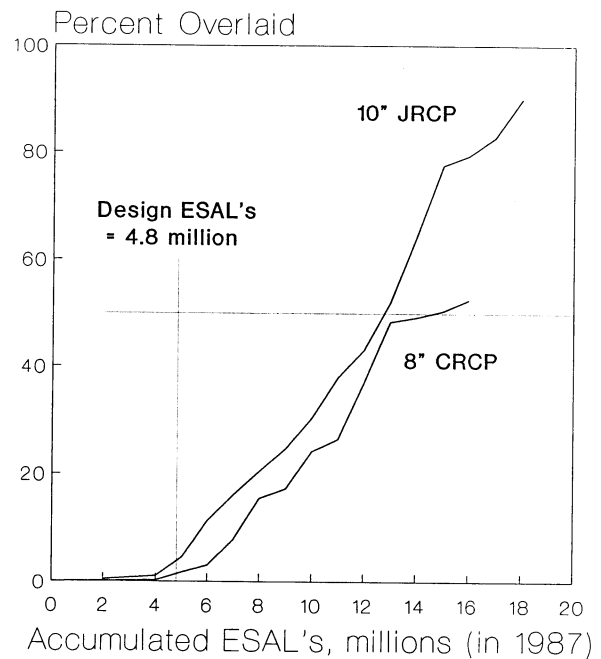


Figure 8. Performance comparison of 8 in CRCP and 10 in JRCP.

Survival curves in terms of ESALs for 7-inch CRCP, 8-inch CRCP, 9-inch CRCP, and 10-inch JRCP are shown together for comparison in Figure 9.

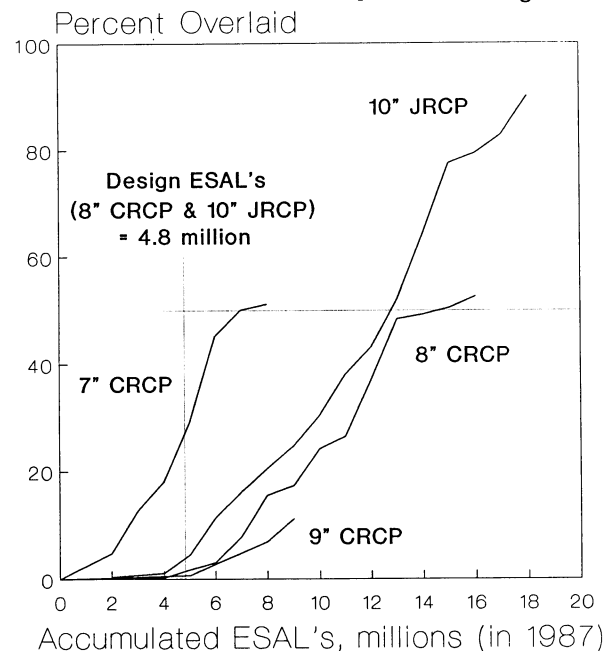


Figure 9. Survival curves by ESAL for 7 in CRCP, 8 in CRCP, 9 in CRCP, and 10 in JRCP.

These results show an expected trend, that the thicker CRCP slabs carried more traffic than thinner slabs.

A summary of pavement life for each design type that has shown deterioration is shown in Figure 10. For example, a typical 7 in CRCP has received 6 million ESALs at an age of 15 years. This pavement was designed for about 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 on the average that actual pavement life exceeds design life in terms of age (an average of 3 years) and far exceeds design life in terms of traffic loading.

Pavement Type	Average Life (yrs)	Actual Average ESAL's	ESAL Design Ratio *
7" CRCP	15	6	3.0
8" CRCP	22	13	2.9
10" JOINTED	23	13	2.9

* ESAL's Actually Applied/Design ESAL's

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.

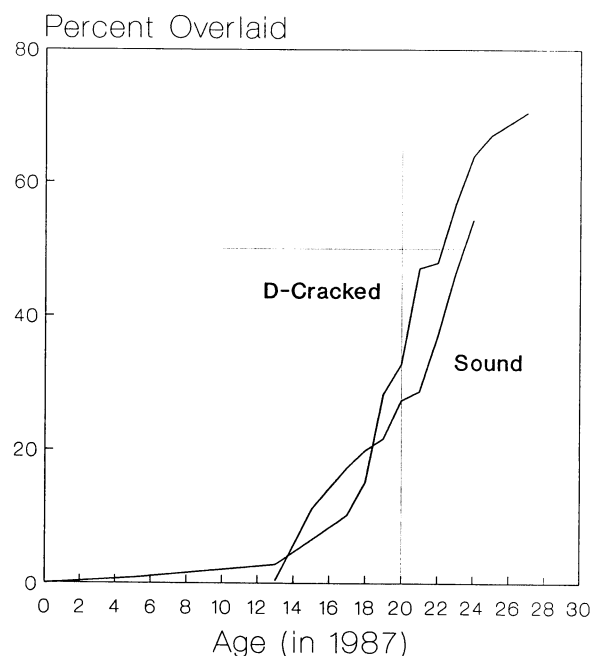


Figure 11. Performance comparison of "D" cracked and sound 10 in JRCP.

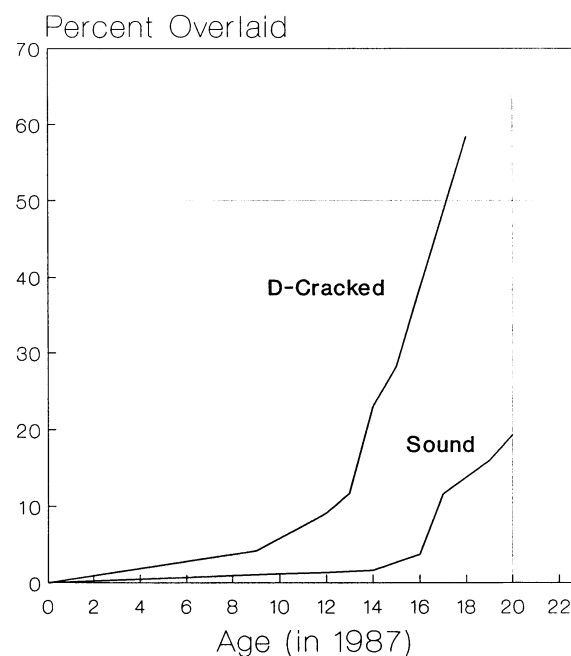


Figure 12. Performance comparison of "D" cracked and sound 8-inch CRCP.

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 CRCP pavements constructed with D-cracking susceptible aggregates and CRCP pavements constructed with sound aggregate as shown in Figure 12. Conversely, there is little difference in JRCF life between D-cracked and sound pavements as seen in Figure 11.

A comparison of Figures 11 and 12 indicate that an 8-inch CRCP constructed with sound aggregates survived much longer than a 10-inch JRCF with sound aggregates. IDOT has taken steps to prevent the use of aggregates that are highly susceptible to D-cracking.

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 survival of non D-cracked (sound) 7-inch CRCP is shown estimated to 15 years in Figure 13. Fifteen years was the greatest age at which an overlay was performed, but there are a few bare 7-inch CRCP pavements left that are as old as 20 years. They are not represented in the survival plots because no 7-inch CRCP between 16 and 20 years old has been overlaid.

All of the 9 in CRCP that has been overlaid exhibited "D" cracking as shown in Figure 14.

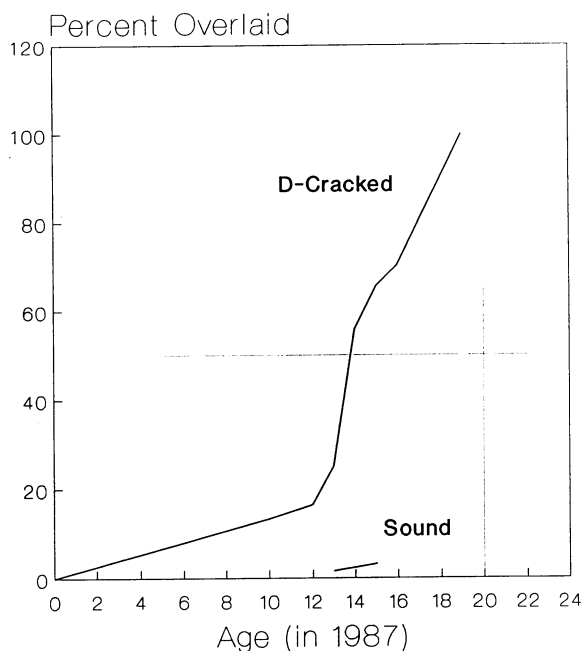


Figure 13. Performance comparison of "D" cracked and sound 7-inch CRCP.

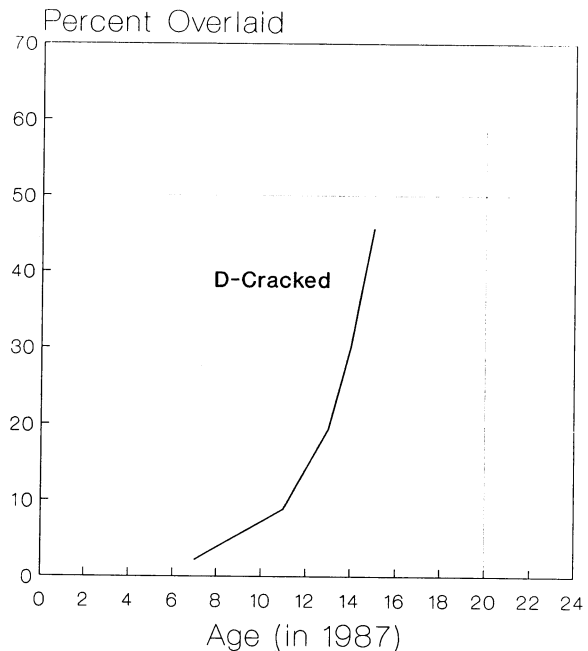


Figure 14. Performance comparison of "D" cracked and sound 9 in CRCP.

CONCLUSIONS

The JRCF 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. The average ESAL application rate in the outside lane has increased from 150,000 per year in 1961 to 900,000 per year in 1987, representing an annual compounded growth rate of seven percent over 26 years. Even with the greatly increased traffic loadings, the average life span of the pavements is 23 years.

The 7 in CRCP carried 6 million, the 8 in CRCP 14 million and the 9 in CRCP probably over 20 million ESALs until 50 percent were overlaid (all of the 9 in overlaid thus far were "D" cracked). Data for 10 in CRCP are available in the Chicago area, and show ESALs far in excess of these values (about 35 million for the Stevenson Expressway, over 50 million for the Dan Ryan Expressway local lanes which are not yet rehabilitated). The 10 in JRCF carried 13 million ESALs until 50 percent of the sections were overlaid.

The overall performance of 8-inch CRCP was equal to that of 10-inch JRCF, which was the design intent. D-cracking, however, severely affects performance of CRCP. Eight-inch CRCP constructed with a "D" cracking susceptible aggregate showed at least a 5 year shorter life than with a non "D" cracked aggregate.

The research for this study was conducted by the 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 the 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 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 6 percent had been overlaid as shown on the survival curve plot for all pavements. Conversely, there is a 94 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.

Improvements to the conventional designs included in this study should increase the capability to carry heavy traffic and resist the effects of climate.

REFERENCE LIST

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