Performance of Asphalt Concrete Resurfacing of Jointed Reinforced Concrete Pavement on the Illinois Interstate Highway System

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A study was conducted on the survival of asphalt concrete (AC) overlays on the Illinois Interstate highway system. Data were obtained from the Illinois Pavement Feedback System (IPFS) data base for 410 AC overlay construction sections placed on jointed reinforced and continuously reinforced concrete pavement (JRCP and CRCP) between 1964 and 1989. The overlays ranged in thickness from 1.5 to 6.0 in. Both in-service life and 18-kip equivalent single-axle loads (ESALs) carried to rehabilitation of the overlay were analyzed through the use of survival curves. The survival of the 213 AC overlays of JRCP sections is reported. The mean age and accumulated ESALs at the time of overlay rehabilitation were estimated for categories of overlay thickness (thin and thick) and portland cement concrete durability (with and without D cracking). The analysis indicated that each of the factors considered, along with traffic level, had a significant effect on the life of the overlays. Thick overlays lasted substantially longer and carried substantially more traffic than thin overlays on both D-cracked and non-D-cracked pavement. Both thin and thick overlays performed much better on pavements without D cracking than on pavements with D cracking.

Resurfacing has been used extensively to extend the life of deteriorating portland cement concrete (PCC) pavements. Resurfacing is by far the most common method of rehabilitation used today throughout the United States. Other major rehabilitation techniques include restoration without overlay and reconstruction, which is often used in conjunction with recycling.

The Illinois Interstate highway system consists of approximately 800 pavement sections (1,700 centerline miles total) of heavily trafficked multiple-lane pavements that were constructed largely between 1957 and 1980. These pavement sections range in length from one-quarter to 10 mi, with an average length of about 3 mi. About one-third of these pavements were originally constructed as jointed reinforced concrete pavement (JRCP); the remaining two-thirds were originally constructed as continuously reinforced concrete pavement (CRCP). The performance of these sections was analyzed by Dwiggins et al. (*1*).

Traffic on these pavements, expressed in terms of 18-kip equivalent single-axle loads (ESALs) has been far greater than anticipated. A recent traffic loading evaluation (*2*) indicated that in 1986, ESALs on Illinois Interstates averaged 1.2 million per year in one direction in the outer traffic lane, ranging from 300,000 to 7 million per year. The same study indicated that annual ESALs on these pavements grew at a compounded rate of 8 percent between 1956 and 1986. An Illinois Interstate pavement section subjected to an average traffic level and overlaid in 1986 could therefore be expected to accumulate more than 17 million additional ESALs in the next 10 years.

As of 1990, the Illinois Department of Transportation (IDOT) had resurfaced nearly one-half of the 1,700-mi Interstate highway system. Nearly all of the resurfacing has been with asphalt concrete (AC) overlays of various thicknesses. A few CRCP overlays have been placed (*3*). Before resurfacing, some repairs are typically done on the JRCP or CRCP, including full-depth repair with AC or PCC, partial-depth repairs with AC, edge drain installation, and shoulder repair.

Information on the performance of AC overlays placed JRCP is presented. (An insufficient number of AC overlays of CRCP sections has failed to provide reliable estimates of their mean performance life.) Data for this evaluation were obtained from the Illinois Pavement Feedback System (IPFS) data base (*4*). Comparisons are made between the performance of different AC thicknesses (thin and thick) on JRCP and the effect of durability D cracking of the original JRCP. These results can be used to feed back information to improve the overlay design and construction procedures to enhance service life.

CAUSES OF AC OVERLAY FAILURE

The predominant distresses in AC overlays of PCC pavements that most often determine when a second rehabilitation is required are deteriorated reflection cracks, localized distress caused by D cracking in the PCC layer, rutting, and deterioration of AC patches and expansion joints.

Reflection Cracking

The basic mechanism of reflection cracking in AC overlays of PCC pavements is strain concentration in the overlay caused

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by movement in the vicinity of joints or cracks in the existing PCC slab. This movement may be either bending or shear induced by loads, or may be horizontal contraction induced by temperature changes. Load-induced movements are influenced by the thickness of the overlay and the thickness and stiffness of the existing pavement. Temperature-induced movements are influenced by daily and seasonal temperature variations, the coefficient of thermal expansion of the existing pavement, and the spacing of cracks (*5*).

In an AC overlay of jointed PCC pavement (JPCP or JRCP), reflection cracks typically develop relatively soon after the overlay is placed (often in less than 1 year). The rate at which they deteriorate depends on the factors listed earlier as well as the traffic level. Thorough repair of deteriorated joints and working cracks using full-depth dowelled PCC repairs reduces the rate of reflection crack occurrence and deterioration, so long as good load transfer is obtained at the full-depth repair joints. Other preoverlay repairs that will discourage reflection crack occurrence and subsequent deterioration include subdrainage improvement, subsealing of slabs that have lost support, and restoring load transfer at joints and cracks with dowels grouted in slots (*5*).

A variety of reflection crack control measures have been used in attempts to control the rates of reflection crack occurrence and deterioration. Any one of the following treatments may be used in an effort to control reflection cracking in an AC overlay of jointed PCC pavement (*5*).

1. Placing a synthetic fabric or a stress-absorbing interlayer before or within the AC overlay. The effectiveness of this technique is questionable.
2. Placing a bituminous-stabilized granular interlayer (large-sized stone) before or in combination with placement of the AC overlay.
3. Sawing and sealing joints in the AC overlay at locations coinciding with joints in the underlying PCC slab.
4. Breaking or cracking and seating the PCC slab before placement of the AC overlay. This technique is intended to reduce the size of PCC pieces and seats them in the underlying base material, which reduces horizontal (and possibly vertical) movements across the cracks.
5. Rubblizing the PCC slab before placement of the AC overlay. This technique reduces the size of PCC pieces to a maximum of about 12 in. and essentially reduces the slab to a high-strength granular base course.
6. Increasing AC overlay thickness. Reflection cracks will take more time to propagate through a thicker overlay and will deteriorate more slowly.

Reflection cracking can have a considerable (often controlling) influence on the life of an AC overlay of jointed PCC pavement. Deteriorated reflection cracks reduce a pavement's serviceability and also require frequent maintenance, such as sealing and patching. Reflection cracks also permit water to enter the pavement structure, which may result in loss of bond between the AC overlay and existing PCC surface and result in stripping in the AC. For this reason, reflection cracks should be sealed as soon as they appear and be resealed periodically throughout the life of the overlay. Sealing low-severity reflection cracks may also be effective in retarding their progression to medium and high severity levels (*5*).

With an AC overlay on CRCP, permanent patching of punchouts and working cracks with tied or welded reinforced PCC full-depth repairs will delay for many years the occurrence and deterioration of reflection cracks. Improving subdrainage conditions and subsealing in areas where the slab has lost support will also discourage reflection crack occurrence and deterioration. Reflection crack control treatments are not necessary for AC overlays on CRCP as long as permanent PCC-tied repairs are used for deteriorated areas and cracks (*5*).

The importance of preoverlay repair to the prevention of reflection cracking in an AC overlay of CRCP was demonstrated in a 10-year overlay performance study conducted from 1978 to 1988 (*6*). Every patch, crack, and joint in a 6.6-mi section of Interstate 57 near Manteno, Illinois, was mapped before the AC overlay was placed. Distress surveys and nondestructive deflection tests were performed on the overlaid pavement immediately after overlay placement, and after 1, 5, and 10 years. The only cracks that reflected through the overlay were those that were deteriorated (medium or high severity) and were not repaired with a permanent reinforced concrete patch before overlay. More than 90 percent of the tied PCC patches that were placed before the overlay could not be detected in the AC overlay by reflection cracks even after 10 years of service. However, the patch locations are known by station, and also by patch numbers stamped in the overlay. A more detailed description of the performance of this project was provided by Hall and Darter (*6*).

D Cracking

D cracking is progressive deterioration of PCC that occurs as a result of freeze-thaw damage. D cracking occurs frequently in PCC pavements in the northeastern, north central, and south-central regions of the United States (*7*). The major factors which influence the likelihood that a pavement will develop D cracking are availability of moisture (including quality of base drainage) (*8*), occurrence of freeze-thaw cycles (*9*), coarse aggregate composition (sedimentary rocks such as limestone and dolomite are generally most susceptible) (*10*), pore size distribution of the coarse aggregate (*11–14*), and maximum aggregate size (*15,16*). The fine aggregate does not influence the likelihod of D cracking (*9,17*). The level of air entrainment, likewise, does not affect D cracking (*18*) (although air entrainment does improve resistance to scaling caused by freeze-thaw damage in the cement mortar). The composition or brand of cement has little or no influence on D cracking (*9–11,17,19*). Although D cracking is not caused by traffic loads, it eventually results in severe deterioration of the PCC, particularly near joints and cracks, and reduces the structural capacity of the pavement.

D cracking occurs in Illinois primarily in PCC pavements constructed with gravel, rather than crushed stone. The Illinois DOT found in a 1979 survey that only 42 percent of the Interstate system was free of D cracking. Low-severity D cracking was present on 40 percent of the system, medium-severity D cracking on 12 percent, and high-severity D cracking on 6 percent (*20*). It has also been Illinois' experience that D cracking results in more severe deterioration in CRCP than in JRCP. One explanation proposed for this is that the many fine cracks that naturally occur in CRCP offer more locations for infiltration of water into the PCC (*7*). Another possible explanation is that CRCP sections in Illinois are constructed on cement- or asphalt-stabilized base courses, which have worse drainage characteristics than the granular base courses on which JRCP sections are constructed.

In a thorough investigation of D cracking in AC-PCC pavements in Illinois, it was found that AC overlays do not halt the progression of D cracking, and in some cases accelerate it (*21*). Although the AC layer insulates the PCC to some extent, thereby increasing the minimum pavement temperature and decreasing the number of freeze-thaw cycles in the PCC, it also decreases the rate of freezing, which is detrimental. In the laboratory, PCC samples subjected to 400 freeze-thaw cycles (equivalent to, for example, about 4 years of exposure near St. Louis), experienced reductions in split tensile strength of 20 percent. Samples with 2- and 4-in. AC overlays experienced greater strength losses than samples with no overlays (*21*).

It has also been observed in the laboratory that autogenous healing occurs in D-cracked PCC samples when freeze-thaw testing is stopped and the samples are exposed to warmer temperatures. In the field, this autogenous healing may recover some of the strength lost because of D cracking. It is conceivable that in some areas in Illinois, for example, warming during the summer could achieve strength gains that would offset strength losses caused by freeze-thaw damage in the winter. This recovery process could only continue until the unhydrated cement in the PCC was consumed, after which the strength would be expected to steadily decline with successive winters. Although only a hypothesis, this process may explain why some pavements do not manifest significant D cracking until they are 10 years old or more.

D cracking may also reduce the bond between the PCC and an AC overlay (*21*). Loss of bond can result in increased rutting in the AC and reduced structural response of the AC-PCC pavement.

The strength loss caused by D cracking is evident on a 9-mi AC overlay section on Interstate 70 near Marshall, Illinois. Severe D cracking of the 8-in. CRCP existed before the AC overlay was placed in 1980. The D cracking has continued, and in combination with a high volume of repeated heavy loads (10 million ESALs since 1980), has caused the concrete to completely disintegrate in some locations. Pumping of concrete fines is evident at several locations in the wheelpaths and at the edge joint. Nondestructive deflection testing was performed along the project using a falling weight deflectometer (FWD). Sixteen cores were also taken at various cracks, localized failures, and apparently sound sections. Nearly all of the cores indicated severe disintegration of the CRCP slab. Higher FWD deflections and lower backcalculated moduli of the CRCP slab corresponded to higher-severity cracks or failures and to more deteriorated area in the underlying CRCP. Large areas along this project are exhibiting major localized slab disintegration.

Rutting

Rutting is another major distress in AC overlays of PCC pavements. Wheelpath ruts of ⅓ to ½ in. are considered by many highway agencies to pose a safety hazard, because of the potential for hydroplaning, wheel spray, and vehicle handling difficulties (*22*).

The four mechanisms that cause rutting in AC are deformation of supporting layers, consolidation caused by insufficient compaction during construction, surface wear caused by studded tires and tire chains, and plastic deformation of the AC mix. Rutting caused by permanent deformation of supporting layers occurs only in flexible pavements (e.g., AC over granular base). Rutting caused by insufficient compaction generally does not contribute significantly to rutting in AC overlays of PCC. Rutting caused by surface wear occurs on both AC and PCC pavements in some western states where studded tires are still used, but it is not seen in Illinois.

The primary mechanism of rutting in AC-PCC pavements is plastic flow of the mix laterally away from the wheelpaths, because of shear stress produced by applied loads. This plastic deformation normally occurs relatively slowly and develops into ruts of significant depth after several years. Mix deficiencies that increase an AC overlay's tendency to rut are rounded aggregates, excessive fines, improper aggregate gradation, stripping-susceptible aggregates, low air void content, low asphalt cement viscosity, and high asphalt content (*22*).

The magnitude of shear stress experienced by the overlay under loading also depends on the AC-PCC interface bonding condition and the AC thickness, as shown in Figure 1. Shear stress in the AC is lowest when the AC and PCC are fully bonded, and increases when bond is lost. When the AC and PCC are fully bonded, AC shear stress increases with overlay thickness. This process has been cited as a possible reason that thin overlays do not fail primarily because of rutting. When the AC and PCC are not bonded, AC shear stress is highest for overlays between 4 and 6 in. thick (*23*). Premature rutting, which develops unusually rapidly and reaches a critical level within 1 or 2 years, occurs sometimes in a poorly designed AC mix as a result of shear failure. Premature rutting has occurred in some AC overlays on Illinois Interstates, particularly in overlays placed before about 1984, as a result of poor AC mix design or poor field control. For example, several miles of AC overlays placed on I-55 and I-70 before 1984 rutted prematurely. These overlays were either removed by cold milling and replaced with new overlays or were cold milled and not replaced. An IDOT task force investigated the occurrences of premature rutting and concluded that the AC

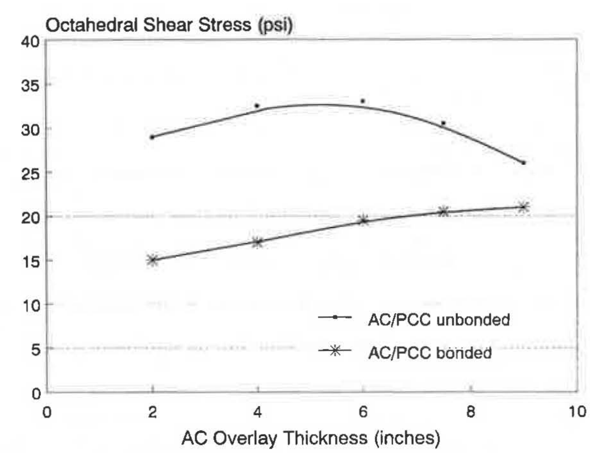

FIGURE 1 Variation of maximum octahedral shear stress in AC overlay of PCC pavement (*23*).

mix used for overlays at that time had gradation problems and low air voids. Changes in the mix design were made to correct these and other minor problems and were implemented during the 1984 construction season (*24*). This change in Illinois' AC mix design must be taken into consideration when comparing the rutting behavior of overlays placed before 1984 with the rutting behavior of overlays placed after that time.

Preoverlay AC Patches and Expansion Joints

Placement of full-depth AC patches and expansion joints in many CRCP and JRCP pavements before overlay often results in significant distress in the AC overlay. Besides creating a hump in the overlay surface, transverse cracks reflect through the overlay and typically deteriorate quickly. This increases roughness and maintenance requirements.

Major Deterioration Modes by Pavement Type

The relative performance of different types of AC-PCC pavement in Illinois might be generalized in the following descending order:

1. AC with Sound CRCP. When adequate preoverlay repair is done, good to excellent performance has been observed for pavements in this category. The experimental project on I-57 at Manteno is a good example (*6*). The performance life of AC over non-D-cracked CRCP is most likely to be controlled by rutting rather than reflection cracking or structural distress.
2. AC with Sound JRCP. Fair to good performance has been observed for pavements in this category. Reflection cracking at joints, including full-depth repair joints, is often the predominant mode of failure, unless premature rutting occurs.
3. AC with D-Cracked JRCP. Fair to poor performance has been observed for pavements in this category. Extensive preoverlay repair (i.e., full-depth repair at nearly every joint and midslab cracks in many slabs) is typically required, and even so, the D cracking may continue to progress in the PCC slab after being overlaid. Reflection cracking competes with D cracking as the predominant mode of failure.
4. AC with D-Cracked CRCP. Fair to very poor performance has been observed for pavements in this category. D cracking has been found to shorten the life of bare CRCP in Illinois much more than it does the life of bare JRCP (*1*). Although not yet quantified, the same trend may exist after overlay. Field investigations of AC with D-cracked CRCP sections (e.g., I-70 at Marshall) suggest that the deterioration of the PCC slab may be much more extensive than distress observations indicate.

SURVIVAL ANALYSIS OF AC-PCC

Previous AC Overlay Survival Studies

Perhaps the only systematic study of the performance lives of AC-PCC pavements was conducted by Elliott for the IDOT in 1971 (*25*). In the course of developing a design procedure for AC overlays of PCC pavements, Elliott studied the time to second overlay for AC overlays placed in the 1950s and 1960s on PCC pavements in Illinois and produced the survival curve shown in Figure 2. The average performance life of first AC overlays greater than 2 in. thick on PCC pavements was found to be 14 years. Elliott also attempted to determine the average performance life of second AC overlays, but found the number of these in service at the time too few and their performance too inconsistent to draw any clear conclusions.

Since 1971, truck traffic volumes and load magnitudes on Illinois highways have increased substantially. The mix design used for AC overlays in Illinois has also changed since 1971, and the PCC pavements have gotten older, have sustained more structural damage, and in many cases, have deteriorated dramatically as a result of D cracking. The average life of the AC overlays Elliott studied is not likely to be the same as the average life of AC overlays placed in the 1970s and 1980s. Thus, for this study, Elliott's analysis of the life of AC overlays in Illinois was repeated using the most recent performance data available.

Description of Overlay Database

The data used for this analysis were obtained from the IPFS data base (*4*). Only pavement sections that received an AC overlay were selected for the overlay analysis. Data retrieved from the IPFS data base included the route number, beginning milepost, length, direction, pavement type, D cracking variable, first overlay thickness and year, second overlay thickness and year, age of first overlay, and cumulative ESALs on the first overlay. A few sections were discarded because first overlay thickness or ESAL data were missing.

The method used to calculate ESALs was described by Darter et al. (*2*). The ESALs used in the overlay survival analysis were derived from load equivalency factors for PCC pavements. Because there were no AC-PCC pavement sections studied at the AASHO Road Test, strictly speaking there are no load equivalency factors available for calculating ESALs for this type of pavement. Rigid pavement load equivalency factors were considered more appropriate for use in this analysis than flexible pavement load equivalency factors,

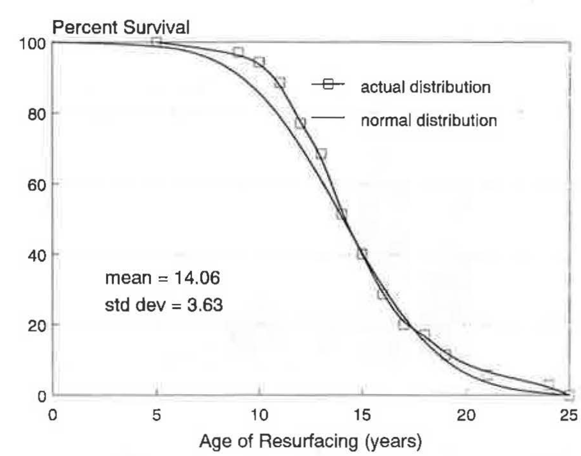

FIGURE 2 Survival of AC overlays of PCC placed in Illinois in the 1950s and 1960s (*25*).

because the structural response of AC-PCC pavement to traffic loading is more like that of PCC pavement than AC pavement. In addition, rigid load equivalency factors can be shown to more closely indicate the development of AC rutting under different axle weights and configurations than flexible load equivalency factors (S. H. Carpenter, unpublished data).

The overlaid pavements were placed in eight different categories, defined by the original pavement type (JRCP or CRCP), D cracking, and AC overlay thickness. The number of overlaid pavement sections in each of the categories is presented in Table 1.

The distribution of AC overlay thicknesses in the data base is shown in Figure 3. Of the 410 total sections, 323 received thin overlays (less than 4 in.) and 87 received thick overlays (4 in. or more). Most of the overlays were 3 or 3.25 in. thick (119 and 201 sections, respectively). The means and ranges of thin and thick overlays of JRCP and CRCP are presented in Table 2.

The distribution of AC overlay ages is shown in Figure 4. Eighty-seven percent of the overlaid sections are 10 years old or fewer. The distribution of AC overlay ESALs is shown in Figure 5. Eighty-three percent of the sections have carried fewer than 10 million ESALs.

Description of Survival Analysis Method

Survival analysis is a statistical method for determining the distribution of lives, as well as the life expectancy, or mean life, of subjects in an experiment. This analysis method, which is widely used in scientific and actuarial research, is more appropriate than simple computation of the average life of subjects whose life has ended when not all subjects in the experiment have yet reached the end of their life. (In statistical terms, such subjects are termed "right-censored observations.") Survival analysis is described in greater detail in the literature (e.g., *26–28*).

The survival analysis of AC overlays was conducted by the same procedure used in a previous study for bare JRCP and CRCP (*1*). The points for the survival curves were obtained using the LIFETEST procedure available in the PC SAS software (*26*). Survival curves were generated for each category on the basis of both overlay age and cumulative 18-kip ESALs in the outer traffic lane on the overlay.

An overlay was considered to have failed when a second overlay was placed, or in a few cases, if the first overlay was

TABLE 1 NUMBER OF AC OVERLAY SECTIONS IN EACH CATEGORY

OVERLAY CATEGORY	JRCP		CRCP	
	non D cracked	D cracked	non D cracked	D cracked
THIN	81	72	65	105
THICK	35	25	2	25

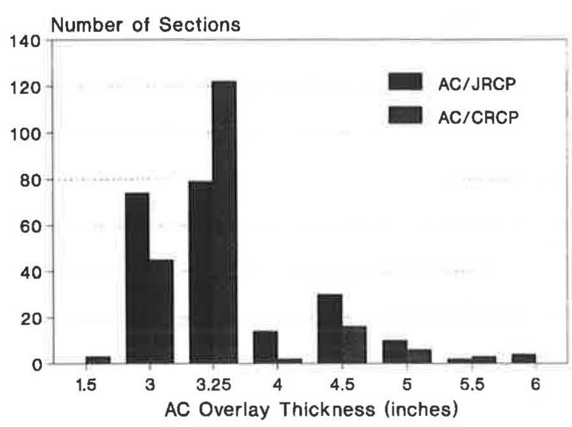

FIGURE 3 Distribution of AC overlay thicknesses on Illinois Interstates.

TABLE 2 MEAN AND RANGE OF AC OVERLAY THICKNESSES

OVERLAY CATEGORY	JRCP			CRCP		
	Mean (in)	Min (in)	Max (in)	Mean (in)	Min (in)	Max (in)
THIN	3.13	3.0	3.25	3.15	1.5	3.25
THICK	4.60	4.0	6.0	4.69	4.0	5.5

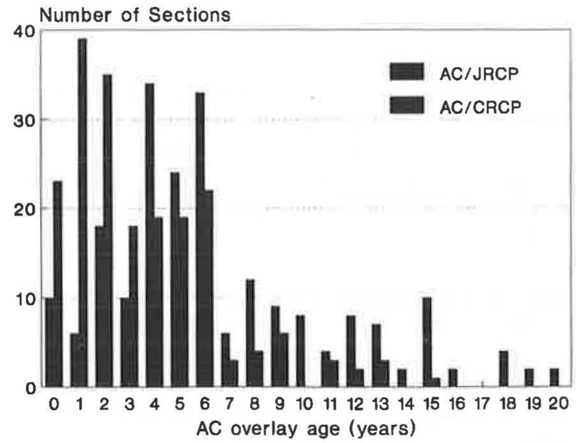

FIGURE 4 Distribution of AC overlay ages on Illinois Interstates.

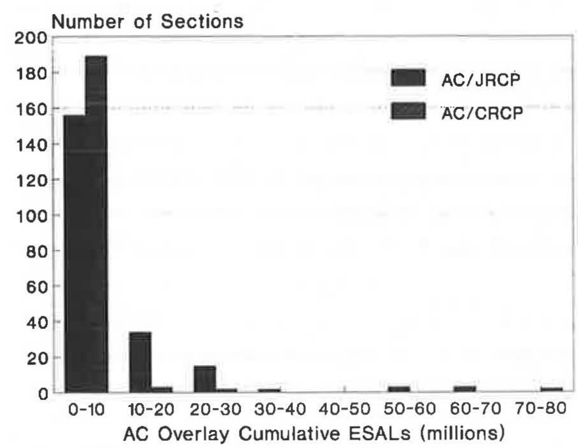

FIGURE 5 Distribution of cumulative ESALs on AC overlays on Illinois Interstates.

cold milled because of severe rutting. A point is generated on a survival curve for each age or ESAL corresponding to at least one failed section. Ages or ESALs that do not correspond to at least one failed section are not used in the analysis. The percent failure for a given age or number of ESALs is equal to the probability that a given section will fail when it reaches that age or number of ESALs. The greater the number of surviving sections at a given age, the lower the percent failures is for that age, hence, the lower the probability of failure at that age.

In addition to the survival distribution, a mean life is computed by the LIFETEST procedure. The computed mean life sometimes differs from the median (50th percentile) life, which is an indication that the survival distribution is not symmetric. Furthermore, if the last observation in the data set is censored (e.g., if the oldest overlay in the data set has not yet failed), the estimated mean life is biased and may be lower than the true mean.

SURVIVAL OF AC OVERLAYS OF JRCP

The mean lives of AC overlays (in terms of age and number of ESALs) in each of the four JRCP categories are presented in Table 3. Clear differences in AC overlay survival exist between D-cracked and non-D-cracked JRCP, and between thin and thick overlays.

AC-JRCP Survival in Years

The age survival curves for thin AC overlays of D-cracked and non-D-cracked JRCP are shown in Figure 6. The age survival curves for thick AC overlays of D-cracked and non-D-cracked JRCP are shown in Figure 7. In terms of age, the survival analysis indicates that D cracking of the existing JRCP slab affects the lives of thin AC overlays more than the lives of thick AC overlays. Thin AC overlays lasted 60 percent longer on non-D-cracked JRCP than on D-cracked JRCP (11.9 versus 7.3 years), whereas thick AC overlays lasted 13 percent longer on non-D-cracked JRCP than on D-cracked JRCP (16.4 versus 14.5 years).

The survival analysis also indicates that in terms of age, overlay thickness affects the lives of AC overlays on D-cracked JRCP more than the lives of AC overlays on non-D-cracked JRCP. Thick AC overlays of D-cracked JRCP sections lasted twice as long as thin AC overlays of D-cracked JRCP sections (14.5 versus 7.3 years). Thick AC overlays of non-D-cracked JRCP sections lasted about 40 percent longer than thin AC overlays of non-D-cracked JRCP sections (16.4 versus 11.9 years).

TABLE 3 MEAN LIVES OF AC OVERLAYS OF JRCP

OVERLAY CATEGORY	AGE (years)		ESAL (million)	
	non D cracked	D cracked	non D cracked	D cracked
THIN	11.9	7.3	18.4	6.3
THICK	16.4	14.5	45.4	14.7

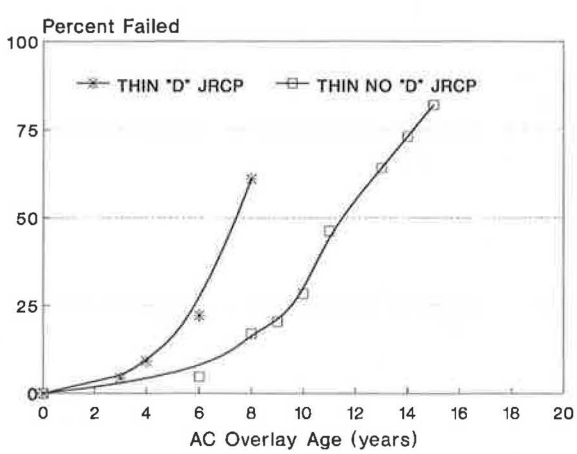

FIGURE 6 Age survival curves for thin AC overlays of JRCP.

AC-JRCP Survival Under Traffic

The ESAL survival curves for thin AC overlays of D-cracked and non-D-cracked JRCP are shown in Figure 8. The ESAL

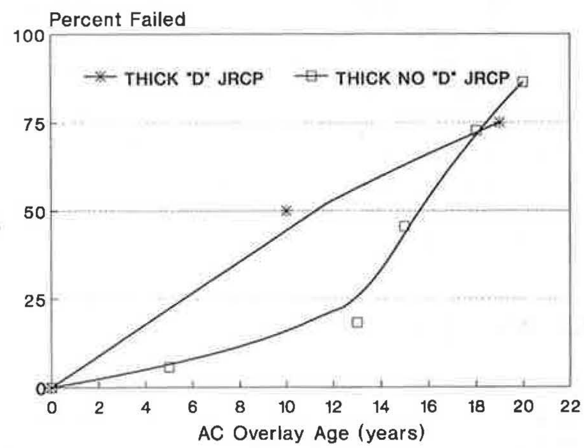

FIGURE 7 Age survival curves for thick AC overlays of JRCP.

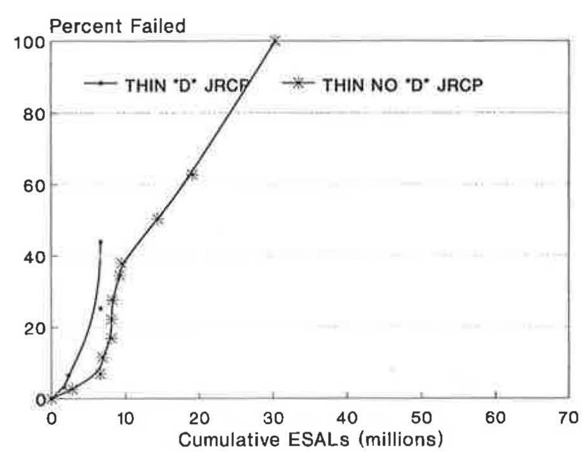

FIGURE 8 ESAL survival curves for thin AC overlays of JRCP.

survival curves for thin AC overlays of D-cracked and non-D-cracked JRCP are shown in Figure 9. In terms of traffic, the effect of D cracking on overlay survival is similar for thin and thick overlays. Thin AC overlays of non-D-cracked JRCP carried 2.9 times more traffic than thin AC overlays of D-cracked JRCP (18.4 versus 6.3 million ESALs). Thick AC overlays of non-D-cracked JRCP carried 3.1 times more traffic than thick AC overlays of D-cracked JRCP (45.4 versus 14.7 million ESALs).

The effect of overlay thickness on survival is also similar for D-cracked and non-D-cracked JRCP when considered in terms of traffic. Thick AC overlays of D-cracked JRCP sections lasted 2.3 times longer than thin AC overlays of D-cracked JRCP sections (14.7 versus 6.3 million ESALs). Thick AC overlays of non-D-cracked JRCP sections lasted 2.5 times longer than thin AC overlays of non-D-cracked JRCP sections (45.4 versus 18.4 million ESALs).

Percent AC-JRCP Sections Failed

At the time of this analysis, 25 percent of the thin AC overlays on non-D-cracked JRCP sections had failed, and 11 percent of the thin AC overlays on D-cracked JRCP had failed. Roughly the same proportions of thick AC overlays had failed as well: 31 percent on non-D-cracked sections and 12 percent on D-cracked sections. These failure percentages are considered sufficiently large for preliminary estimation of the AC overlay survival distributions. However, the shapes of the survival distributions and the mean lives in each of the categories examined are expected to change in the future as more sections reach failure and the ability to estimate the means and distributions improves.

SURVIVAL OF AC OVERLAYS OF CRCP

At the time of this analysis, most of the AC overlays of CRCP were less than 7 years old, and only 6 percent had failed. It is therefore too early to draw any reliable conclusions about the probable shapes of the survival curves or the mean lives of thin or thick AC overlays on D-cracked or non-D-cracked

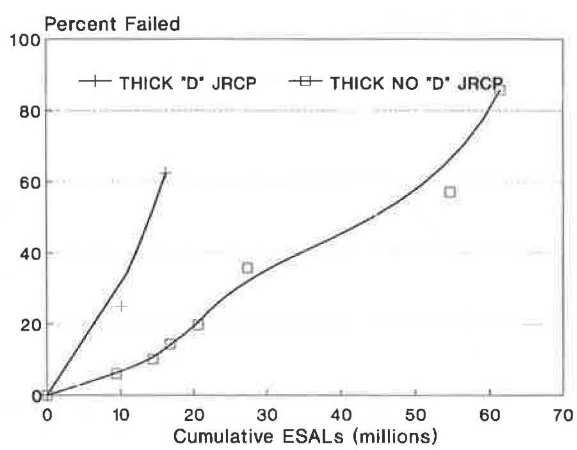

FIGURE 9 ESAL survival curves for thick AC overlays of JRCP.

CRCP. However, subjective assessments of the performance of several AC-overlaid CRCP sections suggest that the trends will be similar to those of AC-overlaid JRCP; that is, better performance on non-D-cracked pavement and better performance with thicker overlays.

SUMMARY

The predominant distresses that most often control the life of AC-PCC pavement are reflection cracking, D cracking, rutting, and AC patch deterioration. The degree to which these distresses affect AC overlay life depends primarily on the thickness of the AC overlay, the type of original slab (JRCP or CRCP), and whether or not the PCC has D cracking.

In terms of age, the beneficial effect of increased overlay thickness is significant for both non-D-cracked JRCP and D-cracked JRCP, and is more pronounced for the latter (40 and 100 percent longer life, respectively). The detrimental effect of D cracking is significant for both thick and thin AC overlays, and is more pronounced for the latter (12 and 38 percent shorter life, respectively). In terms of traffic, the effects of overlay thickness and D cracking are similar—thick AC overlays carry about 2.5 times more traffic than thin AC overlays, and AC overlays of non-D-cracked JRCP carry about 3 times more traffic than AC overlays of D-cracked JRCP. The analysis highlights the notably poor performance of thin AC overlays of D-cracked JRCP (mean life 7.3 years, 6.3 million ESALs), as well as the notably good performance of thick AC overlays of non-D-cracked JRCP (mean life 16.4 years, 45.4 million ESALs). Too few AC overlays of CRCP sections have yet failed to reliably estimate the mean lives or survival distributions of AC-CRCP on Illinois Interstates.

For the purposes of this analysis, an overlay was considered to have failed either when a second overlay was placed or when cold milling was done. This measure of overlay performance is rough, but it is the only measure available for use in the analysis. Historical distress data that might be used to determine the condition of an overlay before placement of a second overlay are not available.

The performance of AC overlays of PCC pavements is strongly influenced by the condition of the overlaid PCC, i.e., the extent of deterioration present in the original pavement and the type and amount of preoverlay repair performed. Funding limitations frequently necessitate delaying resurfacing projects, and performing less than complete repair of deteriorated areas on projects that are resurfaced. Thus, the availability of funds has a definite impact on the performance of resurfacing projects.

REFERENCES

1. M. E. Dwiggins, M. I. Darter, J. P. Hall, C. F. Flowers, and J. B. DuBose. *Pavement Performance Analysis of the Illinois Interstate Highway System*. Report FHWA-IL-UI-220. University of Illinois at Champagne-Urbana and Illinois Department of Transportation, Springfield, 1989.
2. M. I. Darter, R. A. Salsilli, M. E. Dwiggins, T. Fitch, and A. Lundberg. *Analysis of Traffic Loadings on Interstate Highways in Illinois*. Report FHWA-IL-UI-222, University of Illinois at Urbana-Champaign and Illinois Department of Transportation, Springfield, 1989.

3. D. L. Lippert and J. B. DuBose. Performance Evaluation of Concrete Overlays. Report FHWA/IL/PR-101, Illinois Department of Transportation, Springfield, 1988.
4. M. E. Dwiggins, J. P. Hall, M. I. Darter, C. F. Flowers, and J. B. DuBose. Logical and Physical Design of the Illinois Pavement Feedback System. Report FHWA-IL-UI-219. University of Illinois at Urbana-Champaign and Illinois Department of Transportation, Springfield, 1988.
5. M. I. Darter, R. P. Elliott, and K. T. Hall. *Revision of AASHTO Overlay Design Procedures*. Draft Final Report, NCHRP Project 20-7/Task 39, TRB, National Research Council, Washington, D.C., 1990.
6. K. T. Hall and M. I. Darter. Rehabilitation Performance and Cost-Effectiveness: A Ten-Year Case Study. In *Transportation Research Record 1215*, TRB, National Research Council, Washington, D.C., 1990.
7. D. R. Schwartz. *NCHRP Synthesis of Highway Practice 134: D-Cracking of Concrete Pavements*. TRB, National Research Council, Washington, D.C., 1987.
8. D. Stark. Field and Laboratory Studies of the Effects of Subbase Type on the Development of D-Cracking. In *Highway Research Record 342*, HRB, National Research Council, Washington, D.C., 1970.
9. R. J. Girard, E. W. Meyers, G. D. Manchester, and W. L. Trimm. D-Cracking: Pavement Design and Construction Variables. In *Transportation Research Record 853*, TRB, National Research Council, Washington, D.C., 1982.
10. D. Stark. *Characteristics and Utilization of Coarse Aggregates Associated with D-Cracking*. Research and Development Bulletin RD047.01p. Portland Cement Association, Skokie, Ill., 1976.
11. P. Klieger, G. Monfore, D. Stark, and W. Teske. D-Cracking of Concrete Pavements in Ohio. Report Ohio-DOT-11-74, Portland Cement Association, Skokie, Ill., 1974.
12. M. R. Thompson, M. P. Olsen, and B. J. Dempsey. *Synthesis Report: D-Cracking in Portland Cement Concrete Pavements*. Report FHWA/IL/UI-187, University of Illinois at Urbana-Champaign, 1980.
13. M. Kaneuji. *Correlation Between Pore Size Distribution and Freeze-Thaw Durability of Coarse Aggregate in Concrete*. Report JHRP-78-15, Purdue University, West Lafayette, Ind., 1978.
14. V. J. Marks and W. Dubberke. Durability of Concrete and the Iowa Pore Index Test. In *Transportation Research Record 853*, TRB, National Research Council, Washington, D.C., 1982.
15. G. Verbeck, P. Klieger, D. Stark, and W. Teske. *D-Cracking of Concrete Pavements in Ohio*. First Interim Report, No. 72-04, Ohio Department of Highways, Columbus, 1972.
16. D. Stark and P. Klieger. Effect of Maximum Size of Coarse Aggregate on D-Cracking in Concrete Pavements. In *Highway Research Record 441*, HRB, National Research Council, Washington, D.C., 1973.
17. P. Klieger, D. Stark, and W. Teske. *The Influence of Environment and Materials on D-Cracking*. Report FHWA-OH-78-06, Ohio Department of Transportation, Columbus, 1978.
18. *Twenty-Year Report on the Long-Time Study of Cement Performance in Concrete*. Research Department Bulletin 175, Research and Development Laboratories, Portland Cement Association, Skokie, Ill., 1965.
19. *Investigations of "D" Cracking in PCC Pavements: Phase 2*. Report 72-4. Division of Materials and Research, Missouri State Highway Department. Jefferson City, Mo., 1972.
20. *A Preliminary Investigation of the D-Cracking Problem in Illinois*. Bureau of Materials and Physical Research, Illinois Department of Transportation, Springfield, 1979.
21. D. J. Janssen, B. J. Dempsey, J. B. DuBose, and A. J. Patel. Predicting the Progression of D Cracking. IHR Project 417, University of Illinois at Urbana-Champaign and Illinois Department of Transportation, Springfield, 1986.
22. *Report of the AASHTO Joint Task Force on Rutting*. AASHTO, Washington, D.C., 1989.
23. S. H. Carpenter and T. J. Freeman. Characterizing Premature Deformation in Asphalt Concrete Placed over Portland Cement Concrete Pavements. In *Transportation Research Record 1070*, TRB, National Research Council, Washington, D.C., 1986.
24. E. E. Harm. *Illinois Rutting Report*. 13th Annual Asphalt Paving Seminar, Fort Collins, Colo., Bituminous Task Force on Stability and Durability, Illinois Department of Transportation, Springfield, 1985.
25. R. P. Elliott. *Thickness Design Procedure for Bituminous Resurfacings of Portland Cement Concrete Pavements*. Research and Development Report 30, Illinois Department of Transportation, Springfield, 1971.
26. SAS Institute, Inc. *SAS User's Guide: Statistics*, Version 5. Cary, N.C., 1985.
27. E. T. Lee, *Statistical Methods for Survival Data Analysis*. Wadsworth, 1980.
28. D. R. Cox and D. Oakes. *Analysis of Survival Data*, Chapman and Hall, 1984.

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