Nationwide Evaluation Study of Asphalt Concrete Overlays Placed on Fractured Portland Cement Concrete Pavements

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Historically, agencies responsible for pavement rehabilitation have tried a wide variety of materials, processes, and construction methods to eliminate or minimize reflective cracking of asphaltic concrete overlays placed on existing portland cement concrete (PCC) pavements. Over the last 10 years, the fractured slab approach using rubblize, crack and seat, and break and seat has gained increased acceptance. Because the fractured slab approach has gradually evolved through field demonstration and actual projects, very little fundamental knowledge concerning design, construction, and performance models is available. Understandably, performance to date has been variable. To improve the state of the art and develop a better understanding of these techniques, a nationwide study was undertaken. A literature review resulted in the location of nearly 500 highway projects throughout the United States. From this generalized data base, approximately 100 sites were selected for detailed field studies. Field crews conducted visual distress surveys to assess pavement performance and nondestructive deflection testing to assess the in situ characteristics of the pavement layers. The general approach used for the research study and the analysis of field performance and structural data obtained is presented. Performance predictive equations are presented along with the evaluation of the back-calculated effective moduli of fractured PCC slabs for each technique. Analysis of within and between project variability is presented.

The selection of optimal rehabilitation procedures and strategies for deteriorating highway pavements requires a knowledge of the type and cause of the distress, determination of candidate rehabilitation procedures, and selection of an optimal strategy based on economic and other considerations. For portland cement concrete (PCC) pavements, the array of possible rehabilitation procedures includes nonoverlay methods such as undersealing, grinding of the surface, and removal and replacement of distressed areas; full reconstruction by replacement or recycling; PCC overlays; and asphaltic concrete (AC) overlays.

Review of current practice indicates that AC overlays are the most commonly used PCC rehabilitation procedure, with about $1 billion of AC overlays placed each year, and this amount will likely increase in the future (*1*). Even though they are commonly used, the performance of AC overlays on PCC pavements is often hampered by the occurrence of reflection cracks over existing joints and cracks. This type of distress constitutes the most frequent cause of the loss of performance for AC overlays.

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Reflection cracks in the AC overlays are caused by a combination of thermal and traffic-induced stresses. Expansion and contraction of the PCC pavement results in horizontal movements that produce strains in the AC overlay exceeding its tensile strength. Traffic loads can cause vertical differential movements at the location of joints and working cracks in the PCC slab and induce critical shear stresses at the bottom of the AC layer. The overlay immediately over the joints and working cracks in the PCC is not able to accommodate these localized movements, resulting in the development of reflection cracks.

A wide variety of rehabilitation techniques aimed at preventing the formation of, or minimizing, reflection cracking have been attempted. They include thick (conventional) overlays, crack relief layers, the saw and seal technique, special overlay and interface materials, and the fractured slab approach. Of these, the technique that has been used increasingly over the last 10 years has been the fractured slab approach.

The major objective of the fractured slab approach is to reduce the effective in situ slab length before the overlay is placed. If this is effectively accomplished, the likelihood of having reflective cracks appear is significantly reduced or eliminated. The probability of reflective cracking is proportional to the horizontal movement at joints and cracks, which in turn is directly proportional to the spacing between joints and cracks.

The fractured slab category is generally subdivided into three major types of rehabilitation: rubblize, crack and seat, and break and seat. Rubblize is a fractured slab process intended to transform the existing PCC layers into fragments having textural and gradational characteristics similar to those of a large aggregate size crushed stone base. It is most effectively accomplished with a resonant pavement breaker, which has been successfully used on all types of existing PCC pavements [i.e., jointed plain (JPC), jointed reinforced (JRC), and continuously reinforced (CRC) concrete pavements].

Crack/seat and break/seat are fracture techniques intended to produce very short rigid slabs whose effective lengths vary from 12 to 48 in. The techniques are similar, with guillotines or spring-arm (whip) hammers being used to develop reduced crack spacings in the existing PCC pavement. There is, however, a significant distinction between the two techniques. Crack/seat is associated with the fractured slab process conducted solely on JPC pavements. For these pavements, the objective of the crack/seat process is to develop closely spaced, tight cracks that permit load transfer across the crack through aggregate interlock with little loss of structural value. Fracture or cracking through the entire depth of the PCC layer is the ultimate goal.

Break/seat is associated with the fractured slab process on JRC pavements. The ultimate objective of this technique is to physically fracture the distributed steel or completely debond the steel from the concrete. Whereas cracking may result through the entire PCC layer depth, if steel fracture or debonding is not accomplished, the effective slab length is not reduced in the construction process, and what remains is a series of smaller slabs tied together into a longer effective slab by the bonded distributed steel.

A corequisite to the slab fracturing process is the seating portion of the construction. For both cracking and breaking, it is customary to have five to seven passes of a 35- to 50-ton rubber-tired roller seat the fractured slab fragments. This provides a relatively smooth and uniform grade for paving operations and serves as an excellent means of proof-rolling before the AC overlay is placed. For rubblized projects, steel vibratory rollers (generally 10 tons) are normally used for the compaction or seating process.

NATIONAL EVALUATION STUDY

Objectives and Overview

Over the past 10 years, there has been a dramatic increase in the use of the fractured slab techniques for the rehabilitation of deteriorating PCC pavements. Much field experience has been gained during this time. However, little technical guidance, relative to the design and construction of these techniques, is available to adequately predict their performance in minimizing reflective cracking under specific traffic and climatic conditions for a particular pavement structure and existing condition.

In recognition of the critical need for a sound technical basis to support the use of the fractured slab approach, a major state-of-the-art research study was undertaken. The overall objective of the study was to develop national guidelines and methodologies for the use of these three rehabilitation techniques.

This paper presents the general approach used for the research study and concentrates on the analysis of field performance and structural data obtained. Performance predictive equations, using the pavement condition index (PCI), are presented along with the evaluation of the backcalculated effective moduli of fractured PCC slabs for each rehabilitation category. Analysis of within-project and between-project variability is presented and forms the basis for an overall design methodology described in a companion paper in this Record by Witczak and Rada.

Synthesis of Current Practice and Data Base Development

Sources of information initially collected and evaluated were obtained from various state asphalt pavement organizations, federal and state highway agencies, the Transportation Research Board, the National Asphalt Pavement Association, the Asphalt Institute, and other highway-oriented organizations. During the conduct of this study, several extremely relevant studies were completed, including *NCHRP Synthesis 144* (*2*), FHWA Contract DTFH 61-86-C-00079 (*3,4*), and individual state highway agency investigations. A complete list of the information sources may be found in the final report of this study (*5*).

The collected information was used to prepare a synthesis of current practice. This included design, construction, specifications, costs, and performance experience for projects using the crack-controlling techniques being studied. The data base was also used to identify AC overlay rehabilitation projects that used slab fracture techniques to control reflection cracking as candidates for the field investigations.

A total of 454 field projects in 34 states were identified for which at least partial design, construction, and performance information was available. Of the 454 projects, 250 were crack/seat, 150 break/seat, 19 rubblize, and 35 unknown (steel information was not available; thus, they could not be grouped into the crack/seat or break/seat categories). The geographic distribution of the projects by rehabilitation type is shown in Figure 1. In general, crack/seat projects were concentrated in the upper midwest and western states, break/seat projects in the northeastern portion of the country, and rubblize projects in the eastern half of the country.

Of interest from a practical viewpoint is a summary of several key variables given in Table 1 for each of the three re-

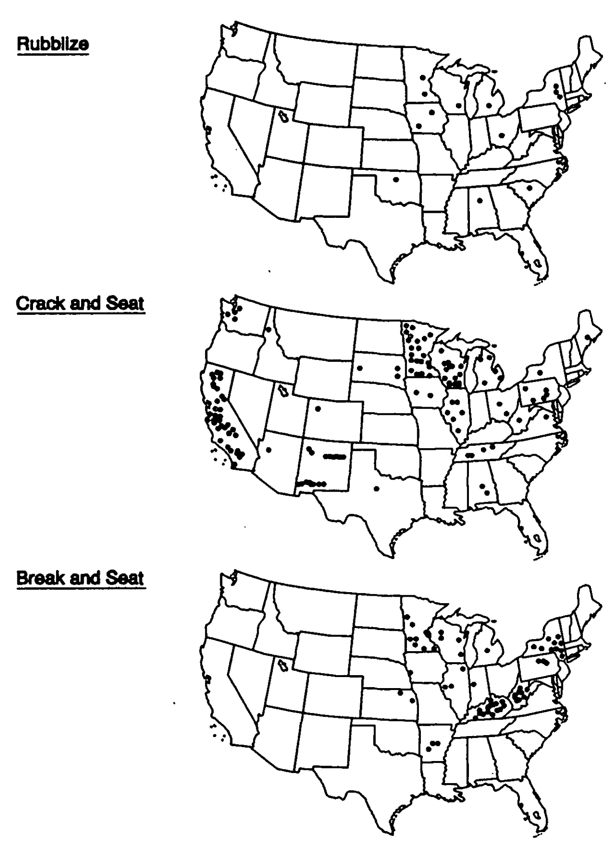

FIGURE 1 Geographical distribution of projects by rehabilitation type.

habilitation types. As can be observed, the average dates of the rehabilitation options clearly show the relative "youthfulness" of the methods discussed, particularly for the rubblize technique. The table also indicates that the average PCC thicknesses range between 8 and 10 in., which are typical of highway pavements. Finally, the resulting average statistics for the AC overlay thicknesses show that the rubblize technique had the largest average overlay thickness. This is consistent with the fact that the rubblization process is intended to truly transform an existing rigid layer into a conventional flexible layer.

A computerized data base was produced by compiling information on these projects from available documents and reports plus follow-up contacts with state highway agency personnel to search files for additional information. In this study, two types of data bases were developed: (*a*) general data base and (*b*) detailed data base. The general data base contains available data and information found previously through the literature search. Wherever possible, this information was used during the analysis portion of the study. However, the major use of this data base was to select pavement test sections for the field investigation program. These projects formed the detailed data base.

A primary consideration in the selection of the field test sections was to include a range of variables that influence pavement performance—for example, climate, AC overlay thickness, rehabilitation age, and age of existing PCC pavement before overlay. A total of 93 pavement sections—17 rubblize, 35 crack/seat, and 41 break/seat projects—were eventually selected from the general data base for the field investigation program. An additional 54 sections were included in the detailed data base as a result of deflection testing and other pertinent data provided by the Kentucky, Illinois, and Michigan highway agencies.

Field Investigations

Because of the limited availability of documented field performance for the fracture slab techniques, a primary activity of this research study was a field investigation of existing highway pavement sections where these techniques had been used. The two major field testing activities were visual distress surveys made in accordance with the PCI highway methodology and nondestructive deflection testing (NDT) using a falling weight deflectometer (FWD).

The test sections generally consisted of a 1,000-ft strip in one direction. For the PCI data collection effort, this strip was divided into five 200-ft segments. The segments in the driving lane, as well as the adjoining five segments in the passing lane, made up the 10 sample units used for recording PCI data. For each sample unit, the types of distress present were identified and their severity and extent were quantified.

The deflection testing was conducted every 25 ft for the 1,000-ft length, in the outside wheelpath of the driving lane. Each test point consisted of three drops at a target 9,000-lb load with a Phonix M10000 FWD. Deflections were measured for every drop by means of six geophones located at distances ranging from 0 to 60 in. from the center of the load plate. Deflection data were also received for 42 test sections in Illinois, 8 test sections in Michigan, and 4 test sections in Kentucky. In all, 4,700 NDT test points on 140 sections were obtained and subsequently used in the structural analyses—1,019 points on 24 rubblized sections, 1,776 points on 64 crack/seat sections, and 1,905 points on 52 break/seat sections.

Data Analysis and Interpretation

Once the field testing was completed on all test sections and data incorporated into the detailed data base, an extensive analysis was initiated. The major thrust of the analysis was to evaluate the rehabilitated pavements from both a functional and structural point of view. The results of the PCI visual condition surveys were used to estimate performance trends. Nondestructive deflection data, coupled with available cross section information, were used to backcalculate the effective in situ modulus for the pavement section layers.

The PCI values were determined according to the U.S. Army Corps of Engineers procedure (*6*). In addition, a new index value was introduced into the analysis: PCI_{lt}. The PCI_{lt} value reflects the PCI value due only to the presence of longitudinal/transverse cracking in the overlay—it excludes all distress types other than the cracking. Because prevention of reflective cracking is a major concern to the efficiency of the rehabilitation activity investigated, it was believed that the PCU_{lt} value would perhaps be another appropriate statistic to analyze.

Effective moduli of the pavement layers were backcalculated from elastic layer theory and the measured deflection basins for each specific test location. One of the major underlying hypotheses of the backcalculation study deals with the fundamental concept that a direct relationship exists between the fractured PCC modulus (E_{PCC}) value and the overall effectiveness of the construction operation in reducing the effective in situ moduli. Thus, the lower the E_{PCC} value, the greater the effectiveness of the construction operation in min-

TABLE 1 Summary of Average Statistics of Field Test Sections

Rehabilitation Type	Average Date of Rehabilitation	Average AC Overlay, in.	Average PCC Thickness, in.
Crack and Seat	1984	4.4	8.3
Break and Seat	1985	5.6	9.4
Rubblize	1986	6.0	8.9
Saw and Seal	1983	3.4	8.3

imizing the potential for eventual reflective cracking of the AC overlay.

All sections were analyzed as three-layer structures, with the bottom (subgrade) layer being of semi-infinite thickness. These structures were analyzed with a PCS/LAW in-house program called EMOD. This program uses the Chevron N-Layer elastic solution as a subroutine within the backcalculation analysis, and the respective moduli given in the output are those that result in the minimum cumulative residual square error at all deflection readings. Required thickness data were obtained from the respective state DOTs. Poisson's ratios were assumed to be 0.35 for the AC overlay, 0.30 for the fractured PCC layer, and 0.4 for the subgrade.

On the basis of the resulting PCI, PCI_{lt}, and fractured PCC modulus (E_{PCC}) data, three analyses were conducted: (*a*) development of PCI and E_{PCC} predictive models, (*b*) investigation of the influence of crack spacing on the E_{PCC}, and (*c*) investigation of the variability of the E_{PCC} values between and within projects. This paper cannot address all of the results and findings that were generated from these analyses, but several key results are presented that form the basis for the design methodology described in the companion paper in this Record.

MAJOR STUDY RESULTS

PCI Predictive Equations

One of the major objectives of the data analysis was the development of equations to predict both the pavement condition index (PCI and PCI_{lt}) and the in situ modulus of the fractured PCC layer (E_{PCC}). To accomplish this, multiple regression techniques were used to develop hundreds of models, using as many as 15 independent variables. Only the best regression models are presented in this paper. The ultimate criteria used to select the best models were the correlation coefficient (R^2) value and engineering reasonableness of the significant parameters (independent variables) coupled with the respective sign of the coefficients.

Before discussing the results of the multivariate PCI predictive equations, it is both important and revealing to present global trends of PCI versus time from the rehabilitation construction. Table 2 summarizes the PCI_{lt}-time predictive equation developed for each of the three fractured slab techniques studied and the average time to reach typical failure conditions. The rubblized and crack/seat techniques appear to be the best-performing systems, whereas the typical break/seat sections do not respond quite as well. On the basis of these results, it can be stated that the ranking of techniques, in order of decreasing typical performance life, appears to be rubblization (best), crack/seat, and break/seat (worst).

The multivariate PCI predictive equations indicate that relatively good models were developed for each rehabilitation technique except the break/seat. The recommended models are summarized in Table 3 for both PCI and PCI_{lt}. As can be observed, the R^2 values for the rubblize and crack/seat equations are good. However, this fact must be tempered with the small data base coupled with the relative youth of these techniques. Furthermore, the use of these equations in a design sense is not recommended because of the significant degree of extrapolation outside the data variable levels that would be required.

Whereas the rubblize and crack/seat equations are limited in use, the rationality and sign of the coefficients for both time and overlay thickness are reasonable; PCI decreases with time and increases with overlay thickness. The subbase modulus is likewise considered to be a logical variable, reflecting a portion of the existing pavement support capacity. Because of the small data base, only a linear variable in time was found, although it is reasonable to expect that a nonlinear time variable would best model the behavior. Attempts to incorporate traffic and other variables proved fruitless due to the lack of accurate information in the data base. Finally, the presence of the precipitation and temperature terms in the models cannot be conclusively rationalized because they may either be false indicators of other more important geographical factors not studied or they may indeed reflect the significant influence of the environment on the performance of these sections. Their inclusion, however, was found to significantly increase the overall R^2 value of the predictive models.

For the break/seat technique, the models given in Table 3 were the best models developed. However, they are considered to be poor performance predictors, as judged by the low R^2 values obtained. A significant effort was expended toward obtaining models with greater predictive accuracy, but this effort proved fruitless, even though the maximum performance period and number of sections within the data base were the greatest for this technique. Several equations were developed with R^2 values in the 0.40 to 0.57 range, but they were rejected due to the unreasonable coefficient signs. Thus, the high variability of the performance could not be explained in an analytical manner.

TABLE 2 Global PCI-Time Models and Times to Failure

Rehabilitation Type	General PCI-Time Model	Time to PCI = 50	Time to PCI = 40
Rubblize	$PCI_{1t} = 100 - 1.613t + 0.092t^2$	*	*
Crack/Seat	$PCI_{1t} = 100 - 0.343t - 0.136t^2$	18.0 years	19.8 years
Break/Seat	$PCI_{1t} = 100 - 0.050t - 0.316t^2$	12.5 years	13.6 years
All Fractured Slabs	$PCI_{1t} = 100 - 0.149t - 0.252t^2$	13.8 years	15.2 years

(*) Unable to project time as PCI>90 at t=8 to 10 years.

TABLE 3 PCI Predictive Equations

Rehabilitation Type	PCI Prediction Model	R^2
Rubblize	$PCI = 173.77 - 0.878t + 0.389h_o - 0.744P - 0.719T$	0.753
	$PCI_{1t} = 217.28 - 0.615t + 0.310h_o - 1.14P - 1.13T$	0.665
Crack/Seat	$PCI = 127.02 - 3.03t + 2.4h_o - 0.34P - 0.44T + 0.09E_{SUB}$	0.755
	$PCI_{1t} = 116.8 - 1.42t + 0.658h_o - 0.13P - 0.25T + 0.001E_{SUB}$	0.511
Break/Seat	$PCI = 100.0 - 0.249t^2 - 0.0027(T*JS) + 0.072E_{SUB} + 0.465h_o$	0.393
	$PCI_{1t} = 100.0 + 5.61t - 0.77t^2 - 0.0032(T*JS) + 0.81h_o$	0.443

Note: t = time in years; h_o - HMA overlay thickness (inches); P = annual average precipitation (inches); T = annual average temperature range (F°); E_{SUB} = subgrade (subbase) modulus (ksi); JS = joint spacing (feet).

Fractured PCC Modulus Predictive Equations

Like the PCI analysis, reasonable predictive models for the fractured PCC modulus (E_{PCC}) were obtained for the rubblized and the crack/seat techniques. The recommended model for the rubblized technique is

$$E_{PCC} = 1690 - 15.4P - 17.34T + 2.2E_{SUB} + 1.9JS + 34.7CS \qquad R^2 = 0.603 \tag{1}$$

whereas that for the crack/seat technique is

$$E_{PCC} = -968.39 + 20.34E_{SUB} + 34.89CS + 5.37SL \qquad R^2 = 0.776 \tag{2}$$

where

P = annual average precipitation (in.),
T = annual average temperature range (°F),
E_{SUB} = subgrade (subbase) modulus (ksi),
CS = crack spacing (in.), and
SL = seating load (tons).

For the rubblized data, the relatively good R^2 value probably reflects the small range of E_{PCC} values (200 to 700 ksi). The presence of the precipitation and temperature variables cannot be conclusively rationalized; they may indirectly reflect other geographic or environmental variables not considered in the analysis. The joint spacing variable is not of real significance as indicated by the small coefficient. The subbase modulus variable is believed to be reasonable and important; it implies that as the subbase becomes stiffer, more energy is required to achieve a given E_{PCC} value. Finally, the influence of the crack spacing appears to be significant at first glance, but a closer look at the data reveals that this variable only ranges from 6 to 12 in.

On the basis of the significant data base size and the relatively high R^2 value obtained, it is believed that the predictive model developed for the crack/seat technique is quite good. The model indicates that the three primary variables influencing the modulus are the subbase stiffness, crack spacing, and seating load used in the construction process. As one would expect, the E_{PCC} value increases as these variables are increased.

Finally, the statistical analysis to develop an E_{PCC} predictive model for the break/seat technique did not result in a positive conclusion. More than 35 model forms were tried, but in no case was a model found with an R^2 value greater than 0.20. This finding is consistent with the large scatter and range of modulus values determined in the study. It was concluded that the primary cause of this problem is the large variability within the construction process to fully achieve steel debonding or steel fracture, or both.

Influence of Crack Spacing on the Fractured PCC Modulus Values

The effective modulus of a fractured slab is a function of the nominal fragment size actually achieved during the construction process. In practice, this concept has been applied to specifications that substitute the proposed crack spacing to be achieved as an indirect indicator of the effective modulus of the fractured layer. Whereas general correlations exist between crack spacing and modulus, the use of visual assessments is not always accurate for estimating the fractured moduli of the PCC layer. As the spacing is reduced, the PCC layer behaves less like a slab having a sound modulus of approximately 5,000 ksi and more like a flexible layer with a significantly lower modulus value.

It is common to denote the relationship between spacing and reduced effective PCC modulus by the use of a modular ratio parameter (E_r):

$$E_r = \frac{E_{PCC}}{E_{sound}} \tag{3}$$

where E_{PCC} is the effective PCC modulus of fractured slab and E_{sound} is the modulus of elasticity of sound PCC (E = 5,000 ksi).

Using the fractured PCC moduli found in this study, average E_r values as a function of crack spacing were developed and compared with the recommended 1986 AASHTO relationship (7). Figure 2 shows that relatively good agreement exists for the rubblized and crack/seat sections. However, major differences are present for the break/seat sections. As shown, the modular ratio results are approximately two to three times as large as those for the crack/seat sections at the same specified crack spacing. This fact, reinforcing previous results and analyses, led the authors to conclude that the break/seat process may not effectively achieve full debonding of the steel from the PCC or successful fracturing of the steel. Because of this, the actual effective slab length after fracturing is much greater than one would conclude by looking at the actual crack spacing.

In the previous section, predictive equations for the E_{PCC} values were presented for both rubblized and crack/seat sections. These models illustrate the importance of crack spacing on the fractured PCC modulus. As the spacing is increased, E_{PCC} increases. In the case of the crack/seat technique, historic information has shown that crack spacings typically range from 12 to 60 in. However, on the basis of the results of this study (i.e., E_{PCC} predictive equation), the following crack spacings as a function of the foundation type are recommended: 30 in. for subgrade soils, 24 in. for granular subbase, and 12 in. for stabilized subbase. Target spacings decrease as the stiffness of the underlying foundation is increased. Rubblization generally results in fragment sizes in the range of 6 to 12 in., which appears satisfactory for this technique.

Variability of Fractured PCC Modulus Values

The analysis of the deflection test data consisted of 4,700 backcalculated estimates of the in situ fractured PCC modulus (E_{PCC}) on 140 sections (64 crack/seat, 52 break/seat, and 24 rubblize). For each section, the average E_{PCC} value, standard deviation, and other statistics were calculated. Whereas the results appeared to be highly variable at first glance, further detailed analyses of the data led to important conclusions regarding the two major forms of variation encountered: "between" and "within" project variability.

The between project variability reflects the variation between the average project predicted E_{PCC} values. As such, the standard deviation (σ_b) or variance (σ_b^2) reflects the variations attributable to each construction process on a national scale. Specifically, factors such as the type of equipment, specific breaking energy, specified crack spacing, and the specific site factors and pavement cross section are all reflected within the σ_b (σ_b^2) parameter.

The analysis of the statistical frequency distribution patterns of the average project E_{PCC} value was used to assess the variability (σ_b or σ_b^2) of a particular rehabilitation type for the spectrum of construction projects examined across the United States. Figure 3 shows the between project E_{PCC} frequency distributions for each of the three techniques in question. Table 4 summarizes the between project E_{PCC} statistics.

Figure 3 shows that the rubblized E_{PCC} project distribution is somewhat normal (actually bimodal) and contained within a relatively small range of E_{PCC} values. Similarly, the frequency distribution for the crack/seat sections investigated is normally distributed and is contained within a small range of E_{PCC} values. There are, however, several outliers of data found at high modulus values.

Unlike the rubblized and crack/seat projects, the break/seat E_{PCC} values are widely distributed and highly indicative of the variable success in fracturing or debonding distributed steel in the concrete. Typical values of as low as 250 ksi to as large as 2,750 ksi were obtained. The distribution appears to be more uniform across these limits rather than normally distributed.

In contrast to the between project variation, the within project variability (σ_w or σ_w^2) reflects the variation of the E_{PCC} values obtained within a given rehabilitation project. As such,

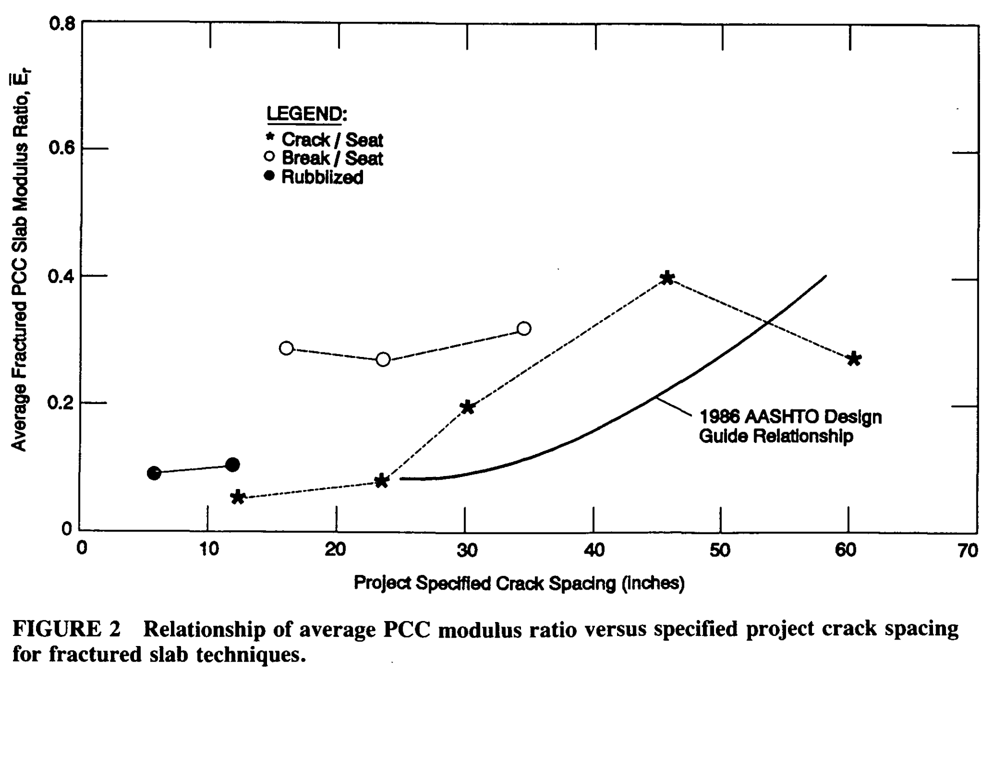

FIGURE 2 Relationship of average PCC modulus ratio versus specified project crack spacing for fractured slab techniques.

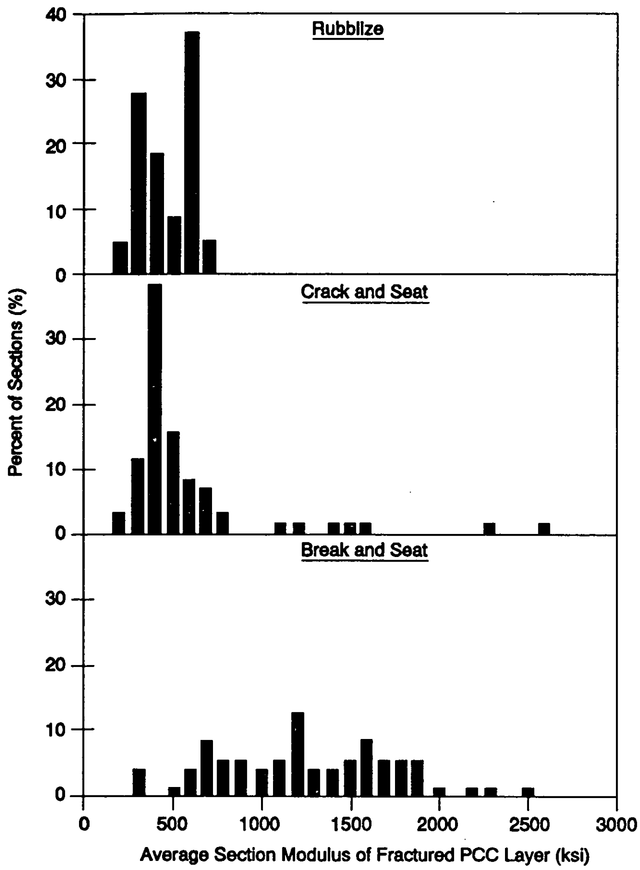

FIGURE 3 Frequency distribution of in situ PCC modulus values by rehabilitation values.

the magnitude of this variation within a given site reflects the ability of the contractor to develop a uniform fractured slab "product" after cracking, breaking, or rubblization has taken place.

To determine whether meaningful trends in the magnitude of the within project variation were evident, studies examining both the standard deviation (σ_w) and coefficient of variation (CV_w) were undertaken. The results indicated that a wide range of σ_w values existed for all three rehabilitation types and that no single value of the σ_w was typical for a particular rehabilitation activity.

The results comparing the within project standard deviation (σ_w) to the average E_{PCC} (project) modulus value for all of the fractured slab project data are shown in Figure 4. The line passing through the origin represents the average best-fit relationship to the data points. In turn, the slope of this line represents the average coefficient of variation (CV_w) for the within project variation.

As observed, a typical coefficient of variation of CV_w = 40 percent may be viewed as appropriate for all construction projects studied. Although not shown, the distribution of these values was also normally distributed for all three rehabilitation types. These important findings gave way to defining guidelines for project construction uniformity for all fractured slab techniques, regardless of the actual average E_{PCC} value achieved at the project site.

Recommended construction control categories for various levels of project uniformity are given below:

Category	*Range*
Good to excellent	$CV_w < 30$ percent
Fair to good	30 percent $\leq CV_w \leq$ 50 percent
Poor to fair	$CV_w > 50$ percent

For the "good to excellent" and "poor to fair" categories, the percentage of the projects evaluated was approximately 22 percent. The "fair to good" CV_w values contained about 56 percent of all computed within project CV_w values found.

SUMMARY AND CONCLUSIONS

This paper presented the results of a nationwide study on three new and innovative methodologies for rehabilitation of PCC pavement involving the fracturing of the slabs before the placement of an AC overlay. The major objective was to develop guidelines to eliminate or minimize the occurrence of reflective cracks in the overlay. The specific techniques evaluated were rubblization, crack and seat, and break and seat.

On the basis of the results of this study, the following major observations were made:

- The relative ranking of the fracturing techniques, in order of decreasing performance life, appears to be rubblization (best), crack/seat, and break/seat (worst). Reasonable PCI predictive models were developed for the first two techniques.

TABLE 4 Summary of Between Project E_{PCC} Statistics

Type of Rehab	No. of Sections	Between Project Results			Remarks
		E_{PCC}	σ_b	CV_b(%)	
Rubblized	22	412.5 ksi	154.4 ksi	37.4%	Recommended (excludes 2 outliers)
	24	501.8 ksi	338.9 ksi	67.5%	All data
Crack/Seat	46	409.0 ksi	140.7 ksi	34.4%	Recommended (excludes all values greater than 1000 ksi; i.e., Crack spacings greater than 48")
	64	780.6 ksi	665.6 ksi	85.3%	All data
Break/Seat	52	1271.5 ksi	548.7 ksi	43.2%	All data; Recommended
All Fractured Slabs	120	783.4 ksi	377.4 ksi	48.2%	All Recommended results
	140	915.1 ksi	578.0 ksi	63.2%	All data

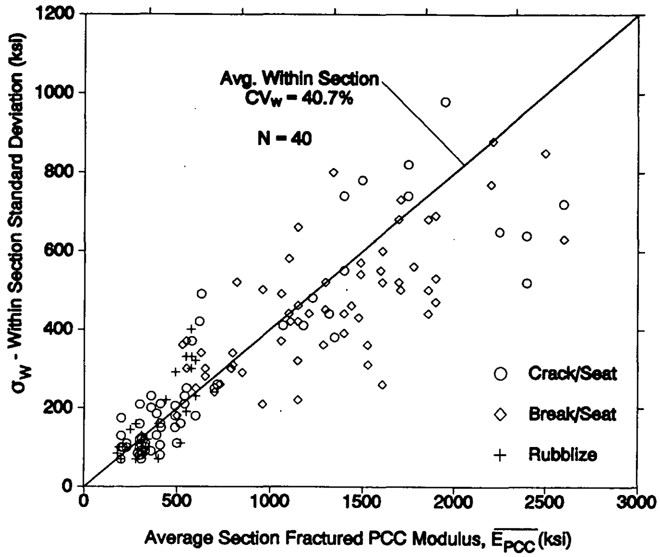

FIGURE 4 Within section variability of fractured PCC slab modulus.

- Reasonable predictive models for the fractured PCC modulus were obtained for the rubblized and crack/seat techniques. These models clearly show the importance of crack spacing and the foundation support of the existing PCC pavement. As both of these variables are increased, the E_{PCC} value of the fractured slab increases. The development of a similar model for the break and seat technique was not possible because of extreme variation in PCC values apparently due to inefficient fracturing or debonding of the distributed steel.
- Some of the most significant and important findings of the study involve the statistical frequency distributions of the effective E_{PCC} values for each rehabilitation technique. Both between project and within project variability were analyzed.
- For the crack/seat and rubblized pavement sections, the resulting frequency distributions of the project mean E_{PCC} value were quite similar: average E_{PCC} = 400 to 500 ksi and a between project coefficient of variation value of approximately 35 percent.
- In contrast, the break/seat distribution was uniformly distributed across a wide range of E_{PCC} values (i.e., 250 to 2,750 ksi). This clearly reinforces the conclusion that the break/seat process on JRC pavements is not uniformly efficient in fully debonding or fracturing the distributed steel.
- On the basis of the analysis results of the within project variability, guidelines for project uniformity were developed.

From these and other observations, the following major conclusions and recommendations were developed:

- Rubblization of deteriorating PCC pavements followed by an AC overlay is an excellent rehabilitation method that is equally effective for all types of existing PCC pavements. This technique is the preferred rehabilitation method for all types of PCC pavements.
- The crack and seat technique followed by an AC overlay is a very effective rehabilitation method for deteriorating JPC pavements. Improvements in equipment over the past years, coupled with the tendency to use smaller crack spacings, should result in improved performance. However, it is strongly recommended that the suggested minimum crack spacing guidelines presented in the paper be followed.
- The currently used construction techniques for break and seat rehabilitation of JRC pavements result in a high degree of variability in effective moduli, indicating inadequate breaking or debonding of the reinforcing steel. Until improvements are made in the breaking operations, this rehabilitation option should be used with extreme caution and coupled with field quality control measures based on deflection testing during the construction process unless local experience shows otherwise.

Finally, whereas much useful information was obtained from this initial nationwide study, additional research is required to further refine and improve the recommended guidelines and methodologies. This can only be accomplished through a combined process of data collection and periodic analysis of long-term pavement performance information. The detailed data base developed in this study can serve as the basic framework upon which additional projects can be added to expand the total number of experimental sections and performance data.

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