Performance Evaluation of Retrofit Edge Drain Projects

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Accelerated slab breakup was noted on many retrofit-edge-drain-only and rehabilitated concrete pavements in California. Concern about the earlier-than-anticipated need for further rehabilitation led to an evaluation of 26 projects that incorporated retrofit edge drains. Results of this study show that before retrofit edge drain installation, the amount of slab breakup and environmental factors significantly affect subsequent pavement performance. More important, it is also suggested that environmental factors strongly influence the undrained performance of concrete pavement. Therefore, the future use of current and alternative concrete pavement designs should address environmental factors that can contribute to poor pavement performance in California.

In January 1986, the California Department of Transportation (Caltrans) Pavement Management System (PMS) coordinator sent New Technology, Materials and Research (NTMR), a list of recently retrofitted-edge-drain-only projects where substantial cracking occurred. These portland cement concrete pavement (PCCP) projects were sufficiently cracked to warrant unplanned rehabilitation. In May 1986, FHWA Region 9 independently sent Caltrans a list including the same projects along with additional major rehabilitation projects where FHWA reviews noted accelerated cracking. Despite differences in repair strategies, these two programs (retrofit edge drain only versus PCCP major rehabilitation) were both experiencing cracking faster than expected. In short, Caltrans' PCPP strategies to extend the service life for these projects using retrofit edge drains did not appear to be entirely successful. As a result, NTMR evaluated the effectiveness of retrofit edge drains to determine the actual success of retrofit edge drains and identify causes of accelerated cracking. At that time potential implications for alternative PCCP design criteria in California were unknown.

BACKGROUND

The original methods of selecting candidate retrofit-edge-drain-only projects that were programmed into the PMS system are

1. Ride Score <30—Ride score (a dimensionless number) equals the sum of the 3.2 mm (1/8 in.) displacements between an automobile chassis and its rear axle as determined by a Portland Cement Association type of road meter device.

$$\text{Ride score} = \frac{\text{sum of 3.2-mm displacements}}{(\text{distance, km}) * 31} = \frac{\text{sum of } 1/8\text{-in. displacements}}{(\text{distance, mi}) * 50} \qquad (1)$$

2. Third-Stage slab cracking <10 percent—Third-stage cracking is defined as a fragmented slab, as shown in Figure 1.

Starting in March 1982, retrofit-edge-drain-only projects were selected on the basis of a ride score criteria of <45 instead of <30. In addition, guidelines were recommended for ranking retrofit edge drain projects that applied factors for truck traffic using the estimated accumulated 80 kN (18 kip) equivalent single-axle load (ESAL) converted to a traffic index (TI)

$$\mathrm{TI} = 9.0 \left(\frac{\mathrm{ESAL}}{10^6}\right)^{0.119} \qquad (2)$$

The TI, pavement age, and annual rainfall (*1*) were subsequently revised for implementation, as given in the following tables:

Age (years)	*Factor*
1–4.9	2
5–9.9	4
10–14.9	6
≥15	8

Annual Rainfall [*cm (in.)*]	*Factor*
<25.4 (<10)	1.5
25.4–50.5 (10–19.9)	1.2
50.6–101.3 (20–39.9)	0.8
101.4–152.1 (40–59.9)	0.6
≥152.2 (≥60)	0.5

TI	*Factor*
≤12	1.0
>12	0.8

The product of these three factors resulted in ranking (the lowest number representing the highest rank) for proposed retrofit-edge-drain-only projects. The intent was to obtain a desired 10-year service life extension for pavements with a ride score of less than 45.

Further NTMR evaluation resulted in revised retrofit-edge-drain-only project selection guidelines in October 1986 (*2*). The recommended criteria were (a) first-stage cracking (nonintersecting cracks; see Figure 1) ≤10 percent, (b) third-stage cracking ≤1 percent, (c) service life ≤10 years, and (d) ac-

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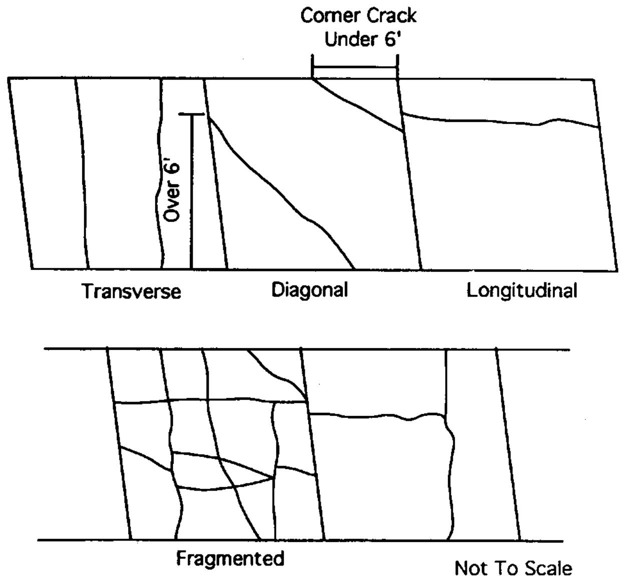


FIGURE 1 Diagram of (*top*) first- and (*bottom*) third-stage JPCP cracking.

cumulated ESAL ≤13 million. The ride score was still required to be <45.

Unfortunately, these guidelines were not adopted for Caltrans' PCCP major rehabilitation program. Different project priority criteria were established for PCCP major rehabilitation (see Table 1). For Priority 1 and 2 projects [bad ride (rough) and major structural damage], the following criteria were used: (a) ride score >45 and (b) third-stage cracking (fragmented slabs) >10 percent. The rehabilitation strategy for these projects is to crack and seat the PCCP, then place a 30.5-mm (0.10-ft) asphalt concrete pavement (ACP) leveling course, pavement reinforcing fabric, a 30.5-mm (0.10-ft) ACP lift, and then a 45.7-mm (0.15-ft) ACP surface course. Retrofit edge drains are also installed.

The subject of this study is the performance of Priority 5 and 6 major rehabilitation projects (see Table 1), where the ride score >45. The rehabilitation strategies were as follows:

1. Subseal slabs using a cement/fly-ash grout,
2. Diamond-grind the surface,
3. Install retrofit edge drains,
4. Rout and seal random cracks, and
5. Replace fragmented slabs (in rare cases where necessary).

Table 1 presents the PMS Priority Guide for PCCP Major Rehabilitation as discussed. The state highway system has been divided into three classes for rehabilitation purposed on the basis of their functional classification as follows:

- Class 1—Rural principal arterials and their extensions into urban areas;
- Class 2—Roads that are not defined as Class 1 or 3, primarily minor arterials; and
- Class 3—Collectors, low-volume roads, and other logical segments added for continuity.

METHODOLOGY

The study of retrofit edge drain effectiveness was based mostly on retrofit-edge-drain-only projects described in the work by Wells, *Evaluation of Edge Drain Performance* (*1*), as well as additional rehabilitation projects that included retrofit edge drains constructed in the same and other geographic locations not described in the work by Wells. The PCCP projects investigated in this study are 203- or 229-mm (8- or 9-in.) thick, nonreinforced, nondowelled, jointed plain concrete pavement (JPCP) with random joint spacings of 4.0, 5.8, 5.5, and 3.7 m (13, 19, 18, and 12 ft), with weakened plain joints skewed counter clockwise 2 in 12. All these JPCP projects were constructed on cement treated bases 101.6 to 152.4 mm (4 to 6 in.) thick.

Data bases were developed using the biennial PMS Rigid Pavement Survey before and after installing retrofit edge drains. The mean percentages of first- and third-stage cracking (for each project) were calculated to establish the JPCP structural condition at the time of edge drain construction for all 26 projects incorporating retrofit edge drains (15 retrofit-edge-drain-only and 11 major rehabilitation projects). These data were used as the baseline for comparison and evaluation of subsequent performance. The data base included

1. Project location;
2. Service life (years) before edge drain installation or rehabilitation;

TABLE 1 PMS Priority Guide For PCCP Rehabilitation Projects (1986)

Class of Highway	1	2	3
1. Major Structural Problem and Bad Ride (Ride Score >45, Third Stage Cracking >10 Percent).	1	2	11
2. Bad Ride Only (Ride Score >45.	5	6	*

*Maintenance only work.

3. Mean percent first- and third-stage cracking (as mentioned);
4. Average grout subsealing quantity, in kilograms (or pounds) per hole,
5. Accumulated ESAL between construction and rehabilitation (*3*);
6. Average annual rainfall, in centimeters (*4*);
7. Average annual heating and cooling degree days, in degree-days Celsius (*4*); and
8. When applicable, the year when the project with retrofit edge drains was triggered again for rehabilitation.

Review of the 26 projects resulted in quantitative conclusions about factors that affect JPCP performance where retrofit edge drains were installed and provided insight about incorporating environmental criteria explicitly in new PCCP design.

EVALUATION OF PERFORMANCE

An analysis of all 26 projects was performed to identify causes of failure. Performance data are given in Table 2. For purposes of this study, a retrofit edge drain project failure is defined as (a) >10 percent third-stage cracking on a PMS survey before the 10-year design service life extension or (b) when NTMR and Office of Highway Construction project reviews indicated that premature distress, in the form of new third-stage or corner cracking, was occurring or that cracking had occurred in the repaired or replaced slabs.

Seven failed and 10 nonfailed retrofit edge drain projects where grout subsealing was done in conjunction with installation of retrofit edge drains were compared by analyzing the average grout quantity. These projects were analyzed using the two-sample Students' *t*-test and nonparametric Mann-Whitney (*5*) statistical test comparing the failed and nonfailed projects to determine whether the grout subsealing quantity significantly influenced pavement performance. A 95 percent confidence level was used for the two-tail tests. The results showed that grout subsealing quantity is not significantly different for the failed and nonfailed projects, thus showing that subsealing was not a significant factor in pavement performance for this study.

The 26 projects were stratified into failed or nonfailed projects and were analyzed using the following variables (Descriptive statistics of these variables are shown in Table 3.):

1. Mean percent first- (percent Stage 1) and third-stage (percent Stage 3) cracking before installation of retrofit edge drains,
2. Undrained service life accumulated ESAL,
3. Undrained service life in years (Life),
4. Average annual rainfall (Rain), and
5. Average annual heating (Heat) and cooling (Cool) degree-days.

An annual heating degree-day is used as an indication of fuel consumption. In the United States, one heating degree is given for each degree that the average daily mean temperature goes below a baseline of 18.3°C (65°F). Temperatures over 18.3°C (65°F) are not counted for heating degree-days. Average heating degree-days are totaled for each month and then for the year.

One cooling degree is given for each degree the average daily temperature rises above the baseline of 18.3°C (65°F). Temperatures under 18.3°C (65°F) are not counted for cooling degree-days. The annual cooling degree-days are calculated in the same manner as previously defined for annual heating degree-days.

The variables given in Table 3 were analyzed by using the two-sample *t*-test and the Mann-Whitney test to determine whether there were significant differences between the failed and nonfailed sites. Two-tail tests at a 95 percent confidence

TABLE 2 Performance of 26 Retrofit Edge Drain Projects

Cracking Stage	%	Total Projects	Failed Projects	% Failed	Average Years To Failure*
First	≤5	11	3	27	3.0
	>5	15	8	53	4.3
	≤10	18	6	33	3.8
	>10	8	5	63	4.0
Third	≤1	13	1	8	3.0
	>1	13	10	77	4.0
Undrained Service Life (Years)					
≤10		6	1	17	8.0
>10		20	10	50	3.5

*Of 11 failed projects.

TABLE 3 Variable Descriptive Statistics

Variable-11 Failed Sites	Mean	Std Dev
%Stage 1	13.36	9.95
%Stage 3	4.09	3.62
Life	15.27	4.43
ESAL	10.86	4.23
Rain (cm)	53.80 (21.18 in)	29.41 (11.58 in)
Heat (°C-Days)	1671.61 (3040.9 °F-Days)	522.92 (973.26 °F)
Cool (°C-Days)	724.33 (1335.8 °F-Days)	270.41 (518.74 °F)
Rain*Cool (°C-Days)[a]	15574.3 (28065.8 °F-Days)	12748.0 (22978.4 °F)
Variable-15 Nonfailed Sites		
%Stage 1	7.67	8.16
%Stage 3	1.13	1.24
Life	14.93	6.31
ESAL	13.10	7.57
Rain (cm)	38.61 (15.20 in)	22.50 (8.86 in)
Heat (°C-Days)	1343.1 (2449.5 °F-Days)	238.86 (461.95 °F-Days)
Cool (°C-Days	733.5 (1352.3 °F-Days)	272.17 (521.90 °F-Days)
Rain*Cool (°C-Days)[a]	10094.1 (18201.3 °F-Days)	4310.9 (7791.7 °F-Days)

[a] Interaction variable.

level (p = .05) were used. Table 4 gives the probability of the variables being different due to chance alone.

TABLE 4 Two-Sample *t*-Test and Mann-Whitney Test Probabilities

Variable	t-test Probability	Mann-Whitney Probability
%Stage 1	0.122	0.046[a]
%Stage 3	0.007[a]	0.001[a]
Life	0.880	0.959
ESAL	0.386	0.452
Rain	0.148	0.204
Heat	0.050[a]	0.055
Cool	0.937	0.917
Rain*Cool	0.133	0.421[b]

[a] Significant difference.

[b] Interaction variable)

The test results in Table 4 show a strong significant difference (<99 percent confidence) in the percentage of Stage 3 cracking between the failed and nonfailed sites; also, test results suggest a significant difference in the percentage of Stage 1 cracking and Heat between failed and nonfailed sites. These results will be discussed later in the analysis.

Correlation of third-stage to first-stage cracking before installing edge drains was studied using linear regression. Correlation of postinstallation cracking was not possible because of the rapid failures and subsequent Priority 1 and 2 rehabilitation. All 26 projects were studied to see whether third-stage cracking is readily predictable from early, less-critical first-stage cracking. A statistically significant regression equation resulted for the 11 failed projects when third-stage cracking was modeled as a function of first-stage cracking (Figure 2). No significant correlation was found for either the 15 nonfailed or the combined 26 project data set.

Cumulative frequency distributions were plotted to examine and further evaluate differences between failed and nonfailed projects. Figure 3 shows that retrofit edge drain projects

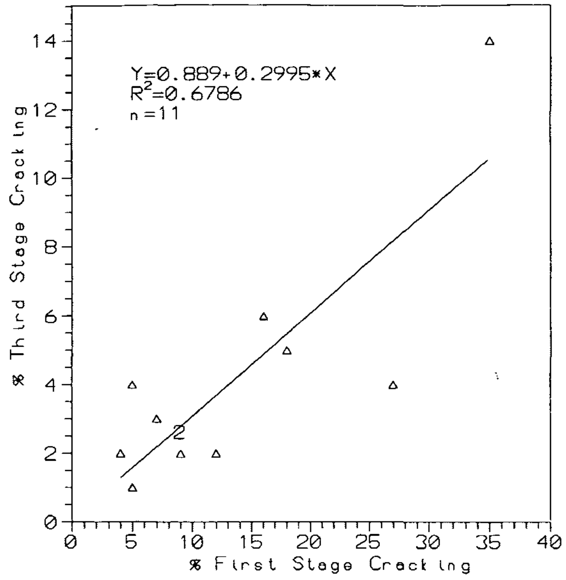


FIGURE 2 Percentage first- and third-stage cracking.

that ultimately failed had a higher amount of both first- and third-stage cracking before installation of edge drains. Although this may explain why 11 retrofit edge drain projects failed, it does not explain why these projects had cracked so badly to begin with or how cracking would have progressed if edge drains had not been installed. Service life and accumulated ESAL were studied to investigate further the causes of preretrofit cracking. Additional cumulative frequency plots, shown in Figures 4 and 5, indicate no significant difference between failed and nonfailed projects in terms of service life and accumulated ESAL.

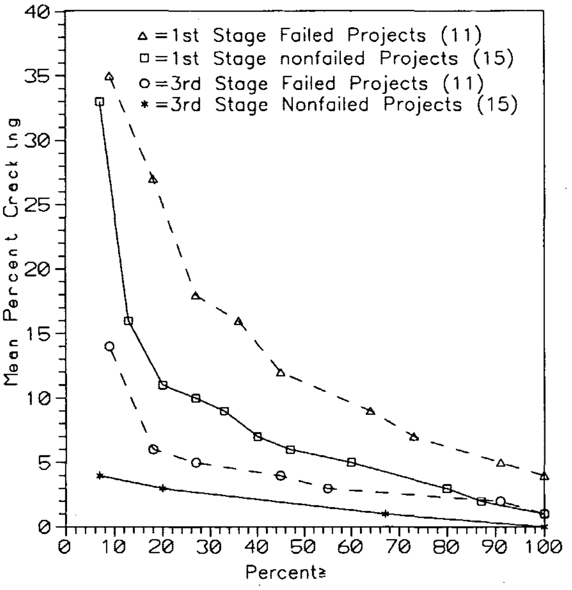


FIGURE 3 Cumulative frequency distribution, first- and third-stage cracking.

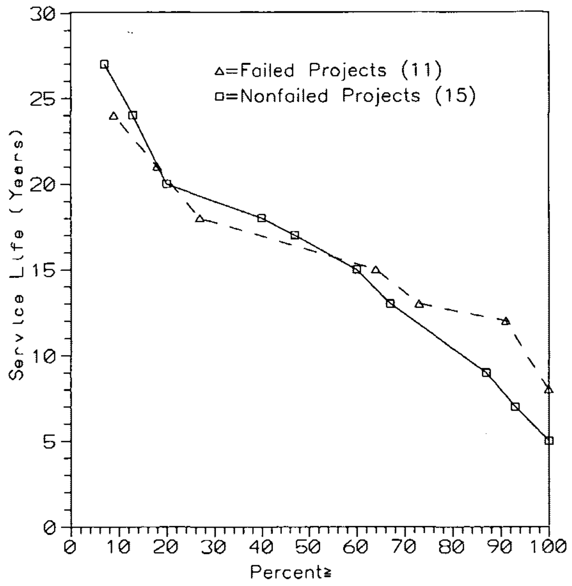


FIGURE 4 Cumulative frequency distribution, service life (years).

Ultimately, environmental conditions were found to significantly affect the performance of the JPCP. Figure 6 shows a trend toward higher annual rainfall at projects that failed (however probabilities were not significant at 95 percent confidence, as shown in Table 4). Figure 7 shows that annual heating degree-days are higher at failed projects (differences are significant at 95 percent confidence in Table 4) but annual cooling degree-days are generally similar. These plots were influential in showing how the environment affects the JPCP as well as suggesting the need for explicit consideration of environmental variables in PCCP design. The points plotted

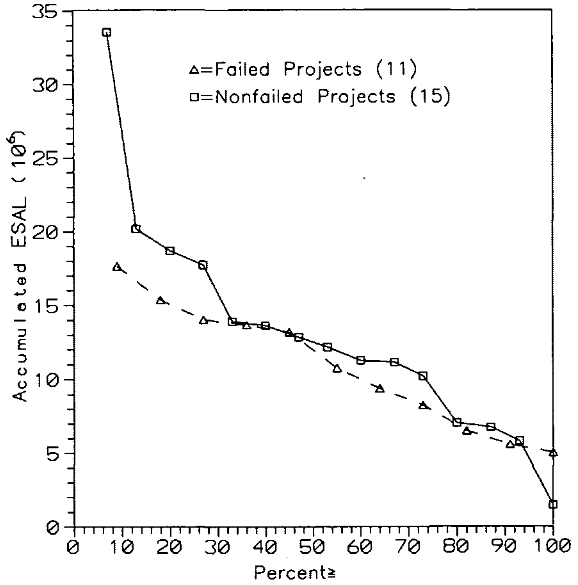


FIGURE 5 Cumulative frequency distribution, ESAL.

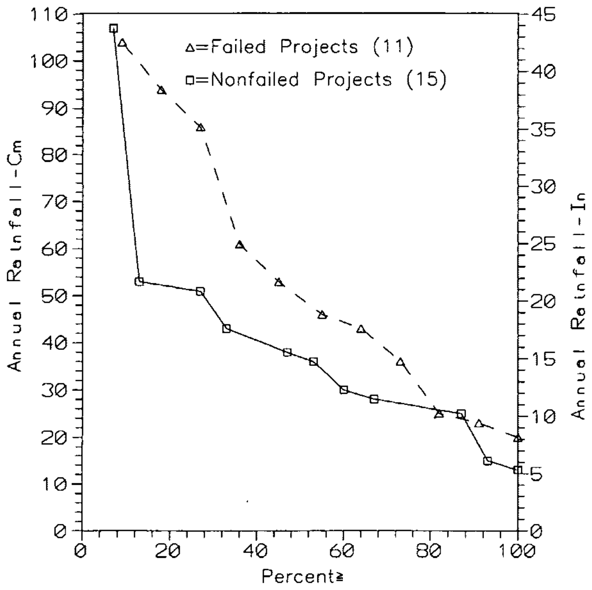
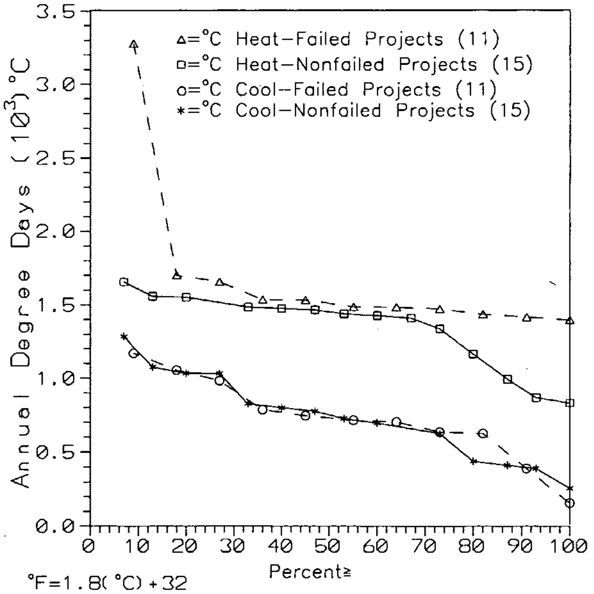


FIGURE 6 Cumulative frequency distribution, annual rainfall.

in Figures 3 through 7 represent the maximum values within each interval. These results showed the need to incorporate environmental variables into regression studies.

Subsequent linear regression studies of the 11 failed projects suggest that susceptibility of slabs to third-stage cracking is more predictable using environmental parameters instead of first-stage cracking only, as discussed earlier. This is evident from multiple linear regression analyses that investigated environmental factors, traffic load (ESAL), and service life, which are known to cause cracking via the faulting process (*1,6*).



°F=1.8(°C)+32

FIGURE 7 Cumulative frequency distribution, annual heating and cooling degree-days.

Environmental parameters that were investigated included annual heating degree days and an interaction variable of the product of annual rainfall and annual cooling degree days. All the variables were statistically significant at a 99 percent confidence level, as shown in Table 5.

Note that the regression equation in Table 5 has an adjusted $r^2 = .96$, showing much stronger correlation than that based only on first-stage cracking where $r^2 = .68$. The multiple regression equation appears well suited for potential use in design for rehabilitation and new construction for California PCCP.

First-stage cracking was subsequently modeled as a function of the environmental parameters annual rainfall, annual heating and cooling degree-days, and the interaction variable of the product of annual rain and annual heating degree-days to further evaluate nontraffic influences. First-stage cracking has a much weaker correlation with environmental factors than does third-stage cracking.

CONCLUSIONS

Analysis of the data from the 26 retrofit edge drain projects revealed that the amount of third-stage cracking before retrofit edge drain installation is a critical factor in subsequent JPCP performance (Table 2). Only 1 project out of 13 with third-stage cracking ≤ 1 percent failed prematurely, but 10 projects out of 13 failed with third-stage cracking >1 percent.

The data suggest that preretrofit edge drain cracking on the 11 projects that ultimately failed is correlated with environmental factors, service life, and ESAL. Other research suggests that the rate and variation of heating may be even more important than thermal gradients within the pavement (*7*). This research may explain why previous research (*1,6*) attempting to relate only rainfall to the rate of JPCP faulting (and eventual cracking) was inconclusive.

Despite limitations in the data base, these results show that third-stage cracking is significantly related to environmental conditions, service life, and accumulated ESAL on those projects where premature failure of the JPCP occurred after retrofit edge drains were installed. Limitations include (a) small data base (11 failure projects), (b) measurements of cracking are subjective judgments, (c) values for environmental parameters were estimated using data from the closest meteorological station, and (d) ESAL estimates are samples of partial-day, 24-hr and 7-day counts (*3*), which can be subject to error.

Related reports support the results of the study. A PMS study (*8*) indicated, for JPCP exhibiting between 1 and 10 percent third-stage cracking, that third-stage cracking can be expected to double every 2 years. An FHWA research paper presented at the 1988 Annual Meeting of TRB (*9*) included the statement

> . . . when 5% or more of the right lane required full depth replacement, the project was probably not a suitable CPR candidate, projects requiring between 2 and 5 percent full depth replacement of the right lane were marginal CPR candidates.

These findings show a need for careful consideration of the amount of third-stage cracking and environmental factors before placement of retrofit edge drains on JPCP. More im-

TABLE 5 Multiple Regression Analysis

Dependent Variable: %3rd Stage Cracking

Ind Var	B Coef	Std Err(B)	t-value	Prob
Heat	.002784	.000283	9.8225	<.0001
Rain*Cool	.000213	.000015	14.6358	<.0001
Life	-.543476	.058189	-9.3399	<.0001
ESAL	.483927	.077947	6.2084	.0008

Multiple r = .9897

Std Err Est = .668

F = 71.8507

Constant = -7.309712

Multiple Correlation Summary

	Multiple r	r-square
Unadjusted	.989722	.97955
Adjusted	.982811	.965917

Std Error of Estimate = .667964

Sample size = 11

portant, this study suggests that environmental factors strongly influence the undrained performance of JPCP. Therefore, the future use of current PCCP designs and development of alternative PCCP designs should address environmental factors that can contribute to poor PCCP performance in California.

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Publication of this paper sponsored by Committee on Pavement Rehabilitation.