A Comprehensive Pavement Evaluation System Applied to Continuously Reinforced Concrete Pavement

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This paper presents a comprehensive pavement evaluation system developed at the Joint Highway Research Project, Purdue University. In addition to the purpose of presenting the method, a secondary purpose is to demonstrate the use of the method as it was used to evaluate continuously reinforced concrete pavements (CRCPs) in Indiana. The evaluation system consists of a hierarchy of increasingly detailed pavement survey strategies—reconnaissance surveys, condition surveys, and evaluation surveys. The complete system, encompassing the three different types of surveys, permits an evaluation of maintenance priorities conveniently with the determination of the reasons for pavement deterioration. Although the demonstration of the evaluation system as applied to CRCP is incidental to the central theme of the paper, it contributes to the understanding of the comprehensive evaluation system. The paper presents a summary of the results obtained at the completion of each stage of CRCP evaluation. Some of the significant findings of the CRCP study and the resultant maintenance strategies are also included.

During the past several years, a great amount of research has been concentrated on methods of making condition surveys and on techniques for pavement rehabilitation. This is particularly important from the standpoint of the Interstate Highway System in the United States since, because of its age, there is a need to plan for its maintenance. Further, the states and counties have large investments in highways that are in need of maintenance.

The need for developing maintenance strategies has focused on development of methods for surveying and analyzing the condition of an existing pavement. These techniques have, by and large, centered on rapid methods of measuring pavement condition and have attempted to relate the condition of the pavement to the present serviceability index (PSI). Along parallel lines, but often not coordinated with condition survey methods, has been the development of techniques for optimizing design and maintenance of pavement systems.

The purpose of this paper is to present a comprehensive pavement evaluation system that was developed at the Joint Highway Research Project, Purdue University. Another purpose is to demonstrate the use of the method as it was used to evaluate continuously reinforced concrete pavements (CRCPs) in the state of Indiana.

SURVEY STRATEGIES

At the outset, various surveys that might be made must be defined. Each of the surveys has its use, and each has its limitation depending upon many factors. For purposes of this discussion, use will be made of terms relating to three basic types of surveys: reconnaissance surveys, condition surveys, and evaluation surveys.

Reconnaissance Surveys

Reconnaissance surveys are generally carried out on a routine basis by most highway departments. They consist of visual inspection and a qualitative judgment of the condition of pavements made by a qualified field engineer. Often, this type of survey is the only one required and conclusions can be derived from it.

Condition Surveys

Condition surveys, at a given time, are made to determine the condition of a pavement generally by use of roughometers, profilometers, and the like. This type of survey is not intended to evaluate the structural strength of the pavement, and generally no attempt is made to determine the reason for the pavement condition. Information from this type of survey can lead to the establishment of priorities and cost estimates for pavement rehabilitation.

Evaluation Surveys

The purpose of evaluation surveys is to determine the structural adequacy of the pavement and to determine causes for pavement defects that might be observed. These surveys are more comprehensive and include both laboratory and field tests; the resultant data can lead to evaluation of the pavement structure. Results

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of evaluation surveys can be used for establishment of priorities and cost estimates, but, in addition, they permit recommendations relative to new designs and maintenance alternatives that might be considered.

SEQUENCE OF COMPREHENSIVE EVALUATION SYSTEM

The complete system encompasses all of the steps just defined and permits an evaluation of maintenance priorities concurrently with the determination of the reasons for pavement defects. Figure 1 shows the sequence that is followed in the comprehensive pavement evaluation system. This is a six-step process as outlined on the flow diagram. Each of the phases of the survey is self-explanatory.

The evaluation process can be stopped during any one of the phases depending on the needs of the highway department. For completeness, however, it is necessary to follow all of the phases sequentially.

The condition survey, as envisioned in Figure 1, has at its heart two principal steps. First, the data must be stratified on the basis of known conditions at the site. Second, the road sections falling under each combination of the strata are statistically sampled and only a predetermined number of randomly selected road sections are actually surveyed. Hence stratification of the data along with a statistical sampling procedure immediately dictates that a statistical analysis be made of the data.

In the condition survey analysis, the factors that significantly affect the observed condition of the pavement must be determined. Many of the factors listed in the stratification process can be shown to be statistically nonsignificant by appropriate tests and therefore may be dropped from further consideration. As indicated by the flow diagram, the significance tests can be bypassed if one wishes merely to obtain data that indicate the extent of pavement distress.

After the significant factors influencing performance are determined, it is possible to make an evaluation survey in which field tests are performed on statistically laid-out test sections and samples of pavement components are also obtained on a statistical basis. Appropriate field and laboratory tests can then be made on these samples and an evaluation made of the pavement as shown in phase V in Figure 1. The primary feature of the evaluation survey is, again, stratification and random sampling of pavement sections.

The process can be completed during any one of the phases listed on the flow diagram. The details of any given step depend on the results of the preceding phase. The decision whether to proceed through the comprehensive evaluation system is dependent on the needs of the particular situation.

ILLUSTRATION OF METHOD

Use of the method will be illustrated by means of a study made of CRCP in Indiana. The evaluation system, however, is equally applicable to other types of pavement. In 1972, a continuing study of the performance of CRCPs was initiated by the Joint Highway Research Project at Purdue University. The objective of the study was to evaluate and recommend design and construction techniques that would result in better performance of CRCPs. The evaluation of CRCP in Indiana followed the sequential steps outlined in Figure 1.

PHASE 1, RECONNAISSANCE SURVEY

Distress was noted on some sections of CRCP in Indiana as early as 1970. The development of distress reached alarming proportions at certain locations by 1972. It was at this time that the evaluation process was started.

A reconnaissance survey was conducted on a section of one road, I-65, and encompassed only the northbound lanes of the four-lane divided facility. The road at the location surveyed traverses glacial drift of Wisconsin Age and the subgrade is highly variable, ranging from sands and gravels to plastic clays. Subbase materials were largely nonstabilized gravels with some crushed stone and bitumen-stabilized gravel. A variety of construction and design variables were incorporated in the road with the result that several design and construction features affecting performance became immediately noticeable.

The results of the reconnaissance survey indicated, although not conclusively, that factors probably contributing to poor performance were (a) clay subgrades, (b) gravel subbases, (c) use of bar mats, and (d) slip-form paving. Because no definitive conclusions could be reached on the basis of the first survey, a statewide condition survey was subsequently planned. Note that these were tentative conclusions and that they were changed after further study.

PHASE 2, STATEWIDE CONDITION SURVEY

To arrive at definitive conclusions and to include a large range of construction and design variables, we set up the scope of the condition survey to include all CRCPs in Indiana. A sampling procedure was used to design the field survey, and statistical methods were used to analyze the resulting data.

Study Design

The intent of the study design was to ensure inclusion in the study of every CRCP contract that had been completed up to the time of the survey. A further purpose was to provide an inference space for the proposed analysis that would encompass all the factors under investigation.

Sampling Procedure

A stratified random sample of CRCPs was used in the field survey. Stratified random sampling is a plan by which the population under consideration (in this case, all the CRCP contracts in Indiana) is divided into strata or classes according to some principle significant to the projected analysis. This is followed by sampling within each class as if it were a separate universe. The aim in stratification is to break up the population into classes that are fundamentally different with respect to the average or level of some quality characteristics (3, pp. 213-214).

Only one simple random sample was obtained from each stratum or class. Such a sample or unit of evaluation was designated as a field survey section. Each field survey section was a 1524-m (5000-ft) length of pavement. The survey sections were stratified on the basis of the following factors: contract, method of paving, method of steel placement, method of steel fabrication, type of subbase, and type of subgrade. Data relative to these factors were obtained from construction records.

Statistical Design

A $2 \times 2 \times 3 \times 4 \times 2$ completely randomized factoral design with unequal subclass frequencies was used to study the factors influencing the performance of CRCPs. A

Figure 1. Sequential process of pavement evaluation.

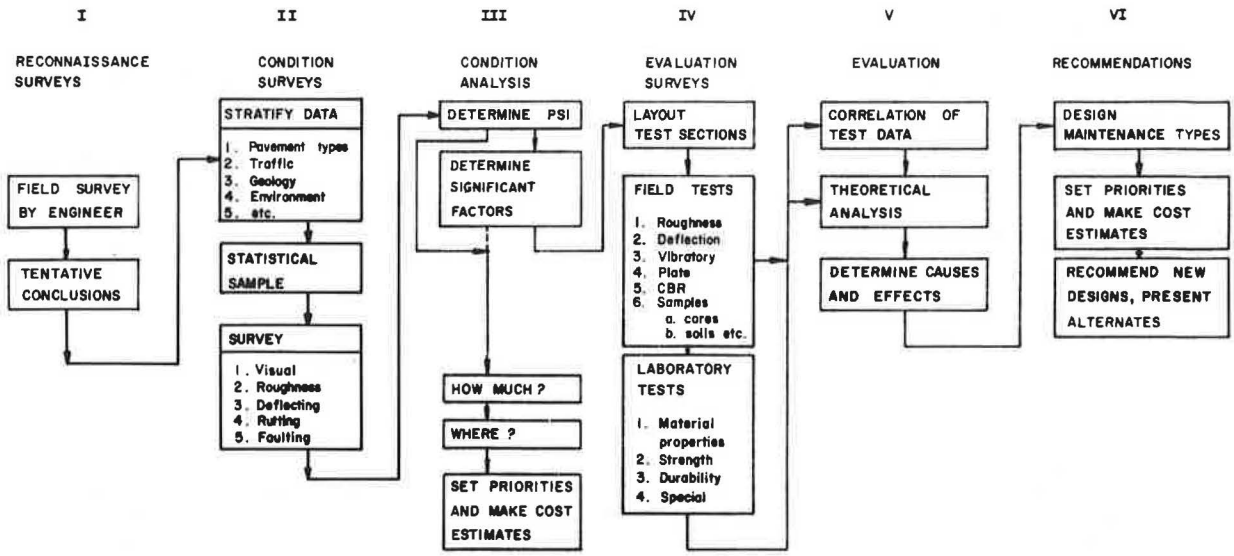


Figure 2. Factorial design for study of factors influencing CRCP performance.

Method of Paving	Method of Steel Placement	Method of Steel Fabrication	Type of Subbase	Type of Subgrade	Slipformed						Side Formed					
					Chairs			Depressor			Chairs			Depressor		
					Loose Bars	Bar Mats	Wire Fabric	Loose Bars	Bar Mats	Wire Fabric	Loose Bars	Bar Mats	Wire Fabric	Loose Bars	Bar Mats	Wire Fabric
Fine Grained	Bituminous Stabilized				X	X		X	X	X						
	Gravel				X	X	X		X	X			X		X	X
	Crushed Stone				X		X			X		X				X
	Slag								X	X						X
Granular	Bituminous Stabilized				X			X	X							
	Gravel					X	X		X	X			X		X	X
	Crushed Stone						X			X		X				X
	Slag								X							

number of covariates or concomitant variables were superimposed on the factorial. The layout of the statistical design is shown in Figure 2, which also indicates the independent factors and their corresponding levels selected for this investigation.

Data Collection

The survey was conducted by five parties who were assigned survey sections at random. Subsequent statistical tests showed that no restriction on randomization had resulted from using five different survey parties.

PHASE 3, CONDITION ANALYSIS

The data obtained from the statewide CRCP condition survey were statistically analyzed by using a weighted least squares analysis of covariance procedure. The method of analysis and the supporting statistical package were the least squares maximum likelihood general purpose program of the Purdue University Computer Center.

Results From Statewide Condition Survey

The analysis of data collected during the statewide survey of CRCPs in Indiana revealed a number of significant results and correlations. The results of the statewide survey provided some definite indications relative to causes of distress in CRCPs.

With regard to just the extent of distress in the state, 69.7 percent of CRCP sections surveyed did not show any defects, 26.9 percent of the sections had from one to five defects, and 3.4 percent had more than five defects. This information was based on a stratified sample of 89 sections, each of which was 1524 m (5,000 ft) long and had equivalent two-lane or three-lane CRCP.

Gravel subbases showed the poorest performance; crushed stone and slag subbases showed good performance; and, at the time of the survey, bitumen-stabilized subbases showed little or no distress (since the condition survey, some structural failures have occurred on sections with bitumen-stabilized subbase). For most cases depressed steel performed better than preset steel on chairs. Better performance was indicated when loose bars were used compared to when bar mats and wire fabric were used. Pavements that were slipformed performed the same as did those that were sideformed. Relative to good performance, the optimum slump range was between 5.1 and 6.3 cm (2.0 to 2.5 in); slump values of 3.8 cm (1.5 in) and greater generally showed good results. Distress in CRCPs was found to be linked with traffic intensity. Subgrade parent material (granular or fine grained) was not a significant performance factor.

Summary Statement of Condition Survey

The conclusions reached from the results of the condition survey were valid from the standpoint of identifying significant factors that influenced performance of CRCP. The conclusions differed in some respects from those reached in the first survey. The data also showed the extent of distress of the pavements on a statewide basis. One could infer reasons for suspect performance on a comparative basis (for example, gravel subbases versus stone subbases or use of chairs versus depressed steel), but one could not determine them with certainty. Hence an evaluation survey was set up to delineate possible causes and effects for the relative performance.

PHASE 4, DETAILED EVALUATION SURVEY

With respect to the broad framework of the study, the detailed field investigation followed by a laboratory testing program constituted the fourth phase of the research. These two steps (field and laboratory tests) of the research are presented together because the results obtained from the two parts must be analyzed together. A primary purpose of phase 4 was to determine the effect of pavement materials on performance.

Study Design

The design of the detailed evaluation study was based on the results of the statewide condition survey. The factors that were found to be statistically significant in the condition survey were incorporated in the stratification criterion for sampling the test sections for the field study. The stratification scheme consisted of the following factors: method of paving (slip-formed, side-formed); method of steel placement (depressed steel, steel preset on chairs); type of steel reinforcement (wire fabric, bar mats, loose bars); and type of subbase (gravel, slag, crushed stone, bitumen stabilized).

A total of 31 test sections with the same thickness [23 cm (9 in)] and percentage of steel reinforcement (0.6 percent) were included in the field investigation. These CRCP sections are part of the Interstate Highway System in Indiana. Each test section was 300 m (1000 ft) in length.

Collection of Field Data

The typical layout and the data collected at each test section are shown in Figure 3.

The battery of tests performed at a test section consisted of

1. Deflection measurements,
2. Crack width measurements,
3. Crack interval measurements,
4. Subgrade and subbase evaluation, and
5. Concrete core testing.

Dynaflect (4) was used to obtain deflection measurements at 30-m (100-ft) intervals along the centerline of the traffic lane. In addition, at each test location, deflection measurements were obtained transversely at 0.3 m (1.0 ft), 1.07 m (3.5 ft), and 1.83 m (6.0 ft) from the pavement edge. At any point, deflection measurements were taken at both a crack position and an adjacent midspan position between two transverse cracks.

Crack width measurements were made at each test location by means of a 50x, direct-measuring pocket microscope.

Crack interval measurements were made along the pavement edge over a 30-m (100-ft) section centered on a test location. The number of crack intersections was also counted over the 30-m (100-ft) length.

In-place penetration tests were made on subbase and subgrade by means of the high load penetrometer (2, pp. 1-16) and the dynamic cone penetrometer (5) respectively. These tests were performed at both core-hole and shoulder positions at each of the two test locations. The two methods of penetration tests are shown in Figure 4. In addition to the penetration tests, in-place density and water content determinations were made on the subbase and the subgrade. At the completion of a series of tests on the subbase or subgrade, material was sampled from under the edge of the pavement slab for laboratory testing.

Concrete cores were taken at each test location from the traffic lane close to the point from which other pavement materials were sampled.

Laboratory Testing Program

Concrete cores, as obtained from the field, were tested for specific gravity, water absorption, bulk density, and pulse velocity. Next the cores were cut, and segments without any steel from above and below the level of reinforcement were subjected to specific gravity, water absorption, pulse velocity, bulk density, and splitting tensile strength tests.

The series of tests on subgrade soil and granular subbase samples included standard classification and compaction tests. Permeability tests, which used a constant head permeameter, were made on selected samples of slag, crushed stone, and gravel subbases. For bitumen-stabilized materials, grain-size distribution and asphalt content were determined.

PHASE 5, EVALUATION

Approach to Data Analysis

The characteristics of the design of the field study offered two dichotomies that could be profitably used in data analysis:

1. Comparison of failed test locations with good test locations within test sections showing significant distress and
2. Comparison of test sections showing distress (with failures as indicated by a breakup or a patch) with test sections in good condition and showing no apparent distress (without failures).

The primary aim of this comparative analysis was to identify material properties and performance characteristics that are indicators of potential distress in CRCP. Only data from structurally sound locations were included in the study. The objective of using such data was to isolate inherent deficiencies in the pavement structure even where no superficial evidence of distress was present.

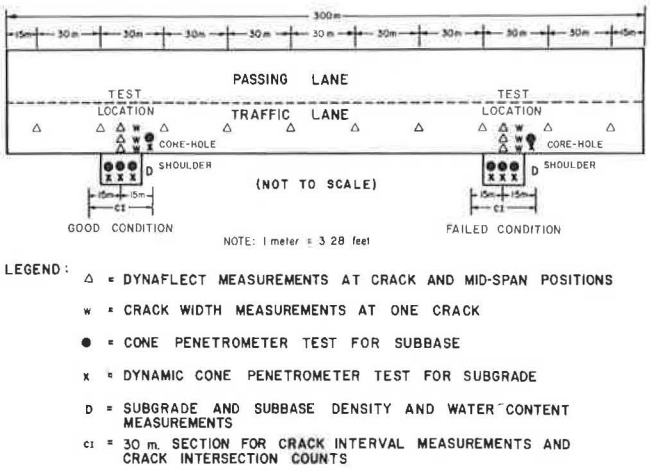
Analysis of Data

The number of test sections in each of the without-failure and with-failure categories were 15 and 16 respectively. Differences between the two categories with respect to material properties and performance characteristics were tested by the t-test. In other cases, in which a factorial arrangement was used, data were analyzed within the framework of a nested factorial design (1). An equal number of randomly selected test sections were nested within each of the pavement condition categories.

Comparison of Types of Subbases

The data given in Table 1 describe the variation of subbase California bearing ratio (CBR), permeability, and degree of compaction with type of subbase. Although no clear differences in the properties of the gravel subbases were evident between sections with failures and sections showing no apparent distress, gravel subbases at structurally sound test locations were found to have a moderately high permeability but showed poor stability characteristics, probably a function of insufficient compaction. Crushed stone subbase at the section without failures was found to possess a high strength (CBR of 90 percent) and excellent internal drainage (over 0.71 cm/s or 2000 ft/day). The failure on another section with a crushed stone subbase was a function of poor stability (very low CBR), resulting from inadequate compaction. The good condition of pavements on slag subbases, despite relatively poor water transmission characteristics of this type of subbase, was probably due to its very high stability (CBR of more than 100 percent).

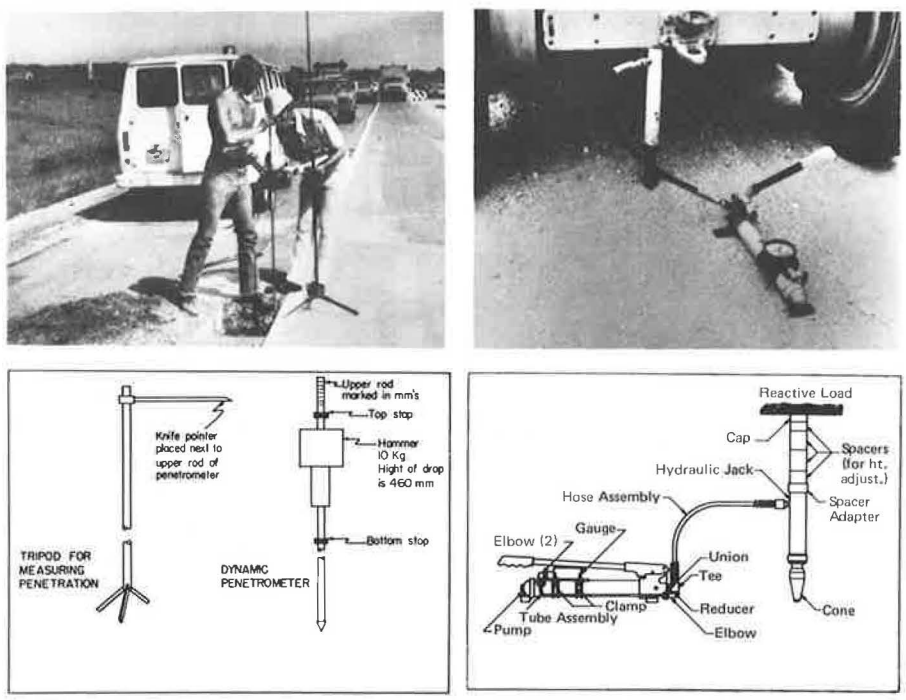
Figure 3. Typical layout of test sections.



Interaction of Permeability and Strength

It is worthwhile to note that concrete pavement performance is also a function of the interaction between subbase permeability and strength (CBR). In Figure 5, estimated field permeability values from 46 test locations of the detailed field study are plotted against field subbase CBR values measured at the shoulder-slab interface. Test data for crushed stone and slag subbases are shown with separate indicators. In addition, values obtained at failed test locations are differentiated from the values at good test locations. The data were grouped

Figure 4. Two methods of rapid CBR tests.



(a) DYNAMIC CONE (FINE GRAINED SOILS) (b) HIGH LOAD CONE (GRANULAR SOIL)

Table 1. Effect of type of subbase on pavement condition.

Type of Subbase	Condition of Test Sections	Number of Test Sections	Subbase CBR (%) Shoulder	Subbase CBR (%) Core	Permeability (cm/s)	Compaction (%)
Gravel	With failures	13	33.5	38.0	0.345[a]	91.5[a]
	Without failures	10	35.9	45.2	0.247[b]	93.2[b]
Slag	With failures	1	95.0	100.0	0.01	117.2
	Without failures	3	81.0	96.6	0.05	100.6
Crushed stone	With failures	1	32.0	41.0	0.483	89.9
	Without failures	1	90.0	59.0	0.880	85.3

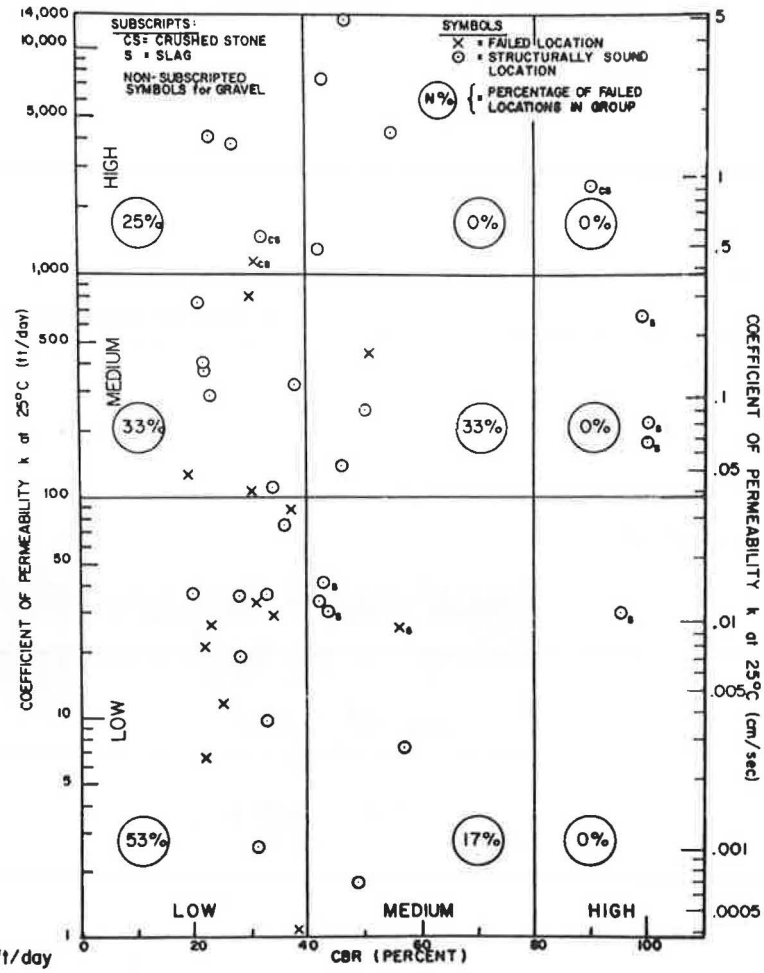
Notes: 1 cm/s = 2835 ft/day.
Data are from structurally sound test sections.
[a]Average of values from nine test sections. [b]Average of values from ten test sections.

in nine categories corresponding to three levels each of subbase CBR and permeability. For low subbase strength (CBR less than 40 percent) in mainly gravel subbases, the percentage of failed test locations decreased from 53 percent in the low permeability group to 25 percent in the high permeability group. For medium subbase strength (CBR between 40 and 80 percent), no failures were observed where permeability was high. Where subbase strength was high (CBR greater than 80 percent, applicable only to slag and crushed stone subbases) no failures were indicated irrespective of permeability.

Deflection as Predictor of Performance

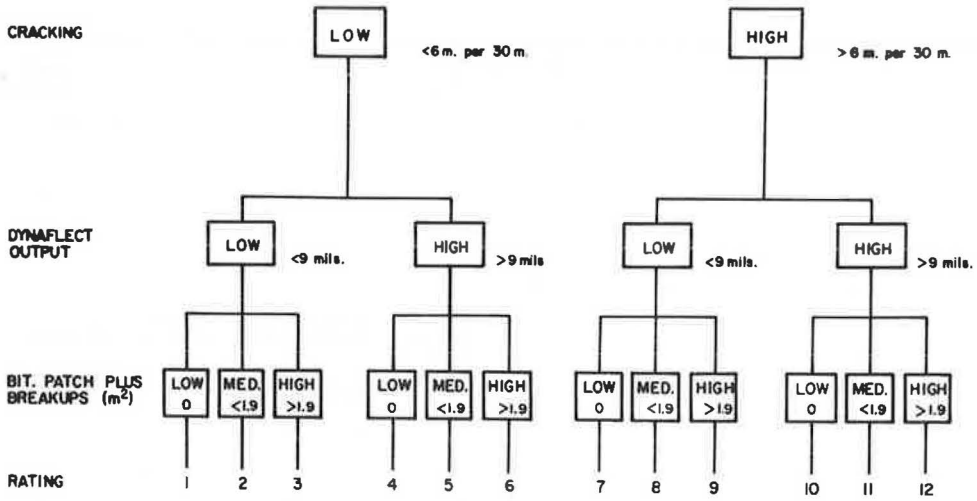
The major interest in the analysis of deflection measurements, taken over the total extent of each test section at

Figure 5. Effect of subbase strength and permeability on CRCP performance.



NOTE: 1 cm/sec = 2835 ft/day

Figure 6. Rating of test sections.



NOTE: 1 meter = 3.28 feet

Table 2. Possible maintenance.

Rating Number	Total Number of Sections Involved	Maintenance: Type	Maintenance: Number of Sections Involved
1	7	None	7
2	10	None	5
		Patch	5
3	2	None	1
		Patch	1
4	5	None	1
		Underseal and overlay	2
		Underseal	0
		Overlay	1
		Concrete shoulders	1
		Drain	0
5	11	None	1
		Patch, underseal, and overlay	4
		Patch and underseal	1
		Patch and overlay	1
		Patch and concrete shoulders	0
		Patch and drain	3
		Patch, drain, and concrete shoulders	1
6	3	None	½
		Patch, underseal, and overlay	½
		Patch and underseal	1
		Patch and overlay	0
		Patch and concrete shoulders	0
		Patch and drain	1
7	3	None	1
		Drain	1
		Overlay	1
8	5	None	1
		Patch and overlay	1
		Patch and concrete shoulders	1
		Patch and drain	2
		Patch	0
9	7	None	2
		Patch and overlay	2
		Patch and concrete shoulders	2
		Patch and drain	1
		Patch	0
10	2	None	½
		Underseal and overlay	½
		Concrete shoulders	1
		Drain	0
11	0	None	0
		Patch, underseal, and overlay	0
		Patch and drain	0
		Patch and concrete shoulders	0
		Full-depth bitumen	0
12	5	None	1
		Patch, underseal, and overlay	0
		Patch and drain	1
		Patch and concrete shoulders	½
		Full-depth bitumen	1
		Patch, underseal, overlay, drain, and concrete shoulders	1
		Patch, drain, and concrete shoulders	½

Note: This list of possible maintenance is considered a "shopping list" of various procedures. These were greatly reduced in number based on length of sections and the like.

30-m (100-ft) intervals, was to determine whether pavement condition, as indicated by the presence or absence of failures, could be differentiated by such sectionwide measurements.

Deflection profiles were developed for sections that were in excellent condition, those showing signs of distress, and those that, according to crack patterns and the like, indicated potential failures.

As a rule, pavement sections showing signs of potential distress had higher deflections than those that had already failed. Therefore, it was concluded that pavement deflections, if used judiciously, are a good indicator of potential distress. After the continuous slab breaks up into discrete segments, the usefulness of deflection measurements is impaired.

Using measurements taken at 1.8 m (6 ft) from the pavement edge for 23-cm (9-in) CRCP, Dynaflect readings of less than 0.012 mm (0.5 mil) are indicators of good pavement condition. Values in the range of 0.015 to 0.022 mm (0.6 to 0.9 mil) spell a potential distress condition; values above 0.025 mm (1.0 mil) are indicators of severe distress with a high probability of pavement breakups.

PHASE 6, DESIGN OF MAINTENANCE STRATEGIES

The evaluation of significant factors relating to performance of CRCP led to recommendations for altering future CRCP designs. These recommendations are not included here. As a part of these recommendations, however, it became obvious that there was a need to recommend maintenance strategies that might be adopted.

Data relative to the most economical maintenance were meager; as a result, a field experiment was established to evaluate this factor. This field experiment was evolved on the basis of known factors that have significantly influenced performance of CRCP in Indiana (poor drainage condition, high deflections, and the like).

The end point of the research could only be accomplished by dividing a section of highway into smaller units with similar characteristics. A pavement section of I-65 7.4 km (4.6 miles) in each direction was selected as the test pavement because it contains all of the significant features identified as major contributors to performance of CRCP. It has a gravel subbase and bar mats on chairs. This pavement has shown, as predicted, very poor performance.

Objective of Research

The types of maintenance considered were determined on the basis of results of the evaluation. Therefore, the types of maintenance considered were directed at three principal factors:

1. Improvement of drainage of subbase,
2. Methods of reducing pavement deflection, and
3. Methods of patching failed areas.

Initial Tests

Deflection readings were taken in the fall of 1974 with Dynaflect at 7.6-m (25-ft) intervals over the study area. At the same time, a condition survey of the pavement was made noting the locations of breakups, patches, intersecting cracks, and combination cracks.

Method of Selecting Study Sections

Using the data derived from the above tests, we chose three factors as indicative of the overall condition of the pavement. These were (a) linear meters of cracks spaced less than 76 cm (30 in) plus linear meters of intersecting

cracks per 30-m (100-ft) section, (b) total area of patching or breakups per section, and (c) maximum deflection per 30-m (100-ft) section.

By using this technique, we then stratified the pavement sections and assigned rating numbers of 1 to 12 as shown in Figure 6.

Selection of Maintenance Methods

An attempt was made to apply as many types of appropriate maintenance as possible to the various ratings. Table 2 gives the types of maintenance that were considered appropriate for the given rating numbers. Input into this selection was provided by Federal Highway Administration, Indiana Highway Commission, and Purdue University personnel.

Layout of Study Sections

The layout of study sections for a given type of maintenance was governed by four criteria.

1. A section of one type of maintenance was made as long as possible.
2. At least one no-maintenance control section for each of the rating numbers, 1 to 12, was retained.
3. As many different types of maintenance methods as possible were used for each rating number.
4. The maintenance to be used was allocated first to the rating categories having the fewest actual sections with that rating. (Note that this criterion is a means for attaining the first three criteria.)

SUMMARY

In this paper a comprehensive system for pavement condition evaluation has been outlined. It has been the primary purpose to present principles that can be used for a variety of pavements. The method has been illustrated by using an evaluation of continuously reinforced concrete pavements. The techniques, however, are not unique to this type of pavement but have application to all types of pavements under a variety of traffic and environmental conditions.

The heart of the method lies in stratification of the known factors surrounding the pavement and, along with this, a statistical analysis of the data. The sequential series of events must be followed although the process can be concluded at any of the several stages depending on the needs of the engineer.

REFERENCES

1. V. L. Anderson and R. A. McLean. Design of Experiments—A Realistic Approach. Marcel Dekker, Inc., New York, 1974, 418 pp.
2. High Load Penetrometer Soil Strength Tester. Commercial Airplane Division, Boeing Co., Renton, Wash., Document D6-24555, 1971.
3. W. E. Deming. Some Theory of Sampling. Dover Publications, New York, 1950.
4. F. H. Scrivner, R. Peohl, W. M. Moore, and M. B. Phillips. Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements. NCHRP, Rept. 76, 1969, 37 pp.
5. D. J. Van Vuuren. Rapid Determination of CBR With the Portable Dynamic Cone Penetrometer. Rhodesian Engineer, Paper 105, 1969.