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Rehabilitation of Concrete Pavements

Volume III: Concrete Pavement Evaluation and Rehabilitation System

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This report is one volume of a four-volume set presenting the results of a research study to develop improved evaluation procedures and rehabilitation techniques for concrete pavements. Each report includes the Table of Contents for all four volumes. Eight rehabilitation techniques were selected for detailed investigation by field inspection and analytical study. These eight techniques are diamond grinding, load transfer restoration, edge support, full-depth repair, partial-depth repair, bonded concrete overlays, unbonded concrete overlays, and crack-and-seat with AC overlay. Based on analysis of the field data, a series of distress models were developed to predict the performance of the various rehabilitation techniques under a variety of conditions. These models and other information were then used to develop a comprehensive prototype system for jointed plain, jointed reinforced, and continuously reinforced pavement evaluation and rehabilitation.

This report will be of interest to engineers involved in planning, designing, or performing rehabilitation of concrete pavements.

Sufficient copies of this report are being distributed by FHWA memorandum to provide one copy to each FHWA Region and Division and two copies to each State highway agency. Direct distribution is being made to the division offices. Additional copies for the public are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Thomas J. Pasko

Thomas J. Pasko, Jr.
Director, Office of Engineering
and Highway Operations
Research and Development

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16. Abstract

Extensive field, laboratory and analytical studies were conducted into the evaluation and rehabilitation of concrete pavements. Field studies included over 350 rehabilitated pavement sections throughout the U.S., and the construction of two field experiments. A laboratory study was conducted on anchoring dowels in full-depth repairs. Analyses of field and laboratory data identified performance characteristics, improved design and construction procedures, and provided deterioration models for rehabilitated pavements. A concrete pavement advisory system was developed to assist engineers in project level evaluation and rehabilitation.

Volume III presents a comprehensive concrete pavement evaluation and rehabilitation advisory system for jointed plain, jointed reinforced and continuously reinforced concrete pavements.

This volume is the third in a series. The others in the series are:

FHWA NO.	Vol. No.	Title
RD-88-071	I	Repair Rehabilitation Techniques
RD-88-072	II	Overlay Rehabilitation Techniques
RD-88-074	IV	Appendixes

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

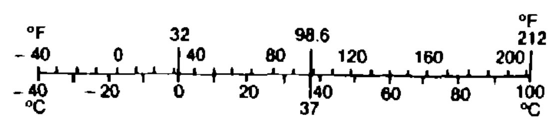
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT AND RESEARCH OBJECTIVE

The objective of this research effort was to develop a practical and comprehensive system to assist practicing engineers in:

- Evaluating concrete highway pavements.
- Identifying types of deterioration present and determining their causes.
- Selecting rehabilitation techniques which will effectively correct existing deterioration and prevent its recurrence.
- Combining individual rehabilitation techniques for each lane and shoulder into feasible rehabilitation strategies.
- Predicting the performance of rehabilitation strategy alternatives.

The pavement types that are addressed by the system include the following:

- Jointed reinforced concrete pavement (JRCP).
- Jointed plain concrete pavement (JPCP).
- Continuously reinforced concrete pavement (CRCP).

The system is intended for use by State highway engineers in project-level rehabilitation planning and design for high-type (i.e., Interstate) concrete pavements. The system is not a pavement design procedure in terms of thickness design or joint design. The engineer must utilize existing design procedures to determine these details for overlays and reconstruction.

1.2 RESEARCH APPROACH

The evaluation and rehabilitation system has been developed in the form of a knowledge-based system, which simulates a consultation between the engineer and an expert in concrete pavements. The system uses information about the pavement provided by the engineer to guide him or her through evaluation of the pavement's present condition and development of one or more feasible rehabilitation strategies. The procedure was developed through extensive interviewing of and interaction with authorities on concrete pavement performance. In addition, predictive models are included to show future pavement performance both and without rehabilitation.

This volume describes the system and provides guidance on its usage. A computer program has been developed for each of the three pavement types addressed. The programs operate on any IBM-compatible personal computer with 256 K memory. Use of the computer programs is highly recommended due to the complexity of the manual procedure.

1.3 BRIEF DESCRIPTION OF EVALUATION AND REHABILITATION SYSTEM

Evaluation of a pavement and development of feasible rehabilitation alternatives is performed according to the following steps:

1. **Project data collection.** The engineer collects key inventory (office) and monitoring (field) data for the project. Inventory data includes design, traffic, materials, soils and climate. Monitoring data includes distress, drainage characteristics, rideability, and other items collected during a field visit to the project. The data are entered into a personal computer using a full-screen editor.

2. **Extrapolation of project condition over the entire project length.** The overall condition of the project is extrapolated from the sample unit monitoring data and extrapolated distress quantities are summarized.

3. **Evaluation of present condition.** The engineer utilizes the pavement evaluation procedure to analyze all of the data and develop a specific detailed evaluation in several major problem areas, including roughness, structural adequacy, joint deterioration, foundation movement, skid resistance, construction deficiencies, drainage, loss of support, joint sealant condition, concrete durability, and shoulder condition.

4. **Prediction of future condition without rehabilitation.** The future condition of the pavement without rehabilitation is predicted. Faulting, cracking, joint deterioration, pumping, and present serviceability rating are projected for jointed pavements (and punchouts for CRCP) and the years in which they will become serious problems are identified.

5. **Physical testing as needed.** The initial data collection does not require physical testing. Based upon the available information, the engineer identifies types of physical testing needed to verify the evaluation recommendations and to provide data needed for rehabilitation design. Recommended testing may included nondestructive deflection testing, coring/material sampling and laboratory testing, and roughness and friction measurement.

6. **Selection of main rehabilitation approach.** Based upon the evaluation results, the engineer then interacts with the system to select the most appropriate main rehabilitation approach for each traffic lane and shoulder. These include all 4R options: reconstruction (including recycling), resurfacing (with concrete or asphalt), or restoration.

7. **Development of detailed rehabilitation strategy.** Once a main rehabilitation approach is selected for each traffic lane and shoulder, the engineer proceeds to develop the detailed rehabilitation alternative, by selecting a feasible set of individual rehabilitation techniques to correct the deficiencies present. This may include such items as subdrainage, shoulder repair, full-depth repairs, joint resealing, etc. This is performed for each traffic lane and shoulder by interaction with the system.

8. **Prediction of rehabilitation strategy performance.** The future performance of the developed rehabilitation strategy is then predicted in terms of key distress types for 20 years into the future, based upon assumed traffic growth. For concrete restoration, overlays and reconstruction alternatives, faulting, cracking, joint deterioration and present serviceability rating (and punchouts for CRCP) are projected. For asphalt overlay alternatives, rutting and reflection cracking are projected. The engineer then evaluates the results and determines whether or not the proposed alternative provides an acceptable life. If so, a cost estimate can be prepared based on computed repair quantities. If not, the engineer can revise the rehabilitation alternative.

9. **Cost analysis of alternatives.** Approximate quantities for each rehabilitation technique included in the alternative strategy are computed from the extrapolated distress quantities for each lane and shoulder. The engineer then computes the total cost for each item and totals all costs for the strategy. The engineer determines the life of the rehabilitation from the projected deterioration information and computes an annual cost for the alternative.

10.. **Selection of preferred rehabilitation strategy alternative.** There are typically two to four feasible rehabilitation alternatives for a given project. To select the preferred alternative, the engineer must consider not only life-cycle cost but also constraints that exist for the project, such as traffic control, construction time, available funding, etc. Based upon estimated initial and annual costs, expected life and performance and various constraints, the engineer selects the preferred rehabilitation strategy from among the feasible alternatives available.

1.4 ONGOING DEVELOPMENT OF COMPUTER PROGRAMS

The three computer programs described in this volume are collectively named EXPEAR. The version of the programs originally developed for the Federal Highway Administration in this study was EXPEAR 1.1.

Since the completion of this study, development of the programs has continued with the support of the Illinois Department of Transportation. The version of the programs current at the time of publication of this report is EXPEAR 1.3. The capabilities to delay rehabilitation and to do life-cycle cost analysis are incorporated into EXPEAR 1.3, as well as improvements to some of the performance prediction models. These added features are described in this volume.

CHAPTER 2

KNOWLEDGE-BASED SYSTEM APPROACH TO CONCRETE PAVEMENT EVALUATION AND REHABILITATION

2.1 PROBLEM STATEMENT

Over the past 20 to 30 years, many of the United States' high-type pavements, including those making up the vital Interstate system, have carried volumes of heavy truck traffic far in excess of those for which they were designed, and are deteriorating rapidly. Prolonging the lives of these pavements through rehabilitation has become a major concern (and expense) of State highway agencies, and promises to continue to be so for many years to come.

Project-level rehabilitation design involves two distinct activities:

1. **Evaluation of a pavement's present condition,** which includes recognition of various types of distress and identification of the mechanisms responsible for them.

2. **Development of rehabilitation alternatives** which will cost-effectively **repair** the distress and **prevent** its recurrence.(1)

Distresses are, to use a medical analogy, only symptoms of a problem, and treating the symptoms does not necessarily treat the problem. "Quick fix" repairs, which correct the existing distress without arresting the mechanisms which caused it, have a high probability of premature failure and thus are ultimately not cost-effective.

Obviously, pavement rehabilitation design requires a good understanding of how pavements perform. However, concrete pavement performance is a complex phenomenon, which is influenced by a large number of factors relating to design, construction, materials, environment, and traffic. These factors interact to influence performance in ways which are not clearly understood. Thus, while some aspects of concrete pavement performance can be explained by mechanistic models and well established principles (e.g., calculation of stresses and fatigue damage), many other aspects cannot.

2.2 NATURE OF ENGINEERING PROBLEM-SOLVING

As with many areas of engineering, problem solutions in pavement rehabilitation must be arrived at by relying on two different types of knowledge: **deterministic** knowledge and **heuristic** knowledge.(2) Deterministic knowledge, sometimes called "public" or "textbook" knowledge, is that body of factual information which is widely accepted by and available to engineers in the pavement field. Heuristic knowledge is the subjective or "private" knowledge possessed by each engineer individually, which is largely characterized by beliefs, opinions, and rules of thumb.

Engineering problems typically cannot be solved by applying deterministic knowledge alone, for two major reasons. First, the complexity of the problem may be so great that available deterministic knowledge is incomplete. The engineer may have to apply rules of thumb which are not well proven or necessarily valid in all cases, but which allow him or her to make "educated guesses" which fill in the gaps in the available deterministic knowledge and bring the engineer closer to a solution. It is good engineering practice to recognize that the validity of a problem solution arrived at in this manner is subject to the validity of the assumptions made by the engineer.

The second deterrent to purely deterministic problem-solving is that many engineering problems do not have clear-cut right and wrong answers. Often, the engineer must find a "good enough" answer, given a limited amount of information about a problem, or must select the best option from among a number of feasible alternatives. This demands that the engineer apply good judgment, which may include such things as reasonable safety factors and weighted decision criteria. This too requires considerable technical skill on the engineer's part, as these decisions must be based on familiarity with the problem domain and experience in solving similar problems. Extreme conservatism applied without a good understanding of the problem generally does not produce the best solution, as it often results in overdesign and unnecessarily high costs.

An important distinction between deterministic knowledge and heuristic knowledge lies in the way in which they are acquired by the engineer. Deterministic knowledge may be obtained in school, from textbooks, training manuals, and published literature. Heuristic knowledge, however, is acquired through experience gained in solving problems. Novice engineers learn by trial and error to make guesses and assumptions when solving problems, to fill in the gaps created by the incomplete nature of their deterministic knowledge. In doing so, they gradually build up a base of heuristic knowledge about the problem domain, which tends to increase their success at problem solving. In any scientific or professional field, be it engineering, medicine, law, etc. acknowledged "experts" are those individuals who have an extensive background of experience in the field, and who are highly successful at solving difficult problems.(3) Although precise definitions of "knowledge" and "expertise" are elusive, a good description of an expert is someone who has a considerable amount of high-level knowledge about a problem domain, acquired through direct experience in solving many problems in that domain, and who is capable of applying that knowledge to solve difficult problems quickly, efficiently, and with a high degree of success.

2.3 KNOWLEDGE-BASED APPROACH TO ENGINEERING PROBLEM SOLVING

While deterministic knowledge is preservable in references and textbooks, heuristic knowledge definitely is not. Since it is acquired through individual experience, it is not easily communicated to others and, as experienced engineers retire, it is often lost. The challenge of organizing and preserving this wealth of heuristic problem-solving knowledge is the basis for development of a relatively new type of engineering tool known as "knowledge-based systems." These are computer programs in which heuristic knowledge which has been acquired from humans is utilized to solve problems which are intractable with a purely deterministic approach. A subset of knowledge-based systems are "expert systems," which employ both the knowledge and reasoning methods of human experts to solve difficult problems in a narrowly defined problem domain.

2.4 KNOWLEDGE-BASED APPROACH TO PAVEMENT EVALUATION AND REHABILITATION

As described earlier, project-level pavement rehabilitation really involves two distinct engineering activities: evaluation and rehabilitation. Insofar as the nature of these activities differs, so must the approach taken to them. Thus, the concrete pavement evaluation and rehabilitation system was developed as a two-phase system, in which the separate activities of evaluation and rehabilitation are each performed in as efficient and robust a manner as possible.

2.4.1 Pavement Evaluation: A Diagnostic Activity

Pavement evaluation is a **diagnostic** activity, similar to medical diagnosis, in which conclusions about aspects of the condition of the pavement are drawn from an examination of relevant factual data. For example, facts about the pavement's design, materials, traffic history, and existing load-related distresses might be examined to determine whether the pavement had a structural deficiency. Other diagnostic activities include classification (e.g., of distress types) and prediction (e.g., of future pavement condition).

A variety of approaches exist for performing diagnostic activities with knowledge-based systems. The approach selected here for concrete pavement evaluation was a decision tree format. By developing a decision tree for each major problem area considered in evaluation (e.g., roughness, structural adequacy, etc.), both factual knowledge and reasoning processes could be conceptually expressed and graphically illustrated in a form which was easy to understand, examine, and revise. This ensures that all potential problem areas are investigated adequately, and a truly comprehensive pavement evaluation is conducted. The decision tree for structural adequacy of JRCP is shown in figure 1 as an example.

The decision trees are made up of nodes, branches, and conclusions. Nodes represent pieces of information about the pavement, including distress types and quantities, design and materials data, environmental conditions, and traffic level. At each node, a choice must be made as to which branch of the tree should be followed, according to the values for the choice shown for the branches. Conclusions about the presence or absence of specific deficiencies within the major problem area are reached by proceeding down the branches of the tree. Conclusions are represented on the decision trees by a three-letter code for the major problem area and the number of the specific conclusion reached (e.g., STR 4 for the fourth possible conclusion on the structural deficiency tree). These codes correspond to one or more sentences of text which explain whether or not a particular deficiency exists, and if so, what factors were considered in reaching that determination.

Evaluation is typically associated with badly distressed pavements which are clearly in need of rehabilitation at the present time. However, to develop a pavement evaluation system which can only identify current rehabilitation needs is to limit the system's usefulness as a pavement management tool. What about a pavement that does not need rehabilitation now, but will within the next 5 years? What about a relatively new pavement which does not exhibit much visible distress, but which is inadequately designed or constructed to withstand the traffic loadings and environmental influences which will act upon it over its design life?

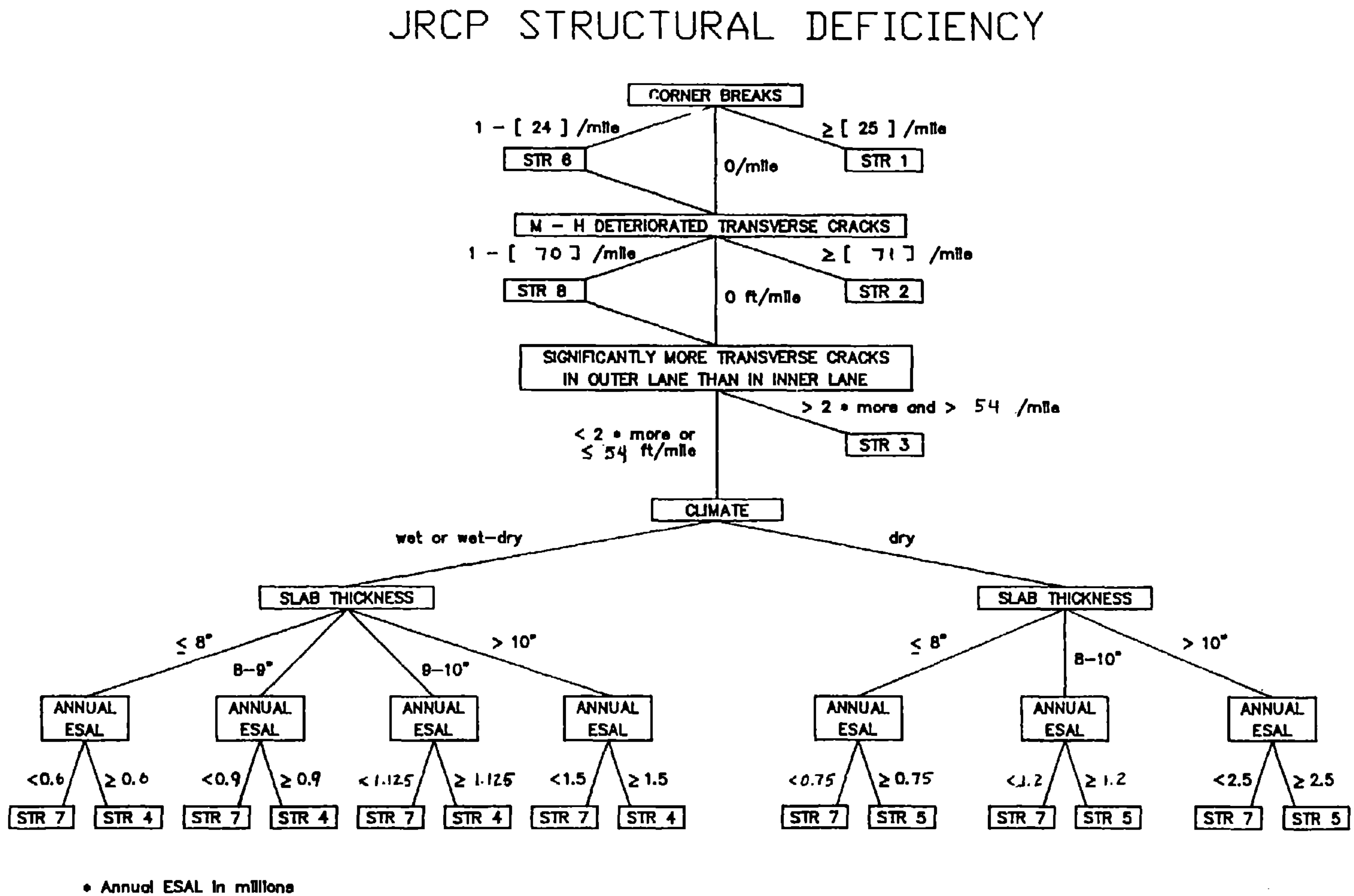


Figure 1. Structural adequacy decision tree for JRCP.

Deterministic knowledge can be applied here, using existing models for predicting concrete pavement performance. In addition to the decision trees, a number of predictive models for key concrete pavement distress types are employed to project the future condition of the pavement without rehabilitation. The system uses these future predicted values to "reevaluate" the pavement each year for the next 20 years into the future, and identify the years in which the distresses will reach critical levels indicative of deficiencies in the various problem areas. By combining deterministic and heuristic knowledge in this way, the knowledge-based evaluation system produces a more comprehensive and useful evaluation than would be possible using either type of knowledge alone.

2.4.2 Pavement Rehabilitation: A Design Activity

Rehabilitation strategy development, however, is a very different type of engineering problem. This is really a **design** activity, in which the engineer must generate a rehabilitation strategy which satisfies the needs for repair and/or improvement identified by the evaluation. Whereas evaluation generally considers a limited set of potential problems, rehabilitation design involves a huge number of combinations of many individual rehabilitation techniques. Some thirty or more rehabilitation techniques can be identified for concrete pavements, ranging from reconstruction to crack sealing. From these options, a set of techniques must be selected for each traffic lane and shoulder which correct all of the existing distresses and prevent their recurrence. The techniques selected must be compatible within each lane and with the techniques selected for the other lanes and shoulders. For example, a structural overlay may be a potential rehabilitation technique for an outer traffic lane which has a structural deficiency, but if it is selected, it will necessitate overlaying the inner lane and the shoulders as well, even if the inner lane and shoulders are not themselves structurally deficient. As a result, the overlay may supersede some nonstructural rehabilitation techniques which might otherwise have been selected for the inner lane (e.g., grinding) or the shoulders (e.g., chip seal).

Generating all the possible combinations of techniques and evaluating their feasibility would be a formidable task even for a high-speed computer, if done using conventional programming methods. Using a knowledge-based approach, however, rehabilitation strategies (compatible combinations of techniques) can be developed much more quickly and easily by generating **only feasible combinations**, thus greatly reducing the number of strategies which the engineer must consider. This is done by applying restrictions on the generation of strategies which reflect heuristic knowledge about the compatibility of various techniques.

A key decision to be made when developing rehabilitation strategies is the selection of the main rehabilitation approach (reconstruction, resurfacing, or restoration) for each traffic lane. This decision is best made early in the strategy development process, as it dictates much of the subsequent selection of rehabilitation techniques. Since there are three main rehabilitation approaches available, and two traffic lanes, theoretically nine combinations of approaches exist for a project. However, an engineer examining the list of combinations would quickly point out that it isn't feasible to place an overlay in only one lane, so in fact there are fewer than nine combinations:

1. Reconstruct both lanes.
2. Reconstruct outer lane and restore inner lane.
3. Reconstruct inner lane and restore outer lane.
4. Overlay both lanes.
5. Restore both lanes.

This is an example of how heuristic knowledge of the problem domain can be applied to limit the search for feasible solutions.

After feasible rehabilitation strategies have been developed, the engineer must still choose the best alternative. This may be done on the basis of a variety of selection criteria, the most important of which is usually life-cycle cost. However, the engineer cannot perform a life-cycle cost comparison of the strategy alternatives without some idea of the lives of the alternatives. Here too, deterministic knowledge can be applied, by employing available models for predicting rehabilitation performance in terms of key distress types. Several such models were developed in this study and incorporated in the system. Thus in rehabilitation as in evaluation, deterministic and heuristic knowledge are combined to improve the quality of the problem solution.

2.5 IMPLEMENTATION OF THE SYSTEM

One approach to knowledge-based system development is to implement a prototype with a commercially available, off-the-shelf software tool known as a "shell" which provides a suitable development environment (knowledge representation scheme, text editor, compiler, etc.), and then to rewrite the system for maximum efficiency when most of the difficult development is finished.(8) However, shells can actually hinder system development in some ways, because of their stylized input/output languages and reasoning methods. Furthermore, complex knowledge often cannot be easily fit into any predefined formal structure; rather, the characteristics of the problem should dictate the most efficient implementation approach.

Initially, a shell was used to develop a demonstration prototype for the evaluation portion of the system, largely for the purpose of investigating the suitability of a knowledge-based approach. The shell used was Insight 2+, developed by Level V Research, Inc. This shell was chosen after experimentation with a variety of representation schemes which led to the selection of the decision tree format. Insight 2+ is a production-rule-based system shell, meaning that knowledge is expressed in terms of "if-then" rules. To solve problems, it uses a reasoning method known as "backward chaining," meaning that it makes assertions and then sets about to prove or disprove these assertions by matching the "if" and "then" clauses of the rules as needed, working backwards to known facts. Each rule represents a discrete piece of knowledge, and the logic of the problem-solving strategy is merely sequential association of these pieces of knowledge.

One problem with production rule systems is that complex lines of reasoning may not be easily expressed in discrete pieces, and thus are hard to represent in production rules.(8) Production rule systems are also hard to analyze for completeness and consistency, to ensure that all possible combinations of the data are covered.(4,11) By representing the problem-solving strategy of the pavement evaluation system with decision trees, these problems were eliminated. The decision trees imposed a structure on the problem-solving strategy which would not normally exist in a typical production rule system. It was still possible, although not very convenient, to express this structure in production rule format. To incorporate the decision trees into the Insight 2+ shell, each path down each tree (a path being composed of a set of nodes and connecting branches terminating at a conclusion) was programmed as a single rule.

Although the production rule approach employed using Insight 2+ was helpful in developing the initial prototype, it soon became too restrictive for continued development of the system. The major reason for this was that stated above: the problem was too complex for the shell structure. Representing the decision trees with a set of rules was inefficient and unwieldy. Long compilation and execution times slowed the development of the system and detracted from the program's ease of use. In addition, it was very difficult to interface the decision trees with other sections of the system (e.g., data entry and retrieval). To circumvent the limitations of the system as implemented in the shell, the system was rewritten in Pascal, using Borland International, Inc.'s Turbo Pascal.

The conversion to Pascal transformed the decision trees into large nested if-then-else structures. Each node was transformed into an if-then-else statement, with one path from the node being the "then" consequence, and other paths being the "else" consequences. This transformation changed the system from a traditional backward-chaining production rule format to a hard-coded format. Hence, some of the transparency of the knowledge was lost, and modifications became more difficult. These problems were more than offset, however, by the increased ease of interfacing the evaluation portion with the rest of the system, and a tenfold increase in execution speed. Perhaps more significant, the models for predicting future performance with and without rehabilitation, which were programmable in Pascal without much difficulty, would have been extremely difficult to program in production rule format, and the capability of production rule shells such as Insight 2+ to interface with external programs to perform such computations is very limited.

2.6 FUTURE OF KNOWLEDGE-BASED SYSTEMS IN ENGINEERING

It has long been known that many difficult problems facing engineers are intractable by algorithmic means. Until recently, such problems could only be solved by reliance on human experts with extensive practical experience and considerable knowledge of the problem domain. The new technology of knowledge-based systems offers a powerful means for acquiring and organizing this human expertise so that it may be preserved and communicated to others, and also so that the resources of high-speed computers may be applied to solving these difficult problems.

As potential applications of knowledge-based systems are explored in engineering domains, it will become increasingly apparent that both the best available deterministic and heuristic knowledge must be employed to obtain satisfactory problem solutions quickly and efficiently. This is certainly true in the case of this concrete pavement evaluation and rehabilitation system. As the understanding of concrete pavement performance grows, the system will need to be modified to keep pace with advances in deterministic and heuristic knowledge of the domain. It is hoped that this knowledge-based approach to this difficult engineering problem will provide practicing highway engineers with a valuable tool for pavement evaluation and rehabilitation, and thereby contribute to better and more cost-effective pavement rehabilitation designs in the future.

CHAPTER 3

DESCRIPTION OF EVALUATION AND REHABILITATION SYSTEM

3.1 INTRODUCTION

EXPEAR consists of three separate, stand-alone evaluation/rehabilitation systems, one for each of three concrete pavement types (JRCP, JPCP, and CRCP). To use EXPEAR in either computerized or manual form for a particular pavement type, the engineer simply selects the appropriate computer program or sections of this report, as shown below:

Pavement Type	Computer Program	Manual Form
JRCP	JRCP EXPEAR	chapter 4 and appendix A
JPCP	JPCP EXPEAR	chapter 5 and appendix B
CRCP	CRCP EXPEAR	chapter 6 and appendix C

Although the systems for the three pavement types differ in details, they all follow the same basic structure. The purpose of this chapter is to describe this structure in general terms applicable to all three pavement types. The engineer should read this section before attempting to use the programs or chapters and appendixes listed above.

3.2 PAVEMENT GEOMETRY

EXPEAR is intended for use on Interstate-type divided highways with two lanes in each direction and either asphalt or concrete shoulders. It cannot accommodate routes with fewer than two or greater than two lanes in one direction, nor routes with unpaved shoulders.

A "project" is defined as a pavement section of any length consisting of two lanes in one direction, with inner and outer paved shoulders, which is uniform throughout its length with respect to the following:

- Year of construction.
- Concrete slab design (thickness, joint spacing if any, quantity of steel reinforcement if any, and transverse and longitudinal joint design and construction).
- Type of base course.
- Type of subgrade.
- Subsurface drainage conditions.
- Past and current truck traffic volume and composition.

If a pavement section is not uniform with respect to these items, it should be split up into two or more uniform sections which should be evaluated separately. Sections containing intersections should also be split up, unless site-specific traffic data verifies that truck traffic is approximately consistent in volume and composition throughout the length of the section. Opposing lanes of the same section of highway (e.g., northbound vs. southbound lanes) should be evaluated as separate projects.

3.3 STEPS IN EVALUATION/REHABILITATION PROCEDURE

Evaluation of a concrete pavement and development of feasible rehabilitation strategy alternatives are performed by the following steps:

1. Project data collection.
2. Extrapolation of project condition.
3. Evaluation of present condition.
4. Prediction of future condition without rehabilitation.
5. Physical testing.
6. Selection of main rehabilitation approach (reconstruction, resurfacing, or restoration).
7. Development of rehabilitation strategy.
8. Prediction of rehabilitation strategy performance.
9. Cost analysis of strategies.

These steps are described in this chapter, independent of pavement type. Chapters 4, 5, and 6 provide additional details relevant to the specific pavement types addressed.

3.4 PROJECT DATA COLLECTION

Survey sheets for JRCP, JPCP, and CRCP are provided in appendixes A1, B1, and C1. The survey sheets consist of two parts: inventory data and monitoring data. Inventory (office) data includes:

- Project identification (State, route, and mileposts).
- Climate (temperature, precipitation, and climatic zone).
- Concrete slab design and construction.
- Joint design and construction.
- Base type and strength.
- Subgrade classification.
- Shoulders.
- Traffic (cumulative ESAL, ADT, and percent trucks).

Since the project must be consistent throughout its length with respect to all inventory data items, only one set of inventory data sheets is completed for a project. All of the requested inventory information should be easily accessible to a State highway engineer from office records.

A set of supplemental information sheets are provided with the project survey sheets to assist the engineer in obtaining the inventory information requested. These sheets include:

- Climatic zone map of the United States.
- Freezing Index contour map of the United States.
- Reinforcing steel size table for JRCP and CRCP.
- Subgrade k-value correlation table.
- Effective (base) k-value correlation table.

The engineer should refer to the most reliable and accurate sources of information available to obtain the inventory data for a project. County soil maps provide information not only on subgrade type but also drainage conditions and local weather conditions. Detailed climatic data for the nearest weather station can be obtained from the "Monthly Normals of Temperature, Precipitation and Heating and Cooling Degree Days" reports compiled for each state by the National Climatic Center, Asheville, North Carolina, 28801-2696. Data on actual subgrade soil classification, subgrade k-value, and effective base k-value are preferable to approximate correlations. The project survey sheets are intended to utilize this type of detailed data if it is available to the engineer, but also to accommodate the possibility that it is not and that estimates must be made.

Monitoring data is the information about the pavement's present condition that is collected during a visit to the project site, including:

- Ride quality.
- Load-related distresses.
- Joint condition.
- Settlements and heaves.
- Drainage conditions.
- Pumping.
- Concrete surface condition.
- Joint sealant condition.
- Concrete durability.
- Previous repair.
- Shoulder condition.

3.4.1 Conducting the Project Survey

Before the actual field survey, the engineer collects and records on the project survey sheets all inventory data requested. Monitoring data is collected and recorded on the project survey sheets at the project site. Distress types, severities, and quantities are recorded on the monitoring data sheets in a manner consistent with standard distress identification procedures.(6) Monitoring data must be collected for each traffic lane and for both the inner and outer shoulder so that each of the lanes and shoulders can be evaluated separately.

Ride quality is expressed as a Present Serviceability Rating, using the following scale:

```
0           1           2           3           4           5
+-----------+-----------+-----------+-----------+-----------+
  Very Poor     Poor        Fair        Good      Very Good
```

Among the questions that the engineer should ask himself or herself when rating the pavement are: "How well would this pavement serve me if I had to drive on it for 8 hours?" and "How would I like to drive over 500 miles [800 km] of this pavement?" Additional guidance on rating pavement serviceability is provided in reference 13.

The serviceability (ride quality) of the pavement should be rated in each traffic lane over the length of the project, while driving over the project at 50 miles per hour [80 km/h]. Ideally, two or more persons should participate in conducting the project survey. A serviceability rating should be obtained for each lane from each person, and the average values recorded on the survey sheets. Two passes over the project are necessary to obtain serviceability ratings for both lanes.

The one other monitoring data item which must be assessed over the project length is condition of terminal treatments for CRCP, as explained on the CRCP survey sheets. All other monitoring data items are recorded by sample unit.

3.4.2 Number and Length of Sample Units

Since it may not be practical to conduct a 100 percent survey of the project for purposes of evaluation and preliminary rehabilitation design, it is recommended that the project be surveyed by representative sampling. A sufficient number of sample units distributed throughout the project's length should be surveyed to obtain an accurate representation of the overall project condition. For JRCP and JPCP, a sample unit length and distribution of 1000 ft [304 m] in each mile (perhaps started at each milepost for convenience), which provides approximately 20 percent coverage, is recommended. CRCP may be surveyed more quickly due to the absence of transverse joints, so sample units may be longer and spaced further apart if desired. The actual length of the sample units is up to the engineer; they do not all have to be the same length. A set of monitoring data sheets must be completed for each sample unit surveyed.

The EXPEAR computer programs can accommodate up to ten sample units. If it is desired to survey more than ten sample units (e.g., for a project more than 10 miles [16 km] long), the project should be split up into two or more projects of 10 or fewer sample units each. This restriction does not apply when using the system in manual form.

3.4.3 Project Survey Data Entry

When using one of the EXPEAR computer programs, collection of the project survey data is followed by entry of the data into files on diskette. This is done using a full-screen editor included in the EXPEAR programs. The full-screen editor provides screens for entry of the inventory data and asks the user for the number of sample units surveyed. It provides sets of monitoring data screens for as many sample units as were surveyed. The inventory data and monitoring data comprise a data record which is saved in a permanent file on diskette. More instructions on project survey data entry are given in appendixes A6, B6, and C6.

3.5 EXTRAPOLATION OF PROJECT CONDITION

Before the project can be evaluated, its overall condition must be determined by extrapolation from the sample unit monitoring data. The EXPEAR computer programs perform this function automatically. When using EXPEAR in manual form, the engineer must perform the calculations to extrapolate overall project condition by hand. It is recommended that a blank set of sample unit monitoring data sheets be used to record the results of the extrapolations. This set of sheets, along with the inventory data sheets and project monitoring data sheet, represent the project record in manual form.

Sample unit monitoring data consists of two different types of items: **real numbers and toggle values.** Real numbers represent distress quantities or measurements, such as feet of longitudinal cracking, number of corner breaks, or average transverse joint faulting. Toggle values represent the engineer's responses to a set of choices provided to describe distress severities and other aspects of the pavement's condition, such as presence of incompressibles in transverse joints (yes/no), severity of D cracking (none/low/medium/high), or AC shoulder alligator cracking (none/some/extensive).

In general, real number data items are extrapolated from the sample unit data sheets and expressed in the project record as an average quantity per mile (e.g., number per mile, feet per mile, etc.), except faulting, which is expressed as an overall average in inches. Toggle data values recorded for each sample unit are averaged to represent typical values over the length of the project.

In chapters 4, 5, and 6, the specific distress items collected for JRCP, JPCP, and CRCP respectively are categorized as real numbers or toggle items and extrapolation instructions are given.

3.6 EVALUATION OF PRESENT CONDITION

3.6.1 Major Problem Areas

For each concrete pavement type, several major problem areas were identified which should be considered in a comprehensive evaluation. Twelve major problem areas were identified for JRCP and JPCP, and nine were identified for CRCP. All three pavement types have the following seven major problem areas in common:

1. Structural adequacy.
2. Drainage.
3. Foundation stability.
4. Concrete durability.
5. Skid resistance.
6. Roughness.
7. Shoulders.

The following two problem areas are considered for CRCP in addition to the common seven:

8. Longitudinal joint construction.
9. Construction joints and terminal treatments.

Due to the presence of transverse joints, JRCP and JPCP have the following additional problem areas which must be considered:

8. Transverse and longitudinal joint construction.
9. Transverse joint sealant condition.
10. Load transfer.
11. Loss of support.
12. Joint deterioration.

Within a given problem area, a number of specific deficiencies may exist. For example, poor skid resistance may be the result of inadequate texturing of the pavement surface at construction, polishing of the surface in the wheelpaths under traffic, or even rutting caused by studded tires. A thorough assessment of a pavement's present condition requires a determination of whether or not one or more deficiencies serious enough to warrant corrective action exists in each of the major problem areas related to that type of pavement.

Each of the problem areas represents a different mode of deterioration commonly observed in concrete pavements. Each mode of deterioration is controlled by certain significant factors in the design, materials, soils, traffic and environment of the pavement, and has associated with it certain characteristic types of distress. In this sense, the problem areas are independent of each other. In another sense, however, they can never be truly independent, since pavement deterioration is a complex phenomenon encompassing many different mechanisms and their interactions.

3.6.2 Evaluation Decision Trees and Conclusions

For each major problem area, a decision tree was developed to identify specific deficiencies warranting repair. The decision trees organize pertinent design, traffic, environment, and distress factors into structures for determining whether or not specific deficiencies exist within that problem area.

The decision trees are made up of nodes, branches, and conclusions. Nodes represent data about the pavement, including distress types and quantities, design and materials data, environmental conditions, and traffic. Conclusions about the presence or absence of specific deficiencies within the major problem area are reached by proceeding down the branches of the tree. Conclusions are represented on the decision trees by three-letter codes identifying the major problem area and specific conclusion reached (e.g., STR 4 for the fourth possible conclusion on the structural deficiency tree). These codes correspond to one or more sentences of text which explain whether or not a particular deficiency exists, and if so, what factors were considered in reaching that determination.

The evaluation decision trees and conclusions for JRCP, JPCP, and CRCP are provided in appendixes A2, B2, and C2.

3.6.3 Critical Distress Levels

In several of the problem areas, certain quantities of distress and PSR values are considered indicative of deficiencies. Default values for these critical distress levels are incorporated in EXPEAR. These values are enclosed in brackets on the evaluation decision trees and in the evaluation conclusions shown in appendixes A2, B2, and C2. The specific survey data items which have default critical levels are listed for each pavement type in chapters 4, 5, and 6.

The engineer may modify these default values if desired to reflect his or her own experience or agency's policies. In the EXPEAR programs, the capability is provided to save the engineer's choices for critical distress levels permanently in a disk file, so that they do not have to be modified every time the program is run. The default values are always available for use as well.

3.6.4 Candidate Rehabilitation Techniques

Each of the evaluation conclusions is accompanied by one or more candidate rehabilitation techniques which could be performed to correct that deficiency. These are provided for illustrative purposes primarily; they tell the engineer what types of repairs are considered appropriate for correcting the stated deficiency, independent of any other deficiencies present.

These techniques are not used at this point to develop rehabilitation strategies. As described in chapter 2, if rehabilitation techniques were selected for each deficiency independently, the rehabilitation strategy developed would probably contain redundant or incompatible techniques, and would therefore be infeasible. The actual technique selection process is structured to utilize the candidate rehabilitation techniques, but with restrictions applied to prevent redundant or incompatible techniques from being included in a single strategy.

3.7 PREDICTION OF FUTURE CONDITION WITHOUT REHABILITATION

Performance prediction models are used to project the future condition of the pavement for 20 years into the future, to illustrate the consequences of not performing rehabilitation in the present year. The performance of the pavement is predicted in terms of serviceability and key distress types for the concrete pavement type: faulting, cracking, joint deterioration, pumping, and PSR for JRCP and JPCP; and punchouts and steel ruptures for CRCP.

In order to solve the predictive equations each year for 20 years, it is necessary to calculate the number of 18-kip equivalent single-axle loads (ESALs) accumulated in each lane for each year. This is done using the following equation:

$$ESAL = ADT * DD * (PTRUCKS / 100) * TF * 365$$

where:

ESAL = current annual ESAL for the project (both lanes, both directions)

ADT = current two-way average daily traffic, from the project inventory data

DD = directional distribution (distribution of ADT between opposing direction lanes (assumed to be 0.5)

PTRUCKS = percent trucks, from the project inventory data

TF = truck factor (ESAL/truck)
= 1.15 for rigid pavement

The annual ESAL in each lane is computed from the following equations (6):

$$\text{outer ESAL} = \text{annual ESAL} * [\, 1.567 - 0.0826 \ln (ADT * DD) \,]$$

$$\text{inner ESAL} = \text{annual ESAL} - \text{outer ESAL}$$

For each subsequent year, the annual ESAL is increased using the truck traffic growth rate from the inventory data. The cumulative ESAL in each lane is then computed for each year, starting with the cumulative ESAL from construction to the the year of the survey, and adding the annual ESAL computed each year.

Since these key distress and serviceability values are inputs into the evaluation decision trees, the engineer can use them to "reevaluate" the pavement in future years, and identify the years in which they will reach critical levels indicative of deficiencies. The system performs this function automatically and displays one or more sentences of text describing the deficiencies predicted to occur in the future, the years in which they are triggered, and the critical levels (either the defaults or the engineer's values) of distress or serviceability which triggered them.

The performance prediction models for JRCP and JPCP are those developed under NCHRP Project 1-19, using data from more than 400 pavement sections in seven states.(6) CRCP distresses are predicted from models developed under an Illinois DOT study using data from CRCP sections in Illinois.(12) All of the models are "calibrated" to the actual current distress levels, so that future distress levels are predicted accurately for future years. The models are given in appendixes A3, B3, and C3.

The predicted future condition without rehabilitation serves two purposes. For a pavement which doesn't need rehabilitation now, the future condition predictions indicate when rehabilitation will be needed, and what type of rehabilitation will be required. For a pavement which should be rehabilitated now, the future condition predictions illustrate the consequences of delaying rehabilitation. Every year that rehabilitation is delayed, the pavement condition worsens and distress quantities increase. The resulting increase in the cost of the work must be weighed against the discounting effect of deferring the expenditure one or more years. EXPEAR version 1.3 possess the capabilities to delay rehabilitation up to 5 years and to account for the consequences of delay in its cost analysis.

3.8 PHYSICAL TESTING RECOMMENDATIONS

After performing the evaluation and before beginning to develop rehabilitation strategies, the engineer may choose to perform physical testing of the pavement. Physical testing serves the following two purposes: (1) verifying the results of the evaluation based on visual condition data, and (2) obtaining quantitative data needed to design the rehabilitation.

EXPEAR was developed to function without being dependent on physical testing data, so that lack of availability of such data would not hinder an engineer's use of the system. However, EXPEAR does have the capability to recommend specific types of physical testing which would be appropriate for the pavement, based on the results of the present condition evaluation. The types of testing which may be recommended include nondestructive deflection testing, destructive testing (coring and boring), laboratory testing, and roughness and skid measurement.

3.8.1 Nondestructive Deflection Testing

Nondestructive deflection testing (NDT) is recommended to investigate structural deficiencies, poor joint load transfer, and loss of slab support. A Falling Weight Deflectometer (FWD) or other NDT device capable of applying dynamic loads comparable in magnitude to moving truck wheel loads over a range of load levels, i.e., 9000 to 16000 pounds. Specific testing locations (at slab centers, across joints, at corners, etc.) are recommended based on the types of deficiencies present. Deflection data also serves as an input to structural analysis and overlay design for a pavement in need of a structural improvement.

3.8.2 Destructive Testing and Laboratory Testing

Destructive testing is recommended when needed to obtain material samples from the concrete slab, base, or subgrade to investigate a variety of deficiencies. For reasons of safety and efficiency, nondestructive testing and destructive testing should be conducted concurrently.

Critical levels of structural distress (cracking, corner breaks, punchouts, etc.) trigger recommendations for coring to determining the thickness of each of the pavement layers and the strength of the concrete (and stabilized base, if any). Coring at joints is recommended to investigate the extent of significant joint deterioration resulting from reactive aggregate, D cracking, infiltration of incompressibles, or other causes. When reactive aggregate appears to be the cause of the joint deterioration, petrographic examination of the cores is also recommended. Evidence of poor transverse or longitudinal joint construction may also trigger a recommendation for coring through representative joints and cracks, to determine which joints and cracks are actually working.

Boring samples of the base and subgrade should be obtained to investigate drainage deficiencies and foundation movement (settlements and heaves). As a minimum, the permeability of the base as well as the Atterberg limits and classification of the subgrade material should be determined in the laboratory. Additional investigation of swelling subgrade soils is also recommended.

3.8.3 Skid Testing

Wheelpath rutting caused by studded tires should be quantified by rut depth measurements. Skid testing is recommended to investigate other deficiencies such as polishing. Testing should be performed with a standard ASTM tire (E 501 or E 524) mounted on a locked-wheel trailer.

Skid testing need not be performed if it has already been determined from the results of the nondestructive and destructive testing that the pavement is in need of a structural improvement, since overlaying and reconstruction supersede the need for a surface friction improvement.

3.8.4 Roughness Testing

Roughness measurement is recommended when the pavement exhibits excessive faulting, joint deterioration, foundation movement, or low PSR. Response-type roughness testing, which produces an overall estimate of roughness in inches per mile, is adequate for faulting and low PSR. Profile measurement should be performed to locate and measure settlements and heaves.

As with skid resistance deficiencies, it is not necessary to quantify overall roughness if it has already been determined that the pavement has to be reconstructed or overlaid. The pavement's profile should still be measured if settlements and/or heaves are present, however, since these must be corrected by appropriate preoverlay repair.

3.8.5 Use of Physical Testing Data

EXPEAR does not require that physical testing be performed, nor does it interpret physical testing data or use it in its evaluation of the pavement and selection of rehabilitation techniques. It is the engineer's responsibility to decide which types of testing may be performed with the equipment, resources, and time available. The engineer should use the testing results to assess the correctness of EXPEAR's evaluation and to select and design the appropriate rehabilitation. The capability to interpret and utilize physical testing data in the pavement evaluation and rehabilitation strategy development will be included in future improvements to EXPEAR.

3.9 SELECTION OF MAIN REHABILITATION APPROACH

On the basis of the evaluation and the physical testing results, the main rehabilitation approach (reconstruction, resurfacing, or restoration) must be selected for each traffic lane. A decision tree has been developed for each pavement type to guide the engineer in this decision. The decision tree is structured according to the following guidelines:

- A structural deficiency indicated by substantial load-related distress is correctable by either a structural overlay or reconstruction.

- A structural deficiency indicated by factors of design, traffic, etc., is correctable by a structural overlay.

- A durability deficiency indicated by high-severity D cracking or reactive aggregate distress is correctable by either a structural overlay (unbonded PCC only) or reconstruction.

- In the absence of significant structural or durability deficiencies as defined above, all other pavement deficiencies are correctable by restoration techniques.

As described in chapter 2, there are five feasible combinations of the three main rehabilitation approaches for two lanes. If the three approaches are numbered as follows:

1. Reconstruction.

2. Overlay.

3. Restoration.

then the five feasible pairs can be identified as:

1-1 Reconstruct both lanes.

1-3 Reconstruct outer lane and restore inner lane.

3-1 Restore outer lane and reconstruct inner lane.

2-2 Overlay both lanes.

3-3 Restore both lanes.

Figure 2 illustrates the decision tree for selecting the appropriate pair. This is the general form of the decision tree which is the same for all pavement types. For each pavement type, a copy of this decision tree exists on which the branches are labeled with specific deficiency codes. For example, for JRCP the structural deficiencies which are indicated by substantial load-related distress are identified by the codes STR 1 and STR 2, and the appropriate branches for this case are labeled as such on the JRCP main rehabilitation approach decision tree. The decision trees for JRCP, JPCP, and CRCP are provided in appendixes A4, B4, and C4.

To allow the engineer some flexibility in selecting rehabilitation approaches, the combinations involving reconstructing one lane and restoring the other (1-3 and 3-1) include the option to "upgrade" to reconstructing both lanes (1-1), which may be considered more convenient. Similarly, when EXPEAR recommends restoration of both lanes (3-3) in the absence of serious structural or durability deficiencies, the engineer is given the option to override this recommendation and select any of the following three combinations instead: reconstruct both lanes (1-1), reconstruct the outer lane only (1-3), or overlay both lanes (2-2). The fifth option, to reconstruct only the inner lane (3-1), is not likely to be warranted except in some highly unusual cases (e.g., urban areas where truck traffic is restricted to the inner lane), so this combination is not given as an option to overriding the recommendation to restore both lanes.

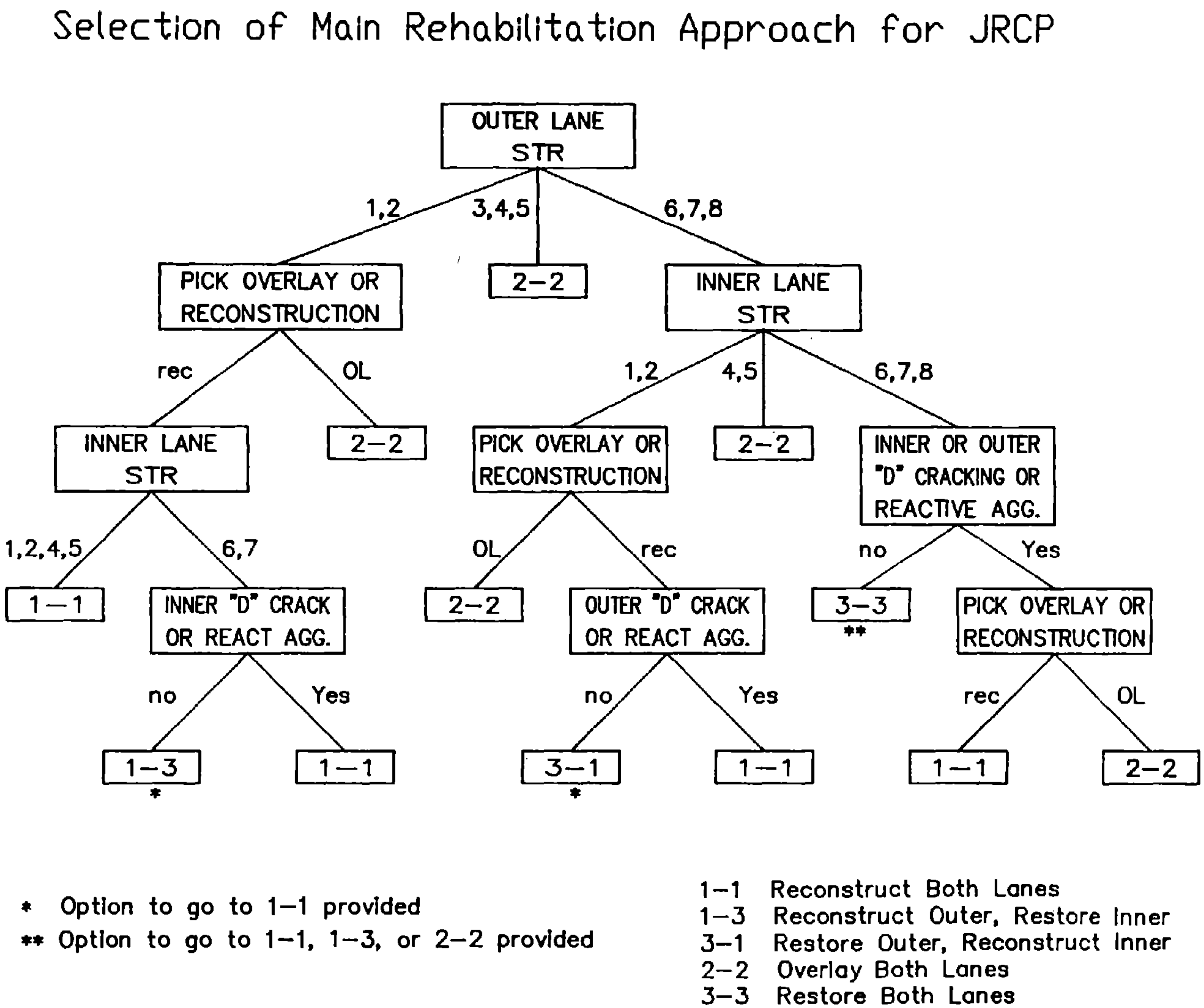


Figure 2. Main rehabilitation approach decision tree.

3.10 DEVELOPMENT OF COMPLETE REHABILITATION STRATEGY

Once the main rehabilitation approach has been selected, the engineer proceeds to develop the complete rehabilitation strategy for the project. This is done by interacting with the system to select specific rehabilitation techniques to correct deficiencies in each lane and on each shoulder. Which deficiencies need to be corrected in a lane is dependent on the rehabilitation approach selected for that lane, or in the case of the shoulders, the rehabilitation approach for the adjacent lane.

The selection of rehabilitation techniques is performed in EXPEAR using a set of decision trees. There are three detailed decision trees for the traffic lanes:

1. Decision tree for reconstructing a lane.
2. Decision tree for overlaying a lane.
3. Decision tree for restoring a lane (inner or outer).

and four detailed decision trees for the shoulders:

1. Decision tree for shoulder adjacent to reconstructed lane.
2. Decision tree for AC shoulder adjacent to overlaid lane.
3. Decision tree for PCC shoulder adjacent to overlaid lane.
4. Decision tree for shoulder adjacent to restored lane.

The rehabilitation decision trees are provided in appendixes A4, B4, and C4. The decision trees for the traffic lanes consist of nodes for each major problem area which must be considered, followed by the specific deficiencies in that problem area which, if present, must be corrected by one of the technique choices given. Deficiencies are identified by their code numbers to the left of the choices. Not all deficiencies within a problem area need to be addressed in all cases; some deficiencies are overridden by the main rehabilitation approach. If within a problem area being considered, the lane possesses none of the deficiencies listed, the engineer proceeds down the tree to the next problem area. Shoulder decision trees address the single problem area of shoulder condition, treating AC and PCC shoulders separately.

3.10.1 Traffic Lane Reconstruction

Reconstruction of a traffic lane eliminates all existing deficiencies in that lane, except drainage deficiencies, since drainage is not assumed to be inherently included in reconstruction. The drainage improvement options differ by lane, depending on the geometry of the pavement cross section. If needed, a drainage improvement is selected for the outer lane first. The type of improvement selected for the outer lane and the direction that the inner lane slopes (toward the outer lane or toward the inner shoulder) dictate the available drainage improvement choices for the inner lane.

3.10.2 Shoulder Rehabilitation Adjacent to a Reconstructed Lane

Unless shoulder reconstruction is necessitated by extensive "D" cracking or reactive aggregate distress (for PCC shoulders only), shoulder deficiencies can be corrected individually. However, since reconstructing the adjacent traffic lane is likely to cause damage to the shoulder by construction equipment, the engineer is given the option of reconstructing the shoulder with either AC or PCC instead of repairing it.

3.10.3 Traffic Lane Overlay

This decision tree must be used for both lanes. The engineer must first select the type of structural overlay to be placed, given the following choices:

- Unbonded PCC overlay.
- Bonded PCC overlay.
- AC structural overlay.
- Crack and seat and AC structural overlay (for JRCP and JPCP).

The type of overlay is restricted to being the same in both lanes, so the overlay type selected for the outer lane will automatically be selected for the inner lane. In the case of high-severity "D" cracking or reactive aggregate distress, the overlay type is restricted to unbonded PCC. Otherwise, the type of overlay is the choice of the engineer.

The engineer proceeds to select rehabilitation techniques to correct other deficiencies in each lane. The type of overlay dictates the types of deficiencies which must be addressed: some deficiencies are considered to be corrected by specific overlay types. All overlay types are considered to correct skid resistance deficiencies, so this problem area is not considered in the overlay decision tree.

In general, the overlay decision tree is conservative in prescribing preoverlay repair: all deficiencies which might significantly influence the performance of the overlay are required to be corrected by the overlay or by appropriate preoverlay repair. AC structural overlays and bonded PCC overlays require the most preoverlay repair, followed by crack and seat AC overlays, while unbonded PCC overlays require the least preoverlay repair. Furthermore, it is assumed that the quantity of each type of preoverlay repair done matches the quantity of distress present. This is important to the prediction of rehabilitation performance which is conducted subsequent to rehabilitation strategy development.

The engineer must go through the overlay decision tree twice, one time for each traffic lane, since the lanes will not necessarily have the same deficiencies and thus will not have the same preoverlay repair needs. The only technique which must be imposed on both lanes is pressure relief joint installation for jointed concrete pavements. Pressure relief joints, if needed, should be cut across the full width of both traffic lanes to prevent unequal pressures in and differential longitudinal movements of the concrete slabs. As with reconstruction, drainage improvement selection depends on the direction of slope of the inner lane.

Note that **structural** overlay options only are addressed by the overlay decision tree; AC nonstructural overlay as a technique for roughness and skid resistance improvement is included in the restoration decision tree.

3.10.4 Shoulder Rehabilitation Adjacent to an Overlaid Lane

The shoulders must always be overlaid if the traffic lanes are being overlaid, but the type of overlay placed on the shoulder need not be the same as on the traffic lanes, nor do the two shoulders need to have the same type of overlay. The engineer is given the choice of repairing or reconstructing the shoulder prior to overlaying it with asphalt or concrete, except in the case of extensive durability distress on a PCC shoulder, for which reconstruction of the shoulder is required.

3.10.5 Traffic Lane Restoration

This decision tree addresses all of the same major problem areas as the overlay decision tree, with the addition of skid resistance. As with overlays, it is assumed that all existing distress is repaired by the techniques selected, i.e., that the repair quantities match the distress quantities.

When both lanes are being restored, this decision tree is used twice. When restoring one lane and reconstructing the other, this decision tree is used for the lane being restored, and the reconstruction decision tree (specifically, selection of drainage improvements for the reconstructed lane) is used for the other lane. The appropriate decision trees for the adjacent shoulders are used.

AC nonstructural overlay is included as a technique in this decision tree for correction of certain roughness and skid resistance deficiencies. When a nonstructural overlay is selected for one lane, it must be placed in the other lane as well. Also, a nonstructural overlay is considered to supersede grinding and grooving. Pressure relief joints for jointed concrete pavements must also be imposed in both lanes if needed in either lane. When using the decision trees to develop a rehabilitation strategy by hand, these restrictions must be kept in mind; when using the computer system, these restrictions are imposed automatically.

3.10.6 Shoulder Rehabilitation Adjacent to a Restored Lane

As with the other shoulder rehabilitation decision trees, reconstruction is required for a PCC shoulder with severe durability distress. For AC shoulders, reconstruction with AC or PCC is provided as an option to the engineer in the cases of extensive linear cracking and extensive alligator cracking. For all other shoulder deficiencies, appropriate repair techniques are selected. When both traffic lanes are being restored, this decision tree is used twice, since the two shoulders may have different deficiencies and thus need different repairs.

3.11 PREDICTION OF REHABILITATION STRATEGY PERFORMANCE

For each type of pavement, regression equations are used to predict the performance of the rehabilitation strategy developed. As is done in the evaluation of the pavement, performance is predicted in terms of key distress types. For reconstruction, the key distress types and the models used are the same as in the evaluation (from NCHRP Project 1-19, reference 6), although some of the inputs are different.

For AC overlays, the key distress types are rutting and reflective cracking. The predictive models for crack and seat AC overlays of jointed concrete pavements were developed under this study and are described in detail in volume II of this report. Conventional AC overlay reflective cracking models were developed from a database of Illinois Interstate highway pavements. Reflective cracking is predicted in two ways: in **total** feet of reflective cracking per mile, and in feet of **medium- and high-severity** reflective cracking per mile. Total reflective cracking is of interest in predicting the time required for cracks to propagate through the overlay. Medium- and high-severity reflective cracking, on the other hand, more directly determines the life of the overlay, since at some point it will require repair. Medium- and high-severity cracks may develop gradually as low-severity cracks deteriorate under traffic, or they may develop quickly at locations of deterioration or poor load transfer in the underlying pavement. If all existing deficiencies of the pavement are adequately repaired prior to overlay, medium- and high-severity cracks should not appear for at least a few years after the overlay is placed, and should not reach a critical level for several years more.

Note that the only reflection crack control treatment considered is crack and seat, since models are not available to predict the influence of other crack control treatments on conventional overlay performance. Other treatments, such as sawing and sealing joints in the AC overlay, could be incorporated into the system in the future when reliable predictive models for them become available.

Key distresses for bonded and unbonded concrete overlays are faulting, cracking and joint deterioration. Most of the models for predicting these distresses were developed under this study and are described in detail in volume II of this report. Key distresses for restoration are the same as those used in evaluation. Most of the models for JRCP and JPCP restoration were developed under this study and are described in detail in volume I. The CRCP model for failures is the same as that used in the evaluation.

EXPEAR does not perform overlay thickness design or reconstruction design. Before the performance of a rehabilitation strategy can be predicted, the engineer must provide rehabilitation design details needed by EXPEAR for use in the predictive models, such as overlay or reconstructed slab thickness, reinforcement size, dowel diameter, joint spacing, etc.

The predictive models for JRCP, JPCP, and CRCP are given in appendixes A5, B5, and C5. The models are used to predict the performance of the rehabilitation, in terms of the key distress types, each year for the next 20 years. The critical levels of the key distress types (either default values or values input by the engineer) are used to identify the years in which the distresses reach unacceptable levels. When using the system manually, the engineer should solve for the age or accumulated traffic at which the distress levels become critical, and from this determine the life of the rehabilitation. Note that the future distress predictions are strongly influenced by the 18-kip ESAL growth rate input by the engineer in the project inventory data.

It must be noted here that most of these predictive models have significant limitations and should not be used outside the ranges of data from which they were developed. The models should be evaluated for validity with respect to the pavement designs and climatic conditions of the State in which the project is located. The capability to adjust the models to more accurately reflect local conditions, or utilize alternate models provided by the engineer, will be included in future improvements to EXPEAR.

3.12 QUANTITY ESTIMATES FOR LIFE-CYCLE COST ANALYSIS

Using the extrapolated distress quantities computed during the evaluation, the selected rehabilitation techniques, and a few additional items of information provided by the engineer, EXPEAR determines approximate rehabilitation quantities.

These are expressed in convenient units (linear feet, square yards, etc.) over the total length of the project. This information can be used to evaluate the strategy on the basis of life-cycle cost.

EXPEAR version 1.3 possesses the capability to do life-cycle cost analysis. The performance period is determined from the predicted future development of key distresses. The first critical level reached determines the life of the rehabilitation. For example, if an AC overlay is predicted to have excessive reflective cracking after 16 years and excessive rutting after 12 years, the lesser of these two, or 12 years, will be taken as the life of the overlay. In the case when no critical levels are predicted to be reached within 20 years, the life of the rehabilitation is taken as 20 years. The engineer is given the option to override the predicted life and enter some other value, up to a maximum of 20 years. The output of the cost analysis reports whether the life used was the program's prediction or a user input.

The analysis period used in the cost analysis is restricted to be the same as the first rehabilitation performance period. Thus it is not possible to include subsequent rehabilitation in the strategy in order to fill out a desired analysis period. This is largely due to the lack of available predictive models for such things as second overlays. It is also not possible to attach a salvage value to a strategy with a predicted lives in excess of 20 years. When interpreting the results of the cost analyses for several strategies, the engineer must keep in mind that the performance periods will in most cases be unequal. These limitations will be addressed in future improvements to EXPEAR.

The engineer must select a value for the discount rate to be used in the analysis, as well as unit costs for the various rehabilitation techniques included in the strategy. A range for discount rate between 0 and 7 percent, with a default value of 3 percent. Default unit costs for all of the rehabilitation techniques are also incorporated in EXPEAR. Since each pavement type has about 40 different items on its list of rehabilitation techniques, the engineer generally will not want to review the entire set of unit costs every time a cost analysis is done. Therefore, EXPEAR gives the engineer the option to modify the entire set of costs or to modify only the costs for the set of techniques actually included in the strategy currently being analyzed. As with the critical distress levels used in evaluation, the engineer may save the modified unit costs to a file and retrieve them when needed.

Rehabilitation techniques, quantities, unit costs, and total costs over the length of the project are reported for each traffic lane and shoulder. The total cost for all lanes and shoulders is expressed in three ways: present worth, actual cost in the year performed, and equivalent annual cost over the life of the strategy. In the case when rehabilitation is not delayed, the present worth and actual cost are the same.

The cost analysis included in EXPEAR is a simple and approximate procedure, the primary purpose of which is to facilitate rapid generation and comparison of rehabilitation alternatives. It should help the engineer identify alternatives which are comparable in cost-effectiveness and deserve further investigation, and also eliminate alternatives which are clearly not cost-effective. It does not, however, take the place of the detailed evaluation and cost analysis which is required for preparation of plans, specifications, and bid estimates. It also does not consider cost items not directly related to improvement of the pavement, such as raising guardrails, maintaining bridge clearances, and correcting side slopes.

CHAPTER 4
JRCP EVALUATION AND REHABILITATION

This chapter provides additional details on the evaluation and rehabilitation system which relate specifically to JRCP. The system may be applied to a JRCP project by following the steps described for all pavement types in chapter 3, referring to this chapter for specific details on JRCP, and using the materials provided in appendix A. These materials consist of the following:

- A-1 JRCP Project Survey and Supplemental Information.
- A-2 JRCP Evaluation Decision Trees and Conclusions.
- A-3 JRCP Evaluation Performance Prediction Models.
- A-4 JRCP Rehabilitation Decision Trees.
- A-5 JRCP Rehabilitation Performance Prediction Models.
- A-6 JRCP Computer Program Operating Instructions.

The use of the system for JRCP is illustrated with a comprehensive example of evaluation and rehabilitation of a JRCP project. The project selected for the example is a 0.9-mile [1.45 km] section of Interstate 74 near Urbana, Illinois.

4.1 JRCP PROJECT SURVEY

A complete set of survey sheets for JRCP consists of three pages of inventory data for the project, one page of project monitoring data, and four pages of monitoring data for each sample unit surveyed. A complete set of survey sheets for the I-74 example are shown in figure 3. Due to the short length of the project, it was surveyed as one sample unit.

4.2 EXTRAPOLATION OF OVERALL PROJECT CONDITION

4.2.1 Average Per Mile Data Items

The following JRCP monitoring data items must be extrapolated from the sample unit data and expressed as an average quantity per mile:

Data Item	Extrapolated Quantity
Longitudinal cracking	Feet/mile
Longitudinal spalling	Feet/mile
Transverse crack deterioration	Feet/mile
Corner breaks	Number/mile
Joints with construction cracks	Number/mile
Settlements	Number/mile
Heaves	Number/mile
Full-depth repairs	Number/mile
Full-depth repair joints	Number/mile
Transverse joints	Number/mile

PROJECT SURVEY FOR JRCP

Design Engineer: KT HALL

Date of Survey (mo/day/yr): 8 / 10 / 86

PROJECT INVENTORY DATA

Collect the following information about the project to be evaluated prior to the actual field survey.

Project Identification

Highway Designation (example I-57): I-74

State: ILLINOIS

Direction of Survey: east

Starting Milepost: 183.00

Ending Milepost: 183.90

Climate

Climatic Zone (See climatic zone map in "Supplemental Information"):

✔ wet freeze	____ wet-dry freeze	____ dry freeze
____ wet freeze-thaw	____ wet-dry freeze-thaw	____ dry freeze-thaw
____ wet nonfreeze	____ wet-dry nonfreeze	____ dry nonfreeze

Estimated Annual Temperature Range (degrees Fahrenheit): 68.5

Mean Annual Precipitation (inches) (See precipitation map in "Supplemental Information"): 37

Corps of Engineers Freezing Index (Fahrenheit degree-days) (See Freezing Index map in "Supplemental Information"): 250

Slab Construction

Year Constructed: 1957

Slab Thickness (inches): 10

Width of Traffic Lanes (feet): 12

PCC Modulus of Rupture (28 days, 3rd-point loading)(psi): 650

Area of Longitudinal Reinforcement (square inches steel/foot) (See wire size table in "Supplemental Information"): 0.17

Figure 3. Project survey sheets for I-74 example.

Transverse and Longitudinal Joints

Pattern of Joint Spacing:
✓ uniform
_____ random

Transverse joint spacing, if uniform (feet): 100
Transverse joint sequence, if random (feet): _____

Type of Sealant:
✓ liquid (asphalt)
_____ field-molded (silicone)
_____ preformed compression (neoprene)

Average Transverse Joint Sealant Reservoir Dimensions
Width (inches): 0.125 Depth (inches): 2.50

Method Used to Form Transverse Joints:
✓ sawing
_____ inserts
_____ Unitube inserts

Transverse Joint Sawed Depth (inches): 2.50

Type of Load Transfer System:
_____ aggregate interlock only
✓ dowels
_____ other mechanical devices

If dowels are present, dowel bar diameter (inches): 1.25

Method Used to Form Longitudinal Joints Between Lanes:
✓ sawing
_____ inserts

Longitudinal Joint Sawed or Formed Depth (inches): 2.75

Base

Type of Base Course:
_____ fine-grained soil only
_____ cement-treated aggregate
_____ lean PCC
✓ dense-graded untreated aggregate
_____ asphalt-treated aggregate
_____ open-graded drainage layer

Modulus of Subgrade Reaction on Top of Base (psi/inch) (See k-value correlation chart in "Supplemental Information"): 130

Figure 3. Project survey sheets for I-74 example (continued).

Subgrade

Predominant Subgrade Soil AASHTO Classification (See Unified-AASHTO conversion table in "Supplemental Information"): A6

Are swelling soils a problem in the area? ____ yes ✓ no

If so, were steps taken in construction of the pavement to correct the swelling soil problem? ____ yes ____ no

Shoulder

Type of Shoulder:
✓ AC
____ tied PCC

Width of Shoulders (feet): 6 inner 10 outer

Inner Lane Slope Direction:
____ toward outer lane
✓ toward inner shoulder

Traffic

Estimated Current Through Two-way ADT: 26,100

Percent Commercial Trucks (excluding pickups and panels): 17

Total Number of Lanes in Direction of Survey: 2

Future 18-kip ESAL Growth Rate (percent per year): 4.0

Total Accumulated 18-kip Equivalent Single Axle Loads (ESALs) from Date of Construction to Date of Survey (millions) (See procedure for computing ESALs in AASHTO Guide for Design of Pavement Structures, Appendix D, 1986):

LANE TWO (inner)	LANE ONE (outer)
3.9	13

Figure 3. Project survey sheets for I-74 example (continued).

PROJECT MONITORING DATA

Ride Quality

Rate the ride quality of the pavement in each lane during a drive over the entire project at the posted speed limit. Two or more people should participate in the survey. Obtain ratings for each lane from each person and report the average value below.

```
0         1         2         3         4         5
+---------+---------+---------+---------+---------+
Very Poor   Poor      Fair      Good    Very Good
```

LANE TWO (inner)	LANE ONE (outer)
3.1	2.6

Figure 3. Project survey sheets for I-74 example (continued).

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately 1000 feet in each mile is recommended for each sample unit surveyed. If only one sample unit is to be surveyed on the project, a length of at least a half mile is recommended. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: 1 Starting Milepost: 183.0 Length of Sample Unit (feet): (0.9 mile) (4750 ft)

Use the tally sheet provided to record information on cracking, spalling, and full-depth repairs for each slab surveyed. Compute the totals and averages indicated on the tally sheet and record these values below.

	LANE TWO (inner)	LANE ONE (outer)
Number of deteriorated transverse cracks, M-H only:	53	57
Mean faulting at deteriorated transverse cracks (inches):	0.15	0.25
Number of deteriorated transverse joints, M-H including blowups:	19	19
Mean faulting at transverse joints (inches):	0.13	0.27
Number of transverse joints:	47	47
Mean faulting at full-depth repair joints (inches):	0.00	0.20
Number of full-depth repair joints:	0	4
Number of full-depth repairs:	0	2
Number of corner breaks:	0	0

Longitudinal Joint

	LANE TWO (inner)	LANE ONE (outer)
Total length of longitudinal cracking, M-H only (feet):	0	0
Total length of longitudinal joint spalling, M-H only (feet):		0

Figure 3. Project survey sheets for I-74 example (continued).

	LANE TWO (inner)	LANE ONE (outer)
Cracking at Transverse Joints		
Number of transverse joints with transverse cracks within 2 feet:	0	0
Foundation Movement		
Number of settlements (M-H only):	1	1
Number of heaves (M-H only):	0	0

Drainage

Are longitudinal subdrains present and functional along the sample unit? ____ yes ✓ no

What is the typical height of the pavement surface above the side ditchline (feet)? 5

Do the ditches have standing water or cattails in them? ____ yes ✓ no

	LANE TWO (inner)	LANE ONE (outer)
Loss of Support		
Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):	✓ N __ L __ M __ H	__ N ✓ L __ M __ H

Surface Condition

Method used to texture the pavement surface at construction:
____ transverse tining
✓ other

	LANE TWO (inner)	LANE ONE (outer)
Is the surface polished smooth in the wheelpaths?	✓ yes __ no	✓ yes __ no
Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?	__ yes ✓ no	__ yes ✓ no
Joint Sealant Condition		
What is the general condition of the transverse joint sealant?	__ L ✓ M __ H	__ L ✓ M __ H
What is the general condition of the longitudinal joint sealant?		__ L ✓ M __ H
Are substantial amounts of incompressibles visible in the transverse joints?	✓ yes __ no	✓ yes __ no

Figure 3. Project survey sheets for I-74 example (continued).

	LANE TWO (inner)	LANE ONE (outer)
Concrete Durability		
Extent of "D" cracking at joints and cracks (indicate highest severity level present in sample unit):	✓ N	✓ N
	___ L	___ L
	___ M	___ M
	___ H	___ H
Extent of reactive aggregate distress (indicate highest severity level present in sample unit):	✓ N	✓ N
	___ L	___ L
	___ M	___ M
	___ H	___ H
Extent of scaling (indicate highest severity level present in sample unit):	✓ N	✓ N
	___ L	___ L
	___ M	___ M
	___ H	___ H
Previous Repair		
If full-depth repairs are present, are they dowelled?	___ yes	___ yes
	___ no	✓ no
Are partial-depth repairs (rigid material only) present at most of the joints?	___ yes	___ yes
	✓ no	✓ no
Has diamond grinding been done?	___ yes	___ yes
	✓ no	✓ no
Has grooving been done?	___ yes	___ yes
	✓ no	✓ no

Figure 3. Project survey sheets for I-74 example (continued).

	INNER SHOULDER	OUTER SHOULDER
AC Shoulders (Check all that apply.)		
Alligator cracking	✓ none	___ none
	___ some	___ some
	___ extensive	✓ extensive
Linear cracking	___ none	___ none
	___ some	___ some
	✓ extensive	✓ extensive
Weathering/ravelling	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint dropoff	✓ none	✓ none
	___ <1"	___ <1"
	___ ≥1"	___ ≥1"
Settlements or heaves along outer edge	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Blowholes at transverse joints	___ none	___ none
	✓ some	✓ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	✓ poor	✓ poor
PCC Shoulders (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
"D" cracking or reactive aggregate distress	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Settlements or heaves along outer edge	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	___ poor	___ poor

Figure 3. Project survey sheets for I-74 example (continued).

This is performed using the following equation:

$$\text{Average Per Mile} = \left(\sum_{i=1}^{n} \frac{\text{value}_i * 5280}{\text{length}_i} \right) * \frac{1}{n}$$

where:

n = number of sample units

value_i = quantity of data item to be averaged in sample unit i

length_i = length of sample unit i, feet

Using this equation, the following extrapolated quantities were computed for I-74 for the data items with nonzero values (rounded to the nearest whole number):

Data Item	Extrapolated Quantity inner lane	Extrapolated Quantity outer lane
Full-depth repairs	0/mile	2/mile
Det. transverse cracks	706 ft/mile [134 m/km]	760 ft/mile [144 m/km]
Settlements	1/mile	1/mile
Full-depth repair joints	0/mile	4/mile
Transverse joints	53/mile	53/mile

4.2.2 Deteriorated Joints Per Mile

Joint deterioration is also expressed as an extrapolated quantity per mile, but since it is a function of the transverse joint spacing, its computation is somewhat more difficult. The procedure used in the system is to compute the average proportion of joints that are deteriorated, and multiply this times the number of joints per mile. This is performed according to the following equation:

$$\text{Jt Det Per Mile} = \left[\left(\sum_{i=1}^{n} \frac{\text{detjt}_i}{(\text{length}_i/\text{jtspace})} \right) * \frac{1}{n} \right] * \frac{5280}{\text{jtspace}}$$

where:

Jt Det Per Mile = average number of deteriorated joints per mile

det jt_i = number of deteriorated joints in sample unit i

length_i = length of sample unit i, feet

n = number of sample units

jtspace = transverse joint spacing, feet

Using this equation, I-74 was computed to have an average of 21 deteriorated joints per mile in both the inner and outer lanes.

4.2.3 Faulting

Average faulting at joints, cracks, and full-depth repair joints is computed by the engineer and recorded on the survey sheets. The extrapolated number of joints, cracks, and full-depth repair joints are computed as described before. From this information, the average faulting of any combinations of these items can be computed as a weighted average. Total faulting can also be computed as the sum of the products of average faulting values and quantities of joints, cracks, and full-depth repair joints. The faulting parameters used in the JRCP evaluation decision trees are as follows:

Decision Tree	Faulting Parameter
Roughness	Total faulting, inches/mile
Load Transfer	Average joint faulting, inches
Load Transfer	Average crack faulting, inches
Load Transfer	Average FDR faulting, inches
Loss of Support	Weighted average joint and crack faulting, inches
Drainage	Weighted average joint and crack faulting, inches

For I-74, the following faulting values were computed or obtained from the survey:

	Inner Lane	Outer Lane
Total faulting	15.74 in/mile	30.86 in/mile
Average joint faulting	0.13 in	0.27 in
Average crack faulting	0.15 in	0.25 in
Average FDR faulting	n/a	0.20 in
Weighted average joint crack faulting	0.14 in	0.26 in

[1 in = 2.54 cm, 1 mile = 1.61 km]

4.2.4 Toggle Values

For JRCP, the following toggle data items must be extrapolated:

- Pumping.
- Polished wheelpaths.
- Studded tire rutting.
- Incompressibles in transverse joints.
- Dowelling of existing full-depth repairs.
- Previously performed grinding.
- Previously performed grooving.
- Transverse joint sealant damage.
- Longitudinal joint sealant damage.
- D cracking.
- Reactive aggregate distress.
- Scaling.
- Existing partial-depth repairs.
- Shoulder distresses.

Extrapolation of toggle data items is performed by converting the toggle values given in each sample unit to numerical values (e.g., none = 1, some = 2, and extensive = 3), averaging the numerical values, and rounding off the result to the nearest whole number.

For the I-74 example, only one sample unit was surveyed (a 100 percent survey of the project) so the extrapolated toggle values are the same as those that appear on the sample unit monitoring data sheets.

4.3 EVALUATION OF PRESENT CONDITION

Evaluation of a JRCP project is conducted using the evaluation decision trees developed for the following twelve problem areas:

1. Structural adequacy.
2. Drainage.
3. Foundation movement.
4. Durability.
5. Skid resistance.
6. Roughness.
7. Joint construction.
8. Transverse joint sealant.
9. Load transfer.
10. Loss of support.
11. Joint deterioration.
12. Shoulders.

As described in chapter 3, certain critical distress and serviceability levels are subject to modification by the engineer. The levels which may be modified for JRCP and their default values are shown below.

Distress/Serviceability	Default Critical Level
PSR	2.0 for ADT $\leq$ 3,000 2.5 for 3,000 < ADT $\leq$ 10,000 3.0 for ADT $\geq$ 10,000
Total Faulting	34 inches per mile
Average Faulting	0.26 inches
Settlements	5 per mile
Heaves	5 per mile
M-H deteriorated joints	27 per mile
Corner breaks	25 per mile
M-H transverse crack deterioration	71 cracks per mile
Longitudinal cracking	500 feet per mile

[1 in = 2.54 cm, 1 ft = 0.3048 m, 1 mile = 1.61 km]

The evaluation conclusions reached for the I-74 example using the default critical distress and PSR levels are shown in figure 4. The pavement has several deficiencies, including large numbers of deteriorated transverse cracks and deteriorated joints, poor drainage, poor joint sealant condition, and in the outer lane, poor rideability and polished wheelpaths. However, since the extrapolated quantity of cracking does not exceed the critical level, the pavement is a candidate for restoration as well as for structural improvement.

The types of physical testing recommended for the I-74 example include: nondestructive deflection testing for structural analysis, load transfer, and void detection; coring and materials evaluation for structural analysis and drainage analysis; profile measurement to identify sources of roughness, and skid testing.

4.4 PREDICTION OF FUTURE CONDITION

The predictive models given in appendix A3 for pumping, faulting, joint deterioration, cracking, and PSR were used to predict the future condition of I-74 without rehabilitation. The models were calibrated to the existing condition of the pavement at the time of the survey (1986). The results are shown in table 1.

The distress and PSR predictions are used to reevaluate the pavement each year for 20 years into the future, and identify the years in which the predicted distresses and PSR will reach critical levels. The critical levels used here are the same as those used in the evaluation of the pavement's present condition (for the I-74 example, the default values were used). The results are shown in figure 5.

4.5 REHABILITATION STRATEGY DEVELOPMENT

One or more rehabilitation strategies can be developed for a JRCP project using the decision trees provided in appendix A4. The procedure for developing a rehabilitation strategy is thoroughly described in chapter 3.

4.5.1 Restoration Alternative

At the time of the project survey, the I-74 example project had less than 71 deteriorated transverse cracks per mile, and it did not have any high-severity "D" cracking or reactive aggregate distress. Therefore, EXPEAR permits restoration as well as structural improvement options. Since several of the deficiencies which must be corrected have more than one rehabilitation technique option associated with them, typically more than one strategy alternative can be developed within the restoration approach. The techniques making up one such strategy are shown in table 2, along with approximate quantities for the techniques.

The predictive models provided in appendix A5 are used to predict the performance of the rehabilitation strategies developed. The results for the I-74 example are shown in table 3.

The results show that about 7 years after restoration, outer lane cracking, faulting, and PSR will reach unacceptable levels. The inner lane is not predicted to deteriorate to an unacceptable condition for almost 20 years.

The rapid deterioration of the outer lane is due primarily to continued development of deteriorated cracks and joints and increased faulting. Recall that the extrapolated distress quantities for I-74 included 21 deteriorated joints per mile, 63 and 57 deteriorated transverse cracks per mile in the outer and inner lanes respectively, and 2 undowelled full-depth repairs per mile in the outer lane.

CURRENT PAVEMENT EVALUATION

****
LANE 1
****

JOINT CONSTRUCTION:

The pavement in lane 1 shows no indications of a longitudinal joint construction deficiency.

a. do nothing

The pavement in lane 1 shows no indications of a transverse joint construction deficiency.

a. do nothing

JOINT SEALANT:

A transverse joint sealant deficiency is indicated in lane 1 by medium- to high-severity joint sealant damage and an inadequate joint sealant reservoir shape factor for the existing sealant type.

a. reseal transverse joints

ROUGHNESS:

Poor rideability in lane 1 is indicated by an unacceptably low PSR for the pavement's ADT level.

a. grinding
b. AC nonstructural overlay

DURABILITY:

The pavement in lane 1 shows no indications of significant surface or concrete durability problems.

a. do nothing

JOINT DETERIORATION:

Joint deterioration or other pavement deterioration in lane 1 may be accelerated by water infiltration permitted by poor longitudinal joint sealant condition.

a. reseal longitudinal centerline joint

Some joint deterioration exists (between 1 and 26 joints per mile) in lane 1, likely due to poor joint sealant condition permitting infiltration of water and incompressibles, and large joint movements associated with the long joint spacing.

a. reseal transverse joints, full-depth repair of joints

Figure 4. Evaluation of present condition for I-74 example.

STRUCTURAL DEFICIENCY:

The pavement in lane 1 exhibits some load-associated distress (between 1 and 70 deteriorated transverse cracks per mile) which requires repair but does not indicate a structural deficiency.

a. full-depth repair of cracks

SKID RESISTANCE:

Loss of skid resistance in lane 1 is indicated by polished wheel paths.

a. grinding
b. grooving
c. AC nonstructural overlay

LOAD TRANSFER:

Dowels or other mechanical devices present are providing inadequate load transfer in lane 1 at the transverse joints, as indicated by mean transverse joint faulting of more than 0.26 inches.

a. load transfer restoration at joints
b. do nothing

No load transfer deficiency is indicated at deteriorated transverse cracks in lane 1.

a. do nothing

A potential load transfer deficiency exists at undowelled full-depth repairs in lane 1, but mean full-depth repair faulting is not significant.

a. do nothing

FOUNDATION MOVEMENT:

Foundation movement in lane 1, likely due to either frost heave or localized consolidation, is indicated by settlements and/or heaves.

a. reconstruct heaves, AC level-up settlements
b. reconstruct heaves, slab jack settlements

LOSS OF SUPPORT:

Loss of slab support in the lane 1 is indicated by pumping and average faulting of between 0.05 inches and 0.26 inches.

a. subseal at joints

Figure 4. Evaluation of present condition for I-74 example (continued).

DRAINAGE:

A drainage deficiency in lane 1 is indicated by pumping occurring in a wet or wet-dry climate.

a. install or repair longitudinal subdrains
b. install or repair longitudinal subdrains, seal all joints and cracks

****
LANE 2
****

JOINT CONSTRUCTION:

The pavement in lane 2 shows no indications of a transverse joint construction deficiency.

a. do nothing

JOINT SEALANT:

A transverse joint sealant deficiency is indicated in lane 2 by medium- to high-severity joint sealant damage and an inadequate joint sealant reservoir shape factor for the existing sealant type.

a. reseal transverse joints

ROUGHNESS:

Rideability in lane 2 is acceptable.

a. do nothing

DURABILITY:

The pavement in lane 2 shows no indications of significant surface or concrete durability problems.

a. do nothing

JOINT DETERIORATION:

Some joint deterioration exists (between 1 and 26 joints per mile) in lane 2, likely due to poor joint sealant condition permitting infiltration of water and incompressibles, and large joint movements associated with the long joint spacing.

a. reseal transverse joints, full-depth repair of joints

STRUCTURAL DEFICIENCY:

The pavement in lane 2 exhibits some load-associated distress (between 1 and 70 deteriorated transverse cracks per mile) which requires repair but does not indicate a structural deficiency.

a. full-depth repair of cracks

Figure 4. Evaluation of present condition for I-74 example (continued).

SKID RESISTANCE:

Loss of skid resistance in lane 2 is indicated by polished wheel paths.

a. grinding
b. grooving
c. AC nonstructural overlay

LOAD TRANSFER:

No load transfer deficiency is indicated at transverse joints in lane 2.

a. do nothing

No load transfer deficiency is indicated at deteriorated transverse cracks in lane 2.

a. do nothing

No undowelled full-depth repairs are present in lane 2.

a. do nothing

FOUNDATION MOVEMENT:

Foundation movement in lane 2, likely due to either frost heave or localized consolidation, is indicated by settlements and/or heaves.

a. reconstruct heaves, AC level-up settlements
b. reconstruct heaves, slab jack settlements

LOSS OF SUPPORT:

The pavement in the lane 2 shows no indications of loss of slab support.

a. do nothing

DRAINAGE:

A drainage deficiency in lane 2 is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded aggregate base, an A6 subgrade, and heavy traffic of 0.73 million annual 18-kip ESALs.

a. install or repair longitudinal subdrains

Figure 4. Evaluation of present condition for I-74 example (continued).

****

INNER SHOULDER

****

Deterioration of the inner AC shoulder is indicated by extensive linear cracking.

a. in-place recycle
b. patch
c. reconstruct with AC
d. reconstruct with PCC

Excessive infiltration of water beneath the pavement and inner AC shoulder is indicated by poor lane/shoulder joint sealant condition.

a. reseal lane/shoulder joint
b. do nothing

****

OUTER SHOULDER

****

Structural deterioration of the outer AC shoulder is indicated by extensive alligator cracking.

a. in-place recycle
b. patch
c. reconstruct with AC
d. reconstruct with PCC

Deterioration of the outer AC shoulder is indicated by extensive linear cracking.

a. in-place recycle
b. patch
c. reconstruct with AC
d. reconstruct with PCC

Excessive infiltration of water beneath the pavement and outer AC shoulder is indicated by poor lane/shoulder joint sealant condition.

a. reseal lane/shoulder joint
b. do nothing

Figure 4. Evaluation of present condition for I-74 example (continued).

Table 1. Future condition predictions for I-74 example.

DISTRESS AND PSR PROJECTIONS FOR LANE 1

Cumulative ESAL	Annual ESAL	Year	Pumping	Faulting	Deter. Joints	Transverse Cracking	PSR
13.0	0.73	1986	1.0	0.27	21	63	2.6
13.8	0.76	1987	1.1	0.28	22	70	2.4
14.5	0.79	1988	1.2	0.29	23	78	2.4
15.4	0.82	1989	1.3	0.30	24	86	2.4
16.2	0.85	1990	1.4	0.31	25	96	2.3
17.1	0.89	1991	1.5	0.32	26	106	2.3
18.0	0.92	1992	1.6	0.33	27	117	2.2
19.0	0.96	1993	1.7	0.34	28	129	2.2
20.0	1.00	1994	1.8	0.35	29	143	2.1
21.0	1.04	1995	1.9	0.36	30	158	2.1
22.1	1.08	1996	2.0	0.38	32	175	2.0
23.2	1.12	1997	2.1	0.39	33	194	2.0
24.4	1.17	1998	2.2	0.40	34	215	1.9
25.6	1.22	1999	2.3	0.42	36	238	1.9
26.9	1.26	2000	2.4	0.43	37	264	1.8
28.2	1.32	2001	2.6	0.45	39	293	1.8
29.6	1.37	2002	2.7	0.47	40	326	1.8
31.0	1.42	2003	2.8	0.49	42	363	1.7
32.5	1.48	2004	2.9	0.51	44	405	1.7
34.0	1.54	2005	3.0	0.52	45	445	1.6
18-kip millions	18-kip millions		0 = none 1 = low 2 = medium 3 = high	Inches	Joints per mile	Cracks per mile	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Table 1. Future condition predictions for I-74 example (continued).

DISTRESS AND PSR PROJECTIONS FOR LANE 2

Cumulative ESAL	Annual ESAL	Year	Pumping	Faulting	Deter. Joints	Transverse Cracking	PSR
3.9	0.20	1986	0.0	0.13	21	59	3.1
4.1	0.21	1987	0.0	0.13	22	60	3.1
4.3	0.22	1988	0.1	0.14	23	61	3.1
4.6	0.23	1989	0.1	0.14	23	62	3.0
4.8	0.24	1990	0.1	0.14	24	63	3.0
5.0	0.24	1991	0.2	0.15	25	64	3.0
5.3	0.25	1992	0.2	0.15	26	65	3.0
5.6	0.26	1993	0.3	0.16	27	67	2.9
5.8	0.27	1994	0.3	0.16	28	68	2.9
6.1	0.29	1995	0.4	0.16	29	70	2.9
6.4	0.30	1996	0.4	0.17	30	71	2.9
6.7	0.31	1997	0.4	0.17	31	73	2.8
7.0	0.32	1998	0.5	0.18	32	75	2.8
7.4	0.33	1999	0.5	0.18	33	77	2.8
7.7	0.35	2000	0.6	0.19	34	79	2.8
8.1	0.36	2001	0.6	0.19	36	81	2.7
8.5	0.38	2002	0.7	0.20	37	83	2.7
8.9	0.39	2003	0.7	0.20	38	86	2.7
9.3	0.41	2004	0.8	0.21	40	89	2.7
9.7	0.42	2005	0.9	0.21	41	92	2.6
18-kip millions	18-kip millions		0 = none 1 = low 2 = medium 3 = high	Inches	Joints per mile	Cracks per mile	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

FUTURE PAVEMENT EVALUATION

****
LANE 1
****

ROUGHNESS:

Poor rideability in lane 1 occurs in 1986 as indicated by an unacceptably low predicted PSR for the pavement's ADT level.

a. grinding
b. AC nonstructural overlay

JOINT DETERIORATION:

Significant joint deterioration in lane 1 occurs in 1992 as indicated by 27 or more deteriorated joints per mile.

a. full-depth repair at joints

STRUCTURAL DEFICIENCY:

Structural deficiency of the pavement in lane 1 occurs in 1988 as indicated by 71 or more deteriorated transverse cracks per mile.

a. full-depth repair of cracks, AC structural overlay
b. full-depth repair of cracks, crack and seat and AC structural overlay
c. full-depth repair of cracks, PCC bonded overlay
d. full-depth repair of cracks, PCC unbonded overlay
e. reconstruct

LOAD TRANSFER:

Inadequate load transfer at transverse joints in lane 1 occurs in 1986 as indicated by predicted faulting of 0.26 inches or more.

a. load transfer restoration at joints
b. do nothing

LOSS OF SUPPORT:

Loss of slab support in lane 1 occurs in 1986 as indicated by predicted faulting greater than 0.26 inches at transverse joints.

a. subseal at joints

Figure 5. Evaluation of future condition of I-74 without rehabilitation.

****

LANE 2

****

ROUGHNESS:

Poor rideability in lane 2 occurs in 1989 as indicated by an unacceptably low predicted PSR for the pavement's ADT level.

a. grinding
b. AC nonstructural overlay

JOINT DETERIORATION:

Significant joint deterioration in lane 2 occurs in 1993 as indicated by 27 or more deteriorated joints per mile.

a. full-depth repair at joints

STRUCTURAL DEFICIENCY:

Structural deficiency of the pavement in lane 2 occurs in 1996 as indicated by 71 or more deteriorated transverse cracks per mile.

a. full-depth repair of cracks, AC structural overlay
b. full-depth repair of cracks, crack and seat and AC structural overlay
c. full-depth repair of cracks, PCC bonded overlay
d. full-depth repair of cracks, PCC unbonded overlay
e. reconstruct

LOAD TRANSFER:

No load transfer deficiency at transverse joints in lane 2 occurs based on predicted joint faulting over the next 20 years.

LOSS OF SUPPORT:

No loss of slab support in lane 2 occurs based on predicted joint faulting over the next 20 years.

Figure 5. Evaluation of future condition of I-74 without rehabilitation (continued).

Table 2. Restoration strategy for I-74 example including estimated quantities.

Complete Rehabilitation Strategy for Outer Lane:

Seal longitudinal centerline joint	4752 feet
Full-depth repair of cracks	456 sq yards
Full-depth repair of joints	152 sq yards
Reseal transverse joints	342 feet
Subseal at joints and cracks	78 cubic ft of grout
AC level-up settlements	267 sq yards
Diamond grinding	6336 sq yards
Install/repair longitudinal subdrains	4752 feet

Complete Rehabilitation Strategy for Inner Lane:

Full-depth repair of cracks	424 sq yards
Full-depth repair of joints	152 sq yards
Reseal transverse joints	342 feet
AC level-up settlements	267 sq yards
Diamond grinding	6336 sq yards
Install/repair longitudinal subdrains	4752 feet

Complete Rehabilitation Strategy for Outer Shoulder:

Reconstruct shoulder with PCC	5280 sq yards
Reseal lane/shoulder joint	4752 feet

Complete Rehabilitation Strategy for Inner Shoulder:

Reconstruct shoulder with PCC	3168 sq yards
Reseal lane/shoulder joint	4752 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 3. Restoration performance prediction for I-74 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING RESTORATION

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	FDR FAULTING	TRANSVERSE CRACKING	JOINT DETERIOR.	PUMPING	PSR
1986	29	13.00	0.00	0.00	0	0	0.0	4.5
1987	30	13.76	0.04	0.05	7	1	0.2	4.1
1988	31	14.55	0.06	0.08	14	2	0.4	3.9
1989	32	15.37	0.07	0.10	22	3	0.5	3.7
1990	33	16.23	0.08	0.12	32	4	0.6	3.5
1991	34	17.11	0.10	0.13	41	5	0.7	3.3
1992	35	18.04	0.11	0.15	52	6	0.8	3.2
1993	36	19.00	0.12	0.17	63	7	0.9	3.0
1994	37	20.00	0.12	0.19	76	8	1.0	2.8
1995	38	21.04	0.13	0.20	89	9	1.1	2.6
1996	39	22.12	0.14	0.22	104	11	1.2	2.4
1997	40	23.24	0.15	0.24	121	12	1.3	2.2
1998	41	24.41	0.16	0.26	138	13	1.4	2.1
1999	42	25.63	0.17	0.27	166	15	1.5	1.8
2000	43	26.89	0.17	0.29	187	16	1.6	1.6
2001	44	28.21	0.18	0.31	210	18	1.7	1.4
2002	45	29.58	0.19	0.33	235	19	1.8	1.2
2003	46	31.00	0.20	0.35	263	21	1.9	0.9
2004	47	32.48	0.20	0.36	292	22	2.0	0.7
2005	48	34.02	0.21	0.38	325	24	2.2	0.4
		18-kip millions	Inches	Inches	Cracks per mile	Joints per mile	0 - none 1 - low 2 - medium 3 - high	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the restored pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Full-depth repair faulting on the restored pavement in lane 1 is predicted to equal or exceed an unacceptable level of 0.26 inches in 1998.

Cracking on the restored pavement in lane 1 is predicted to equal or exceed an unacceptable level of 71 cracks per mile in 1994.

Joint deterioration on the restored pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Pumping on the restored pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

PSR on the restored pavement in lane 1 is predicted to equal or fall below an unacceptable level of 3.0 in 1993.

Table 3. Restoration performance prediction for I-74 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING RESTORATION

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	FDR FAULTING	TRANSVERSE CRACKING	JOINT DETERIOR.	PUMPING	PSR
1986	29	3.90	0.00	0.00	0	0	0.0	4.5
1987	30	4.11	0.03	0.03	1	1	0.1	4.2
1988	31	4.33	0.05	0.05	2	1	0.2	4.1
1989	32	4.55	0.06	0.06	3	2	0.2	4.1
1990	33	4.79	0.07	0.06	4	3	0.3	4.0
1991	34	5.03	0.08	0.07	5	4	0.3	3.9
1992	35	5.29	0.09	0.08	6	5	0.3	3.8
1993	36	5.55	0.09	0.09	8	6	0.4	3.8
1994	37	5.83	0.10	0.09	9	7	0.4	3.7
1995	38	6.11	0.11	0.10	11	8	0.5	3.6
1996	39	6.41	0.11	0.11	12	9	0.5	3.6
1997	40	6.72	0.12	0.12	14	10	0.6	3.5
1998	41	7.04	0.13	0.12	16	11	0.6	3.4
1999	42	7.37	0.13	0.13	18	12	0.6	3.4
2000	43	7.72	0.14	0.14	20	13	0.7	3.3
2001	44	8.08	0.14	0.14	22	15	0.7	3.3
2002	45	8.46	0.15	0.15	25	16	0.8	3.2
2003	46	8.85	0.15	0.16	27	17	0.8	3.1
2004	47	9.26	0.16	0.17	30	19	0.9	3.0
2005	48	9.68	0.16	0.17	33	20	0.9	3.0
		18-kip millions	Inches	Inches	Cracks per mile	Joints per mile	0 - none 1 - low 2 - medium 3 - high	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Full-depth repair faulting on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Cracking on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Pumping on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

PSR on the restored pavement in lane 2 is predicted to equal or fall below an unacceptable level of 3.0 in 2004.

Repairing the joints and cracks and replacing the undowelled full-depth repairs results in 86 full-depth repairs per mile being placed in the outer lane, and 78 per mile in the inner lane.

The PSR predictive model for restoration includes a term for total faulting at joints, cracks, and full-depth repairs, computed as the sum of the products of the numbers of joints, cracks, and full-depth repairs and the average faulting of each, the large number of full-depth repairs needed for the restoration strategy contributes to a large total faulting value. This along with cracking and joint deterioration contributes to a rapid loss in serviceability.

Using the default unit costs in EXPEAR, the predicted life of 7 years, and the default discount rate of 3 percent, the equivalent annual cost of this restoration strategy over the 0.9-mile project is $ 56,275. This annual cost should be compared with those for other rehabilitation alternatives. Aside from cost-effectiveness, the engineer should consider the desired minimum performance period. The 7-year life of the restoration alternative may unacceptable.

4.5.2 AC Structural Overlay Alternative

Table 4 shows the list of techniques making up an AC overlay rehabilitation strategy for I-74. The overlay thickness used for this example was 6 in [15.3 cm]. The performance predictions for this strategy are shown in table 5. The results show that rutting on this overlay is predicted to reach a critical level of 0.5 in [1.27 cm] after about 16 years. However, medium-high reflective cracking is predicted to reach an unacceptable level in only 5 years. This is understandable, considering the large number of new full-depth repairs needed, and the poor load transfer present at joints and cracks. The AC overlay alternative has an equivalent annual cost of $ 121,048, considerably more than the restoration alternative.

4.5.3 Unbonded Concrete Overlay Alternative

An 8-inch [20.3 cm] JRCP overlay was designed, assuming a 1-inch [2.54 cm] AC separation layer and a joint spacing of 40 ft [12.2. m]. Table 6 shows the list of techniques making up the unbonded PCC overlay rehabilitation strategy for I-74. The performance predictions for this strategy are shown in table 7. The results show that the life of the alternative is controlled by development of cracking, which reaches a critical level in about 15 years. Joint deterioration becomes excessive soon afterward. This alternative could be redesigned using a shorter joint spacing and higher reinforcement content to reduce joint deterioration and cracking.

The unbonded overlay alternative has an annual cost of $69,588, considerably less than that of the AC overlay alternative. The difference is due to the longer life and the elimination of several preoverlay repair techniques that were included in the AC overlay strategy. The unbonded overlay costs about 30 percent more than the restoration alternative, but its performance period is more than twice as long.

4.6 REHABILITATION ALTERNATIVE SELECTION

For this example, other overlay types (bonded PCC or crack and seat) could be investigated, as well as reconstruction of one or both lanes. Within each of the alternatives, the engineer can vary one or more of the inputs to develop a large

Table 4. AC overlay strategy for I-74 example.

Complete Rehabilitation Strategy for Outer Lane:

AC structural overlay	6336 sq yards
Seal longitudinal centerline joint	4752 feet
Full-depth repair of joints	152 sq yards
Reseal transverse joints	342 feet
Full-depth repair of cracks	456 sq yards
Subseal at joints and cracks	78 cubic ft of grout
AC level-up settlements	267 sq yards
Install/repair longitudinal subdrains	4752 feet

Complete Rehabilitation Strategy for Inner Lane:

AC structural overlay	6336 sq yards
Full-depth repair of joints	152 sq yards
Full-depth repair of cracks	424 sq yards
Reseal transverse joints	342 feet
AC level-up settlements	267 sq yards
Install/repair longitudinal subdrains	4752 feet

Complete Rehabilitation Strategy for Outer Shoulder:

AC overlay	5280 sq yards
Patching	1584 sq yards

Complete Rehabilitation Strategy for Inner Shoulder:

AC overlay	3168 sq yards
Patching	950 sq yards

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 5. AC overlay performance prediction for I-74 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING AC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUM ESALs	TOTAL REFLECTIVE CRACKING	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0	0.00
1987	1	0.76	160	66	0.01
1988	2	1.55	166	87	0.04
1989	3	2.37	169	102	0.06
1990	4	3.23	172	114	0.09
1991	5	4.11	174	125	0.12
1992	6	5.04	176	135	0.15
1993	7	6.00	177	143	0.18
1994	8	7.00	178	151	0.22
1995	9	8.04	179	159	0.25
1996	10	9.12	181	166	0.28
1997	11	10.24	181	173	0.32
1998	12	11.41	182	180	0.35
1999	13	12.63	183	183	0.39
2000	14	13.89	184	184	0.42
2001	15	15.21	185	185	0.46
2002	16	16.58	185	185	0.50
2003	17	18.00	186	186	0.54
2004	18	19.48	187	187	0.58
2005	19	21.02	187	187	0.62
		18-kip millions	Cracks per mile	Cracks per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Summary:

Total reflective cracking of the AC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Medium- to high-severity reflective cracking of the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 125 cracks per mile in 1991.

Rutting on the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 0.50 inches in 2002.

Table 5. AC overlay performance prediction for I-74 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING AC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUM ESALs	TOTAL REFLECTIVE CRACKING	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0	0.00
1987	1	0.21	156	52	0.00
1988	2	0.43	162	68	0.01
1989	3	0.65	165	79	0.03
1990	4	0.89	168	89	0.05
1991	5	1.13	170	97	0.07
1992	6	1.39	171	105	0.08
1993	7	1.65	173	112	0.10
1994	8	1.93	174	118	0.12
1995	9	2.21	175	124	0.14
1996	10	2.51	176	130	0.15
1997	11	2.82	177	135	0.17
1998	12	3.14	178	140	0.19
1999	13	3.47	179	145	0.21
2000	14	3.82	179	150	0.23
2001	15	4.18	180	155	0.25
2002	16	4.56	181	159	0.27
2003	17	4.95	181	164	0.29
2004	18	5.36	182	168	0.31
2005	19	5.78	183	172	0.33
		18-kip millions	Cracks per mile	Cracks per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Summary:

Total reflective cracking of the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Medium- to high-severity reflective cracking of the AC overlay in lane 2 is predicted to equal or exceed an unacceptable level of 125 cracks per mile in 1996.

Rutting on the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Table 6. Unbonded PCC overlay strategy for I-74 example.

Complete Rehabilitation Strategy for Outer Lane:

Unbonded PCC overlay	6336 sq yards
AC level-up settlements	267 sq yards
Install/repair longitudinal subdrains	4752 feet

Complete Rehabilitation Strategy for Inner Lane:

Unbonded PCC overlay	6336 sq yards
AC level-up settlements	267 sq yards
Install/repair longitudinal subdrains	4752 feet

Complete Rehabilitation Strategy for Outer Shoulder:

PCC overlay	5280 sq yards
Patching	1584 sq yards

Complete Rehabilitation Strategy for Inner Shoulder:

PCC overlay	3168 sq yards
Patching	950 sq yards

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 7. Unbonded PCC overlay performance prediction for I-74 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING UNBONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	JOINT DETERIORATION	TRANSVERSE CRACKING
1986	0	0.00	0.00	0	0
1987	1	0.76	0.02	0	3
1988	2	1.55	0.02	0	7
1989	3	2.37	0.03	1	10
1990	4	3.23	0.03	1	13
1991	5	4.11	0.03	2	17
1992	6	5.04	0.04	3	21
1993	7	6.00	0.04	4	25
1994	8	7.00	0.04	5	30
1995	9	8.04	0.04	7	35
1996	10	9.12	0.04	8	40
1997	11	10.24	0.05	11	46
1998	12	11.41	0.05	13	52
1999	13	12.63	0.05	16	60
2000	14	13.89	0.05	19	67
2001	15	15.21	0.05	22	76
2002	16	16.58	0.06	25	86
2003	17	18.00	0.06	29	96
2004	18	19.48	0.06	33	107
2005	19	21.02	0.06	38	120
		18-kip millions	Inches	Joints per mile	Cracks per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the PCC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the PCC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 27 joints per mile in 2003.

Transverse cracking of the PCC overlay is predicted to equal or exceed an unacceptable level of 71 cracks per mile in 2001.

Table 7. Unbonded PCC overlay performance prediction for I-74 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING UNBONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	JOINT DETERIORATION	TRANSVERSE CRACKING
1986	0	0.00	0.00	0	0
1987	1	0.21	0.01	0	1
1988	2	0.43	0.01	0	2
1989	3	0.65	0.02	0	3
1990	4	0.89	0.02	1	4
1991	5	1.13	0.02	1	5
1992	6	1.39	0.02	2	6
1993	7	1.65	0.02	3	7
1994	8	1.93	0.02	4	8
1995	9	2.21	0.03	6	9
1996	10	2.51	0.03	7	10
1997	11	2.82	0.03	9	12
1998	12	3.14	0.03	11	13
1999	13	3.47	0.03	13	14
2000	14	3.82	0.03	15	16
2001	15	4.18	0.03	18	17
2002	16	4.56	0.03	21	19
2003	17	4.95	0.04	24	20
2004	18	5.36	0.04	28	22
2005	19	5.78	0.04	32	24
		18-kip millions	Inches	Joints per mile	Cracks per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the PCC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the PCC overlay in lane 2 is predicted to equal or exceed an unacceptable level of 27 joints per mile in 2004.

Transverse cracking of the PCC overlay is not predicted to reach an unacceptable level within the next twenty years.

number of candidate rehabilitation strategies. Some of the variations possible include the following:

Rehabilitation Alternative	Input to Vary
AC overlay	Thickness
Unbonded PCC overlay	Thickness Joint spacing Reinforcement
Bonded PCC overlay	Thickness Joint spacing
Crack and seat and AC overlay	Thickness Cracking pattern
Reconstruct one or both lanes	Thickness Base Joint spacing Dowel diameter Etc.

It must be emphasized again that the responsibility for thickness design and joint design to meet structural requirements rests with the engineer. EXPEAR will predict the performance of any design input by the engineer in terms of key distress types.

Having developed one or more candidate rehabilitation strategies, the engineer can then use EXPEAR to compute the life-cycle costs of the strategies and identify the most cost-effective strategy. Cost-effectiveness and other factors will probably enter into the final selection of the preferred rehabilitation strategy.

CHAPTER 5
JPCP EVALUATION AND REHABILITATION

This chapter provides additional details on the evaluation and rehabilitation system which relate specifically to JPCP. The system may be applied to a JPCP project by following the steps described for all pavement types in chapter 3, referring to this chapter for specific details on JPCP, and using the materials provided in appendix B. These materials consist of the following:

- B-1 JPCP Project Survey and Supplemental Information
- B-2 JPCP Evaluation Decision Trees and Conclusions
- B-3 JPCP Evaluation Performance Prediction Models
- B-4 JPCP Rehabilitation Decision Trees
- B-5 JPCP Rehabilitation Performance Prediction Models
- B-6 JPCP Computer Program Operating Instructions

The use of the system for JPCP is illustrated with a comprehensive example of evaluation and rehabilitation of a JPCP project. The project selected for the example is a 7.5-mile [12.1 km] section of Interstate 10 near Tallahassee, Florida.

5.1 JPCP PROJECT SURVEY

A complete set of survey sheets for JPCP consists of three pages of inventory data for the project, one page of project monitoring data, and four pages of monitoring data for each sample unit surveyed. A complete set of survey sheets for the I-10 example is shown in figure 6. Two 500-ft [152.4 m] sample units were surveyed on the project.

5.2 EXTRAPOLATION OF OVERALL PROJECT CONDITION

5.2.1 Average Per Mile Data Items

The following JPCP monitoring data items must be extrapolated from the sample unit data and expressed as an average quantity per mile:

Data Item	Extrapolated Quantity
Longitudinal cracking	Feet/mile
Longitudinal spalling	Feet/mile
Transverse cracks	Feet/mile
Corner breaks	Number/mile
Joints with construction cracks	Number/mile
Settlements	Number/mile
Heaves	Number/mile
Full-depth repairs and slab replacements	Number/mile
Full-depth repair/slab replacement joints	Number/mile
Transverse joints	Number/mile

PROJECT SURVEY FOR JPCP

Design Engineer: MI Darter

Date of Survey (mo/day/yr): 9 / 30 / 86

PROJECT INVENTORY DATA

Collect the following information about the project to be evaluated prior to the actual field survey.

Project Identification

Highway Designation (example I-57): I-10

State: FLORIDA

Direction of Survey: west

Starting Milepost: 191.79

Ending Milepost: 184.27

Climate

Climatic Zone (See climatic zone map in 'Supplemental Information"):

____ wet freeze	____ wet-dry freeze	____ dry freeze
____ wet freeze-thaw	____ wet-dry freeze-thaw	____ dry freeze-thaw
✓ wet nonfreeze	____ wet-dry nonfreeze	____ dry nonfreeze

Estimated Annual Temperature Range (degrees Fahrenheit): 50

Mean Annual Precipitation (inches) (See precipitation map in "Supplemental Information"): 56

Corps of Engineers Freezing Index (Fahrenheit degree-days) (See Freezing Index map in "Supplemental Information"): 0

Average Annual Temperature (degrees Fahrenheit): 68

Slab Construction

Year Constructed: 1974

Slab Thickness (inches): 9

Width of Traffic Lanes (feet): 12

PCC Modulus of Rupture (28 days, 3rd-point loading)(psi): 650

Figure 6. Project survey sheets for I-10 example.

Transverse and Longitudinal Joints

Pattern of Joint Spacing:
__✓__ uniform
_____ random

Transverse joint spacing, if uniform (feet): __20__
Transverse joint sequence, if random (feet): _____

Type of Sealant:
_____ liquid (asphalt)
_____ field-molded (silicone)
__✓__ preformed compression (neoprene)

Average Transverse Joint Sealant Reservoir Dimensions
Width (inches): __0.38__ Depth (inches): __2.25__

Method Used to Form Transverse Joints:
__✓__ sawing
_____ inserts
_____ Unitube inserts

Transverse Joint Sawed Depth (inches): __2.25__

Type of Load Transfer System:
__✓__ aggregate interlock only
_____ dowels
_____ other mechanical devices

If dowels are present, dowel bar diameter (inches): _____

Method Used to Form Longitudinal Joints Between Lanes:
__✓__ sawing
_____ inserts

Longitudinal Joint Sawed or Formed Depth (inches): __2.25__

Base

Type of Base Course:
_____ fine-grained soil only
__✓__ cement-treated aggregate
_____ lean PCC
_____ dense-graded untreated aggregate
_____ asphalt-treated aggregate
_____ open-graded drainage layer

Modulus of Subgrade Reaction on Top of Base (psi/inch) (See k-value correlation chart in "Supplemental Information"): __200__

Figure 6. Project survey sheets for I-10 example (continued).

Subgrade

Predominant Subgrade Soil AASHTO Classification (See Unified-AASHTO conversion table in "Supplemental Information"): A-4

Are swelling soils a problem in the area? ____ yes ✓ no

If so, were steps taken in construction of the pavement to correct the swelling soil problem? ____ yes ____ no

Shoulder

Type of Shoulder:
✓ AC
____ tied PCC

Width of Shoulders (feet): 6 inner 10 outer

Inner Lane Slope Direction:
✓ toward outer lane
____ toward inner shoulder

Traffic

Estimated Current Through Two-way ADT: 12,000

Percent Commercial Trucks (excluding pickups and panels): 40

Total Number of Lanes in Direction of Survey: 2

Future 18-kip ESAL Growth Rate (percent per year): 7.0

Total Accumulated 18-kip Equivalent Single Axle Loads (ESALs) from Date of Construction to Date of Survey (millions) (See procedure for computing ESALs in AASHTO Guide for Design of Pavement Structures, Appendix D, 1986):

LANE TWO (inner)	LANE ONE (outer)
0.8	5.6

Figure 6. Project survey sheets for I-10 example (continued).

Ride Quality

Rate the ride quality of the pavement in each lane during a drive over the entire project at the posted speed limit. Two or more people should participate in the survey. Obtain ratings for each lane from each person and report the average value below.

```
0         1         2         3         4         5
+---------+---------+---------+---------+---------+
Very Poor   Poor      Fair      Good    Very Good
```

LANE TWO (inner)	LANE ONE (outer)
3.8	3.1

Figure 6. Project survey sheets for I-10 example (continued).

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately 1000 feet in each mile is recommended for each sample unit surveyed. If only one sample unit is to be surveyed on the project, a length of at least a half mile is recommended. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: 1 Starting Milepost: 191 Length of Sample Unit (feet): 500

Use the tally sheet provided to record information on cracking, spalling, and full-depth repairs for each slab surveyed. Compute the totals and averages indicated on the tally sheet and record these values below.

	LANE TWO (inner)	LANE ONE (outer)
Number of transverse cracks, L-M-H:	0	6
Mean faulting at transverse cracks (inches):	0	0.03
Number of deteriorated transverse joints, M-H including blowups:	0	0
Mean faulting at transverse joints (inches):	0.10	0.19
Number of transverse joints:	25	25
Mean faulting at full-depth repair and slab replacement joints (inches):	0.00	0.00
Number of full-depth repair and slab replacement joints (inches):	0	0
Number of full-depth repairs and slab replacements:	0	0
Number of corner breaks:	0	1

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	5	22
Total length of longitudinal joint spalling, M-H only (feet):		0

Figure 6. Project survey sheets for I-10 example (continued).

	LANE TWO (inner)	LANE ONE (outer)
Cracking at Transverse Joints		
Number of transverse joints with transverse cracks within 2 feet:	0	0
Foundation Movement		
Number of settlements (M-H only):	0	0
Number of heaves (M-H only):	0	0

Drainage

Are longitudinal subdrains present and functional along the sample unit? ____ yes ✔ no

What is the typical height of the pavement surface above the side ditchline (feet)? 10

Do the ditches have standing water or cattails in them? ✔ yes ____ no

Loss of Support

	LANE TWO (inner)	LANE ONE (outer)
Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):	✔ N ____ L ____ M ____ H	____ N ✔ L ____ M ____ H

Surface Condition

Method used to texture the pavement surface at construction:
✔ transverse tining
____ other

	LANE TWO (inner)	LANE ONE (outer)
Is the surface polished smooth in the wheelpaths?	____ yes ✔ no	____ yes ✔ no
Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?	____ yes ✔ no	____ yes ✔ no
Joint Sealant Condition		
What is the general condition of the transverse joint sealant?	✔ L ____ M ____ H	✔ L ____ M ____ H
What is the general condition of the longitudinal joint sealant?		✔ L ____ M ____ H
Are substantial amounts of incompressibles visible in the transverse joints?	____ yes ✔ no	____ yes ✔ no

Figure 6. Project survey sheets for I-10 example (continued).

	LANE TWO (inner)	LANE ONE (outer)

<u>Concrete Durability</u>

Extent of "D" cracking at joints and cracks (indicate highest severity level present in sample unit):

	LANE TWO (inner)	LANE ONE (outer)
N	✓	✓
L		
M		
H		

Extent of reactive aggregate distress (indicate highest severity level present in sample unit):

	LANE TWO (inner)	LANE ONE (outer)
N	✓	✓
L		
M		
H		

Extent of scaling (indicate highest severity level present in sample unit):

	LANE TWO (inner)	LANE ONE (outer)
N	✓	✓
L		
M		
H		

<u>Previous Repair</u>

If full-depth repairs are present, are they dowelled?

	LANE TWO (inner)	LANE ONE (outer)
yes		
no		

Are partial-depth repairs (rigid material only) present at most of the joints?

	LANE TWO (inner)	LANE ONE (outer)
yes		
no	✓	✓

Has diamond grinding been done?

	LANE TWO (inner)	LANE ONE (outer)
yes		
no	✓	✓

Has grooving been done?

	LANE TWO (inner)	LANE ONE (outer)
yes		
no	✓	✓

Figure 6. Project survey sheets for I-10 example (continued).

	INNER SHOULDER	OUTER SHOULDER
<u>AC Shoulders</u> (Check all that apply.)		
Alligator cracking	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Linear cracking	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Weathering/ravelling	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint dropoff	✓ none	___ none
	___ <1"	✓ <1"
	___ ≥1"	___ ≥1"
Settlements or heaves along outer edge	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Blowholes at transverse joints	✓ none	___ none
	___ some	✓ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	✓ poor	✓ poor
<u>PCC Shoulders</u> (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
"D" cracking or reactive aggregate distress	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Settlements or heaves along outer edge	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	___ poor	___ poor

Figure 6. Project survey sheets for I-10 example (continued).

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately 1000 feet in each mile is recommended for each sample unit surveyed. If only one sample unit is to be surveyed on the project, a length of at least a half mile is recommended. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: 2 Starting Milepost: 188 Length of Sample Unit (feet): 500

Use the tally sheet provided to record information on cracking, spalling, and full-depth repairs for each slab surveyed. Compute the totals and averages indicated on the tally sheet and record these values below.

	LANE TWO (inner)	LANE ONE (outer)
Number of transverse cracks, L-M-H:	0	9
Mean faulting at transverse cracks (inches):	0	0.25
Number of deteriorated transverse joints, M-H including blowups:	0	0
Mean faulting at transverse joints (inches):	0.06	0.19
Number of transverse joints:	25	25
Mean faulting at full-depth repair and slab replacement joints (inches):	0	0
Number of full-depth repair and slab replacement joints (inches):	0	0
Number of full-depth repairs and slab replacements:	0	0
Number of corner breaks:	0	1

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	0	0
Total length of longitudinal joint spalling, M-H only (feet):		0

Figure 6. Project survey sheets for I-10 example (continued).

	LANE TWO (inner)	LANE ONE (outer)
Cracking at Transverse Joints		
Number of transverse joints with transverse cracks within 2 feet:	0	0
Foundation Movement		
Number of settlements (M-H only):	0	0
Number of heaves (M-H only):	0	0

Drainage

Are longitudinal subdrains present and functional along the sample unit?	____ yes	✓ no
What is the typical height of the pavement surface above the side ditchline (feet)?	10	
Do the ditches have standing water or cattails in them?	✓ yes	____ no

Loss of Support

	LANE TWO (inner)	LANE ONE (outer)
Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):	✓ N ____ L ____ M ____ H	____ N ✓ L ____ M ____ H

Surface Condition

Method used to texture the pavement surface at construction:
✓ transverse tining
____ other

	LANE TWO (inner)	LANE ONE (outer)
Is the surface polished smooth in the wheelpaths?	____ yes ✓ no	____ yes ✓ no
Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?	____ yes ✓ no	____ yes ✓ no

Joint Sealant Condition

	LANE TWO (inner)	LANE ONE (outer)
What is the general condition of the transverse joint sealant?	✓ L ____ M ____ H	✓ L ____ M ____ H
What is the general condition of the longitudinal joint sealant?		✓ L ____ M ____ H
Are substantial amounts of incompressibles visible in the transverse joints?	____ yes ✓ no	____ yes ✓ no

Figure 6. Project survey sheets for I-10 example (continued).

	LANE TWO (inner)	LANE ONE (outer)
Concrete Durability		
Extent of "D" cracking at joints and cracks (indicate highest severity level present in sample unit):	✓ N ___ L ___ M ___ H	✓ N ___ L ___ M ___ H
Extent of reactive aggregate distress (indicate highest severity level present in sample unit):	✓ N ___ L ___ M ___ H	✓ N ___ L ___ M ___ H
Extent of scaling (indicate highest severity level present in sample unit):	✓ N ___ L ___ M ___ H	✓ N ___ L ___ M ___ H
Previous Repair		
If full-depth repairs are present, are they dowelled?	___ yes ___ no	___ yes ___ no
Are partial-depth repairs (rigid material only) present at most of the joints?	___ yes ✓ no	___ yes ✓ no
Has diamond grinding been done?	___ yes ✓ no	___ yes ✓ no
Has grooving been done?	___ yes ✓ no	___ yes ✓ no

Figure 6. Project survey sheets for I-10 example (continued).

	INNER SHOULDER	OUTER SHOULDER
AC Shoulders (Check all that apply.)		
Alligator cracking	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Linear cracking	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Weathering/ravelling	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint dropoff	✓ none	✓ none
	___ <1"	___ <1"
	___ ≥1"	___ ≥1"
Settlements or heaves along outer edge	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Blowholes at transverse joints	✓ none	✓ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	✓ poor	✓ poor
PCC Shoulders (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
"D" cracking or reactive aggregate distress	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Settlements or heaves along outer edge	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	___ poor	___ poor

Figure 6. Project survey sheets for I-10 example (continued).

This is performed with the following equation:

$$\text{Average Per Mile} = \left(\sum_{i=1}^{n} \frac{\text{value}_i * 5280}{\text{length}_i} \right) * \frac{1}{n}$$

where:

n = number of sample units

value_i = quantity of data item to be averaged in sample unit i

length_i = length of sample unit i, feet

Using this equation, the following extrapolated quantities were computed for I-10 for the data items with nonzero values (rounded to the nearest whole number):

Data Item	Extrapolated Quantity inner lane	Extrapolated Quantity outer lane
Longitudinal cracking	26 ft/mile [4.9 m/km]	116 ft/mile [22 m/km]
Corner breaks	0/mile	11/mile
Transverse cracks	0 ft/mile	948 ft/mile [179 m/km]
Transverse joints	264/mile	264/mile

5.2.2 Deteriorated Joints Per Mile

Joint deterioration is also expressed as an extrapolated quantity per mile, but since it is function of the transverse joint spacing, its computation is somewhat more difficult. The procedure used in the system is to compute the average proportion of joints that are deteriorated, and multiply this times the number of joints per mile. This is performed according to the following equation:

$$\text{Jt Det Per Mile} = \left[\left(\sum_{i=1}^{n} \frac{\text{detjt}_i}{(\text{length}_i/\text{jtspace})} \right) * \frac{1}{n} \right] * \frac{5280}{\text{jtspace}}$$

where:

Jt Det Per Mile = average number of deteriorated joints per mile

det jt_i = number of deteriorated joints in sample unit i

length_i = length of sample unit i, feet

n = number of sample units

jtspace = transverse joint spacing, feet

No deteriorated joints were observed in either lane of the two surveyed sample units on I-10.

5.2.3 Faulting

Average faulting at joints, cracks, full-depth repair/slab replacement joints is computed by the engineer and recorded on the survey sheets. The extrapolated number of joints, cracks, and full-depth repair/slab replacement joints are computed as described before. From this information, the average faulting of any combinations of these items can be computed as a weighted average. Total faulting can also be computed as the sum of the products of average faulting values and quantities of joints, cracks, and full-depth repair joints. The faulting parameters used in the JPCP evaluation decision trees are as follows:

Decision Tree	Faulting Parameter
Roughness	Total faulting, inches/mile
Load Transfer	Average joint faulting, inches Average crack faulting, inches Average FDR faulting, inches
Loss of Support	Weighted average joint and crack faulting, inches
Drainage	Weighted average joint and crack faulting, inches

[1 in = 2.54 cm, 1 mile = 1.61 km]

For I-10, the following faulting values were computed or obtained from the survey:

	Inner Lane	Outer Lane
Total faulting, inches/mile	21.12	62.80
Average joint faulting, inches	0.08	0.19
Average crack faulting, inches	0.00	0.16
Average FDR faulting, inches	n/a	n/a
Weighted average joint and crack faulting, inches	0.08	0.18

5.2.4 Toggle Values

For JPCP, the following toggle data items must be extrapolated:

- Pumping.
- Polished wheelpaths.
- Studded tire rutting.
- Incompressibles in transverse joints.
- Dowelling of existing full-depth repairs.
- Previously performed grinding.
- Previously performed grooving.
- Transverse joint sealant damage.
- Longitudinal joint sealant damage.
- D cracking.
- Reactive aggregate distress.
- Scaling.
- Existing partial-depth repairs.
- Shoulder distresses.

Extrapolation of toggle data items is performed by converting the toggle values given in each sample unit to numerical values (e.g., none = 1, some = 2, and extensive = 3), averaging the numerical values, and rounding off the result to the nearest whole number.

5.3 EVALUATION OF PRESENT CONDITION

Evaluation of a JPCP project is conducted using the evaluation decision trees developed for the following twelve problem areas:

1. Structural adequacy.
2. Drainage.
3. Foundation movement.
4. Durability.
5. Skid resistance.
6. Roughness.
7. Joint construction.
8. Transverse joint sealant.
9. Load transfer.
10. Loss of support.
11. Joint deterioration.
12. Shoulders.

As described in chapter 3, certain critical distress and serviceability levels in the evaluation decision trees are subject to modification by the engineer. The levels which may be modified for JPCP and their default values are shown below:

Distress/Serviceability	Default Critical Level
PSR	2.0 for ADT $\leq$ 3,000
PSR	2.5 for 3,000 < ADT $\leq$ 10,000
PSR	3.0 for ADT > 10,000
Total faulting	46 inches per mile
Average faulting	0.13 inches
Settlements	5 per mile
Heaves (for roughness)	5 per mile
M-H deteriorated joints	55 per mile
Corner breaks	25 per mile
Transverse cracks	67 cracks per mile
Longitudinal cracking	500 feet per mile

[1 in = 2.54 cm, 1 ft = 0.3048 m, 1 mile = 1.61 km]

The evaluation conclusions reached for the I-10 example using the default critical distress and PSR levels are shown in figure 7. The outer lane has a substantial amount of distress, including transverse cracks and corner breaks, longitudinal cracking, and poor drainage. The inner lane, on the other hand, has almost no distress. Since cracking in the outer lane exceeds the critical level, the pavement is not a candidate for restoration. Recommended physical testing for the I-10 example includes nondestructive testing for structural analysis, load transfer, and void detection; coring and materials evaluation for structural analysis and drainage analysis; and coring longitudinal cracks and joints.

CURRENT PAVEMENT EVALUATION

****

LANE 1

****

JOINT CONSTRUCTION:

The pavement in lane 1 shows no indications of a longitudinal joint construction deficiency.

a. do nothing

The pavement in lane 1 shows no indications of a transverse joint construction deficiency.

a. do nothing

JOINT SEALANT:

The pavement in lane 1 shows no indications of a joint sealant deficiency.

a. do nothing

ROUGHNESS:

Rideability in lane 1 is acceptable.

a. do nothing

DURABILITY:

The pavement in lane 1 shows no indications of significant surface or concrete durability problems.

a. do nothing

JOINT DETERIORATION:

No joint deterioration exists in lane 1.

a. do nothing

STRUCTURAL DEFICIENCY:

The pavement in lane 1 exhibits some load-associated distress (between 1 and 24 corner breaks per mile) which requires repair but does not indicate a structural deficiency.

a. full-depth repair of corner breaks

Structural deficiency of the pavement in lane 1 is indicated by 67 or more transverse cracks per mile.

a. full-depth repair of cracks, AC structural overlay
b. full-depth repair of cracks, crack and seat and AC structural overlay
c. full-depth repair of cracks, PCC bonded overlay
d. full-depth repair of cracks, PCC unbonded overlay
e. reconstruct

Figure 7. Evaluation of present condition for I-10 example.

SKID RESISTANCE:

The pavement in lane 1 shows no indications of loss of skid resistance or hydroplaning potential.

a. do nothing

LOAD TRANSFER:

Aggregate interlock is providing inadequate load transfer in lane 1 at the transverse joints, as indicated by mean transverse joint faulting of more than 0.13 inches.

a. load transfer restoration at joints
b. do nothing

A load transfer deficiency in lane 1 is indicated at deteriorated transverse cracks by mean crack faulting of more than 0.13 inches.

a. full-depth repair of cracks
b. load transfer restoration at cracks

No undowelled full-depth repairs are present in lane 1.

a. do nothing

FOUNDATION MOVEMENT:

The pavement in lane 1 shows no indications of foundation movement.

a. do nothing

LOSS OF SUPPORT:

Loss of slab support in the lane 1 is indicated by the presence of corner breaks.

a. subseal at joints

Loss of slab support in the lane 1 is indicated by faulting greater than 0.13 inches at joints and cracks.

a. subseal at joints

DRAINAGE:

A drainage deficiency in lane 1 is indicated by pumping occurring in a wet or wet-dry climate.

a. install or repair longitudinal subdrains
b. install or repair longitudinal subdrains, seal all joints and cracks

Figure 7. Evaluation of present condition for I-10 example (continued).

****
LANE 2
****

JOINT CONSTRUCTION:

The pavement in lane 2 shows no indications of a transverse joint construction deficiency.

a. do nothing

JOINT SEALANT:

The pavement in lane 2 shows no indications of a joint sealant deficiency.

a. do nothing

ROUGHNESS:

Rideability in lane 2 is acceptable.

a. do nothing

DURABILITY:

The pavement in lane 2 shows no indications of significant surface or concrete durability problems.

a. do nothing

JOINT DETERIORATION:

No joint deterioration exists in lane 2.

a. do nothing

STRUCTURAL DEFICIENCY:

The pavement in lane 2 shows no indications of structural deficiency.

a. do nothing

SKID RESISTANCE:

The pavement in lane 2 shows no indications of loss of skid resistance or hydroplaning potential.

a. do nothing

LOAD TRANSFER:

No load transfer deficiency is indicated at transverse joints in lane 2.

a. do nothing

No undowelled full-depth repairs are present in lane 2.

a. do nothing

Figure 7. Evaluation of present condition for I-10 example (continued).

FOUNDATION MOVEMENT:

The pavement in lane 2 shows no indications of foundation movement.

a. do nothing

LOSS OF SUPPORT:

The pavement in the lane 2 shows no indications of loss of slab support.

a. do nothing

DRAINAGE:

For the pavement's current traffic level, no significant drainage deficiency is indicated in lane 2.

a. do nothing

****
INNER SHOULDER
****

Excessive infiltration of water beneath the pavement and inner AC shoulder
is indicated by poor lane/shoulder joint sealant condition.

a. reseal lane/shoulder joint
b. do nothing

****
OUTER SHOULDER
****

Excessive infiltration of water beneath the pavement and outer AC shoulder is indicated by poor lane/shoulder joint sealant condition.

a. reseal lane/shoulder joint
b. do nothing

Figure 7. Evaluation of present condition for I-10 example (continued).

5.4 PREDICTION OF FUTURE CONDITION

The predictive models provided in appendix B3 for pumping, faulting, joint deterioration, cracking, and PSR were used to predict the future condition of I-10 without rehabilitation. The models were calibrated to the existing condition of the pavement at the time of the survey (1986). The results are shown in table 8.

The distress and PSR predictions are used to reevaluate the pavement each year for 20 years into the future, and identify the years in which the predicted distresses and PSR will reach critical levels. The critical levels used here are the same as those used in the evaluation of the pavement's present condition (for the I-10 example, the default values were used). The results are shown in figure 8.

5.5 REHABILITATION STRATEGY DEVELOPMENT

One or more rehabilitation strategies can be developed for a JPCP project using the decision trees provided in appendix B4. The outer lane of the I-10 example project has a sufficient amount of cracking to require a structural improvement. Thus, four overlay options (AC structural, crack and seat and AC structural, PCC bonded, or PCC unbonded) can be investigated for this project, as well as two reconstruction options (reconstruct both lanes, or reconstructing the outer lane and restoring the inner lane). The first five of these options were investigated for the I-10 example. Though reconstruction of both lanes is an option permitted by the EXPEAR program, the inner lane is in very good condition and reconstructing would probably not be a very cost-effective improvement.

5.5.1 AC Structural Overlay Alternative

The rehabilitation techniques and associated quantities making up an AC structural overlay rehabilitation alternative for I-10 are given in table 9. An appropriate overlay thickness which will satisfy structural requirements must be selected by the engineer. Table 10 illustrates the predicted performance for an overlay thickness of 4 in [10.2 cm].

The predicted life of the AC structural overlay is very short. Medium- to high-severity reflective cracking is predicted to reach a critical level in just 4 years. This is understandable, considering the short joint spacing and the large number of full-depth repairs required as part of the preoverlay repair. The overlay thickness could be increased to extend the time before critical levels of reflective cracking are reached, but the time to reach a critical level of rutting would probably decrease as a result. Overall, it does not appear that a satisfactory performance period can be obtained from a conventional AC overlay for the I-10 example project. The equivalent annual cost computed by EXPEAR for the 7.5-mile project length is $ 891,646.

5.5.2 Crack and Seat and AC Structural Overlay Alternative

Another available alternative is cracking and seating the pavement prior to placing an AC overlay. The rehabilitation techniques and associated quantities making up a crack and seat and AC structural overlay rehabilitation alternative for I-10 are given in table 11.

Again, an appropriate overlay thickness which will satisfy structural requirements must be selected by the engineer. Table 12 illustrates the predicted performance for an overlay thickness of 4 in [10.2 cm], a seating roller weight of 50 tons [45400 kg], and a cracking pattern of 6 ft by 6 ft [1.8 m by 1.8 m].

Table 8. Future condition predictions for I-10 example.

DISTRESS AND PSR PROJECTIONS FOR LANE 1 WITHOUT REHABILITATION

Cumulative ESAL	Annual ESAL	Year	Pumping	Faulting	Deter. Joints	Transverse Cracking	PSR
5.6	0.85	1986	1.0	0.19	0	79	3.1
6.5	0.91	1987	1.1	0.19	0	80	3.0
7.5	0.98	1988	1.2	0.19	0	81	3.0
8.5	1.05	1989	1.3	0.19	0	82	2.9
9.7	1.12	1990	1.4	0.20	0	83	2.9
10.9	1.20	1991	1.5	0.20	0	85	2.8
12.1	1.28	1992	1.6	0.20	0	86	2.7
13.5	1.37	1993	1.6	0.20	0	88	2.6
15.0	1.47	1994	1.7	0.20	0	90	2.6
16.6	1.57	1995	1.8	0.20	0	93	2.5
18.2	1.68	1996	1.9	0.20	0	96	2.4
20.0	1.80	1997	2.0	0.20	0	100	2.3
22.0	1.92	1998	2.1	0.20	0	105	2.2
24.0	2.06	1999	2.2	0.21	0	111	2.1
26.2	2.20	2000	2.3	0.21	0	119	1.9
28.6	2.36	2001	2.4	0.21	0	128	1.8
31.1	2.52	2002	2.5	0.21	0	139	1.7
33.8	2.70	2003	2.6	0.21	0	152	1.5
36.7	2.89	2004	2.8	0.21	0	169	1.4
39.8	3.09	2005	2.9	0.21	0	189	1.2
18-kip millions	18-kip millions		0 - none 1 - low 2 - medium 3 - high	Inches	Joints per mile	Cracks per mile	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Table 8. Future condition predictions for I-10 example (continued).

DISTRESS AND PSR PROJECTIONS FOR LANE 2 WITHOUT REHABILITATION

Cumulative ESAL	Annual ESAL	Year	Pumping	Faulting	Deter. Joints	Transverse Cracking	PSR
0.8	0.15	1986	0.0	0.08	0	0	3.8
1.0	0.16	1987	0.0	0.08	0	0	3.8
1.1	0.17	1988	0.1	0.08	0	1	3.8
1.3	0.19	1989	0.1	0.08	0	1	3.7
1.5	0.20	1990	0.2	0.08	0	1	3.7
1.7	0.21	1991	0.2	0.09	0	1	3.7
2.0	0.23	1992	0.3	0.09	0	2	3.7
2.2	0.25	1993	0.3	0.09	0	2	3.6
2.5	0.26	1994	0.4	0.09	0	2	3.6
2.8	0.28	1995	0.4	0.09	0	3	3.6
3.1	0.30	1996	0.5	0.09	0	3	3.5
3.4	0.32	1997	0.5	0.09	0	3	3.5
3.7	0.34	1998	0.6	0.09	0	4	3.5
4.1	0.37	1999	0.6	0.09	0	4	3.4
4.5	0.39	2000	0.7	0.09	0	4	3.4
4.9	0.42	2001	0.7	0.09	0	5	3.4
5.4	0.45	2002	0.8	0.09	0	5	3.3
5.8	0.48	2003	0.8	0.10	0	5	3.3
6.4	0.52	2004	0.9	0.10	0	6	3.2
6.9	0.55	2005	0.9	0.10	0	6	3.2
18-kip millions	18-kip millions		0 - none 1 - low 2 - medium 3 - high	Inches	Joints per mile	Cracks per mile	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

FUTURE PAVEMENT EVALUATION

****

LANE 1

****

ROUGHNESS:

Poor rideability in lane 1 occurs in 1987 as indicated by an unacceptably low predicted PSR for the pavement's ADT level.

a. grinding
b. AC nonstructural overlay

JOINT DETERIORATION:

No significant joint deterioration in lane 1 occurs over the next 20 years.

STRUCTURAL DEFICIENCY:

Structural deficiency of the pavement in lane 1 occurs in 1986 as indicated by 67 or more transverse cracks per mile.

a. full-depth repair of cracks, AC structural overlay
b. full-depth repair of cracks, crack and seat and AC structural overlay
c. full-depth repair of cracks, PCC bonded overlay
d. full-depth repair of cracks, PCC unbonded overlay
e. reconstruct

LOAD TRANSFER:

Inadequate load transfer at transverse joints in lane 1 occurs in 1986 as indicated by predicted faulting of 0.13 inches or more.

a. load transfer restoration at joints
b. do nothing

LOSS OF SUPPORT:

Loss of slab support in lane 1 occurs in 1986 as indicated by predicted faulting greater than 0.13 inches at transverse joints.

a. subseal at joints

Figure 8. Evaluation of future condition of I-10 without rehabilitation.

****
LANE 2
****

ROUGHNESS:

Rideability in lane 2 is acceptable based on ADT and PSR levels predicted over the next 20 years.

JOINT DETERIORATION:

No significant joint deterioration in lane 2 occurs over the next 20 years.

STRUCTURAL DEFICIENCY:

No structural deficiency in lane 2 occurs based on predicted transverse cracking over the next 20 years.

LOAD TRANSFER:

No load transfer deficiency at transverse joints in lane 2 occurs based on predicted joint faulting over the next 20 years.

LOSS OF SUPPORT:

No loss of slab support in lane 2 occurs based on predicted joint faulting over the next 20 years.

Figure 8. Evaluation of future condition of I-10 without rehabilitation (continued).

Table 9. AC structural overlay strategy for I-10 example.

Complete Rehabilitation Strategy for Outer Lane:

AC structural overlay	52941 sq yards
Full-depth repair of corner breaks	635 sq yards
Full-depth repair of cracks	4765 sq yards
Load transfer restoration at joints	993 joints
Subseal at cracks	1489 cubic ft of grout
Install/repair longitudinal subdrains	39706 feet

Complete Rehabilitation Strategy for Inner Lane:

AC structural overlay	52941 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

AC overlay	44117 sq yards
Reseal lane/shoulder joint	39706 feet

Complete Rehabilitation Strategy for Inner Shoulder:

AC overlay	26470 sq yards
Reseal lane/shoulder joint	39706 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 10. AC overlay performance prediction for I-10 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING AC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUM ESALs	TOTAL REFLECTIVE CRACKING	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0	0.00
1987	1	0.91	167	76	0.00
1988	2	1.89	173	100	0.00
1989	3	2.94	176	118	0.02
1990	4	4.06	179	133	0.05
1991	5	5.26	181	146	0.08
1992	6	6.54	183	157	0.12
1993	7	7.91	185	168	0.16
1994	8	9.38	186	178	0.20
1995	9	10.95	187	187	0.24
1996	10	12.64	189	189	0.29
1997	11	14.43	190	190	0.34
1998	12	16.36	191	191	0.39
1999	13	18.42	191	191	0.44
2000	14	20.62	192	192	0.49
2001	15	22.98	193	193	0.55
2002	16	25.50	194	194	0.61
2003	17	28.20	195	195	0.68
2004	18	31.09	195	195	0.74
2005	19	34.18	196	196	0.82
		18-kip millions	Cracks per mile	Cracks per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Summary:

Total reflective cracking of the AC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Medium- to high-severity reflective cracking of the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 125 cracks per mile in 1990.

Rutting on the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 0.50 inches in 2001.

Table 10. AC overlay performance prediction for I-10 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING AC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUM ESALs	TOTAL REFLECTIVE CRACKING	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0	0.00
1987	1	0.16	161	55	0.00
1988	2	0.34	167	72	0.00
1989	3	0.53	171	85	0.00
1990	4	0.73	173	95	0.00
1991	5	0.94	175	105	0.00
1992	6	1.17	177	113	0.02
1993	7	1.41	179	121	0.04
1994	8	1.68	180	128	0.05
1995	9	1.96	181	135	0.07
1996	10	2.26	182	142	0.09
1997	11	2.58	183	148	0.11
1998	12	2.92	184	154	0.13
1999	13	3.29	185	160	0.15
2000	14	3.68	186	166	0.17
2001	15	4.11	187	172	0.19
2002	16	4.56	188	177	0.21
2003	17	5.04	188	183	0.23
2004	18	5.56	189	189	0.25
2005	19	6.11	190	190	0.28
		18-kip millions	Cracks per mile	Cracks per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Summary:

Total reflective cracking of the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Medium- to high-severity reflective cracking of the AC overlay in lane 2 is predicted to equal or exceed an unacceptable level of 125 cracks per mile in 1994.

Rutting on the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Table 11. Crack and seat strategy for I-10 example.

Complete Rehabilitation Strategy for Outer Lane:

Crack and seat and AC structural overlay	52941 sq yards
Load transfer restoration at joints	993 joints
Full-depth repair of cracks	4765 sq yards
Full-depth repair of corner breaks	635 sq yards
Install/repair longitudinal subdrains	39706 feet

Complete Rehabilitation Strategy for Inner Lane:

Crack and seat and AC structural overlay	52941 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

AC overlay	44117 sq yards
Reseal lane/shoulder joint	39706 feet

Complete Rehabilitation Strategy for Inner Shoulder:

AC overlay	26470 sq yards
Reseal lane/shoulder joint	39706 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 12. Crack and seat performance prediction for I-10 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING CRACK & SEAT

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUM ESALs	TOTAL REFLECTIVE CRACKING	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0	0.00
1987	1	0.91	88	17	0.00
1988	2	1.89	92	18	0.00
1989	3	2.94	98	20	0.02
1990	4	4.06	107	23	0.05
1991	5	5.26	119	27	0.08
1992	6	6.54	134	31	0.12
1993	7	7.91	153	37	0.16
1994	8	9.38	177	44	0.20
1995	9	10.95	205	52	0.24
1996	10	12.64	238	62	0.29
1997	11	14.43	276	74	0.34
1998	12	16.36	321	88	0.39
1999	13	18.42	372	103	0.44
2000	14	20.62	431	121	0.49
2001	15	22.98	498	141	0.55
2002	16	25.50	573	163	0.61
2003	17	28.20	658	189	0.68
2004	18	31.09	754	218	0.74
2005	19	34.18	861	250	0.82
		18-kip millions	Cracks per mile	Cracks per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Summary:

Total relfective cracking of the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 350 cracks per mile in 1999.

Medium- to high-severity reflective cracking of the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 125 cracks per mile in 2001.

Rutting on the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 0.50 inches in 2001.

Table 12. Crack and seat performance prediction for I-10 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING CRACK & SEAT

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUM ESALs	TOTAL REFLECTIVE CRACKING	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0	0.00
1987	1	0.16	87	17	0.00
1988	2	0.34	88	17	0.00
1989	3	0.53	89	18	0.00
1990	4	0.73	91	18	0.00
1991	5	0.94	93	19	0.00
1992	6	1.17	96	20	0.02
1993	7	1.41	99	21	0.04
1994	8	1.68	103	22	0.05
1995	9	1.96	108	23	0.07
1996	10	2.26	114	25	0.09
1997	11	2.58	121	27	0.11
1998	12	2.92	129	30	0.13
1999	13	3.29	138	32	0.15
2000	14	3.68	149	36	0.17
2001	15	4.11	161	39	0.19
2002	16	4.56	174	43	0.21
2003	17	5.04	189	48	0.23
2004	18	5.56	206	53	0.25
2005	19	6.11	225	59	0.28
		18-kip millions	Cracks per mile	Cracks per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Summary:

Total reflective cracking of the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Medium- to high-severity reflective cracking of the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Rutting on the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Cracking and seating is predicted to improve the performance of an AC structural overlay on this pavement. Medium- to high-severity reflective cracking is predicted to reach a critical level in 13 years. Total reflective cracking and rutting both become critical after 15 years. The equivalent annual cost of the crack and seat alternative is $332,245, only about a third of the conventional AC overlay cost, due to the longer life and the elimination of some preoverlay repair techniques.

5.5.3 Bonded Concrete Overlay Alternative

The list of techniques and associated quantities which would be included in a bonded concrete overlay rehabilitation alternative for I-10 are given in table 13. An appropriate overlay thickness which will satisfy structural requirements must be selected by the engineer. Table 14 illustrates the predicted performance for a JPCP bonded overlay thickness of 3 in [12.7 cm]. Other overlay thicknesses could be investigated as well.

The bonded overlay alternative is predicted to perform very well. Almost no distress is predicted in the overlay through the 20 years of the analysis. However, extensive preoverlay repair is required. The equivalent annual cost for the unbonded overlay is $ 480,052.

5.5.4 Unbonded Concrete Overlay Alternative

The list of techniques and associated quantities which would be included in an unbonded concrete overlay rehabilitation alternative for I-10 are given in table 15. Table 16 illustrates the predicted performance for a 9-inch [22.9 cm] JPCP unbonded overlay with a 1-inch [2.54 cm] AC separation layer, a 15-foot [4.6 m] joint spacing, and 1.25-inch [3.175 cm] dowel bars in the overlay. These parameters could be varied by the engineer to produce different alternatives with different costs and predicted lives.

The unbonded overlay is also predicted to provide at least 20 years of good performance. Despite the substantially greater thickness of concrete, the elimination of some preoverlay repair techniques brings the cost of this alternative ($ 392,806) below that of the bonded overlay.

5.5.5 Reconstruct/Restore Alternative

The last alternative investigated for the I-10 example is reconstruction of the outer lane. This alternative seems intuitively to be very appropriate for this project, since there is significant structural damage in the outer lane (cracking and corner breaks), but almost no distress in the inner lane.

The list of techniques and associated quantities which would be included in a reconstruct/restore rehabilitation alternative for I-10 is given in table 17. Note that no rehabilitation work is required in the inner lane for this strategy.

Table 18 illustrates the predicted performance for a 12-inch [30.5 cm] JPCP reconstructed outer lane, with a 20-foot [6.1 m] joint spacing, a stabilized base with a k-value of 200 pci [5.5 kg/cubic m], 1.25-inch [3.175 cm] dowel bars, and a PCC modulus of rupture of 650 psi [45 kg/sq cm]. This particular alternative has a predicted life of 19 years, and an equivalent annual cost of $ 158,115, the lowest of any of the alternatives examined for this example project.

Table 13. Bonded PCC overlay strategy for I-10 example.

Complete Rehabilitation Strategy for Outer Lane:

Bonded PCC overlay	52941 sq yards
Full-depth repair of corner breaks	635 sq yards
Full-depth repair of cracks	4765 sq yards
Load transfer restoration at joints	993 joints
Subseal at cracks	1489 cubic ft of grout
Install/repair longitudinal subdrains	39706 feet

Complete Rehabilitation Strategy for Inner Lane:

Bonded PCC overlay	52941 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

PCC overlay	44117 sq yards
Reseal lane/shoulder joint	39706 feet

Complete Rehabilitation Strategy for Inner Shoulder:

PCC overlay	26470 sq yards
Reseal lane/shoulder joint	39706 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 14. Bonded PCC overlay performance prediction for I-10 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING BONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	JOINT DETERIORATION	TRANSVERSE CRACKING
1986	0	0.00	0.00	0	0
1987	1	0.91	0.00	0	0
1988	2	1.89	0.00	0	0
1989	3	2.94	0.00	0	0
1990	4	4.06	0.00	0	1
1991	5	5.26	0.00	0	1
1992	6	6.54	0.00	0	1
1993	7	7.91	0.00	0	1
1994	8	9.38	0.00	0	1
1995	9	10.95	0.00	0	1
1996	10	12.64	0.00	0	1
1997	11	14.43	0.00	0	1
1998	12	16.36	0.00	0	1
1999	13	18.42	0.00	0	1
2000	14	20.62	0.00	0	1
2001	15	22.98	0.00	0	2
2002	16	25.50	0.00	0	2
2003	17	28.20	0.00	0	2
2004	18	31.09	0.00	0	2
2005	19	34.18	0.00	0	2
		18-kip millions	Inches	Joints per mile	Cracks per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the PCC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the PCC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Transverse cracking of the PCC overlay is not predicted to reach an unacceptable level within the next twenty years.

Table 14. Bonded PCC overlay performance prediction for I-10 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING BONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	JOINT DETERIORATION	TRANSVERSE CRACKING
1986	0	0.00	0.00	0	0
1987	1	0.16	0.00	0	0
1988	2	0.34	0.00	0	0
1989	3	0.53	0.00	0	0
1990	4	0.73	0.00	0	0
1991	5	0.94	0.00	0	1
1992	6	1.17	0.00	0	1
1993	7	1.41	0.00	0	1
1994	8	1.68	0.00	0	1
1995	9	1.96	0.00	0	1
1996	10	2.26	0.00	0	1
1997	11	2.58	0.00	0	1
1998	12	2.92	0.00	0	1
1999	13	3.29	0.00	0	1
2000	14	3.68	0.00	0	1
2001	15	4.11	0.00	0	1
2002	16	4.56	0.00	0	1
2003	17	5.04	0.00	0	1
2004	18	5.56	0.00	0	2
2005	19	6.11	0.00	0	2
		18-kip millions	Inches	Joints per mile	Cracks per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the PCC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the PCC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Transverse cracking of the PCC overlay is not predicted to reach an unacceptable level within the next twenty years.

Table 15. Unbonded PCC overlay strategy for I-10 example.

Complete Rehabilitation Strategy for Lane 1:

Unbonded PCC overlay	52941 sq yards
Install/repair longitudinal subdrains	39706 feet

Complete Rehabilitation Strategy for Lane 2:

Unbonded PCC overlay	52941 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

PCC overlay	44117 sq yards
Reseal lane/shoulder joint	39706 feet

Complete Rehabilitation Strategy for Inner Shoulder:

PCC overlay	26470 sq yards
Reseal lane/shoulder joint	39706 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 16. Unbonded PCC overlay performance prediction for I-10 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING UNBONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	JOINT DETERIORATION	TRANSVERSE CRACKING
1986	0	0.00	0.00	0	0
1987	1	0.91	0.02	0	2
1988	2	1.89	0.02	0	3
1989	3	2.94	0.03	0	4
1990	4	4.06	0.03	0	5
1991	5	5.26	0.04	0	5
1992	6	6.54	0.04	0	6
1993	7	7.91	0.04	0	7
1994	8	9.38	0.05	0	7
1995	9	10.95	0.05	0	8
1996	10	12.64	0.05	0	9
1997	11	14.43	0.05	0	10
1998	12	16.36	0.06	0	12
1999	13	18.42	0.06	0	13
2000	14	20.62	0.06	0	15
2001	15	22.98	0.06	0	17
2002	16	25.50	0.07	0	20
2003	17	28.20	0.07	0	23
2004	18	31.09	0.07	0	27
2005	19	34.18	0.08	0	32
		18-kip millions	Inches	Joints per mile	Cracks per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the PCC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the PCC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Transverse cracking of the PCC overlay is not predicted to reach an unacceptable level within the next twenty years.

Table 16. Unbonded PCC overlay performance prediction for I-10 example (continued.

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING UNBONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	JOINT DETERIORATION	TRANSVERSE CRACKING
1986	0	0.00	0.00	0	0
1987	1	0.16	0.01	0	1
1988	2	0.34	0.01	0	1
1989	3	0.53	0.01	0	2
1990	4	0.73	0.02	0	2
1991	5	0.94	0.02	0	2
1992	6	1.17	0.02	0	2
1993	7	1.41	0.02	0	3
1994	8	1.68	0.02	0	3
1995	9	1.96	0.02	0	3
1996	10	2.26	0.03	0	3
1997	11	2.58	0.03	0	4
1998	12	2.92	0.03	0	4
1999	13	3.29	0.03	0	4
2000	14	3.68	0.03	0	4
2001	15	4.11	0.03	0	5
2002	16	4.56	0.03	0	5
2003	17	5.04	0.04	0	5
2004	18	5.56	0.04	0	5
2005	19	6.11	0.04	0	6
		18-kip millions	Inches	Joints per mile	Cracks per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the PCC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the PCC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Transverse cracking of the PCC overlay is not predicted to reach an unacceptable level within the next twenty years.

Table 17. Reconstruct/restore strategy for I-10 example.

Complete Rehabilitation Strategy for Outer Lane:	
Reconstruction	52941 sq yards
Install/repair longitudinal subdrains	39706 feet
Complete Rehabilitation Strategy for Inner Lane:	
[no rehabilitation required]	
Complete Rehabilitation Strategy for Outer Shoulder:	
Reseal lane/shoulder joint	39706 feet
Complete Rehabilitation Strategy for Inner Shoulder:	
Reseal lane/shoulder joint	39706 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 18. Reconstruct/restore performance prediction for I-10 example

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING RECONSTRUCTION

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	TRANSVERSE CRACKING	JOINT DETERIORATION	PUMPING	PSR
1986	0	0.00	0.00	0	0	0.0	4.5
1987	1	0.91	0.00	1	0	0.2	4.1
1988	2	1.89	0.00	1	0	0.2	4.1
1989	3	2.94	0.00	1	0	0.3	4.1
1990	4	4.06	0.00	2	0	0.3	4.1
1991	5	5.26	0.00	2	0	0.4	4.1
1992	6	6.54	0.00	2	0	0.4	4.0
1993	7	7.91	0.00	2	0	0.5	4.0
1994	8	9.38	0.00	2	0	0.5	3.9
1995	9	10.95	0.00	3	0	0.5	3.9
1996	10	12.64	0.00	3	0	0.6	3.8
1997	11	14.43	0.00	3	0	0.6	3.8
1998	12	16.36	0.00	3	0	0.6	3.7
1999	13	18.42	0.00	3	0	0.7	3.6
2000	14	20.62	0.00	4	0	0.7	3.5
2001	15	22.98	0.00	4	0	0.7	3.4
2002	16	25.50	0.00	4	0	0.8	3.3
2003	17	28.20	0.00	4	0	0.8	3.2
2004	18	31.09	0.00	5	0	0.8	3.1
2005	19	34.18	0.00	5	0	0.9	3.0
		18-kip millions	Inches	Cracks per mile	Joints per mile	0 - none 1 - low 2 - medium 3 - high	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the reconstructed pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Transverse cracking of the reconstructed pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the reconstructed pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Pumping on the reconstructed pavement in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

PSR on the reconstructed pavement in lane 1 is predicted to equal or exceed an unacceptable level of 3.00 in 2005.

Table 18. Reconstruct/restore performance prediction for I-10 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING RESTORATION

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	JOINT FAULTING	FDR FAULTING	TRANSVERSE CRACKING	JOINT DETERIOR.	PUMPING	PSR
1986	12	0.80	0.08	0.00	0	0	0.0	4.1
1987	13	0.96	0.08	0.00	0	0	0.3	4.1
1988	14	1.14	0.08	0.00	1	0	0.4	4.1
1989	15	1.33	0.08	0.00	1	0	0.5	4.1
1990	16	1.53	0.09	0.00	1	0	0.5	4.1
1991	17	1.74	0.09	0.00	1	0	0.6	4.1
1992	18	1.97	0.09	0.00	2	0	0.7	4.1
1993	19	2.21	0.09	0.00	2	0	0.7	4.1
1994	20	2.48	0.09	0.00	2	0	0.8	4.1
1995	21	2.76	0.09	0.00	3	0	0.8	4.1
1996	22	3.06	0.09	0.00	3	0	0.9	4.1
1997	23	3.38	0.09	0.00	3	0	0.9	4.1
1998	24	3.72	0.09	0.00	4	0	1.0	4.1
1999	25	4.09	0.09	0.00	4	0	1.1	4.1
2000	26	4.48	0.10	0.00	4	0	1.1	4.0
2001	27	4.91	0.10	0.00	5	0	1.2	4.0
2002	28	5.36	0.10	0.00	5	0	1.2	4.0
2003	29	5.84	0.10	0.00	5	0	1.3	4.0
2004	30	6.36	0.10	0.00	6	0	1.3	4.0
2005	31	6.91	0.10	0.00	6	0	1.4	4.0
		18-kip millions	Inches	Inches	Cracks per mile	Joints per mile	0 = none 1 = low 2 = medium 3 = high	0-5

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Joint faulting on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Full-depth repair faulting on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Cracking on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Joint deterioration on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Pumping on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

PSR on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

5.6 REHABILITATION ALTERNATIVE SELECTION

Within each of the alternatives, the engineer can vary one or more of the inputs to develop a large number of candidate rehabilitation strategies. Some of the variations possible include the following:

Rehabilitation Alternative	Input to Vary
AC overlay	Thickness
Unbonded PCC overlay	Thickness Joint spacing Reinforcement
Bonded PCC overlay	Thickness Joint spacing
Crack and seat and AC overlay	Thickness Cracking pattern
Reconstruct one or both lanes	Thickness Base Joint spacing Dowel diameter Etc.

It must be emphasized again that the responsibility for thickness design and joint design to meet structural requirements rests with the engineer. EXPEAR will predict the performance of any design input by the engineer in terms of key distress types.

Having developed one or more candidate rehabilitation strategies, the engineer can then use EXPEAR to compute the life-cycle costs of the strategies and identify the most cost-effective strategy. Cost-effectiveness and other factors will probably enter into the final selection of the preferred rehabilitation strategy.

CHAPTER 6
CRCP EVALUATION AND REHABILITATION

This chapter provides additional details on the evaluation and rehabilitation system which relate specifically to CRCP. The system may be applied to a CRCP project by following the steps described for all pavement types in chapter 3, referring to this chapter for specific details on CRCP, and using the materials provided in appendix C. These materials consist of the following:

C-1 CRCP Project Survey and Supplemental Information
C-2 CRCP Evaluation Decision Trees and Conclusions
C-3 CRCP Evaluation Performance Prediction Models
C-4 CRCP Rehabilitation Decision Trees
C-5 CRCP Rehabilitation Performance Prediction Models
C-6 CRCP Computer Program Operating Instructions

The use of the system for CRCP is illustrated with a comprehensive example of evaluation and rehabilitation of a CRCP project. The project selected for the example is a 5.2-mile [8.4 km] section of Interstate 57 near Champaign, Illinois.

6.1 CRCP PROJECT SURVEY

A complete set of survey sheets for CRCP consists of three pages of inventory data for the project, one page of project monitoring data, and three pages of monitoring data for each sample unit surveyed. A complete set of survey sheets for the I-57 example are shown in figure 9. Two 0.5-mile [0.8 km] sample units were surveyed on the project.

6.2 EXTRAPOLATION OF OVERALL PROJECT CONDITION

6.2.1 Average Per Mile Data Items

The following CRCP monitoring data items are extrapolated from the sample unit data and expressed as an average quantity per mile:

Data Item	Extrapolated Quantity
Deteriorated transverse cracks	Number/mile
Full-depth repairs	Number/mile
Deteriorated full-depth repairs	Number/mile
Punchouts	Number/mile
Deteriorated construction joints	Number/mile
Longitudinal cracking	Feet/mile
Longitudinal joint spalling	Feet/mile
Settlements	Number/mile
Heaves	Number/mile
D crack spalling (M-H)	Number spalled areas/mile
Reactive aggegate spalling (M-H)	Number spalled areas/mile

PROJECT SURVEY FOR CRCP

Design Engineer: KT HALL

Date of Survey (mo/day/yr): 12 / 9 / 86

PROJECT INVENTORY DATA

Collect the following information about the project to be evaluated prior to the actual field survey.

Project Identification

Highway Designation (example I-57): I-57

State: ILLINOIS

Direction of Survey: south

Starting Milepost: 233.27

Ending Milepost: 228.09

Climate

Climatic Zone (See climatic zone map in "Supplemental Information"):

✔ wet freeze	___ wet-dry freeze	___ dry freeze
___ wet freeze-thaw	___ wet-dry freeze-thaw	___ dry freeze-thaw
___ wet nonfreeze	___ wet-dry nonfreeze	___ dry nonfreeze

Estimated Annual Temperature Range (degrees Fahrenheit): 68.5

Mean Annual Precipitation (inches) (See precipitation map in "Supplemental Information"): 37

Corps of Engineers Freezing Index (Fahrenheit degree-days) (See Freezing Index map in "Supplemental Information"): 250

Construction

Year Constructed: 1963

Slab Thickness (inches): 8

Width of Traffic Lanes (feet): 12

PCC Modulus of Rupture (28 days, 3rd-point loading)(psi): 650

Amount of Longitudinal Steel (percent of slab cross-sectional area) (See wire size table in "Supplemental Information"): 0.61

Figure 9. Project survey sheets for I-57 example.

Longitudinal Joints

Method Used to Form Longitudinal Joints Between Lanes:
__✓__ sawing
_____ inserts

Longitudinal Joint Sawed or Formed Depth (inches): __2__

Base

Type of Base Course:
_____ fine-grained soil only
_____ cement-treated aggregate
_____ lean PCC
__✓__ dense-graded untreated aggregate
_____ asphalt-treated aggregate
_____ open-graded drainage layer

Modulus of Subgrade Reaction on Top of Base (psi/inch) (See k-value correlation chart in "Supplemental Information"): __130__

Subgrade

Predominant Subgrade Soil AASHTO Classification (See Unified-AASHTO conversion table in "Supplemental Information"): __A-6__

Are swelling soils a problem in your area? _____ yes __✓__ no

If so, were steps taken in construction of the pavement to correct the swelling soil problem? _____ yes _____ no

Shoulder

Type of Shoulder:
__✓__ AC
_____ tied PCC

Width of Shoulders (feet): __6__ inner __10__ outer

Inner Lane Slope Direction:
__✓__ toward outer lane
_____ toward inner shoulder

Traffic

Estimated Current Through Two-way ADT: __16,500__

Percent Commercial Trucks (excluding pickups and panels): __20__

Total Number of Lanes in Direction of Survey: __2__

Future Truck Traffic Volume Growth Rate (percent increase per year): __4__

Figure 9. Project survey sheets for I-57 example (continued).

Total Accumulated 18-kip Equivalent Single Axle Loads (ESALs) from Date of Construction to Date of Survey (millions) (See procedure for computing ESALs in AASHTO <u>Guide for Design of Pavement Structures</u>, Appendix D, 1986):

LANE TWO (inner)	LANE ONE (outer)
0.9	8.0

Figure 9. Project survey sheets for I-57 example (continued).

PROJECT MONITORING DATA

Ride Quality

Rate the ride quality of the pavement in each lane during a drive over the entire project at the posted speed limit. Two or more people should participate in the survey. Obtain ratings for each lane from each person and report the average value below.

```
0         1         2         3         4         5
+---------+---------+---------+---------+---------+
 Very Poor  Poor      Fair      Good     Very Good
```

	LANE TWO (inner)	LANE ONE (outer)
Ride quality	3.5	2.8

Terminal Treatments

Stop at the beginning and end of the project where the pavement abuts different pavement types, and also at each bridge which the pavement abuts within the project, and observe the condition of the terminal treatments present.

	LANE TWO (inner)	LANE ONE (outer)
Number of deteriorated anchor lug terminal treatments (i.e., M-E roughness due to rotation of anchor lugs):	0	0
Number of expansion joint terminal treatments which are completely closed:	0	0

Figure 9. Project survey sheets for I-57 example (continued).

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately one half mile is recommended for each sample unit surveyed. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: 1 Starting Milepost: 230.7 (sta. 255+00) Length of Sample Unit (feet): 2640 (0.5 mile)

Failures

	LANE TWO (inner)	LANE ONE (outer)
Number of deteriorated transverse cracks, M-H only:	1	4
Number of full-depth repairs:	0	13
Number of deteriorated full-depth repairs, M-H only:	0	3
Number of punchouts:	0	10
Number of deteriorated construction joints (M-H only):	0	0

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	0	0
Total length of longitudinal joint spalling, M-H only (feet):		0

What is the general condition of the longitudinal joint sealant?

___ L

___ M

✓ H

Transverse Crack Spacing

Select a section of the pavement several hundred feet long for determining the transverse crack spacing. Measure the section with a wheel and count the number of transverse cracks observed.

Length of section:	500	500
Number of transverse cracks:	49	49

Figure 9. Project survey sheets for I-57 example (continued).

	LANE TWO (inner)	LANE ONE (outer)
Foundation Movement		
Number of settlements (M-H only):	0	0
Number of heaves (M-H only):	0	0
Drainage		
Are longitudinal subdrains present and functional along the sample unit?.	✓ yes	___ no
What is the typical height of the pavement surface above the side ditchline (feet)?	8	
Do the ditches have standing water or cattails in them?	✓ yes	___ no
Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):	✓ N ___ L ___ M ___ H	___ N ___ L ✓ M ___ H
Surface Condition		
Method used to texture the pavement surface at construction: ___ transverse tining ✓ other		
Is the surface polished smooth in the wheelpaths?	___ yes ✓ no	✓ yes ___ no
Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?	___ yes ✓ no	___ yes ✓ no
Concrete Durability		
Number of areas spalled (M-H only) due to "D" cracking:	0	0
Number of areas spalled (M-H only) due to reactive aggregate distress:	0	0
Extent of scaling (indicate highest severity level present):	✓ N ___ L ___ M ___ H	✓ N ___ L ___ M ___ H
Previous Repair		
Has diamond grinding been done?	___ yes ✓ no	___ yes ✓ no
Has grooving been done?	___ yes ✓ no	___ yes ✓ no

Figure 9. Project survey sheets for I-57 example (continued).

	INNER SHOULDER	OUTER SHOULDER
<u>AC Shoulders</u> (Check all that apply.)		
Alligator cracking	✔ none	✔ none
	___ some	___ some
	___ extensive	___ extensive
Linear cracking	✔ none	___ none
	___ some	✔ some
	___ extensive	___ extensive
Weathering/ravelling	___ none	___ none
	✔ some	✔ some
	___ extensive	___ extensive
Lane/shoulder joint dropoff	✔ none	✔ none
	___ <1"	___ <1"
	___ ≥1"	___ ≥1"
Settlements or heaves along outer edge	✔ none	✔ none
	___ some	___ some
	___ extensive	___ extensive
Blowholes at transverse joints	___ none	___ none
	✔ some	✔ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	✔ poor	✔ poor
<u>PCC Shoulders</u> (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
"D" cracking or reactive aggregate distress	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Settlements or heaves along outer edge	___ none	___ none
	___ some	___ some
	___ extensive	___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good	___ good
	___ poor	___ poor

Figure 9. Project survey sheets for I-57 example (continued).

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately one half mile is recommended for each sample unit surveyed. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: 2 Starting Milepost: 231 Length of Sample Unit (feet): 2640 (0.5 mile)

Failures

	LANE TWO (inner)	LANE ONE (outer)
Number of deteriorated transverse cracks, M-H only:	0	3
Number of full-depth repairs:	1	1
Number of deteriorated full-depth repairs, M-H only:	1	0
Number of punchouts:	0	4
Number of deteriorated construction joints (M-H only):	0	0

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	0	0
Total length of longitudinal joint spalling, M-H only (feet):		0

What is the general condition of the longitudinal joint sealant?

___ L
___ M
✓ H

Transverse Crack Spacing

Select a section of the pavement several hundred feet long for determining the transverse crack spacing. Measure the section with a wheel and count the number of transverse cracks observed.

Length of section:	500	500
Number of transverse cracks:	49	49

Figure 9. Project survey sheets for I-57 example (continued).

	LANE TWO (inner)	LANE ONE (outer)

Foundation Movement

	LANE TWO (inner)	LANE ONE (outer)
Number of settlements (M-H only):	0	0
Number of heaves (M-H only):	0	0

Drainage

Are longitudinal subdrains present and functional along the sample unit? ✔ yes ____ no

What is the typical height of the pavement surface above the side ditchline (feet)? 8

Do the ditches have standing water or cattails in them? ✔ yes ____ no

Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):	LANE TWO (inner)	LANE ONE (outer)
N	✔	✔
L		
M		
H		

Surface Condition

Method used to texture the pavement surface at construction:
____ transverse tining
✔ other

	LANE TWO (inner)	LANE ONE (outer)
Is the surface polished smooth in the wheelpaths?	no ✔	yes ✔
Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?	no ✔	no ✔

Concrete Durability

	LANE TWO (inner)	LANE ONE (outer)
Number of areas spalled (M-H only) due to "D" cracking:	0	0
Number of areas spalled (M-H only) due to reactive aggregate distress:	0	0

Extent of scaling (indicate highest severity level present):	LANE TWO (inner)	LANE ONE (outer)
N	✔	✔
L		
M		
H		

Previous Repair

	LANE TWO (inner)	LANE ONE (outer)
Has diamond grinding been done?	no ✔	no ✔
Has grooving been done?	no ✔	no ✔

Figure 9. Project survey sheets for I-57 example (continued).

	INNER SHOULDER	OUTER SHOULDER
AC Shoulders (Check all that apply.)		
Alligator cracking	✔ none ___ some ___ extensive	✔ none ___ some ___ extensive
Linear cracking	✔ none ___ some ___ extensive	___ none ✔ some ___ extensive
Weathering/ravelling	✔ none ___ some ___ extensive	✔ none ___ some ___ extensive
Lane/shoulder joint dropoff	✔ none ___ <1" ___ ≥1"	✔ none ___ <1" ___ ≥1"
Settlements or heaves along outer edge	✔ none ___ some ___ extensive	✔ none ___ some ___ extensive
Blowholes at transverse joints	___ none ✔ some ___ extensive	___ none ✔ some ___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good ✔ poor	___ good ✔ poor
PCC Shoulders (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none ___ some ___ extensive	___ none ___ some ___ extensive
"D" cracking or reactive aggregate distress	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Settlements or heaves along outer edge	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good ___ poor	___ good ___ poor

Figure 9. Project survey sheets for I-57 example (continued).

This is performed with the following equation:

$$\text{Average Per Mile} = \left(\sum_{i=1}^{n} \frac{\text{value}_i * 5280}{\text{length}_i} \right) * \frac{1}{n}$$

where: n = number of sample units

value_i = quantity of data item to be averaged in sample unit i

length_i = length of sample unit i, feet

Using this equation, the following extrapolated quantities were computed for I-57 for the data items with nonzero values (rounded to the nearest whole number):

Data Item	Extrapolated Quantity inner lane	Extrapolated Quantity outer lane
Punchouts	0 / mile	14 / mile
Deteriorated transverse cracks	1 / mile	7 / mile
Full-depth repairs	1 / mile	14 / mile
Deteriorated full-depth repairs	1 / mile	3 / mile
Transverse crack spacing	10.2 ft [3.1 m]	10.2 ft [3.1 m]

6.2.2 Toggle Values

For CRCP, the following toggle data items must be extrapolated:

- Pumping.
- Polished wheelpaths.
- Studded tire rutting.
- Previously performed grinding.
- Previously performed grooving.
- Longitudinal joint sealant damage.
- Scaling.
- Shoulder distresses.

Extrapolation of toggle data items is performed by converting the toggle values given in each sample unit to numerical values (e.g., none = 1, some = 2, and extensive = 3), averaging the numerical values, and rounding off the result to the nearest whole number.

6.3 EVALUATION OF PRESENT CONDITION

Evaluation of a CRCP project is conducted using the evaluation decision trees developed for the following nine problem areas:

1. Structural adequacy.
2. Drainage.
3. Foundation movement.

4. Durability.
5. Skid resistance.
6. Roughness.
7. Longitudinal joint construction and sealant condition.
8. Construction joints and terminal treatments.
9. Shoulders.

As described in chapter 3, certain critical distress and serviceability levels in the evaluation decision trees are subject to modification by the engineer. The levels which may be modified for CRCP and their default values are shown below. The evaluation conclusions reached for for the I-57 example using the default critical distress and PSR levels are shown in figure 10.

Types of physical testing recommended for I-57 include nondestructive testing for structural analysis, crack load transfer, and void detection; and coring and materials evaluation for structural analysis. Roughness and skid resistance deficiencies were noted in the evaluation, but since the pavement requires a structural improvement, roughness and skid measurement are not warranted.

Distress/Serviceability	Default Critical Level
PSR	2.0 for ADT ≤ 3,000 2.5 for 3,000 < ADT ≤ 10,000 3.0 for ADT > 10,000
Settlements	5 per mile
Heaves	5 per mile
Failures (punchouts, full-depth repairs, and deteriorated transverse cracks)	10 per mile
Longitudinal cracking	500 feet per mile

[1 in = 2.54 cm, 1 ft = 0.3048 m, 1 mile = 1.61 km]

6.4 PREDICTION OF FUTURE CONDITION

The predictive model given in appendix C3 for CRCP failures (punchouts, deteriorated transverse cracks, and full-depth repairs) was used to predict the future condition of I-57 without rehabilitation. The model was calibrated to the existing condition of the pavement at the time of the survey (1986). The results for I-57 are shown in table 19.

The future predictions are used to reevaluate the pavement each year for 20 years into the future, and identify the years in which the predicted number of failures will reach a critical level. The critical level used here is the same as that used in the evaluation of the pavement's present condition (for the I-57 example, the default values were used). The results are shown in figure 11.

6.5 REHABILITATION STRATEGY DEVELOPMENT

One or more rehabilitation strategies can be developed for a CRCP project using the decision trees provided in appendix C4. The procedure for developing a rehabilitation strategy is thoroughly described in chapter 3.

Figure 10. Evaluation of present condition for I-57 example.

CURRENT PAVEMENT EVALUATION

****
LANE 1
****

CONSTRUCTION JOINTS AND TERMINAL TREATMENTS:

No construction joint or terminal treatment deficiency is indicated in lane 1.

a. do nothing

LONGITUDINAL JOINT CONSTRUCTION AND SEALANT CONDITION:

Pavement deterioration in lane 1 may be accelerated by water infiltration permitted by poor longitudinal joint sealant condition.

a. reseal longitudinal joint

The pavement in lane 1 shows no indications of a longitudinal joint construction deficiency.

a. do nothing

ROUGHNESS:

Poor rideability in lane 1 is indicated by 10 or more punchouts and/or deteriorated transverse cracks and/or full-depth repairs and/or deteriorated construction joints per mile, and an unacceptably low PSR for the pavement's ADT level.

a. full-depth repair of slab failures
b. non-structural overlay

DURABILITY:

The pavement in lane 1 shows no indications of significant surface or concrete durability problems.

a. do nothing

STRUCTURAL DEFICIENCY:

Structural deficiency of the pavement is indicated in lane 1 by 10 or more punchouts and/or deteriorated transverse cracks and/or full-depth repairs and/or deteriorated construction joints per mile.

a. full-depth repair of slab failures, AC structural overlay
b. full-depth repair of slab failures, PCC bonded overlay
c. full-depth repair of slab failures, PCC unbonded overlay
c. reconstruct

Figure 10. Evaluation of present condition for I-57 example (continued).

SKID RESISTANCE:

Loss of skid resistance in lane 1 is indicated by polished wheel paths.

a. grooving
b. AC nonstructural overlay

FOUNDATION MOVEMENT:

A potential for frost heave is indicated by a mean Freezing Index greater than 0.

a. do nothing

DRAINAGE:

A drainage deficiency is indicated in lane 1 by medium- to high-severity pumping occurring in a wet or wet-dry climate.

a. install or repair longitudinal subdrains, subseal

****
LANE 2
****

CONSTRUCTION JOINTS AND TERMINAL TREATMENTS:

No construction joint or terminal treatment deficiency is indicated in lane 2.

a. do nothing

ROUGHNESS:

Rideability in lane 2 is acceptable.

a. do nothing

DURABILITY:

The pavement in lane 2 shows no indications of significant surface or concrete durability problems.

a. do nothing

Figure 10. Evaluation of present condition for I-57 example (continued).

STRUCTURAL DEFICIENCY:

A potential structural deficiency of the pavement in lane 2 is indicated by between 1 and 9 punchouts and/or deteriorated transverse cracks and/or full-depth repairs and/or deteriorated construction joints per mile.

a. full-depth repair of slab failures

A potential structural deficiency of the pavement in lane 2, in the form of a high probability for transverse crack deterioration, is indicated by an average transverse crack spacing of more than 10.0 feet.

a. do nothing

SKID RESISTANCE:

The method used to texture the original pavement surface may contribute to loss of skid resistance in lane 2 in the future.

a. do nothing

FOUNDATION MOVEMENT:

A potential for frost heave is indicated by a mean Freezing Index greater than 0.

a. do nothing

DRAINAGE:

The pavement in lane 2 shows no indications of a drainage deficiency.

a. do nothing

****
INNER SHOULDER
****

Excessive infiltration of water beneath the pavement and inner AC shoulder is indicated by poor lane/shoulder joint sealant condition.

a. reseal lane/shoulder joint
b. do nothing

****
OUTER SHOULDER
****

Excessive infiltration of water beneath the pavement and outer AC shoulder is indicated by poor lane/shoulder joint sealant condition.

a. reseal lane/shoulder joint
b. do nothing

Table 19. Future condition predictions for I-57 example.

TOTAL FAILURE PROJECTIONS FOR LANE 1

Cumulative ESAL	Annual ESAL	Year	Total Failures
8.0	0.57	1986	35
8.6	0.60	1987	36
9.2	0.63	1988	37
9.9	0.66	1989	38
10.6	0.69	1990	39
11.3	0.73	1991	40
12.1	0.76	1992	41
12.9	0.80	1993	43
13.7	0.84	1994	45
14.6	0.88	1995	47
15.5	0.93	1996	49
16.5	0.97	1997	51
17.5	1.02	1998	54
18.6	1.07	1999	57
19.7	1.13	2000	61
20.9	1.18	2001	64
22.1	1.24	2002	69
23.4	1.31	2003	73
24.8	1.37	2004	78
26.3	1.44	2005	84
18-kip millions	18-kip millions		per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Table 19. Future condition predictions for I-57 example (continued).

TOTAL FAILURE PROJECTIONS FOR LANE 2

Cumulative ESAL	Annual ESAL	Year	Total Failures
0.9	0.12	1986	2
1.0	0.13	1987	2
1.2	0.14	1988	2
1.3	0.14	1989	2
1.5	0.15	1990	2
1.6	0.16	1991	2
1.8	0.17	1992	2
2.0	0.17	1993	2
2.1	0.18	1994	2
2.3	0.19	1995	2
2.5	0.20	1996	2
2.7	0.21	1997	3
3.0	0.22	1998	3
3.2	0.23	1999	3
3.4	0.24	2000	3
3.7	0.26	2001	3
4.0	0.27	2002	3
4.2	0.28	2003	3
4.5	0.30	2004	4
4.9	0.31	2005	4
18-kip millions	18-kip millions		per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Figure 11. Evaluation of future condition of I-57 without rehabilitation.

FUTURE PAVEMENT EVALUATION

****
LANE 1
****

STRUCTURAL DEFICIENCY:

An excessive number of failures in lane 1 occurs in 1986.

a. full-depth repair of slab failures, AC structural overlay
b. full-depth repair of slab failures, PCC bonded overlay
c. full-depth repair of slab failures, PCC unbonded overlay
d. reconstruct lane

****
LANE 2
****

STRUCTURAL DEFICIENCY:

Lane 2 is not predicted to produce an excessive number of failures over the next 20 years.

The evaluation results show that the outer lane of the I-57 example project currently has a sufficient number of failures per mile to indicate a structural deficiency, thus requiring a structural improvement. The inner lane does not exhibit a structural deficiency, and could probably perform well without a structural improvement for several more years. Therefore, the following types of rehabilitation strategies are feasible for this project:

- AC structural overlay.
- PCC bonded overlay.
- PCC unbonded overlay.
- Reconstruct outer lane, restore inner lane.
- Reconstruct both lanes.

The AC structural overlay, PCC bonded overlay, and reconstruct/restore options were investigated for the I-57 example.

The predictive models provided in appendix C5 are used to predict the performance of the rehabilitation strategies developed. These models include rutting of AC overlays, reflection crack deterioration of AC overlays and failures of bonded PCC overlays.

6.5.1 AC Structural Overlay Alternative

The rehabilitation techniques and associated quantities making up an AC structural overlay rehabilitation alternative for I-57 are given in table 20. An appropriate overlay thickness which will satisfy structural requirements must be selected by the engineer. Table 21 illustrates the predicted performance for an overlay thickness of 4 inches [10.2 cm].

Reflection cracking is predicted to develop at about the same rate in both lanes, but rutting develops almost twice as fast in the outer lane as in the inner lane. Rutting is predicted to reach a critical level of 0.50 in [1.27 cm] in the outer lane in 18 years. The equivalent annual cost over the 5.2-mile project length is $ 134,909.

6.5.2 Bonded Concrete Overlay Alternative

The list of techniques and associated quantities which would be included in a bonded concrete overlay rehabilitation alternative for I-57 are given in table 22. Table 23 illustrates the predicted performance for a bonded PCC overlay thickness of 4 in [10.2 cm]. Other overlay thicknesses could be investigated as well.

The bonded PCC overlay alternative is predicted to perform well. The predicted number of faiures (punchouts, full-depth repairs and deteriorated transverse cracks) is predicted to reach a critical level in about 18 years. The equivalent annual cost of this strategy is $ 249,930.

Table 20. AC structural overlay strategy for I-57 example.

Complete Rehabilitation Strategy for Outer Lane:

Full-depth repair of failures	995 sq yards
AC structural overlay	36467 sq yards
Reseal longitudinal joint	27350 feet
Install/repair longitudinal subdrains	27350 feet

Complete Rehabilitation Strategy for Inner Lane:

Full-depth repair of failures	83 sq yards
AC structural overlay	36467 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

AC overlay	30389 sq yards
Reseal lane/shoulder joint	27350 feet

Complete Rehabilitation Strategy for Inner Shoulder:

AC overlay	18234 sq yards
Reseal lane/shoulder joint	27350 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 21. AC overlay performance prediction for I-57 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING AC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0.00
1987	1	0.60	0	0.01
1988	2	1.23	1	0.03
1989	3	1.88	1	0.06
1990	4	2.58	2	0.08
1991	5	3.30	2	0.11
1992	6	4.07	3	0.14
1993	7	4.87	3	0.17
1994	8	5.71	3	0.19
1995	9	6.59	4	0.22
1996	10	7.52	4	0.25
1997	11	8.49	5	0.29
1998	12	9.52	5	0.32
1999	13	10.59	6	0.35
2000	14	11.72	6	0.38
2001	15	12.90	6	0.42
2002	16	14.14	7	0.46
2003	17	15.45	7	0.49
2004	18	16.82	8	0.53
2005	19	18.26	8	0.57
		18-kip millions	Number per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Deteriorated reflective cracking of the AC overlay in lane 1 is not predicted to reach an unacceptable level within the next twenty years.

Rutting on the AC overlay in lane 1 is predicted to equal or exceed an unacceptable level of 0.50 inches in 2004.

Table 21. AC overlay performance prediction for I-57 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING AC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	MEDIUM-HIGH REFLECTIVE CRACKING	RUTTING
1986	0	0.00	0	0.00
1987	1	0.13	0	0.00
1988	2	0.27	1	0.01
1989	3	0.41	1	0.03
1990	4	0.56	2	0.05
1991	5	0.71	2	0.06
1992	6	0.88	3	0.08
1993	7	1.05	3	0.09
1994	8	1.24	3	0.11
1995	9	1.43	4	0.12
1996	10	1.63	4	0.14
1997	11	1.84	5	0.16
1998	12	2.06	5	0.17
1999	13	2.29	6	0.19
2000	14	2.54	6	0.21
2001	15	2.79	6	0.23
2002	16	3.06	7	0.24
2003	17	3.34	7	0.26
2004	18	3.64	8	0.28
2005	19	3.95	8	0.30
		18-kip millions	Number per mile	Inches

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Deteriorated reflective cracking of the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Rutting on the AC overlay in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

Table 22. Bonded concrete overlay strategy for I-57 example.

Complete Rehabilitation Strategy for Outer Lane:

Full-depth repair of failures	995 sq yards
Bonded PCC overlay	36467 sq yards
Reseal longitudinal joint	27350 feet
Install/repair longitudinal subdrains	27350 feet

Complete Rehabilitation Strategy for Inner Lane:

Full-depth repair of failures	83 sq yards
Bonded PCC overlay	36467 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

AC overlay	30389 sq yards
Reseal lane/shoulder joint	27350 feet

Complete Rehabilitation Strategy for Inner Shoulder:

AC overlay	18234 sq yards
Reseal lane/shoulder joint	27350 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 23. Bonded concrete overlay performance prediction for I-57 example.

PREDICTED PREFORMANCE FOR LANE 1 FOLLOWING BONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	FAILURES
1986	0	0.00	0
1987	1	0.60	0
1988	2	1.23	0
1989	3	1.88	0
1990	4	2.58	0
1991	5	3.30	0
1992	6	4.07	1
1993	7	4.87	1
1994	8	5.71	1
1995	9	6.59	2
1996	10	7.52	2
1997	11	8.49	3
1998	12	9.52	3
1999	13	10.59	4
2000	14	11.72	5
2001	15	12.90	6
2002	16	14.14	7
2003	17	15.45	9
2004	18	16.82	10
2005	19	18.26	12
		18-kip millions	number per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

Table 23. Bonded concrete overlay performance prediction for I-57 example (continued).

PREDICTED PREFORMANCE FOR LANE 2 FOLLOWING BONDED PCC OVERLAY

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	FAILURES
1986	0	0.00	0
1987	1	0.13	0
1988	2	0.27	0
1989	3	0.41	0
1990	4	0.56	0
1991	5	0.71	0
1992	6	0.88	0
1993	7	1.05	0
1994	8	1.24	0
1995	9	1.43	0
1996	10	1.63	0
1997	11	1.84	0
1998	12	2.06	0
1999	13	2.29	0
2000	14	2.54	0
2001	15	2.79	0
2002	16	3.06	0
2003	17	3.34	0
2004	18	3.64	0
2005	19	3.95	1
		18-kip millions	number per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

6.5.3 Reconstruct/Restore Alternative

The last alternative investigated for the I-57 example was reconstruction of the outer lane. This alternative seems intuitively to be very appropriate for this project, since there is significant structural damage in the outer lane (punchouts and deteriorated transverse cracks), but almost none of this type of deterioration in the inner lane.

The list of techniques and associated quantities which would be included in a reconstruct/restore rehabilitation alternative for I-57 are given in table 24. Note that very little rehabilitation work is required in the inner lane for this strategy. Table 25 illustrates the predicted performance for a 9-inch [22.9 cm] CRCP reconstructed outer lane, with 0.60 percent reinforcement, a stabilized base with an effective k value of 200 pci [5.5 kg/cubic cm], and deformed rebars. All of these parameters could be varied by the engineer to produce different alternatives with different costs and predicted lives.

This alternative design performs well for most of the prediction period. In the reconstructed outer lane, failures per mile are predicted to reach a critical level in 18 years. The restored inner lane is not expected to develop a critical number of failures within the next 20 years. The equivalent annual cost of this alternative is $ 114,485, substantially less than the bonded overlay cost and even less than the AC overlay cost.

6.6 REHABILITATION ALTERNATIVE SELECTION

The engineer could investigate several variations to the three basic options illustrated in this example, by changing one or more of the rehabilitation design parameters. The other two available options, unbonded concrete overlay and reconstruction of both lanes, could also be investigated.

It must be emphasized again that the responsibility for thickness design and reinforcement design to meet structural requirements rests with the engineer. The system will predict the performance of any design input by the engineer in terms of key distress types.

Having developed one or more candidate rehabilitation strategies, the engineer could then use EXPEAR to compute the life-cycle costs of the strategies and identify the most cost-effective strategy. Cost-effectiveness and other factors will probably enter into the final selection of the preferred rehabilitation strategy.

Table 24. Reconstruct/restore strategy for I-57 example.

Complete Rehabilitation Strategy for Outer Lane:

Reconstruction	36467 sq yards
Install/repair longitudinal subdrains	27350 feet

Complete Rehabilitation Strategy for Inner Lane:

Full-depth repair of slab failures	83 sq yards

Complete Rehabilitation Strategy for Outer Shoulder:

Reseal lane/shoulder joint	27350 feet

Complete Rehabilitation Strategy for Inner Shoulder:

Reseal lane/shoulder joint	27350 feet

[1 ft = 0.3048 m, 1 sq yard = 1.2 sq m, 1 cubic ft = 0.028 cubic m]

Table 25. Reconstruct/restore performance prediction for I-57 example.

PREDICTED PERFORMANCE FOR LANE 1 FOLLOWING RECONSTRUCTION

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	FAILURES
1986	0	0.00	0
1987	1	0.60	0
1988	2	1.23	0
1989	3	1.88	0
1990	4	2.58	0
1991	5	3.30	0
1992	6	4.07	1
1993	7	4.87	1
1994	8	5.71	1
1995	9	6.59	2
1996	10	7.52	2
1997	11	8.49	3
1998	12	9.52	3
1999	13	10.59	4
2000	14	11.72	5
2001	15	12.90	6
2002	16	14.14	7
2003	17	15.45	8
2004	18	16.82	10
2005	19	18.26	12
		18-kip millions	number per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Total failures on the reconstructed pavement in lane 1 are predicted to equal or exceed an unacceptable level of 10 failures per mile in 2004.

Table 25. Reconstruct/restore performance prediction for I-57 example (continued).

PREDICTED PERFORMANCE FOR LANE 2 FOLLOWING RESTORATION

YEAR(S) REHABILITATION WILL BE DELAYED : 0

YEAR	AGE	CUMULATIVE ESALs	FAILURES
1986	23	0.90	0
1987	24	1.03	0
1988	25	1.17	0
1989	26	1.31	0
1990	27	1.46	0
1991	28	1.61	0
1992	29	1.78	0
1993	30	1.95	0
1994	31	2.14	0
1995	32	2.33	0
1996	33	2.53	1
1997	34	2.74	1
1998	35	2.96	1
1999	36	3.19	1
2000	37	3.44	1
2001	38	3.69	1
2002	39	3.96	1
2003	40	4.24	1
2004	41	4.54	2
2005	42	4.85	2
		18-kip millions	number per mile

NOTE: These projections are estimates of expected performance based on predictive models. They should not be taken as exact values, but instead as relative indicators of performance.

SUMMARY:

Total failures on the restored pavement in lane 2 is not predicted to reach an unacceptable level within the next twenty years.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

A practical and comprehensive system to assist practicing engineers in the evaluation and rehabilitation of conventional concrete pavements (JPCP, JRCP and CRCP) has been developed. This was accomplished using a new and innovative approach that combines human expert knowledge and analytical techniques into a user-friendly personal computer program.

7.1 CONCLUSIONS

Concrete pavement evaluation and rehabilitation is a complex engineering problem which defies traditional analytical solutions, due to the large number of interacting factors involved, and the lack of adequate analytical models to solve all (or even most) aspects of the problem.

Successful concrete pavement evaluation and rehabilitation currently relies heavily on the knowledge and experience of experts in the pavement field for diagnosis of the causes of distress and selection of feasible rehabilitation techniques which cost-effectively correct the deterioration.

Concrete pavement evaluation and rehabilitation is an ideal subject for a knowledge-based system application, by which human expertise is compiled, formalized, and applied to evaluation and rehabilitation of specific concrete pavement projects.

A knowledge-based system for concrete pavement evaluation and rehabilitation must incorporate not only the rules but also the reasoning processes used by experts in order to reach conclusions about the pavement's condition in an efficient manner. The use of decision trees was found to adequately represent factual knowledge and reasoning processes and was easy to understand, examine and revise.

An evaluation procedure based on identifying mechanisms of deterioration rather than merely categorizing types of distress provides a better understanding of the causes of distress and the most appropriate rehabilitation techniques.

The selection of rehabilitation techniques and strategies can be effectively accomplished using a knowledge-based system.

The inclusion of analytical techniques in the form of prediction models was essential for the system to perform as desired. This permits the prediction of future pavement life of the existing pavement with no rehabilitation or with selected rehabilitation techniques. **The combining of the human knowledge base with analytical techniques helps to provide workable solutions for the evaluation and rehabilitation of concrete pavements.**

A knowledge-based system for concrete pavement evaluation and rehabilitation has been developed to the stage of a demonstration prototype. The system provided reasonable results in a few example applications, but has not been fully tested over a wide range of conditions. More than 30 months of professional person-effort was expended in the development of the system to this stage. The results achieved thus far demonstrate that the approach used shows great promise in assisting the practicing engineer in the difficult job of pavement evaluation and rehabilitation.

7.2 RECOMMENDATIONS

Extensive field testing, including review by State DOT personnel and case studies on concrete pavement projects throughout the United States, is needed to increase the quality, efficiency, speed and reliability of the system to the level of a research prototype. Each subtopic addressed by the system could be the subject of a major research study (e.g., subdrainage evaluation, loss of support evaluation, load transfer restoration needs). Further work in developing the system is continuing.

The following are some key items that need further development:

- **Life-cycle cost analysis.** The capability to compare rehabilitation strategy alternatives on the basis of life-cycle costs greatly increases the usefulness of the system. Ideally, the cost analysis should address unequal performance periods of different alternatives and should consider additional costs that cannot now be computed by the program (bridge clearance, guardrail replacement, side slope improvements, traffic control, user costs, etc.). A first step toward providing this capability is the addition of a simple life-cycle cost computation routine in EXPEAR 1.3.

- **Delay of rehabilitation.** The latest version of EXPEAR, 1.3, includes the capability to delay rehabilitation up to 5 years. Where appropriate, distress quantities are increased for each year of delay, using the predictive models where available or a constant factor (e.g., 5 percent per year) where models are not available.

- **Improved predictive models.** Many models were utilized to predict the future performance of the existing pavement without rehabilitation and the performance of the rehabilitated pavement. Most of these models have significant limitations, and are not applicable nationwide over the range of climatic zones. The development of improved models is a necessity to improve the validity of the system. These may best be developed for individual States or regions of the country (e.g., the southeastern United States). Eventually, reliable models will be provided by the SHRP/LTPP program. Existing models are most deficient in predicting the effect of retrofit subdrainage on performance of the rehabilitated pavement. In EXPEAR 1.3, some models have already been improved over those used in the original version of EXPEAR.

- **Other rehabilitation techniques.** The system does not yet consider some existing concrete pavement rehabilitation techniques for which performance prediction models are not available. Some key techniques which are not included are AC overlays with fabrics or interlayers, AC overlays with sawed and sealed joints, CRCP overlays, and reconstructed pavements with drainage layers.

- **Physical testing recommendations.** The importance of physical testing to concrete pavement evaluation and rehabilitation design is addressed to a limited extent in the current system. However, the improvement of the physical testing recommendations, and the incorporation of physical testing results directly into the evaluation procedure and the development of rehabilitation strategies remain among the most urgently needed improvements.

- **Extension of the system to existing AC overlaid concrete pavements.** The system currently is restricted to pavements in their first performance period. Many concrete pavements exist that have been overlaid with AC already and are in need of further rehabilitation. Work on this addition to the system is currently underway.

- **Extension of the system to other pavement geometries,** i.e., pavements with only one or more than two lanes in each direction. This would make the system more applicable to the variety of concrete pavements throughout the United States.

APPENDIX A1

PROJECT SURVEY FOR JRCP

Design Engineer: ______________________________

Date of Survey (mo/day/yr): ____ / ____ / ____

PROJECT INVENTORY DATA

Collect the following information about the project to be evaluated prior to the actual field survey.

Project Identification

Highway Designation (example I-57): ____________

State: ______________________________

Direction of Survey: ______________________

Starting Milepost: ________________________

Ending Milepost: __________________________

Climate

Climatic Zone (See climatic zone map in "Supplemental Information"):

_____ wet freeze	_____ wet-dry freeze	_____ dry freeze
_____ wet freeze-thaw	_____ wet-dry freeze-thaw	_____ dry freeze-thaw
_____ wet nonfreeze	_____ wet-dry nonfreeze	_____ dry nonfreeze

Estimated Annual Temperature Range (degrees Fahrenheit): __________

Mean Annual Precipitation (inches) (See precipitation map in "Supplemental Information"): ______________________

Corps of Engineers Freezing Index (Fahrenheit degree-days) (See Freezing Index map in "Supplemental Information"): ____________

Slab Construction

Year Constructed: ____________________

Slab Thickness (inches): ______________

Width of Traffic Lanes (feet): __________

PCC Modulus of Rupture (28 days, 3rd-point loading)(psi): __________

Area of Longitudinal Reinforcement (square inches steel/foot) (See wire size table in "Supplemental Information"): ____________

Transverse and Longitudinal Joints

Pattern of Joint Spacing:
_____ uniform
_____ random

Transverse joint spacing, if uniform (feet): ________________
Transverse joint sequence, if random (feet): ________________

Type of Sealant:
_____ liquid (asphalt)
_____ field-molded (silicone)
_____ preformed compression (neoprene)

Average Transverse Joint Sealant Reservoir Dimensions
Width (inches): ____________ Depth (inches): ____________

Method Used to Form Transverse Joints:
_____ sawing
_____ inserts
_____ Unitube inserts

Transverse Joint Sawed Depth (inches): ____________________________

Type of Load Transfer System:
_____ aggregate interlock only
_____ dowels
_____ other mechanical devices

If dowels are present, dowel bar diameter (inches): __________

Method Used to Form Longitudinal Joints Between Lanes:
_____ sawing
_____ inserts

Longitudinal Joint Sawed or Formed Depth (inches): ________________

Base

Type of Base Course:
_____ fine-grained soil only _____ dense-graded untreated aggregate
_____ cement-treated aggregate _____ asphalt-treated aggregate
_____ lean PCC _____ open-graded drainage layer

Modulus of Subgrade Reaction on Top of Base (psi/inch) (See k-value correlation chart in "Supplemental Information"): ________________

Subgrade

Predominant Subgrade Soil AASHTO Classification (See Unified-AASHTO conversion table in "Supplemental Information"): __________

Are swelling soils a problem in the area? ______ yes ______ no

If so, were steps taken in construction of the pavement to correct the swelling soil problem? ______ yes ______ no

Shoulder

Type of Shoulder:
_____ AC
_____ tied PCC

Width of Shoulders (feet): __________ inner __________ outer

Inner Lane Slope Direction:
_____ toward outer lane
_____ toward inner shoulder

Traffic

Estimated Current Through Two-way ADT: __________

Percent Commercial Trucks (excluding pickups and panels): __________

Total Number of Lanes in Direction of Survey: __________

Future 18-kip ESAL Growth Rate (percent per year): __________

Total Accumulated 18-kip Equivalent Single Axle Loads (ESALs) from Date of Construction to Date of Survey (millions) (See procedure for computing ESALs in AASHTO Guide for Design of Pavement Structures, Appendix D, 1986):

LANE TWO (inner)	LANE ONE (outer)
__________	__________

PROJECT MONITORING DATA

Ride Quality

Rate the ride quality of the pavement in each lane during a drive over the entire project at the posted speed limit. Two or more people should participate in the survey. Obtain ratings for each lane from each person and report the average value below.

```
0         1        2        3        4         5
+---------+--------+--------+--------+---------+
Very Poor   Poor     Fair     Good   Very Good
```

LANE TWO (inner)	LANE ONE (outer)
________	________

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately 1000 feet in each mile is recommended for each sample unit surveyed. If only one sample unit is to be surveyed on the project, a length of at least a half mile is recommended. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: __________ Starting Milepost: __________ Length of Sample Unit (feet): __________

Use the tally sheet provided to record information on cracking, spalling, and full-depth repairs for each slab surveyed. Compute the totals and averages indicated on the tally sheet and record these values below.

	LANE TWO (inner)	LANE ONE (outer)
Number of deteriorated transverse cracks, M-H only:	______	______
Mean faulting at deteriorated transverse cracks (inches):	______	______
Number of deteriorated transverse joints, M-H including blowups:	______	______
Mean faulting at transverse joints (inches):	______	______
Number of transverse joints:	______	______
Mean faulting at full-depth repair joints (inches):	______	______
Number of full-depth repair joints:	______	______
Number of full-depth repairs:	______	______
Number of corner breaks:	______	______

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	______	______
Total length of longitudinal joint spalling, M-H only (feet):		______

	LANE TWO (inner)	LANE ONE (outer)

Cracking at Transverse Joints

Number of transverse joints with transverse cracks within 2 feet: ______ ______

Foundation Movement

Number of settlements (M-H only): ______ ______

Number of heaves (M-H only): ______ ______

Drainage

Are longitudinal subdrains present and functional along the sample unit? ______ yes ______ no

What is the typical height of the pavement surface above the side ditchline (feet)? ______________

Do the ditches have standing water or cattails in them? ______ yes ______ no

Loss of Support

Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):

	LANE TWO (inner)	LANE ONE (outer)
	____ N	____ N
	____ L	____ L
	____ M	____ M
	____ H	____ H

Surface Condition

Method used to texture the pavement surface at construction:

____ transverse tining

____ other

Is the surface polished smooth in the wheelpaths?

	LANE TWO (inner)	LANE ONE (outer)
	___ yes	___ yes
	___ no	___ no

Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?

	LANE TWO (inner)	LANE ONE (outer)
	___ yes	___ yes
	___ no	___ no

Joint Sealant Condition

What is the general condition of the transverse joint sealant?

	LANE TWO (inner)	LANE ONE (outer)
	____ L	____ L
	____ M	____ M
	____ H	____ H

What is the general condition of the longitudinal joint sealant?

____ L

____ M

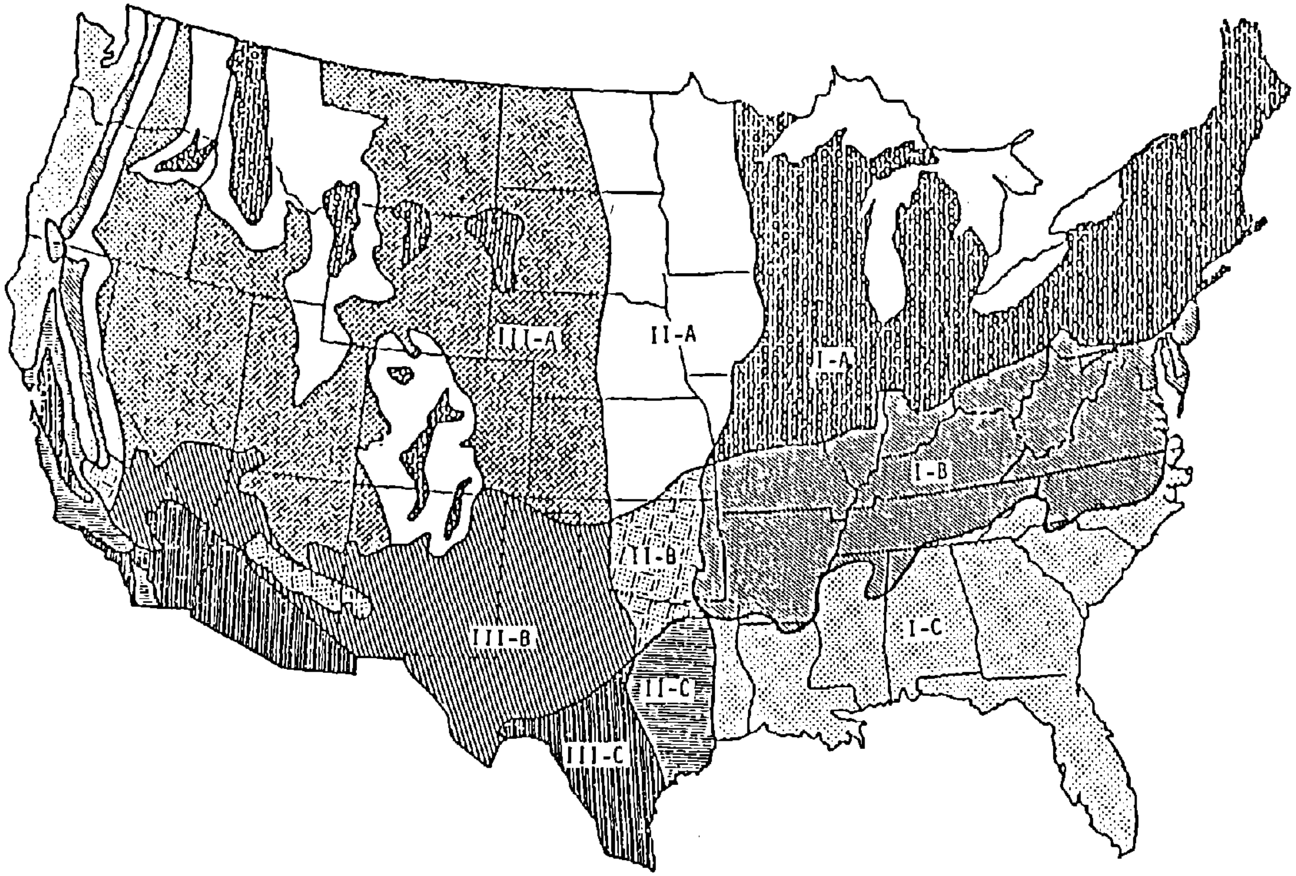
____ H

Are substantial amounts of incompressibles visible in the transverse joints?

	LANE TWO (inner)	LANE ONE (outer)
	___ yes	___ yes
	___ no	___ no

	LANE TWO (inner)	LANE ONE (outer)
Concrete Durability		
Extent of "D" cracking at joints and cracks (indicate highest severity level present in sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Extent of reactive aggregate distress (indicate highest severity level present in sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Extent of scaling (indicate highest severity level present in sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Previous Repair		
If full-depth repairs are present, are they dowelled?	___ yes ___ no	___ yes ___ no
Are partial-depth repairs (rigid material only) present at most of the joints?	___ yes ___ no	___ yes ___ no
Has diamond grinding been done?	___ yes ___ no	___ yes ___ no
Has grooving been done?	___ yes ___ no	___ yes ___ no

	INNER SHOULDER	OUTER SHOULDER
AC Shoulders (Check all that apply.)		
Alligator cracking	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Linear cracking	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Weathering/ravelling	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint dropoff	___ none ___ <1" ___ ≥1"	___ none ___ <1" ___ ≥1"
Settlements or heaves along outer edge	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Blowholes at transverse joints	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good ___ poor	___ good ___ poor
PCC Shoulders (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none ___ some ___ extensive	___ none ___ some ___ extensive
"D" cracking or reactive aggregate distress	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Settlements or heaves along outer edge	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good ___ poor	___ good ___ poor



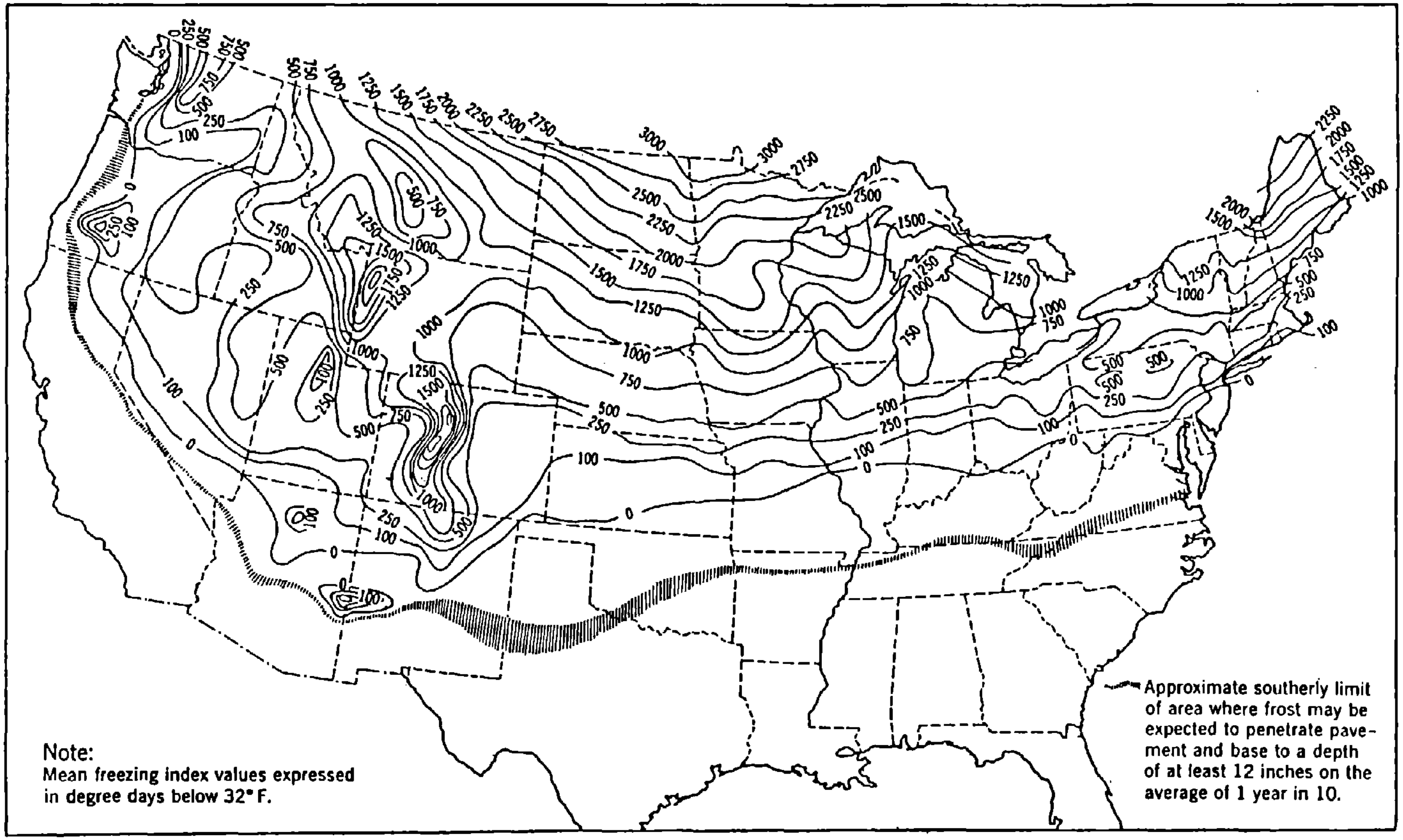
Moisture Zones:

I = wet
II = wet-dry
III = dry

Temperature Zones:

A = freeze
B = freeze-thaw
C = nonfreeze

Climatic Zone Map of the United States. Source: "A Pavement Moisture-Accelerated Distress (MAD) Identification System," FHWA/RD-81/079-80, 1981.



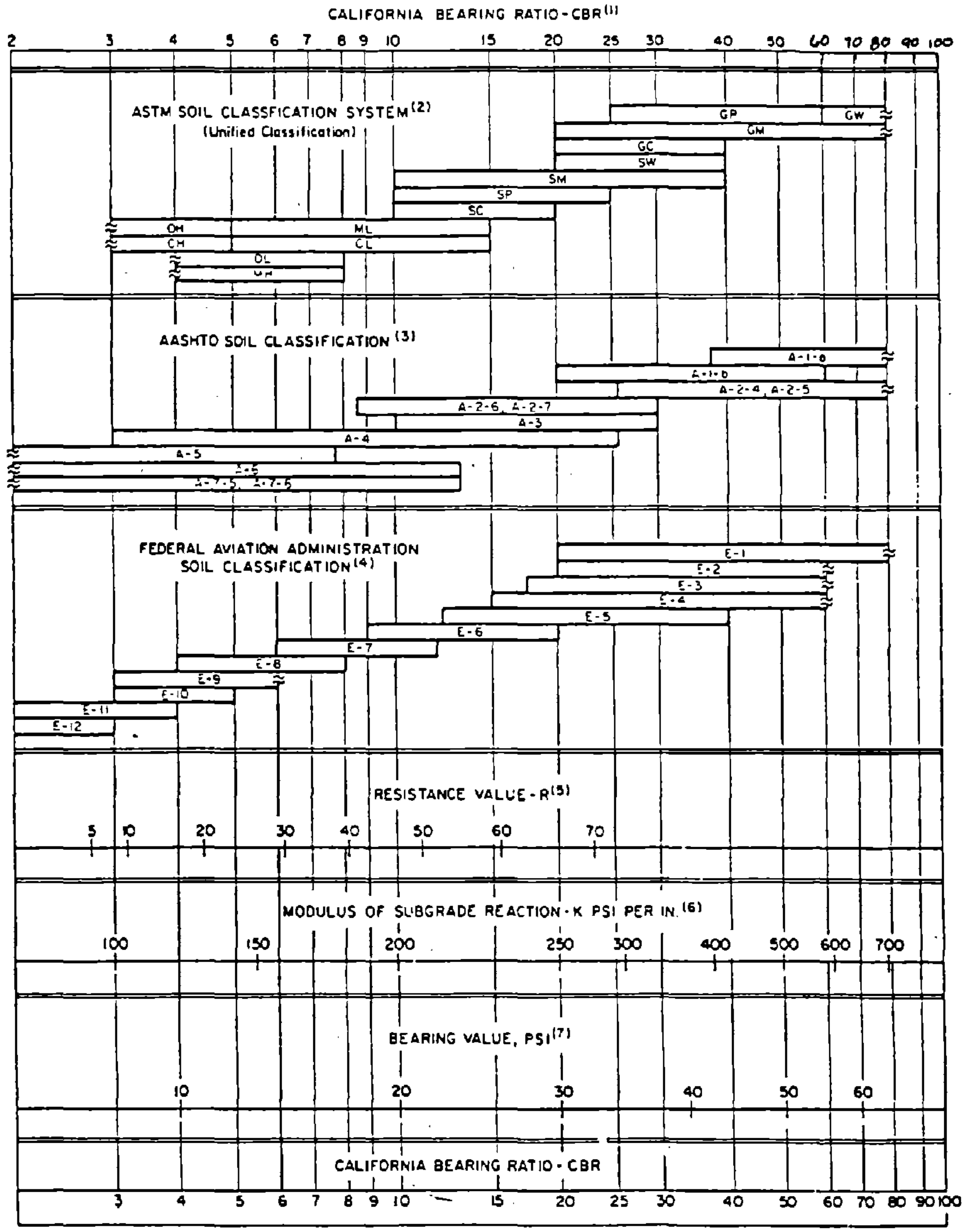
Freezing Index (Fahrenheit Degree-Days), Source: "Engineering and Design, Pavement Design for Frost Conditions", Corps of Engineers EM 1110-345-306

WIRE SIZES, WEIGHTS AND STEEL AREAS PER FT. OF WIDTH

Wire Size Number		Nominal Diameter, Inches	Nominal Weight Lbs./Lin. Ft.	Cross Sectional Areas, Sq. In. Per Lin. Ft. — Center to Center Spacing						
Smooth	Deformed			2"	3"	4"	6"	8"	10"	12"
W31	D31	0.628	1.054	1.86	1.24	.93	.62	.465	.372	.31
W30	D30	0.618	1.020	1.80	1.20	.90	.60	.45	.36	.30
W28	D28	0.597	.952	1.68	1.12	.84	.56	.42	.336	.28
W26	D26	0.575	.934	1.56	1.04	.78	.52	.39	.312	.26
W24	D24	0.553	.816	1.44	.96	.72	.48	.36	.288	.24
W22	D22	0.529	.748	1.32	.88	.66	.44	.33	.264	.22
W20	D20	0.504	.680	1.20	.80	.60	.40	.30	.24	.20
W18	D18	0.478	.612	1.08	.72	.54	.36	.27	.216	.18
W16	D16	0.451	.544	.96	.64	.48	.32	.24	.192	.16
W14	D14	0.422	.476	.84	.56	.42	.28	.21	.168	.14
W12	D12	0.390	.408	.72	.48	.36	.24	.18	.144	.12
W11	D11	0.374	.374	.66	.44	.33	.22	.165	.132	.11
W10.5		0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5		0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5		0.329	.289	.51	.34	.255	.17	.127	.102	.085
W8	D8	0.319	.272	.48	.32	.24	.16	.12	.096	.08
W7.5		0.309	.255	.45	.30	.225	.15	.112	.09	.075
W7	D7	0.298	.238	.42	.28	.21	.14	.105	.084	.07
W6.5		0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5		0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5		0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04

NOTE: Wire sizes other than those listed above may be produced provided the quantity required is sufficient to justify manufacture

Area of Reinforcement (Square Inches of Steel/Foot), Source: Concrete Reinforcing Steel Institute.



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, pages 100-136.
(2) ASTM Designation D2487.
(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting*, 1945, Vol. 25, pages 376-392.
(4) *Airport Paving*, U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements*.(Formerly used FAA Classification; Unified Classification now used.)
(5) C. E. Warnes, "Correlation Between *R* Value and *k* Value," unpublished report, Portland Cement Association, Rocky Mountain-Northwest Region, October 1971 (best-fit correlation with correction for saturation).
(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, page 152.

Subgrade K-value Correlation to Soil Classifications and Bearing Values. Source: "Thickness Design for Concrete Highway and Street Pavements", Portland Cement Association

BASE TYPE

- fine-grained soil only: use k-value of subgrade soil

- dense-graded aggregate

Subgrade k-value, (psi/in)	Subbase Thickness, in 4	6	9	12
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

- cement or asphalt treated aggregate, lean concrete

Subgrade k-value, (psi/in)	Subbase Thickness, in 4	6	8	10
50	170	230	310	390
100	280	400	520	640
200	470	640	830	---

k-value on top of base course (directly beneath PCC slab)
Source: "Thickness Design for Concrete Highway and Street Pavements," Portland Cement Association

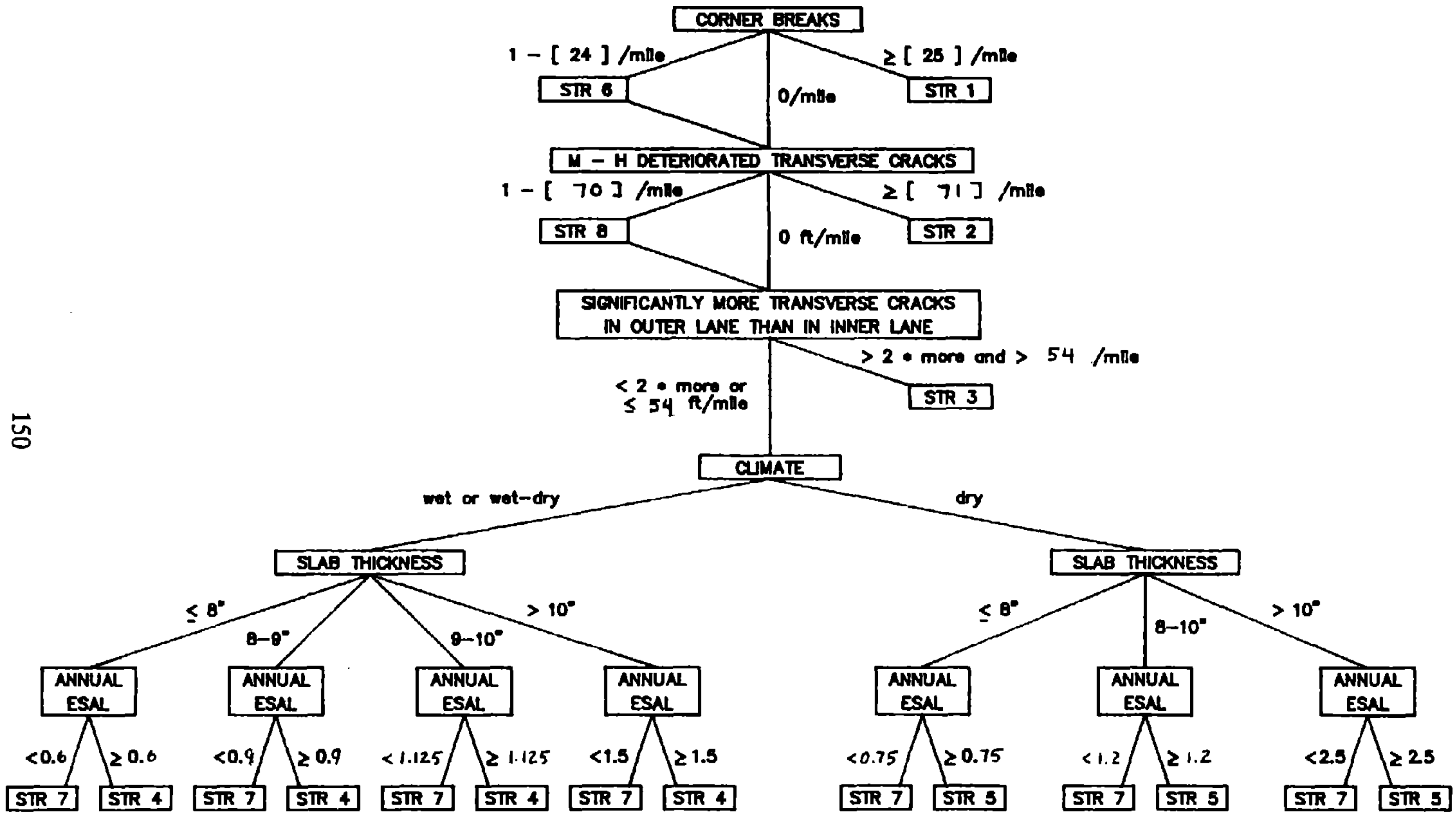
APPENDIX A2

EVALUATION DECISION TREES AND CONCLUSIONS FOR JRCP

Major Problem Areas for JRCP

1. Structural Adequacy
2. Drainage
3. Foundation Movement
4. Durability
5. Skid Resistance
6. Roughness
7. Joint Construction
8. Joint Sealant
9. Load Transfer
10. Loss of Support
11. Joint Deterioration
12. Shoulder

JRCP STRUCTURAL DEFICIENCY



* Annual ESAL in millions

Structural Adequacy

STR 1 Structural deficiency of the pavement is indicated by [25] or more corner breaks per mile.

(a) full-depth repair of corner breaks, AC structural overlay
(b) full-depth repair of corner breaks, crack and seat and AC structural overlay
(c) full-depth repair of corner breaks, PCC bonded overlay
(d) full-depth repair of corner breaks, PCC unbonded overlay
(e) reconstruct

STR 2 Structural deficiency of the pavement is indicated by [850] or more feet of deteriorated transverse cracks per mile.

(a) full-depth repair of cracks, AC structural overlay
(b) full-depth repair of cracks, crack and seat and AC structural overlay
(c) full-depth repair of cracks, PCC bonded overlay
(d) full-depth repair of cracks, PCC unbonded overlay
(e) reconstruct

STR 3 Structural deficiency of the pavement is indicated by significantly more transverse crack deterioration than in the next inner lane.

(a) full-depth repair of cracks, AC structural overlay
(b) full-depth repair of cracks, crack and seat and AC structural overlay
(c) full-depth repair of cracks, PCC bonded overlay
(d) full-depth repair of cracks, PCC unbonded overlay
(e) reconstruct

STR 4 Structural deficiency of the pavement is indicated by a wet or wet-dry climate, a slab thickness of (x) inches, and (y) million annual 18-kip ESALs.

(a) AC structural overlay
(b) crack and seat and AC structural overlay
(c) PCC bonded overlay
(d) PCC unbonded overlay

STR 5 Structural deficiency of the pavement is indicated by a dry climate, a slab thickness of (x) inches, and (y) million annual 18-kip ESALs.

(a) AC structural overlay
(b) crack and seat and AC structural overlay
(c) PCC bonded overlay
(d) PCC unbonded overlay

Note: Values in brackets [ ] are default critical levels. User may modify these values.

STR 6 The pavement exhibits some load-associated distress (between 1 and [24] corner breaks per mile) which requires repair but does not indicate a structural deficiency.

(a) full-depth repair of corner breaks

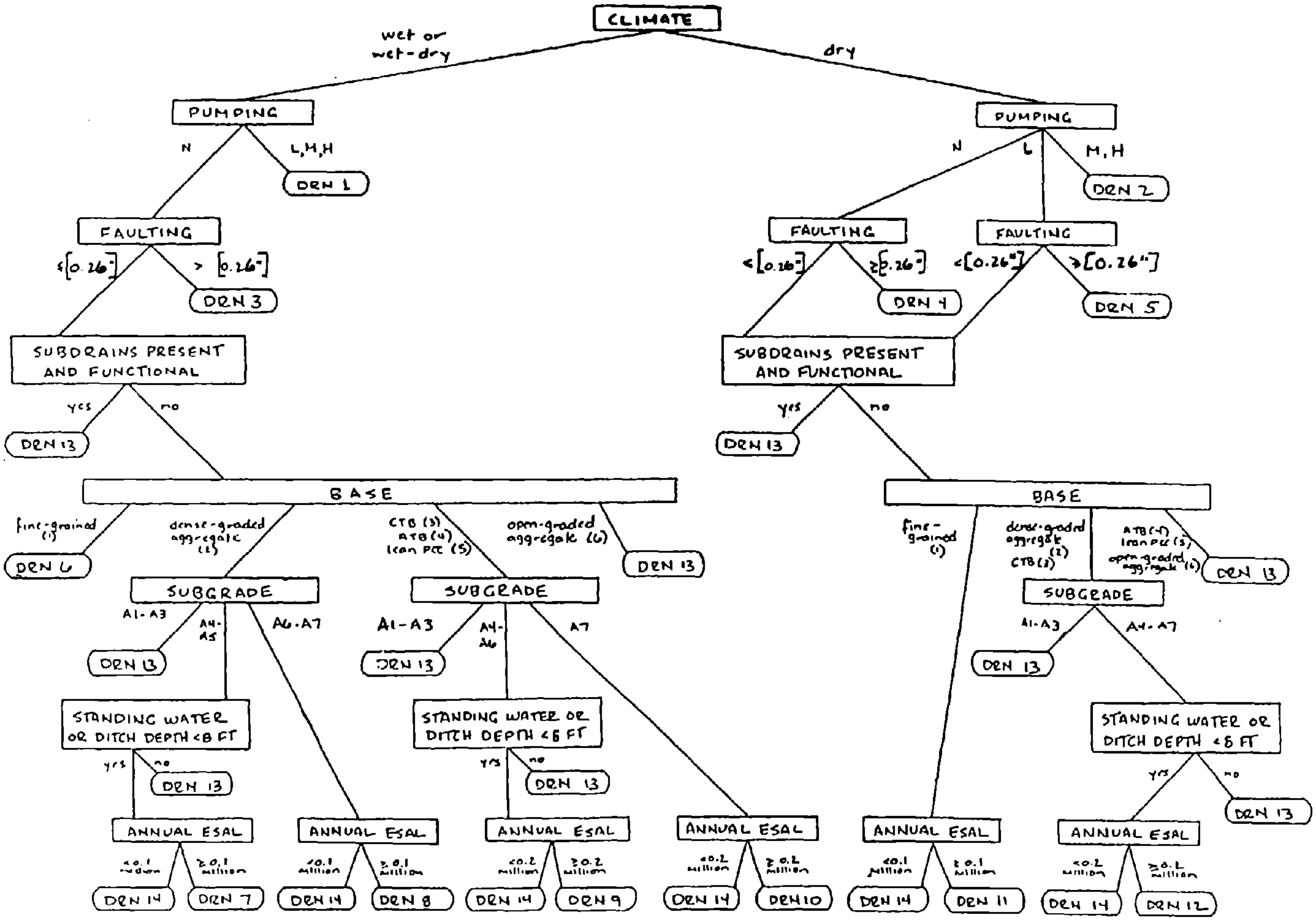
STR 7 The pavement shows no indications of structural deficiency.

(a) do nothing

STR 8 The pavement exhibits some load-associated distress (between 1 and [849] feet of deteriorated transverse cracks per mile) which requires repair but does not indicate a structural deficiency.

(a) full-depth repair of cracks

JRCP DRAINAGE DEFICIENCY



Drainage

DRN 1 A drainage deficiency is indicated by pumping occurring in a wet or wet-dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 2 An intermittent drainage deficiency is indicated by high-severity pumping occurring in a dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 3 A drainage deficiency is indicated by faulting greater than [0.26] inches occurring in a wet or wet-dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 4 A drainage deficiency is indicated by faulting greater than [0.26] inches occurring in a dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 5 An intermittent drainage deficiency is indicated by faulting greater than [0.26] inches and low- or medium-severity pumping occurring in a dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 6 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, and a fine-grained soil base.

(a) install or repair longitudinal subdrains

DRN 7 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded untreated aggregate base, an (x) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (y) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 8 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded untreated aggregate base, an (x) subgrade, and heavy traffic of (y) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 9 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (y) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (z) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 10 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (y) subgrade, and heavy traffic of (z) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 11 A drainage deficiency is indicated by a dry climate, absence or poor functioning of longitudinal subdrains, a fine-grained soil base, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 12 A drainage deficiency is indicated by a dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (y) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (z) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

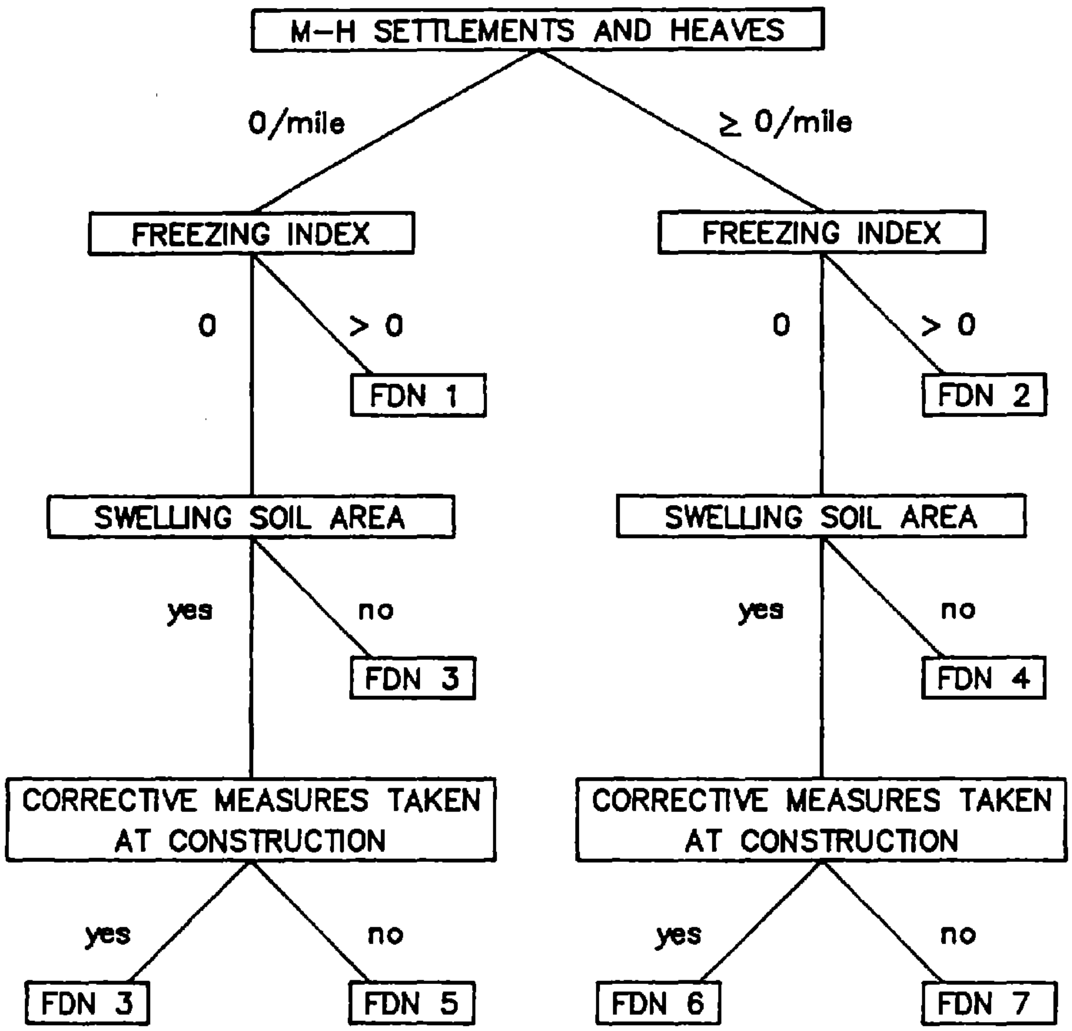
DRN 13 The pavement shows no indications of a drainage deficiency.

(a) do nothing

DRN 14 For the pavement's current traffic level, no significant drainage deficiency is indicated.

(a) do nothing

JRCP FOUNDATION MOVEMENT



Foundation Movement

FDN 1 A potential for frost heave is indicated by a mean Freezing Index greater than 0.

(a) do nothing

FDN 2 Foundation movement, likely due to either frost heave or localized consolidation, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

FDN 3 The pavement shows no indications of foundation movement.

(a) do nothing

FDN 4 Foundation movement, likely due to localized consolidation, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

FDN 5 A potential for foundation movement exists, since the pavement is in a swelling soils area and no measures were taken during construction to control soil swelling.

(a) do nothing

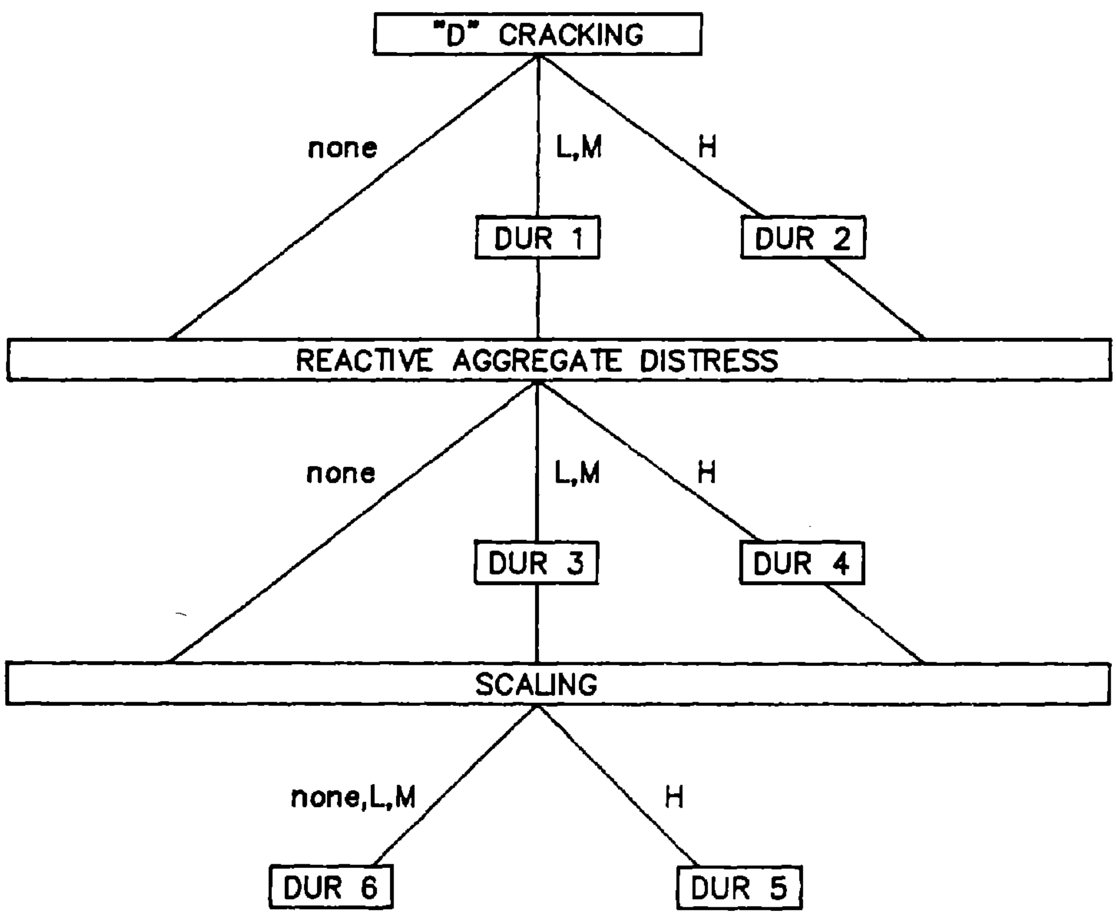
FDN 6 Foundation movement, likely due to either localized consolidation or unsuccessful construction measures to control swelling, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

FDN 7 Foundation movement, likely due to either localized consolidation or lack of construction measures to control swelling, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

JRCP DURABILITY DEFICIENCY



Durability

DUR 1 Poor durability of the concrete is indicated by low- to medium-severity "D" cracking.

(a) full-depth repair of joints, reseal transverse joints

DUR 2 Poor durability of the concrete is indicated by high-severity "D" cracking.

(a) unbonded PCC overlay
(b) reconstruct

DUR 3 Poor durability of the concrete is indicated by low- to medium-severity reactive aggregate distress.

(a) full-depth repair of joints, reseal transverse joints

DUR 4 Poor durability of the concrete is indicated by high-severity reactive aggregate distress.

(a) unbonded PCC overlay
(b) reconstruct

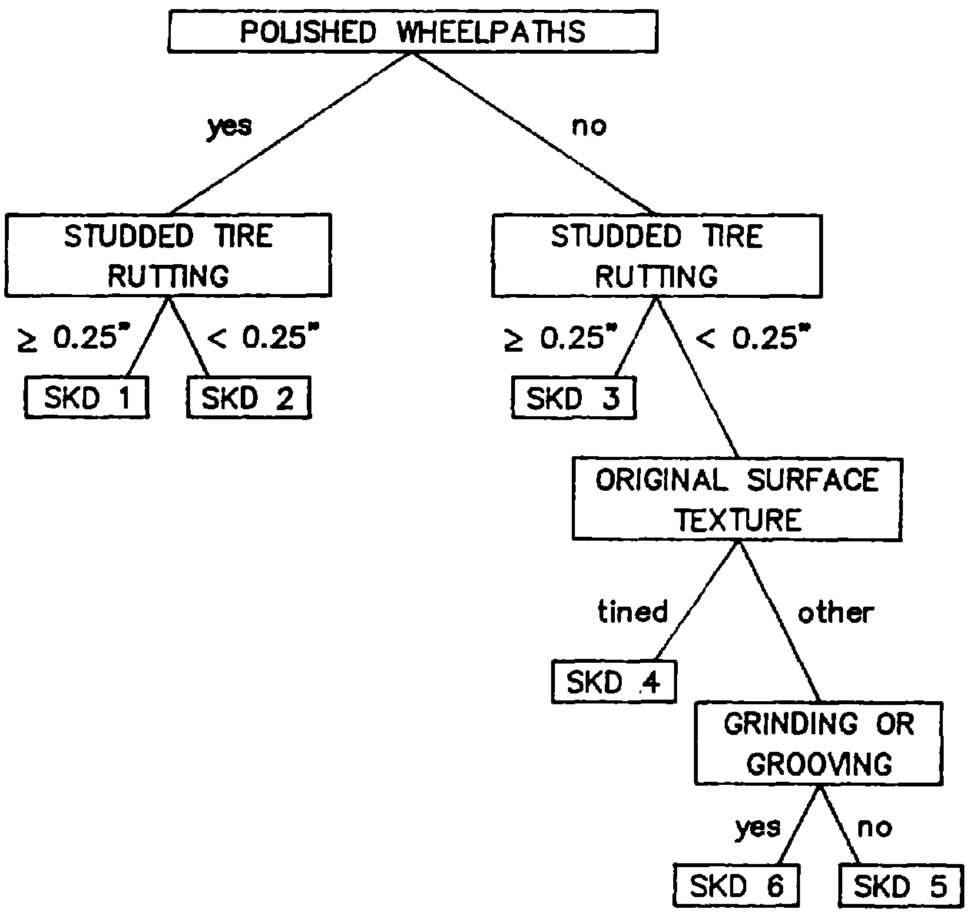
DUR 5 Poor durability of the concrete surface is indicated by high-severity scaling.

(a) do nothing
(b) AC nonstructural OL

DUR 6 The pavement show no indications of significant surface or concrete durability deficiencies.

(a) do nothing

JRCP SKID RESISTANCE DEFICIENCY



Skid Resistance

SKD 1 Loss of skid resistance and potential for hydroplaning are indicated by polished wheel paths and studded tire rutting of 0.25 inches or more.

(a) grinding
(b) AC nonstructural OL

SKD 2 Loss of skid resistance is indicated by polished wheel paths.

(a) grooving
(b) grinding
(c) AC nonstructural OL

SKD 3 Loss of skid resistance and potential for hydroplaning are indicated by studded tire rutting of 0.25 inches or more.

(a) grinding
(b) AC nonstructural OL

SKD 4 The pavement shows no indications of loss of skid resistance or hydroplaning potential.

(a) do nothing

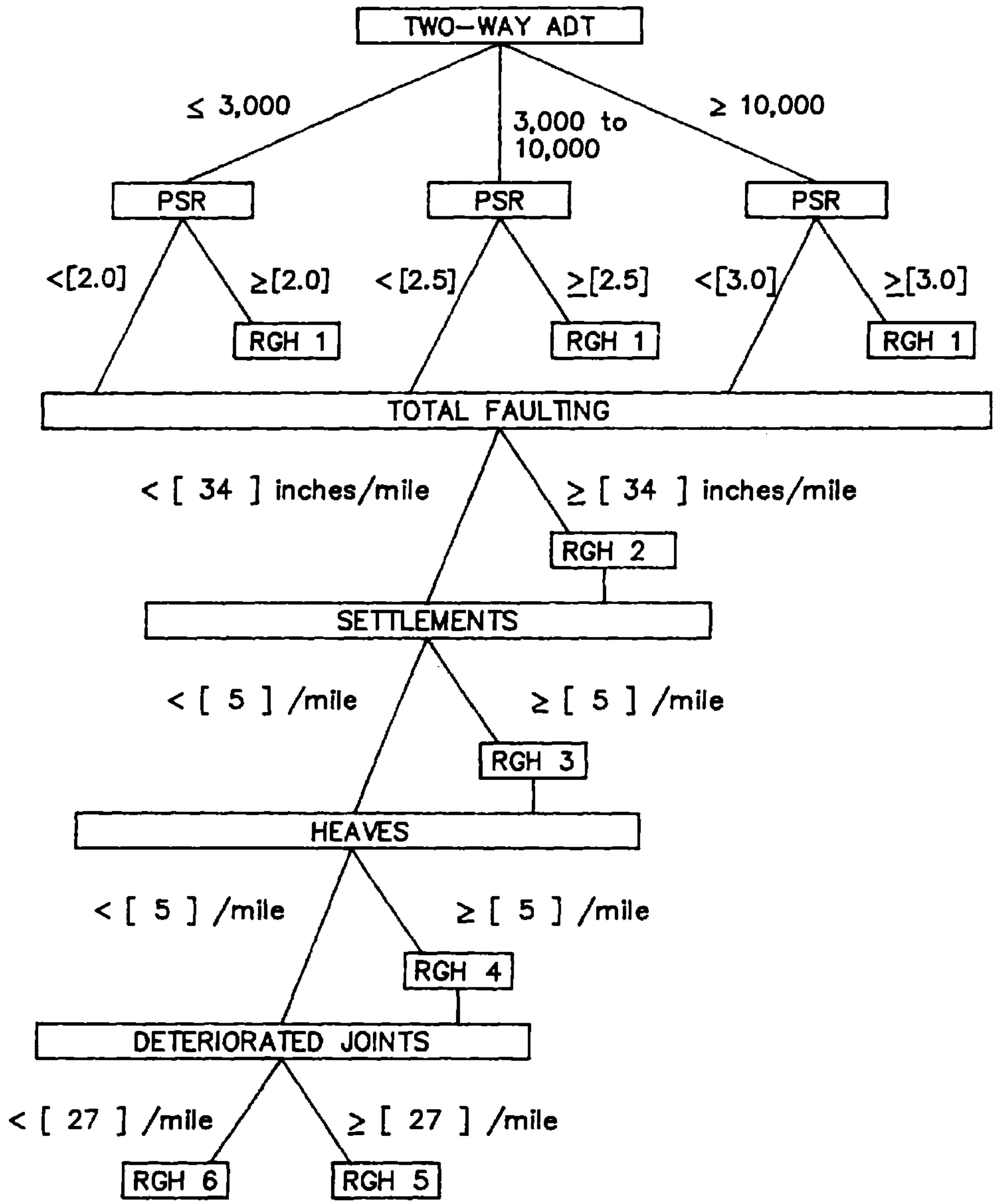
SKD 5 The method used to texture the original pavement surface may contribute to loss of skid resistance in the future.

(a) do nothing

SKD 6 Adequate skid resistance is indicated by surface restoration (grinding or grooving) having been performed on the pavement.

(a) do nothing

JRCP ROUGHNESS DEFICIENCY



Roughness

RGH 1 Rideability is acceptable.

(a) do nothing

RGH 2 Poor rideability is indicated by total faulting of more than [34] inches per mile at joints, cracks, and full-depth repairs (if present), and an unacceptably low PSR for the pavement's ADT level.

(a) grinding
(b) AC nonstructural OL

RGH 3 Poor rideability is indicated by [5] or more settlements per mile and an unacceptably low PSR for the pavement's ADT level.

(a) AC level-up settlements
(b) slab jack settlements

RGH 4 Poor rideability is indicated by [5] or more heaves and an unacceptably low PSR for the pavement's ADT level.

(a) reconstruct heaves

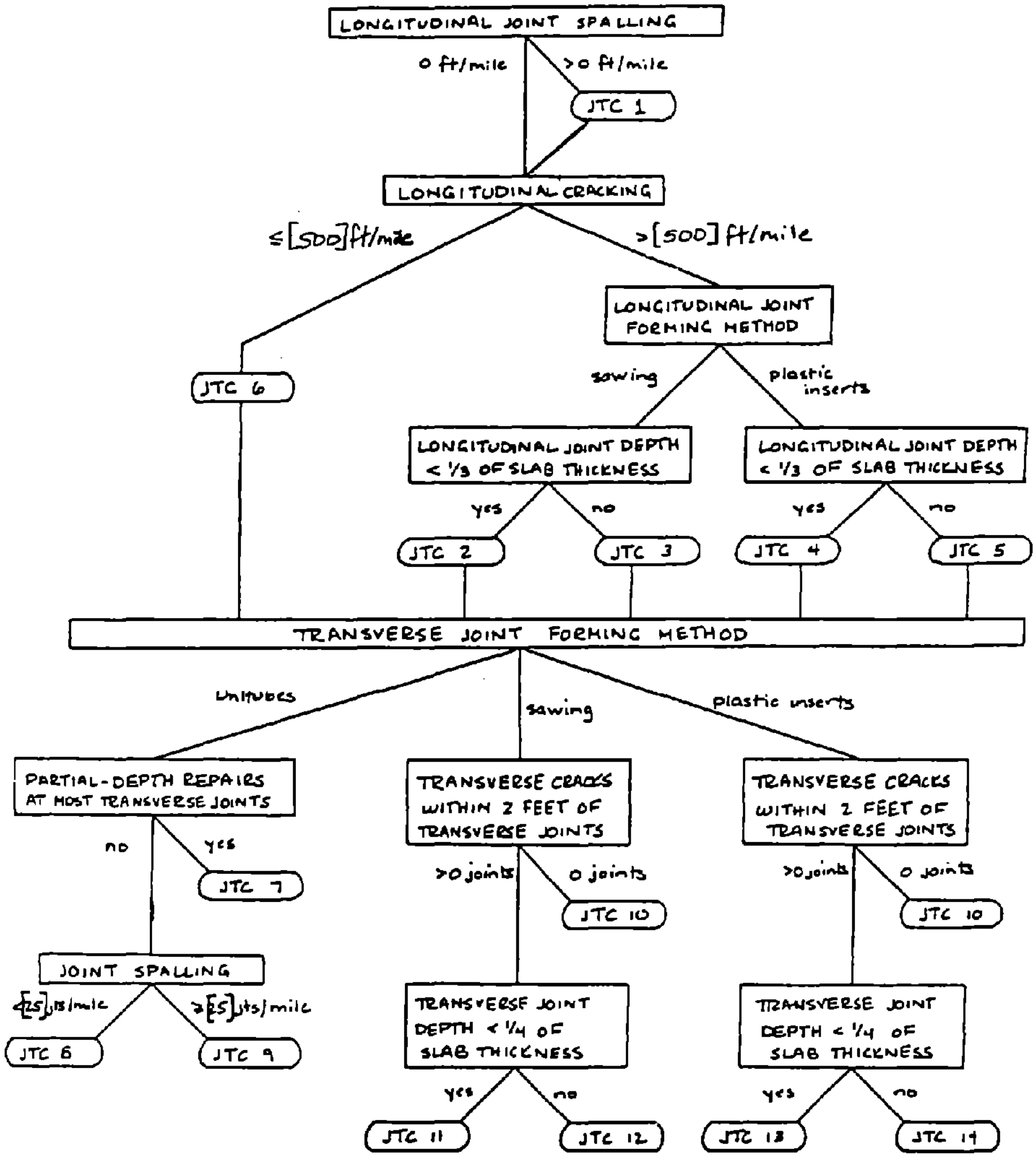
RGH 5 Poor rideability is indicated by [27] or more deteriorated joints per mile and an unacceptably low PSR for the pavement's ADT level.

(a) full-depth repair of joints

RGH 6 Poor rideability is indicated by an unacceptably low PSR for the pavement's ADT level.

(a) grinding
(b) AC nonstructural OL

JRCP JOINT CONSTRUCTION DEFICIENCY



Joint Construction Deficiency

JTC 1 A longitudinal joint construction deficiency is indicated by longitudinal joint spalling.

(a) partial-depth repair of longitudinal joint

JTC 2 A longitudinal joint construction deficiency, likely due to an inadequate depth of saw cut, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 3 A longitudinal joint construction deficiency, likely due to late sawing, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 4 A longitudinal joint construction deficiency, likely due to inadequate depth of plastic insert placement, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 5 A longitudinal joint construction deficiency, likely due to the use of plastic inserts, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 6 The pavement shows no indications of a longitudinal joint construction deficiency.

(a) do nothing

JTC 7 A transverse joint construction deficiency, likely due to the use of Unitubes, is indicated by partial-depth repairs at most of the transverse joints.

(a) do nothing

JTC 8 A potential transverse joint construction deficiency is indicated by the use of Unitubes, which may cause transverse joint spalling in the future.

(a) do nothing

JTC 9 A transverse joint construction deficiency, likely due to the use of Unitubes, is indicated by [27] or more deteriorated transverse joints per mile.

(a) partial-depth repair

JTC 10 The pavement shows no indications of a transverse joint construction deficiency.

(a) do nothing

JTC 11 A transverse joint construction deficiency, likely due to an inadequate depth of saw cut, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

JTC 12 A transverse joint construction deficiency, likely due late sawing, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

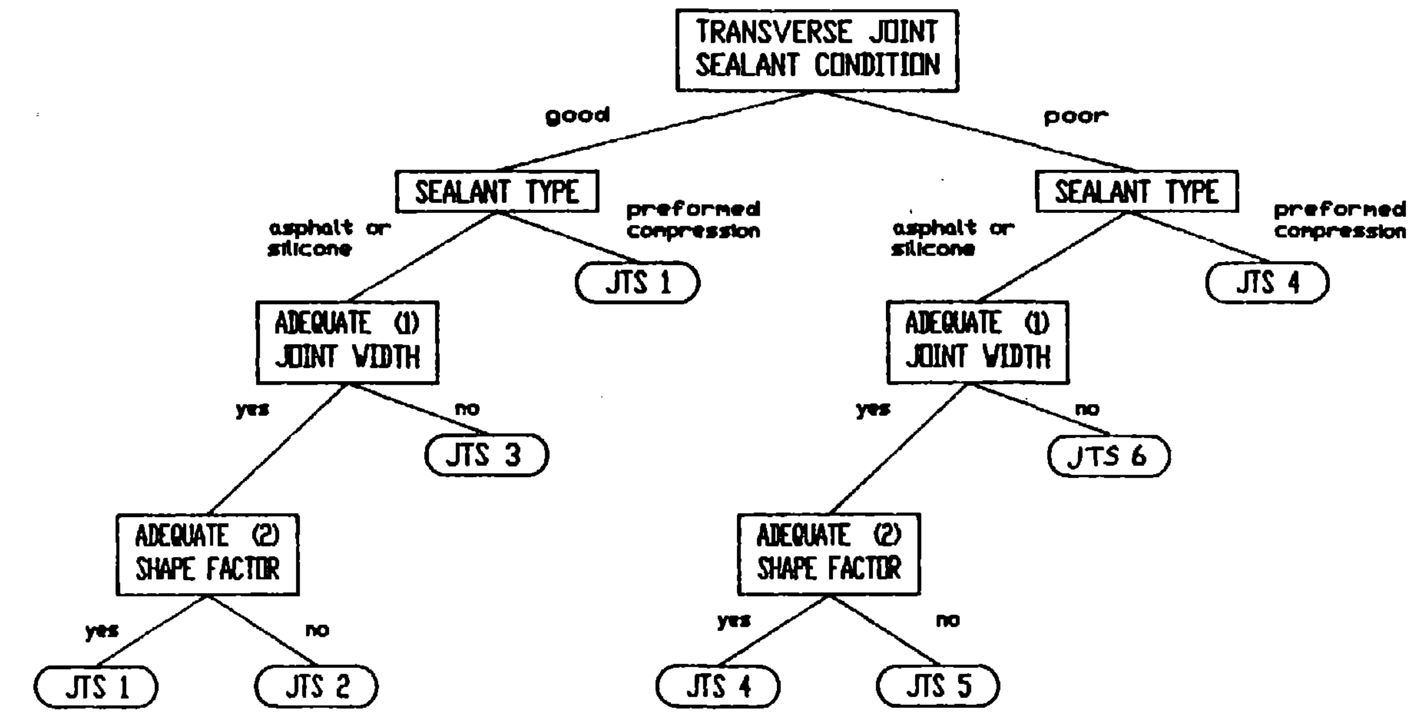
JTC 13 A transverse joint construction deficiency, likely due to inadequate depth of placement of plastic inserts, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

JTC 14 A transverse joint construction deficiency, likely due to use of plastic inserts, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

JRCP JOINT SEALANT DEFICIENCY



(1) joint sealant reservoir width is adequate if:

(a) W > 3/8" and

(b) 0.8 W < 12CL T < 1.2W, for asphalt

0.5 W < 12CL ΔT< 1.5W, for silicone

where: W=existing joint sealant reservoir width (inches)

C=0.65, for stabilized base

0.80 for granular base

$=5.5 \times 10^{-6}/°F$

ΔT=estimated annual temperature range °(F)

(2) joint sealant reservoir shape factor is adequate if:

3/4 < D/W , 2, for asphalt

1/2 < D/W < 2, for silicone

where: D=joint sealant reservoir depth (inches)

W=joint sealant reservoir width (inches)

Joint Sealant

JTS 1 The pavement shows no indications of a joint sealant deficiency.

(a) do nothing

JTS 2 Although the existing sealant is in good condition, a transverse joint sealant deficiency is indicated by an inadequate joint sealant reservoir shape factor for the existing sealant type. This is likely to hinder the performance of the sealant in the future.

(a) do nothing
(b) reseal transverse joints

JTS 3 Although the existing sealant is in good condition, a transverse joint sealant deficiency is indicated by an inadequate joint sealant reservoir width for the existing sealant type. This is likely to hinder the performance of the sealant in the future.

(a) do nothing
(b) reseal transverse joints

JTS 4 A transverse joint sealant deficiency is indicated by medium- to high-severity joint sealant damage.

(a) reseal transverse joints

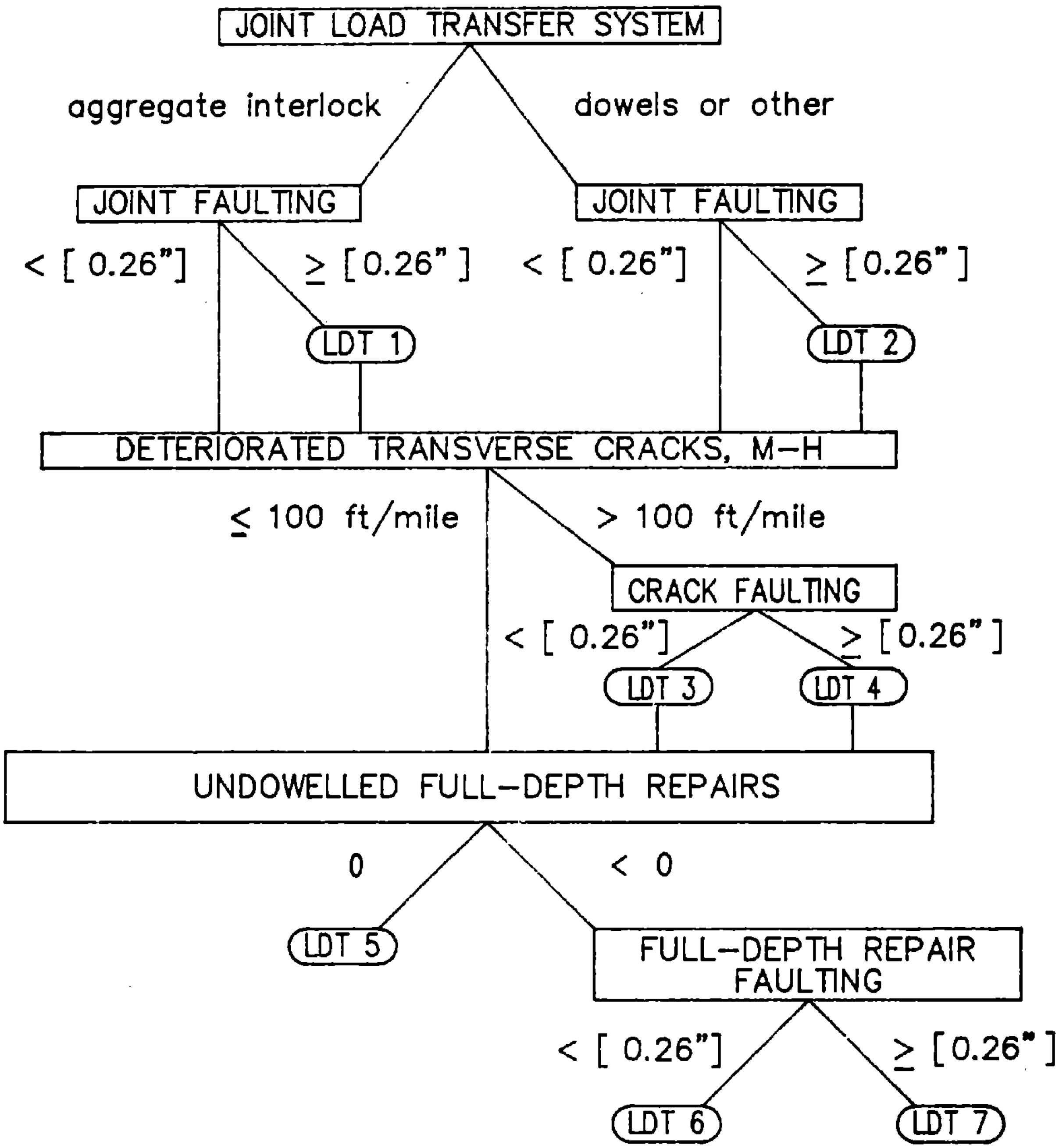
JTS 5 A transverse joint sealant deficiency is indicated by medium- to high-severity joint sealant damage and an inadequate joint sealant reservoir shape factor for the existing sealant type.

(a) reseal transverse joints

JTS 6 A transverse joint sealant deficiency is indicated by medium- to high-severity joint sealant damage and an inadequate joint sealant reservoir width for the existing sealant type.

(a) reseal transverse joints

JRCP LOAD TRANSFER DEFICIENCY



Load Transfer Deficiency

LDT 1 Aggregate interlock is providing inadequate load transfer at the transverse joints, as indicated by mean transverse joint faulting of more than [0.26] inches.

(a) load transfer restoration at joints

LDT 2 Dowels or other mechanical devices present are providing inadequate load transfer at the transverse joints, as indicated by mean transverse joint faulting of more than [0.26] inches.

(a) load transfer restoration at joints
(b) do nothing

LDT 3 No load transfer deficiency is indicated at deteriorated transverse cracks.

(a) do nothing

LDT 4 A load transfer deficiency at deteriorated transverse cracks is indicated by mean crack faulting of more than [0.26] inches.

(a) full-depth repair of cracks
(b) load transfer restoration at cracks

LDT 5 No undowelled full-depth repairs are present.

(a) do nothing

LDT 6 A potential load transfer deficiency exists at undowelled full-depth repairs, but mean full-depth repair faulting is not significant.

(a) do nothing

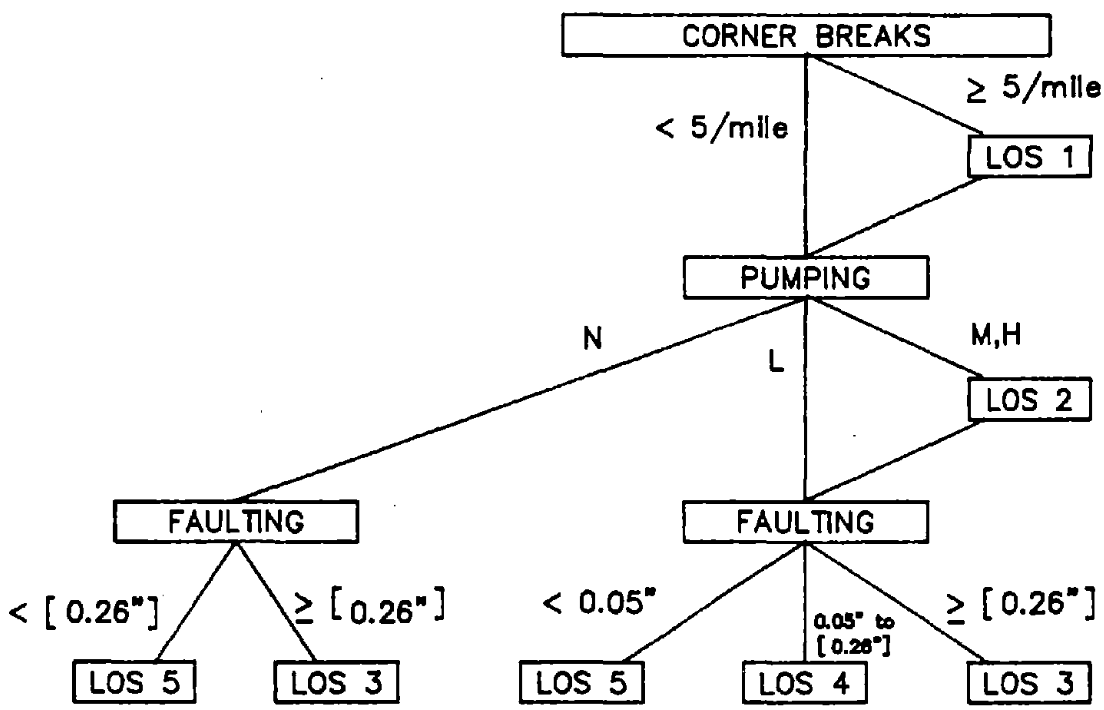
LDT 7 A load transfer deficiency is indicated at undowelled full-depth repairs by mean full-depth repair faulting of more than [0.26] inches.

(a) replace undowelled full-depth repairs with dowelled full-depth repairs

LDT 8 No load transfer deficiency is indicated at transverse joints.

(a) do nothing

JRCP LOSS OF SUPPORT



Loss of Support

LOS 1 Loss of slab support is indicated by 5 or more corner breaks per mile.

(a) subseal at joints and cracks

LOS 2 Loss of slab support is indicated by medium- to high-severity pumping.

(a) subseal at joints and cracks

LOS 3 Loss of slab support is indicated by average faulting greater than [0.26] inches at joints and cracks.

(a) subseal at joints and cracks

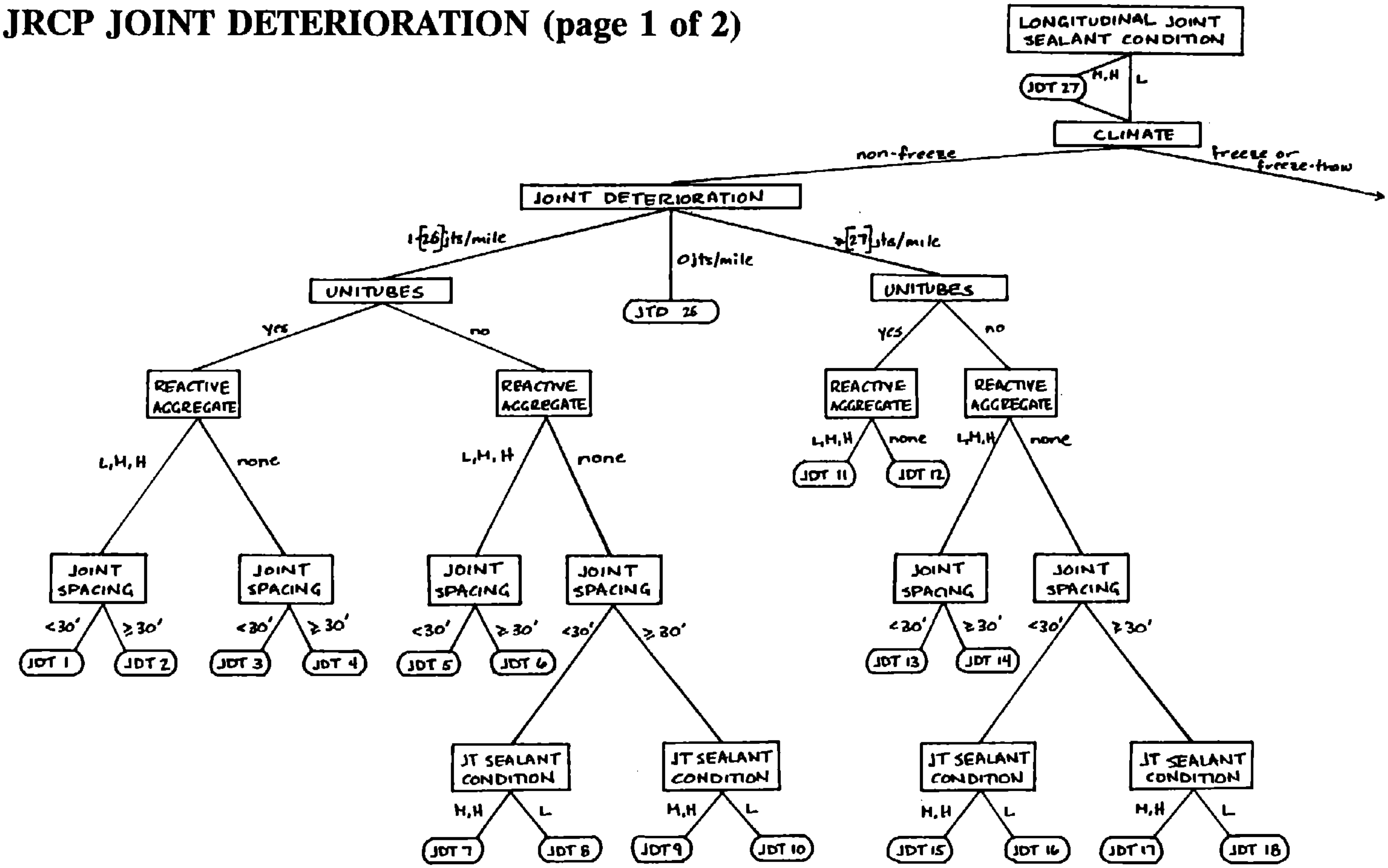
LOS 4 Loss of slab support is indicated by pumping and average faulting of between [0.05] inches and [0.26] inches at joints and cracks.

(a) subseal at joints and cracks

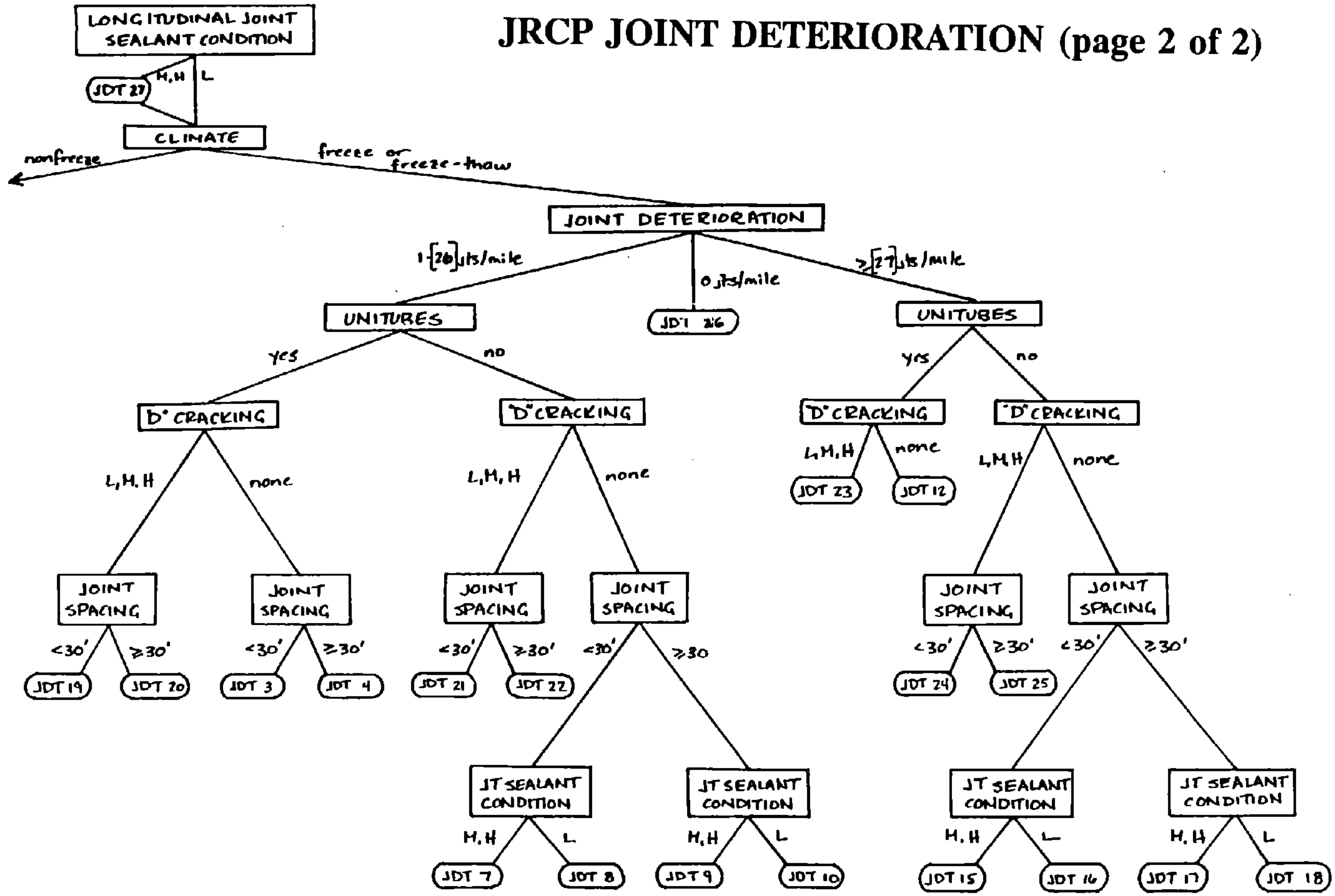
LOS 5 The pavement shows no indications of loss of slab support.

(a) do nothing

JRCP JOINT DETERIORATION (page 1 of 2)



JRCP JOINT DETERIORATION (page 2 of 2)



Joint Deterioration

JDT 1 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts and the presence of reactive aggregate.

(a) full-depth repair of joints

JDT 2 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts, the presence of reactive aggregate, and large joint movements associated with the long joint spacing.

(a) pressure relief joints, partial-depth repair of joints
(b) pressure relief joints, full-depth repair of joints

JDT 3 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts.

(a) partial-depth repair of joints
(b) full-depth repair of joints

JDT 4 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts and large joint movements associated with the long joint spacing.

(a) partial-depth repair of joints
(b) full-depth repair of joints

JDT 5 Some joint deterioration exists, likely due to the presence of reactive aggregate.

(a) full-depth repair of joints

JDT 6 Some joint deterioration exists, likely due to the presence of reactive aggregate and large joint movements associated with the long joint spacing.

(a) pressure relief joints, full-depth repair of joints

JDT 7 Some joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of incompressibles.

(a) reseal transverse joints, full-depth repair of joints

JDT 8 Some joint deterioration exists, but its cause is unknown.

(a) full-depth repair of joints

JDT 9 Some joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of water and incompressibles, and large joint movements associated with the long joint spacing.

(a) reseal transverse joints, full-depth repair of joints

JDT 10 Some joint deterioration exists, likely due to large joint movements associated with the long joint spacing.

(a) full-depth repair of joints

JDT 11 Extensive joint deterioration exists, likely due to the use of Unitube joint forming inserts and the presence of reactive aggregate.

(a) unbonded PCC overlay
(b) reconstruct

JDT 12 Extensive joint deterioration exists, likely due to the use of Unitube joint forming inserts.

(a) partial-depth repair of joints
(b) full-depth repair of joints

JDT 13 Extensive joint deterioration exists, likely due to the presence of reactive aggregate.

(a) unbonded PCC overlay
(b) reconstruct

JDT 14 Extensive joint deterioration exists, likely due to the presence of reactive aggregate and large joint movements associated with the long joint spacing.

(a) full-depth repair of joints, pressure relief joints, unbonded PCC overlay
(b) reconstruct

JDT 15 Extensive joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of water and incompressibles.

(a) full-depth repair of joints, reseal transverse joints

JDT 16 Extensive joint deterioration exists but its cause is unknown.

(a) full-depth repair of joints

JDT 17 Extensive joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of water and incompressibles, and large joint movements associated with the long joint spacing.

(a) full-depth repair of joints, reseal transverse joints

JDT 18 Extensive joint deterioration exists, likely due to large joint movements associated with the long joint spacing.

(a) full-depth repair of joints

JDT 19 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts and "D" cracking weakening the concrete at the joints.

(a) full-depth repair of joints

JDT 20 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts, "D" cracking weakening the concrete at the joints, and large joint movement associated with the long joint spacing.

(a) full-depth repair of joints

JDT 21 Some joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints.

(a) full-depth repair of joints

JDT 22 Some joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints, and large joint movements associated with the long joint spacing.

(a) full-depth repair of joints

JDT 23 Extensive joint deterioration exists, likely due to the use of Unitube joint forming inserts and "D" cracking weakening the concrete at the joints.

(a) unbonded PCC overlay
(b) reconstruct

JDT 24 Extensive joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints.

(a) unbonded PCC overlay
(b) reconstruct

JDT 25 Extensive joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints, and large joint movements associated with the long joint spacing.

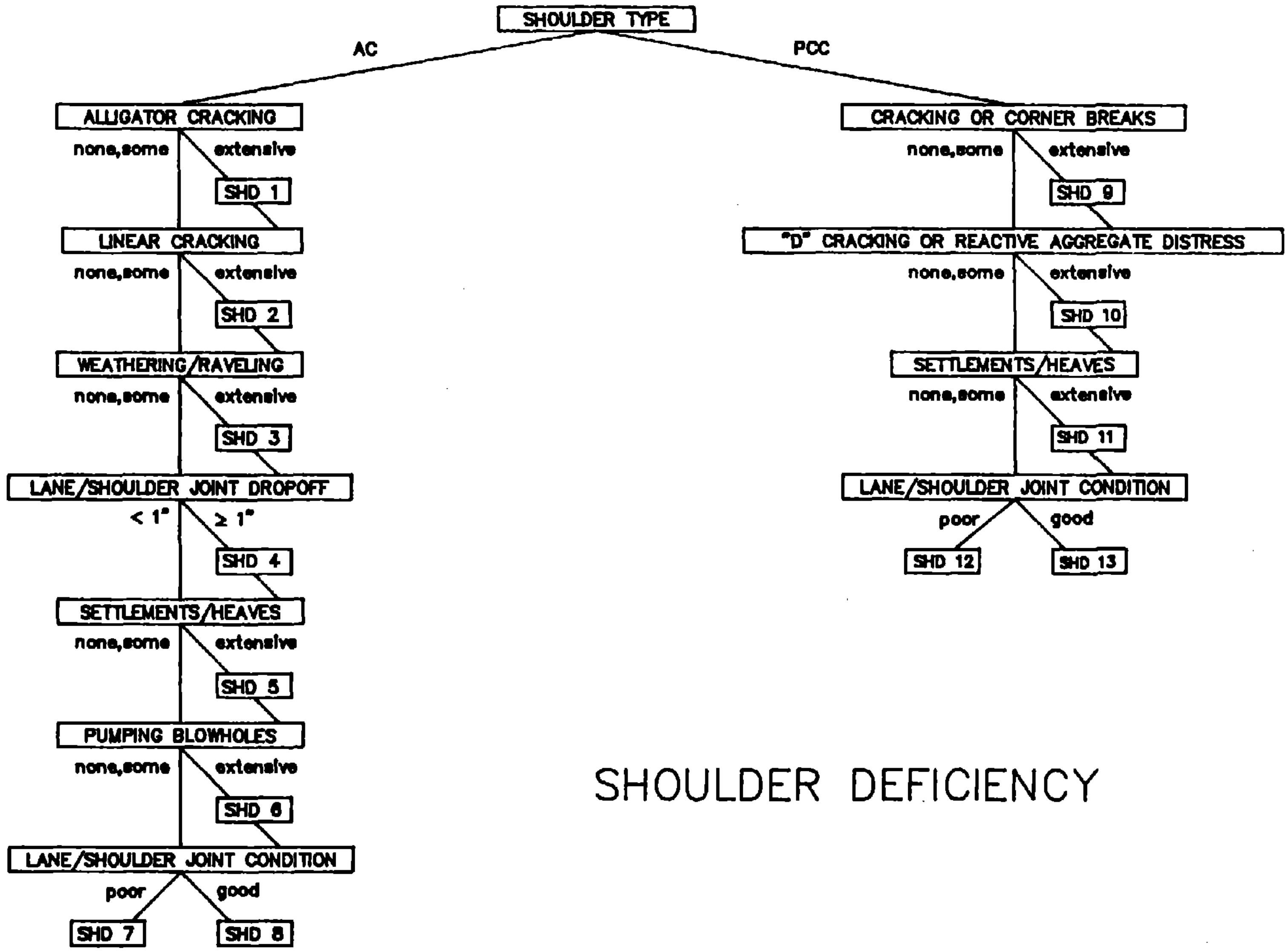
(a) unbonded PCC overlay
(b) reconstruct

JDT 26 No joint deterioration exists.

(a) do nothing

JDT 27 Joint deterioration or other pavement deterioration may be accelerated by water infiltration permitted by poor longitudinal joint sealant condition.

(a) reseal longitudinal centerline joint



SHOULDER DEFICIENCY

Shoulder

SHD 1 Structural deterioration of the AC shoulder is indicated by extensive alligator cracking.

(a) in-place recycle
(b) patch
(c) reconstruct with AC
(d) reconstruct with PCC

SHD 2 Deterioration of the AC shoulder is indicated by extensive linear cracking.

(a) in-place recycle
(b) patch
(c) reconstruct with AC
(d) reconstruct with PCC

SHD 3 Deterioration of the AC shoulder surface is indicated by extensive weathering and/or raveling.

(a) chip seal

SHD 4 A dropoff of 1 inch or more along the AC lane/shoulder joint constitutes a safety hazard.

(a) leveling wedge

SHD 5 Foundation movement beneath the AC shoulder is indicated by extensive settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements

SHD 6 Pumping has resulted in extensive blowhole formation in the AC shoulder.

(a) patch blowholes

SHD 7 Excessive infiltration of water beneath the pavement and AC shoulder is indicated by poor lane/shoulder joint condition.

(a) reseal lane/shoulder joint
(b) do nothing

SHD 8 The AC shoulder shows no indications of significant deterioration.

(a) do nothing

SHD 9 Structural deterioration of the PCC shoulder is indicated by extensive cracking and/or corner breaks.

(a) full-depth repair
(b) reconstruct with AC
(c) reconstruct with PCC

SHD 10 Poor durability of the PCC shoulder is indicated by extensive "D" cracking or reactive aggregate distress.

(a) reconstruct with AC
(b) reconstruct with PCC

SHD 11 Foundation movement beneath the PCC shoulder is indicated by extensive settlements and/or heaves along the outer edge.

(a) reconstruct heaves, AC level-up settlements

SHD 12 Excessive infiltration of water beneath the pavement and PCC shoulder is indicated by poor lane/shoulder joint condition.

(a) reseal lane/shoulder joint
(b) do nothing

SHD 13 The PCC shoulder shows no indications of significant deterioration.

(a) do nothing

APPENDIX A3

EVALUATION PERFORMANCE PREDICTION MODELS FOR JRCP

<u>Distress Types</u>

1. Faulting
2. Cracking
3. Joint Deterioration
4. Pumping
5. PSR

Faulting

$$\text{FAULT} = \{ \text{ESAL}^{0.4731} * [-3.8536 - 1.5355\ \text{SOILCRS} + 197.124\ (\text{THICK} * \text{DOWEL}^{2.0})^{-1.7842} + 0.00024\ \text{FI} + 0.09858\ \text{JTSPACE} + 0.24115\ \text{PUMP}^{2.0}] / 100 \} + \text{FLTCALIB}$$

where:

FAULT = mean transverse joint faulting, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

THICK = thickness of PCC slab, in

DOWEL = diameter of dowels, in
(0.1 if no dowel bars used)

FI = mean Freezing Index, Fahrenheit degree-days

JTSPACE = transverse joint spacing of pavement, ft

PUMP = pumping severity (from pumping model) (Note: PUMP can be any value between 0 and 3, e.g. 2.2)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

FLTCALIB = calibration of model to existing faulting

= actual faulting (in) measured during survey - FAULT predicted for present year by above model

$$= \text{actual faulting} - \{ \text{ESAL}^{0.4731} [-3.8536 - 1.5355\ \text{SOILCRS} + 197.124\ (\text{THICK} * \text{DOWEL}^{2.0})^{-1.7842} + 0.00024\ \text{FI} + 0.09858\ \text{JTSPACE} + 0.24115\ \text{PUMP}^{2.0}] / 100 \}$$

R^2 = 0.69
n = 384
SEE = 0.06 in [0.15 cm]

Source: NCHRP 1-19 (6)

Cracking

$$\text{CRACKS} = \{ \text{ESAL}^{0.897} [7130.0 \text{ JTSPACE} / (\text{ASTEEL} * \text{THICK}^{5.0})]$$
$$+ \text{ESAL}^{0.10} (2.281 \text{ PUMP}^{5.0})$$
$$+ \text{ESAL}^{2.16} [1.81 / (\text{BASETYPE} + 1)]$$
$$+ \text{AGE}^{1.3} [0.0036 (\text{FI} + 1)^{0.36}] \} + \text{CRKCALIB}$$

where:

CRACKS = total length of medium- and high-severity deteriorated cracks, ft/mile

ESAL = accumulated 18-kip equivalent single-axle loads since construction, millions

JTSPACE = transverse joint spacing of pavement, ft

ASTEEL = area of reinforcing steel in pavement, square in/foot width of slab

THICK = thickness of PCC slab, in

PUMP = pumping severity (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

AGE = time since construction, years

FI = mean Freezing Index, Fahrenheit degree-days

CRKCALIB = calibration of model to existing cracking

= actual cracking (M-H cracks, ft/mile) measured during survy - CRACKS predicted for present year by above model

= actual cracking - $\{ \text{ESAL}^{0.897} [7130.0 \text{ JTSPACE}$

$/ (\text{ASTEEL} * \text{THICK}^{5.0})] + \text{ESAL}^{0.10} (2.281 \text{ PUMP}^{5.0})$

$+ \text{ESAL}^{2.16} [1.81 / (\text{BASETYPE} + 1)]$

$+ \text{AGE}^{1.3} [0.0036 (\text{FI} + 1)^{0.36}] \}$

R^2 = 0.41
n = 314
SEE = 280 ft/mile 53 m/km]

Source: NCHRP 1-19 (6)

Joint Deterioration

$$DETJT = AGE^{0.756} * 2.4367\ DCRACK * 2.744\ REACTAGG$$
$$+ AGE^{2.1521}\ ESAL^{0.1419}\ [\ 0.05202 + 0.0000254\ FI$$
$$+ 0.01109\ TJSD - (0.003384 * K1 * JTSPACE)$$
$$- (0.0006446 * K2 * JTSPACE)\ ] + DETJTCALIB$$

where:

DETJT = medium- to high-severity deteriorated transverse joints, number/mile

AGE = time since construction, years

DCRACK = D cracking severity
= 0, if none
= 1, if low, medium, or high severity

REACTAGG = reactive aggregate distress severity
= 0, if none
= 1, if low, medium, or high severity

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if none or low severity
= 1, if medium or high severity

JTSPACE = transverse joint spacing of pavement, ft

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 m]

DETJTCALIB = calibration of model to existing joint deterioration

= actual joint deterioration (M-H deteriorated joints/mile) measured during survey - DETJT predicted for present year by above model

$$= \text{actual joint deterioration} - \{\ AGE^{0.756} * 2.4367\ DCRACK$$
$$* 2.744\ REACTAGG + AGE^{2.1521}\ ESAL^{0.1419}\ [\ 0.05202$$
$$+ 0.0000254\ FI + 0.01109\ TJSD - (0.003384 * K1 * JTSPACE)$$
$$+ (0.0006446 * K2 * JTSPACE)\ ]\ \}$$

R^2 = 0.61
n = 319
SEE = 15 joints/mile [9 joints/km]

Source: NCHRP 1-19 (6)

Note: Do not use model outside of specified ranges for JTSPACE (27 ft [8.2 m] or 39 to 100 ft [11.9 to 30.5 m]).

Pumping

$$PUMP = ESAL^{0.670} [-22.82 + (26102.2 / THICK^{5.0}) - 0.129\ DRAIN - 0.118\ SOILCRS + 13.224\ SUMPREC^{0.0395} + 6.834\ (FI + 1)^{0.00805}]$$

where:

PUMP = pumping severity (PUMP can be any value between 0 and 3)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

ESAL = accumulated 18-kip equivalent single-axle loads since construction, millions

THICK = thickness of PCC slab, in

DRAIN = longitudinal subdrains
= 0, if no subdrains present or present but not functional
= 1, if subdrains present and functional

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.57
n = 481
SEE = 0.52

Source: NCHRP 1-19 (6)

PSR

$$PSR = 4.5 - ESAL^{0.424} (-0.00188 + 14.417\ RATIO^{3.58}$$
$$+ 0.0399\ PUMP + 0.0021528\ JTSPACE + 0.1146\ DCRACK$$
$$+ 0.05903\ REACTAGG + 0.00004156\ FI$$
$$+ 0.00163\ SUMPREC - 0.070535\ BASETYPE)$$

where:

PSR = Present Serviceability Rating

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

RATIO = Westergaard's edge stress/PCC slab modulus of rupture (see following page to calculate Westergaard's edge stress)

PUMP = pumping severity (from pumping model)
= 0, if none or low severity (≤ 1)
= 1, if medium or high severity (> 1)

JTSPACE = transverse joint spacing of pavement, ft

DCRACK = D cracking severity
= 0, if none
= 1, if low, medium, or high severity

REACTAGG = reactive aggregate distress severity
= 0, if none
= 1, if low, medium, or high severity

FI = mean Freezing Index, Fahrenheit degree-days

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

R^2 = 0.78
n = 377
SEE = 0.30

Source: NCHRP 1-19 (6)

Calculation of Westergaard's Edge Stress:

$$L = [\ (4200000 * THICK^{3.0}) \ /\ 12 * (1 - 0.2^{2.0}) * KEFF\ ]^{0.25}$$

$$B = [\ 1.6\ (6.4)^{2} + THICK^{2}\ ]^{0.5} - 0.675\ THICK$$

$$Stress = (0.572 * 9000 \ /\ THICK^{2.0}) * [4 \log_{10} (L/B) + 0.359]$$

where:

THICK = thickness of PCC slab, in

KEFF = effective k value beneath PCC slab, psi/in

4,200,000 = assumed elastic modulus of PCC slab, psi

0.20 = assumed Poisson's ratio of PCC slab

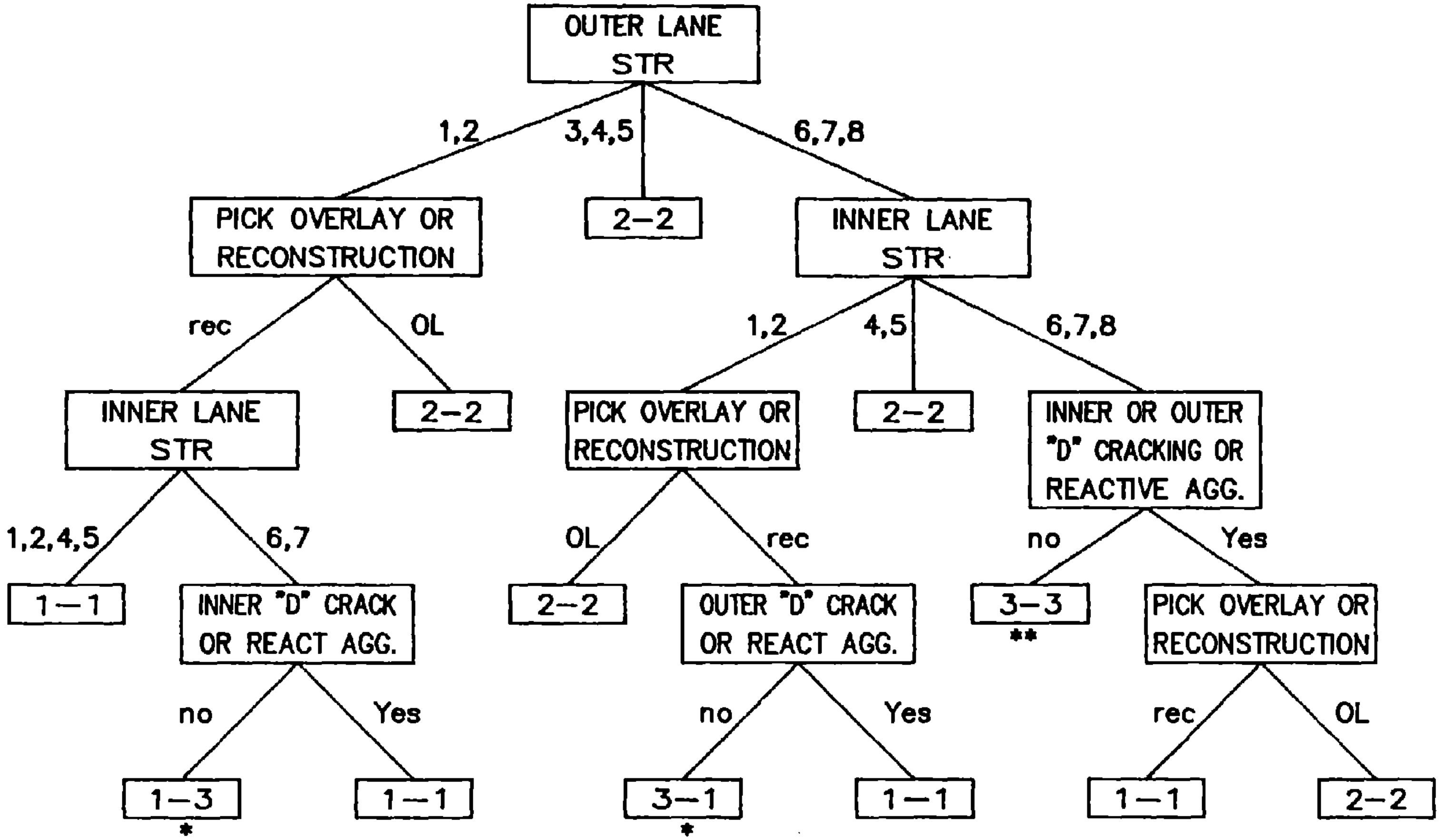
6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/cm = 2.71 kPa/cm

APPENDIX A4

REHABILITATION STRATEGY DEVELOPMENT DECISION TREES

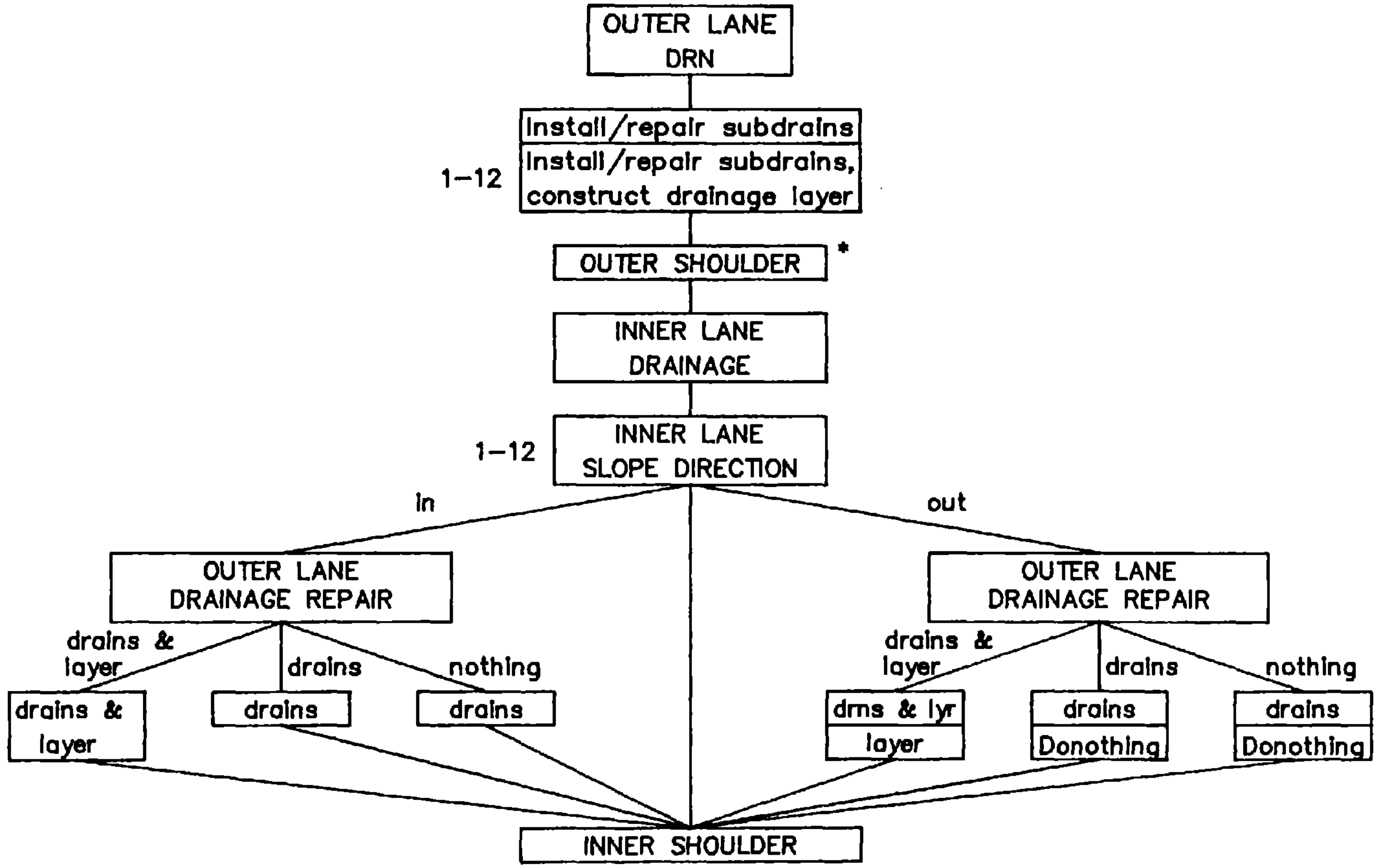
Main Rehabilitation Aproach for JRCP



* Option to go to 1-1 provided
** Option to go to 1-1, 1-3, or 2-2 provided

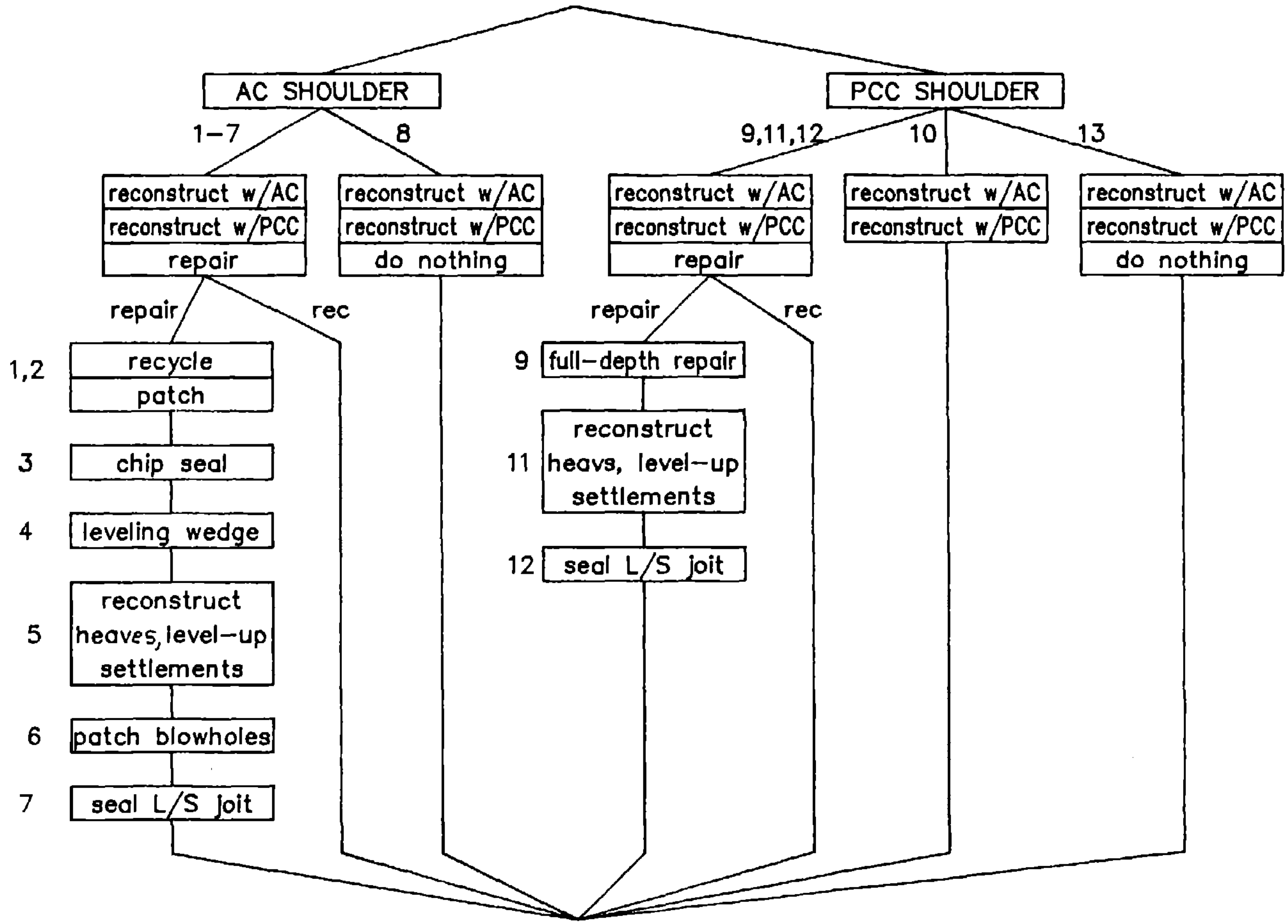
1-1 Reconstruct Both Lanes
1-3 Reconstruct Outer, Restore Inner
3-1 Restore Outer, Reconstruct Inner
2-2 Overlay Both Lanes
3-3 Restore Both Lanes

Reconstruction of A JRCP Lane

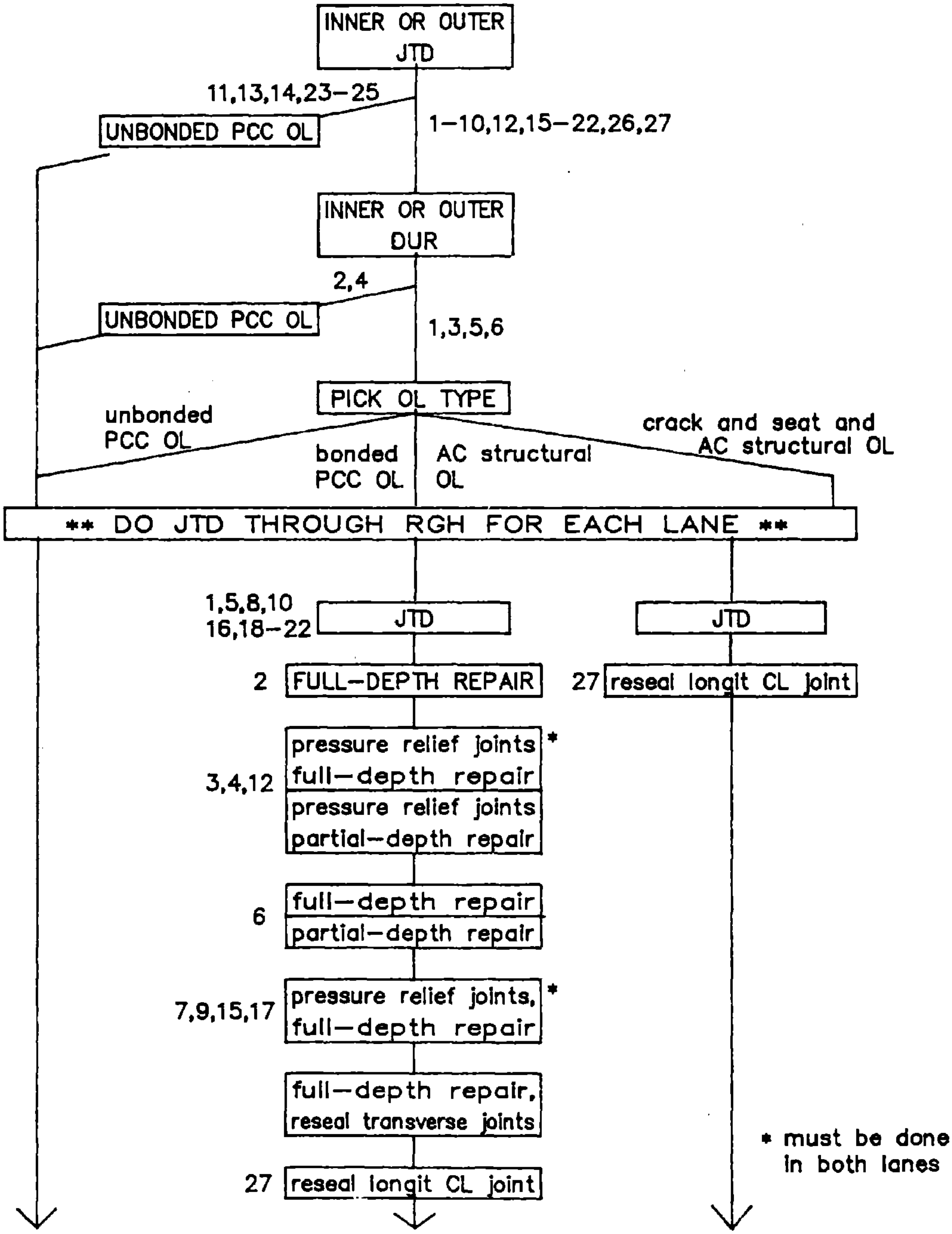


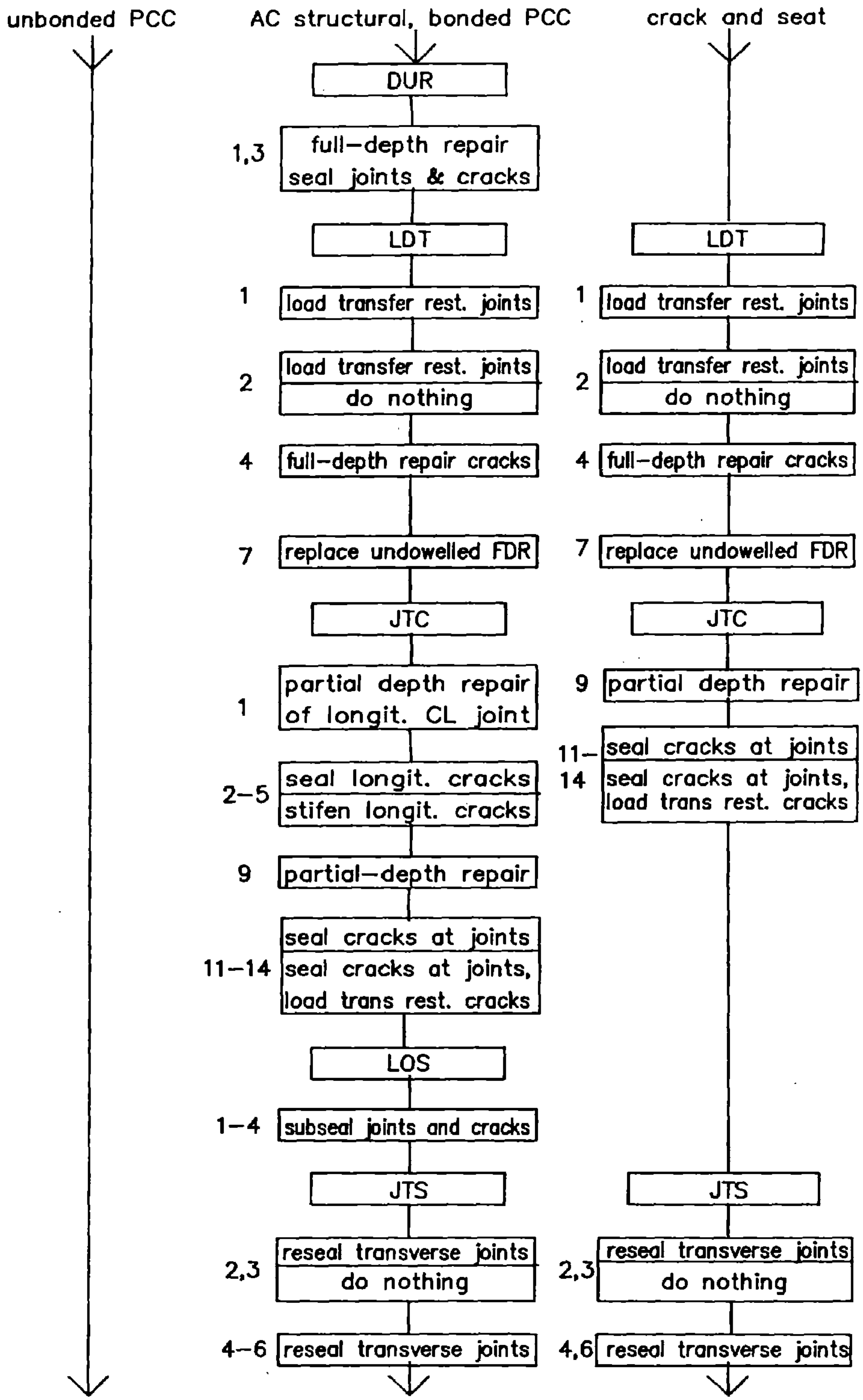
* See decision tree for shoulder rehabilitation adjacent to reconstructed lane.

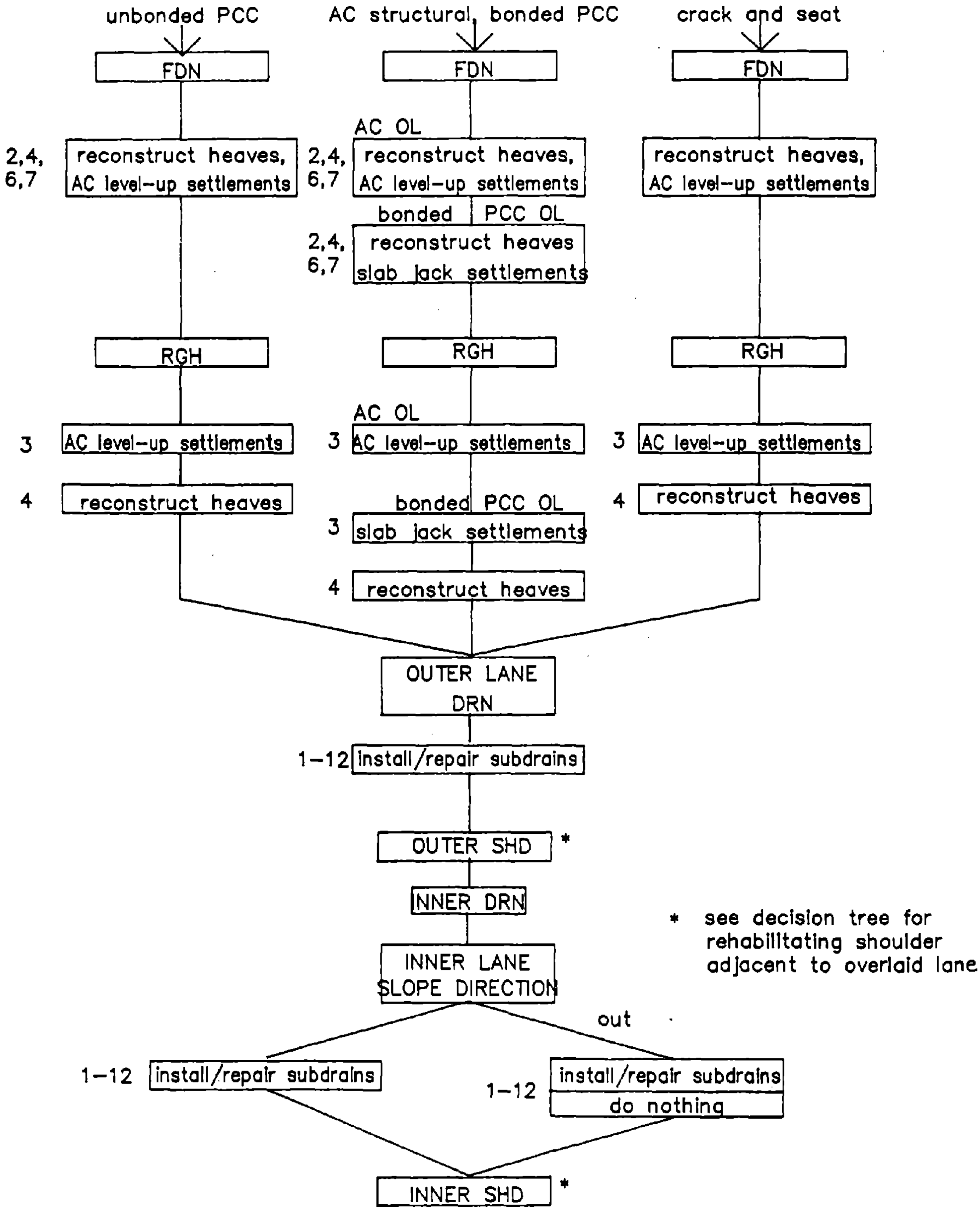
Rehabilitation of Shoulder Adjacent to Reconstructed Lane



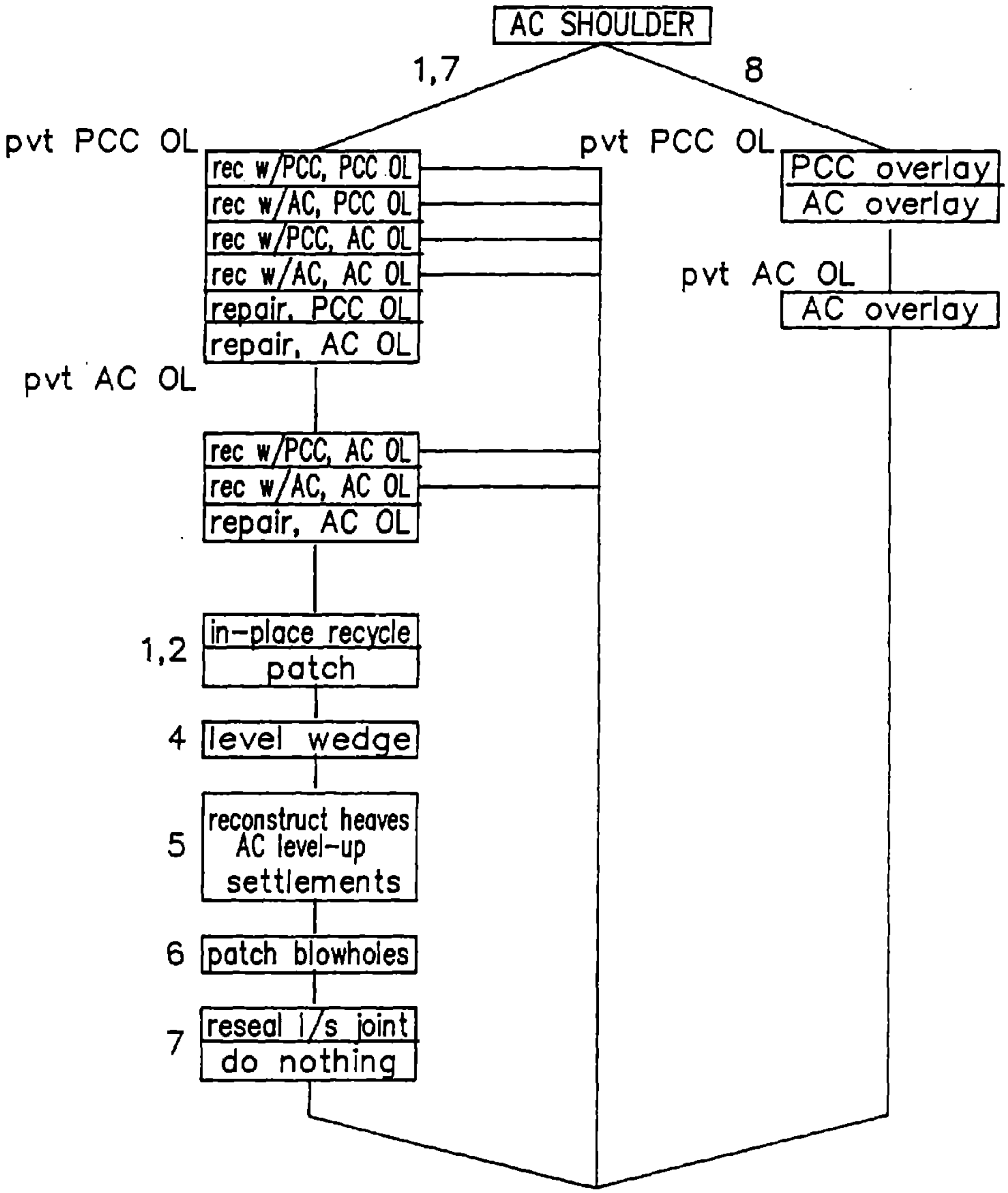
Overlaying A JRCP Lane



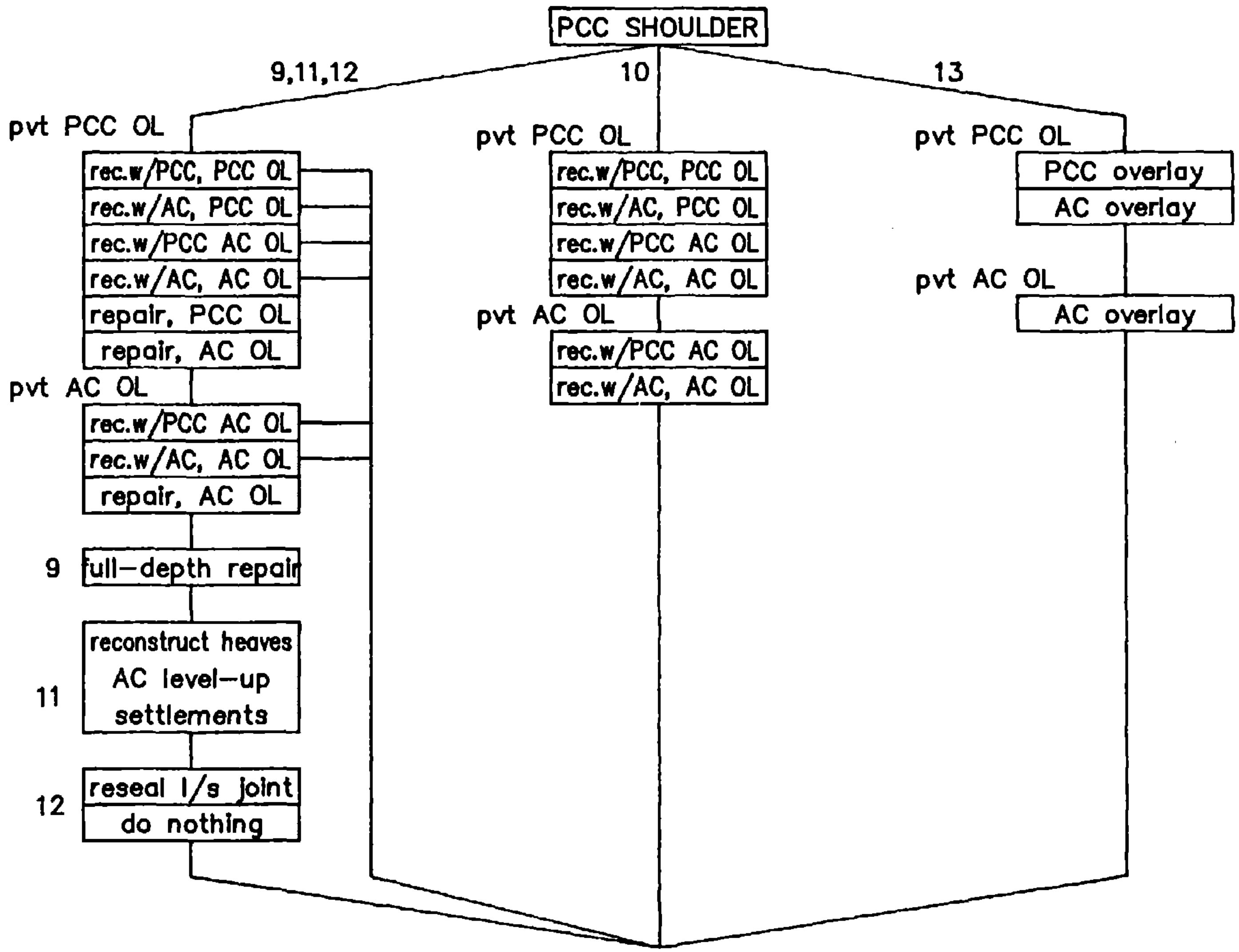

unbonded PCC
AC structural, bonded PCC
crack and seat
DUR
1,3
full-depth repair
seal joints & cracks
LDT
LDT
1
load transfer rest. joints
1
load transfer rest. joints
2
load transfer rest. joints
do nothing
2
load transfer rest. joints
do nothing
4
full-depth repair cracks
4
full-depth repair cracks
7
replace undowelled FDR
7
replace undowelled FDR
JTC
JTC
1
partial depth repair
of longit. CL joint
9
partial depth repair
11-14
seal cracks at joints
seal cracks at joints,
load trans rest. cracks
2-5
seal longit. cracks
stifen longit. cracks
9
partial-depth repair
11-14
seal cracks at joints
seal cracks at joints,
load trans rest. cracks
LOS
1-4
subseal joints and cracks
JTS
JTS
2,3
reseal transverse joints
do nothing
2,3
reseal transverse joints
do nothing
4-6
reseal transverse joints
4,6
reseal transverse joints


unbonded PCC
AC structural, bonded PCC
crack and seat
FDN
FDN
FDN
AC OL
2,4, 6,7
reconstruct heaves, AC level-up settlements
2,4, 6,7
reconstruct heaves, AC level-up settlements
reconstruct heaves, AC level-up settlements
bonded PCC OL
2,4, 6,7
reconstruct heaves slab jack settlements
RGH
RGH
RGH
AC OL
3
AC level-up settlements
3
AC level-up settlements
3
AC level-up settlements
4
reconstruct heaves
4
reconstruct heaves
bonded PCC OL
3
slab jack settlements
4
reconstruct heaves
OUTER LANE DRN
1-12
install/repair subdrains
OUTER SHD *
INNER DRN
INNER LANE SLOPE DIRECTION
out
1-12
install/repair subdrains
1-12
install/repair subdrains
do nothing
INNER SHD *
* see decision tree for rehabilitating shoulder adjacent to overlaid lane

AC Shoulder Rehabilitation Adjacent to Overlaid Lane.

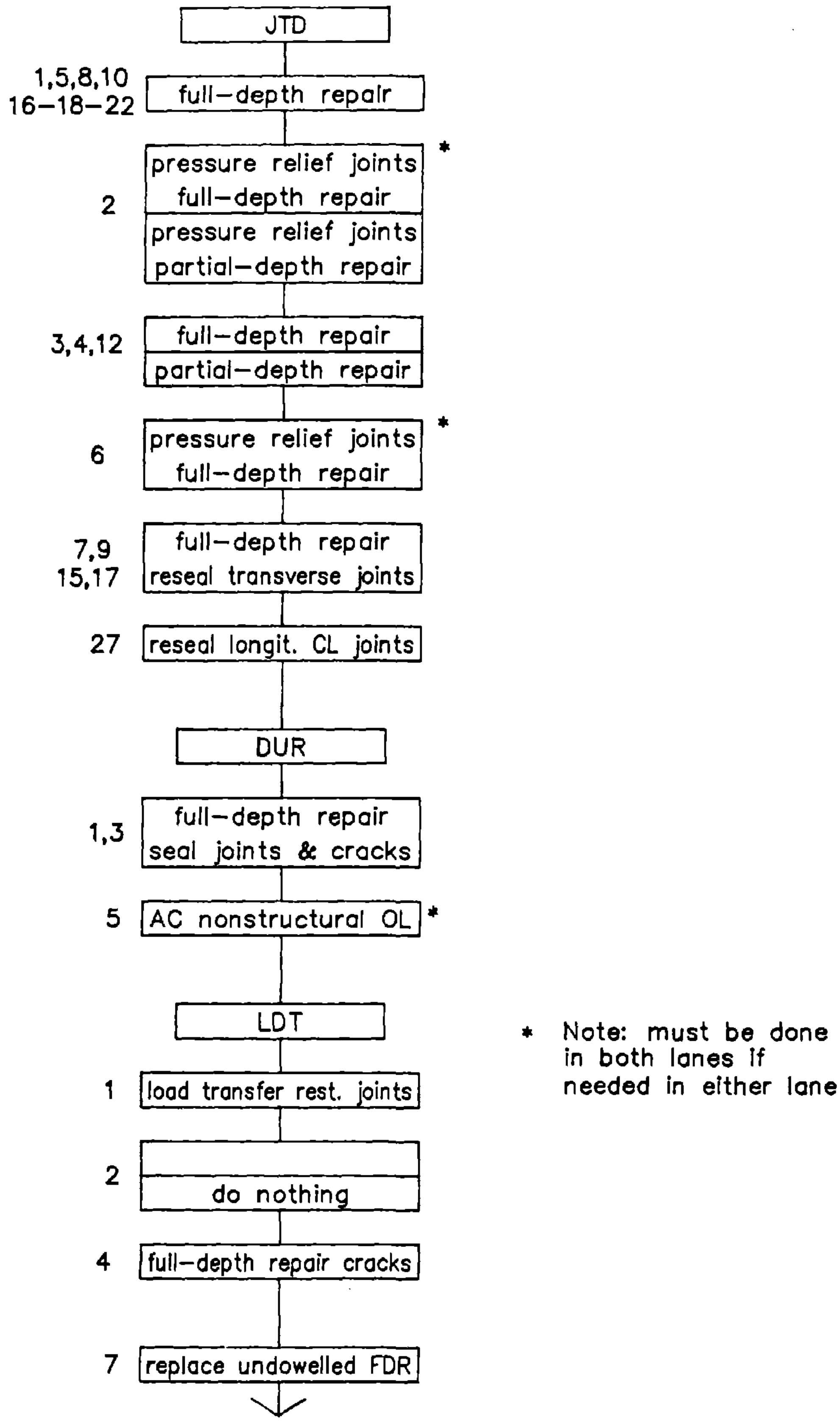


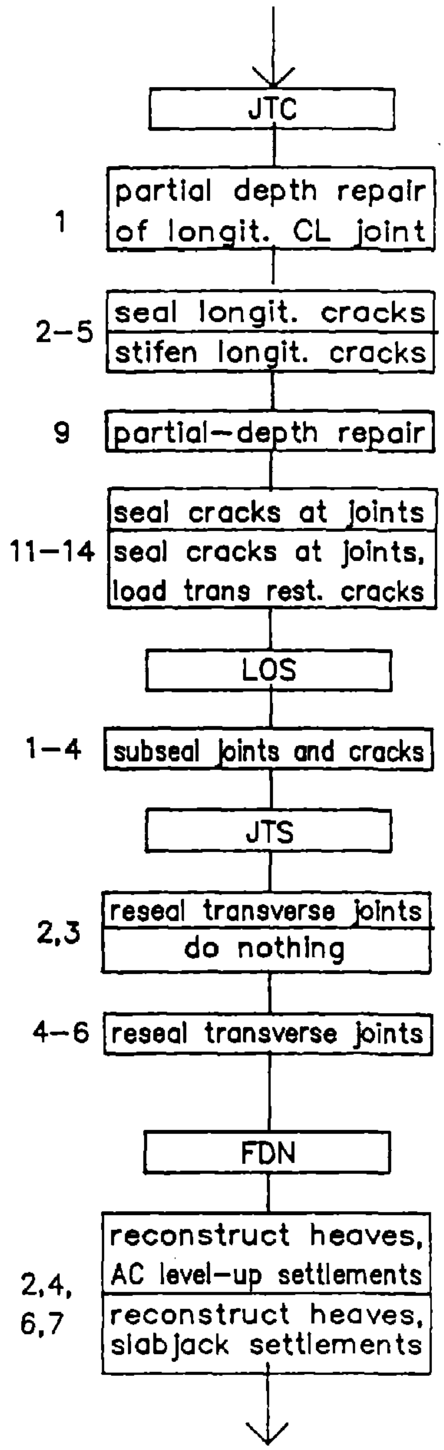
PCC Shoulder Rehabilitation Adjacent to Overlaid Lane

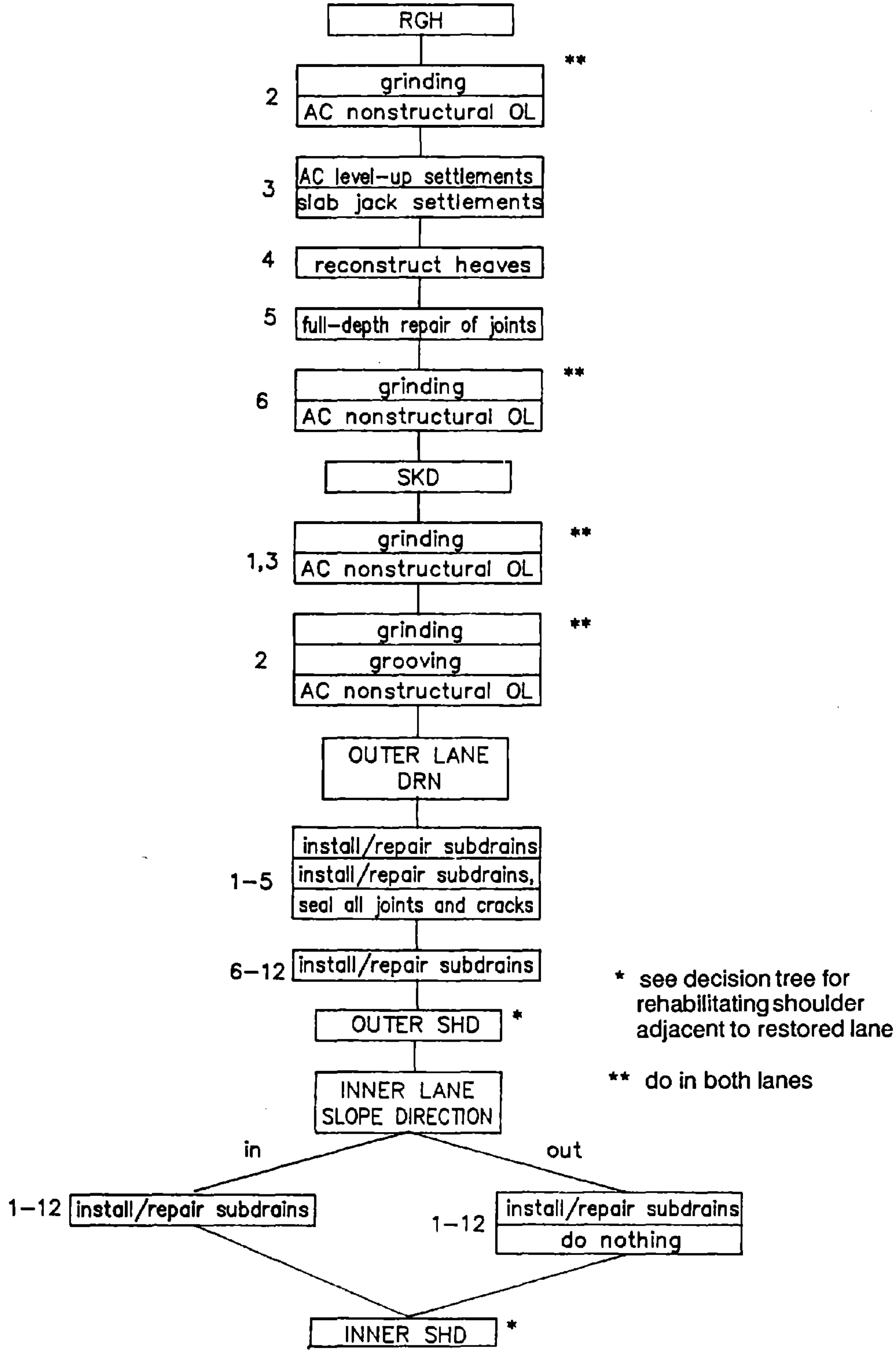


Notes: Pvt PCC OL = bonded PCC OL, unbonded PCC OL
Pvt AC OL = AC structural OL, AC nonstructural OL, crack and seat and AC structural OL

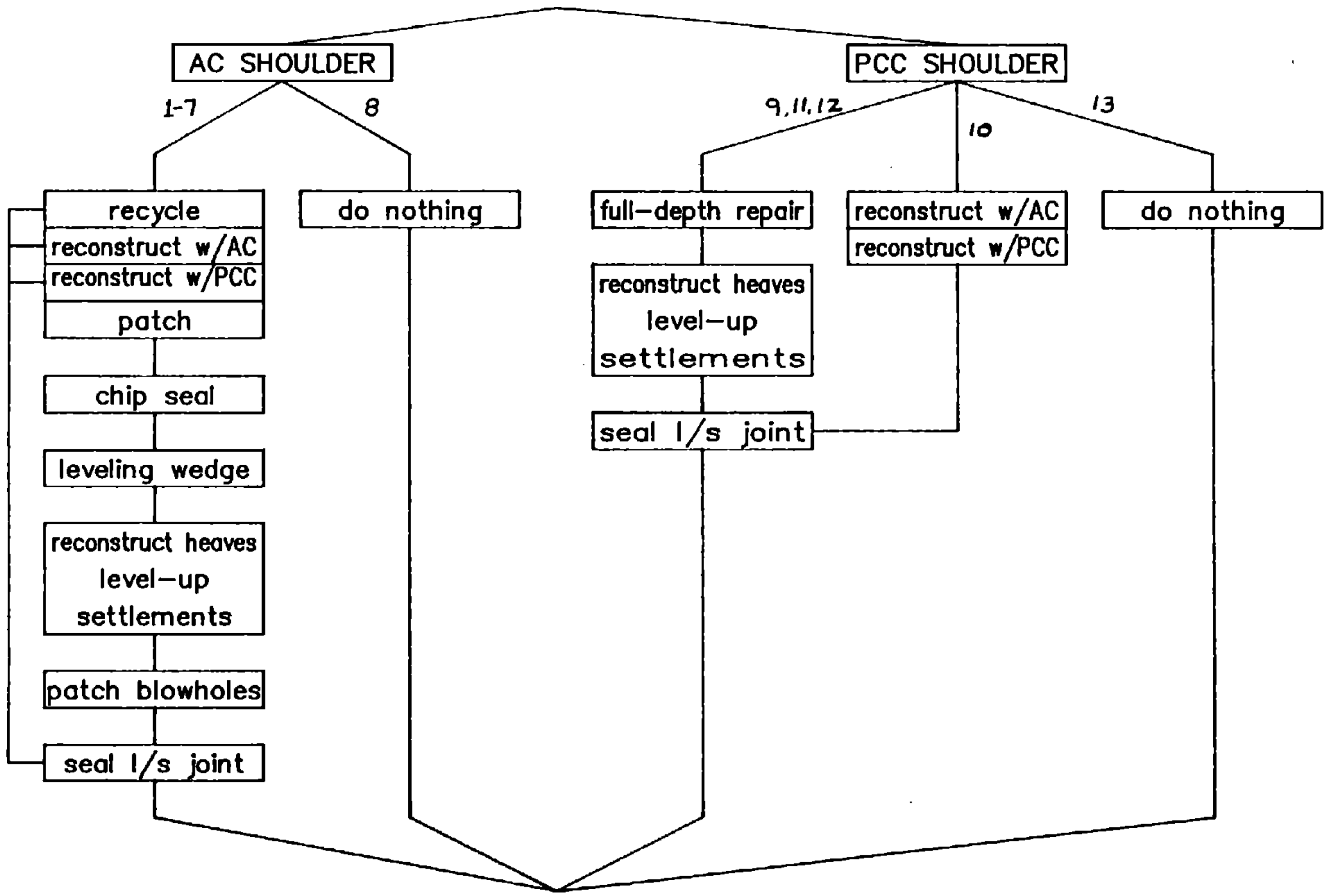
RESTORATION OF JRCP LANE




JTC
1
partial depth repair of longit. CL joint
2–5
seal longit. cracks
stifen longit. cracks
9
partial–depth repair
11–14
seal cracks at joints
seal cracks at joints, load trans rest. cracks
LOS
1–4
subseal joints and cracks
JTS
2,3
reseal transverse joints
do nothing
4–6
reseal transverse joints
FDN
2,4, 6,7
reconstruct heaves, AC level–up settlements
reconstruct heaves, slabjack settlements


RGH
**
2
grinding
AC nonstructural OL
3
AC level-up settlements
slab jack settlements
4
reconstruct heaves
5
full-depth repair of joints
**
6
grinding
AC nonstructural OL
SKD
**
1,3
grinding
AC nonstructural OL
**
2
grinding
grooving
AC nonstructural OL
OUTER LANE DRN
1-5
install/repair subdrains
install/repair subdrains, seal all joints and cracks
6-12
install/repair subdrains
OUTER SHD *
INNER LANE SLOPE DIRECTION
in
out
1-12
install/repair subdrains
1-12
install/repair subdrains
do nothing
INNER SHD *
* see decision tree for rehabilitating shoulder adjacent to restored lane
** do in both lanes

Shoulder Rehabilitation Adjacent to Restored Lane



APPENDIX A5

REHABILITATION PERFORMANCE PREDICTION MODELS FOR JRCP

Rehabilitation	Distress Type
Reconstruction	Faulting Cracking Joint Deterioration Pumping PSR
Bonded PCC OL	Faulting Joint Deterioration Cracking
Unbonded PCC OL	Faulting Joint Deterioration Cracking

AC Structural OL,
 	
AC Nonstructural OL
	Reflective Cracking
	    Total
	    Medium-High Severity
	Rutting

Crack and Seat and AC Structural OL	Reflective Cracking
	    Total
	    Medium-High Severity
	Rutting

Restoration	Joint Faulting
	    With Grinding
	    Without Grinding
	Cracking
	Joint Deterioration
	FDR Faulting
	Pumping
	PSR

Faulting

$$FAULT = ESAL^{0.4731} * [-3.8536 - 1.5355\ SOILCRS + 197.124\ (THICK * DOWEL^{2.0})^{-1.7842} + 0.00024\ FI + 0.09858\ JTSPACE + 0.24115\ PUMP^{2.0}] * PCCSH / 100$$

where:

FAULT = mean transverse joint faulting after reconstruction, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

SOILCRS = subgrade soil classification
= 0, if existing subgrade is fine grained (A4 to A7) and no drainage layer placed beneath reconstructed PCC slab
= 1, if existing subgrade is coarse grained (A1 to A3) or drainage layer is placed beneath reconstructed PCC slab

THICK = thickness of reconstructed PCC slab, in

DOWEL = diameter of dowels in reconstructed pavement, in (0 if no dowel bars used)

FI = mean Freezing Index, Fahrenheit degree-days

JTSPACE = transverse joint spacing of reconstructed pavement, ft

PUMP = pumping severity after reconstruction (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

PCCSH = new or existing tied PCC shoulders
= 1.0, if not present
= 0.5, if present (based upon JPCP model)

R^2 = 0.69
n = 384
SEE = 0.06 in [0.15 cm]

Source: NCHRP 1-19 (6)

Note: Dowel spacing in reconstructed pavement assumed to 12 in [30.5 cm].

Cracking

$$\text{CRACKS} = \text{ESAL}^{0.897}\ [\ 7130.0\ \text{JTSPACE} / (\text{ASTEEL} * \text{THICK}^{5.0})\ ]$$
$$+\ \text{ESAL}^{0.10}\ (2.281\ \text{PUMP}^{5.0})$$
$$+\ \text{ESAL}^{2.16}\ [\ 1.81 / (\text{BASETYPE} + 1)]$$
$$+\ \text{AGE}^{1.3}\ [0.0036\ (\text{FI} + 1)^{0.36}]$$

where:

CRACKS = total length of medium- and high-severity deteriorated cracks after reconstruction, ft/mile

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

JTSPACE = transverse joint spacing of reconstructed pavement, ft

ASTEEL = area of reinforcing steel in reconstructed pavement, square in/foot width of slab

THICK = thickness of reconstructed PCC slab, in

PUMP = pumping severity after reconstruction (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

BASETYPE = type of base under reconstructed PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

AGE = time since reconstruction, years

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.41
n = 314
SEE = 280 ft/mile [53 m/km]

Source: NCHRP 1-19 (6)

Joint Deterioration

$$\text{DETJT} = \text{AGE}^{2.1521}\ \text{ESAL}^{0.1419}\ [\ 0.05202 + 0.0000254\ \text{FI} + 0.01109\ \text{TJSD} - (0.003384 * \text{K1} * \text{JTSPACE}) - (0.0006446 * \text{K2} * \text{JTSPACE})\ ]$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after reconstruction, number/mile

AGE = time since reconstruction, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if transverse joint sealant will be maintained well over the design period
= 1, if transverse joint sealant will not be maintained well over the design period

JTSPACE = transverse joint spacing of reconstructed pavement, ft

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 m]

R^2 = 0.61
n = 319
SEE = 15 joints/mile [9 joints/km]

Source: NCHRP 1-19 (6)

Notes: Do not use model outside of specified ranges for JTSPACE (27 ft [8.2 m] or 39 to 100 ft [11.9 to 30.5 m]).

Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the reconstructed pavement will not contain D cracking or reactive aggregates.

Pumping

$$PUMP = ESAL^{0.670} [-22.82 + (26102.2 / THICK^{5.0})$$

$$- 0.129\ DRAIN - 0.118\ SOILCRS + 13.224\ SUMPREC^{0.0395}$$

$$+ 6.834\ (FI + 1)^{0.00805}]$$

where:

PUMP = pumping severity after reconstruction
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

THICK = thickness of reconstructed PCC slab, in

DRAIN = new or existing longitudinal subdrains or drainage layer
= 0, if no subdrains present or present but not functional, and no drainage layer or subdrains placed under reconstructed PCC slab
= 1, if subdrains present and functional, or drainage layer or subdrains placed beneath reconstructed PCC slab

SOILCRS = subgrade soil classification
= 0, if existing subgrade is fine grained (A4 to A7) and no drainage layer placed beneath reconstructed PCC slab
= 1, if existing subgrade is coarse grained (A1 to A3) or drainage layer is placed beneath reconstructed PCC slab

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.57
n = 481
SEE = 0.52

Source: NCHRP 1-19 (6)

PSR

$$PSR = 4.5 - ESAL^{0.424} (-0.00188 + 14.417\ RATIO^{3.58}$$
$$+ 0.0399\ PUMP + 0.0021528\ JTSPACE + 0.00004156\ FI$$
$$+ 0.00163\ SUMPREC - 0.070535\ BASETYPE)$$

where:

PSR = Present Serviceability Rating after reconstruction

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

RATIO = Westergaard's edge stress/reconstructed PCC slab modulus of rupture (see following page to calculate Westergaard's edge stress)

PUMP = pumping severity after reconstruction (from pumping model)
= 0, if none or low severity ($\leq$ 1)
= 1, if medium or high severity (>1)

JTSPACE = transverse joint spacing of reconstructed pavement, ft

FI = mean Freezing Index, Fahrenheit degree-days

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

BASETYPE = type of base under reconstructed PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

R^2 = 0.78
n = 377
SEE = 0.30

Source: NCHRP 1-19 (6)

Note: Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the reconstructed pavement will not contain D cracking or reactive aggregates.

Calculation of Westergaard's Edge Stress:

$$L = [\ (4200000 * THICK^{3.0}) / 12 * (1 - 0.2^{2.0}) * KEFF\ ]^{0.25}$$

$$B = [\ 1.6\ (6.4)^2 + THICK^2\ ]^{0.5} - 0.675\ THICK$$

$$Stress = (0.572 * 9000 / THICK^{2.0}) * [4 \log_{10} (L/B) + 0.359]$$

where:

THICK = thickness of reconstructed PCC slab, in

KEFF = effective k value beneath reconstructed PCC slab, psi/in

4,200,000 = assumed elastic modulus of reconstructed PCC slab, psi

0.20 = assumed Poisson's ratio of reconstructed PCC slab

6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/in = 2.71 kPa/cm

Faulting

$$FAULT = 0.0015897\ ESAL^{0.233}\ [\ -10.942 - 30.657\ BASETYPE + 0.0005652\ (FI + 1)^{2.299} + 33.322\ (DOWEL + 1)^{-0.8477}\ ]\ /\ 100$$

where:

FAULT = mean transverse joint faulting after overlay, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

BASETYPE = type of base under original PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

FI = mean Freezing Index, Fahrenheit degree-days

DOWEL = diameter of dowels in original PCC slab, in (0 if no dowel bars used)

R^2 = 0.54
n = 27
SEE = 0.02 in [0.05 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Note: Dowel spacing in original pavement assumed to 12 inches.

Joint Deterioration

$$DETJT = AGE^{2.1521}\ ESAL^{0.1419}\ [\ 0.05202 + 0.0000254\ FI$$

$$+\ 0.01109\ TJSD - (0.003384 * K1 * JTSPACE)$$

$$-\ (0.0006446 * K2 * JTSPACE)\ ]$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after overlay, number/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if transverse joint sealant will be maintained well over the design period
= 1, if transverse joint sealant will not be maintained well over the design period

JTSPACE = transverse joint spacing of overlay, ft (assumed to have same joint spacing as original pavement)

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 m]

R^2 = 0.61
n = 319
SEE = 15 joints/mile [9 joints/km]

Source: NCHRP 1-19 (6)

Notes: Do not use model outside of specified ranges for JTSPACE (27 ft [8.2 m] or 39 to 100 ft [11.9 to 30.5 m]).

Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the overlay will not contain D cracking or reactive aggregates.

Cracking

$$CRACKS = 11.328\ ESAL^{0.07546}\ (21.426\ [\ AGE\ (FI + 1)\ /\ 1000\ ]^{0.66876})$$

where:

CRACKS = total length of medium- and high-severity deteriorated cracks after overlay, ft/mile

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

AGE = time since overlay, years

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.75
n = 13
SEE = 326 ft/mile [61.7 m/km]

Source: "Overlay Rehabilitation Techniques," Volume 2

Faulting

$$FAULT = 0.28615\ ESAL^{0.39654}\ [\ 0.0987\ (DOWEL + 1)^{-0.51083}\ ]$$

where:

FAULT = mean transverse joint faulting after overlay, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

DOWEL = diameter of dowels in overlay, in (0 if no dowel bars used)

R^2 = 0.51
n = 23
SEE = 0.02 in [0.05 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Note: Dowel spacing in overlay assumed to 12 in [30.5 cm].

Joint Deterioration

$$DETJT = AGE^{2.1521}\ ESAL^{0.1419}\ [\ 0.05202 + 0.0000254\ FI + 0.01109\ TJSD - (0.003384 * K1 * JTSPACE) - (0.0006446 * K2 * JTSPACE)\ ]$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after overlay, number/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if transverse joint sealant will be maintained well over the design period
= 1, if transverse joint sealant will not be maintained well over the design period

JTSPACE = transverse joint spacing of overlay, ft

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 m]

R^2 = 0.61
n = 319
SEE = 15 joints/mile [9 joints/km]

Source: NCHRP 1-19 (6)

Notes: Do not use model outside of specified ranges for JTSPACE (27 ft [8.2 m] or 39 to 100 ft [11.9 to 30.5 m]).

Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the overlay will not contain D cracking or reactive aggregates.

Cracking

$$\text{CRACKS} = \text{ESAL}^{0.897} \; [\; 7130.0 \;\text{JTSPACE} \;/\; (\text{ASTEEL} * \text{THICK}^{5.0}) \;]$$
$$+ \;\text{ESAL}^{2.16} \; [\; 1.81 \;/\; (\text{BASETYPE} + 1)]$$
$$+ \;\text{AGE}^{1.3} \; [0.0036 \; (\text{FI} + 1)^{0.36}]$$

where:

CRACKS = total length of medium- and high-severity deteriorated cracks after overlay, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

JTSPACE = transverse joint spacing of overlay, ft

ASTEEL = area of reinforcing steel in overlay, square inches/foot width of slab

THICK = thickness of overlay, in

BASETYPE = type of base under overlay
= 1, since layer beneath overlay is original pavement

AGE = time since overlay, years

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.41
n = 314
SEE = 280 ft/mile [53 m/km]

Source: NCHRP 1-19 (6)

Note: Original model contains an additional term for pumping. This term was ommitted since no pumping was observed on the unbonded overlay sections surveyed.

Reflective Cracking (All Severities)

$$CRACKS = \{ 10.745 * AGE^{0.3} * ESAL^{0.0187} * THICK^{-0.064} * [(PATCHES / 8.8) + 1]^{0.293} - 1 \} * 8.8$$

where:

CRACKS = total length of low-, medium-, and high-severity reflective transverse cracks after overlay, ft/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

THICK = thickness of overlay, in

PATCHES = full-depth repairs existing or placed on original pavement prior to overlay, number/mile, computed as follows:
M-H deteriorated transverse cracks/mile
\+ M-H deteriorated joints/mile
\+ corner breaks/mile
\+ existing full-depth repairs/mile

$R^2 = 0.27$
$n = 50$
SEE = 0.40

Source: Development of Illinois Pavement Feedback System, on-going study being conducted for the Illinois Department of Transportation. Data from Illinois Interstate highways.

Reflective Cracking (Medium and High Severity)

$$\text{MHCRACKS} = [\ 2.8594 * (\text{AGE} * \text{ESAL})^{0.19258} * \text{OLTHICK}^{-0.21163} * (\text{PATCHES} / 8.8)^{0.61169}\ ] * 8.8$$

where:

MHCRACKS = total length of medium- and high-severity reflective transverse cracks after overlay, ft/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

THICK = thickness of overlay, in

PATCHES = full-depth repairs existing or placed on original pavement prior to overlay, number/mile, computed as follows:
  M-H deteriorated transverse cracks/mile
  + M-H deteriorated joints/mile
  + corner breaks/mile
  + existing full-depth repairs/mile

R^2 = 0.83
n = 50
SEE = 0.30

Source: Development of Illinois Pavement Feedback System, on-going study being conducted for the Illinois Department of Transportation. Data from Illinois Interstate highways.

Rutting

$$RUT = 0.084807 + 0.019208\ ESAL + 0.012512\ AGE + 0.001199\ PTRUCKS$$
$$- 0.004177\ PRECIP + 0.0002798\ (\ FI\ /\ THICK\ ) + 0.006447\ ZONE$$

where:

RUT = average wheelpath rutting, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

AGE = time since overlay, years

PTRUCKS = percent trucks in average daily traffic

PRECIP = annnual precipitation, in

FI = mean Freezing Index, Fahrenheit degree-days

THICK = overlay thickness, in

ZONE = climatic zone

$$= -5.9531 + 0.14263\ ANNTEMP - 0.12123\ PRECIP + 0.1955\ MRANGE$$

where:

ANNTEMP = average annual temperature, degrees Fahrenheit

MRANGE = average monthly temperature range, degrees Fahrenheit

R^2 = 0.71
n = 101
SEE = 0.06 in [0.15 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Notes: ZONE must be in the range of 0.5 to 9.5 (1 to 9 preferable) to produce realistic values for rutting. Values outside this range represent combinations of climatic inputs which are not within the realm of possible occurrence.

This rutting model represents a linear approximation of a nonlinear phenomenon. For some combinations of the variables, the model may give negative values, which should be interpreted as zeroes.

All-Severity Transverse Cracking

TCRACKS = [-271.76 + 0.2719 FI + 3.91 THICK + 2.833 SRW - 21.55 WDT - 2.327 JTSPACE + 13.66 LEN + 4.828 AREA + 2.706 ESAL*AGE + 0.941 ANNTEMP + 7.457 TRANGE] * 5.28

where:

TCRACKS = total length of low-medium-high severity transverse cracks after overlay, ft/mile (includes all transverse cracks in AC overlay from any cause)

THICK = thickness of PCC slab, in

JTSPACE = transverse joint spacing of original pavement, ft

SRW = seating roller weight, tons

WDT = mean width of cracked pieces (across traffic lane), ft

LEN = mean length of cracked pieces (along traffic lane), ft

AREA = area of cracked section (length * width), square ft

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay in traffic lane, millions

AGE = age of AC overlay, years

ANNTEMP = mean annual temperature, degrees Fahrenheit

TRANGE = mean monthly temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.57
n = 100
SEE = 903 ft/mile ft [171 m/km]

Source: Revised model based upon database developed in "Overlay Rehabilitation Techniques," Volume 2.

Medium- and High-Severity Transverse Cracking

MHCRACKS = [298.82 + 0.0378 FI - 21.29 THICK - 0.572 SRW - 38.54 WDT + 0.59 JTSPACE - 18.48 LEN + 7.89 AREA + 0.815 ESAL*AGE + 1.65 ANNTEMP - 5.28 TRANGE] * 5.28

where:

MHCRACKS = total length of medium- and high-severity transverse cracks after overlay, ft/mile

THICK = thickness of PCC slab, in

JTSPACE = transverse joint spacing of original pavement, ft

SRW = seating roller weight, tons

WDT = mean width of cracked pieces (across traffic lane), ft

LEN = mean length of cracked pieces (along traffic lane), ft

AREA = area of cracked section (length * width), square ft

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay in traffic lane, millions

AGE = age of AC overlay, years

ANNTEMP = mean annual temperature, degrees Fahrenheit

TRANGE = mean monthly temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.79
n = 100
SEE = 317 ft/mile [60 m/km]

Source: Revised model based upon database developed in "Overlay Rehabilitation Techniques," Volume 2.

This model represents a linear approximation of the nonlinear progression of medium- to high-severity reflective cracks from low-severity reflective cracks.
For some combinations of the variables, the model may give negative values, which should be interpreted as zeroes (i.e., cracking has not yet progressed to the medium severity level).

Rutting

$$RUT = 0.084807 + 0.019208\ ESAL + 0.012512\ AGE + 0.001199\ PTRUCKS$$
$$- 0.004177\ PRECIP + 0.0002798\ (FI / THICK) + 0.006447\ ZONE$$

where:

RUT = average wheelpath rutting, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

AGE = time since overlay, years

PTRUCKS = percent trucks in average daily traffic

PRECIP = annnual precipitation, in

FI = mean Freezing Index, Fahrenheit degree-days

THICK = overlay thickness, in

ZONE = climatic zone (same as for reflective cracking)

R^2 = 0.71
n = 101
SEE = 0.06 in [0.15 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Notes: ZONE must be in the range of 0.5 to 9.5 (1 to 9 preferable) to produce realistic values for rutting. Values outside this range represent combinations of climatic inputs which are not within the realm of possible occurrence.

This rutting model represents a linear approximation of a nonlinear phenomenon. For some combinations of the variables, the model may give negative values, which should be interpreted as zeroes.

<u>Joint Faulting (With Grinding)</u>

$$\begin{aligned} FAULT = & -5.62\ (ESAL + AGE)^{0.54} \\ & * [\ 5.85 * (DRAIN + SOILCRS + 1)^{0.0529} \\ & - (3.8 * 10^{-9}) * (FI / 100)^{6.29} \\ & + 0.484\ (THICK + PCCSH)^{0.335} + 0.1554\ BASETYPE \\ & - 7.163\ JTSPACE^{0.0137} + 0.1136\ LDTR\ ] / 100 \end{aligned}$$

where:

FAULT = mean transverse joint faulting after restoration, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after restoration, millions

AGE = time since restoration, years

DRAIN = new or existing longitudinal subdrains
= 0, if no subdrains present or present but not functional
= 1, if subdrains present and functional

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

FI = mean Freezing Index, Fahrenheit degree-days

THICK = thickness of PCC slab, in

PCCSH = new or existing tied PCC shoulder
= 0, if not present
= 1, if present

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

JTSPACE = transverse joint spacing of pavement, ft

LDTR = load transfer restoration done by retrofitting dowel bars
= 0, if not done
= 1, if done

R^2 = 0.38
n = 114
SEE = 0.03 in [0.08 cm]

Source: "Repair Rehabilitation Techniques," Volume 1

Note: Joint faulting = 0.00 in immediately after grinding.

Joint Faulting (Without Grinding)

$$\text{FAULT} = [\ (\ \text{ESAL}^{0.4731}\ [\ -3.8536 - 1.5355\ \text{SOILCRS} + 197.124\ (\text{THICK} * \text{DOWEL}^{2.0})^{-1.7842} + 0.00024\ \text{FI} + 0.09858\ \text{JTSPACE} + 0.24115\ \text{PUMP}^{2.0}\ ]\ /\ 100\ )\ + \text{FLTCALIB}\ ] * \text{SHDF} * \text{LDTRF} * \text{DRNF}$$

where:

FAULT = mean transverse joint faulting after restoration, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

THICK = thickness of PCC slab, in

DOWEL = diameter of dowels in PCC slab, in (0 if no dowel bars used)

FI = mean Freezing Index, Fahrenheit degree-days

JTSPACE = transverse joint spacing of reconstructed pavement, ft

PUMP = pumping severity after restoration (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

FLTCALIB = calibration of model to existing faulting

= actual faulting (inches) measured during survey - FAULT predicted for present year by above model

$$= \text{actual faulting} - (\ \text{ESAL}^{0.4731}\ [\ -3.8536 - 1.5355\ \text{SOILCRS} + 197.124\ (\text{THICK} * \text{DOWEL}^{2.0})^{-1.7842} + 0.00024\ \text{FI} + 0.09858\ \text{JTSPACE} + 0.24115\ \text{PUMP}^{2.0}\ ]\ /\ 100\ )$$

SHDF = new or existing tied PCC shoulder
= 0.90, if present
= 1.00, if not present

LDTF = load transfer restoration done
= 0.83, if done
= 1.00, if not done

DRNF = new or existing longitudinal subdrains
= 0.69, if present and functional
= 1.00, if not present or not functional

R^2 = 0.69
n = 384
SEE = 0.06 in [0.15 cm]

Source: NCHRP 1-19 (6)

Note: Initial joint faulting = existing joint faulting measured during survey if grinding not done during restoration.

Cracking

$$\text{CRACKS} = \text{ESAL}^{0.897} [\ 7130.0\ \text{JTSPACE} / (\text{ASTEEL} * \text{THICK}^{5.0})\ ]$$
$$+ \text{ESAL}^{0.10} (2.281\ \text{PUMP}^{5.0})$$
$$+ \text{ESAL}^{2.16} [\ 1.81 / (\text{BASETYPE} + 1)]$$
$$+ \text{AGE}^{1.3} [0.0036\ (\text{FI} + 1)^{0.36}] + \text{CRKCALIB}$$

where:

CRACKS = total length of medium- and high-severity deteriorated cracks after restoration, ft/mile

ESAL = accumulated 18-kip equivalent single-axle loads since construction, millions

JTSPACE = transverse joint spacing of PCC slab, ft

ASTEEL = area of reinforcing steel in PCC slab, square in/foot width of slab

THICK = thickness of PCC slab, in

PUMP = pumping severity after restoration (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

AGE = time since construction, years

FI = mean Freezing Index, Fahrenheit degree-days

CRKCALIB = calibration of model to existing cracking

= actual cracking (M-H cracks, feet/mile) measured during survey - CRACKS predicted for present year by above model

$$= \text{actual cracking} - \{\ \text{ESAL}^{0.897} [\ 7130.0\ \text{JTSPACE}$$
$$/ (\text{ASTEEL} * \text{THICK}^{5.0})\ ] + \text{ESAL}^{0.10} (2.281\ \text{PUMP}^{5.0})$$
$$+ \text{ESAL}^{2.16} [\ 1.81 / (\text{BASETYPE} + 1)]$$
$$+ \text{AGE}^{1.3} [0.0036\ (\text{FI} + 1)^{0.36}]\ \}$$

$R^2 = 0.41$
$n = 314$
SEE = 280 ft/mile [53 m/km]

Source: NCHRP 1-19 (6)

Note: Initial cracking after restoration = 0 ft/mile, assuming all medium- to high-severity cracks are full-depth repaired during restoration. Cracking after restoration continues at same rate as before.

Joint Deterioration

$$\begin{aligned} DETJT = {} & AGE^{0.756} * 2.4367\ DCRACK * 2.744\ REACTAGG \\ & + AGE^{2.1521}\ ESAL^{0.1419}\ [\ 0.05202 + 0.0000254\ FI \\ & + 0.01109\ TJSD - (0.003384 * K1 * JTSPACE) \\ & - (0.0006446 * K2 * JTSPACE)\ ] + DETJTCALIB \end{aligned}$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after restoration, number/mile

AGE = time since construction, years

DCRACK = D cracking severity before restoration
= 0, if none
= 1, if low, medium, or high severity

REACTAGG = reactive aggregate distress severity before restoration
= 0, if none
= 1, if low, medium, or high severity

ESAL = accumulated 18-kip equivalent single-axle loads since construction, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if existing transverse joint sealant damage is none or low severity or if transverse joints are resealed during restoration
= 1, if transverse joint sealant damage is medium or high severity and transverse joints are not resealed during restoration

JTSPACE = transverse joint spacing of reconstructed pavement, ft

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 m]

DETJTCALIB = calibration of model to existing joint deterioration

= actual joint deterioration (M-H deteriorated joints/mile) measured during survey - DETJT predicted for present year by above model

= actual joint deterioration - ($AGE^{0.756}$ * 2.4367 DCRACK

* 2.744 REACTAGG

+ $AGE^{2.1521}$ $ESAL^{0.1419}$ [0.05202 + 0.0000254 FI

+ 0.01109 TJSD - (0.003384 * K1 * JTSPACE)

+ (0.0006446 *K2 * JTSPACE)])

where:

TJSD = existing transverse joint sealant damage before restoration
= 0, if existing transverse joint sealant damage is none or low severity
= 1, if transverse joint sealant damage is medium or high severity

R^2 = 0.61
n = 319
SEE = 15 joints/mile [9 joints/km]

Source: NCHRP 1-19 (6)

Notes: Do not use model outside of specified ranges for JTSPACE (27 ft [8.2 m] or 39 to 100 ft [11.9 to 30.5 m]).

Initial number of deteriorated joints = 0 per mile, assuming all medium- to high-severity joint deterioration is full-depth repaired during restoration.

Full-Depth Repair Faulting

FDRFAULT = (NEWFDR * NEWFDRFAULT) + (EXISTFDR + EXFDRFAULT)

/ (NEWFDR + EXISTFDR)

where:

FDRFAULT = weighted average faulting at new and existing full-depth repair joints since restoration, in

NEWFDR = full-depth repairs placed during restoration, number/mile

NEWFDRFAULT = average faulting at new full-depth repair joints since restoration, in

$= ESAL^{0.74} * (0.0364 - 0.292\ BASETYPE)$

$+ 0.275 (AGE * FI)^{0.019} - 0.283$

where:

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since restoration, millions

BASETYPE = type of base under PCC slab
= 0, if granular
= 1, if stabilized (asphalt, cement, etc.)

AGE = time since restoration, years

FI = mean Freezing Index, Fahrenheit degree-days

EXISTFDR = number of existing full-depth repairs before restoration, number/mile

EXFDRFAULT = average faulting at existing full-depth repair joints since restoration, in

$= FDRESAL^{0.74} * (0.0364 - 0.292\ BASETYPE)$

$+ 0.275 (FDRAGE * FI)^{0.019} - 0.283$

where:

FDRESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since placement of existing FDRs, millions

BASETYPE = type of base under PCC slab
= 0, if granular
= 1, if stabilized (asphalt, cement, etc.)

FDRAGE = time since placement of existing FDRs, years

FI = mean Freezing Index, Fahrenheit degree-days

$R^2 = 0.41$
$n = 113$
SEE = 0.048 in [0.122 cm]

Source: "Repair Rehabilitation Techniques," Volume 1

Notes: Initial faulting of new full-depth repairs = 0 inches, assuming full-depth repairs are constructed and finished to match existing pavement profile.

If grinding is done or if existing full-depth repairs are replaced during restoration, then initial faulting of existing full-depth repair joints = 0 inches.

If grinding is not done and existing full-depth repairs are not replaced during restoration, then initial faulting of existing full-depth repair joints = faulting measured during survey.

Backcalculation of Cumulative ESALs in Existing Full-Depth Repairs:

If FDRAGE is provided by user:

$$FDRESAL = 10 ** \{ (\log_{10} [\text{actual FDR faulting} - 0.275 (FDRAGE * FI)^{0.019} + 0.283] - \log_{10} [0.033364 - 0.292 \, BASETYPE])/0.74 \}$$

Pumping

$$\text{PUMP} = \text{ESAL}^{0.670} [-22.82 + (26102.2 / \text{THICK}^{5.0})$$
$$- 0.129\ \text{DRAIN} - 0.118\ \text{SOILCRS} + 13.224\ \text{SUMPREC}^{0.0395}$$
$$+ 6.834\ (\text{FI} + 1)^{0.00805}]$$

where:

PUMP = pumping severity after restoration
= 0, no pumping
= 1, low severity
= 2, medium severity
= 3, high severity

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

THICK = thickness of PCC slab, in

DRAIN = new or existing longitudinal subdrains
= 0, if no subdrains present or present but not functional
= 1, if subdrains present and functional

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.57
n = 481
SEE = 0.52

Source: NCHRP 1-19 (6)

Note: Initial pumping = 0, assuming existing pumping is corrected by subsealing and/or subdrainage during restoration.

PSR

PSR = 4.5 - 0.068 TFAULT - 0.00032 CRACKS - 0.0052 DETJT

where:

PSR = Present Serviceability Rating after restoration (0 to 5 scale)

TFAULT = total faulting at joints, cracks, and full-depth repairs, in/mile (to calculate see below)

CRACKS = medium- to high-severity transverse cracks after restoration, ft/mile (from cracking model)

DETJT = medium- to high-severity deteriorated transverse joints after restoration, number/mile (from joint deterioration model)

R^2 = 0.73
n = 389
SEE = 0.33

Source: NCHRP 1-19 database for JRCP.

Calculation of Total Faulting for PSR Model:

TFAULT = [(5280/JTSPACE) - EXISTDETJT] * JTFAULT

+ (NEWFDR * NEWFDRFLT)

+ (EXISTFDR * EXISTFDRFLT)

where:

JTSPACE = transverse joint spacing of pavement, ft

EXISTDETJT = medium- to high-severity deteriorated joints before restoration, number/mile

JTFAULT = average transverse joint faulting after restoration, inches (from applicable joint faulting model, with or without grinding)

NEWFDR = full-depth repairs placed during restoration, number/mile

= EXISTDETJT + CRACKS + CORBRKS

where:

EXISTDETJT = medium- to high-severity deteriorated joints before restoration, number/mile

CRACKS = medium- to high-severity transverse cracks before restoration, number/mile

CORBRKS = corner breaks before restoration, number/mile

NEWFDRFLT = average faulting at full-depth repair joints after restoration, in (from full-depth repair faulting model)

EXISTFDR = existing full-depth repairs before restoration, number/mile

EXISTFDRFLT = average faulting at existing full-depth repair joints after restoration, in (from full-depth repair faulting model).

Notes: For purposes of computing PSR, only one joint per full-depth repair is counted and multiplied times mean full-depth repair faulting, since full-depth repair joints are sufficiently close to represent one noticeable fault to the user.

Initial faulting of new full-depth repairs = 0 in, assuming full-depth repairs are constructed and finished to match existing pavement profile.

If grinding is done or if existing full-depth repairs are replaced during restoration, then initial faulting of existing full-depth repair joints = 0 in.

If grinding is not done and existing full-depth repairs are not replaced during restoration, then initial faulting of existing full-depth repair joints = faulting measured during survey.

Appendix A6

User's Guide for

EXPEAR

Expert System for Concrete Pavement

Evaluation and Rehabilitation

EXPEAR EXPERT SYSTEM FOR CONCRETE PAVEMENT EVALUATION AND REHABILITATION

CAPABILITIES AND APPLICATIONS

The EXpert system for Pavement Evaluation And Rehabilitation (EXPEAR) was originally developed by the University of Illinois for the Federal Highway Administration and is currently being further developed for the Illinois Department of Transportation. EXPEAR is an advisory system to assist the practicing engineer in evaluating a specific pavement section and selecting rehabilitation alternatives.

An EXPEAR program currently exists for each of three pavement types: JPCP, JRCP, and CRCP. Programs for AC-overlaid pavements and other AC pavements are under development. The current version of the system is EXPEAR 1.3, which includes the capabilities to delay rehabilitation for up to 5 years and to perform life-cycle cost analysis of rehabilitation alternatives.

INPUTS

Project-level evaluation using EXPEAR begins with the collection of some basic design, construction, traffic, and climate data for the project in question, and a visual condition survey. Back in the office, the design and condition data are entered into EXPEAR by the engineer using a full-screen editor. The program extrapolates the overall condition of the project from the distress data for one or more sample units.

ENGINEERING LOGIC

EXPEAR evaluates the project in several key problem areas related to specific aspects of performance for that pavement type. For example, the problem areas for JPCP and JRCP are: structural adequacy, roughness, drainage, joint deterioration, foundation movement, skid resistance, joint sealant condition, joint construction, concrete durability, load transfer, loss of support, and shoulders. The evaluation is performed using decision trees which compare the pavement's condition to predefined critical levels for key design and distress variables. EXPEAR produces a summary of the deficiencies found, and by interacting with the engineer, formulates a rehabilitation strategy which will correct all of the deficiencies. The major rehabilitation options are: reconstruction of both lanes, reconstruction of the outer lane and restoration of the inner lane, bonded or unbonded PCC overlay, AC overlay, crack and seat and AC overlay, and restoration. Appropriate repair techniques for the shoulders which are compatible with the mainline pavement rehabilitation strategy are also selected.

PERFORMANCE PREDICTION AND COST ANALYSIS

A large number of predictive models for concrete pavement performance with and without rehabilitation are incorporated into EXPEAR. Some of the models were developed from national databases of new construction and rehabilitation projects, while others were developed using data from Illinois pavements. The models allow the engineer to predict the performance of the rehabilitation strategy developed. This information is then used, along with rehabilitation unit costs (either default values built into the program or values provided by the engineer) to compute the cost of the strategy over the predicted life.

OUTPUTS

EXPEAR produces a summary of the project's data file, the evaluation results, recommendations for physical testing, predictions of the pavement's future condition without rehabilitation, and rehabilitation techniques, performance predictions, and cost calculations for as many rehabilitation strategies as the engineer wishes to investigate.

REFERENCES AND FURTHER INFORMATION

References on EXPEAR:

Hall, K. T., M. I. Darter, S. H. Carpenter, and J. M. Connor, "Concrete Pavement Evaluation and Rehabilitation System," Rehabilitation of Concrete Pavements, Volume 3, Federal Highway Administration Report No. FHWA/RD-88/073, April 1989.

Hall, K. T., J. M. Connor, M. I. Darter, and S. H. Carpenter, "Development of an Expert System for Concrete Pavement Evaluation and Rehabilitation, Proceedings, Second North American Conference on Managing Pavements, Volume 3, November 1987.

Questions or comments about EXPEAR:

Dr. Michael I. Darter
1212 Newmark CE Lab
205 North Mathews
Urbana, IL 61801

(217) 333-6253

Kathleen T. Hall
1206 Newmark CE Lab
205 North Mathews
Urbana, IL 61801

(217) 333-5966

1.0 INTRODUCTION

The objective of this research effort was to develop a practical and comprehensive system to assist practicing engineers in evaluating concrete highway pavements, identifying types of deterioration present and determining their causes, selecting rehabilitation techniques which will effectively correct existing deterioration and prevent its recurrence, combining individual rehabilitation techniques into feasible rehabilitation strategies, and predicting the performance of rehabilitation strategy alternatives.

EXPEAR is intended for use by state highway engineers in project-level rehabilitation planning and design for high-type (i.e., Interstate) conventional concrete pavements (JRCP, JPCP, and CRCP). EXPEAR does not perform thickness or joint design, the engineer must use existing design procedures to determine these details.

EXPEAR has been developed in the form of a knowledge-based expert system, which simulates a consultation between the engineer and an expert in concrete pavements. EXPEAR uses information about the pavement provided by the engineer to guide him or her through evaluation of a pavement's present condition and development of one or more feasible rehabilitation strategies. The procedure was developed through extensive interviewing of authorities on concrete pavement performance. In addition, predictive models are included to show future pavement performance with and without rehabilitation.

Evaluation of a pavement and development of feasible rehabilitation alternatives is performed according to the following steps:

1. Project data collection.
2. Extrapolation of overall project condition.
3. Evaluation of present condition.
4. Prediction of future condition without rehabilitation.
5. Recommendations for physical testing.
6. Selection of main rehabilitation approach.
7. Development of detailed rehabilitation strategy.
8. Prediction of rehabilitation strategy performance.
9. Cost analysis.
10. Selection of preferred rehabilitation strategy.

A computer program has been developed for each of the three pavement types addressed. The programs operate on any IBM-compatible personal computer. Use of the programs is highly recommended due to the complexity of the manual procedure.

2.0 PAVEMENT EVALUATION

Data Collection and Entry

The engineer collects key inventory and monitoring data for the project. Inventory data, which should be available from office records, includes design traffic, materials, soils and climate. Monitoring data includes distress, drainage characteristics, rideability, and other items collected during a field visit to the project. Monitoring data is collected by sample unit; a sufficient number of sample units distributed throughout the projects's length should be surveyed to obtain an accurate representation of the project's condition.

It is recommended that a team of two engineers perform the project survey together. They should drive over the entire length of the project and rate the present serviceability in each lane. They should also note the number and location of settlements and heaves. They should then return to the start of the project and perform the distress survey by sample unit. It is convenient to start sample units at mileposts.

The pavement distress identification manual provided in NCHRP Report No. 277 should be used for reference. It provides standard definitions for distresses by type, severity, and unit of measurement. It also provides photographs of distresses to assist the engineers in rating their severity. The engineers must also measure faulting at joints, cracks, and full-depth repair joints.

In the office, the data are entered into a personal computer using a full-screen editor. The format of the data entry screens is very similar to that of the field survey sheets. The editor provides function keys for moving forward and backward through the data items and screens. The editor will provide screens for inventory data (one set for each sample unit, up to a maximum of ten).

Extrapolation of Overall Project Condition

Using the project length and lengths of the sample units, EXPEAR extrapolates from the sample unit distress data to compute the overall average condition of the project. The project is then evaluated on the basis of this average condition.

Evaluation of Present Condition

EXPEAR utilizes a set of decision trees to analyze all of the data and develop a specific detailed evaluation in several major problem areas, including roughness, structural adequacy, joint deterioration, foundation movement, skid resistance, construction deficiencies, drainage, loss of support, joint sealant condition, concrete durability, and shoulder condition. From the evaluation, a set of evaluation conclusions is produced for each traffic lane and each shoulder.

Prediction of Future Condition Without Rehabilitation

Based on the current traffic level (annual 18-kip ESAL) and the anticipated ESAL growth rate, the future condition of the pavement without rehabilitation is predicted. Faulting, cracking, joint deterioration, pumping, and present serviceability rating are projected for jointed pavements (and punchouts for CRCP) and the years in which they will become serious problems are identified. The predictive models used are calibrated to the existing condition of the pavement at the time of the survey.

Physical Testing Recommendations

The initial data collection does not require physical testing. Based upon the available information, the program identifies types of physical testing needed to verify the evaluation recommendations and to provide data needed for rehabilitation design. Testing may include nondestructive deflection testing, coring/material sampling and laboratory testing, and roughness and friction measurement. Types of deficiencies which may warrant physical testing include structural inadequacy, poor rideability, poor surface friction, poor drainage conditions, poor concrete durability ("D" racking or reactive aggregate distress), foundation movement (due to swelling soil or frost heave), loss of load transfer at joints, loss of slab support, joint deterioration, and evidence of poor joint construction.

3.0 PAVEMENT REHABILITATION

Selection of Main Rehabilitation Approach

Based upon the evaluation results, the system interacts with the engineer to select the most appropriate main rehabilitation approach for each traffic lane and shoulder. These include all 4R options: reconstruction (including recycling), resurfacing (with concrete or asphalt), or restoration. The major factors in determining whether a pavement needs reconstruction, resurfacing, or merely restoration are the extent of structural distress (e.g., cracking and corner breaks) and the extent of deterioration due to poor concrete durability ("D" cracking or reactive aggregate distress).

Development of Detailed Rehabilitation Strategy

Once an approach is selected for each traffic lane and shoulder, the engineer proceeds to develop the detailed rehabilitation alternative by selecting a feasible set of individual rehabilitation techniques to correct the deficiencies present. This may include such items as subdrainage, shoulder repair, full-depth repairs, joint resealing, etc. This is performed for each traffic lane and shoulder by interaction with the system. The system displays each of the evaluation conclusions reached earlier and recommends one or more appropriate rehabilitation techniques. A set of decision trees has been developed to guide the rehabilitation strategy development process for traffic lanes and for adjacent shoulders. Where more than one choice exists for an appropriate technique to repair a specific distress, the system presents the engineer with the choice to make.

Computation of Rehabilitation Quantities

EXPEAR computes needed quantities for the rehabilitation techniques selected based on the data in the project survey and additional information rovided by the engineer. In general, the program assumes that 100 percent repair will be performed; that is, that the quantity of a certain type of distress to be repaired is equal to the quantity of that distress observed during the field survey.

If the rehabilitation work is being delayed, the quantities are increased where appropriate for each year

the user are necessary; EXPEAR will detect what type of monitor is available and whether or not a math chip is present.

Each of the three EXPEAR versions (for the three pavement types: JPCP, JRCP, and CRCP) is distributed on a set of two 360 K, 5.25-inch floppy disks. One disk contains the executable program (EXPEAR.EXE) and the other disk contains several other files needed to run EXPEAR.

One other note about the disk files: several of the file names (EXPEAR.EXE, DISPLAYS.REC, STNDRD.DAT, etc.) are common to the programs for all three pavement types (JRCP, JPCP, and CRCP), so if you want to run the programs for different pavement types, keep them on separate disks! If you copy them to a hard disk, place them in different directories.

Running EXPEAR

After the EXPEAR title screen and a few screens of introductory information, the system displays the main menu, which has four options:

1. ENTER OR EDIT PROJECT DATA
2. CONDUCT PROJECT EVALUATION
3. DEVELOP REHABILITATION STRATEGY
4. QUIT, RETURN TO DOS

Enter or Edit Project Data

When this option is selected, a menu will appear to ask whether you want to create a new data file or edit an existing file. A new data file is created by modifying the STNDRD.DAT file. If an existing data file is to be modified, the program will ask for the name of the data file without the .DAT extension.

A full-screen data editor is incorporated into the system for data entry and editing. Function keys for moving through the data items and screens are defined at the bottom of the screen. Some data items are defined as "toggle variables," meaning that you can toggle through the available values (such as low, medium, high) using the tab key. The editor will tell you which data items are toggle variables. When you are finished editing the file, SHIFT-10 will exit the editor. This command does <u>not</u> however, save the file on disk. The program will prompt you to save the file before continuing.

Conduct Project Evaluation

When this option is selected, the program asks for the name of the data file to be evaluated. It also asks whether you want to use the default critical distress levels incorporated in the program, or use your own values. These may be selected each time you run the program, or may be saved to disk and retrieved when needed. The program will prompt you for a file name for your critical distress values and save it with a .CVL extension. Whether using your own values or the default values, you must select critical distress levels before proceeding with the evaluation.

The evaluation runs very quickly. When it is done, EXPEAR will display the results of the evaluation, which consists of evaluation conclusions for the traffic lanes and shoulders, predicted performance without rehabilitation, and physical testing recommendations.

EXPEAR will ask if you want to print the data summary file and the project evaluation summary file. You may print these from the program, or exit to DOS and print the output files with .REP and .TXT extensions.

Develop Rehabilitation Strategy

When this option is selected, EXPEAR interacts with you to select the main rehabilitation approach (reconstruct, overlay, or restore) and the specific rehabilitation techniques needed to correct the deficiencies identified in the evaluation. EXPEAR recommends appropriate rehabilitation approaches and techniques and gives you the option to choose whenever more than one appropriate technique exists. EXPEAR does not have the capability to permit you to enter options other than the ones given. When the rehabilitation strategy has been developed, it will be displayed along with approximate quantities (in some instances additional information must be provided for computing quantities, such as size of full-depth repairs). You may print the strategy and quantities out from the program, or exit to DOS and print the output file with the .STS extension.

After a strategy has been developed, a menu appears with the following options:

1. REVISE REHABILITATION STRATEGY
2. PREDICT REHABILITATION PERFORMANCE
3. PERFORM LIFE-CYCLE COST ANALYSIS
4. RETURN TO MAIN MENU

The second option will predict the performance of the rehabilitation strategy developed, using predictive models for key distresses. EXPEAR may prompt you for additional information needed, such as thickness of overlay. After the program finishes computing the predicted performance, it will display the predictions. You may print these out from the program or exit to DOS and print the output file with the .RHB extension.

Only after a rehabilitation strategy has been developed and its performance predicted can a cost analysis of the strategy be performed. EXPEAR will prompt you for a discount rate and delay to be used in the program, and will also ask you to select unit cost values for the rehabilitation techniques. You may use the default unit costs provided, or (in the same manner as for the critical distress levels), save a file containing your own set of unit costs to disk (the extension will be .UCC), and retrieve it when needed.

The program computes the present costs over the project length for the rehabilitation strategy analyzed. The results are displayed on the screen and may be printed from the program or from DOS (the extension is .LCC).

Each set of EXPEAR disks includes an example data file for that pavement type. The example files for the three programs are:

JRCP: I74183, on I-74 near Urbana, Illinois
JPCP: I10191, on I-10 near Tallahassee, Florida
CRCP: I57230, on I-57 near Champaign, Illinois

Comments, questions, or suggestion for improvements to EXPEAR or this User's Guide are very welcome. Please direct them to Ms. Kathleen T. Hall or Dr. Michael I. Darter at the University of Illinois. The addresses and phone numbers are given in the introductory screens of the EXPEAR programs.

APPENDIX B1

PROJECT SURVEY FOR JPCP

Design Engineer: ______________________________

Date of Survey (mo/day/yr): ____ / ____ / ____

PROJECT INVENTORY DATA

Collect the following information about the project to be evaluated prior to the actual field survey.

Project Identification

Highway Designation (example I-57): ____________

State: ______________________________

Direction of Survey: ______________________

Starting Milepost: ________________________

Ending Milepost: __________________________

Climate

Climatic Zone (See climatic zone map in "Supplemental Information"):

____ wet freeze	____ wet-dry freeze	____ dry freeze
____ wet freeze-thaw	____ wet-dry freeze-thaw	____ dry freeze-thaw
____ wet nonfreeze	____ wet-dry nonfreeze	____ dry nonfreeze

Estimated Annual Temperature Range (degrees Fahrenheit): __________

Mean Annual Precipitation (inches) (See precipitation map in "Supplemental Information"): ______________________

Corps of Engineers Freezing Index (Fahrenheit degree-days) (See Freezing Index map in "Supplemental Information"): ______________

Average Annual Temperature (degrees Fahrenheit): ________________

Slab Construction

Year Constructed: ____________________

Slab Thickness (inches): ______________

Width of Traffic Lanes (feet): _________

PCC Modulus of Rupture (28 days, 3rd-point loading)(psi): _________

Transverse and Longitudinal Joints

Pattern of Joint Spacing:
_____ uniform
_____ random

Transverse joint spacing, if uniform (feet): ________________
Transverse joint sequence, if random (feet): ________________

Type of Sealant:
_____ liquid (asphalt)
_____ field-molded (silicone)
_____ preformed compression (neoprene)

Average Transverse Joint Sealant Reservoir Dimensions
Width (inches): ____________ Depth (inches): ____________

Method Used to Form Transverse Joints:
_____ sawing
_____ inserts
_____ Unitube inserts

Transverse Joint Sawed Depth (inches): ____________________________

Type of Load Transfer System:
_____ aggregate interlock only
_____ dowels
_____ other mechanical devices

If dowels are present, dowel bar diameter (inches): __________

Method Used to Form Longitudinal Joints Between Lanes:
_____ sawing
_____ inserts

Longitudinal Joint Sawed or Formed Depth (inches): ________________

Base

Type of Base Course:

_____ fine-grained soil only	_____ dense-graded untreated aggregate
_____ cement-treated aggregate	_____ asphalt-treated aggregate
_____ lean PCC	_____ open-graded drainage layer

Modulus of Subgrade Reaction on Top of Base (psi/inch) (See k-value correlation chart in "Supplemental Information"): _________________

Subgrade

Predominant Subgrade Soil AASHTO Classification (See Unified-AASHTO conversion table in "Supplemental Information"): ________________

Are swelling soils a problem in the area? ______ yes ______ no

If so, were steps taken in construction of the pavement to correct the swelling soil problem? ______ yes ______ no

Shoulder

Type of Shoulder:
_____ AC
_____ tied PCC

Width of Shoulders (feet): ____________ inner ____________ outer

Inner Lane Slope Direction:
_____ toward outer lane
_____ toward inner shoulder

Traffic

Estimated Current Through Two-way ADT: __________________________

Percent Commercial Trucks (excluding pickups and panels): _________

Total Number of Lanes in Direction of Survey: ___________________

Future 18-kip ESAL Growth Rate (percent per year): _______________

Total Accumulated 18-kip Equivalent Single Axle Loads (ESALs) from Date of Construction to Date of Survey (millions) (See procedure for computing ESALs in AASHTO Guide for Design of Pavement Structures, Appendix D, 1986):

LANE TWO (inner)	LANE ONE (outer)
_________	_________

Ride Quality

Rate the ride quality of the pavement in each lane during a drive over the entire project at the posted speed limit. Two or more people should participate in the survey. Obtain ratings for each lane from each person and report the average value below.

0	1	2	3	4	5
Very Poor	Poor	Fair	Good	Very Good	

LANE TWO (inner)	LANE ONE (outer)
______	______

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately 1000 feet in each mile is recommended for each sample unit surveyed. If only one sample unit is to be surveyed on the project, a length of at least a half mile is recommended. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: __________ Starting Milepost: __________ Length of Sample Unit (feet): __________

Use the tally sheet provided to record information on cracking, spalling, and full-depth repairs for each slab surveyed. Compute the totals and averages indicated on the tally sheet and record these values below.

	LANE TWO (inner)	LANE ONE (outer)
Number of transverse cracks, L-M-H:	_______	_______
Mean faulting at transverse cracks (inches):	_______	_______
Number of deteriorated transverse joints, M-H including blowups:	_______	_______
Mean faulting at transverse joints (inches):	_______	_______
Number of transverse joints:	_______	_______
Mean faulting at full-depth repair and slab replacement joints (inches):	_______	_______
Number of full-depth repair and slab replacement joints (inches):	_______	_______
Number of full-depth repairs and slab replacements:	_______	_______
Number of corner breaks:	_______	_______

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	_______	_______
Total length of longitudinal joint spalling, M-H only (feet):		_______

	LANE TWO (inner)	LANE ONE (outer)

<u>Cracking at Transverse Joints</u>

Number of transverse joints with transverse cracks within 2 feet: ______ ______

<u>Foundation Movement</u>

Number of settlements (M-H only): ______ ______

Number of heaves (M-H only): ______ ______

<u>Drainage</u>

Are longitudinal subdrains present and functional along the sample unit? ______ yes ______ no

What is the typical height of the pavement surface above the side ditchline (feet)? ____________

Do the ditches have standing water or cattails in them? ______ yes ______ no

<u>Loss of Support</u>

Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):

	LANE TWO	LANE ONE
	______ N	______ N
	______ L	______ L
	______ M	______ M
	______ H	______ H

<u>Surface Condition</u>

Method used to texture the pavement surface at construction:
____ transverse tining
____ other

Is the surface polished smooth in the wheelpaths?

	LANE TWO	LANE ONE
	____ yes	____ yes
	____ no	____ no

Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?

	LANE TWO	LANE ONE
	____ yes	____ yes
	____ no	____ no

<u>Joint Sealant Condition</u>

What is the general condition of the transverse joint sealant?

	LANE TWO	LANE ONE
	______ L	______ L
	______ M	______ M
	______ H	______ H

What is the general condition of the longitudinal joint sealant?

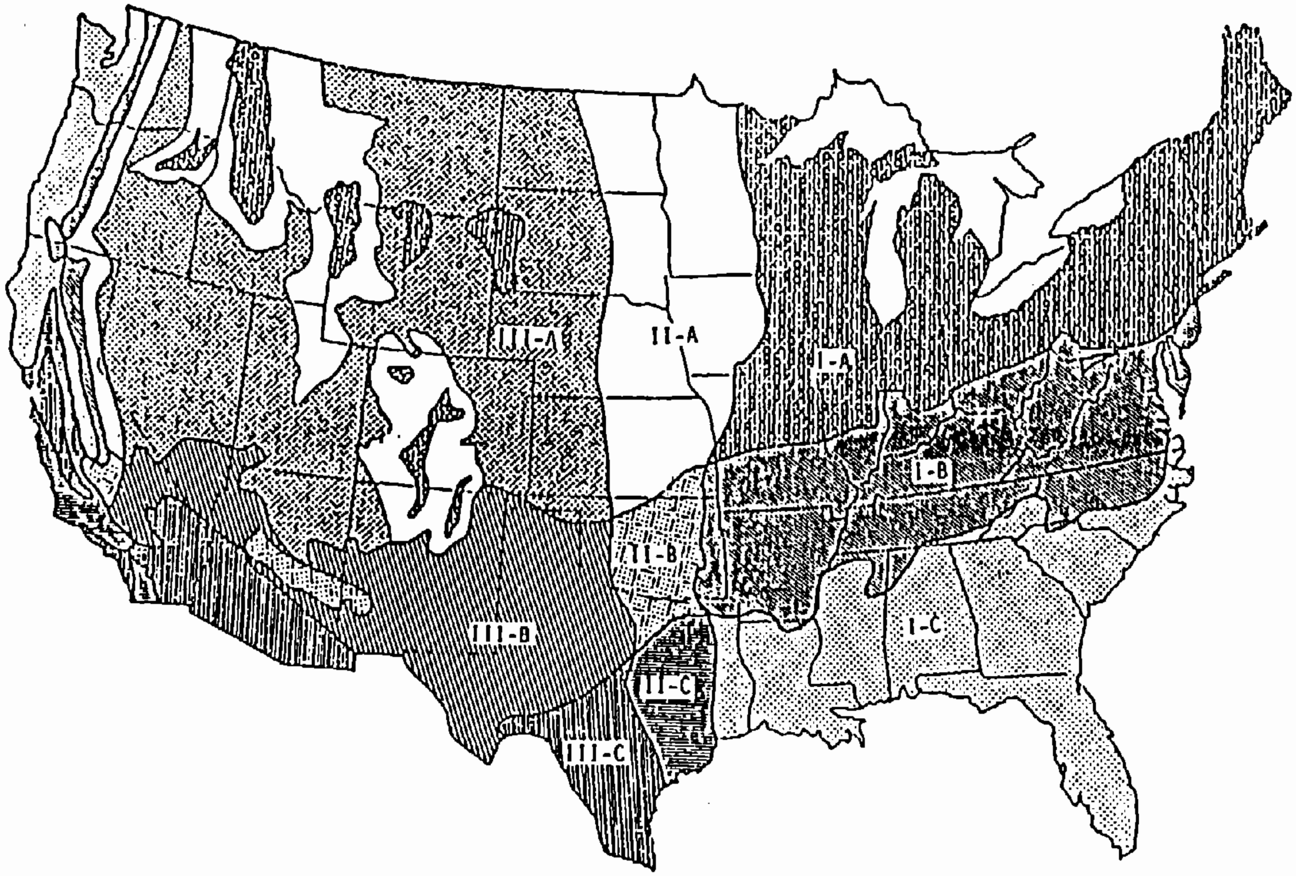
______ L
______ M
______ H

Are substantial amounts of incompressibles visible in the transverse joints?

	LANE TWO	LANE ONE
	____ yes	____ yes
	____ no	____ no

	LANE TWO (inner)	LANE ONE (outer)
Concrete Durability		
Extent of "D" cracking at joints and cracks (indicate highest severity level present in sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Extent of reactive aggregate distress (indicate highest severity level present in sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Extent of scaling (indicate highest severity level present in sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Previous Repair		
If full-depth repairs are present, are they dowelled?	___ yes ___ no	___ yes ___ no
Are partial-depth repairs (rigid material only) present at most of the joints?	___ yes ___ no	___ yes ___ no
Has diamond grinding been done?	___ yes ___ no	___ yes ___ no
Has grooving been done?	___ yes ___ no	___ yes ___ no

	INNER SHOULDER	OUTER SHOULDER
AC Shoulders (Check all that apply.)		
Alligator cracking	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Linear cracking	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Weathering/ravelling	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint dropoff	___ none ___ <1" ___ ≥1"	___ none ___ <1" ___ ≥1"
Settlements or heaves along outer edge	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Blowholes at transverse joints	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good ___ poor	___ good ___ poor
PCC Shoulders (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	___ none ___ some ___ extensive	___ none ___ some ___ extensive
"D" cracking or reactive aggregate distress	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Settlements or heaves along outer edge	___ none ___ some ___ extensive	___ none ___ some ___ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	___ good ___ poor	___ good ___ poor



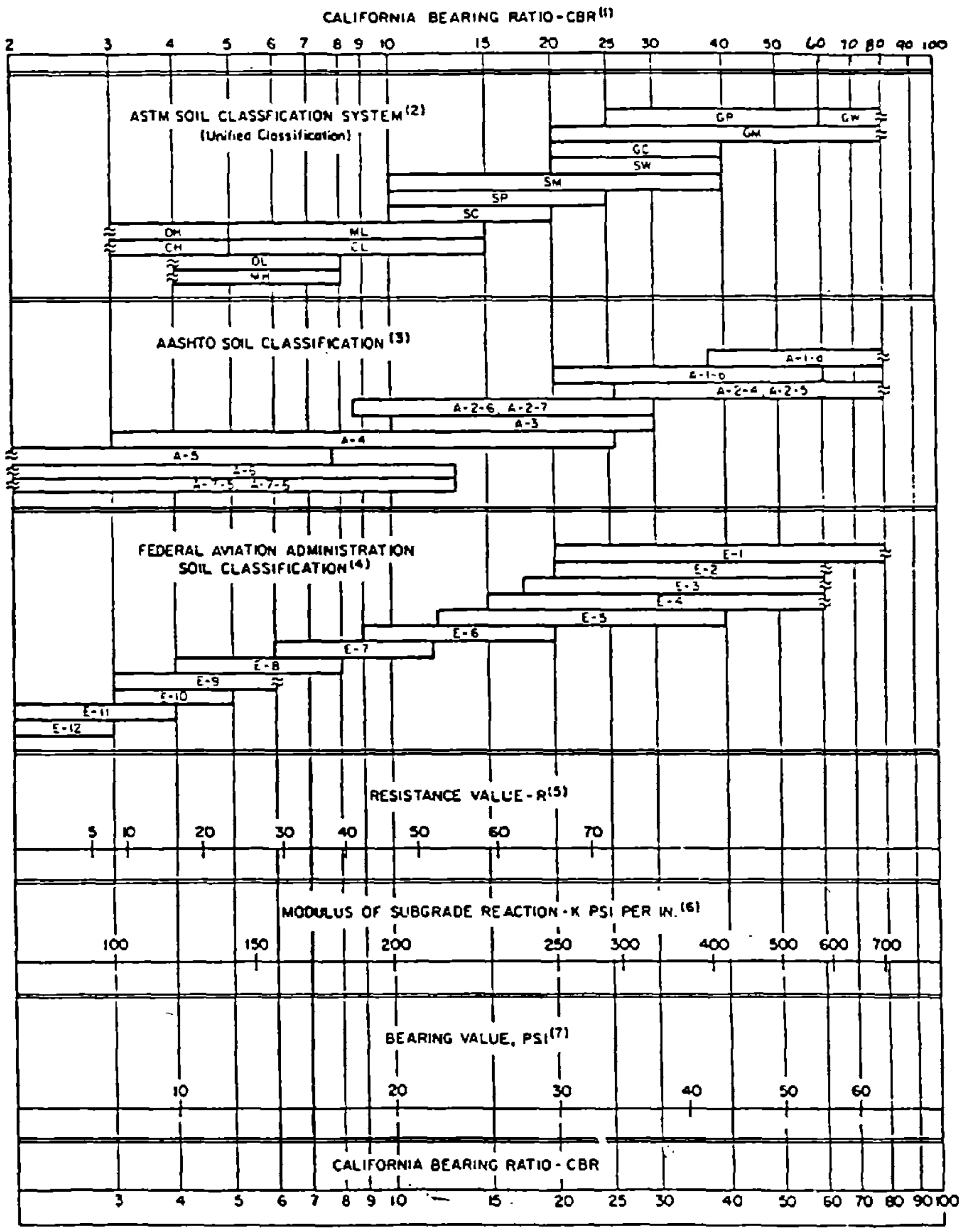
Moisture Zones:

I = wet
II = wet-dry
III = dry

Temperature Zones:

A = freeze
B = freeze-thaw
C = nonfreeze

Climatic Zone Map of the United States. Source: "A Pavement Moisture-Accelerated Distress (MAD) Identification System," FHWA/RD-81/079-80, 1981.



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, pages 100-136.
(2) ASTM Designation D2487.
(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting*, 1945, Vol. 25, pages 376-392.
(4) *Airport Paving*, U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements*.(Formerly used FAA Classification; Unified Classification now used.)
(5) C. E.Warnes, "Correlation Between R Value and k Value," unpublished report, Portland Cement Association, Rocky Mountain-Northwest Region, October 1971 (best-fit correlation with correction for saturation).
(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, page 152.

Subgrade K-value Correlation to Soil Classifications and Bearing Values. Source: "Thickness Design for Concrete Highway and Street Pavements", Portland Cement Association

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BASE TYPE

- fine-grained soil only: use k-value of subgrade soil

- dense-graded aggregate

Subgrade k-value, (psi/in)	Subbase Thickness, in 4	6	9	12
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

- cement or asphalt treated aggregate, lean concrete

Subgrade k-value, (psi/in)	Subbase Thickness, in 4	6	8	10
50	170	230	310	390
100	280	400	520	640
200	470	640	830	---

k-value on top of base course (directly beneath PCC slab)
Source: "Thickness Design for Concrete Highway and Street Pavements," Portland Cement Association

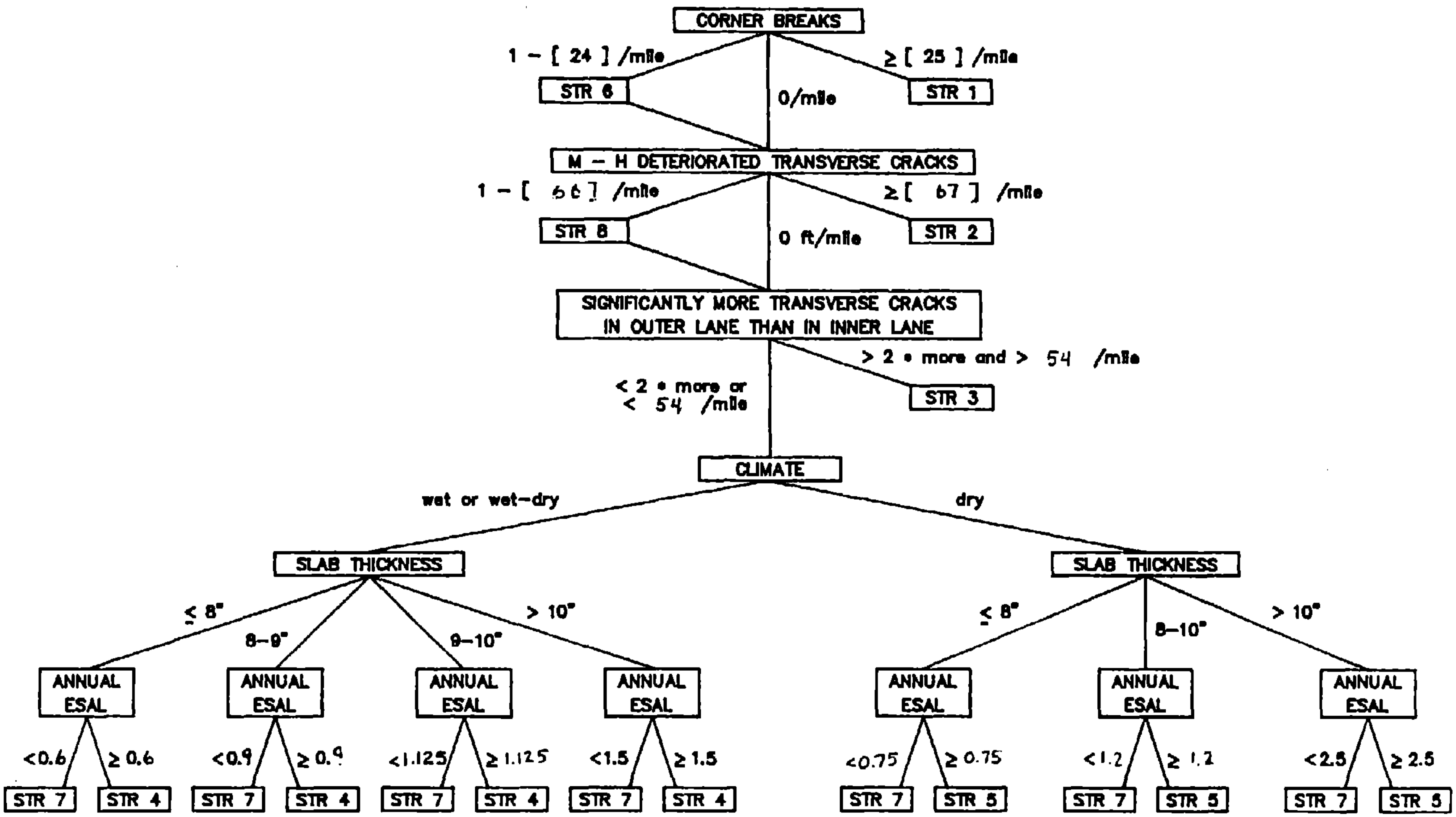
APPENDIX B2

EVALUATION DECISION TREES AND CONCLUSIONS FOR JPCP

Major Problem Areas for JPCP

1. Structural Adequacy
2. Drainage
3. Foundation Movement
4. Durability
5. Skid Resistance
6. Roughness
7. Joint Construction
8. Joint Sealant
9. Load Transfer
10. Loss of Support
11. Joint Deterioration
12. Shoulder

JPCP STRUCTURAL DEFICIENCY



* Annual ESAL in millions

Structural Adequacy

STR 1 Structural deficiency of the pavement is indicated by [25] or more corner breaks per mile.

(a) full-depth repair of corner breaks, AC structural overlay
(b) full-depth repair of corner breaks, crack and seat and AC structural overlay
(c) full-depth repair of corner breaks, PCC bonded overlay
(d) full-depth repair of corner breaks, PCC unbonded overlay
(e) reconstruct

STR 2 Structural deficiency of the pavement is indicated by [800] or more feet of deteriorated transverse cracks per mile.

(a) full-depth repair of cracks, AC structural overlay
(b) full-depth repair of cracks, crack and seat and AC structural overlay
(c) full-depth repair of cracks, PCC bonded overlay
(d) full-depth repair of cracks, PCC unbonded overlay
(e) reconstruct

STR 3 Structural deficiency of the pavement is indicated by significantly more transverse crack deterioration than in the next inner lane.

(a) full-depth repair of cracks, AC structural overlay
(b) full-depth repair of cracks, crack and seat and AC structural overlay
(c) full-depth repair of cracks, PCC bonded overlay
(d) full-depth repair of cracks, PCC unbonded overlay
(e) reconstruct

STR 4 Structural deficiency of the pavement is indicated by a wet or wet-dry climate, a slab thickness of (x) inches, and (y) million annual 18-kip ESALs.

(a) AC structural overlay
(b) crack and seat and AC structural overlay
(c) PCC bonded overlay
(d) PCC unbonded overlay

STR 5 Structural deficiency of the pavement is indicated by a dry climate, a slab thickness of (x) inches, and (y) million annual 18-kip ESALs.

(a) AC structural overlay
(b) crack and seat and AC structural overlay
(c) PCC bonded overlay
(d) PCC unbonded overlay

Note: Values in brackets [ ] are default critical levels. User may modify these values.

STR 6 The pavement exhibits some load-associated distress (between 1 and [24] corner breaks per mile) which requires repair but does not indicate a structural deficiency.

(a) full-depth repair of corner breaks

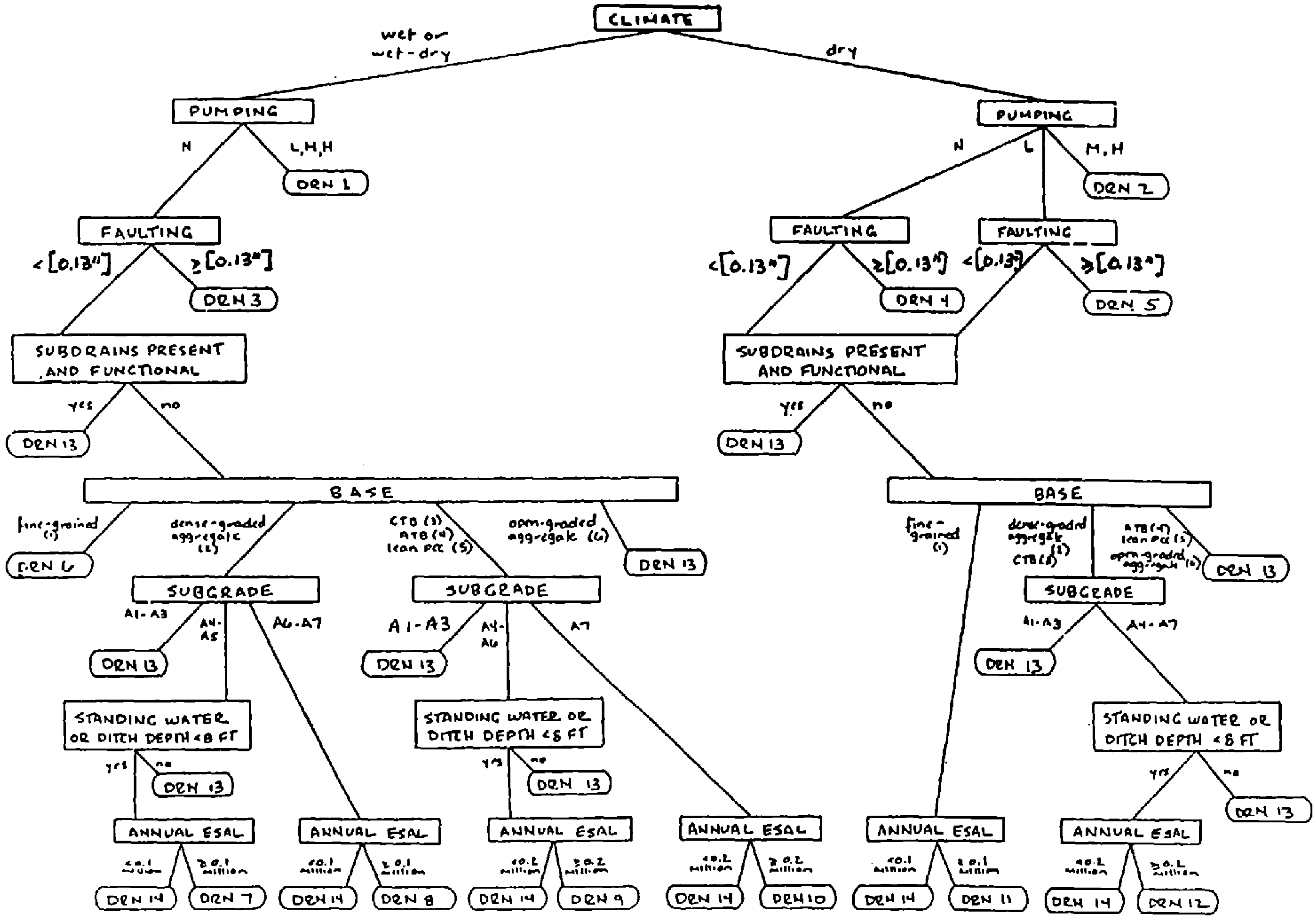
STR 7 The pavement shows no indications of structural deficiency.

(a) do nothing

STR 8 The pavement exhibits some load-associated distress (between 1 and [799] feet of deteriorated transverse cracks per mile) which requires repair but does not indicate a structural deficiency.

(a) full-depth repair of cracks

JPCP DRAINAGE DEFICIENCY



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Drainage

DRN 1 A drainage deficiency is indicated by pumping occurring in a wet or wet-dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 2 An intermittent drainage deficiency is indicated by high-severity pumping occurring in a dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 3 A drainage deficiency is indicated by faulting greater than [0.13] inches occurring in a wet or wet-dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 4 A drainage deficiency is indicated by faulting greater than [0.13] inches occurring in a dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 5 An intermittent drainage deficiency is indicated by faulting greater than [0.13] inches and low- or medium-severity pumping occurring in a dry climate.

(a) install or repair longitudinal subdrains
(b) install or repair longitudinal subdrains, seal all joints and cracks

DRN 6 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, and a fine-grained soil base.

(a) install or repair longitudinal subdrains

DRN 7 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded untreated aggregate base, an (x) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (y) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 8 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded untreated aggregate base, an (x) subgrade, and heavy traffic of (y) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 9 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (y) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (z) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 10 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (y) subgrade, and heavy traffic of (z) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 11 A drainage deficiency is indicated by a dry climate, absence or poor functioning of longitudinal subdrains, a fine-grained soil base, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 12 A drainage deficiency is indicated by a dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (y) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (z) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

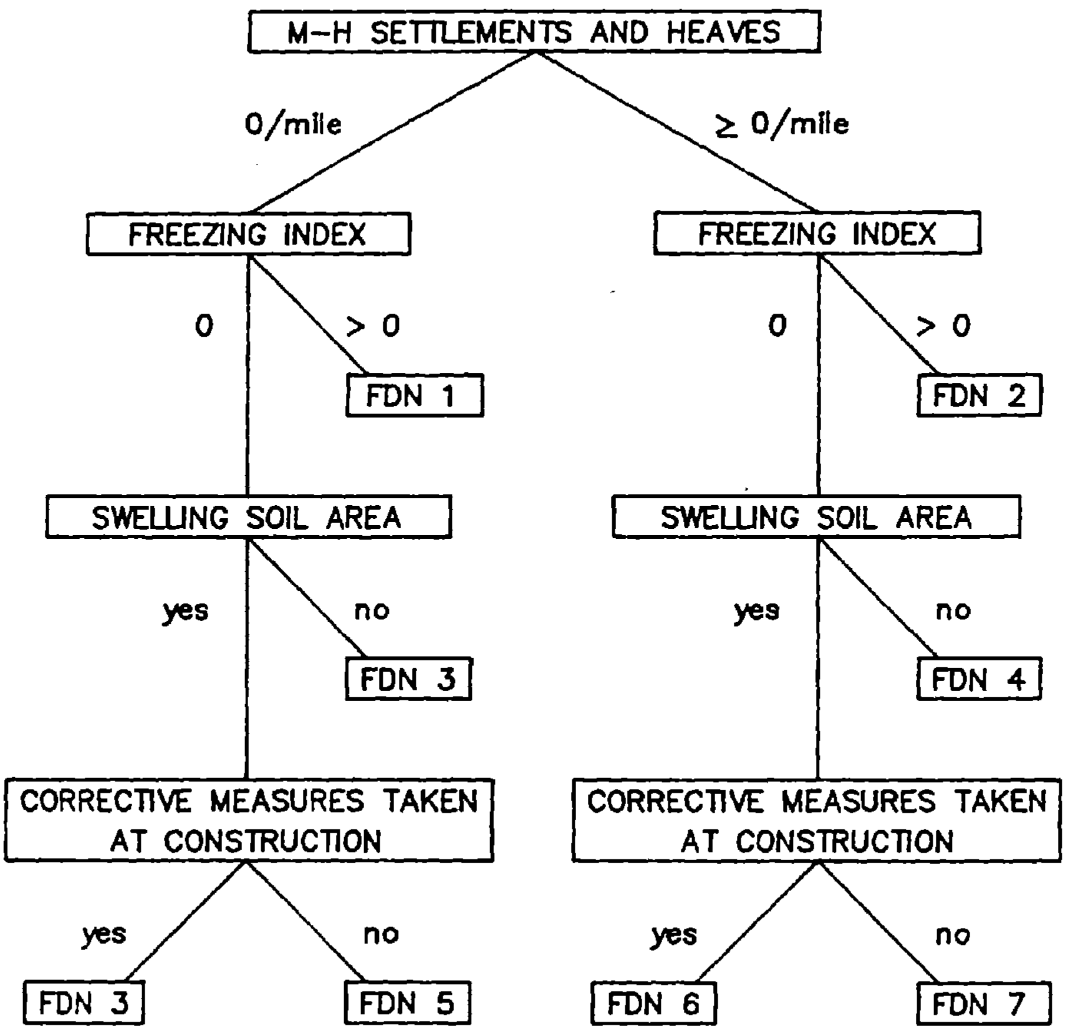
DRN 13 The pavement shows no indications of a drainage deficiency.

(a) do nothing

DRN 14 For the pavement's current traffic level, no significant drainage deficiency is indicated.

(a) do nothing

JPCP FOUNDATION MOVEMENT



Foundation Movement

FDN 1 A potential for frost heave is indicated by a mean Freezing Index greater than 0.

(a) do nothing

FDN 2 Foundation movement, likely due to either frost heave or localized consolidation, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

FDN 3 The pavement shows no indications of foundation movement.

(a) do nothing

FDN 4 Foundation movement, likely due to localized consolidation, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

FDN 5 A potential for foundation movement exists, since the pavement is in a swelling soils area and no measures were taken during construction to control soil swelling.

(a) do nothing

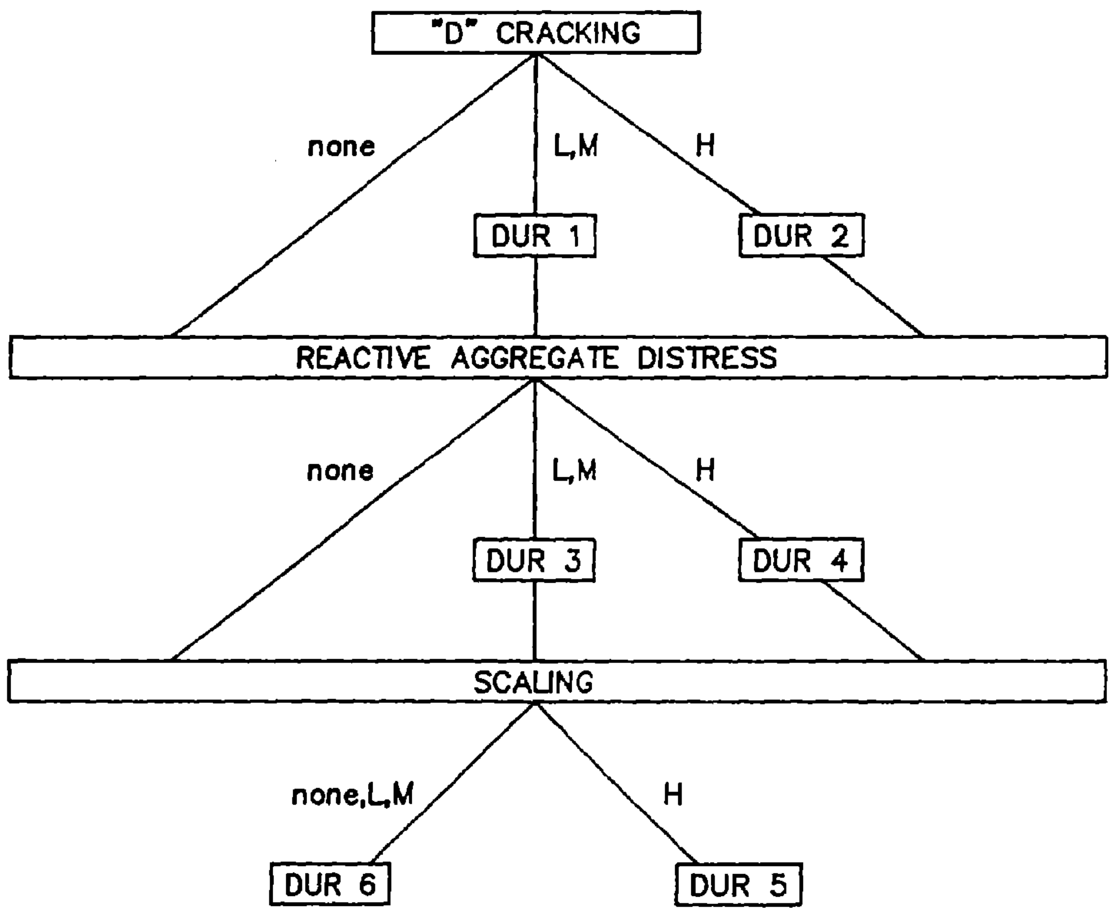
FDN 6 Foundation movement, likely due to either localized consolidation ore unsuccessful construction measures to control swelling, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

FDN 7 Foundation movement, likely due to either localized consolidation or lack of construction measures to control swelling, is indicated by settlements and/or heaves.

(a) reconstruct heave areas, AC level-up settled areas
(b) reconstruct heave areas, slab jack settled areas

JPCP DURABILITY DEFICIENCY



Durability

DUR 1 Poor durability of the concrete is indicated by low- to medium-severity "D" cracking.

(a) full-depth repair of joints, reseal transverse joints

DUR 2 Poor durability of the concrete is indicated by high-severity "D" cracking.

(a) unbonded PCC overlay
(b) reconstruct

DUR 3 Poor durability of the concrete is indicated by low- to medium-severity reactive aggregate distress.

(a) full-depth repair of joints, reseal transverse joints

DUR 4 Poor durability of the concrete is indicated by high-severity reactive aggregate distress.

(a) unbonded PCC overlay
(b) reconstruct

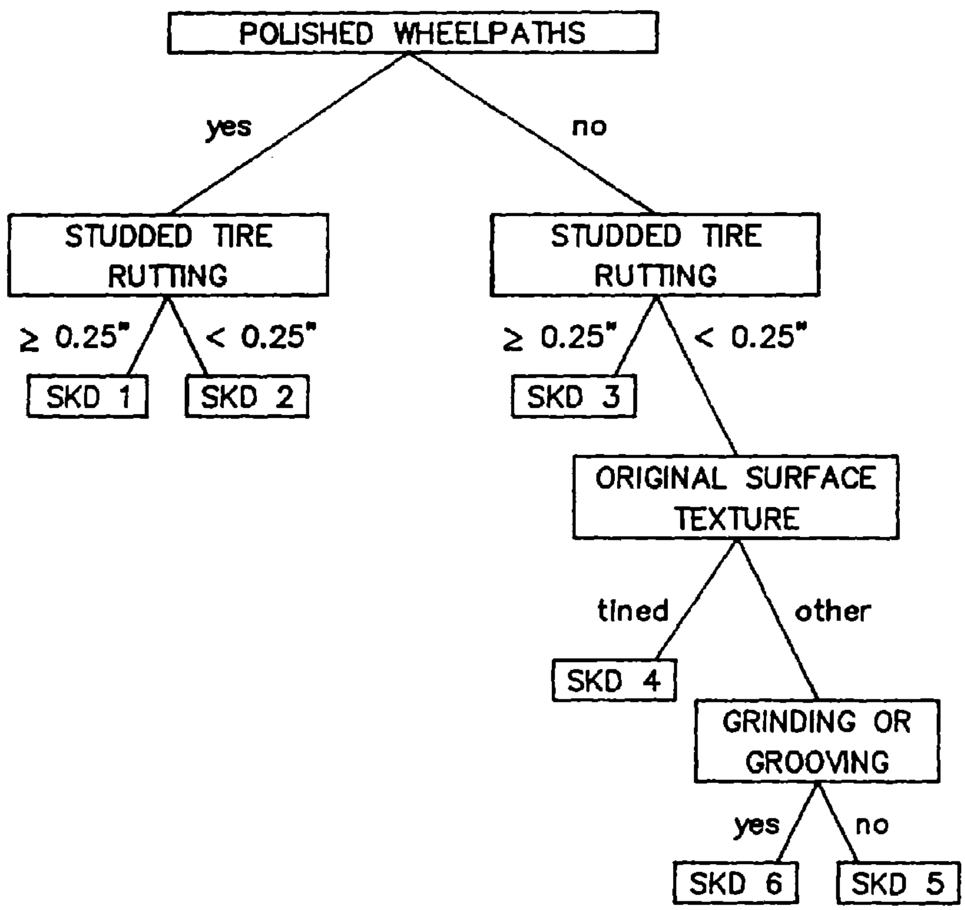
DUR 5 Poor durability of the concrete surface is indicated by high-severity scaling.

(a) do nothing
(b) AC nonstructural OL

DUR 6 The pavement show no indications of significant surface or concrete durability deficiencies.

(a) do nothing

JPCP SKID RESISTANCE DEFICIENCY



Skid Resistance

SKD 1 Loss of skid resistance and potential for hydroplaning are indicated by polished wheel paths and studded tire rutting of 0.25 inches or more.

(a) grinding
(b) AC nonstructural OL

SKD 2 Loss of skid resistance is indicated by polished wheel paths.

(a) grooving
(b) grinding
(c) AC nonstructural OL

SKD 3 Loss of skid resistance and potential for hydroplaning are indicated by studded tire rutting of 0.25 inches or more.

(a) grinding
(b) AC nonstructural OL

SKD 4 The pavement shows no indications of loss of skid resistance or hydroplaning potential.

(a) do nothing

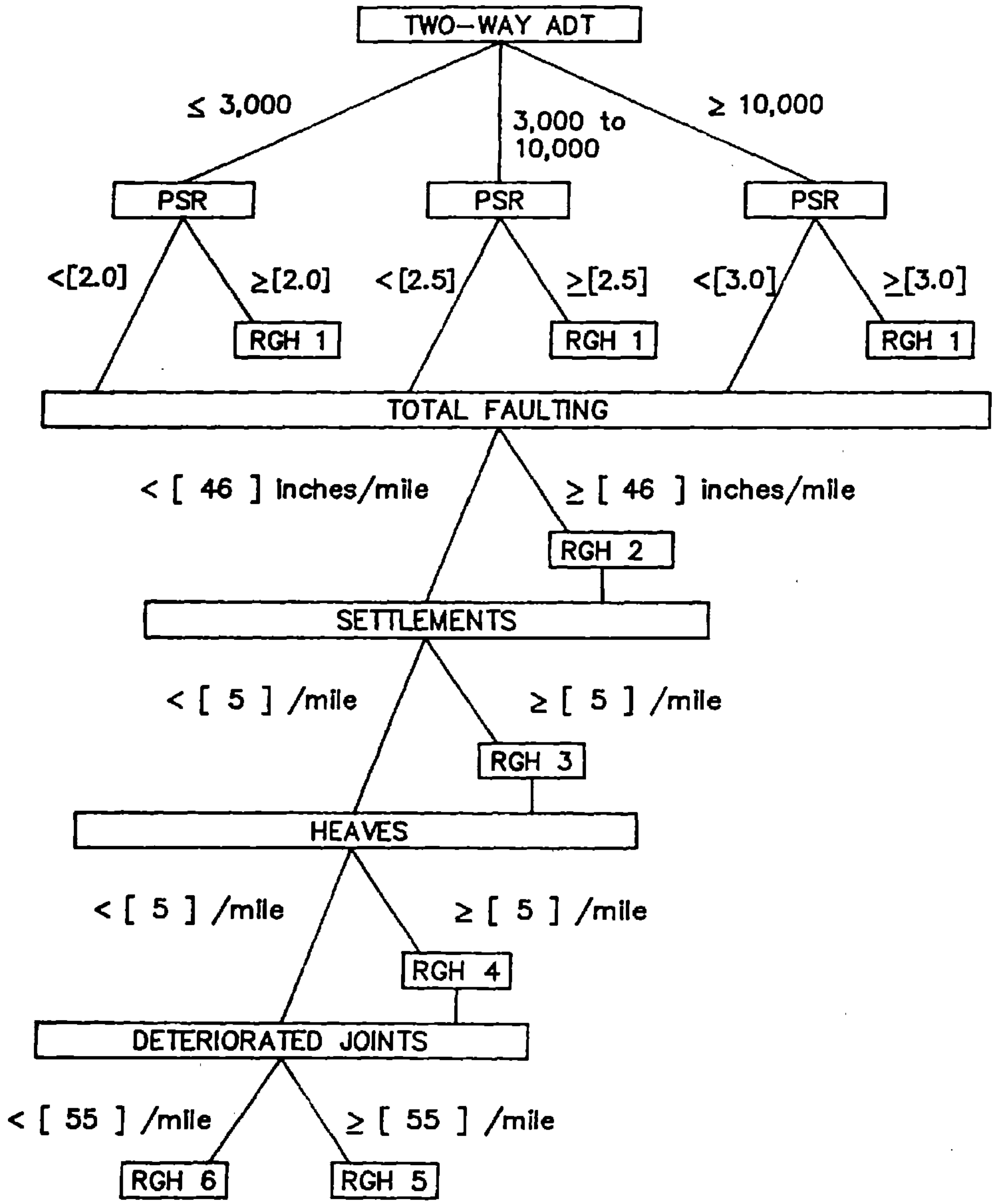
SKD 5 The method used to texture the original pavement surface may contribute to loss of skid resistance in the future.

(a) do nothing

SKD 6 Adequate skid resistance is indicated by surface restoration (grinding or grooving) having been performed on the pavement.

(a) do nothing

JPCP ROUGHNESS DEFICIENCY



Roughness

RGH 1 Rideability is acceptable.

(a) do nothing

RGH 2 Poor rideability is indicated by total faulting of more than [46] inches per mile at joints, cracks, and full-depth repairs (if present), and an unacceptably low PSR for the pavement's ADT level.

(a) grinding
(b) AC nonstructural OL

RGH 3 Poor rideability is indicated by [5] or more settlements per mile and an unacceptably low PSR for the pavement's ADT level.

(a) AC level-up settlements
(b) slab jack settlements

RGH 4 Poor rideability is indicated by [5] or more heaves and an unacceptably low PSR for the pavement's ADT level.

(a) reconstruct heaves

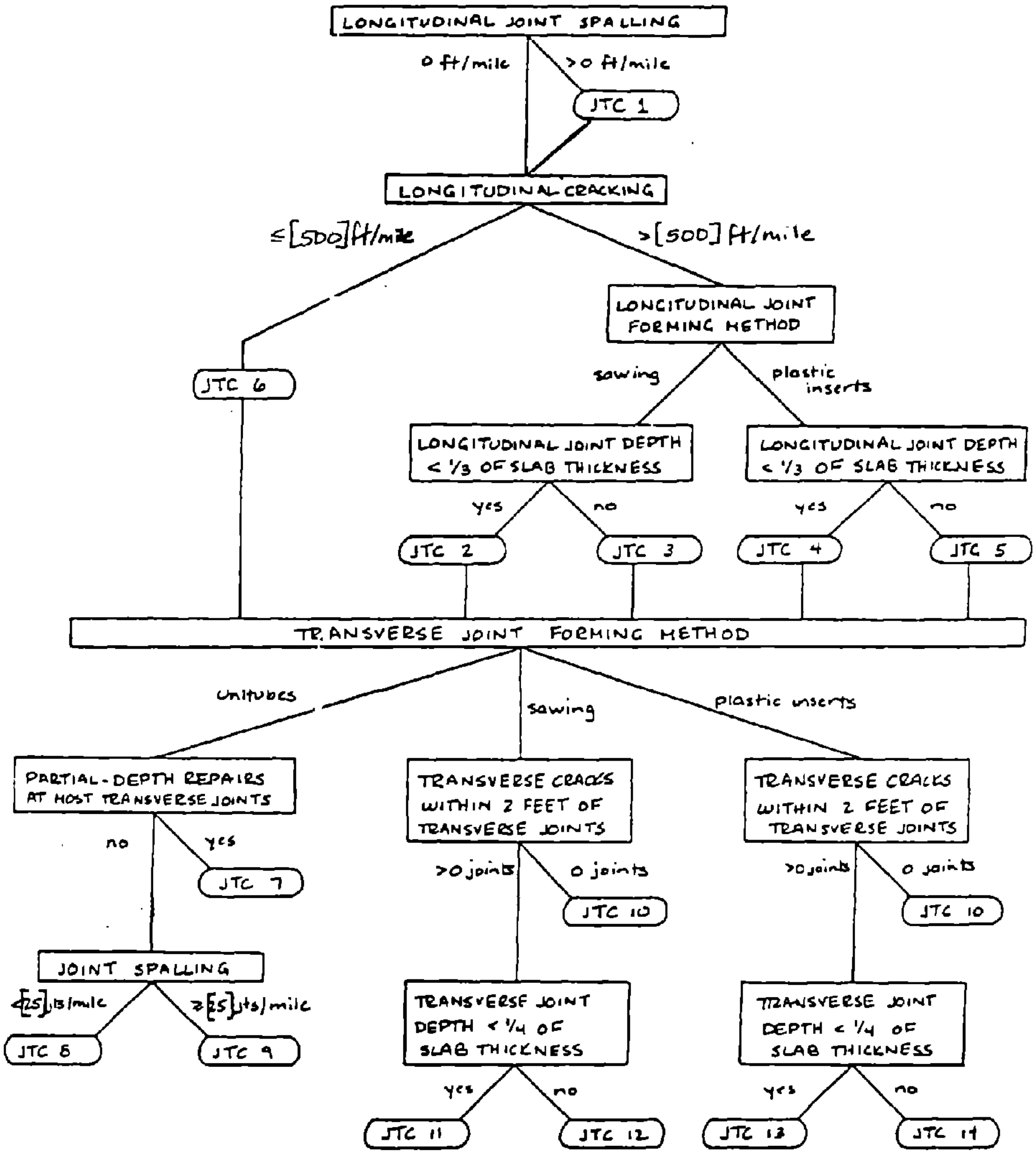
RGH 5 Poor rideability is indicated by [55] or more deteriorated joints per mile and an unacceptably low PSR for the pavement's ADT level.

(a) full-depth repair of joints

RGH 6 Poor rideability is indicated by an unacceptably low PSR for the pavement's ADT level.

(a) grinding
(b) AC nonstructural OL

JPCP JOINT CONSTRUCTION DEFICIENCY



Joint Construction Deficiency

JTC 1 A longitudinal joint construction deficiency is indicated by longitudinal joint spalling.

(a) partial-depth repair of longitudinal joint

JTC 2 A longitudinal joint construction deficiency, likely due to an inadequate depth of saw cut, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 3 A longitudinal joint construction deficiency, likely due to late sawing, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 4 A longitudinal joint construction deficiency, likely due to inadequate depth of plastic insert placement, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 5 A longitudinal joint construction deficiency, likely due to the use of plastic inserts, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 6 The pavement shows no indications of a longitudinal joint construction deficiency.

(a) do nothing

JTC 7 A transverse joint construction deficiency, likely due to the use of Unitubes, is indicated by partial-depth repairs at most of the transverse joints.

(a) do nothing

JTC 8 A potential transverse joint construction deficiency is indicated by the use of Unitubes, which may cause transverse joint spalling in the future.

(a) do nothing

JTC 9 A transverse joint construction deficiency, likely due to the use of Unitubes, is indicated by [55] or more deteriorated transverse joints per mile.

(a) partial-depth repair

JTC 10 The pavement shows no indications of a transverse joint construction deficiency.

(a) do nothing

JTC 11 A transverse joint construction deficiency, likely due to an inadequate depth of saw cut, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

JTC 12 A transverse joint construction deficiency, likely due late sawing, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

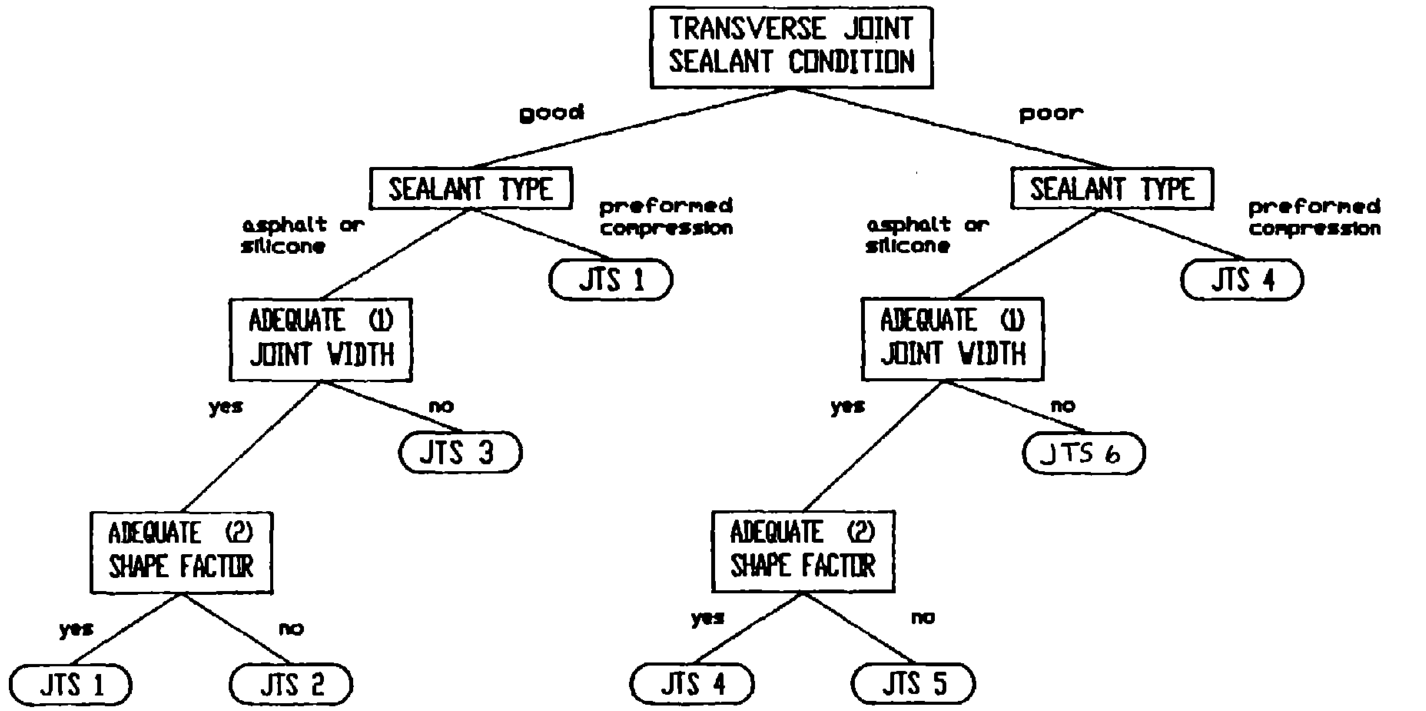
JTC 13 A transverse joint construction deficiency, likely due to inadequate depth of placement of plastic inserts, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

JTC 14 A transverse joint construction deficiency, likely due to use of plastic inserts, is indicated by transverse cracking within 2 feet of transverse joints.

(a) seal cracks near transverse joints
(b) load transfer restoration at cracks near transverse joints, seal cracks at transverse joints

JPCP JOINT SEALANT DEFICIENCY



(1) Joint sealant reservoir width is adequate if:

(a) W > 3/8" and
(b) 0.8 W < 12CL T < 1.2W, for asphalt
 0.5 W < 12CL ΔT< 1.5W, for silicone
 where: W=existing joint sealant reservoir width (inches)
 C=0.65, for stabilized base
 0.80 for granular base
 $=5.5\times10^{-6}$/°F
 ΔT=estimated annual temperature range (°F)

(2) Joint sealant reservoir shape factor is adequate if:

3/4 < D/W , 2, for asphalt
1/2 < D/W < 2, for silicone

where: D=joint sealant reservoir depth (inches)
 W=joint sealant reservoir width (inches)

Joint Sealant

JTS 1 The pavement shows no indications of a joint sealant deficiency.

(a) do nothing

JTS 2 Although the existing sealant is in good condition, a transverse joint sealant deficiency is indicated by an inadequate joint sealant reservoir shape factor for the existing sealant type. This is likely to hinder the performance of the sealant in the future.

(a) do nothing
(b) reseal transverse joints

JTS 3 Although the existing sealant is in good condition, a transverse joint sealant deficiency is indicated by an inadequate joint sealant reservoir width for the existing sealant type. This is likely to hinder the performance of the sealant in the future.

(a) do nothing
(b) reseal transverse joints

JTS 4 A transverse joint sealant deficiency is indicated by medium- to high-severity joint sealant damage.

(a) reseal transverse joints

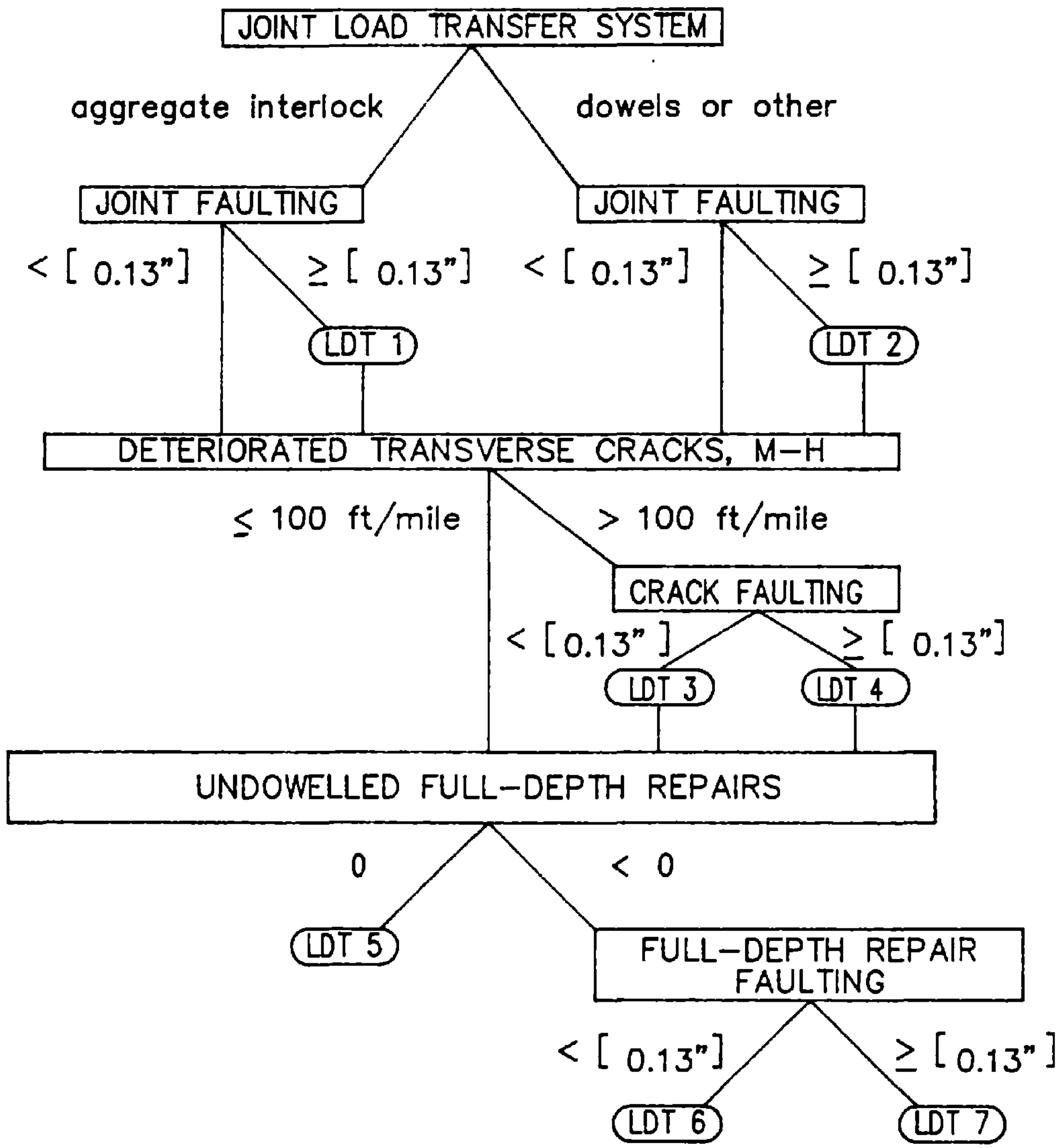
JTS 5 A transverse joint sealant deficiency is indicated by medium- to high-severity joint sealant damage and an inadequate joint sealant reservoir shape factor for the existing sealant type.

(a) reseal transverse joints

JTS 6 A transverse joint sealant deficiency is indicated by medium- to high-severity joint sealant damage and an inadequate joint sealant reservoir width for the existing sealant type.

(a) reseal transverse joints

JPCP LOAD TRANSFER DEFICIENCY



Load Transfer Deficiency

LDT 1 Aggregate interlock is providing inadequate load transfer at the transverse joints, as indicated by mean transverse joint faulting of more than [0.13] inches.

(a) load transfer restoration at joints

LDT 2 Dowels or other mechanical devices present are providing inadequate load transfer at the transverse joints, as indicated by mean transverse joint faulting of more than [0.13] inches.

(a) load transfer restoration at joints
(b) do nothing

LDT 3 No load transfer deficiency is indicated at deteriorated transverse cracks.

(a) do nothing

LDT 4 A load transfer deficiency at deteriorated transverse cracks is indicated by mean crack faulting of more than [0.13] inches.

(a) full-depth repair of cracks
(b) load transfer restoration at cracks

LDT 5 No undowelled full-depth repairs are present.

(a) do nothing

LDT 6 A potential load transfer deficiency exists at undowelled full-depth repairs, but mean full-depth repair faulting is not significant.

(a) do nothing

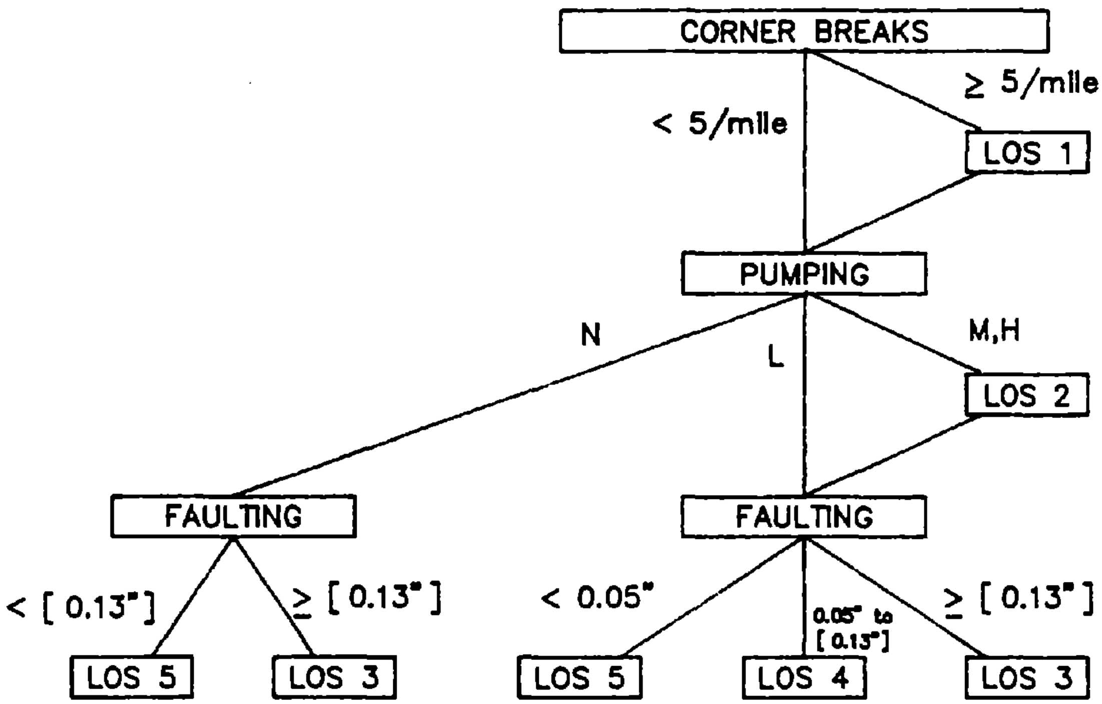
LDT 7 A load transfer deficiency is indicated at undowelled full-depth repairs by mean full-depth repair faulting of more than [0.13] inches.

(a) replace undowelled full-depth repairs with dowelled full-depth repairs

LDT 8 No load transfer deficiency is indicated at transverse joints.

(a) do nothing

JPCP LOSS OF SUPPORT



Loss of Support

LOS 1 Loss of slab support is indicated by 5 or more corner breaks per mile.

(a) subseal at joints and cracks

LOS 2 Loss of slab support is indicated by medium- to high-severity pumping.

(a) subseal at joints and cracks

LOS 3 Loss of slab support is indicated by average faulting greater than [0.13] inches at joints and cracks.

(a) subseal at joints and cracks

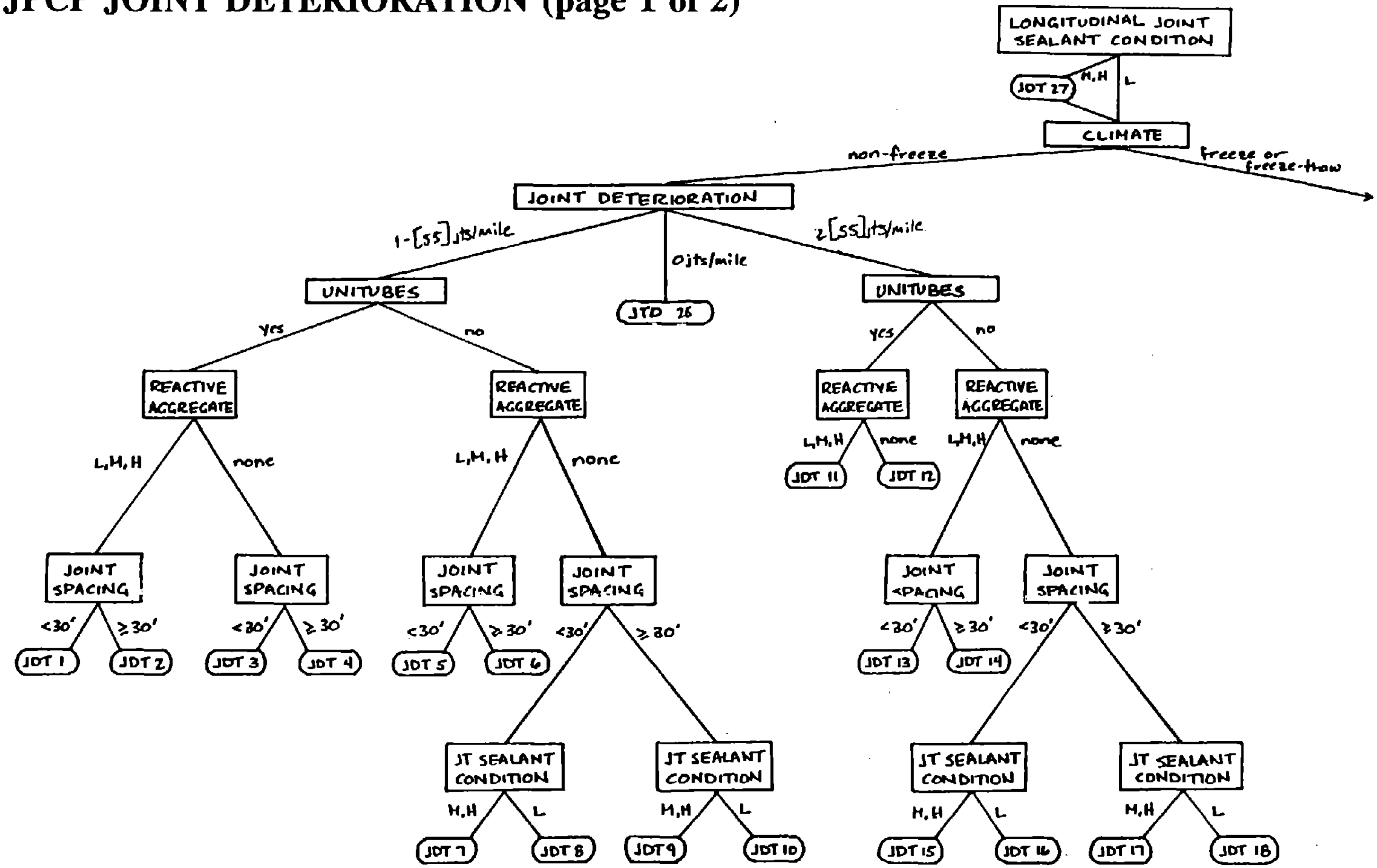
LOS 4 Loss of slab support is indicated by pumping and average faulting of between [0.05] inches and [0.13] inches at joints and cracks.

(a) subseal at joints and cracks

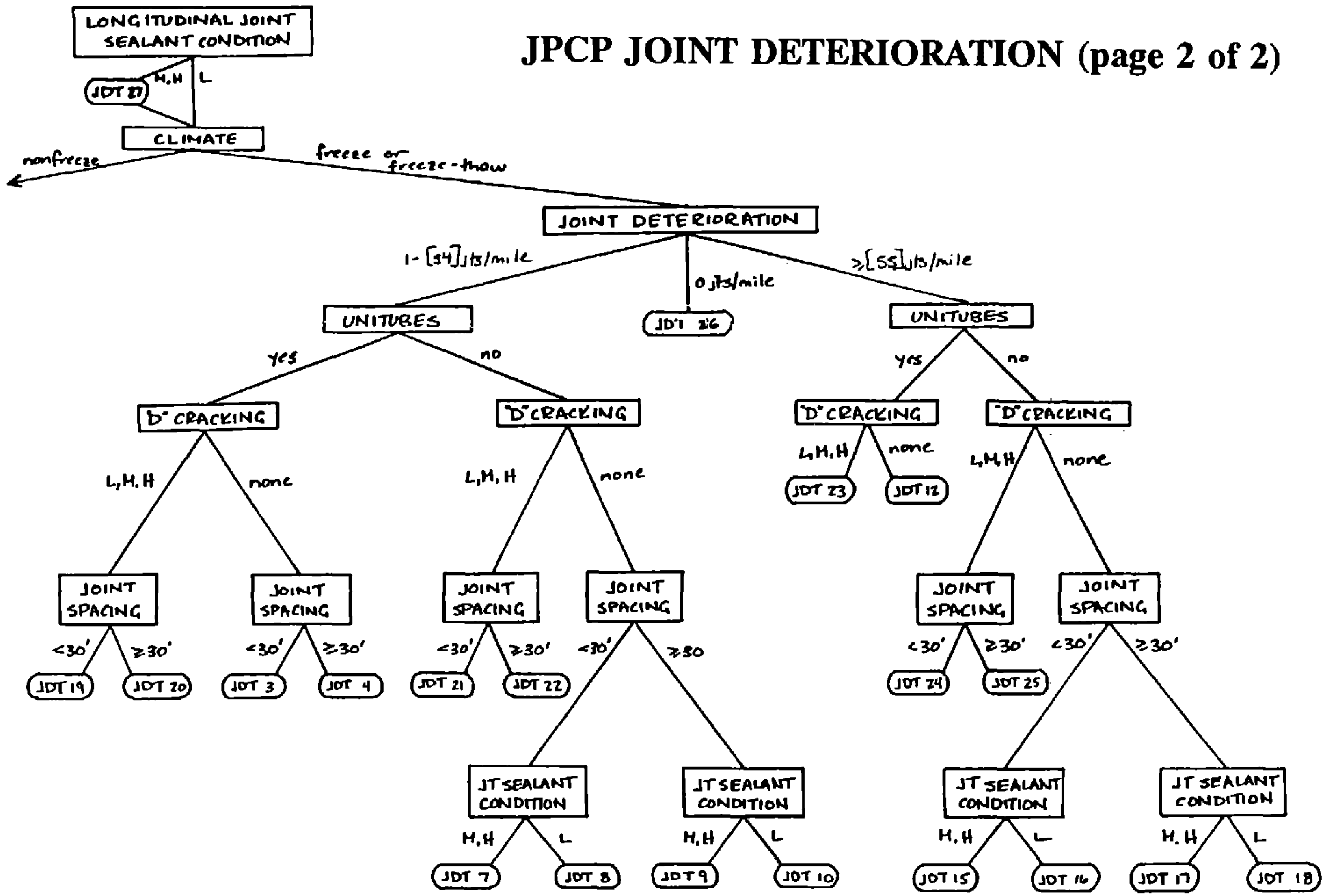
LOS 5 The pavement shows no indications of loss of slab support.

(a) do nothing

JPCP JOINT DETERIORATION (page 1 of 2)



JPCP JOINT DETERIORATION (page 2 of 2)



Joint Deterioration

JDT 1 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts and the presence of reactive aggregate.

(a) full-depth repair of joints

JDT 2 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts, the presence of reactive aggregate, and large joint movements associated with the long joint spacing.

(a) pressure relief joints, partial-depth repair of joints
(b) pressure relief joints, full-depth repair of joints

JDT 3 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts.

(a) partial-depth repair of joints
(b) full-depth repair of joints

JDT 4 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts and large joint movements associated with the long joint spacing.

(a) partial-depth repair of joints
(b) full-depth repair of joints

JDT 5 Some joint deterioration exists, likely due to the presence of reactive aggregate.

(a) full-depth repair of joints

JDT 6 Some joint deterioration exists, likely due to the presence of reactive aggregate and large joint movements associated with the long joint spacing.

(a) pressure relief joints, full-depth repair of joints

JDT 7 Some joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of incompressibles.

(a) reseal transverse joints, full-depth repair of joints

JDT 8 Some joint deterioration exists, but its cause is unknown.

(a) full-depth repair of joints

JDT 9 Some joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of water and incompressibles, and large joint movements associated with the long joint spacing.

(a) reseal transverse joints, full-depth repair of joints

JDT 10 Some joint deterioration exists, likely due to large joint movements associated with the long joint spacing.

(a) full-depth repair of joints

JDT 11 Extensive joint deterioration exists, likely due to the use of Unitube joint forming inserts and the presence of reactive aggregate.

(a) unbonded PCC overlay
(b) reconstruct

JDT 12 Extensive joint deterioration exists, likely due to the use of Unitube joint forming inserts.

(a) partial-depth repair of joints
(b) full-depth repair of joints

JDT 13 Extensive joint deterioration exists, likely due to the presence of reactive aggregate.

(a) unbonded PCC overlay
(b) reconstruct

JDT 14 Extensive joint deterioration exists, likely due to the presence of reactive aggregate and large joint movements associated with the long joint spacing.

(a) full-depth repair of joints, pressure relief joints, unbonded PCC overlay
(b) reconstruct

JDT 15 Extensive joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of water and incompressibles.

(a) full-depth repair of joints, reseal transverse joints

JDT 16 Extensive joint deterioration exists but its cause is unknown.

(a) full-depth repair of joints

JDT 17 Extensive joint deterioration exists, likely due to poor joint sealant condition permitting infiltration of water and incompressibles, and large joint movements associated with the long joint spacing.

(a) full-depth repair of joints, reseal transverse joints

JDT 18 Extensive joint deterioration exists, likely due to large joint movements associated with the long joint spacing.

(a) full-depth repair of joints

JDT 19 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts and "D" cracking weakening the concrete at the joints.

(a) full-depth repair of joints

JDT 20 Some joint deterioration exists, likely due to the use of Unitube joint forming inserts, "D" cracking weakening the concrete at the joints, and large joint movement associated with the long joint spacing.

(a) full-depth repair of joints

JDT 21 Some joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints.

(a) full-depth repair of joints

JDT 22 Some joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints, and large joint movements associated with the long joint spacing.

(a) full-depth repair of joints

JDT 23 Extensive joint deterioration exists, likely due to the use of Unitube joint forming inserts and "D" cracking weakening the concrete at the joints.

(a) unbonded PCC overlay
(b) reconstruct

JDT 24 Extensive joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints.

(a) unbonded PCC overlay
(b) reconstruct

JDT 25 Extensive joint deterioration exists, likely due to "D" cracking weakening the concrete at the joints, and large joint movements associated with the long joint spacing.

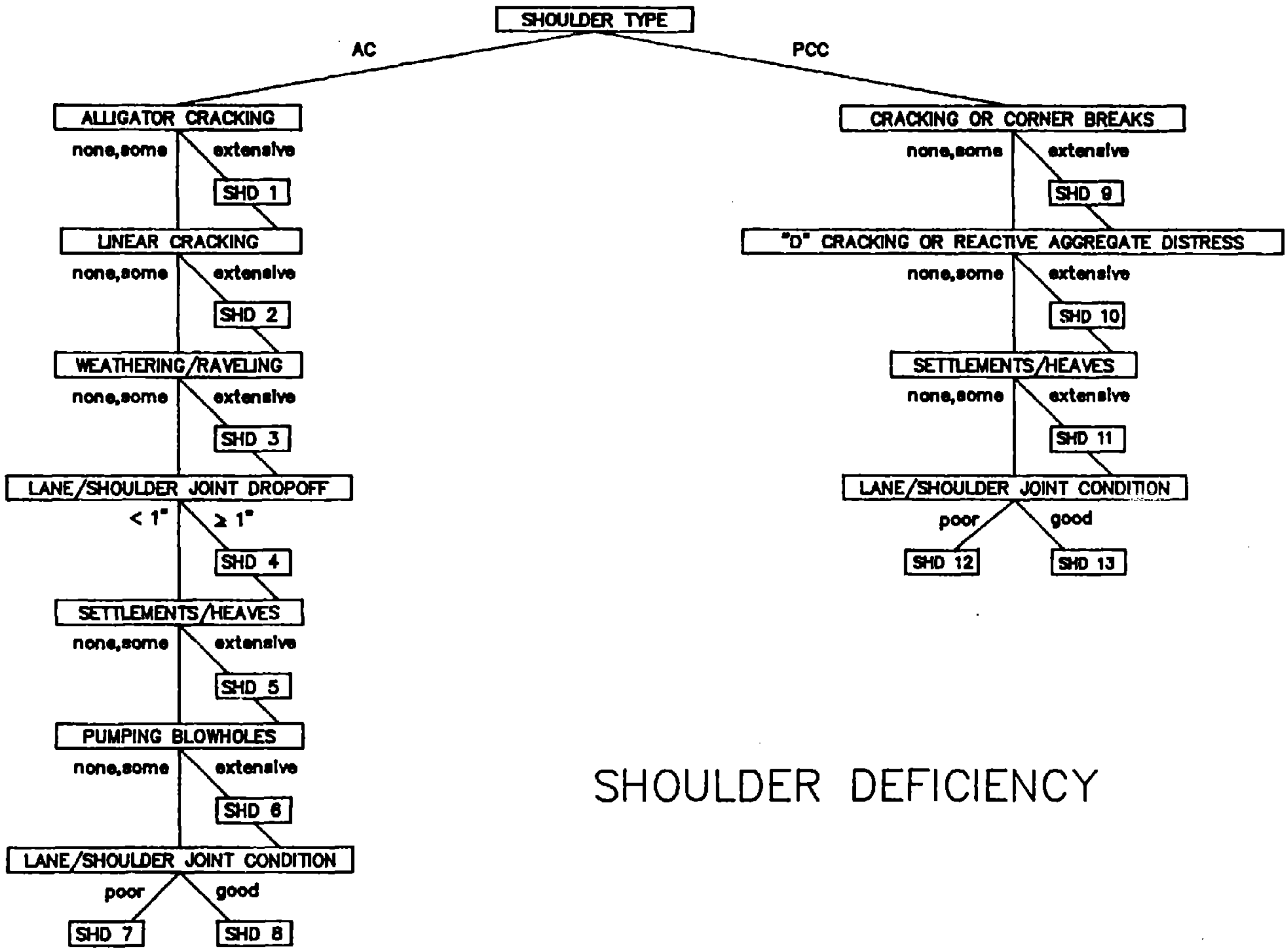
(a) unbonded PCC overlay
(b) reconstruct

JDT 26 No joint deterioration exists.

(a) do nothing

JDT 27 Joint deterioration or other pavement deterioration may be accelerated by water infiltration permitted by poor longitudinal joint sealant condition.

(a) reseal longitudinal centerline joint



SHOULDER DEFICIENCY

Shoulder

SHD 1 Structural deterioration of the AC shoulder is indicated by extensive alligator cracking.

(a) in-place recycle
(b) patch
(c) reconstruct with AC
(d) reconstruct with PCC

SHD 2 Deterioration of the AC shoulder is indicated by extensive linear cracking.

(a) in-place recycle
(b) patch
(c) reconstruct with AC
(d) reconstruct with PCC

SHD 3 Deterioration of the AC shoulder surface is indicated by extensive weathering and/or raveling.

(a) chip seal

SHD 4 A dropoff of 1 inch or more along the AC lane/shoulder joint constitutes a safety hazard.

(a) leveling wedge

SHD 5 Foundation movement beneath the AC shoulder is indicated by extensive settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements

SHD 6 Pumping has resulted in extensive blowhole formation in the AC shoulder.

(a) patch blowholes

SHD 7 Excessive infiltration of water beneath the pavement and AC shoulder is indicated by poor lane/shoulder joint condition.

(a) reseal lane/shoulder joint
(b) do nothing

SHD 8 The AC shoulder shows no indications of significant deterioration.

(a) do nothing

SHD 9 Structural deterioration of the PCC shoulder is indicated by extensive cracking and/or corner breaks.

(a) full-depth repair
(b) reconstruct with AC
(c) reconstruct with PCC

SHD 10 Poor durability of the PCC shoulder is indicated by extensive "D" cracking or reactive aggregate distress.

(a) reconstruct with AC
(b) reconstruct with PCC

SHD 11 Foundation movement beneath the PCC shoulder is indicated by extensive settlements and/or heaves along the outer edge.

(a) reconstruct heaves, AC level-up settlements

SHD 12 Excessive infiltration of water beneath the pavement and PCC shoulder is indicated by poor lane/shoulder joint condition.

(a) reseal lane/shoulder joint
(b) do nothing

SHD 13 The PCC shoulder shows no indications of significant deterioration.

(a) do nothing

APPENDIX B3

EVALUATION PERFORMANCE PREDICTION MODELS FOR JPCP

Distress Types

1. Faulting
2. Cracking
3. Joint Deterioration
4. Pumping
5. PSR

Faulting

$$FAULT = \{ ESAL^{0.144} * [-0.2980 + 0.2671/THICK^{0.3184} - 0.0285\ BASETYPE + 0.00406\ (FI + 1)^{0.3598} - 0.0462\ PCCSH + 0.2384\ (PUMP + 1)^{0.0109} - 0.0340\ DOWEL^{2.0587}] / 100 \} + FLTCALIB$$

where:

FAULT = mean transverse joint faulting, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

THICK = thickness of PCC slab, in

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (asphalt, cement, etc.)

FI = mean Freezing Index, Fahrenheit degree-days

PCCSH = existing tied PCC shoulders
= 0, if not present
= 1, if present

PUMP = pumping severity (from pumping model) (Note: PUMP can be any value between 0 and 3, e.g. 2.2)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

DOWEL = diameter of dowels, in
(0 if no dowel bars used)

FLTCALIB = calibration of model to existing faulting

= actual faulting (in) measured during survey - FAULT predicted for present year by above model

$$= \text{actual faulting} - \{ ESAL^{0.144} * [-0.2980 + 0.2671/THICK^{0.3184} - 0.0285\ BASETYPE + 0.00406\ (FI + 1)^{0.3598} - 0.0462\ PCCSH + 0.2384\ (PUMP + 1)^{0.0109} - 0.0340\ DOWEL^{2.0587}] / 100 \}$$

R^2 = 0.79
n = 259
SEE = 0.02 in [0.05 cm]

Source: NCHRP 1-19 (6)

Cracking

$$\text{CRACKS} = \{ \text{ESAL}^{2.755} [3092.4 (1 - \text{SOILCRS}) \text{ RATIO}^{10.0}]$$
$$+ \text{ESAL}^{0.5} (1.233 \text{ TRANGE}^{2.0} \text{ RATIO}^{2.868})$$
$$+ \text{ESAL}^{2.416} (0.2296 \text{ FI}^{1.53} \text{ RATIO}^{7.31}) \} + \text{CRKCALIB}$$

where:

CRACKS = total length of cracking of all severities, ft/mile

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

RATIO = Westergaard's edge stress/PCC modulus of rupture (see following page to calculate Westergaard's edge stress)

TRANGE = Annual temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

CRKCALIB = calibration of model to existing cracking

= actual cracking (M-H cracks, ft/mile) measured during survey - CRACKS predicted for present year by above model

$$= \text{actual cracking} - \{ \text{ESAL}^{2.755} [3092.4 (1 - \text{SOILCRS}) \text{ RATIO}^{10.0}] + \text{ESAL}^{0.5} (1.233 \text{ TRANGE}^{2.0} \text{ RATIO}^{2.868}) + \text{ESAL}^{2.416} (0.2296 \text{ FI}^{1.53} \text{ RATIO}^{7.31}) \}$$

R^2 = 0.69
n = 303
SEE = 176 ft/mile [33.3 m/km]

Source: NCHRP 1-19 (6)

Calculation of Westergaard's Edge Stress:

$$L = [(4200000 * THICK^{3.0}) / 12 * (1 - 0.2^{2.0}) * KEFF]^{0.25}$$

$$B = [1.6 (6.4)^2 + THICK^2]^{0.5} - 0.675 THICK$$

$$Stress = (0.572 * 9000 / THICK^{2.0}) * [4 \log_{10} (L/B) + 0.359]$$

where:

THICK = thickness of PCC slab, in

KEFF = effective k value beneath PCC slab, psi/in

4,200,000 = assumed elastic modulus of PCC slab, psi

0.20 = assumed Poisson's ratio of PCC slab

6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/in = 2.71 kPa/cm

Joint Deterioration

$$\mathrm{DETJT} = [\ \mathrm{AGE}^{1.695}\ (0.9754\ \mathrm{DUR}) + \mathrm{AGE}^{2.841}\ (0.01247\ \mathrm{UNITUBE}) + \mathrm{AGE}^{3.038}\ (0.001346\ \mathrm{INCOMP})\ ] + \mathrm{DETJTCALIB}$$

where:

DETJT = medium- to high-severity deteriorated transverse joints, number/mile

AGE = time since construction, years

DUR = D cracking or reactive aggregate distress
= 0, if none
= 1, if low, medium, or high severity

UNITUBE = Unitube joint forming inserts
= 0, if not present
= 1, if present

INCOMP = incompressibles in transverse joints
= 0, if no incompressibles observed
= 1, if incompressibles observed

DETJTCALIB = calibration of model to existing joint deterioration

= actual joint deterioration (M-H deteriorated joints/mile) measured during survey - DETJT predicted for present year by above model

$$= \text{actual joint deterioration} - [\ \mathrm{AGE}^{1.695}\ (0.9754\ \mathrm{DUR}) + \mathrm{AGE}^{2.841}\ (0.01247\ \mathrm{UNITUBE}) + \mathrm{AGE}^{3.038}\ (0.001346\ \mathrm{INCOMP})\ ]$$

R^2 = 0.59
n = 252
SEE = 16 joints/mile [10 joints/km]

Source: NCHRP 1-19 (6)

Pumping

$$PUMP = ESAL^{0.443} [-1.479 + 0.255 (1 - SOILCRS) + 0.0605\ SUMPREC^{0.5} + 52.65/THICK^{1.747} + 0.0002269\ FI^{1.205}]$$

where:

PUMP = pumping severity (PUMP can be any value between 0 and 3)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

THICK = thickness of PCC slab, in

FI = mean Freezing Index, Fahrenheit degree-days

$R^2 = 0.68$
n = 289
SEE = 0.42

Source: NCHRP 1-19 (6)

PSR

$$PSR = 4.5 - 1.486\ ESAL^{0.1467}$$

$$+ 0.4963\ ESAL^{0.265}\ RATIO^{-0.5}$$

$$- 0.01082\ ESAL^{0.644}\ AGE^{0.525}\ (SUMPREC^{0.91}/AVGMT^{1.07})$$

where:

PSR = Present Serviceability Rating

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since construction, millions

RATIO = Westergaard's edge stress/PCC slab modulus of rupture

AGE = time since construction, years

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

AVMT = average monthly temperature, ^{o} C [(^{o}F - 32) / 1.8]

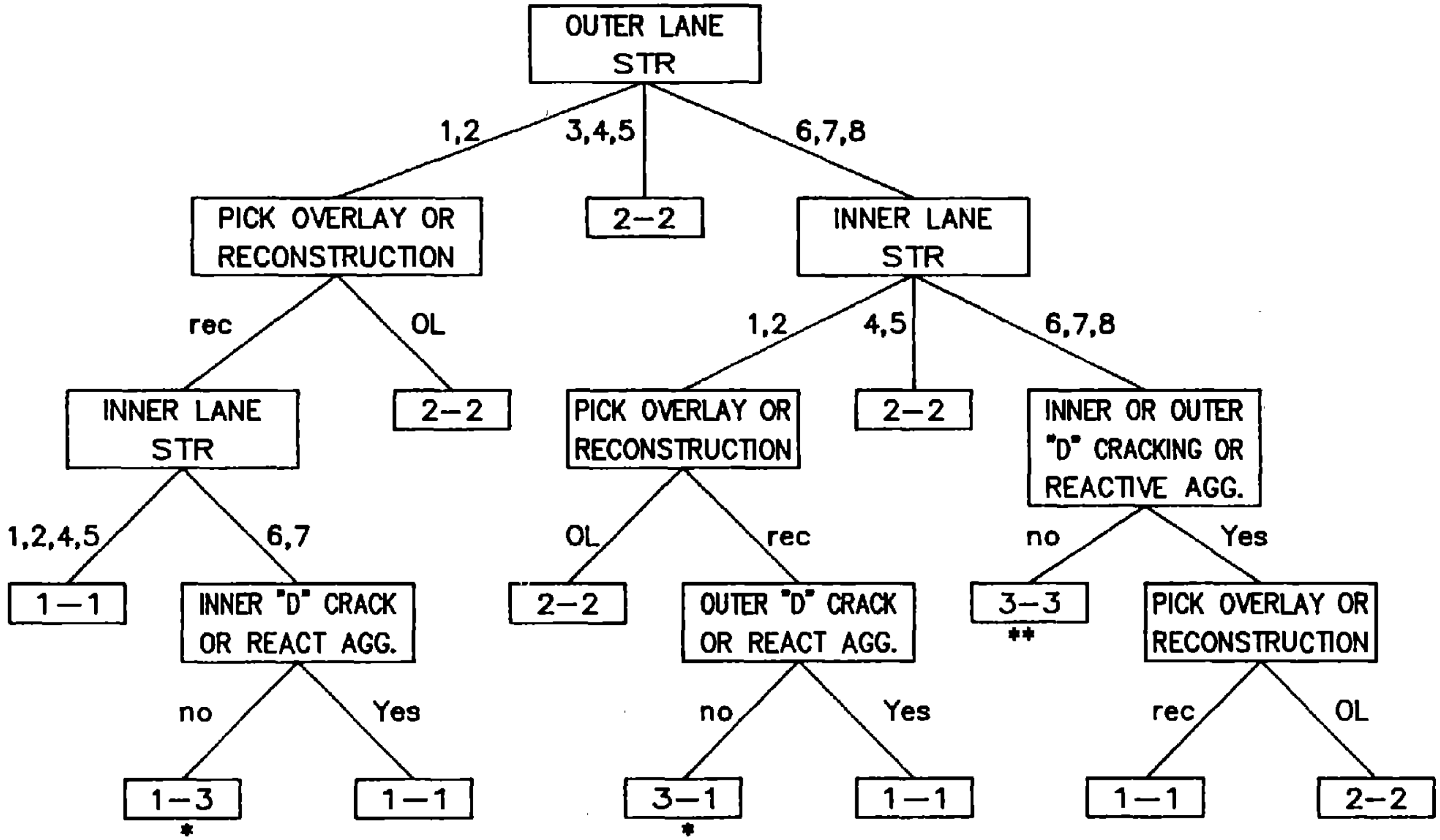
R^2 = 0.69
n = 316
SEE = 0.25

Source: NCHRP 1-19 (6)

APPENDIX B4

REHABILITATION STRATEGY DEVELOPMENT DECISION TREES

Main Rehabilitation Approach for JPCP

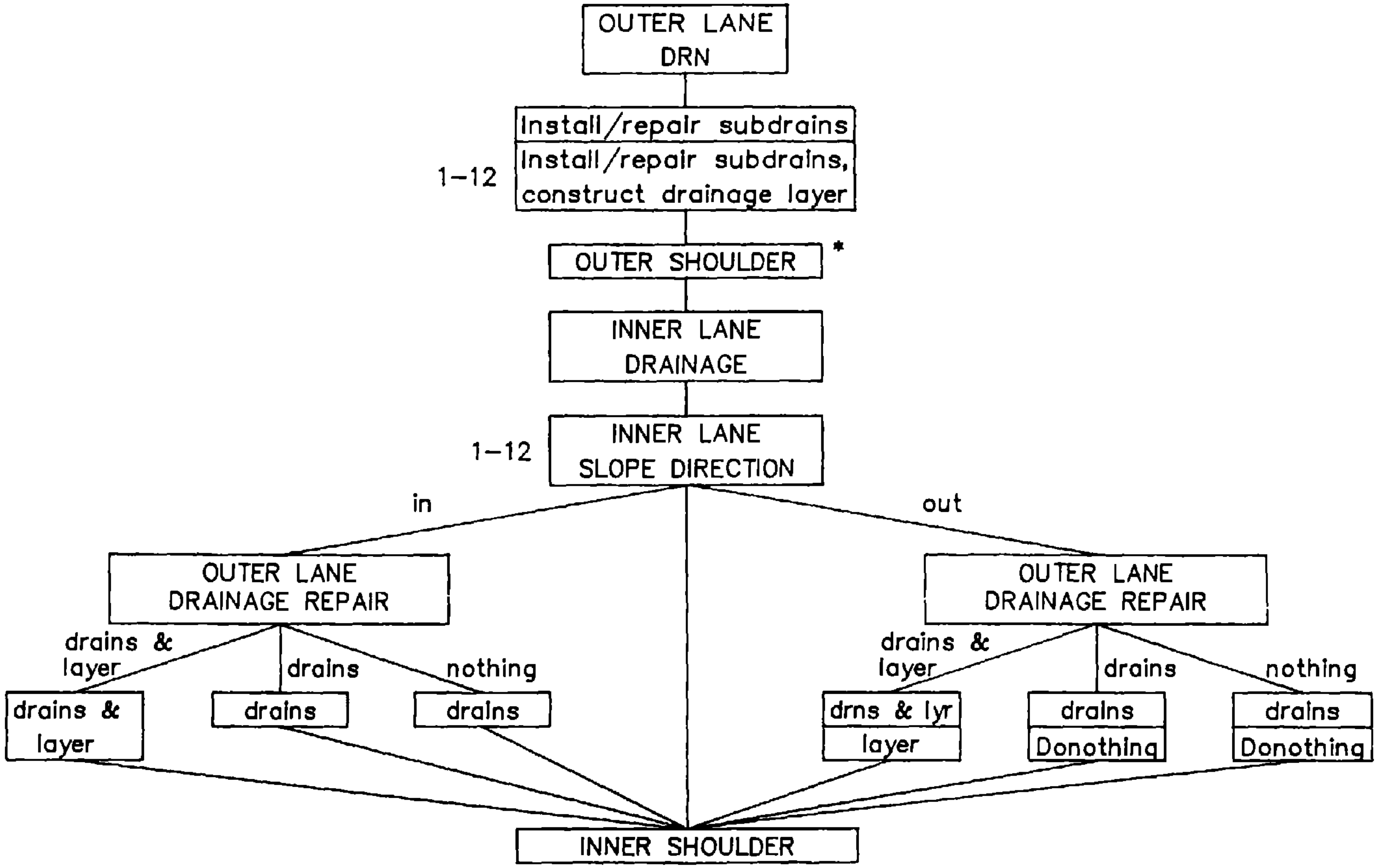


* Option to go to 1–1 provided

** Option to go to 1–1, 1–3, or 2–2 provided

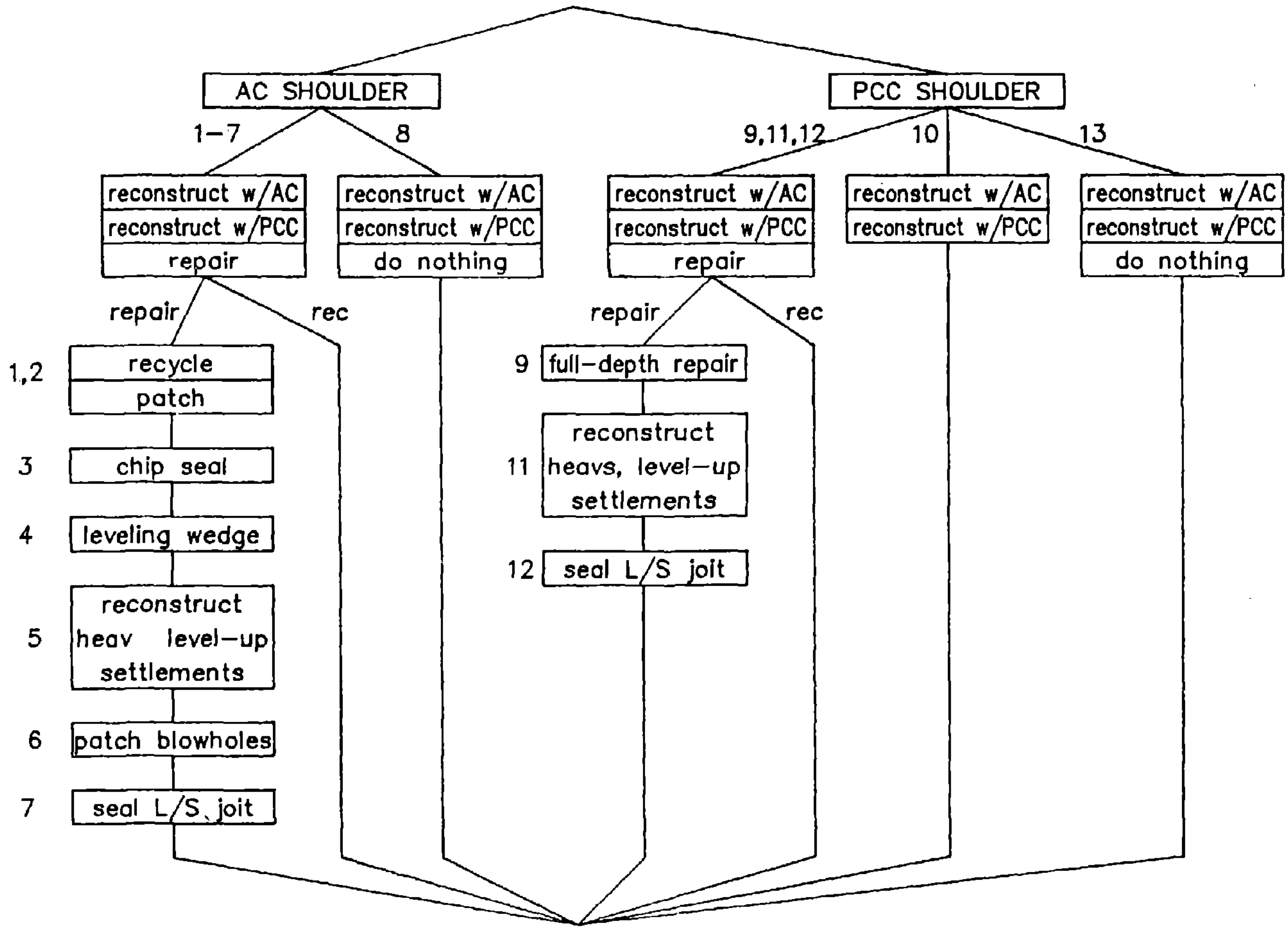
1–1 Reconstruct Both Lanes
1–3 Reconstruct Outer, Restore Inner
3–1 Restore Outer, Reconstruct Inner
2–2 Overlay Both Lanes
3–3 Restore Both Lanes

Reconstruction of A JPCP Lane

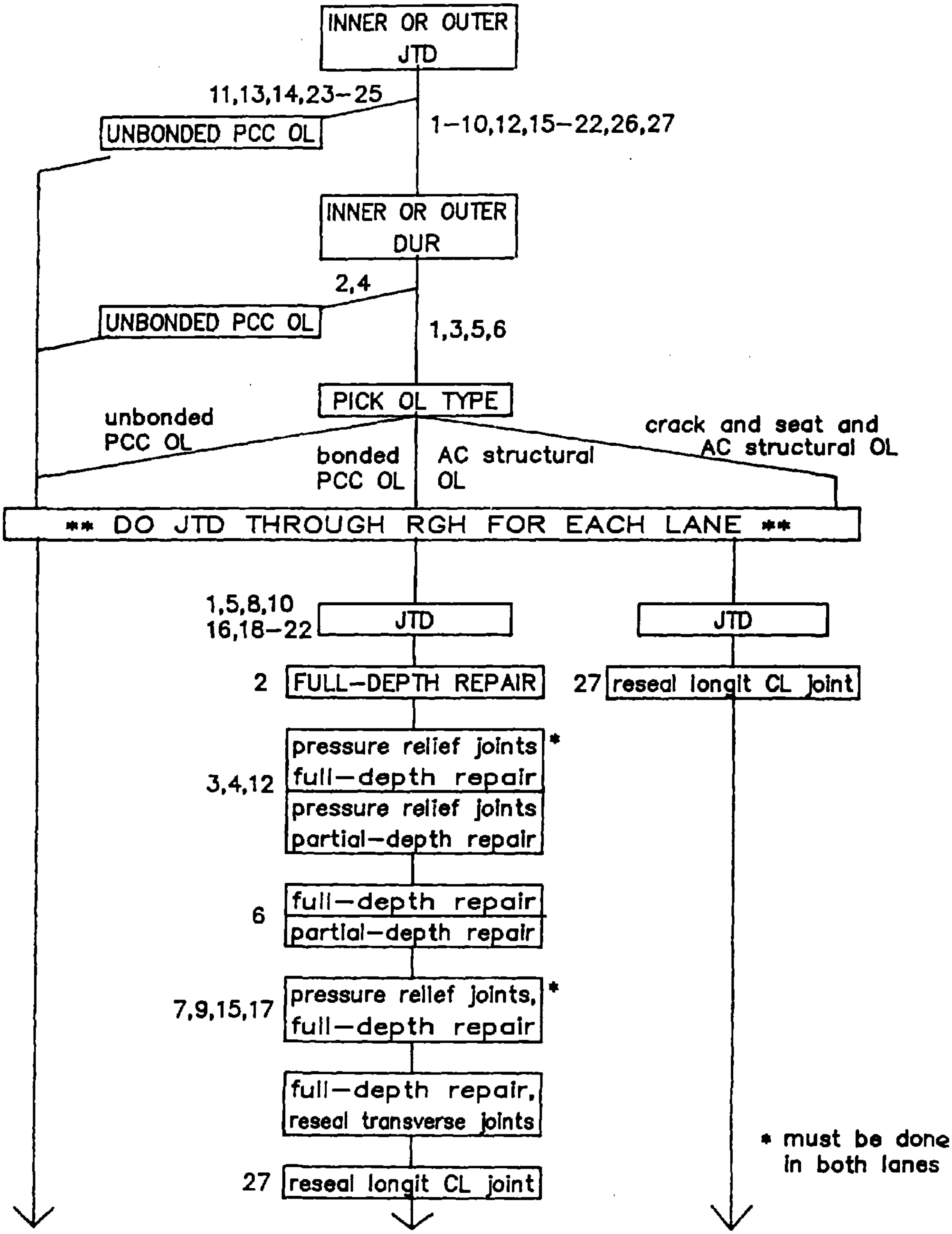


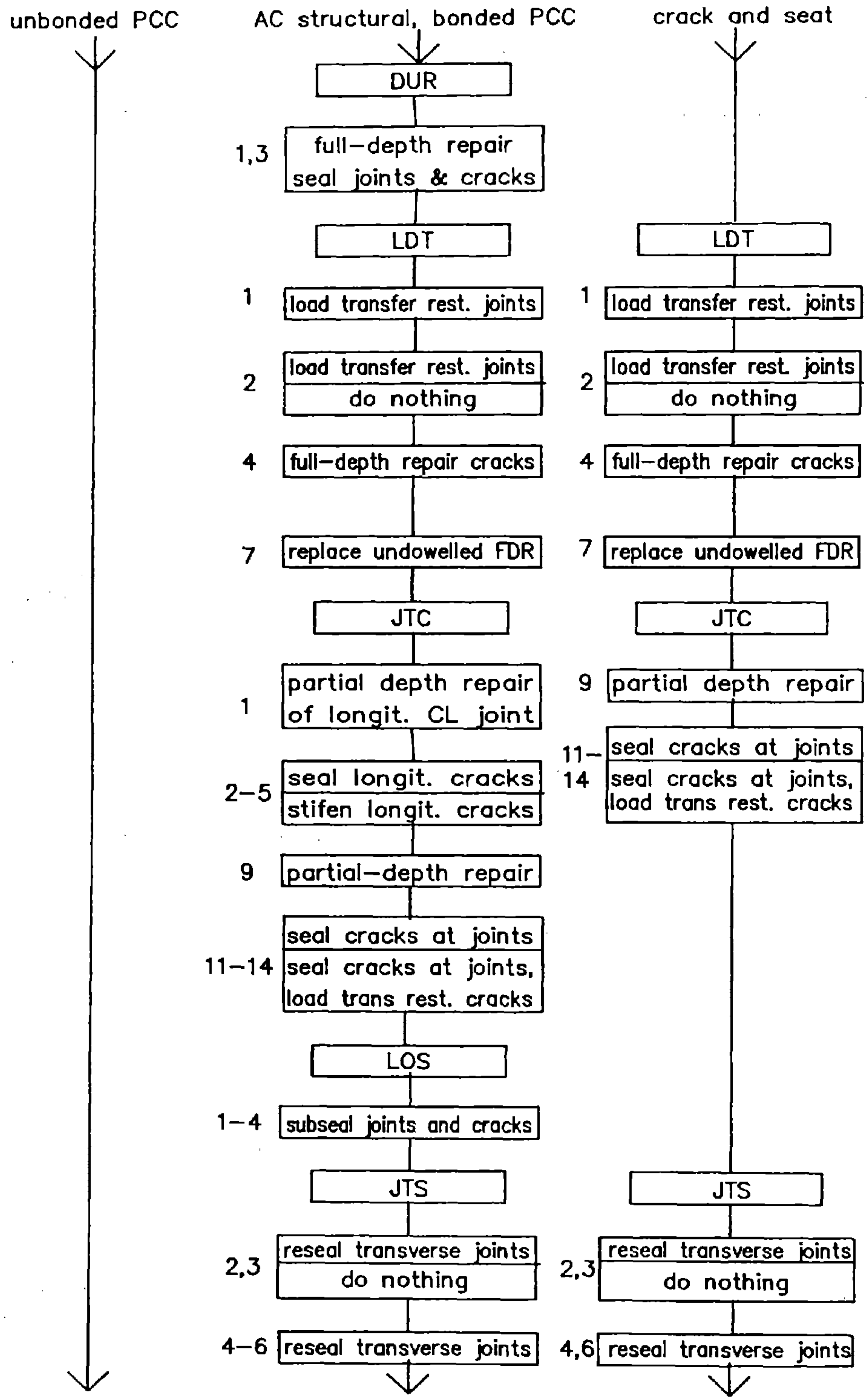
* See decision tree for shoulder rehabilitation adjacent to reconstructed lane.

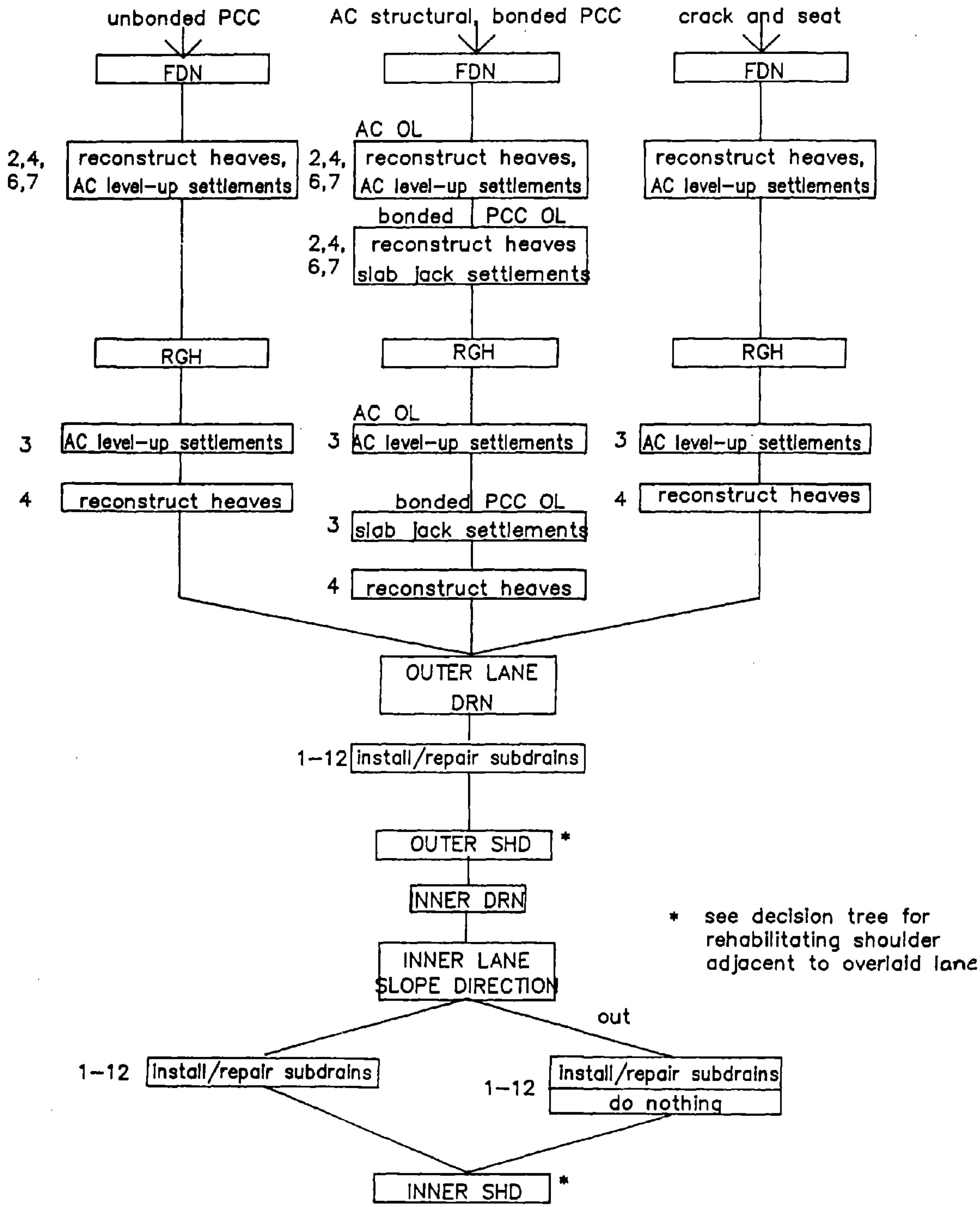
Rehabilitation of Shoulder Adjacent to Reconstructed Lane



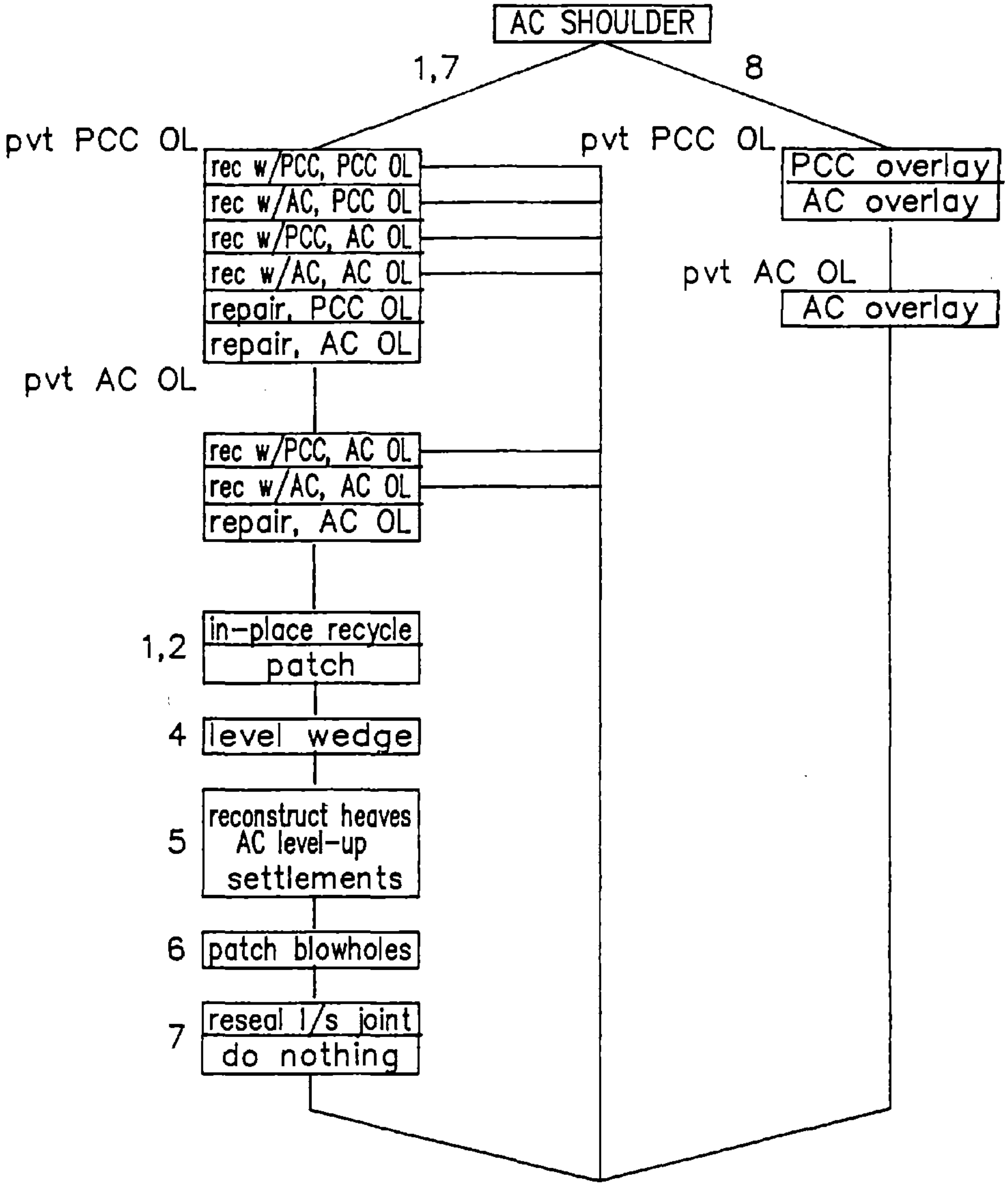
Overlaying A JPCP Lane



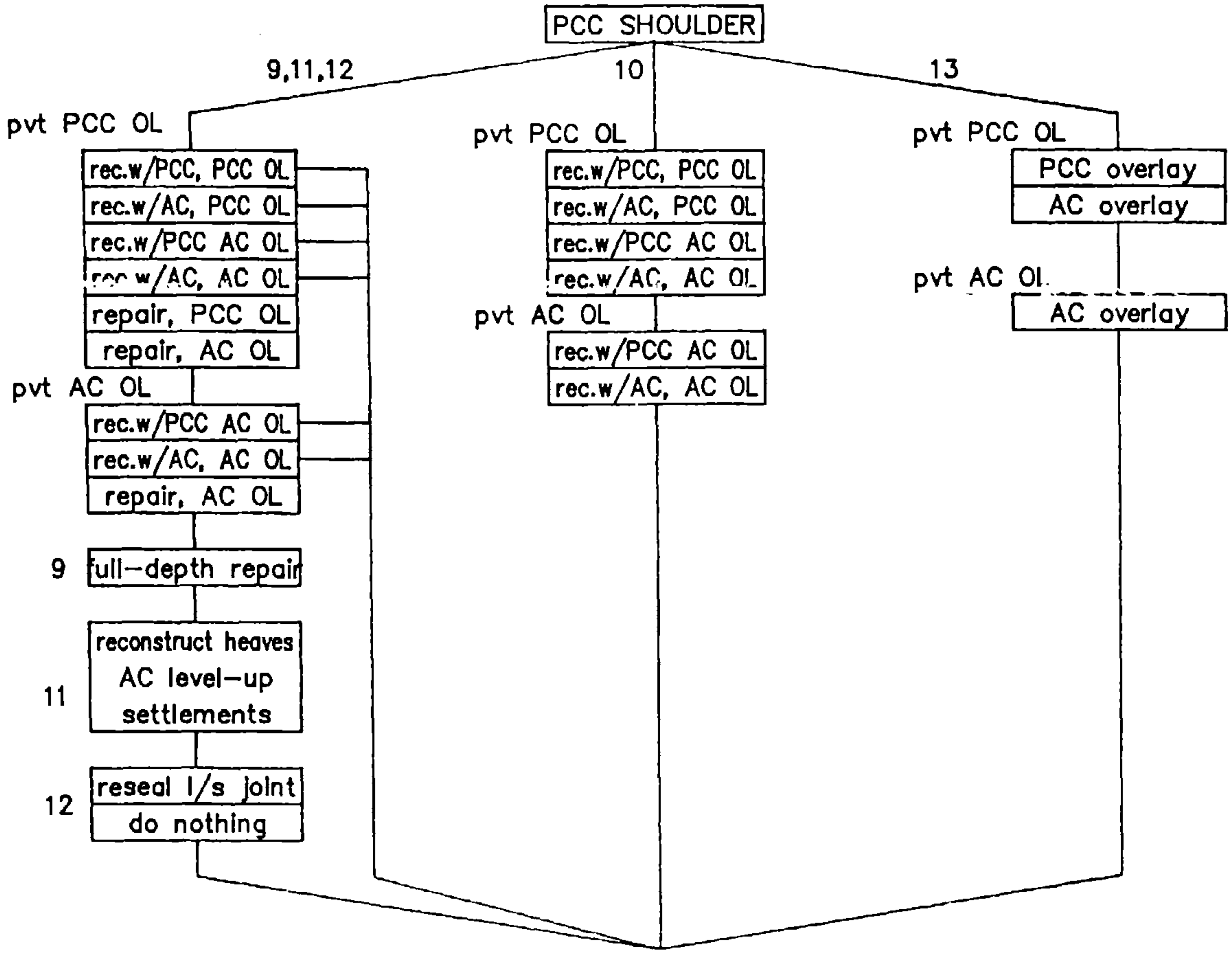

unbonded PCC
AC structural, bonded PCC
crack and seat
DUR
1,3
full-depth repair
seal joints & cracks
LDT
LDT
1
load transfer rest. joints
1
load transfer rest. joints
2
load transfer rest. joints
do nothing
2
load transfer rest. joints
do nothing
4
full-depth repair cracks
4
full-depth repair cracks
7
replace undowelled FDR
7
replace undowelled FDR
JTC
JTC
1
partial depth repair
of longit. CL joint
9
partial depth repair
11–14
seal cracks at joints
seal cracks at joints,
load trans rest. cracks
2–5
seal longit. cracks
stifen longit. cracks
9
partial-depth repair
11–14
seal cracks at joints
seal cracks at joints,
load trans rest. cracks
LOS
1–4
subseal joints and cracks
JTS
JTS
2,3
reseal transverse joints
do nothing
2,3
reseal transverse joints
do nothing
4–6
reseal transverse joints
4,6
reseal transverse joints


unbonded PCC
AC structural, bonded PCC
crack and seat
FDN
FDN
FDN
AC OL
2,4, 6,7
reconstruct heaves, AC level-up settlements
2,4, 6,7
reconstruct heaves, AC level-up settlements
reconstruct heaves, AC level-up settlements
bonded PCC OL
2,4, 6,7
reconstruct heaves slab jack settlements
RGH
RGH
RGH
AC OL
3
AC level-up settlements
3
AC level-up settlements
3
AC level-up settlements
4
reconstruct heaves
bonded PCC OL
4
reconstruct heaves
3
slab jack settlements
4
reconstruct heaves
OUTER LANE DRN
1–12
install/repair subdrains
OUTER SHD *
INNER DRN
* see decision tree for rehabilitating shoulder adjacent to overlaid lane
INNER LANE SLOPE DIRECTION
out
1–12
install/repair subdrains
1–12
install/repair subdrains
do nothing
INNER SHD *

AC Shoulder Rehabilitation Adjacent to Overlaid Lane.

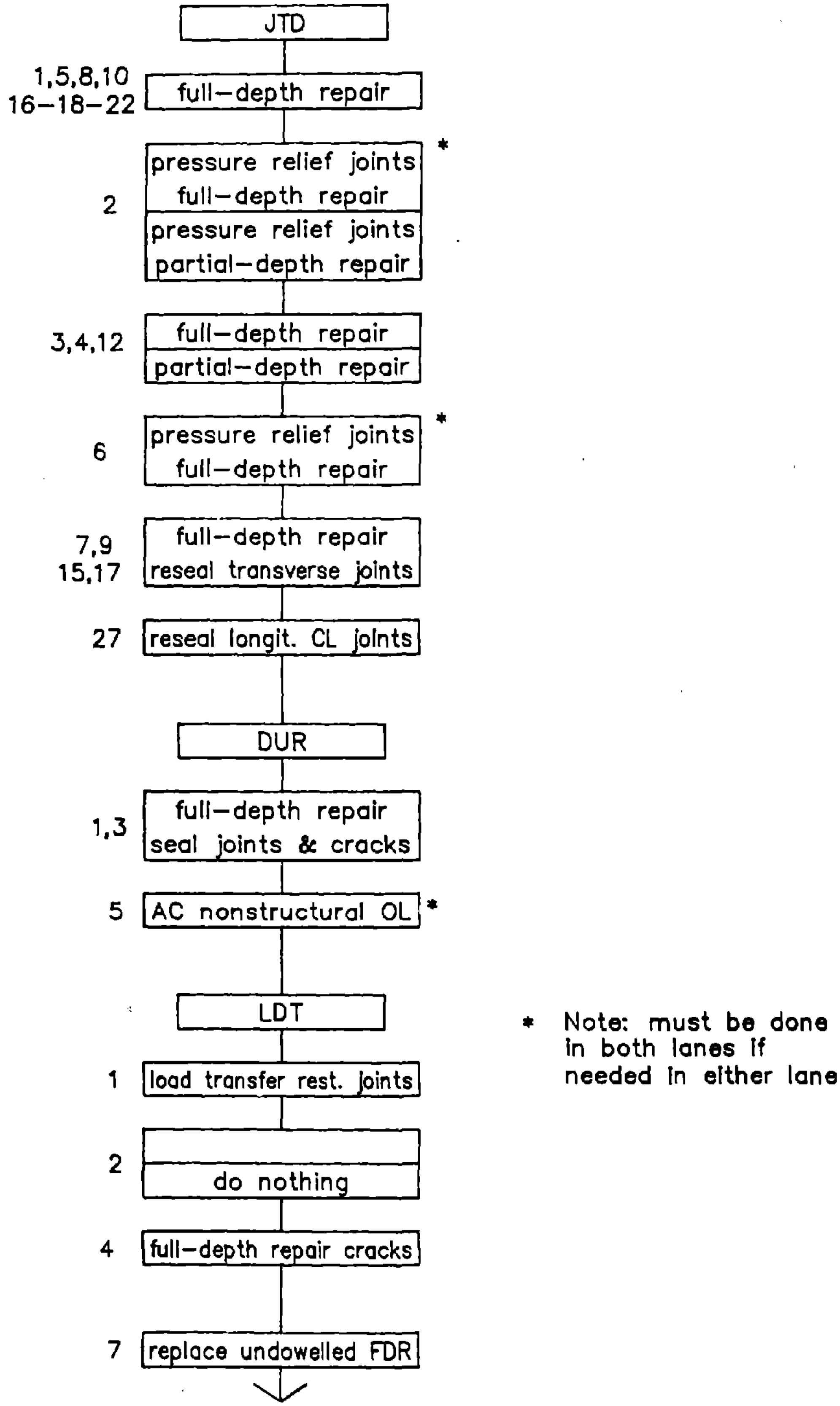


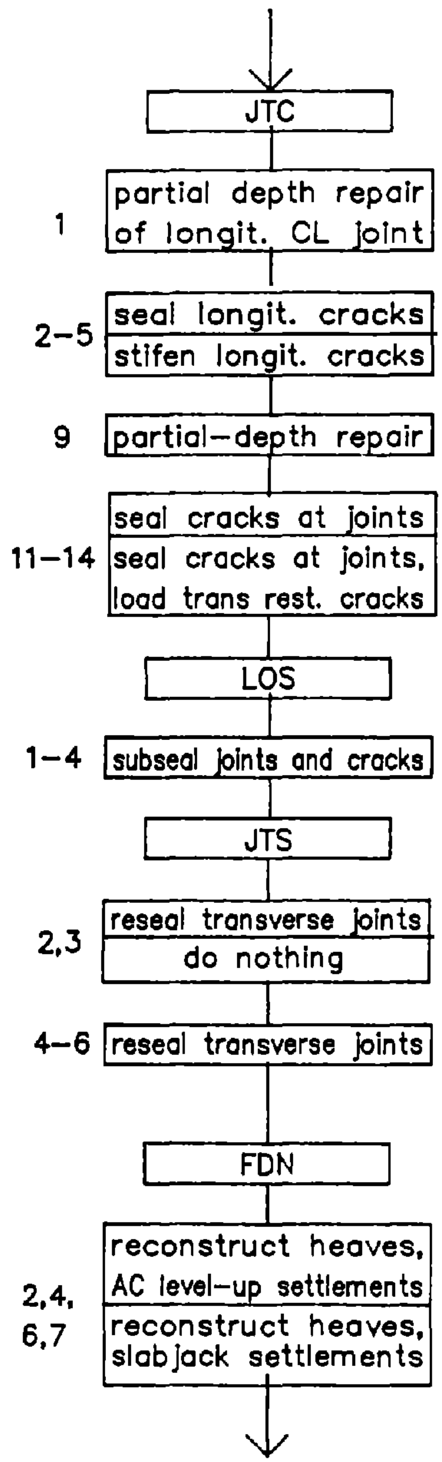
PCC Shoulder Rehabilitation Adjacent to Overlaid Lane

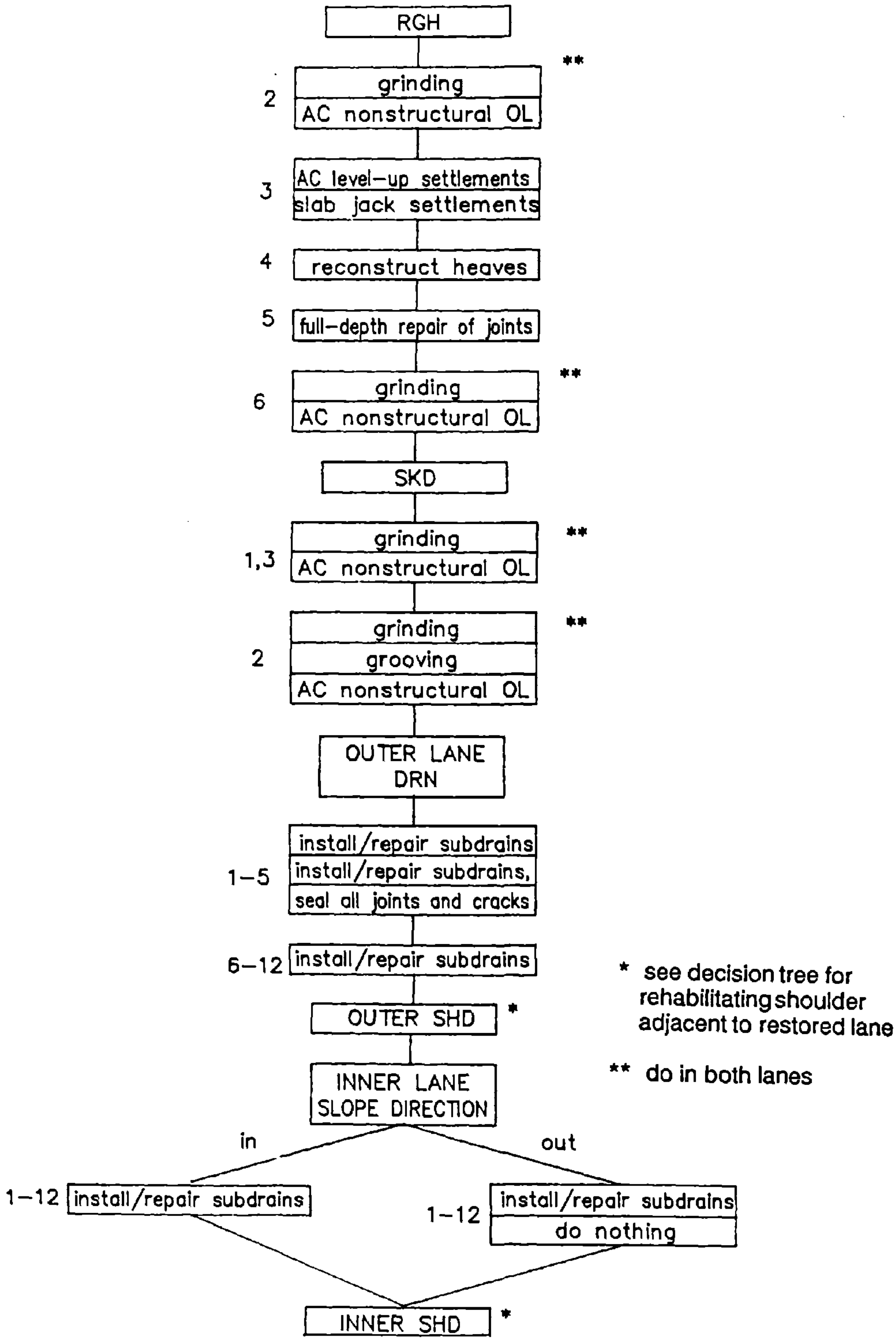


Notes: Pvt PCC OL = bonded PCC OL, unbonded PCC OL
Pvt AC OL = AC structural OL, AC nonstructural OL, crack and seat and AC structural OL

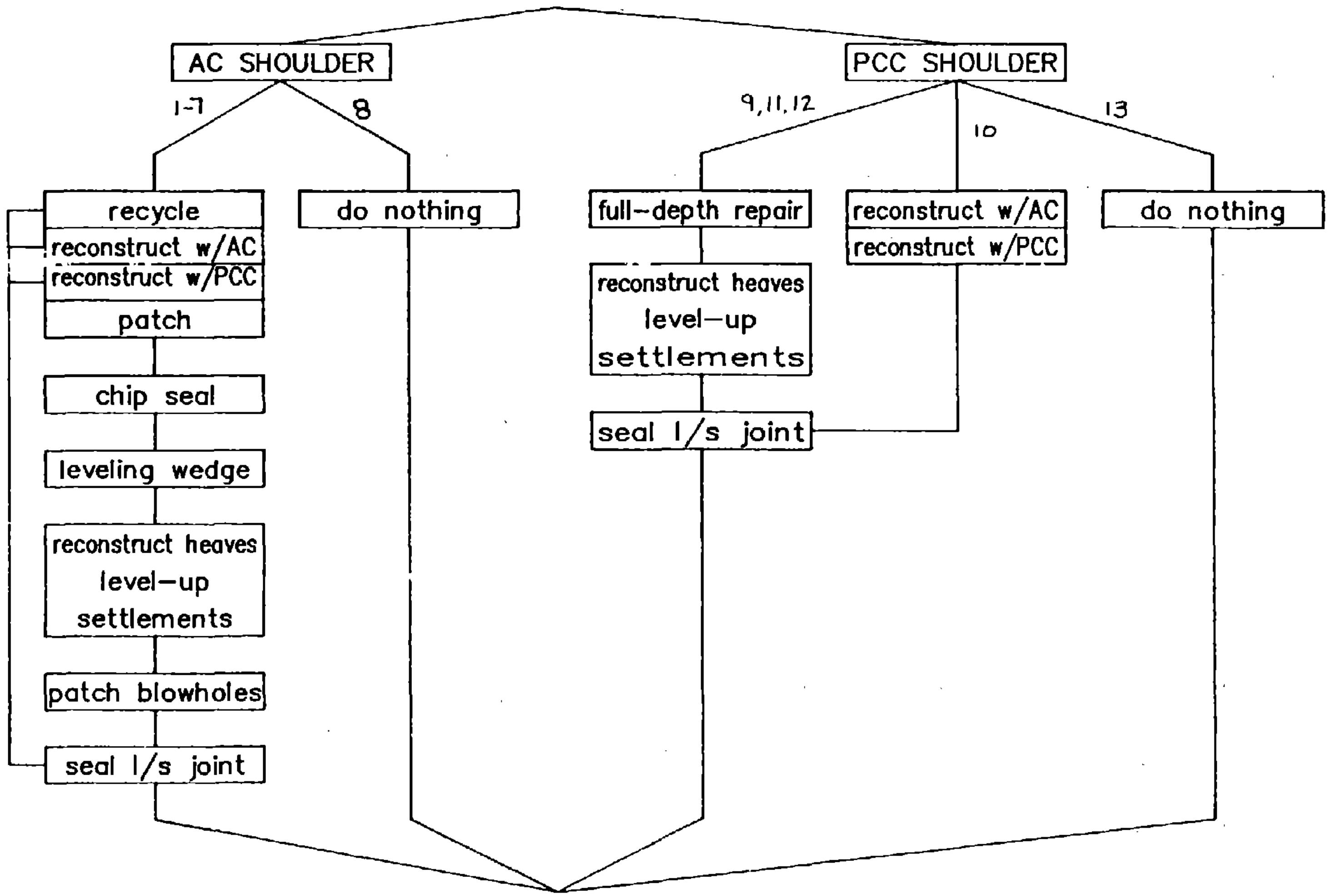
RESTORATION OF JPCP LANE




JTC
1
partial depth repair of longit. CL joint
2–5
seal longit. cracks
stifen longit. cracks
9
partial–depth repair
11–14
seal cracks at joints
seal cracks at joints, load trans rest. cracks
LOS
1–4
subseal joints and cracks
JTS
2,3
reseal transverse joints
do nothing
4–6
reseal transverse joints
FDN
2,4, 6,7
reconstruct heaves, AC level–up settlements
reconstruct heaves, slabjack settlements


RGH
**
2
grinding
AC nonstructural OL
3
AC level-up settlements
slab jack settlements
4
reconstruct heaves
5
full-depth repair of joints
**
6
grinding
AC nonstructural OL
SKD
**
1,3
grinding
AC nonstructural OL
**
2
grinding
grooving
AC nonstructural OL
OUTER LANE DRN
1-5
install/repair subdrains
install/repair subdrains, seal all joints and cracks
6-12
install/repair subdrains
OUTER SHD *
INNER LANE SLOPE DIRECTION
in
out
1-12
install/repair subdrains
1-12
install/repair subdrains
do nothing
INNER SHD *
* see decision tree for rehabilitating shoulder adjacent to restored lane
** do in both lanes

Shoulder Rehabilitation Adjacent to Restored Lane



APPENDIX B5

REHABILITATION PERFORMANCE PREDICTION MODELS FOR JPCP

Rehabilitation	Distress Type
Reconstruction	Faulting Cracking Joint Deterioration Pumping PSR
Bonded PCC OL	Faulting Joint Deterioration Cracking
Unbonded PCC OL	Faulting Joint Deterioration Cracking

AC Structural OL,
AC Nonstructural OL
	Reflective Cracking
	    Total
	    Medium-High Severity
	Rutting

Crack and Seat and AC Structural OL	Reflective Cracking
	    Total
	    Medium-High Severity
	Rutting

Restoration	Joint Faulting
	    With Grinding
	    Without Grinding
	Cracking
	Joint Deterioration
	FDR Faulting
	Pumping
	PSR

Faulting

$$FAULT = ESAL^{0.144} * [\ -0.2980 + 0.2671/THICK^{0.3184} - 0.0285\ BASETYPE + 0.00406\ (FI + 1)^{0.3598} - 0.0462\ PCCSH + 0.2384\ (PUMP + 1)^{0.0109} - 0.0340\ DOWEL^{2.0587}\ ] / 100$$

where:

FAULT = mean transverse joint faulting after reconstruction, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

THICK = thickness of reconstructed PCC slab, in

BASETYPE = type of base under reconstructed PCC slab
= 0, if granular base
= 1, if stabilized base (asphalt, cement, etc.)

FI = mean Freezing Index, Fahrenheit degree-days

PCCSH = new or existing tied PCC shoulders
= 0, if not present
= 1, if present

PUMP = pumping severity after reconstruction (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

DOWEL = diameter of dowels in reconstructed pavement, in (0 if no dowel bars used)

R^2 = 0.79
n = 259
SEE = 0.02 in [0.05 cm]

Source: NCHRP 1-19 (6)

Note: Dowel spacing in reconstructed pavement assumed to be 12 in [30.5 cm].

Cracking

$$CRACKS = \{ ESAL^{2.755} [3092.4 (1 - SOILCRS) RATIO^{10.0}] + ESAL^{0.5} (1.233 TRANGE^{2.0} RATIO^{2.868}) + ESAL^{2.416} (0.2296 FI^{1.53} RATIO^{7.31}) \} + CRKCALIB$$

where:

CRACKS = total length of cracking of all severities after reconstruction, ft/mile

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

RATIO = Westergaard's edge stress/PCC modulus of rupture (see below to calculate Westergaard's edge stress)

TRANGE = Annual temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.69
n = 303
SEE = 176 ft/mile [33.3 m/km]

Source: NCHRP 1-19 (6)

Calculation of Westergaard's Edge Stress:

$$L = [(4200000 * THICK^{3.0}) / 12 * (1 - 0.2^{2.0}) * KEFF]^{0.25}$$

$$B = [1.6 (6.4)^2 + THICK^2]^{0.5} - 0.675 THICK$$

$$Stress = (0.572 * 9000 / THICK^{2.0}) * [4 \log_{10} (L/B) + 0.359]$$

where:

THICK = thickness of PCC slab, in

KEFF = effective k value beneath PCC slab, psi/in

4,200,000 = assumed elastic modulus of PCC slab, psi

0.20 = assumed Poisson's ratio of PCC slab

6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/in = 2.71 kPa/cm

Joint Deterioration

$$DETJT = [\ AGE^{2.841}\ (0.01247\ UNITUBE) + AGE^{3.038}\ (0.001346\ INCOMP)\ ] + DETJTCALIB$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after reconstruction, number/mile

AGE = time since reconstruction, years

UNITUBE = Unitube joint forming inserts
= 0, if not present
= 1, if present

INCOMP = incompressibles in transverse joints
= 0, if no incompressibles observed
= 1, if incompressibles observed

DETJTCALIB = calibration of model to existing joint deterioration

= actual joint deterioration (M-H deteriorated joints/mile) measured during survey - DETJT predicted for present year by above model

= actual joint deterioration - $[\ AGE^{1.695}\ (\ 0.9754\ DUR) + AGE^{2.841}\ (0.01247\ UNITUBE) + AGE^{3.038}\ (0.001346\ INCOMP)\ ]$

R^2 = 0.59
n = 252
SEE = 16 joints/mile [10 joints/km]

Source: NCHRP 1-19 (6)

Note: Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the reconstructed pavement will not contain D cracking or reactive aggregates.

Pumping

$$PUMP = ESAL^{0.443} [-1.479 + 0.255 (1 - SOILCRS) + 0.0605 SUMPREC^{0.5} + 52.65/THICK^{1.747} + 0.0002269 FI^{1.205}]$$

where:

PUMP = pumping severity after reconstruction (PUMP can be any value between 0 and 3)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

ESAL = accumulated 18-kip equivalent single-axle loads after reconstruction, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

THICK = thickness of reconstructed PCC slab, in

FI = mean Freezing Index, Fahrenheit degree-days

$R^2 = 0.68$
n = 289
SEE = 0.42

Source: NCHRP 1-19 (6)

PSR

$$PSR = 4.5 - 1.486\ ESAL^{0.1467} + 0.4963\ ESAL^{0.265}\ RATIO^{-0.5} - 0.01082\ ESAL^{0.644}\ AGE^{0.525}\ (SUMPREC^{0.91}/AVGMT^{1.07})$$

where:

PSR = Present Serviceability Rating after reconstruction

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after reconstruction, millions

RATIO = Westergaard's edge stress/PCC slab modulus of rupture

AGE = time since reconstruction, years

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

AVMT = average monthly temperature, ^{o} C [(^{o}F - 32) / 1.8]

$R^2 = 0.69$
n = 316
SEE = 0.25

Source: NCHRP 1-19 (6)

Calculation of Westergaard's Edge Stress:

$$L = [\ (4200000 * THICK^{3.0})\ /\ 12 * (1 - 0.2^{2.0}) * KEFF\ ]^{0.25}$$

$$B = [\ 1.6\ (6.4)^2 + THICK^2\ ]^{0.5} - 0.675\ THICK$$

$$Stress = (0.572 * 9000\ /\ THICK^{2.0}) * [4\ \log_{10}\ (L/B) + 0.359]$$

where:

THICK = thickness of reconstructed PCC slab, in

KEFF = effective k value beneath reconstructed PCC slab, psi/in

4,200,000 = assumed elastic modulus of reconstructed PCC slab, psi

0.20 = assumed Poisson's ratio of reconstructed PCC slab

6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/in = 2.71 kPa/cm

Faulting

$$FAULT = 0.0015897\ ESAL^{0.233}\ [\ -10.942 - 30.657\ BASETYPE + 0.0005652\ (FI + 1)^{2.299} + 33.322\ (DOWEL + 1)^{-0.8477}\ ]\ /\ 100$$

where:

FAULT = mean transverse joint faulting after overlay, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

BASETYPE = type of base under original PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

FI = mean Freezing Index, Fahrenheit degree-days

DOWEL = diameter of dowels in original PCC slab, in
(0 if no dowel bars used)

R^2 = 0.54
n = 27
SEE = 0.02 in [0.05 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Note: Dowel spacing in original pavement assumed to 12 in [30.5 cm].

Joint Deterioration

$$DETJT = AGE^{2.1521}\ ESAL^{0.1419}\ [\ 0.05202 + 0.0000254\ FI + 0.01109\ TJSD - (0.003384 * K1 * JTSPACE) - (0.0006446 * K2 * JTSPACE)\ ]$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after overlay, number/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

FI = mean Freezing Index, Fahrenheit degree-days

TJSD = transverse joint sealant damage
= 0, if transverse joint sealant will be maintained well over the design period
= 1, if transverse joint sealant will not be maintained well over the design period

JTSPACE = transverse joint spacing of overlay, feet (assumed to have same joint spacing as original pavement)

K1 = 1, if JTSPACE = 27 ft [8.2 m]
0, if JTSPACE is not = 27 ft [8.2 m]

K2 = 1, if JTSPACE = 39 to 100 ft [11.9 to 30.5 m]
0, if JTSPACE is less than 39 ft [11.9 to 30.5 m]

R^2 = 0.61
n = 319
SEE = 15 joints/mile [9 joints/km]

Source: NCHRP 1-19 (6)

Notes: Do not use model outside of specified ranges for JTSPACE (27 ft [8.2 m] or 39 to 100 ft [11.9 to 30.5 m]).

Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the overlay will not contain D cracking or reactive aggregates.

Cracking

$$CRACKS = 11.328\ ESAL^{0.07546}\ \{21.426\ [\ AGE\ (FI + 1)\ /\ 1000\ ]^{0.66876}\}$$

where:

CRACKS = total length of medium- and high-severity deteriorated cracks after overlay, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

AGE = time since overlay, years

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.75
n = 13
SEE = 326 ft/mile [61.7 m/km]

Source: "Overlay Rehabilitation Techniques," Volume 2

Faulting

$$FAULT = 0.28615\ ESAL^{0.39654}\ [\ 0.0987\ (DOWEL + 1)^{-0.51083}\ ]$$

where:

FAULT = mean transverse joint faulting after overlay, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

DOWEL = diameter of dowels in overlay, in (0 if no dowel bars used)

R^2 = 0.51
n = 23
SEE = 0.02 in [0.05 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Note: Dowel spacing in overlay assumed to 12 in [30.5 cm].

Joint Deterioration

$$\text{DETJT} = [\ \text{AGE}^{2.841}\ (0.01247\ \text{UNITUBE}) + \text{AGE}^{3.038}\ (0.001346\ \text{INCOMP})\ ]$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after overlay, number/mile

AGE = time since overlay, years

UNITUBE = Unitube joint forming inserts
= 0, if not present
= 1, if present

INCOMP = incompressibles in existing transverse joints
= 0, if no incompressibles observed
= 1, if incompressibles observed

R^2 = 0.59
n = 252
SEE = 16 joints/mile [10 joints/km]

Source: NCHRP 1-19 (6)

Note: Original model contains additional terms for D cracking and reactive aggregate distress. These terms have been omitted since it is assumed the overlay will not contain D cracking or reactive aggregates.

Cracking

$$\text{CRACKS} = \text{ESAL}^{2.755} [\ 3092.4\ (1 - \text{SOILCRS})\ \text{RATIO}^{\ 10.0}\ ]$$
$$+ \text{ESAL}^{0.5}\ (1.233\ \text{TRANGE}^{2.0}\ \text{RATIO}^{\ 2.868})$$
$$+ \text{ESAL}^{2.416}\ (0.2296\ \text{FI}^{1.53}\ \text{RATIO}^{7.31})$$

where:

CRACKS = total length of cracking of all severities after overlay, ft/mile

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

RATIO = Westergaard's edge stress/PCC modulus of rupture (see below to calculate Westergaard's edge stress)

TRANGE = Annual temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.69
n = 303
SEE = 176 ft/mile [33.3 m/km]

Source: NCHRP 1-19 (6)

Calculation of Westergaard's Edge Stress:

$$L = [\ (4200000 * \text{THICK}^{3.0})\ /\ 12 * (1 - 0.2^{2.0}) * \text{KEFF}\ ]^{0.25}$$

$$B = [\ 1.6\ (6.4)^2 + \text{THICK}^2\ ]^{0.5} - 0.675\ \text{THICK}$$

$$\text{Stress} = (0.572 * 9000\ /\ \text{THICK}^{2.0}) * [4\ \log_{10}\ (L/B) + 0.359]$$

where:

THICK = thickness of PCC overlay slab, in

KEFF = effective k value on top of existing PCC slab, psi/in (500 psi/in recommended)

4,200,000 = assumed elastic modulus of PCC overlay slab, psi

0.20 = assumed Poisson's ratio of PCC overlay slab

6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/cm = 2.71 kPa/cm

AC STRUCTURAL AND NONSTRUCTURAL OVERLAY PERFORMANCE PREDICTION MODELS

Reflective Cracking (All Severities)

$$CRACKS = (10.745 * AGE^{0.3} * ESAL^{0.0187} * THICK^{-0.064} * [(PATCHES / 8.8) + 1]^{0.293} - 1) * 8.8$$

where:

CRACKS = total length of low-, medium-, and high-severity reflective transverse cracks after overlay, ft/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

THICK = thickness of overlay, in

PATCHES = full-depth repairs existing or placed on original pavement prior to overlay, number/mile, computed as follows:
M-H deteriorated transverse cracks/mile
+ M-H deteriorated joints/mile
+ corner breaks/mile
+ existing full-depth repairs/mile

R^2 = 0.27
n = 50
SEE = 0.40

Source: Development of Illinois Pavement Feedback System, on-going study being conducted for the Illinois Department of Transportation. Data from Illinois Interstate highways.

Reflective Cracking (Medium and High Severity)

$$MHCRACKS = [\ 2.8594 * (AGE * ESAL)^{0.19258} * OLTHICK^{-0.21163} * (PATCHES / 8.8)^{0.61169}\ ] * 8.8$$

where:

MHCRACKS = total length of medium- and high-severity reflective transverse cracks after overlay, ft/mile

AGE = time since overlay, years

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay, millions

THICK = thickness of overlay, in

PATCHES = full-depth repairs existing or placed on original pavement prior to overlay, number/mile, computed as follows:
M-H deteriorated transverse cracks/mile
+ M-H deteriorated joints/mile
+ corner breaks/mile
+ existing full-depth repairs/mile

R^2 = 0.83
n = 50
SEE = 0.30

Source: Development of Illinois Pavement Feedback System, on-going study being conducted for the Illinois Department of Transportation. Data from Illinois Interstate highways.

Rutting

$$RUT = 0.084807 + 0.019208\ ESAL + 0.012512\ AGE + 0.001199\ PTRUCKS - 0.004177\ PRECIP + 0.002798\ (FI / THICK) + 0.006447\ ZONE$$

where:

RUT = average wheelpath rutting, in

ESAL = accumulated 18-kip equivalent single-axle loads after overlay, millions

AGE = time since overlay, years

PTRUCKS = percent trucks in average daily traffic

PRECIP = annnual precipitation, in

FI = mean Freezing Index, Fahrenheit degree-days

THICK = overlay thickness, in

ZONE = climatic zone

$$= -5.9531 + 0.14263\ ANNTEMP - 0.12123\ PRECIP + 0.1955\ TRANGE$$

where:

ANNTEMP = average annual temperature, degrees Fahrenheit

TRANGE = average monthly temperature range, degrees Fahrenheit

$R^2 = 0.71$
n = 101
SEE = 0.06 in [0.15 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Notes: ZONE must be in the range of 0.5 to 9.5 (1 to 9 preferable) to produce realistic values for rutting. Values outside this range represent combinations of climatic inputs which are not within the realm of possible occurrence.

This rutting model represents a linear approximation of a nonlinear phenomenon. For some combinations of the variables, the model may give negative values, which should be interpreted as zeroes.

All-Severity Transverse Cracking

$$TCRACKS = [\ -271.76 + 0.2719\ FI + 3.91\ THICK + 2.833\ SRW - 21.55\ WDT - 2.327\ JTSPACE + 13.66\ LEN + 4.828\ AREA + 2.706\ ESAL*AGE + 0.941\ ANNTEMP + 7.457\ TRANGE\ ] * 5.28$$

where:

TCRACKS = total length of low-medium-high severity transverse cracks after overlay, ft/mile (includes all transverse cracks in AC overlay from any cause)

THICK = thickness of PCC slab, in

JTSPACE = transverse joint spacing of original pavement, ft

SRW = seating roller weight, tons

WDT = mean width of cracked pieces (across traffic lane), ft

LEN = mean length of cracked pieces (along traffic lane), ft

AREA = area of cracked section (length * width), square ft

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay in traffic lane, millions

AGE = age of AC overlay, years

ANNTEMP = mean annual temperature, degrees Fahrenheit

TRANGE = mean monthly temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.57
n = 100
SEE = 903 ft/mile ft [171 m/km]

Source: Revised model based upon database developed in "Overlay Rehabilitation Techniques," Volume 2.

Medium- and High-Severity Transverse Cracking

$$MHCRACKS = [\ 298.82 + 0.0378\ FI - 21.29\ THICK - 0.572\ SRW - 38.54\ WDT + 0.59\ JTSPACE - 18.48\ LEN + 7.89\ AREA + 0.815\ ESAL*AGE + 1.65\ ANNTEMP - 5.28\ TRANGE\ ] * 5.28$$

where:

MHCRACKS = total length of medium- and high-severity transverse cracks after overlay, ft/mile

THICK = thickness of PCC slab, in

JTSPACE = transverse joint spacing of original pavement, ft

SRW = seating roller weight, tons

WDT = mean width of cracked pieces (across traffic lane), ft

LEN = mean length of cracked pieces (along traffic lane), ft

AREA = area of cracked section (length * width), square ft

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after overlay in traffic lane, millions

AGE = age of AC overlay, years

ANNTEMP = mean annual temperature, degrees Fahrenheit

TRANGE = mean monthly temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

R^2 = 0.79
n = 100
SEE = 317 ft/mile [60 m/km]

Source: Revised model based upon database developed in "Overlay Rehabilitation Techniques," Volume 2.

This model represents a linear approximation of the nonlinear progression of medium- to high-severity reflective cracks from low-severity reflective cracks.
For some combinations of the variables, the model may give negative values, which should be interpreted as zeroes (i.e., cracking has not yet progressed to the medium severity level).

Rutting

$$RUT = 0.084807 + 0.019208\ ESAL + 0.012512\ AGE + 0.001199\ PTRUCKS - 0.004177\ PRECIP + 0.002798\ (FI / THICK) + 0.006447\ ZONE$$

where:

RUT = average wheelpath rutting, in

ESAL = accumulated 18-kip equivalent single-axle loads after overlay, millions

AGE = time since overlay, years

PTRUCKS = percent trucks in average daily traffic

PRECIP = annnual precipitation, in

FI = mean Freezing Index, Fahrenheit degree-days

THICK = overlay thickness, in

ZONE = climatic zone (same as for reflective cracking)

R^2 = 0.71
n = 101
SEE = 0.06 in [0.15 cm]

Source: "Overlay Rehabilitation Techniques," Volume 2

Notes: ZONE must be in the range of 0.5 to 9.5 (1 to 9 preferable) to produce realistic values for rutting. Values outside this range represent combinations of climatic inputs which are not within the realm of possible occurrence.

This rutting model represents a linear approximation of a nonlinear phenomenon. For some combinations of the variables, the model may give negative values, which should be interpreted as zeroes.

Joint Faulting (With Grinding)

$$
\begin{aligned}
\text{FAULT} = & -5.62\ (\text{ESAL} + \text{AGE})^{0.54} \\
& * [\ 5.85 * (\text{DRAIN} + \text{SOILCRS} + 1)^{0.0529} \\
& - (3.8 * 10^{-9}) * (\text{FI} / 100)^{6.29} \\
& + 0.484\ (\text{THICK} + \text{PCCSH})^{0.335} + 0.1554\ \text{BASETYPE} \\
& - 7.163\ \text{JTSPACE}^{0.0137} + 0.1136\ \text{LDTR}\ ] / 100
\end{aligned}
$$

where:

FAULT = mean transverse joint faulting after restoration, in

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads after restoration, millions

AGE = time since restoration, years

DRAIN = new or existing longitudinal subdrains
= 0, if no subdrains present or present but not functional
= 1, if subdrains present and functional

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

FI = mean Freezing Index, Fahrenheit degree-days

THICK = thickness of PCC slab, in

PCCSH = new or existing tied PCC shoulder
= 0, if not present
= 1, if present

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (cement, asphalt, etc.)

JTSPACE = transverse joint spacing of pavement, ft

LDTR = load transfer restoration done by retrofitting dowel bars
= 0, if not done
= 1, if done

R^2 = 0.38
n = 114
SEE = 0.03 in [0.08 cm]

Source: "Repair Rehabilitation Techniques," Volume 1

Note: Joint faulting = 0.00 in immediately after grinding.

Joint Faulting (Without Grinding)

$$\text{FAULT} = \{ \text{ESAL}^{0.144} * [-0.2980 + 0.2671/\text{THICK}^{0.3184}$$
$$- 0.0285\ \text{BASETYPE} + 0.00406\ (\text{FI} + 1)^{0.3598}$$
$$- 0.0462\ \text{PCCSH} + 0.2384\ (\text{PUMP} + 1)^{0.0109}$$
$$- 0.0340\ \text{DOWEL}^{2.0587}] / 100 \} + \text{FLTCALIB}$$

where:

FAULT = mean transverse joint faulting after restoration, in

ESAL = accumulated 18-kip equivalent single-axle loads after restoration, millions

THICK = thickness of PCC slab, in

BASETYPE = type of base under PCC slab
= 0, if granular base
= 1, if stabilized base (asphalt, cement, etc.)

FI = mean Freezing Index, Fahrenheit degree-days

PCCSH = new existing tied PCC shoulders
= 0, if not present
= 1, if present

PUMP = pumping severity after restoration (from pumping model)
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

DOWEL = diameter of dowels in pavement, in
(0 if no dowel bars used)

FLTCALIB = calibration of model to existing faulting

= actual faulting (in) measured during survey - FAULT predicted for present year by above model

$$= \text{actual faulting} - \{ \text{ESAL}^{0.144} * [-0.2980$$
$$+ 0.2671/\text{THICK}^{0.3184} - 0.0285\ \text{BASETYPE}$$
$$+ 0.00406\ (\text{FI} + 1)^{0.3598} - 0.0462\ \text{PCCSH}$$
$$+ 0.2384\ (\text{PUMP} + 1)^{0.0109} - 0.0340\ \text{DOWEL}^{2.0587}] / 100 \}$$

R^2 = 0.79
n = 259
SEE = 0.02 in [0.05 cm]

Source: NCHRP 1-19 (6)

Cracking

$$CRACKS = \{ ESAL^{2.755} [3092.4 (1 - SOILCRS) RATIO^{10.0}] + ESAL^{0.5} (1.233 TRANGE^{2.0} RATIO^{2.868}) + ESAL^{2.416} (0.2296 FI^{1.53} RATIO^{7.31}) \} + CRKCALIB$$

where:

CRACKS = total length of cracking of all severities after restoraation, ft/mile

ESAL = accumulated 18-kip equivalent single-axle loads after restoration, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

RATIO = Westergaard's edge stress/PCC modulus of rupture (see following page to calculate Westergaard's edge stress)

TRANGE = Annual temperature range, degrees Fahrenheit

FI = mean Freezing Index, Fahrenheit degree-days

CRKCALIB = calibration of model to existing cracking

= actual cracking (M-H cracks, ft/mile) measured during survey - CRACKS predicted for present year by above model

$$= \text{actual cracking} - \{ ESAL^{2.755} * [3092.4 (1 - SOILCRS) RATIO^{10.0}] + ESAL^{0.5} (1.233 TRANGE^{2.0} RATIO^{2.868}) + ESAL^{2.416} (0.2296 FI^{1.53} RATIO^{7.31}) \}$$

R^2 = 0.69
n = 303
SEE = 176 ft/mile [33.3 m/km]

Source: NCHRP 1-19 (6)

Calculation of Westergaard's Edge Stress:

$$L = [(4200000 * THICK^{3.0}) / 12 * (1 - 0.2^{2.0}) * KEFF]^{0.25}$$

$$B = [1.6 (6.4)^2 + THICK^2]^{0.5} - 0.675\ THICK$$

$$Stress = (0.572 * 9000 / THICK^{2.0}) * [4 \log_{10} (L/B) + 0.359]$$

where:

THICK = thickness of PCC slab, in

KEFF = effective k value beneath PCC slab, psi/in

4,200,000 = assumed elastic modulus of PCC slab, psi

0.20 = assumed Poisson's ratio of PCC slab

6.4 = assumed wheel load radius, in

Note: 1 in = 2.54 cm
1 psi = 6.9 kPa
1 psi/cm = 2.71 kPa/cm

Joint Deterioration

$$DETJT = [\ AGE^{1.695}\ (\ 0.9754\ DUR) + AGE^{2.841}\ (0.01247\ UNITUBE) + AGE^{3.038}\ (0.001346\ INCOMP)\ ] + DETJTCALIB$$

where:

DETJT = medium- to high-severity deteriorated transverse joints after restoration, number/mile

AGE = time since restoration, years

DUR = D cracking or reactive aggregate distress severity before restoration
= 0, if none
= 1, if low, medium, or high severity

UNITUBE = Unitube joint forming inserts
= 0, if not present
= 1, if present

INCOMP = incompressibles in transverse joints before restoration
= 0, if no incompressibles observed
= 1, if incompressibles observed

DETJTCALIB = calibration of model to existing joint deterioration

= actual joint deterioration (M-H deteriorated joints/mile) measured during survey - DETJT predicted for present year by above model

$$= \text{actual joint deterioration} - [\ AGE^{1.695}\ (\ 0.9754\ DUR) + AGE^{2.841}\ (0.01247\ UNITUBE) + AGE^{3.038}\ (0.001346\ INCOMP)\ ]$$

R^2 = 0.59
n = 252
SEE = 16 joints/mile [10 joints/km]

Source: NCHRP 1-19 (6)

Full-Depth Repair Faulting

$$FDRFAULT = (NEWFDR * NEWFDRFAULT) + (EXISTFDR + EXFDRFAULT) / (NEWFDR + EXISTFDR)$$

where:

FDRFAULT = weighted average faulting at new and existing full-depth repair joints since restoration, in

NEWFDR = full-depth repairs placed during restoration, number/mile

NEWFDRFAULT = average faulting at new full-depth repair joints since restoration, in

$$= ESAL^{0.74} * (0.0364 - 0.292\ BASETYPE) + 0.275 (AGE * FI)^{0.019} - 0.283$$

where:

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since restoration, millions

BASETYPE = type of base under PCC slab
= 0, if granular
= 1, if stabilized (asphalt, cement, etc.)

AGE = time since restoration, years

FI = mean Freezing Index, Fahrenheit degree-days

EXISTFDR = number of existing full-depth repairs before restoration, number/mile

EXFDRFAULT = average faulting at existing full-depth repair joints since restoration, in

$$= FDRESAL^{0.74} * (0.0364 - 0.292\ BASETYPE) + 0.275 (FDRAGE * FI)^{0.019} - 0.283$$

where:

FDRESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since time of placement of existing full-depth repairs, millions

BASETYPE = type of base under PCC slab
= 0, if granular
= 1, if stabilized (asphalt, cement, etc.)

FDRAGE = time since placement of existing full-depth repairs, years

FI = mean Freezing Index, Fahrenheit degree-days

$R^2 = 0.41$
n = 113
SEE = 0.048 in [0.122 cm]

Source: "Repair Rehabilitation Techniques," Volume 1

Notes: Initial faulting of new full-depth repairs = 0 in, assuming full-depth repairs are constructed and finished to match existing pavement profile.

If grinding is done or if existing full-depth repairs are replaced during restoration, then initial faulting of existing full-depth repair joints = 0 in.

If grinding is not done and existing full-depth repairs are not replaced during restoration, then initial faulting of existing full-depth repair joints = faulting measured during survey.

<u>Backcalculation of Cumulative ESALs on Existing Full-Depth Repairs:</u>

if FDRAGE is provided by user:

$$\text{FDRESAL} = 10 ** (\{\log_{10} [\text{actual FDR faulting} - 0.275 (\text{FDRAGE} * \text{FI})^{0.019} + 0.283] - \log_{10} [0.0364 - 0.292 \text{ BASETYPE}] \} / 0.74)$$

Pumping

$$PUMP = ESAL^{0.443} [-1.479 + 0.255 (1 - SOILCRS) + 0.0605 SUMPREC^{0.5} + 52.65/THICK^{1.747} + 0.0002269 FI^{1.205}] * DRNF$$

where:

PUMP = pumping severity after restoration
= 0, if no pumping
= 1, if low severity
= 2, if medium severity
= 3, if high severity

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads since restoration, millions

SOILCRS = subgrade soil classification
= 0, if fine grained (A4 to A7)
= 1, if coarse grained (A1 to A3)

SUMPREC = average annual precipitation, cm (= 2.54 * inches)

THICK = thickness of PCC slab, in

FI = mean Freezing Index, Fahrenheit degree-days

DRNF = drainage factor applied to pumping increase after restoration
= 0.75, if new or existing longitudinal subdrains present
= 1.00, if no subdrains present

R^2 = 0.68
n = 289
SEE = 0.42

Source: NCHRP 1-19 (6)

PSR

$$PSR = 4.5 - 0.0177\ TFAULT - 0.0001263\ CRACKS - 0.005414\ DETJT$$

where:

PSR = Present Serviceability Rating after restoration (0 to 5 scale)

TFAULT = total faulting at joints, cracks, and full-depth repairs, in/mile (to calculate see below)

CRACKS = transverse cracks (all severities) after restoration, ft/mile (from cracking model)

DETJT = medium- to high-severity deteriorated transverse joints after restoration, number/mile (from joint deterioration model)

$R^2 = 0.73$
$n = 389$
SEE = 0.33

Source: NCHRP 1-19 database for JRCP.

Calculation of Total Faulting for PSR Model:

TFAULT = [(5280/JTSPACE) - EXISTDETJT] * JTFAULT

+ (NEWFDR * NEWFDRFLT)

+ (EXISTFDR * EXISTFDRFLT)

where:

JTSPACE = transverse joint spacing of pavement, ft

EXISTDETJT = medium- to high-severity deteriorated joints before restoration, number/mile

JTFAULT = average transverse joint faulting after restoration, in (from applicable joint faulting model, with or without grinding)

NEWFDR = full-depth repairs placed during restoration, number/mile

= EXISTDETJT + CRACKS + CORBRKS

where:

EXISTDETJT = medium- to high-severity deteriorated joints before restoration, number/mile

CRACKS = transverse cracks (all severities) before restoration, number/mile

CORBRKS = corner breaks before restoration, number/mile

NEWFDRFLT = average faulting at full-depth repair joints after restoration, in (from full-depth repair faulting model)

EXISTFDR = existing full-depth repairs before restoration, number/mile

EXISTFDRFLT = average faulting at existing full-depth repair joints after restoration, in (from full-depth repair faulting model).

Notes: For purposes of computing PSR, only one joint per full-depth repair is counted and multiplied times mean full-depth repair faulting, since full-depth repair joints are sufficiently close to represent one noticeable fault to the user.

Initial faulting of new full-depth repairs = 0 in, assuming full-depth repairs are constructed and finished to match existing pavement profile.

If grinding is done or if existing full-depth repairs are replaced during restoration, then initial faulting of existing full-depth repair joints = 0 in.

If grinding is not done and existing full-depth repairs are not replaced during restoration, then initial faulting of existing full-depth repair joints = faulting measured during survey.

APPENDIX B6

EXPERT SYSTEM FOR PAVEMENT EVALUATION AND REHABILITATION (EXPEAR)

JPCP Computer Program Operating Instructions

INTRODUCTION

EXPEAR (Expert System for Pavement Evaluation and Rehabilitation) has been developed to assist the design engineer in the evaluation and rehabilitation of jointed plain concrete pavement (JPCP). The program is documented in "Rehabilitation Of Concrete Pavements, Volume III - Concrete Pavement Evaluation and Rehabilitation System." Report No. FHWA/RD-88/073, Federal Highway Administration, 1987. Similar programs are also available for jointed reinforced and continuously reinforced concrete pavements.

LIMITATIONS

The EXPEAR program is based primarily on engineering judgement and predictive deterioration models. EXPEAR Version 1.0 has been tested on a few projects for which it performed in a reasonable manner. However, the program will require much more extensive field testing and improvements before it can be used routinely. It will likely require "customizing" to the specific conditions, needs and policies of individual highway agencies (such as different rehabilitation alternatives and the substitution of predictive models developed by the agency).

The EXPEAR program is designed for the specific pavement geometry of two traffic lanes in the same direction with paved shoulders on each side (a typical two-lane one-directional highway). It can also be used for two-directional traffic by treating the opposing lanes as "outer" and "inner" lanes and entering appropriate traffic data for each. Pavements containing three or more lanes in one direction can be considered first through an analysis of the outer two lanes only, and then rerunning EXPEAR for the other lane(s) to determine feasible rehabilitation alternatives. The results would then have to be combined manually. EXPEAR does not consider non-pavement related items such as guard rail, signs, and clearances.

EXPEAR has been programmed in Pascal using Borland International's Turbo Pascal. It will operate on any IBM-compatible personal computer with 256 K memory.

USING EXPEAR FOR EVALUATION

Evaluation is based on inventory and monitoring data collected by engineers and technicians. Inventory data is collected from office records and includes design, construction, traffic, climate and other data. Monitoring data is collected during a field survey of the project. Up to 10 sample units of any length may be surveyed; at least 500 ft [152 m] in each mile [1.6 km] is recommended.

After returning to the office, the inventory and monitoring data are entered into a data file using a full-screen data editor provided with the system. The overall condition of the pavement over the length of the project is extrapolated by EXPEAR from the sample unit monitoring data.

EXPEAR uses the inventory data and extrapolated monitoring data to evaluate the current condition of the pavement in twelve major problem areas. In addition, it uses the NCHRP Project 1-19 (6) predictive models calibrated to existing project conditions to project future transverse cracking, joint faulting, pumping, joint deterioration, and PSR.

Physical testing is recommended by EXPEAR to verify the evaluation conclusions reached using the pavement visual survey and inventory data.

EXPEAR will operate on any IBM-compatible personal computer with 256 K memory. A math coprocessor, while not essential to the program's operation, will increase its execution speed. The program may be run on the floppy disk provided; however, it is recommended that the program be copied to and run on a hard disk when available. This will increase the execution speed and also provide adequate storage for the output files generated by EXPEAR. If EXPEAR is run using a floppy disk, different project output files should be transfered to other disks to provide for adequate storage. If this is not done, the floppy disk being used will fill up with various EXPEAR output files and the program will abort during a run.

To start the system, place the EXPEAR disk in the disk drive and type EXPEAR. A title screen and three screens of introductory information will appear. Press any key to continue.

The following choices are presented on the main menu screen:

1. **ENTER OR EDIT DATA**
2. **CONDUCT PROJECT EVALUATION**
3. **DEVELOP REHABILITATION STRATEGY**
4. **QUIT, RETURN TO DOS**

DATA ENTERING ACTIVITIES

If you select 1, a figure will appear on the screen to illustrate the pavement geometry for the program you are using (in this case, two lanes of JRCP with paved shoulders). Then the data entry menu will appear:

1. **CREATE NEW DATA FILE**
2. **EDIT OLD DATA FILE**
3. **CONDUCT PROJECT EVALUATION**
4. **RETURN TO MAIN MENU**

1. **CREATE NEW DATA FILE:** The data editing program will default to a set of standard data that is only intended as an example. The user may enter data from the project under consideration. It is recommended that project files have the same name, such as "I10191," where this refers to I-10, beginning at milepost 191 for ease in identification. Extensions will be

added by EXPEAR for output files. The file name (e.g., I10191) will continually be requested during the evaluation and rehabilitation process.

2. **EDIT OLD DATA FILE:** The system prompts for the name of an existing data file and enters that file into the data editing program. Data files have .DAT extensions. The program will instruct the user to omit the .DAT when entering the file name in response to this prompt.

3. **CONDUCT PROJECT EVALUATION:** The user may go directly to evaluation of the current data file without returning to the main menu. EXPEAR will prompt for the name of the data file to be run.

4. **RETURN TO MAIN MENU:** Return to main menu.

The data editing program presents the data items in much the same way that they appear on the actual survey sheets. All of the commands needed for editing the data are shown on the bottom of the screen. The system provides screens for as many sample units as requested (up to 10).

When the editing of the data has been completed, type Shift-F10 to exit the data editing program. The engineer will then be presented with the following menu:

1. SAVE EDITED FILE
2. GO TO DOS (SAVE DATA FIRST)
3. EDIT ANOTHER DATA SET
4. RUN THIS DATA (SAVE DATA FIRST)

1. **SAVE EDITED FILE:** The user is prompted for a file name under which to save the input data. If the name of a file that already exists is entered, the user will be asked if is desired to write over the existing file. Use the same name as before (e.g., I10191) and EXPEAR will provide .DAT extension.

2. **GO TO DOS:** Exits the system and returns to DOS. The data entered is not saved by this command.

3. **EDIT ANOTHER DATA SET:** Takes the user to the data entry menu. The data entered is not saved by this command.

4. **RUN A SET OF DATA** EXPEAR begins the evaluation of the current data file.

IMPORTANT: ONLY OPTION 1 SAVES THE EDITED DATA. THE DATA SET MOST RECENTLY EDITED IS THE CURRENT DATA SET.

PROJECT EVALUATION ACTIVITIES

Through either the main menu or the data entry menus, the user can conduct an evaluation of a project. The system will prompt for the name of the file that is desired to run. Before EXPEAR begins the evaluation it will present the following menu:

1. **SPECIFY CRITICAL VALUES FOR DISTRESSES**
2. **READ IN CRITICAL VALUES FROM DISK FILE**
3. **CONDUCT PROJECT EVALUATION**
4. **RETURN TO MAIN MENU**

The program will not begin evaluation before critical values for distress have been selected. Critical values represent decision levels in the pavement evaluation decision trees (e.g., a PSR of 3.0 could be selected as a level, below which the pavement is considered as too rough for continued usage, and rehabilitation must be performed). Option 1 will allow the user to select the default values provided, or select other values to save in a file for future use. The system will prompt for a name for the critical values file (e.g., use the same name I10191), and EXPEAR will give it a .CVL extension. You may retreive these values later using Option 2.

Option 3 will begin the project evaluation. After the program has run, the first evaluation display will consist of an evaluation conclusion for lane 1 (the outer lane) relating to one of the twelve major problem areas, along with one or more recommended rehabilitation techniques (for informational purposes only at this point). Press any key when ready to see the next display and continue on through all lanes and shoulders.

The complete evaluation consists of the following sets of displays:

1. Evaluation conclusions reflecting the <u>present</u> condition of each traffic lane and shoulder.

2. Projections of future pumping, faulting, cracking, joint deterioration and PSR for each of the traffic lanes (each lane in turn, 10 years at a time).

3. Evaluation conclusions which summarize the <u>present</u> and <u>future</u> condition of the pavement based on the above two outputs.

IMPORTANT: Do <u>not</u> attempt to escape from the system without going through all the evaluation displays. Doing so may permanently damage the display file. You can go through the displays very rapidly if you wish by holding down the space bar.

After viewing all of the displays, the system will ask if the user wants to print the summary file. Enter "y" to print out the project data and evaluation displays or "n" to return to the main menu. The print program is set to run on an IBM ProPrinter (or equivalent), but should work on similar IBM or EPSON printers as well. If the summary file will not print on your printer, exit to DOS and print the project's .REP file for the project survey inputs, and the .TXT file for the evaluation conclusions.

USING EXPEAR FOR SELECTING REHABILITATION STRATEGIES

EXPEAR considers the following rehabilitation strategies:

1. Restoration both lanes
2. Overlay both lanes
3. Reconstruct outer lane, restore inner lane
4. Reconstruct both lanes

One or more of these alternatives will be recommended, based upon the pavement evaluation. The engineer normally chooses that rehabilitation strategy and then proceeds to develop the details. This is done through a series of choices for repairing or preventing various types of deterioration that exist in the pavement.

EXPEAR takes the engineer through each traffic lane and shoulder to select rehabilitation techniques to repair and prevent further deterioration.

The program then requests some additional inputs, such as:

> Do you want the quantities for the repairs you selected?
> What will be the length of the full-depth repairs?
> What is the average length of settlements on the project?
> What is the thickness of the overlay?
> What is the transverse joint spacing for the reconstructed traffic lane?

EXPEAR will then output the list of rehabilitation techniques and estimated quantities for the overall project. This is done for each traffic lane and shoulder. The program will then ask if the user wants the rehabilitation techniques printed out.

The program then goes on to the next step:

1. **REVISE REHABILITATION STRATEGY**
2. **PREDICT REHABILITATION PERFORMANCE**
3. **RETURN TO DATA ENTRY/PROJECT EVALUATION**
4. **QUIT, RETURN TO DOS**

If the engineer does not like the selection of rehabilitation techniques for the given strategy, No. 1 can be selected and return to revise the rehabilitation strategy. Normally, the engineer will go on to No.2 to predict the performance of the selected rehabilitation strategy.

If full-depth repairs exist, EXPEAR will ask "how many years ago were the existing full-depth repairs placed?" This is requested to estimate the number of 18-kip ESAL that have passed over the repairs so that their future performance can be estimated.

The predicted deterioration for each traffic lane is then output for each key type of deterioration for which there are predictive models. These models were developed from performance data from inservice rehabilitated concrete pavements.

EXPEAR then asks if the user wants to print out the rehabilitation predictions. The program then interpretates the predictions, and informs the user the estimated year in which critical deterioration will develop. This information is used to estimate the practical service life of the rehabiltation strategy.

If the engineer wishes to develop another alternative rehabilitation strategy, he/she would then return to the rehabilitation menu and repeat the above sequence of steps.

EXPEAR FILES

EXPEAR.COM FORHREP.CHN PROCDATA.CHN PRINTOUT.CHN PREDLIFE.CHN DISPLAYS.REC	Binary files containing the EXPEAR code.
STANDRD. DAT	The default data set to modify to enter data for a new project
I10191.REP	The project survey file for an example project, I-74 in Illinois at milepost 183
I10191.DAT	A binary file containing the saved data for the example project
I10191.TXT	The evaluation text for the example project
I10191.STS	Rehabilitation techniques (and quantities, if requested) making up a strategy
I10191.RST	Binary file containing rehabilitation strategy techniques
I10191.RHB	Future performance predictions for a rehabilitation strategy
I10191.RSD	Binary file containing rehabilitation development information

If any difficulty is experienced in the operation of EXPEAR, try running it on another personal computer. EXPEAR may not be compatible with some computer configurations. If the program will not operate successfully, or any questions arise, please contact one of the following:

Kathleen T. Hall (217) 333-5966

Michael I. Darter (217) 333-6253

208 North Romine St.
University of Illinois
Urbana, Illinois 61801

Appendix B6

User's Guide for

EXPEAR

Expert System for Concrete Pavement

Evaluation and Rehabilitation

EXPEAR EXPERT SYSTEM FOR CONCRETE PAVEMENT EVALUATION AND REHABILITATION

CAPABILITIES AND APPLICATIONS

The EXpert system for Pavement Evaluation And Rehabilitation (EXPEAR) was originally developed by the University of Illinois for the Federal Highway Administration and is currently being further developed for the Illinois Department of Transportation. EXPEAR is an advisory system to assist the practicing engineer in evaluating a specific pavement section and selecting rehabilitation alternatives.

An EXPEAR program currently exists for each of three pavement types: JPCP, JRCP, and CRCP. Programs for AC-overlaid pavements and other AC pavements are under development. The current version of the system is EXPEAR 1.3, which includes the capabilities to delay rehabilitation for up to 5 years and to perform life-cycle cost analysis of rehabilitation alternatives.

INPUTS

Project-level evaluation using EXPEAR begins with the collection of some basic design, construction, traffic, and climate data for the project in question, and a visual condition survey. Back in the office, the design and condition data are entered into EXPEAR by the engineer using a full-screen editor. The program extrapolates the overall condition of the project from the distress data for one or more sample units.

ENGINEERING LOGIC

EXPEAR evaluates the project in several key problem areas related to specific aspects of performance for that pavement type. For example, the problem areas for JPCP and JRCP are: structural adequacy, roughness, drainage, joint deterioration, foundation movement, skid resistance, joint sealant condition, joint construction, concrete durability, load transfer, loss of support, and shoulders. The evaluation is performed using decision trees which compare the pavement's condition to predefined critical levels for key design and distress variables. EXPEAR produces a summary of the deficiencies found, and by interacting with the engineer, formulates a rehabilitation strategy which will correct all of the deficiencies. The major rehabilitation options are: reconstruction of both lanes, reconstruction of the outer lane and restoration of the inner lane, bonded or unbonded PCC overlay, AC overlay, crack and seat and AC overlay, and restoration. Appropriate repair techniques for the shoulders which are compatible with the mainline pavement rehabilitation strategy are also selected.

PERFORMANCE PREDICTION AND COST ANALYSIS

A large number of predictive models for concrete pavement performance with and without rehabilitation are incorporated into EXPEAR. Some of the models were developed from national databases of new construction and rehabilitation projects, while others were developed using data from Illinois pavements. The models allow the engineer to predict the performance of the rehabilitation strategy developed. This information is then used, along with rehabilitation unit costs (either default values built into the program or values provided by the engineer) to compute the cost of the strategy over the predicted life.

OUTPUTS

EXPEAR produces a summary of the project's data file, the evaluation results, recommendations for physical testing, predictions of the pavement's future condition without rehabilitation, and rehabilitation techniques, performance predictions, and cost calculations for as many rehabilitation strategies as the engineer wishes to investigate.

REFERENCES AND FURTHER INFORMATION

References on EXPEAR:

Hall, K. T., M. I. Darter, S. H. Carpenter, and J. M. Connor, "Concrete Pavement Evaluation and Rehabilitation System," Rehabilitation of Concrete Pavements, Volume 3, Federal Highway Administration Report No. FHWA/RD-88/073, April 1989.

Hall, K. T., J. M. Connor, M. I. Darter, and S. H. Carpenter, "Development of an Expert System for Concrete Pavement Evaluation and Rehabilitation, Proceedings, Second North American Conference on Managing Pavements, Volume 3, November 1987.

Questions or comments about EXPEAR:

Dr. Michael I. Darter
1212 Newmark CE Lab
205 North Mathews
Urbana, IL 61801

(217) 333-6253

Kathleen T. Hall
1206 Newmark CE Lab
205 North Mathews
Urbana, IL 61801

(217) 333-5966

1.0 INTRODUCTION

The objective of this research effort was to develop a practical and comprehensive system to assist practicing engineers in evaluating concrete highway pavements, identifying types of deterioration present and determining their causes, selecting rehabilitation techniques which will effectively correct existing deterioration and prevent its recurrence, combining individual rehabilitation techniques into feasible rehabilitation strategies, and predicting the performance of rehabilitation strategy alternatives.

EXPEAR is intended for use by state highway engineers in project-level rehabilitation planning and design for high-type (i.e., Interstate) conventional concrete pavements (JRCP, JPCP, and CRCP). EXPEAR does not perform thickness or joint design, the engineer must use existing design procedures to determine these details.

EXPEAR has been developed in the form of a knowledge-based expert system, which simulates a consultation between the engineer and an expert in concrete pavements. EXPEAR uses information about the pavement provided by the engineer to guide him or her through evaluation of a pavement's present condition and development of one or more feasible rehabilitation strategies. The procedure was developed through extensive interviewing of authorities on concrete pavement performance. In addition, predictive models are included to show future pavement performance with and without rehabilitation.

Evaluation of a pavement and development of feasible rehabilitation alternatives is performed according to the following steps:

1. Project data collection.
2. Extrapolation of overall project condition.
3. Evaluation of present condition.
4. Prediction of future condition without rehabilitation.
5. Recommendations for physical testing.
6. Selection of main rehabilitation approach.
7. Development of detailed rehabilitation strategy.
8. Prediction of rehabilitation strategy performance.
9. Cost analysis.
10. Selection of preferred rehabilitation strategy.

A computer program has been developed for each of the three pavement types addressed. The programs operate on any IBM-compatible personal computer. Use of the programs is highly recommended due to the complexity of the manual procedure.

2.0 PAVEMENT EVALUATION

Data Collection and Entry

The engineer collects key inventory and monitoring data for the project. Inventory data, which should be available from office records, includes design traffic, materials, soils and climate. Monitoring data includes distress, drainage characteristics, rideability, and other items collected during a field visit to the project. Monitoring data is collected by sample unit; a sufficient number of sample units distributed throughout the projects's length should be surveyed to obtain an accurate representation of the project's condition.

It is recommended that a team of two engineers perform the project survey together. They should drive over the entire length of the project and rate the present serviceability in each lane. They should also note the number and location of settlements and heaves. They should then return to the start of the project and perform the distress survey by sample unit. It is convenient to start sample units at mileposts.

The pavement distress identification manual provided in NCHRP Report No. 277 should be used for reference. It provides standard definitions for distresses by type, severity, and unit of measurement. It also provides photographs of distresses to assist the engineers in rating their severity. The engineers must also measure faulting at joints, cracks, and full-depth repair joints.

In the office, the data are entered into a personal computer using a full-screen editor. The format of the data entry screens is very similar to that of the field survey sheets. The editor provides function keys for moving forward and backward through the data items and screens. The editor will provide screens for inventory data (one set for each sample unit, up to a maximum of ten).

Extrapolation of Overall Project Condition

Using the project length and lengths of the sample units, EXPEAR extrapolates from the sample unit distress data to compute the overall average condition of the project. The project is then evaluated on the basis of this average condition.

Evaluation of Present Condition

EXPEAR utilizes a set of decision trees to analyze all of the data and develop a specific detailed evaluation in several major problem areas, including roughness, structural adequacy, joint deterioration, foundation movement, skid resistance, construction deficiencies, drainage, loss of support, joint sealant condition, concrete durability, and shoulder condition. From the evaluation, a set of evaluation conclusions is produced for each traffic lane and each shoulder.

Prediction of Future Condition Without Rehabilitation

Based on the current traffic level (annual 18-kip ESAL) and the anticipated ESAL growth rate, the future condition of the pavement without rehabilitation is predicted. Faulting, cracking, joint deterioration, pumping, and present serviceability rating are projected for jointed pavements (and punchouts for CRCP) and the years in which they will become serious problems are identified. The predictive models used are calibrated to the existing condition of the pavement at the time of the survey.

Physical Testing Recommendations

The initial data collection does not require physical testing. Based upon the available information, the program identifies types of physical testing needed to verify the evaluation recommendations and to provide data needed for rehabilitation design. Testing may include nondestructive deflection testing, coring/material sampling and laboratory testing, and roughness and friction measurement. Types of deficiencies which may warrant physical testing include structural inadequacy, poor rideability, poor surface friction, poor drainage conditions, poor concrete durability ("D" racking or reactive aggregate distress), foundation movement (due to swelling soil or frost heave), loss of load transfer at joints, loss of slab support, joint deterioration, and evidence of poor joint construction.

3.0 PAVEMENT REHABILITATION

Selection of Main Rehabilitation Approach

Based upon the evaluation results, the system interacts with the engineer to select the most appropriate main rehabilitation approach for each traffic lane and shoulder. These include all 4R options: reconstruction (including recycling), resurfacing (with concrete or asphalt), or restoration. The major factors in determining whether a pavement needs reconstruction, resurfacing, or merely restoration are the extent of structural distress (e.g., cracking and corner breaks) and the extent of deterioration due to poor concrete durability ("D" cracking or reactive aggregate distress).

Development of Detailed Rehabilitation Strategy

Once an approach is selected for each traffic lane and shoulder, the engineer proceeds to develop the detailed rehabilitation alternative by selecting a feasible set of individual rehabilitation techniques to correct the deficiencies present. This may include such items as subdrainage, shoulder repair, full-depth repairs, joint resealing, etc. This is performed for each traffic lane and shoulder by interaction with the system. The system displays each of the evaluation conclusions reached earlier and recommends one or more appropriate rehabilitation techniques. A set of decision trees has been developed to guide the rehabilitation strategy development process for traffic lanes and for adjacent shoulders. Where more than one choice exists for an appropriate technique to repair a specific distress, the system presents the engineer with the choice to make.

Computation of Rehabilitation Quantities

EXPEAR computes needed quantities for the rehabilitation techniques selected based on the data in the project survey and additional information rovided by the engineer. In general, the program assumes that 100 percent repair will be performed; that is, that the quantity of a certain type of distress to be repaired is equal to the quantity of that distress observed during the field survey.

If the rehabilitation work is being delayed, the quantities are increased where appropriate for each year

the user are necessary; EXPEAR will detect what type of monitor is available and whether or not a math chip is present.

Each of the three EXPEAR versions (for the three pavement types: JPCP, JRCP, and CRCP) is distributed on a set of two 360 K, 5.25-inch floppy disks. One disk contains the executable program (EXPEAR.EXE) and the other disk contains several other files needed to run EXPEAR.

One other note about the disk files: several of the file names (EXPEAR.EXE, DISPLAYS.REC, STNDRD.DAT, etc.) are common to the programs for all three pavement types (JRCP, JPCP, and CRCP), so if you want to run the programs for different pavement types, keep them on separate disks! If you copy them to a hard disk, place them in different directories.

Running EXPEAR

After the EXPEAR title screen and a few screens of introductory information, the system displays the main menu, which has four options:

1. ENTER OR EDIT PROJECT DATA
2. CONDUCT PROJECT EVALUATION
3. DEVELOP REHABILITATION STRATEGY
4. QUIT, RETURN TO DOS

Enter or Edit Project Data

When this option is selected, a menu will appear to ask whether you want to create a new data file or edit an existing file. A new data file is created by modifying the STNDRD.DAT file. If an existing data file is to be modified, the program will ask for the name of the data file without the .DAT extension.

A full-screen data editor is incorporated into the system for data entry and editing. Function keys for moving through the data items and screens are defined at the bottom of the screen. Some data items are defined as "toggle variables," meaning that you can toggle through the available values (such as low, medium, high) using the tab key. The editor will tell you which data items are toggle variables. When you are finished editing the file, SHIFT-10 will exit the editor. This command does not however, save the file on disk. The program will prompt you to save the file before continuing.

Conduct Project Evaluation

When this option is selected, the program asks for the name of the data file to be evaluated. It also asks whether you want to use the default critical distress levels incorporated in the program, or use your own values. These may be selected each time you run the program, or may be saved to disk and retrieved when needed. The program will prompt you for a file name for your critical distress values and save it with a .CVL extension. Whether using your own values or the default values, you must select critical distress levels before proceeding with the evaluation.

The evaluation runs very quickly. When it is done, EXPEAR will display the results of the evaluation, which consists of evaluation conclusions for the traffic lanes and shoulders, predicted performance without rehabilitation, and physical testing recommendations.

EXPEAR will ask if you want to print the data summary file and the project evaluation summary file. You may print these from the program, or exit to DOS and print the output files with .REP and .TXT extensions.

Develop Rehabilitation Strategy

When this option is selected, EXPEAR interacts with you to select the main rehabilitation approach (reconstruct, overlay, or restore) and the specific rehabilitation techniques needed to correct the deficiencies identified in the evaluation. EXPEAR recommends appropriate rehabilitation approaches and techniques and gives you the option to choose whenever more than one appropriate technique exists. EXPEAR does not have the capability to permit you to enter options other than the ones given. When the rehabilitation strategy has been developed, it will be displayed along with approximate quantities (in some instances additional information must be provided for computing quantities, such as size of full-depth repairs). You may print the strategy and quantities out from the program, or exit to DOS and print the output file with the .STS extension.

After a strategy has been developed, a menu appears with the following options:

1. REVISE REHABILITATION STRATEGY
2. PREDICT REHABILITATION PERFORMANCE
3. PERFORM LIFE-CYCLE COST ANALYSIS
4. RETURN TO MAIN MENU

The second option will predict the performance of the rehabilitation strategy developed, using predictive models for key distresses. EXPEAR may prompt you for additional information needed, such as thickness of overlay. After the program finishes computing the predicted performance, it will display the predictions. You may print these out from the program or exit to DOS and print the output file with the .RHB extension.

Only after a rehabilitation strategy has been developed and its performance predicted can a cost analysis of the strategy be performed. EXPEAR will prompt you for a discount rate and delay to be used in the program, and will also ask you to select unit cost values for the rehabilitation techniques. You may use the default unit costs provided, or (in the same manner as for the critical distress levels), save a file containing your own set of unit costs to disk (the extension will be .UCC), and retrieve it when needed.

The program computes the present costs over the project length for the rehabilitation strategy analyzed. The results are displayed on the screen and may be printed from the program or from DOS (the extension is .LCC).

Each set of EXPEAR disks includes an example data file for that pavement type. The example files for the three programs are:

JRCP: I74183, on I-74 near Urbana, Illinois
JPCP: I10191, on I-10 near Tallahassee, Florida
CRCP: I57230, on I-57 near Champaign, Illinois

Comments, questions, or suggestion for improvements to EXPEAR or this User's Guide are very welcome. Please direct them to Ms. Kathleen T. Hall or Dr. Michael I. Darter at the University of Illinois. The addresses and phone numbers are given in the introductory screens of the EXPEAR programs.

APPENDIX C1

PROJECT SURVEY FOR CRCP

Design Engineer: ______________________________

Date of Survey (mo/day/yr): ____ / ____ / ____

PROJECT INVENTORY DATA

Collect the following information about the project to be evaluated prior to the actual field survey.

Project Identification

Highway Designation (example I-57): ____________

State: ______________________________

Direction of Survey: ______________________

Starting Milepost: ______________________

Ending Milepost: ______________________

Climate

Climatic Zone (See climatic zone map in "Supplemental Information"):

____ wet freeze	____ wet-dry freeze	____ dry freeze
____ wet freeze-thaw	____ wet-dry freeze-thaw	____ dry freeze-thaw
____ wet nonfreeze	____ wet-dry nonfreeze	____ dry nonfreeze

Estimated Annual Temperature Range (degrees Fahrenheit): __________

Mean Annual Precipitation (inches) (See precipitation map in "Supplemental Information"): ______________________

Corps of Engineers Freezing Index (Fahrenheit degree-days) (See Freezing Index map in "Supplemental Information"): ______________

Construction

Year Constructed: ________________

Slab Thickness (inches): ____________

Width of Traffic Lanes (feet): ________

PCC Modulus of Rupture (28 days, 3rd-point loading)(psi): __________

Amount of Longitudinal Steel (percent of slab cross-sectional area) (See wire size table in "Supplemental Information"): ____________

Longitudinal Joints

Method Used to Form Longitudinal Joints Between Lanes:
_____ sawing
_____ inserts

Longitudinal Joint Sawed or Formed Depth (inches): ________________

Base

Type of Base Course:
_____ fine-grained soil only _____ dense-graded untreated aggregate
_____ cement-treated aggregate _____ asphalt-treated aggregate
_____ lean PCC _____ open-graded drainage layer

Modulus of Subgrade Reaction on Top of Base (psi/inch) (See k-value correlation chart in "Supplemental Information"): ________________

Subgrade

Predominant Subgrade Soil AASHTO Classification (See Unified-AASHTO conversion table in "Supplemental Information"): ________________

Are swelling soils a problem in your area? _______ yes _______ no

If so, were steps taken in construction of the pavement to correct the swelling soil problem? _______ yes _______ no

Shoulder

Type of Shoulder:
_____ AC
_____ tied PCC

Width of Shoulders (feet): ____________ inner ____________ outer

Traffic

Estimated Current Through Two-way ADT: ________________________

Percent Commercial Trucks (excluding pickups and panels): __________

Total Number of Lanes in Direction of Survey: ____________________

Future Truck Traffic Volume Growth Rate
(percent increase per year): ________________________________

Total Accumulated 18-kip Equivalent Single Axle Loads (ESALs) from Date of Construction to Date of Survey (millions) (See procedure for computing ESALs in AASHTO <u>Guide for Design of Pavement Structures</u>, Appendix D, 1986):

LANE TWO (inner)	LANE ONE (outer)
________	________

PROJECT MONITORING DATA

Ride Quality

Rate the ride quality of the pavement in each lane during a drive over the entire project at the posted speed limit. Two or more people should participate in the survey. Obtain ratings for each lane from each person and report the average value below.

```
0         1         2         3         4          5
+---------+---------+---------+---------+----------+
Very Poor   Poor      Fair      Good    Very Good
```

	LANE TWO (inner)	LANE ONE (outer)
	______	______

Terminal Treatments

Stop at the beginning and end of the project where the pavement abuts different pavement types, and also at each bridge which the pavement abuts within the project, and observe the condition of the terminal treatments present.

Number of deteriorated anchor lug terminal treatments (i.e., M-E roughness due to rotation of anchor lugs):	______	______	______
Number of expansion joint terminal treatments which are completely closed:	______	______	______

SAMPLE UNIT MONITORING DATA

Collect the following information for each traffic lane and for both shoulders during an inspection of each sample unit. A length of approximately one half mile is recommended for each sample unit surveyed. The survey may include driving slowly on the shoulder, stopping on the shoulder, and (with extreme caution) walking on the shoulder to make measurements. More than one pass over the project will probably be needed to obtain all the information requested. Refer to NCHRP Report No. 277 for standard definitions of distress, severity, and measurement instructions.

Sample Unit Identification

Sample Unit Number: __________ Starting Milepost: __________ Length of Sample Unit (feet): __________

Failures

	LANE TWO (inner)	LANE ONE (outer)
Number of deteriorated transverse cracks, M-H only:	______	______
Number of full-depth repairs:	______	______
Number of deteriorated full-depth repairs, M-H only:	______	______
Number of punchouts:	______	______
Number of deteriorated construction joints (M-H only):	______	______

Longitudinal Joint

Total length of longitudinal cracking, M-H only (feet):	______	______
Total length of longitudinal joint spalling, M-H only (feet):		______

What is the general condition of the longitudinal joint sealant?

______ L
______ M
______ H

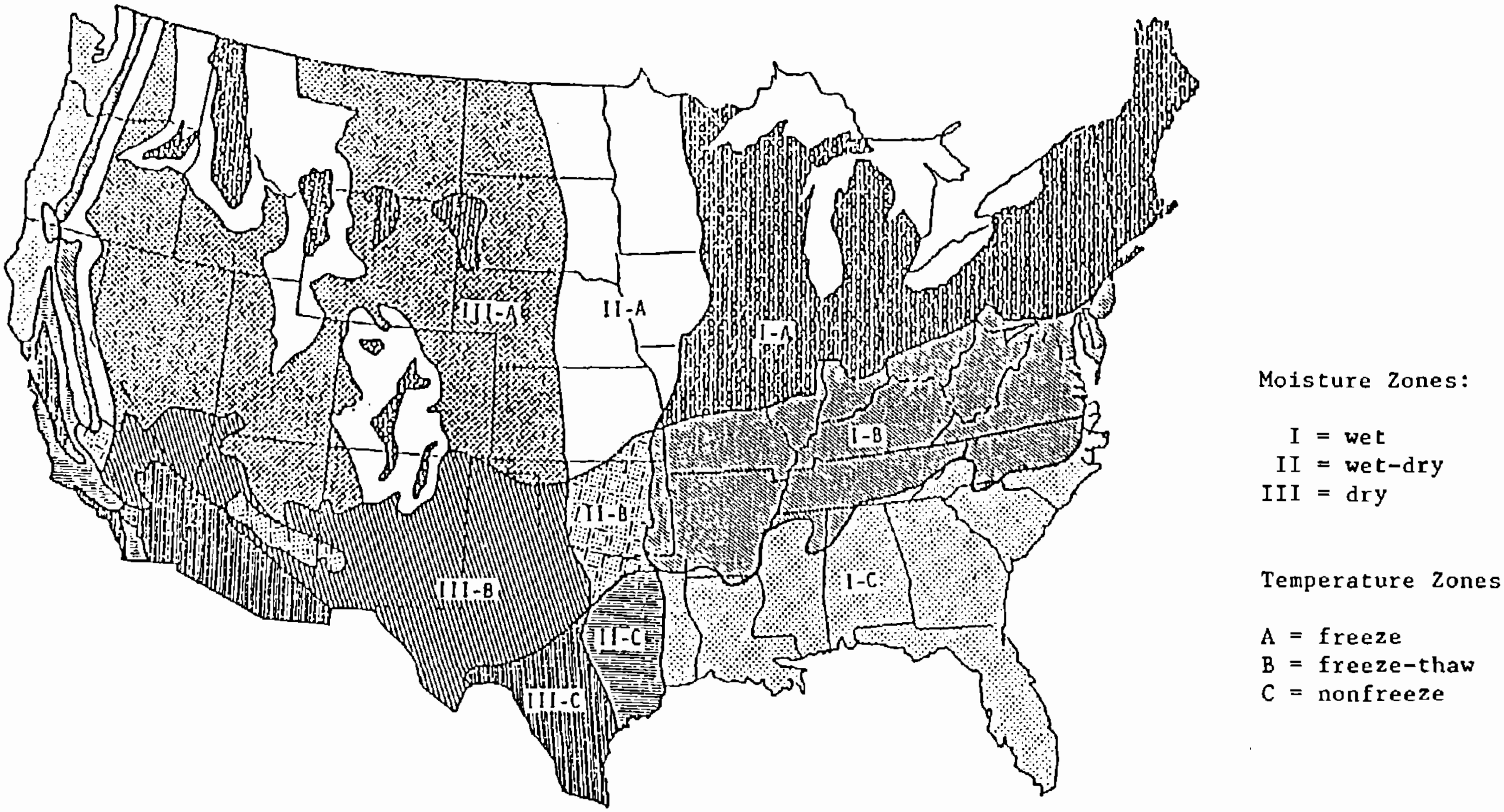
Transverse Crack Spacing

Select a section of the pavement several hundred feet long for determining the transverse crack spacing. Measure the section with a wheel and count the number of transverse cracks observed.

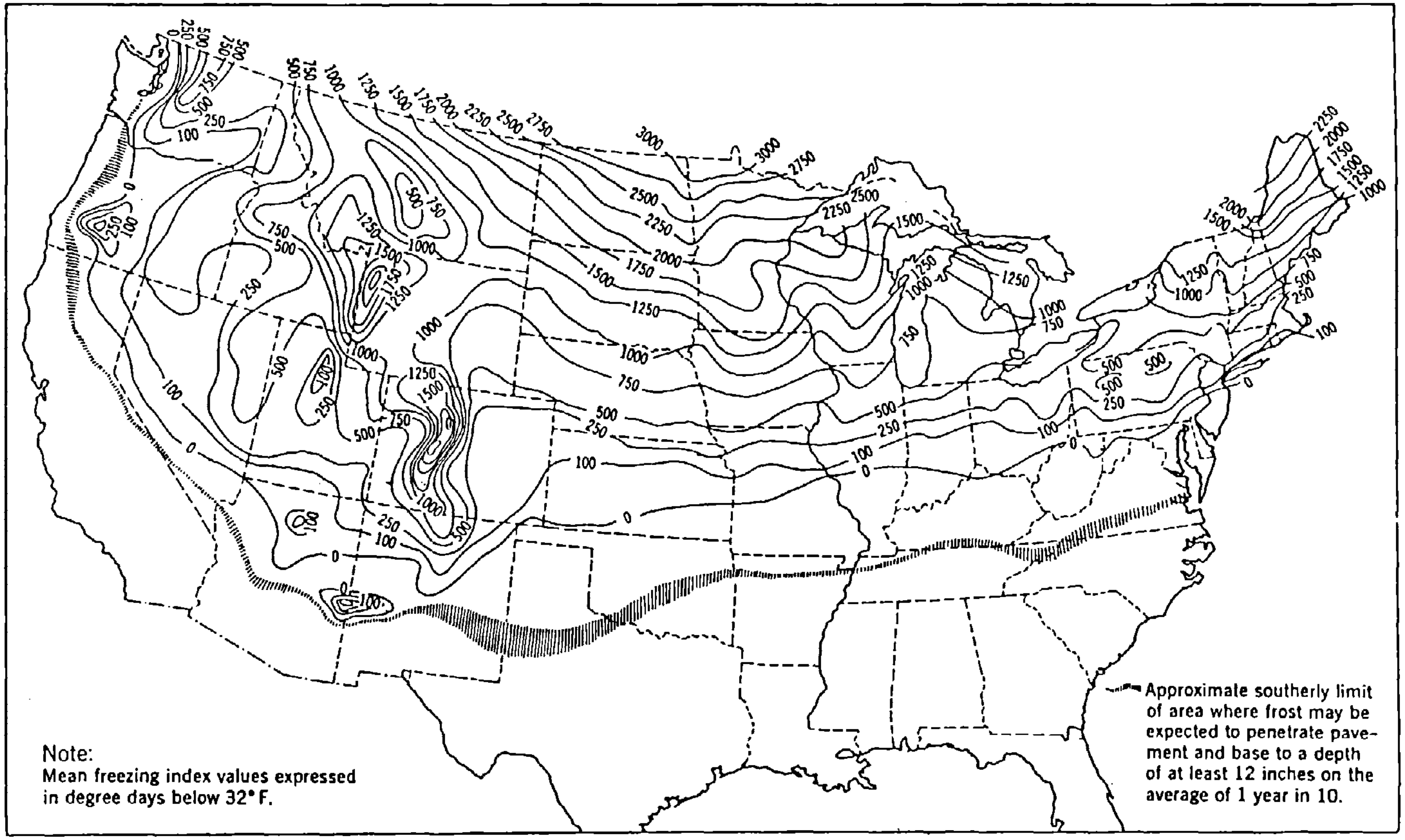
Length of section:	______	______
Number of transverse cracks:	______	______

	LANE TWO (inner)	LANE ONE (outer)
Foundation Movement		
Number of settlements (M-H only):	____	____
Number of heaves (M-H only):	____	____
Drainage		
Are longitudinal subdrains present and functional along the sample unit?	____ yes	____ no
What is the typical height of the pavement surface above the side ditchline (feet)?	____	
Do the ditches have standing water or cattails in them?	____ yes	____ no
Extent of visible evidence of pumping or water bleeding on pavement or shoulder (indicate the highest level of severity occurring in the sample unit):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Surface Condition		
Method used to texture the pavement surface at construction: ____ transverse tining ____ other		
Is the surface polished smooth in the wheelpaths?	____ yes ____ no	____ yes ____ no
Is significant studded tire rutting (0.25 inch or more) evident in the wheel paths?	____ yes ____ no	____ yes ____ no
Concrete Durability		
Number of areas spalled (M-H only) due to "D" cracking:	____	____
Number of areas spalled (M-H only) due to reactive aggregate distress:	____	____
Extent of scaling (indicate highest severity level present):	____ N ____ L ____ M ____ H	____ N ____ L ____ M ____ H
Previous Repair		
Has diamond grinding been done?	____ yes ____ no	____ yes ____ no
Has grooving been done?	____ yes ____ no	____ yes ____ no

	INNER SHOULDER	OUTER SHOULDER
AC Shoulders (Check all that apply.)		
Alligator cracking	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Linear cracking	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Weathering/ravelling	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Lane/shoulder joint dropoff	____ none	____ none
	____ <1"	____ <1"
	____ ≥1"	____ ≥1"
Settlements or heaves along outer edge	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Blowholes at transverse joints	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	____ good	____ good
	____ poor	____ poor
PCC Shoulders (Check all that apply.)		
Transverse or longitudinal cracking or corner breaks	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
"D" cracking or reactive aggregate distress	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Settlements or heaves along outer edge	____ none	____ none
	____ some	____ some
	____ extensive	____ extensive
Lane/shoulder joint sealant condition (good = well sealed or width < 0.10", poor = poorly sealed and width ≥ 0.10")	____ good	____ good
	____ poor	____ poor



Climatic Zone Map of the United States. Source: "A Pavement Moisture-Accelerated Distress (MAD) Identification System," FHWA/RD-81/079-80, 1981.



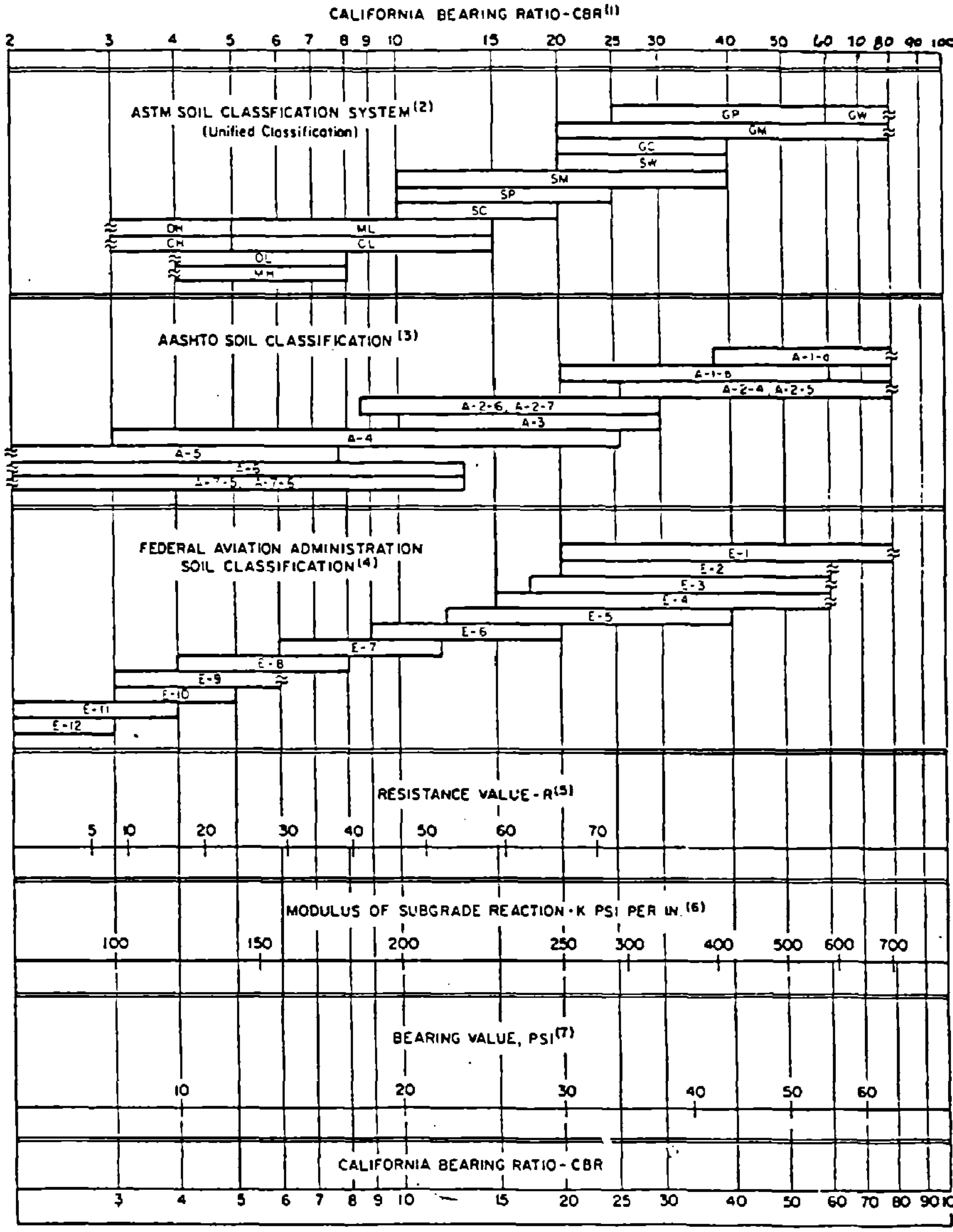
Freezing Index (Fahrenheit degree-days). Source: "Engineering and Design, Pavement Design for Frost Conditions," Corps of Engineers EM 1110-345-306.

WIRE SIZES, WEIGHTS AND STEEL AREAS PER FT. OF WIDTH

Wire Size Number		Nominal Diameter, Inches	Nominal Weight Lbs./Lin. Ft.	Cross Sectional Areas, Sq. In. Per Lin. Ft. — Center to Center Spacing						
Smooth	Deformed			2"	3"	4"	6"	8"	10"	12"
W31	D31	0.628	1.054	1.86	1.24	.93	.62	.465	.372	.31
W30	D30	0.618	1.020	1.80	1.20	.90	.60	.45	.36	.30
W28	D28	0.597	.952	1.68	1.12	.84	.56	.42	.336	.28
W26	D26	0.575	.934	1.56	1.04	.78	.52	.39	.312	.26
W24	D24	0.553	.816	1.44	.96	.72	.48	.36	.288	.24
W22	D22	0.529	.748	1.32	.88	.66	.44	.33	.264	.22
W20	D20	0.504	.680	1.20	.80	.60	.40	.30	.24	.20
W18	D18	0.478	.612	1.08	.72	.54	.36	.27	.216	.18
W16	D16	0.451	.544	.96	.64	.48	.32	.24	.192	.16
W14	D14	0.422	.476	.84	.56	.42	.28	.21	.168	.14
W12	D12	0.390	.408	.72	.48	.36	.24	.18	.144	.12
W11	D11	0.374	.374	.66	.44	.33	.22	.165	.132	.11
W10.5		0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5		0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5		0.329	.289	.51	.34	.255	.17	.127	.102	.085
W8	D8	0.319	.272	.48	.32	.24	.16	.12	.096	.08
W7.5		0.309	.255	.45	.30	.225	.15	.112	.09	.075
W7	D7	0.298	.238	.42	.28	.21	.14	.105	.084	.07
W6.5		0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5		0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5		0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04

NOTE: Wire sizes other than those listed above may be produced provided the quantity required is sufficient to justify manufacture

Area of reinforcement (square inches of steel/foot). Source: Concrete Reinforcing Steel Institute.



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, pages 100-136.
(2) ASTM Designation D2487.
(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting*, 1945, Vol. 25, pages 376-392.
(4) *Airport Paving*, U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements*.(Formerly used FAA Classification; Unified Classification now used.)
(5) C. E.Warnes, "Correlation Between R Value and k Value," unpublished report, Portland Cement Association, Rocky Mountain-Northwest Region, October 1971 (best-fit correlation with correction for saturation).
(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, page 152.

Subgrade K-value Correlation to Soil Classifications and Bearing Values. Source: "Thickness Design for Concrete Highway and Street Pavements", Portland Cement Association

BASE TYPE

- fine-grained soil only: use k-value of subgrade soil
- dense-graded aggregate

Subgrade k-value, (psi/in)	Subbase Thickness, in 4	6	9	12
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

- cement or asphalt treated aggregate, lean concrete

Subgrade k-value, (psi/in)	Subbase Thickness, in 4	6	8	10
50	170	230	310	390
100	280	400	520	640
200	470	640	830	---

k-value on top of base course (directly beneath PCC slab)
Source: "Thickness Design for Concrete Highway and Street Pavements," Portland Cement Association

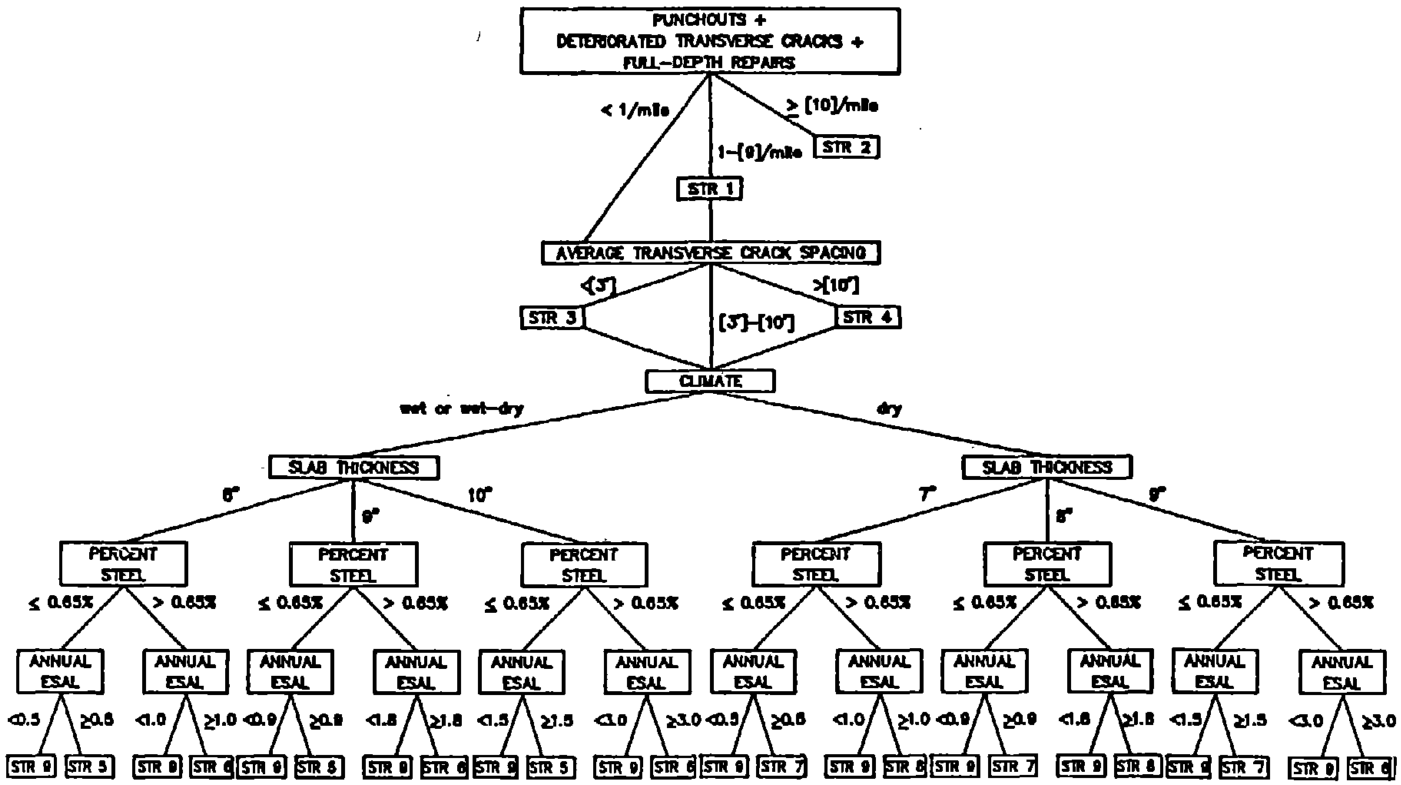
APPENDIX C2

EVALUATION DECISION TREES AND CONCLUSIONS FOR CRCP

Major Problem Areas for CRCP

1. Structural Adequacy
2. Drainage
3. Foundation Movement
4. Durability
5. Skid Resistance
6. Roughness
7. Longitudinal Joint Construction
8. Construction Joints and Terminal Treatments
9. Shoulders

CRCP STRUCTURAL DEFICIENCY



* annual ESAL in millions

Structural Adequacy

STR 1 A potential structural deficiency of the pavement is indicated by between 1 and [9] punchouts and/or deteriorated transverse cracks and/or full-depth repairs per mile.

(a) full-depth repair of slab failures

STR 2 Structural deficiency of the pavement is indicated by [10] or more punchouts and/or deteriorated transverse cracks and/or full-depth repairs per mile.

(a) full-depth repair of slab failures, AC structural overlay
(b) full-depth repair of slab failures, PCC bonded overlay
(c) full-depth repair of slab failures, PCC unbonded overlay
(d) reconstruct lane

STR 3 A potential structural deficiency of the pavement, in the form of a high probability for the development of punchouts, is indicated by an average transverse crack spacing of less than [3] feet.

(a) do nothing

STR 4 A potential structural deficiency of the pavement, in the form of a high probability for transverse crack deterioration, is indicated by an average transverse crack spacing of more than [10] feet.

(a) do nothing

STR 5 Structural deficiency of the pavement is indicated by a wet or wet-dry climate, a slab thickness of (x) inches, (y) percent steel, and (z) million annual 18-kip ESALs.

(a) AC structural overlay
(b) PCC bonded overlay
(c) PCC unbonded overlay

STR 6 Structural deficiency of the pavement is indicated by a wet or wet-dry climate, a slab thickness of (x) inches, and (y) million annual 18-kip ESALs.

(a) AC structural overlay
(b) PCC bonded overlay
(c) PCC unbonded overlay

STR 7 Structural deficiency of the pavement is indicated by a dry climate, a slab thickness of (x) inches, (y) percent steel, and (z) million annual 18-kip ESALs.

(a) AC structural overlay
(b) PCC bonded overlay
(c) PCC unbonded overlay

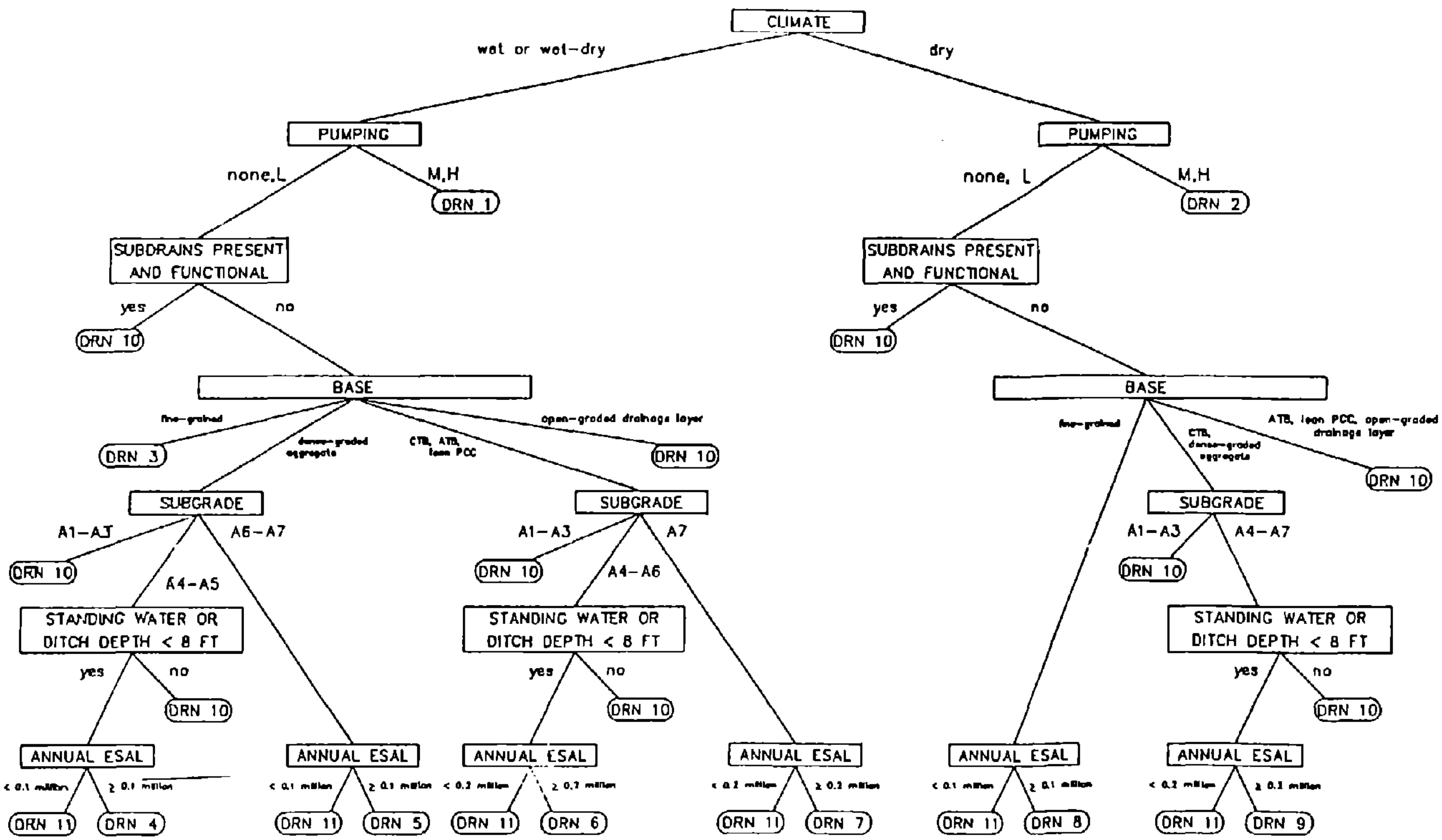
STR 8 Structural deficiency of the pavement is indicated by a dry climate, a slab thickness of (x) inches and (y) million annual 18-kip ESALs.

(a) AC structural overlay
(b) PCC bonded overlay
(c) PCC unbonded overlay

STR 9 The pavement shows no indication of structural deficiency.

(a) do nothing

CRCP DRAINAGE DEFICIENCY



Drainage

DRN 1 A drainage deficiency is indicated by medium- to high-severity pumping occurring in a wet or wet-dry climate.

(a) install or repair longitudinal subdrains

DRN 2 A drainage deficiency is indicated by medium- to high-severity pumping occurring in a dry climate.

(a) install or repair longitudinal subdrains

DRN 3 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, and a fine-grained soil base.

(a) install or repair longitudinal subdrains

DRN 4 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded untreated aggregate base, an (x) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 5 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a dense-graded untreated aggregate base, an (x) subgrade, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 6 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (x) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 7 A drainage deficiency is indicated by a wet or wet-dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (x) subgrade, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 8 A drainage deficiency is indicated by a dry climate, absence or poor functioning of longitudinal subdrains, a fine-grained soil base, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

DRN 9 A drainage deficiency is indicated by a dry climate, absence or poor functioning of longitudinal subdrains, a (x) base, an (x) subgrade, standing water in the ditches and/or an inadequate ditch depth, and heavy traffic of (x) million annual 18-kip ESALs.

(a) install or repair longitudinal subdrains

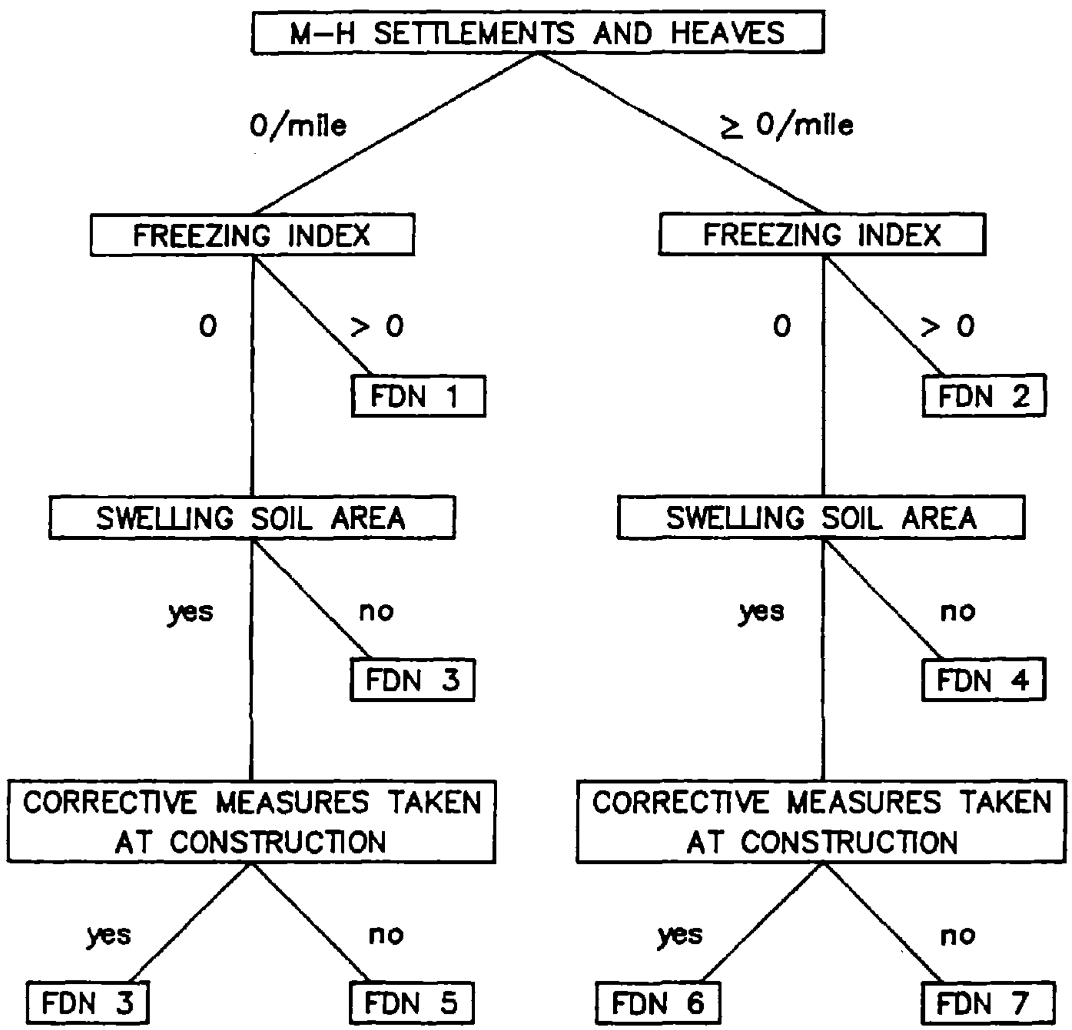
DRN 10 The pavement shows no indications of a drainage deficiency.

(a) do nothing

DRN 11 For the pavement's current traffic level, no significant drainage deficiency is indicated.

(a) do nothing

CRCP FOUNDATION MOVEMENT



Foundation Movement

FDN 1 A potential for frost heave is indicated by a Freezing Index greater than 0.

(a) do nothing

FDN 2 Foundation movement, likely due to either frost heave or localized consolidation, is indicated by settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements
(b) reconstruct heaves, slabjack settlements

FDN 3 The pavement shows no indications of foundation movement.

(a) do nothing

FDN 4 Foundation movement, likely due to localized consolidation, is indicated by settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements
(b) reconstruct heaves, slabjack settlements

FDN 5 A potential for foundation movement exists, since the pavement is in a swelling soils area and no measures were taken during construction to control soil swelling.

(a) do nothing

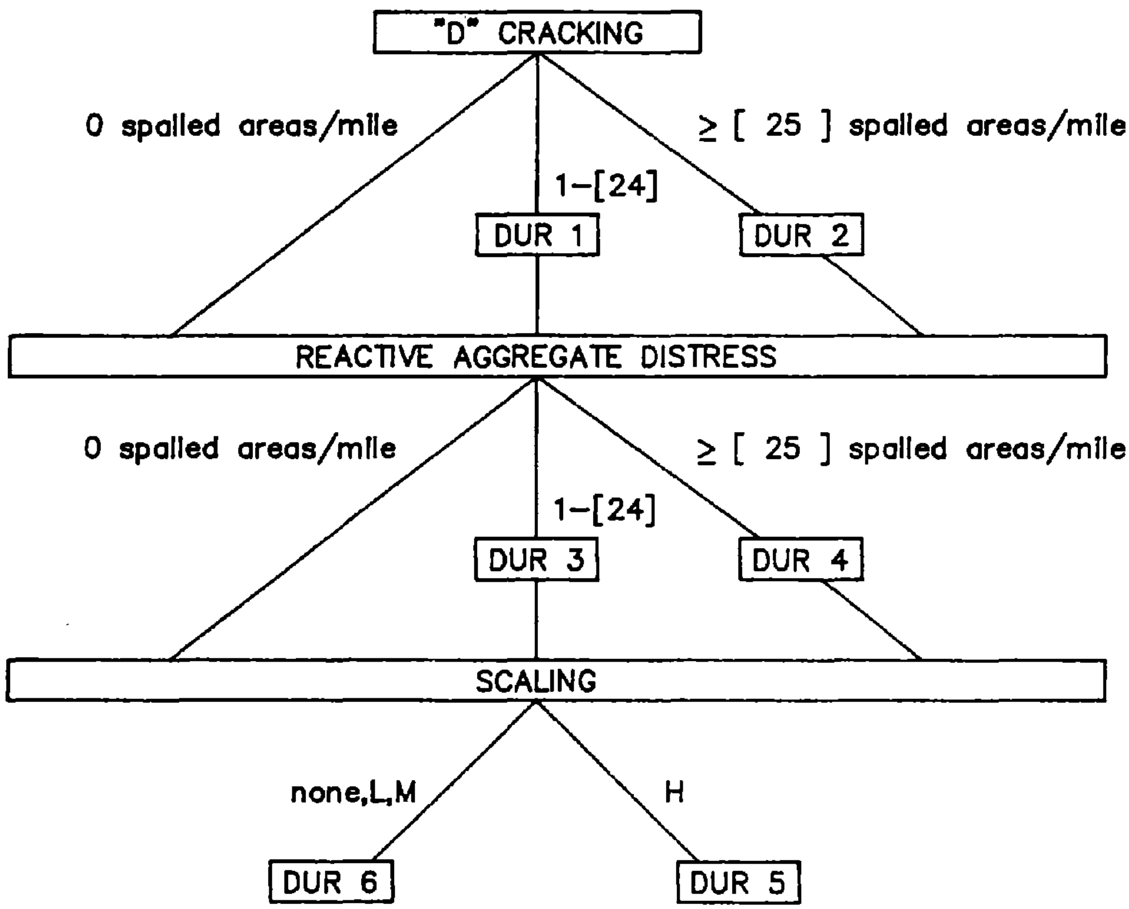
FDN 6 Foundation movement, likely due to either localized consolidation or unsuccessful construction measures to control swelling soil, is indicated by settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements
(b) reconstruct heaves, slabjack settlements

FDN 7 Foundation movement, likely due to either localized consolidation or lack of construction measures to control swelling soil, is indicated by settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements
(b) reconstruct heaves, slabjack settlements

CRCP DURABILITY DEFICIENCY



Durability

DUR 1 Poor durability of the concrete is indicated by low- to medium-severity "D" cracking.

(a) full-depth repair of spalled areas

DUR 2 Poor durability of the concrete is indicated by high-severity "D" cracking.

(a) unbonded PCC overlay
(b) reconstruct

DUR 3 Poor durability of the concrete is indicated by low- to medium-severity reactive aggregate distress.

(a) full-depth repair of spalled areas

DUR 4 Poor durability of the concrete is indicated by high-severity reactive aggregate distress.

(a) unbonded PCC overlay
(b) reconstruct

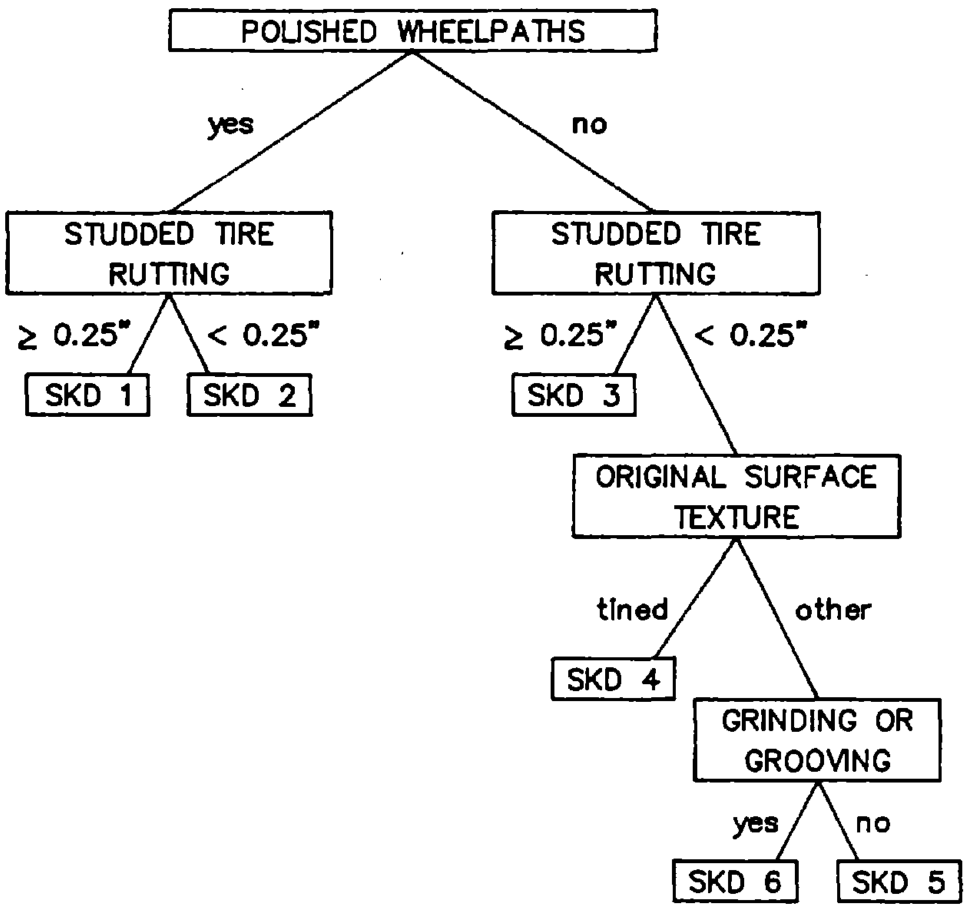
DUR 5 Poor durability of the concrete surface is indicated by high-severity scaling.

(a) AC nonstructural overlay
(b) do nothing

DUR 6 The pavement shows no indications of significant surface or concrete durability deficiencies.

(a) do nothing

CRCP SKID RESISTANCE DEFICIENCY



Skid Resistance

SKD 1 Loss of skid resistance and potential for hydroplaning are indicated by polished wheel paths and studded tire rutting of 0.25 inches or more.

(a) AC nonstructural overlay

SKD 2 Loss of skid resistance is indicated by polished wheel paths.

(a) AC nonstructural overlay

SKD 3 Loss of skid resistance and potential for hydroplaning are indicated by studded tire rutting of 0.25 inches or more.

(a) AC nonstructural overlay

SKD 4 The pavement shows no indications of loss of skid resistance or hydroplaning potential.

(a) do nothing

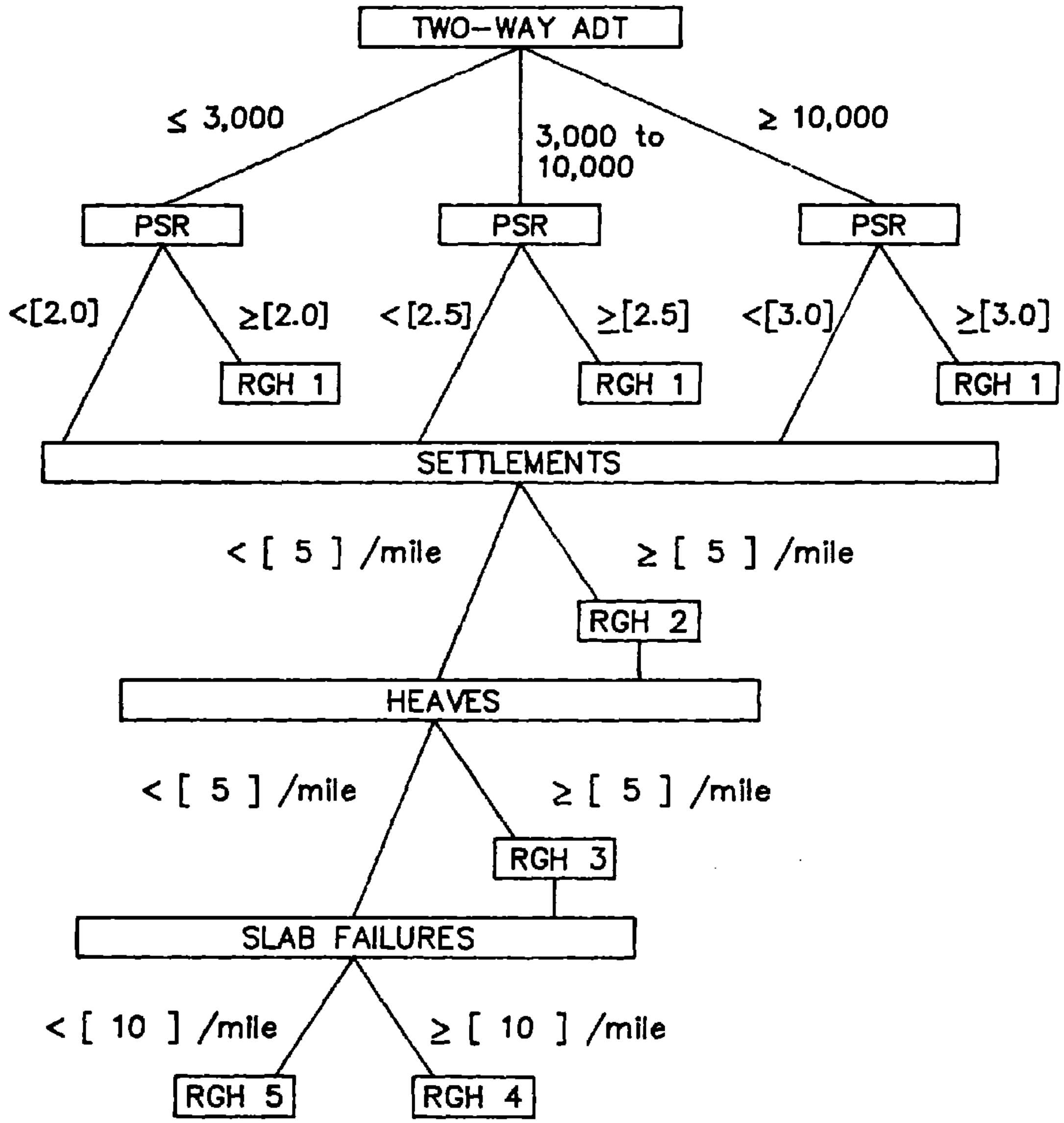
SKD 5 The method used to texture the original pavement surface may contribute to loss of skid resistance in the future.

(a) do nothing

SKD 6 Adequate skid resistance is indicated by surface restoration (grinding or grooving) having been performed on the pavement.

(a) do nothing

CRCP ROUGHNESS DEFICIENCY



Roughness

RGH 1 Rideability of the pavement is acceptable.

(a) do nothing

RGH 2 Poor rideability is indicated by [5] or more settlements per mile and an unacceptably low PSR for the pavement's ADT level.

(a) AC level-up settlements
(b) slabjack settlements

RGH 3 Poor rideability is indicated by [5] or more heaves and an unacceptably low PSR for the pavement's ADT level.

(a) reconstruct heaves

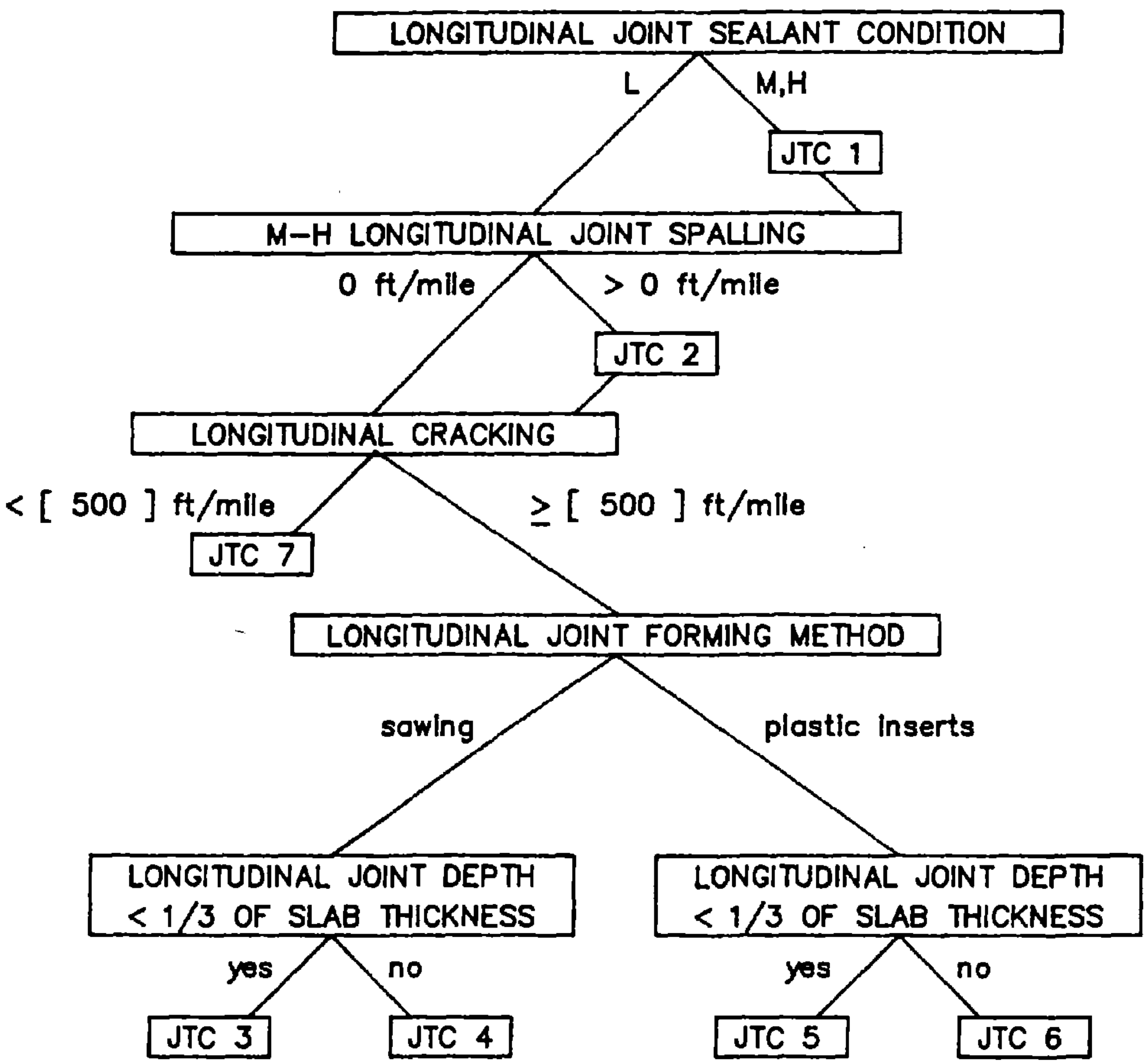
RGH 4 Poor rideability is indicated by [10] or more punchouts, deteriorated transverse cracks, and/or deteriorated full-depth repairs per mile and an unacceptably low PSR for the pavement's ADT level.

(a) full-depth repair of slab failures

RGH 5 Poor rideability is indicated by an unacceptably low PSR for the pavement's ADT level.

(a) AC nonstructural overlay

CRCP LONGITUDINAL JOINT CONSTRUCTION DEFICIENCY



Longitudinal Joint Construction and Sealant Condition

JTC 1 Pavement deterioration may be accelerated by water infiltration permitted by poor longitudinal joint sealant condition.

(a) reseal longitudinal joint

JTC 2 A longitudinal joint construction deficiency is indicated by longitudinal joint spalling.

(a) partial-depth repair

JTC 3 A longitudinal joint construction deficiency, likely due to an inadequate depth of saw cut, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 4 A longitudinal joint construction deficiency, likely due to late sawing, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 5 A longitudinal joint construction deficiency, likely due to inadequate depth of plastic insert placement, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

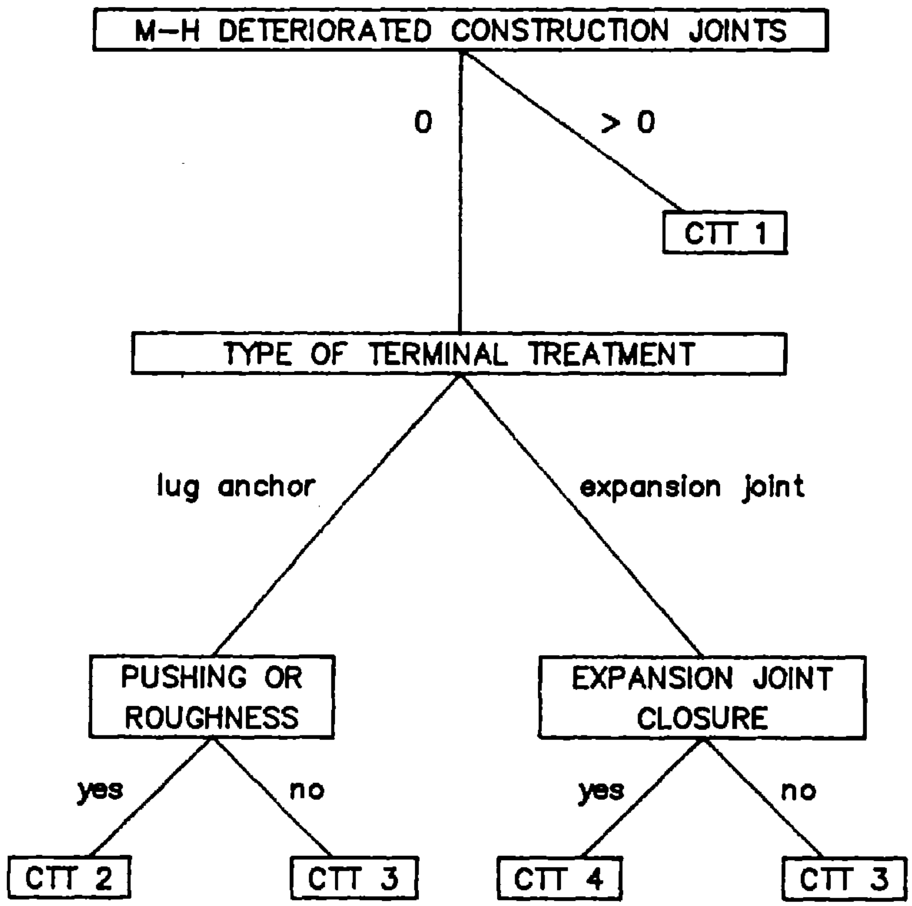
JTC 6 A longitudinal joint construction deficiency, likely due to the use of plastic inserts, is indicated by longitudinal cracking.

(a) seal longitudinal cracks
(b) stitch longitudinal cracks

JTC 7 The pavement shows no indications of a significant longitudinal joint construction or sealant condition deficiency.

(a) do nothing

CRCP CONSTRUCTION JOINTS AND TERMINAL TREATMENTS DEFICIENCY



Construction Joints and Terminal Treatments

CTT 1 A construction joint deficiency is indicated by medium- to high-severity construction joint deterioration.

(a) full-depth repair at construction joints

CTT 2 A terminal treatment deficiency is indicated by roughness due to rotation of lug anchors.

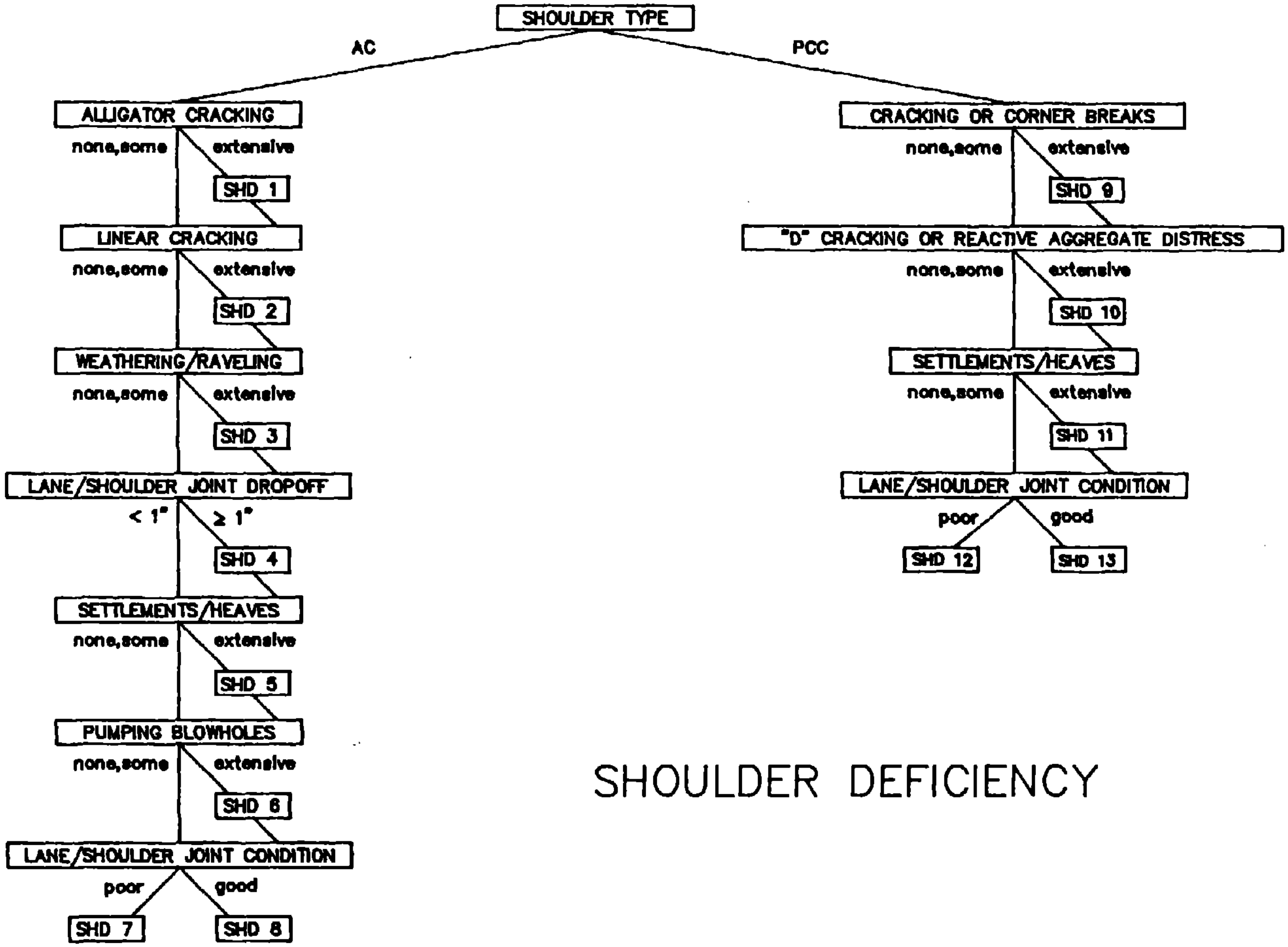
(a) AC level-up at terminal treatments

CTT 3 No construction joint or terminal treatment deficiency is indicated.

(a) do nothing

CTT 4 A terminal treatment deficiency is indicated by deterioration complete closure of expansion joints.

(a) replace expansion joint



SHOULDER DEFICIENCY

Shoulder

SHD 1 Structural deterioration of the AC shoulder is indicated by extensive alligator cracking.

(a) in-place recycling
(b) patching
(c) reconstruct with AC
(d) reconstruct with PCC

SHD 2 Deterioration of the AC shoulder is indicated by extensive linear cracking.

(a) in-place recycling
(b) patching
(c) reconstruct with AC
(d) reconstruct with PCC

SHD 3 Deterioration of the AC shoulder surface is indicated by extensive weathering and/or raveling.

(a) chip seal

SHD 4 A dropoff of 1 inch or more along the AC lane/shoulder joint constitutes a safety hazard.

(a) leveling wedge

SHD 5 Foundation movement beneath the AC shoulder is indicated by extensive settlements and/or heaves.

(a) reconstruct heaves, AC level-up settlements

SHD 6 Pumping has resulted in extensive blowhole formation in the AC shoulder.

(a) patch blowholes

SHD 7 Poor lane/shoulder joint condition exists, likely due to excessive infiltration of water beneath the pavement and AC shoulder.

(a) reseal lane/shoulder joint
(b) do nothing

SHD 8 The AC shoulder shows no indications of significant deterioration.

(a) do nothing

SHD 9 Structural deterioration of the PCC shoulder is indicated by extensive cracking and/or corner breaks.

(a) full-depth repair
(b) reconstruct with AC
(c) reconstruct with PCC

SHD 10 Poor durability of the PCC shoulder is indicated by extensive "D" cracking or reactive aggregate distress.

(a) reconstruct with AC
(b) reconstruct with PCC

SHD 11 Foundation movement beneath the PCC shoulder is indicated by extensive settlements and/or heaves along the outer edge.

(a) reconstruct heaves, AC level-up settlements

SHD 12 Poor lane/shoulder joint condition exists, likely due to excessive infiltration of water beneath the pavement and PCC shoulder.

(a) reseal lane/shoulder joint
(b) do nothing

SHD 13 The PCC shoulder shows no indications of significant deterioration.

(a) do nothing

APPENDIX C3

CRCP EVALUATION PERFORMANCE PREDICTION MODEL

The only predictive model available for CRCP deterioration was recently developed using a large Illinois database. CRCP "failures" were defined as punchouts plus deteriorated transverse cracks plus existing full-depth repairs. The database included 132 projects from a 1977 survey plus 24 of the same sections surveyed in 1985. Some of the factors and their ranges in the database are as follows:

- 18-kip [80 kN] ESAL: 700,000 to 30,800,000 in outer lane (mean = 5,600,000)
- Age: 3 to 20 years (mean = 10.2 years)
- Slab thickness: 7 to 10 in [17.8 to 25.4 cm]
- Base: Bituminous treated, cement treated, untreated aggregate
- Reinforcement content: 0.5 to 0.7 percent
- shoulders: AC
- Subgrade soils: Fine-grained mostly
- Climate: Sections located in wet-freeze climate from north to south in Illinois

The predictive model for failures per mile was developed using nonlinear regression techniques.

$$FAIL = 0.0001673\ ESAL^{1.9838} THICK^{-4.2772} ASTEEL^{-5.0} + 0.4127\ ESAL^{1.9553} (0.01584BAM + 1.9080CAM - 0.02005BAR)$$

where:

FAIL = total number of punchouts plus steel ruptures plus number of patches per lane mile

ESAL = accumulated 18-kip [80 kN] equivalent single-axle loads outer lane, millions

THICK = PCC slab thickness, in

ASTEEL = area of reinforcement, in^2 /<u>inch</u> width of PCC slab

BAM & CAM = both zero (0), if subbase material is granular

1 & 0, if subbase material is BAM

0 & 1, if subbase material is CAM

BAR = 0, if deformed welded steel fabric used

1, if deformed rebars used

Statistics: $R^2 = 0.62$

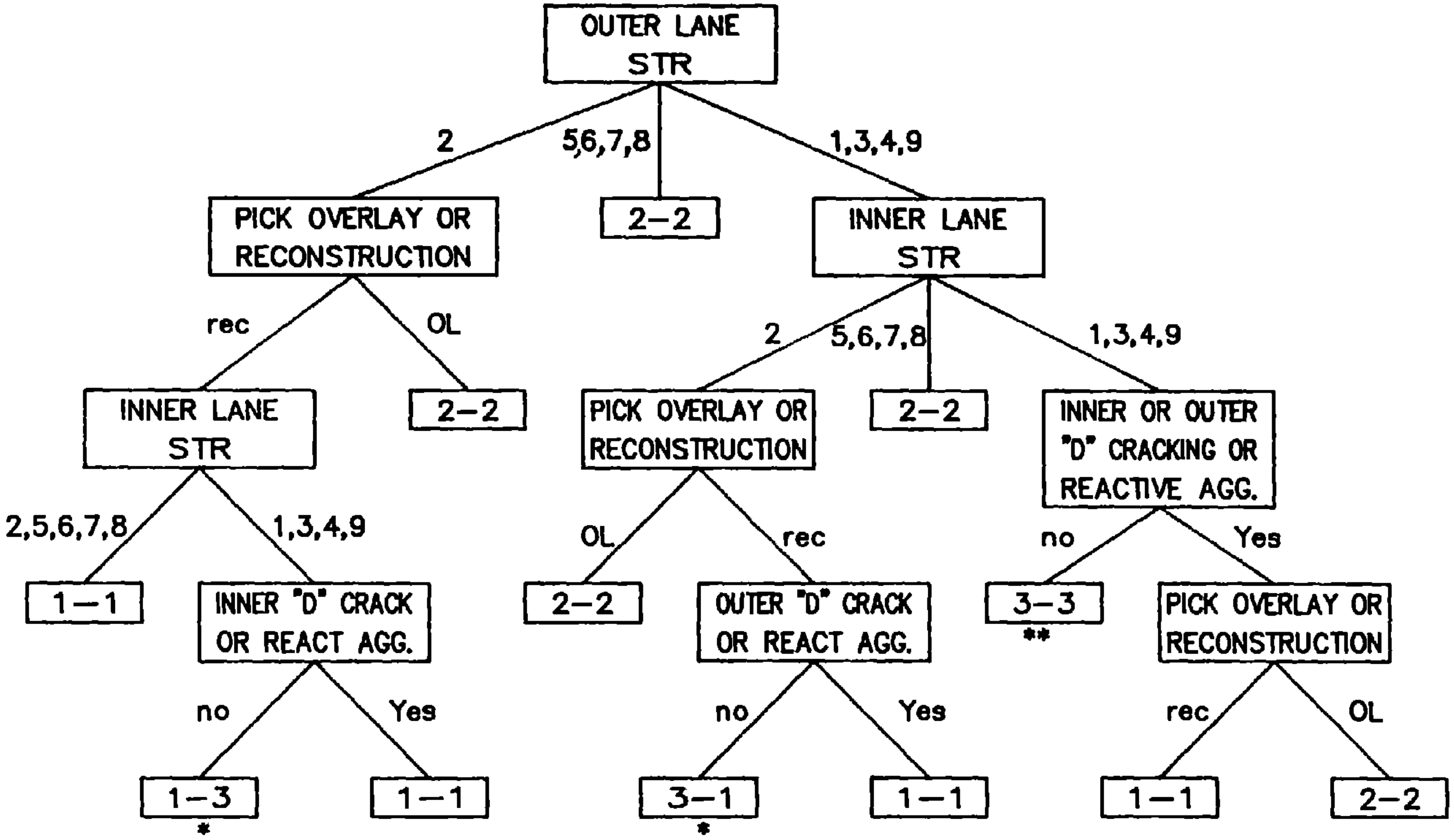
SEE = 2.86 failures/mile [1.8 failures/km]

n = 137

APPENDIX C4

REHABILITATION STRATEGY DEVELOPMENT DECISION TREES

Main Rehabilitation Approach for CRCP

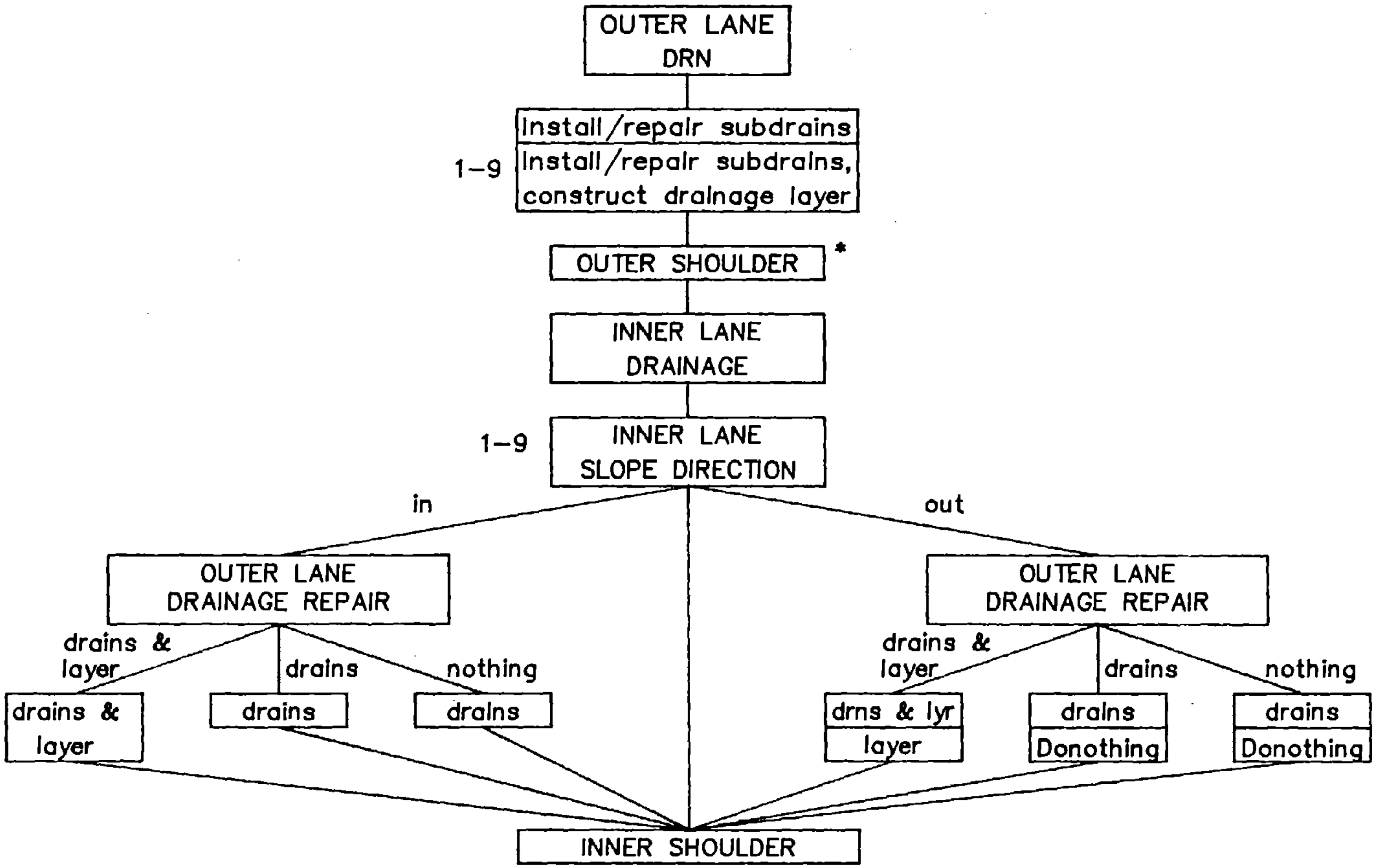


* Option to go to 1-1 provided

** Option to go to 1-1, 1-3, or 2-2 provided

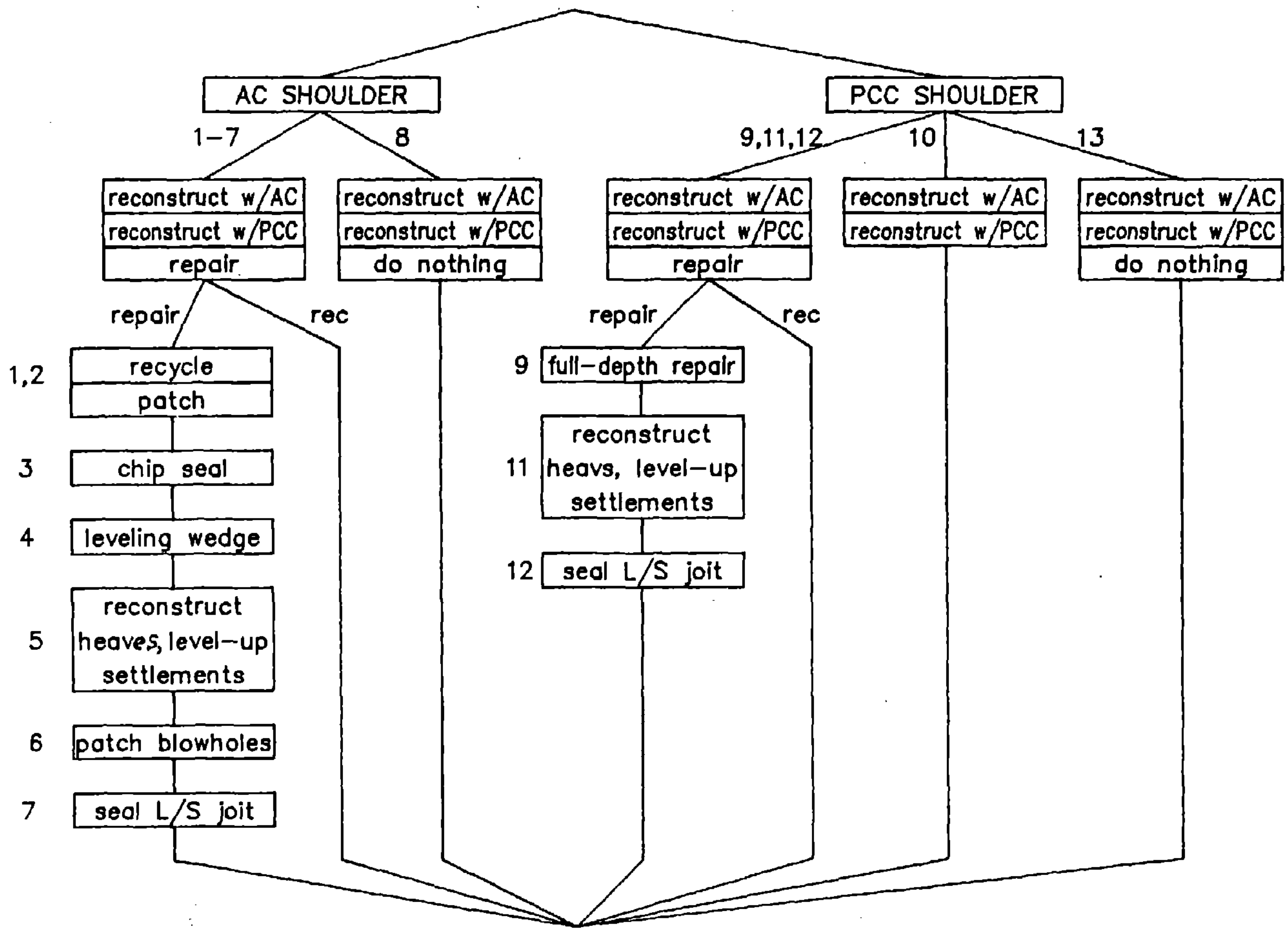
1-1 Reconstruct Both Lanes
1-3 Reconstruct Outer, Restore Inner
3-1 Restore Outer, Reconstruct Inner
2-2 Overlay Both Lanes
3-3 Restore Both Lanes

Reconstruction of A CRCP Lane

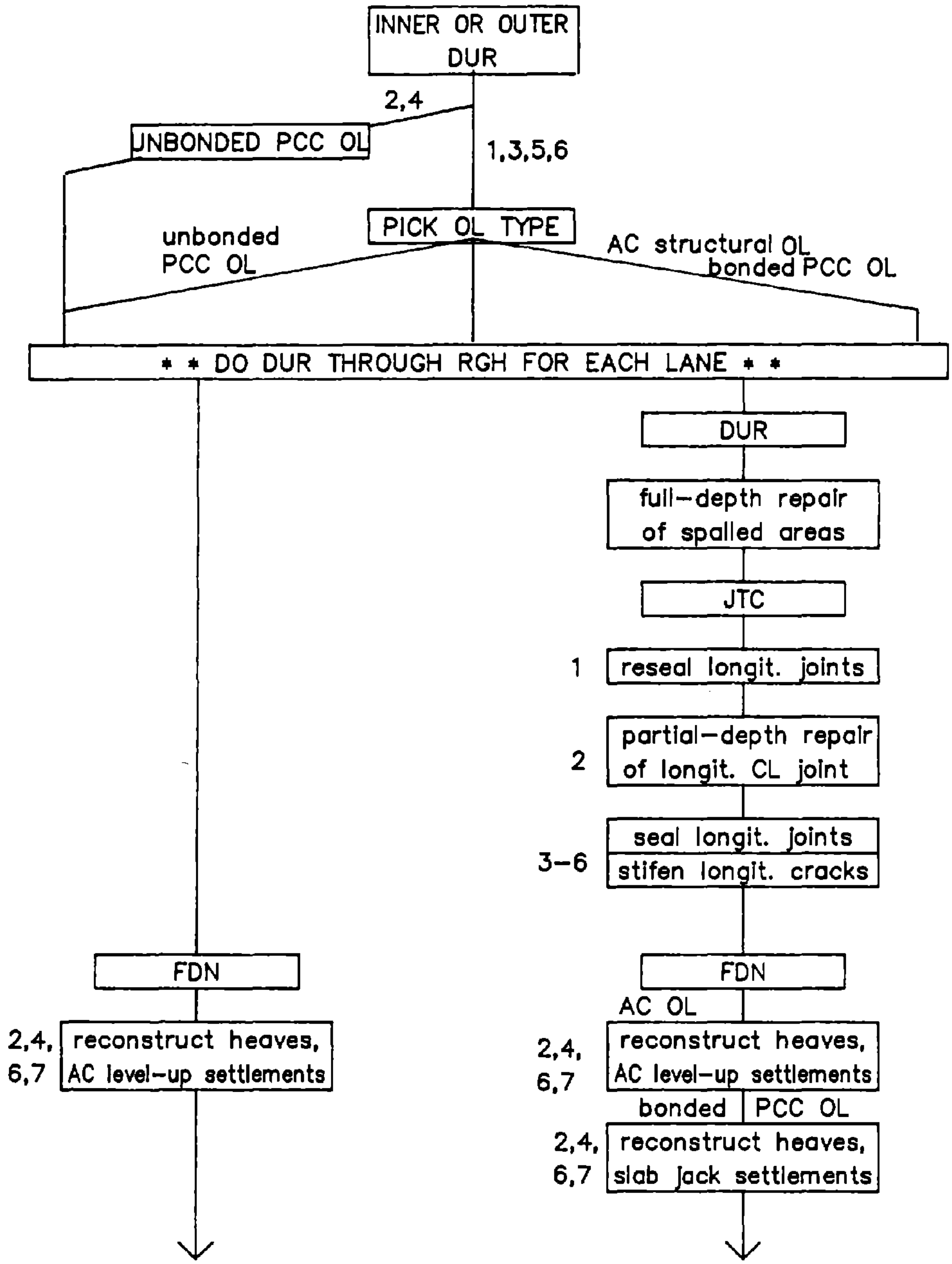


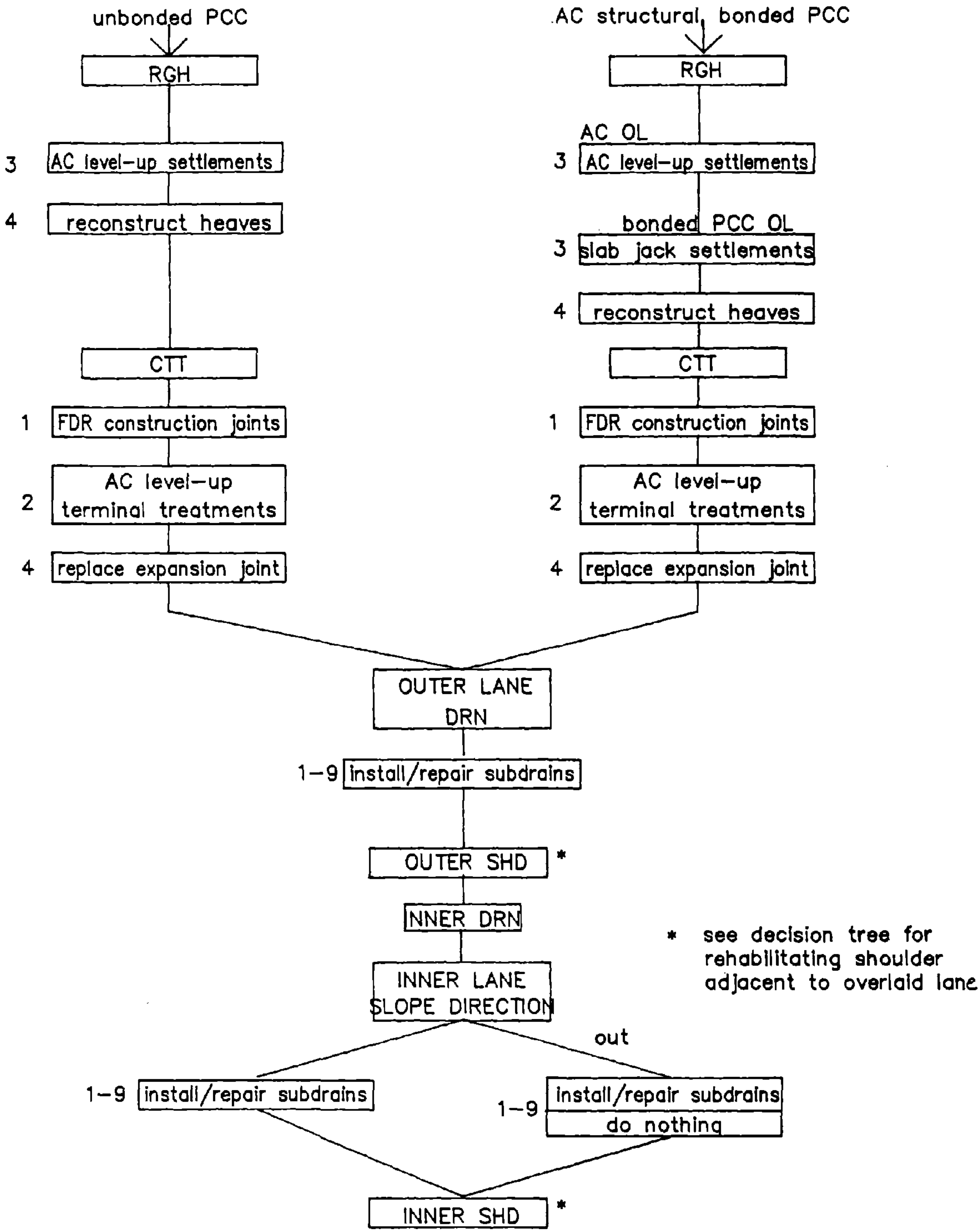
* See decision tree for shoulder rehabilitation adjacent to reconstructed lane.

Rehabilitation of Shoulder Adjacent to Reconstructed Lane

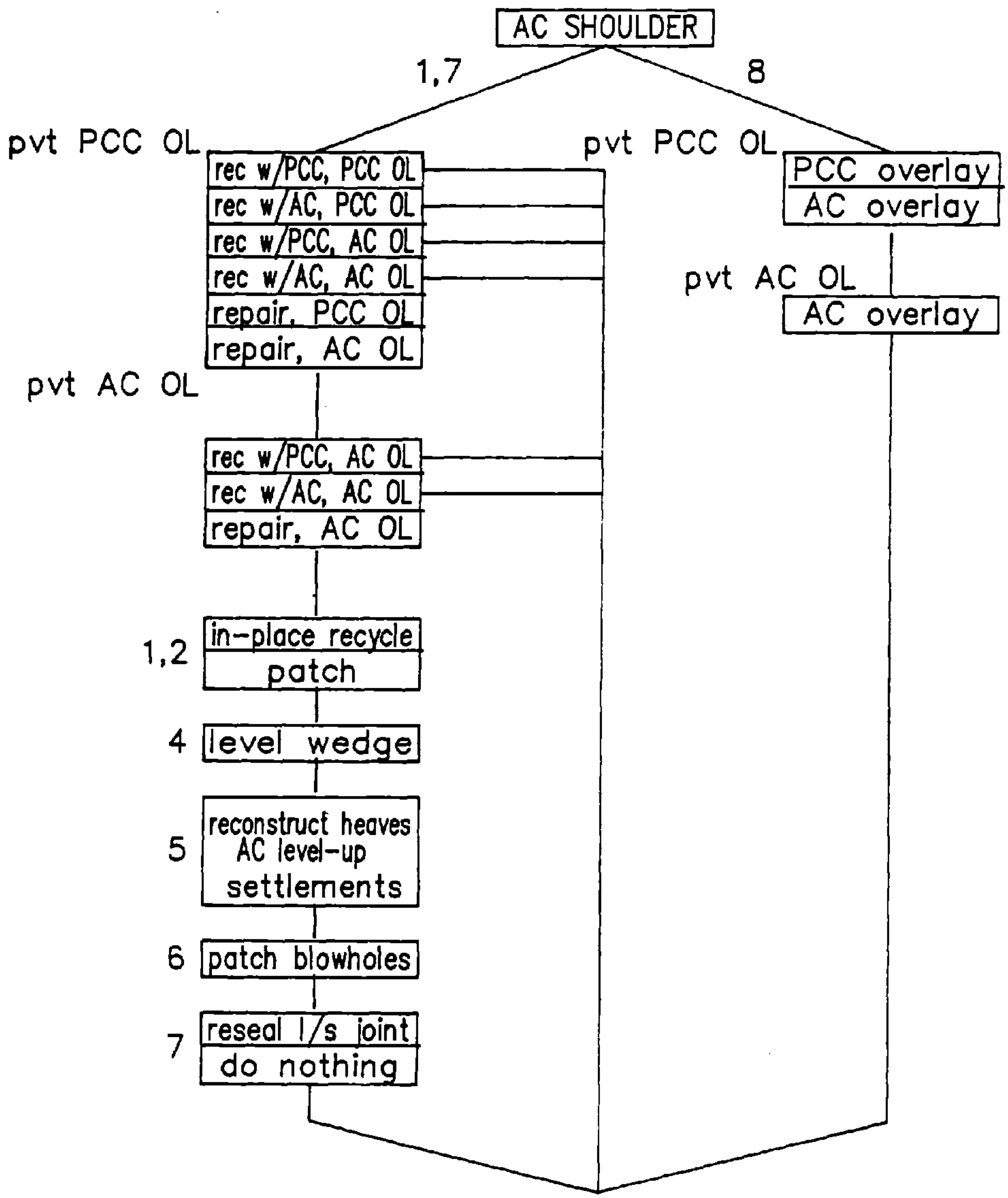


Overlay of CRCP Lane

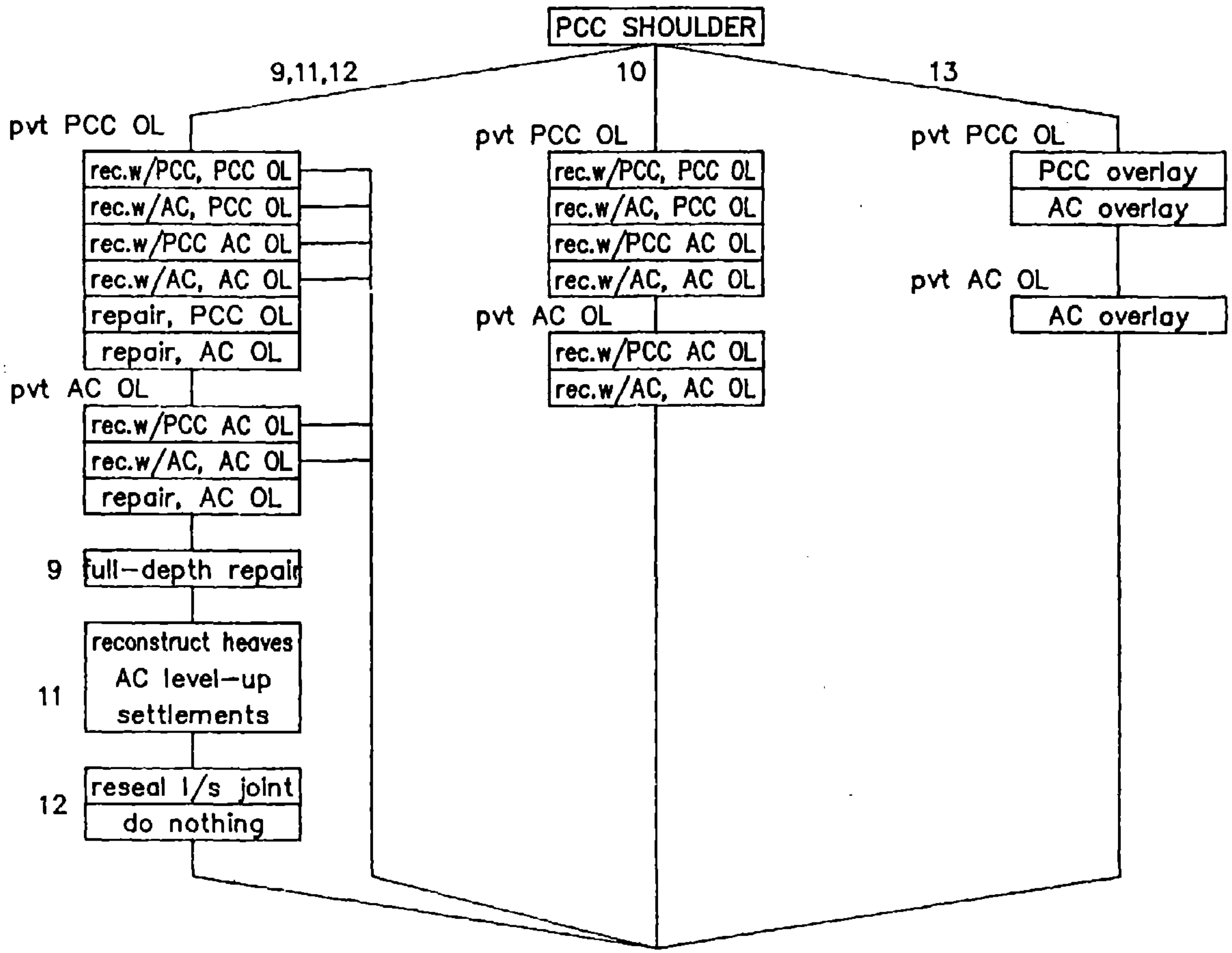



unbonded PCC
AC structural, bonded PCC
RGH
RGH
AC OL
3
AC level-up settlements
3
AC level-up settlements
4
reconstruct heaves
bonded PCC OL
3
slab jack settlements
4
reconstruct heaves
CTT
CTT
1
FDR construction joints
1
FDR construction joints
2
AC level-up terminal treatments
2
AC level-up terminal treatments
4
replace expansion joint
4
replace expansion joint
OUTER LANE DRN
1-9
install/repair subdrains
OUTER SHD *
INNER DRN
INNER LANE SLOPE DIRECTION
out
1-9
install/repair subdrains
1-9
install/repair subdrains
do nothing
INNER SHD *
* see decision tree for rehabilitating shoulder adjacent to overlaid lane

AC Shoulder Rehabilitation Adjacent to Overlaid Lane.

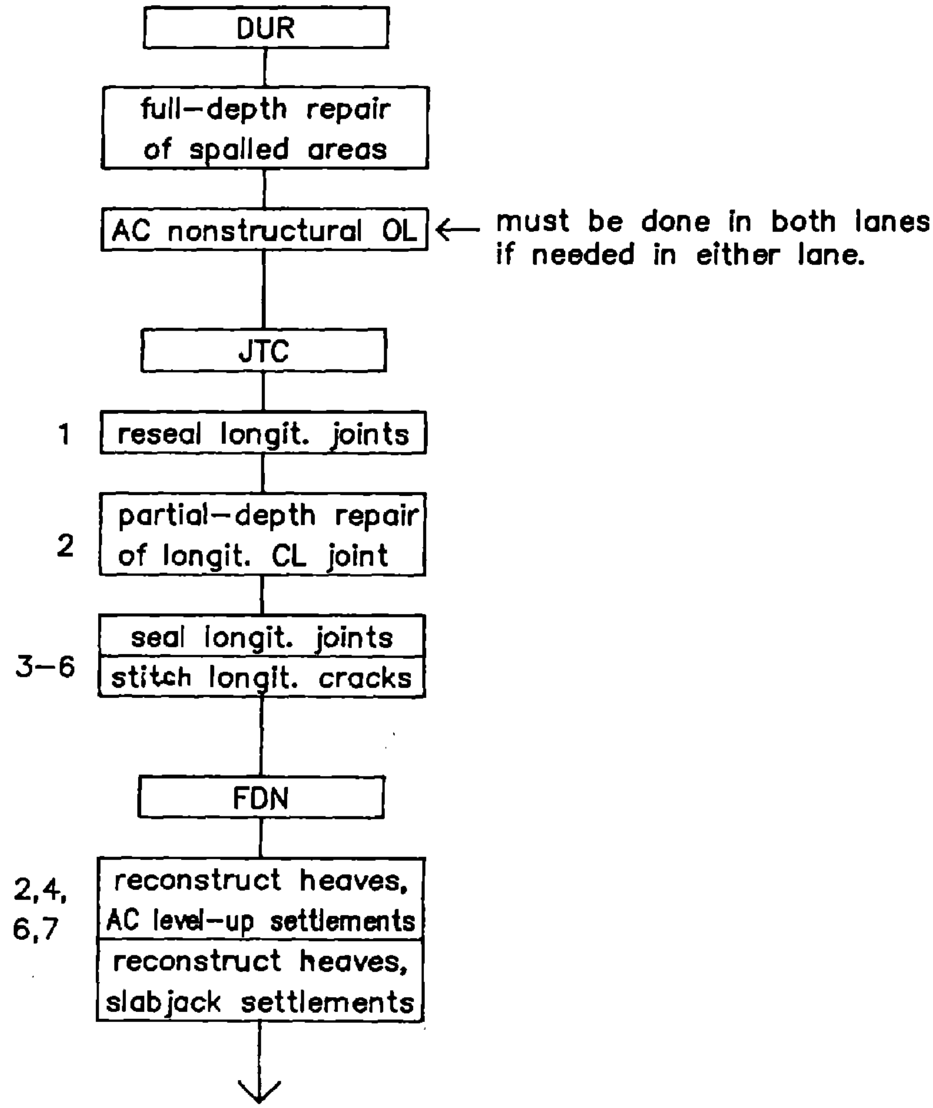


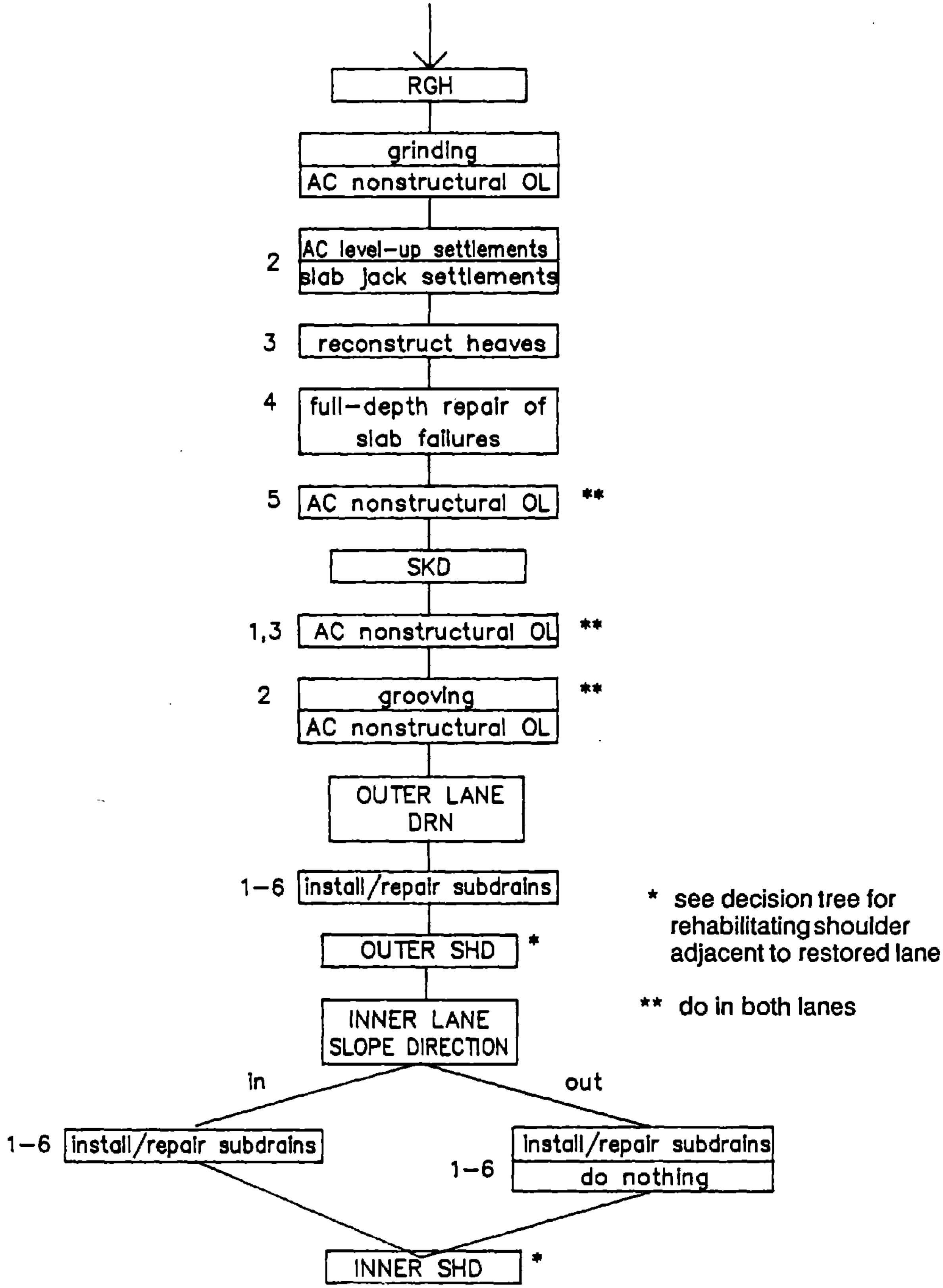
PCC Shoulder Rehabilitation Adjacent to Overlaid Lane



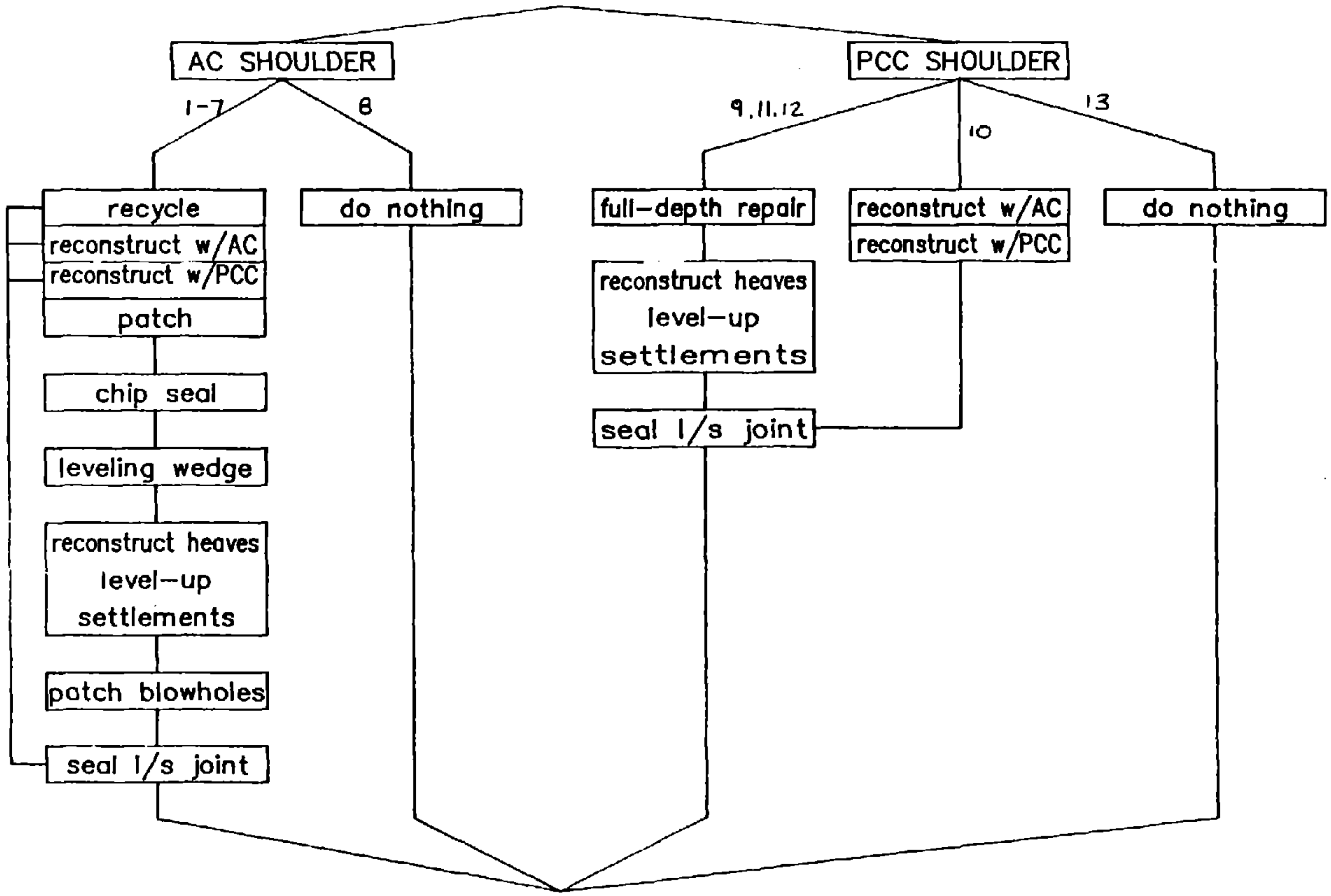
Notes: Pvt PCC OL = bonded PCC OL, unbonded PCC OL
Pvt AC OL = AC structural OL, AC nonstructural OL, crack and seat and AC structural OL

Restoration of a CRCP Lane




RGH
grinding
AC nonstructural OL
2
AC level-up settlements
slab jack settlements
3
reconstruct heaves
4
full-depth repair of slab failures
5
AC nonstructural OL
**
SKD
1,3
AC nonstructural OL
**
2
grooving
AC nonstructural OL
**
OUTER LANE DRN
1-6
install/repair subdrains
OUTER SHD
*
INNER LANE SLOPE DIRECTION
in
out
1-6
install/repair subdrains
1-6
install/repair subdrains
do nothing
INNER SHD
*
* see decision tree for rehabilitating shoulder adjacent to restored lane
** do in both lanes

Shoulder Rehabilitation Adjacent to Restored Lane



APPENDIX C5

CRCP REHABILITATION PERFORMANCE PREDICTION MODELS

Rehabilitation deterioration prediction models were obtained for rutting and reflection cracking of AC overlays, bonded PCC overlays and reconstruction using CRCP. Some of these were modifications of other models as described.

Rutting of AC Overlays

The model used here is the same one that was used for JRCP given in Appendix A5. Each agency must verify this model and modify or substitute a better model before usage. Rutting is highly dependent upon AC mixture characteristics, which varies greatly across the U. S.

Reflection Cracking of AC Overlays of CRCP

This model was obtained from an ongoing study by the University of Illinois and the Illinois Department of Transportation. Reflection cracking data were obtained from 20 projects in Illinois where CRCP had been overlaid with AC. The input data showed the following ranges:

18-kip [80 kN] ESAL: 500,000 to 8,000,000
Thickness of CRCP slab: 7, 8 and 9 in [17.8, 20.3 and 25.4 cm]
AC overlay thickness: 3 to 8 in [7.6 to 20.3 cm]
Age of AC overlay: 1 to 10 years

The following predictive model was developed using nonlinear regression techniques:

$$RCRACK = 535787.[\ PCTHICK^{-5} * ACTHICK^{-2.58} * AGE^{0.982}\ ]$$

Where:

RCRACK = Transverse reflection cracks (medium to high severity), number/mile

PCTHICK = Thickness of concrete slab, in

ACTHICK = Thickness of AC overlay, in

AGE = time since the AC overlay was placed, years

Statistics: $R^2 = 0.53$
SEE = 3.45 cracks/mile [2.16 cracks/km]
n = 20

Bonded PCC Overlay on CRCP

No predictive model exists for this rehabilitation technique. It has been applied to at least three projects: Iowa (1979), Minnesota (1982), and Texas (1985). The Iowa and Minnesota projects were observed during the regular condition surveys for this research contract and the performance is excellent with no structural failures such as punchouts or wide transverse cracks. Based on these observations, the following very approximate procedure was selected.

The CRCP model presented in Appendix C3 will be used and all inputs for the existing pavement used, except for the following. The slab thickness used in the model to project the performance of a bonded PCC overlay will be as follows:

Slab Thickness = Existing CRCP slab + Bonded PCC Overlay - 2 in [5.1 cm]

Therefore, if an existing 8 inch CRCP was being overlayed with a 3 in [7.6 cm] PCC bonded overlay, the slab thickness to be entered into the CRCP failure prediction model would be 8 + 3 - 2 = 9 in [22.9 cm].

A sensitivity analysis of this model shows reasonable performance. However, each agency should verify this model to ensure that it is reasonable for the project under design.

Reconstruction of CRCP

The regular CRCP failure prediction model given in Appendix C3 is used. This model is applicable for reconstruction as well as new construction.

Appendix C6

User's Guide for

EXPEAR

Expert System for Concrete Pavement

Evaluation and Rehabilitation

EXPEAR EXPERT SYSTEM FOR CONCRETE PAVEMENT EVALUATION AND REHABILITATION

CAPABILITIES AND APPLICATIONS

The EXpert system for Pavement Evaluation And Rehabilitation (EXPEAR) was originally developed by the University of Illinois for the Federal Highway Administration and is currently being further developed for the Illinois Department of Transportation. EXPEAR is an advisory system to assist the practicing engineer in evaluating a specific pavement section and selecting rehabilitation alternatives.

An EXPEAR program currently exists for each of three pavement types: JPCP, JRCP, and CRCP. Programs for AC-overlaid pavements and other AC pavements are under development. The current version of the system is EXPEAR 1.3, which includes the capabilities to delay rehabilitation for up to 5 years and to perform life-cycle cost analysis of rehabilitation alternatives.

INPUTS

Project-level evaluation using EXPEAR begins with the collection of some basic design, construction, traffic, and climate data for the project in question, and a visual condition survey. Back in the office, the design and condition data are entered into EXPEAR by the engineer using a full-screen editor. The program extrapolates the overall condition of the project from the distress data for one or more sample units.

ENGINEERING LOGIC

EXPEAR evaluates the project in several key problem areas related to specific aspects of performance for that pavement type. For example, the problem areas for JPCP and JRCP are: structural adequacy, roughness, drainage, joint deterioration, foundation movement, skid resistance, joint sealant condition, joint construction, concrete durability, load transfer, loss of support, and shoulders. The evaluation is performed using decision trees which compare the pavement's condition to predefined critical levels for key design and distress variables. EXPEAR produces a summary of the deficiencies found, and by interacting with the engineer, formulates a rehabilitation strategy which will correct all of the deficiencies. The major rehabilitation options are: reconstruction of both lanes, reconstruction of the outer lane and restoration of the inner lane, bonded or unbonded PCC overlay, AC overlay, crack and seat and AC overlay, and restoration. Appropriate repair techniques for the shoulders which are compatible with the mainline pavement rehabilitation strategy are also selected.

PERFORMANCE PREDICTION AND COST ANALYSIS

A large number of predictive models for concrete pavement performance with and without rehabilitation are incorporated into EXPEAR. Some of the models were developed from national databases of new construction and rehabilitation projects, while others were developed using data from Illinois pavements. The models allow the engineer to predict the performance of the rehabilitation strategy developed. This information is then used, along with rehabilitation unit costs (either default values built into the program or values provided by the engineer) to compute the cost of the strategy over the predicted life.

OUTPUTS

EXPEAR produces a summary of the project's data file, the evaluation results, recommendations for physical testing, predictions of the pavement's future condition without rehabilitation, and rehabilitation techniques, performance predictions, and cost calculations for as many rehabilitation strategies as the engineer wishes to investigate.

REFERENCES AND FURTHER INFORMATION

References on EXPEAR:

Hall, K. T., M. I. Darter, S. H. Carpenter, and J. M. Connor, "Concrete Pavement Evaluation and Rehabilitation System," Rehabilitation of Concrete Pavements, Volume 3, Federal Highway Administration Report No. FHWA/RD-88/073, April 1989.

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Questions or comments about EXPEAR:

Dr. Michael I. Darter
1212 Newmark CE Lab
205 North Mathews
Urbana, IL 61801

(217) 333-6253

Kathleen T. Hall
1206 Newmark CE Lab
205 North Mathews
Urbana, IL 61801

(217) 333-5966

1.0 INTRODUCTION

The objective of this research effort was to develop a practical and comprehensive system to assist practicing engineers in evaluating concrete highway pavements, identifying types of deterioration present and determining their causes, selecting rehabilitation techniques which will effectively correct existing deterioration and prevent its recurrence, combining individual rehabilitation techniques into feasible rehabilitation strategies, and predicting the performance of rehabilitation strategy alternatives.

EXPEAR is intended for use by state highway engineers in project-level rehabilitation planning and design for high-type (i.e., Interstate) conventional concrete pavements (JRCP, JPCP, and CRCP). EXPEAR does not perform thickness or joint design, the engineer must use existing design procedures to determine these details.

EXPEAR has been developed in the form of a knowledge-based expert system, which simulates a consultation between the engineer and an expert in concrete pavements. EXPEAR uses information about the pavement provided by the engineer to guide him or her through evaluation of a pavement's present condition and development of one or more feasible rehabilitation strategies. The procedure was developed through extensive interviewing of authorities on concrete pavement performance. In addition, predictive models are included to show future pavement performance with and without rehabilitation.

Evaluation of a pavement and development of feasible rehabilitation alternatives is performed according to the following steps:

1. Project data collection.
2. Extrapolation of overall project condition.
3. Evaluation of present condition.
4. Prediction of future condition without rehabilitation.
5. Recommendations for physical testing.
6. Selection of main rehabilitation approach.
7. Development of detailed rehabilitation strategy.
8. Prediction of rehabilitation strategy performance.
9. Cost analysis.
10. Selection of preferred rehabilitation strategy.

A computer program has been developed for each of the three pavement types addressed. The programs operate on any IBM-compatible personal computer. Use of the programs is highly recommended due to the complexity of the manual procedure.

2.0 PAVEMENT EVALUATION

Data Collection and Entry

The engineer collects key inventory and monitoring data for the project. Inventory data, which should be available from office records, includes design traffic, materials, soils and climate. Monitoring data includes distress, drainage characteristics, rideability, and other items collected during a field visit to the project. Monitoring data is collected by sample unit; a sufficient number of sample units distributed throughout the projects's length should be surveyed to obtain an accurate representation of the project's condition.

It is recommended that a team of two engineers perform the project survey together. They should drive over the entire length of the project and rate the present serviceability in each lane. They should also note the number and location of settlements and heaves. They should then return to the start of the project and perform the distress survey by sample unit. It is convenient to start sample units at mileposts.

The pavement distress identification manual provided in NCHRP Report No. 277 should be used for reference. It provides standard definitions for distresses by type, severity, and unit of measurement. It also provides photographs of distresses to assist the engineers in rating their severity. The engineers must also measure faulting at joints, cracks, and full-depth repair joints.

In the office, the data are entered into a personal computer using a full-screen editor. The format of the data entry screens is very similar to that of the field survey sheets. The editor provides function keys for moving forward and backward through the data items and screens. The editor will provide screens for inventory data (one set for each sample unit, up to a maximum of ten).

Extrapolation of Overall Project Condition

Using the project length and lengths of the sample units, EXPEAR extrapolates from the sample unit distress data to compute the overall average condition of the project. The project is then evaluated on the basis of this average condition.

Evaluation of Present Condition

EXPEAR utilizes a set of decision trees to analyze all of the data and develop a specific detailed evaluation in several major problem areas, including roughness, structural adequacy, joint deterioration, foundation movement, skid resistance, construction deficiencies, drainage, loss of support, joint sealant condition, concrete durability, and shoulder condition. From the evaluation, a set of evaluation conclusions is produced for each traffic lane and each shoulder.

Prediction of Future Condition Without Rehabilitation

Based on the current traffic level (annual 18-kip ESAL) and the anticipated ESAL growth rate, the future condition of the pavement without rehabilitation is predicted. Faulting, cracking, joint deterioration, pumping, and present serviceability rating are projected for jointed pavements (and punchouts for CRCP) and the years in which they will become serious problems are identified. The predictive models used are calibrated to the existing condition of the pavement at the time of the survey.

Physical Testing Recommendations

The initial data collection does not require physical testing. Based upon the available information, the program identifies types of physical testing needed to verify the evaluation recommendations and to provide data needed for rehabilitation design. Testing may include nondestructive deflection testing, coring/material sampling and laboratory testing, and roughness and friction measurement. Types of deficiencies which may warrant physical testing include structural inadequacy, poor rideability, poor surface friction, poor drainage conditions, poor concrete durability ("D" racking or reactive aggregate distress), foundation movement (due to swelling soil or frost heave), loss of load transfer at joints, loss of slab support, joint deterioration, and evidence of poor joint construction.

3.0 PAVEMENT REHABILITATION

Selection of Main Rehabilitation Approach

Based upon the evaluation results, the system interacts with the engineer to select the most appropriate main rehabilitation approach for each traffic lane and shoulder. These include all 4R options: reconstruction (including recycling), resurfacing (with concrete or asphalt), or restoration. The major factors in determining whether a pavement needs reconstruction, resurfacing, or merely restoration are the extent of structural distress (e.g., cracking and corner breaks) and the extent of deterioration due to poor concrete durability ("D" cracking or reactive aggregate distress).

Development of Detailed Rehabilitation Strategy

Once an approach is selected for each traffic lane and shoulder, the engineer proceeds to develop the detailed rehabilitation alternative by selecting a feasible set of individual rehabilitation techniques to correct the deficiencies present. This may include such items as subdrainage, shoulder repair, full-depth repairs, joint resealing, etc. This is performed for each traffic lane and shoulder by interaction with the system. The system displays each of the evaluation conclusions reached earlier and recommends one or more appropriate rehabilitation techniques. A set of decision trees has been developed to guide the rehabilitation strategy development process for traffic lanes and for adjacent shoulders. Where more than one choice exists for an appropriate technique to repair a specific distress, the system presents the engineer with the choice to make.

Computation of Rehabilitation Quantities

EXPEAR computes needed quantities for the rehabilitation techniques selected based on the data in the project survey and additional information rovided by the engineer. In general, the program assumes that 100 percent repair will be performed; that is, that the quantity of a certain type of distress to be repaired is equal to the quantity of that distress observed during the field survey.

If the rehabilitation work is being delayed, the quantities are increased where appropriate for each year

the user are necessary; EXPEAR will detect what type of monitor is available and whether or not a math chip is present.

Each of the three EXPEAR versions (for the three pavement types: JPCP, JRCP, and CRCP) is distributed on a set of two 360 K, 5.25-inch floppy disks. One disk contains the executable program (EXPEAR.EXE) and the other disk contains several other files needed to run EXPEAR.

One other note about the disk files: several of the file names (EXPEAR.EXE, DISPLAYS.REC, STNDRD.DAT, etc.) are common to the programs for all three pavement types (JRCP, JPCP, and CRCP), so if you want to run the programs for different pavement types, keep them on separate disks! If you copy them to a hard disk, place them in different directories.

Running EXPEAR

After the EXPEAR title screen and a few screens of introductory information, the system displays the main menu, which has four options:

1. ENTER OR EDIT PROJECT DATA
2. CONDUCT PROJECT EVALUATION
3. DEVELOP REHABILITATION STRATEGY
4. QUIT, RETURN TO DOS

Enter or Edit Project Data

When this option is selected, a menu will appear to ask whether you want to create a new data file or edit an existing file. A new data file is created by modifying the STNDRD.DAT file. If an existing data file is to be modified, the program will ask for the name of the data file without the .DAT extension.

A full-screen data editor is incorporated into the system for data entry and editing. Function keys for moving through the data items and screens are defined at the bottom of the screen. Some data items are defined as "toggle variables," meaning that you can toggle through the available values (such as low, medium, high) using the tab key. The editor will tell you which data items are toggle variables. When you are finished editing the file, SHIFT-10 will exit the editor. This command does not however, save the file on disk. The program will prompt you to save the file before continuing.

Conduct Project Evaluation

When this option is selected, the program asks for the name of the data file to be evaluated. It also asks whether you want to use the default critical distress levels incorporated in the program, or use your own values. These may be selected each time you run the program, or may be saved to disk and retrieved when needed. The program will prompt you for a file name for your critical distress values and save it with a .CVL extension. Whether using your own values or the default values, you must select critical distress levels before proceeding with the evaluation.

The evaluation runs very quickly. When it is done, EXPEAR will display the results of the evaluation, which consists of evaluation conclusions for the traffic lanes and shoulders, predicted performance without rehabilitation, and physical testing recommendations.

EXPEAR will ask if you want to print the data summary file and the project evaluation summary file. You may print these from the program, or exit to DOS and print the output files with .REP and .TXT extensions.

Develop Rehabilitation Strategy

When this option is selected, EXPEAR interacts with you to select the main rehabilitation approach (reconstruct, overlay, or restore) and the specific rehabilitation techniques needed to correct the deficiencies identified in the evaluation. EXPEAR recommends appropriate rehabilitation approaches and techniques and gives you the option to choose whenever more than one appropriate technique exists. EXPEAR does not have the capability to permit you to enter options other than the ones given. When the rehabilitation strategy has been developed, it will be displayed along with approximate quantities (in some instances additional information must be provided for computing quantities, such as size of full-depth repairs). You may print the strategy and quantities out from the program, or exit to DOS and print the output file with the .STS extension.

After a strategy has been developed, a menu appears with the following options:

1. REVISE REHABILITATION STRATEGY
2. PREDICT REHABILITATION PERFORMANCE
3. PERFORM LIFE-CYCLE COST ANALYSIS
4. RETURN TO MAIN MENU

The second option will predict the performance of the rehabilitation strategy developed, using predictive models for key distresses. EXPEAR may prompt you for additional information needed, such as thickness of overlay. After the program finishes computing the predicted performance, it will display the predictions. You may print these out from the program or exit to DOS and print the output file with the .RHB extension.

Only after a rehabilitation strategy has been developed and its performance predicted can a cost analysis of the strategy be performed. EXPEAR will prompt you for a discount rate and delay to be used in the program, and will also ask you to select unit cost values for the rehabilitation techniques. You may use the default unit costs provided, or (in the same manner as for the critical distress levels), save a file containing your own set of unit costs to disk (the extension will be .UCC), and retrieve it when needed.

The program computes the present costs over the project length for the rehabilitation strategy analyzed. The results are displayed on the screen and may be printed from the program or from DOS (the extension is .LCC).

Each set of EXPEAR disks includes an example data file for that pavement type. The example files for the three programs are:

JRCP: I74183, on I-74 near Urbana, Illinois
JPCP: I10191, on I-10 near Tallahassee, Florida
CRCP: I57230, on I-57 near Champaign, Illinois

Comments, questions, or suggestion for improvements to EXPEAR or this User's Guide are very welcome. Please direct them to Ms. Kathleen T. Hall or Dr. Michael I. Darter at the University of Illinois. The addresses and phone numbers are given in the introductory screens of the EXPEAR programs.

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