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16. Abstract

This report briefly describes the major accomplishments of Research Study 249, which can be classified within three main areas: (1) condition surveys, (2) network level analysis, and (3) project level analysis. First, condition survey data processing is discussed. Collection and processing of data vary with type of pavement [continuously reinforced concrete pavement (CRCP) and jointed concrete pavement (JCP)] and level of analysis (project and network).

Second, the development of a scheme for prioritizing and scheduling rehabilitation of a rigid-pavement network is summarized. Program PRP01 schedules rehabilitation of rigid pavements (JCP, JRCP, and CRCP) within a certain design period. This program requires as input data condition survey information for every project in the network being analyzed. A list of candidate projects for rehabilitation is printed out by PRP01 for each year of the design period.

Third, certain improvements to the Texas SDHPT procedure for rigid pavement overlay design (RPOD2) are outlined and the main features of program RPRDS-1 are briefly presented. This project-level program permits simultaneous analysis of various rigid-pavement rehabilitation strategies and lists the top 20 feasible strategies in order of increasing net present value. Three different types of overlay are considered by RPRDS-1: ACP, CRCP, and JCP.

A summary of the 1982 CRCP condition survey in Texas is also included in this report. Results from this statewide monitoring are compared with those corresponding to the condition surveys previously conducted.

17. Key Words
rigid pavements, continuously reinforced concrete pavements (CRCP), condition surveys, rigid pavement network rehabilitation scheduling, design system

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Research Report 249-8F

Implementation of a Rigid Pavement Overlay and Design System
Research Project 3-8-79-249

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

November 1983

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

Research Report 249-8F, "Summary and Recommendations for the Implementation of a Rigid Pavement Overlay and Design System," is the eighth and final report for Research Project 249, "Implementation of a Rigid Pavement Overlay and Design System," which was conducted at the Center for Transportation Research (CTR), The University of Texas at Austin, as part of the Cooperative Highway Research Program sponsored by the Texas State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration (FHWA).

The purpose of this final report is to summarize some of the findings that led to the development and implementation of both a rigid pavement design system at the project level and a network planning scheme to assist management authorities in the prioritization, scheduling, and budgeting of maintenance and rehabilitation of rigid pavements. Additionally, a brief description of the collection, processing, and storage of condition survey data is also provided.

We are indebted to all members of the CTR staff and to graduate students and professors of the Civil Engineering Department who participated in the various activities of Research Project 249. However, special acknowledgement is made to Alberto Mendoza and Jeff Kessel, who prepared the material presented in Chapter 5, and Mike Hunt for his collaboration regarding condition survey data processing. The assistance of Dr. Manuel Gutierrez de Velasco in the different stages of this research project is also appreciated. Thanks are extended to the Texas State Department of Highways and Public Transportation personnel for their cooperation, in particular Gerald B. Peck and Richard Rogers (D-8).

B. Frank McCullough
Victor Torres-Verdin
W. Ronald Hudson

LIST OF REPORTS

Report No. 249-1, "Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure," by Arthur Taute, B. Frank McCullough, and W. Ronald Hudson, presents certain improvements to the Texas Rigid Pavement Overlay Design Procedure (RPOD2) with regard to materials characterization and fatigue life predictions. March 1981.

Report No. 249-2, "A Design System for Rigid Pavement Rehabilitation," by Stephen Seeds, B. Frank McCullough, and W. Ronald Hudson, describes the development, use and applicability of a Rigid Pavement Rehabilitation Design System, RPRDS, developed for use by the Texas State Department of Highways and Public Transportation. June 1981.

Report No. 249-3, "Void Detection and Grouting Process," by Francisco Torres and B. Frank McCullough, presents the results of an experiment and a theoretical analysis to determine an optimum procedure for detecting voids beneath CRC pavements. February 1982.

Report No. 249-4, "Effect of Environmental Factors and Loading Position on Dynaflect Deflections in Rigid Pavements," by Victor Torres-Verdin and B. Frank McCullough, discusses several of the factors that affect Dynaflect deflections in rigid pavements and provides a recommended procedure for Dynaflect deflections measurements which can be implemented in the rigid pavement overlay design procedures. February 1982.

Report No. 249-5, "Rigid Pavement Network Rehabilitation Scheduling Using Distress Quantities," by Manuel Gutierrez de Velasco and B. F. McCullough, presents the development and application of a computer program, PRP01, to prioritize and schedule a set of rigid pavements for rehabilitation within a specified time frame and budget constraints. August 1982.

Report No. 249-6, "Design Charts for the Design of HMAC Overlays on PCC Pavements to Prevent Reflection Cracking," by Alberto Mendoza Diaz and B. F. McCullough, presents the development of a series of nomographs and charts for use by the Texas State Department of Highways and Public Transportation as a supplementary tool in the design of asphalt concrete hot mix (ACHM) overlays on portland cement concrete (PCC) pavements against reflection cracking. November 1983.

Report No. 249-7, "The Effect of Coarse-Aggregate Type on CRCP Thickness," by Victor Torres-Verdin, B. Frank McCullough, and Gerald B. Peck, describes the effect of coarse aggregate type on the performance of CRC pavements and presents the development of thickness equivalencies between a limestone and a siliceous river gravel CRCP. November 1983.

Report No. 249-8F, "Summary and Recommendations for the Implementation of a Rigid Pavement Overlay and Design System," by B. Frank McCullough, Victor Torres-Verdin, and W. Ronald Hudson, summarizes important findings that resulted in the development and implementation of both a rigid pavement design system at the project level and a scheme for prioritizing and scheduling rehabilitation of a rigid-pavement network. November 1983.

ABSTRACT

This report briefly describes the major accomplishments of Research Project 249, which can be classified within three main areas: (1) condition surveys, (2) network-level analysis, and (3) project-level analysis.

First, condition survey data processing is discussed. Collection and processing of data vary with type of pavement [continuously reinforced concrete pavement (CRCP) and jointed concrete pavement (JCP)] and level of analysis, (project and network).

Second, the development of a scheme for prioritizing and scheduling rehabilitation of a rigid-pavement network is summarized. Program PRP01 schedules rehabilitation of rigid pavements (JCP, JRCP, and CRCP) within a certain design period. This program requires as input data condition survey information for every project in the network being analyzed. A list of candidate projects for rehabilitation is printed out by PRP01 for each year of the design period.

Third, certain improvements to the Texas SDHPT procedure for rigid pavement overlay design (RPOD2) are outlined and the main features of program RPRDS-1 are briefly presented. This project-level program permits simultaneous analysis of various rigid-pavement rehabilitation strategies and lists the top 20 feasible strategies in order of increasing net present value. Three different types of overlay are considered by RPRDS-1: ACP, CRCP, and JCP.

A summary of the 1982 CRCP condition survey in Texas is also included in this report. Results from this statewide monitoring are compared with those corresponding to the condition surveys previously conducted.

KEYWORDS: Rigid pavements, continuously reinforced concrete pavements (CRCP), condition surveys, rigid pavement network rehabilitation scheduling, rigid pavement design system at the project level.

SUMMARY

The major accomplishments of Research Project 249 are outlined in this final report. These are presented in four different chapters. The collection, processing, and storage of condition survey data, according to the type of rigid pavement analyzed, are briefly described. The development of a scheme for prioritizing and scheduling rehabilitation of a rigid-pavement network is summarized, along with the principal features of program PRP01. Then, several improvements to the Texas SDHPT procedure for rigid pavement overlay design (RPOD2) are discussed, and a general description of a rigid pavement rehabilitation system, RPRDS-1, is provided. Data from the 1982 CRCP statewide condition survey are presented in tables and graphs, and comparisons are made with data collected in previous years. Finally, conclusions and recommendations are drawn from the major findings of Research Project 249.

IMPLEMENTATION STATEMENT

It is recommended that the programs and models developed in Research Project 249 be implemented on the procedures currently in use by the Texas State Department of Highways and Public Transportation, at both the network and the project levels. Analysis and enlargement of the information stored in the condition survey data base will result in significant improvements to the different types of models considered in the mechanistic procedures for design of rigid pavements and overlays.

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CHAPTER 3. DEVELOPMENT OF A RIGID PAVEMENT REHABILITATION AND MAINTENANCE SCHEME AT THE NETWORK LEVEL

CHAPTER 4. DEVELOPMENT OF A RIGID PAVEMENT DESIGN SYSTEM AT THE PROJECT LEVEL

CHAPTER 5. SUMMARY OF THE 1982 CRCP CONDITION SURVEY IN TEXAS

CHAPTER 6. SPECIAL STUDIES

CHAPTER 1. INTRODUCTION

BACKGROUND

The planning and design activities related to providing new portland cement concrete (PCC) pavements or rehabilitating and maintaining existing ones are of capital importance to the primary highway system of the State of Texas. An improved rigid pavement overlay design method was developed by the Center for Transportation Research (CTR) of The University of Texas at Austin in Research Project 117, "Development and Implementation of the Design, Construction, and Rehabilitation of Rigid Pavements" and was made available to the Texas State Department of Highways and Public Transportation (SDHPT) for implementation on its computer facilities. The results defined the course of the investigation to be conducted in Research Project 249, "Implementation of a Rigid Pavement Overlay and Design System."

An extensive data base, which includes information on rigid pavements and data-processing computer programs, was started in Project 177 and continued in Project 249. The information gathered came from in-service pavements (such as CRCP rigid-pavement overlays, and experimental maintenance sections). The type of information collected included materials and environmental factors, riding quality, distress condition, deflection, and traffic volume.

At the network level, procedures were developed and improved for data collection for both rural and urban CRCP in Project 177. Furthermore, a methodology was provided in this project to estimate whether a given pavement has reached its terminal condition by means of a distress index developed from analysis of field data on overlaid and non-overlaid pavement sections.

In 1978, the Texas SDHPT started its own research to develop a rigid pavement overlay design system at the network level. This design procedure uses advanced analytical techniques to predict pavement response and extends the AASHO Road Test data to the analysis of overlays. The design philosophy of this method is to provide an overlay thickness that will minimize the occurrence of both fatigue and/or reflection cracking.

OBJECTIVES OF RESEARCH PROJECT 249

The original general objective of Project 249 was to implement and improve the overlay design method developed in Project 177 for the Texas SDHPT. This overall objective was further divided into the following particular subobjectives:

(1) refinement of the rigid pavement overlay design method to include costs and optimization techniques,
(2) continuous monitoring of rigid-pavement sections that have been overlaid as well as evaluation of innovative maintenance and rehabilitation techniques, and
(3) development and implementation of a design procedure to prevent and/or control reflection cracking in asphaltic concrete overlays.

In the last stage of Project 249, the original objective had to be expanded to include subobjective 4:

(4) development of a scheme for prioritizing and scheduling rehabilitation of a set of rigid pavements.

For the purpose of this report, these subobjectives have been divided into five broad areas:

(1) collection and processing of condition survey information,
(2) development of a rigid pavement rehabilitation and maintenance scheme at the network level,
(3) development of a rigid pavement design system at the project level,
(4) summary of CRCP condition survey information gathered in Project 249, and
(5) special studies.

SUMMARY OF ACCOMPLISHMENTS

Figure 1.1 shows the research reports and their areas of application within a framework based on by the objectives of Project 249.

The research activities are divided into three major areas: (1) condition surveys, (2) network-level analysis, and (3) project-level analysis.

The following are the most significant accomplishments from Project 249:

(1) A network planning scheme to assist management authorities in the prioritization, scheduling, and budgeting of maintenance and rehabilitation of rigid pavements.

(2) Several improvements to the rigid-pavement overlay design system, which include

   (a) an improved detailed condition survey procedure for both jointed and CRC pavements,

   (b) a materials characterization procedure using Dynaflect deflections in conjunction with laboratory testing,

   (c) an improved fatigue overlay design method, which includes costs and optimization techniques, and

   (d) the development of charts for designing overlay thickness to prevent reflection cracking.

(3) Further expansion of the condition survey data base by continued monitoring of rigid pavements, overlays, and experimental sections.

(4) Special projects, such as evaluation of the grouting operation to fill voids beneath the surface layer of CRC pavements.

SCOPE OF REPORT

This report summarizes work accomplished in Project 249.

Chapter 2 deals with a discussion on the collection and processing of condition survey information. Emphasis is placed on the different computer programs available in the CTR for analyzing condition survey data.

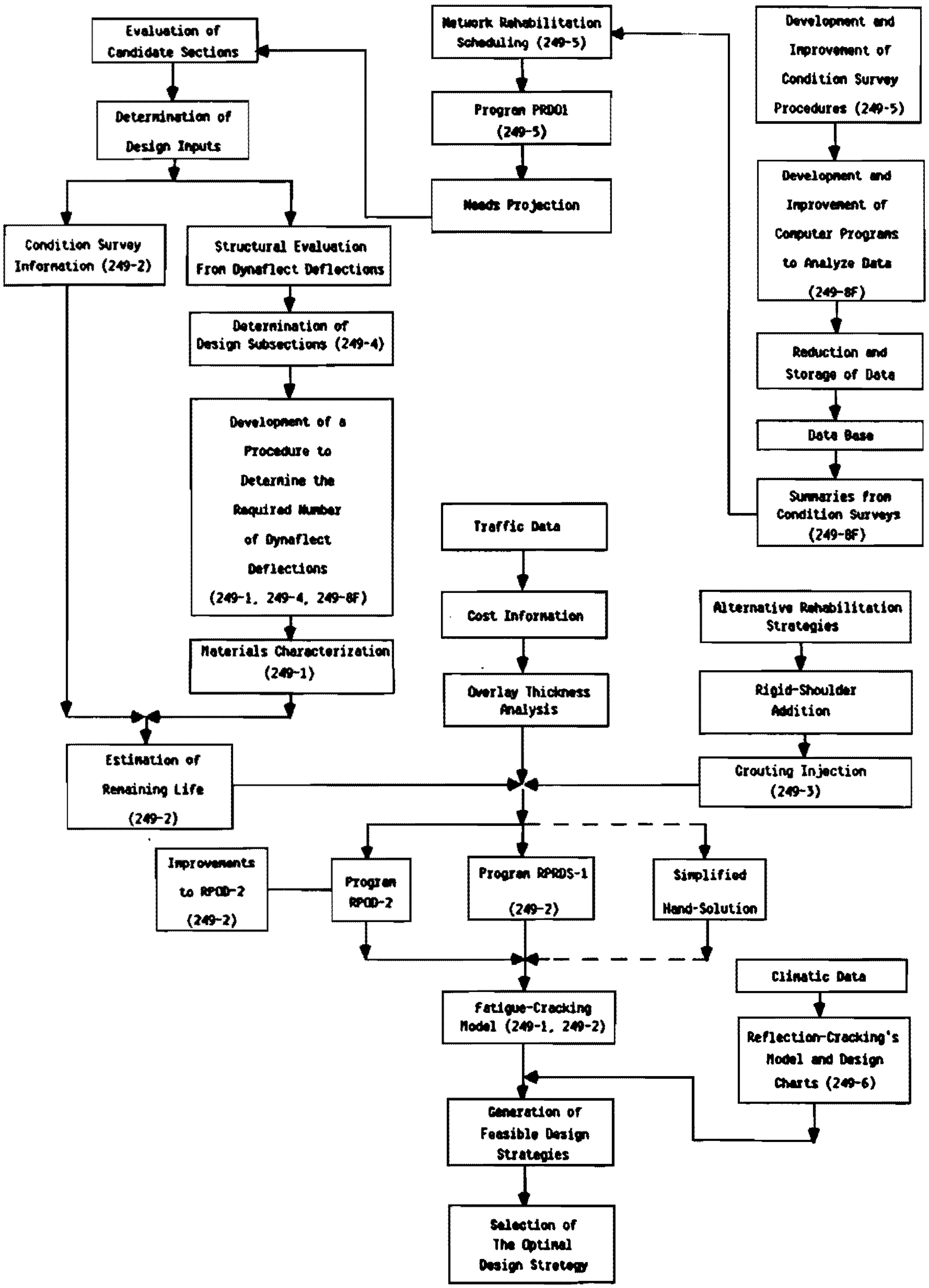


Fig 1.1. Area of application of the various reports prepared in Research Project 249.

249 8 001

Chapter 3 is used to describe the development of a rigid-pavement rehabilitation and maintenance scheme at the network level. There is a brief discussion of computer program PRP01 and its basic algorithm.

The development of a rigid-pavement design system at the project level is presented in Chapter 4. First, there is a description of improvements to the materials characterization and fatigue life prediction methods of the Texas rigid pavement overlay design procedure. This chapter also summarizes the basic principles of a design system for rigid pavement rehabilitation.

Tables and plots are used in Chapter 5 to provide a summary of the CRCP condition survey information gathered in Project 249.

Some special studies that are indirectly related to this project's objectives are briefly described in Chapter 6.

Chapter 7 presents general conclusions and recommendations based on the findings from Project 249.

Input guides to some of the computer programs developed in this project are provided in the appendix.

CHAPTER 2. CONDITION SURVEY DATA PROCESSING

INTRODUCTION

The primary objective of Project 249 was to develop a design method to enable the Texas Department of Highways to keep the Texas road network at its optimal performance level a sound economical basis. A condition survey of the existing road network is the first step in the design method. With the data collected by the survey, a network-level analysis can be done to determine candidate road sections most in need of repair. Once road sections have been designated as needing repair, project-level analysis can be performed to determine the least costly strategy for rehabilitating the road.

Two levels of condition surveys need to be performed. The network-level condition survey gathers standard general information about all the roads to determine those most in need of rehabilitation. The project-level survey gathers detailed information on the distress manifestations of overlaid sections, which is used to evaluate the adequacy of overlay designs.

The activities involved in the network-level analysis include the reduction and storage of the collected data. Also included are the development and improvement of survey procedures and of computer programs to analyze the data. Two major goals of the network-level analysis are to produce input for the computer program PRP01 and to generate summaries of the condition survey.

The primary objective of the project-level analysis is to provide information for use in overlay design. Activities include generating several feasible design strategies for overlaying a particular section and selecting the optimal design strategy. Computer program RPRDS-1 is used to help determine feasible designs.

CONDITION SURVEYS

Network Level

The Texas road network is surveyed to gather information to prioritize pavement sections that require maintenance or rehabilitation. The pavement sections are divided into two major groups: (1) continuously reinforced concrete pavements (CRCP) and (2) jointed concrete pavements (JCP).

Surveys were conducted in 1974, 1976, 1978, 1980, 1981, and 1982. CRCP rural districts were surveyed in 1974, 1978, 1980, and 1982; CRCP urban districts were surveyed in 1976 and 1981; and JCP districts were surveyed in 1982. Reference 1 has a complete description of the procedures used for all the surveys.

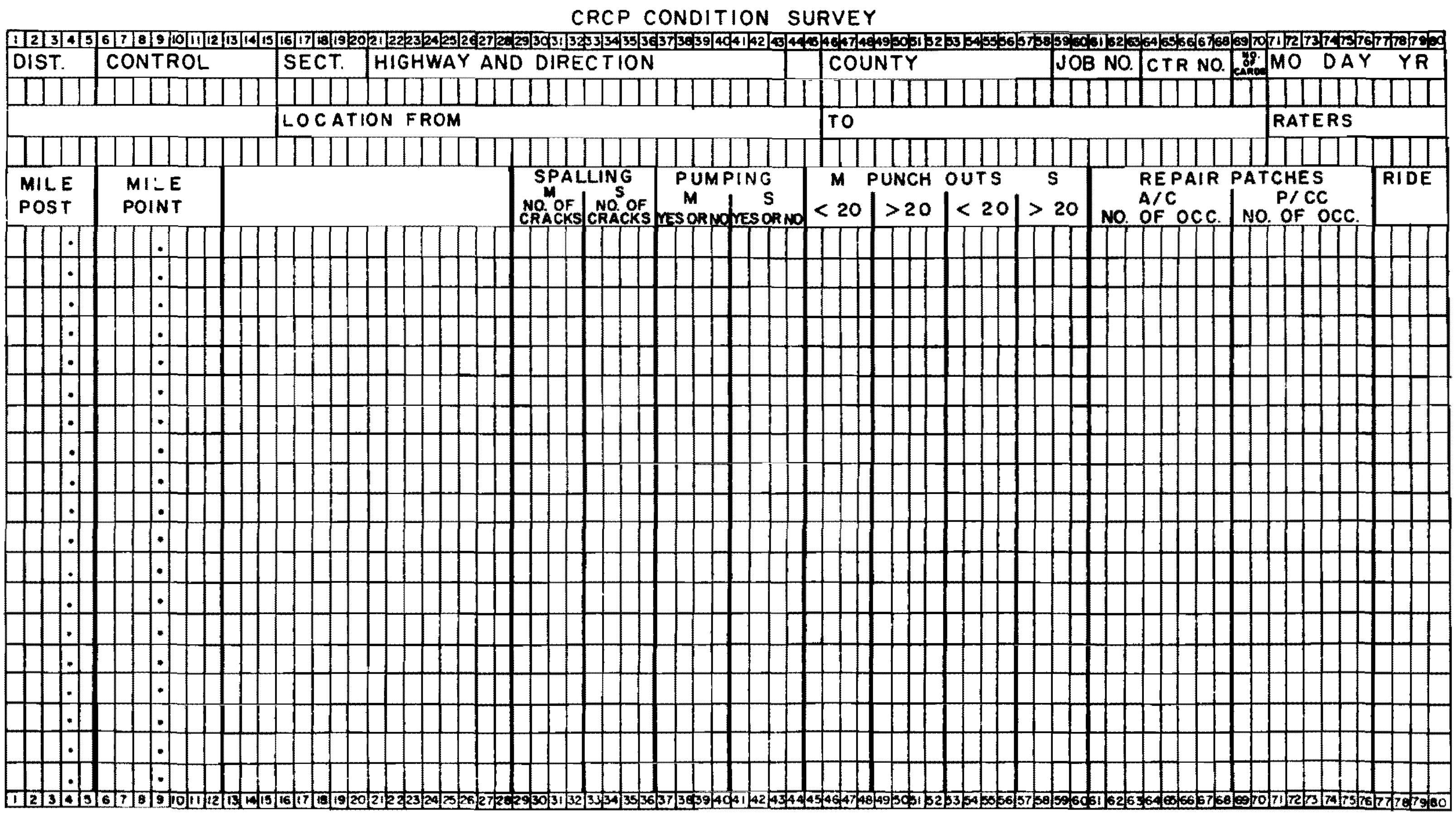
Figure 2.1 shows the form used to collect the 1982 CRCP data. Reference 1 also discusses the proposed procedure for the 1982 JCP survey. This procedure was followed for the actual survey (Fig 2.2) except in Districts 2, 15, and 18. These three districts used a different survey form for recording the data (Fig 2.3). On this form there is a column labeled "failures", which encompasses the most severe condition of the following distress types: transverse cracks, longitudinal cracks, spalls, corner breaks, patches, and faults.

To uniquely identify the surveyed projects, each project is given a permanent five-digit identifying number. The first two digits correspond to the number of the district in which the project is located. The last three digits are numerically sequenced (starting at 001), based on the construction site of the project: the earlier the construction date, the lower the number. Appendix A describes the data input formats for various types of projects surveyed and their identification information.

Appendix A in Reference 1 has a detailed description of the distress manifestations included in the CRCP and JCP surveys as well as other details associated with these surveys.

Project-Level

The various project-level surveys are described in detail in Appendix A of Reference 1. Detailed descriptions of the distress manifestations



CRCP CONDITION SURVEY

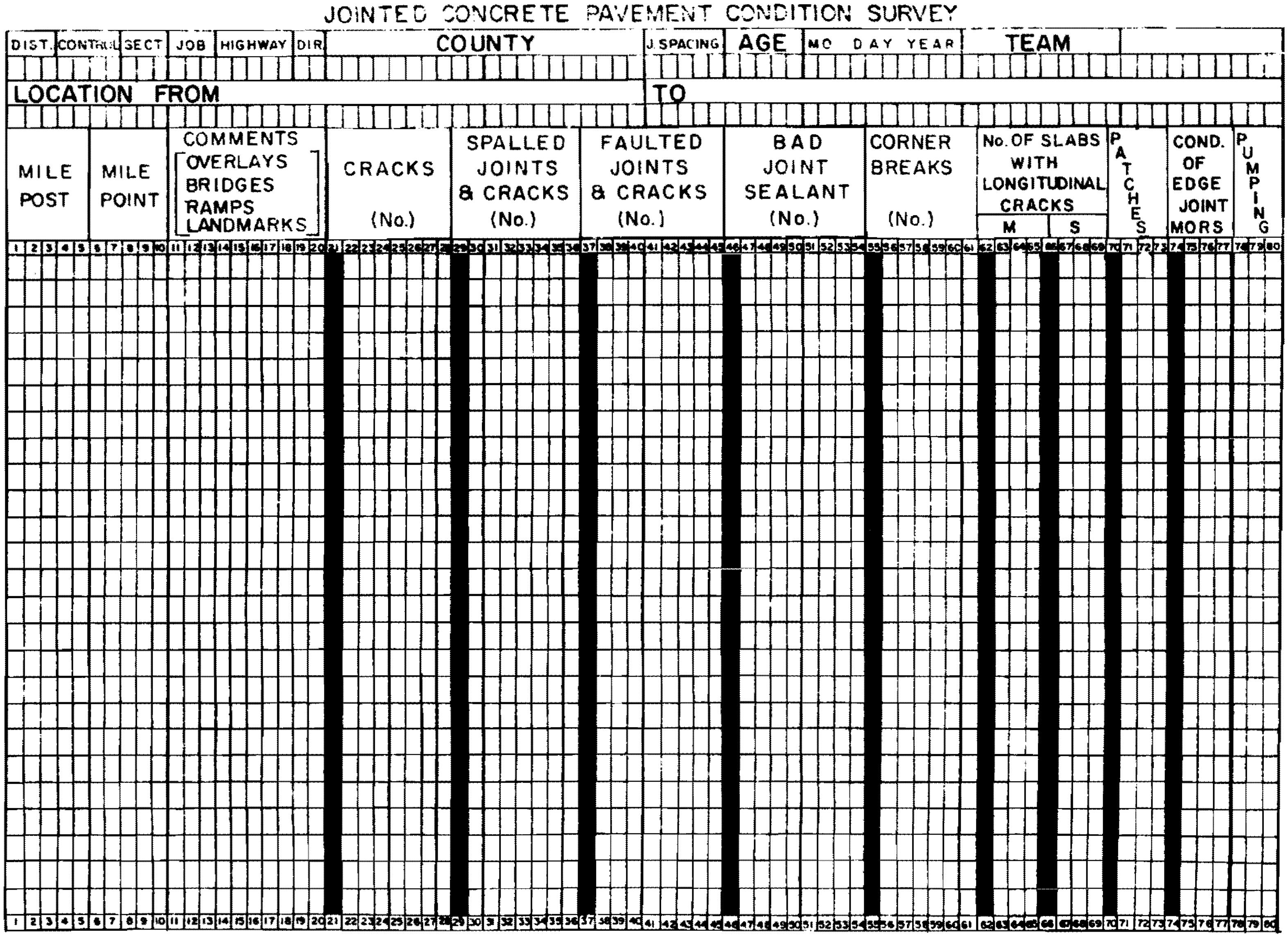
DIST. | CONTROL | SECT. | HIGHWAY AND DIRECTION | COUNTY | JOB NO. | CTR NO. | NO. OF CARDS | MO DAY YR

LOCATION FROM | TO | RATERS

MILE POST | MILE POINT | SPALLING (M: NO. OF CRACKS; S: NO. OF CRACKS) | PUMPING (M: YES OR NO; S: YES OR NO) | PUNCH OUTS (M: < 20, > 20; S: < 20, > 20) | REPAIR PATCHES (A/C: NO. OF OCC.; P/CC: NO. OF OCC.) | RIDE

Fig 2.1. 1982 CRCP condition suvey form (Network Level).

249 8 002

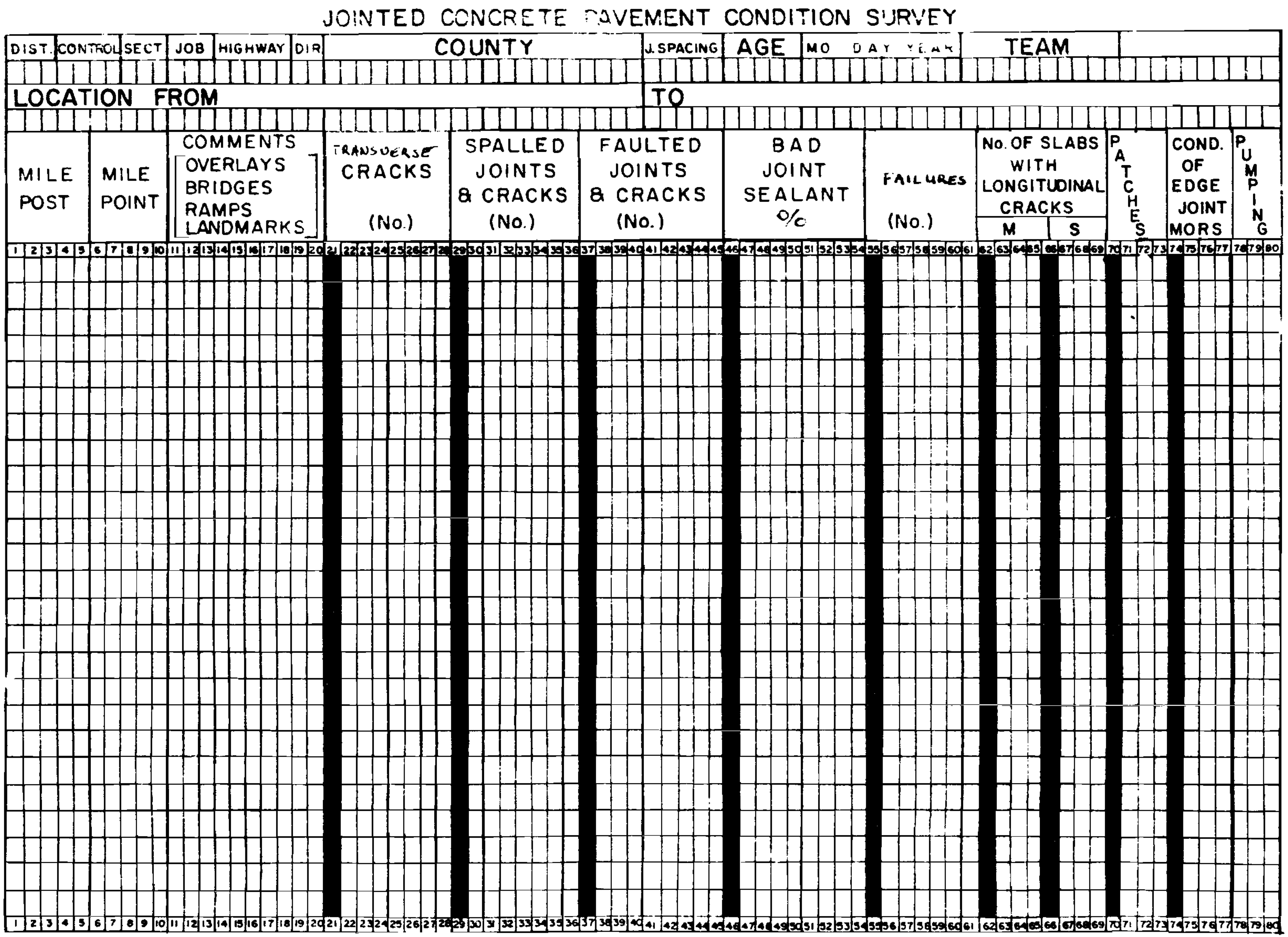

JOINTED CONCRETE PAVEMENT CONDITION SURVEY

DIST. | CONTROL | SECT | JOB | HIGHWAY | DIR | COUNTY | J. SPACING | AGE | MO DAY YEAR | TEAM

LOCATION FROM | TO

MILE POST | MILE POINT | COMMENTS [OVERLAYS BRIDGES RAMPS LANDMARKS] | CRACKS (No.) | SPALLED JOINTS & CRACKS (No.) | FAULTED JOINTS & CRACKS (No.) | BAD JOINT SEALANT (No.) | CORNER BREAKS (No.) | No. OF SLABS WITH LONGITUDINAL CRACKS (M, S) | PATCHES | COND. OF EDGE JOINT MORS | PUMPING

Fig 2.2. 1982 JCP condition survey form (Network Level).



JOINTED CONCRETE PAVEMENT CONDITION SURVEY

DIST. | CONTROL | SECT | JOB | HIGHWAY | DIR | COUNTY | J. SPACING | AGE | MO DAY YEAR | TEAM

LOCATION FROM | TO

MILE POST	MILE POINT	COMMENTS OVERLAYS BRIDGES RAMPS LANDMARKS	TRANSVERSE CRACKS (No.)	SPALLED JOINTS & CRACKS (No.)	FAULTED JOINTS & CRACKS (No.)	BAD JOINT SEALANT %	FAILURES (No.)	No. OF SLABS WITH LONGITUDINAL CRACKS M S	PATCHES	COND. OF EDGE JOINT MORS	PUMPING

Fig 2.3. 1982 JCP condition survey form used in Districts 2, 15, and 18 (Network Level).

recorded are given in the section on the condition survey of overlaid pavements, as is as a copy of the survey form used. Also discussed is the survey procedure for small sections. The survey form for this survey is also presented in this report.

Network-Level Activities

The two major goals of the network-level reduction and storage of condition-survey data are to produce input for computer program PRP01 and to generate summaries of the condition survey. The network-level condition survey data are stored in the computer and reduced by several computer programs. The input for program PRP01 and the condition survey summaries are generated during the data-reduction process. Figure 2.4 is a flowchart showing the general steps needed to produce the desired results.

Once the data have been input into the computer they are handled in one of two ways, depending upon whether they are CRCP data or JCP data. Figures 2.5, 2.6, and 2.7 are flowcharts representing the handling of CRCP data and Fig 2.8 is a flowchart depicting the handling of JCP data.

There are three major applications of CRCP condition-survey data. The first one is to generate PRP01 output. The other two applications are to get a printed summary of the latest condition summary and to merge the latest year of survey data with data from previous years' conditions.

Appendix A describes a step-by-step procedure to reduce the data for input to program PRP01. Figure 2.5 shows the steps necessary to generate PRP01 output. The CRCP data need to be input into program CNVRT to change the data into the form needed for program DSTPRV. DSTPRV will produce the condition survey summary sheets (Figs 2.9, 2.10, and 2.11) and generate a data file called SUMD. The SUMD data file and a traffic data file, which contains the traffic data for the section (18 kip ESAL) TRAFD, are input into program TOPRP. This program creates a data file that can be input into program PRP01. PRP01 produces one of three output formats (see Appendix D in Reference 1) for use in the network-level analysis to determine roads in need of rehabilitation.

To merge already stored survey data with the latest survey data, the latest year of survey data be input into program CNVRT (Fig 2.6). This

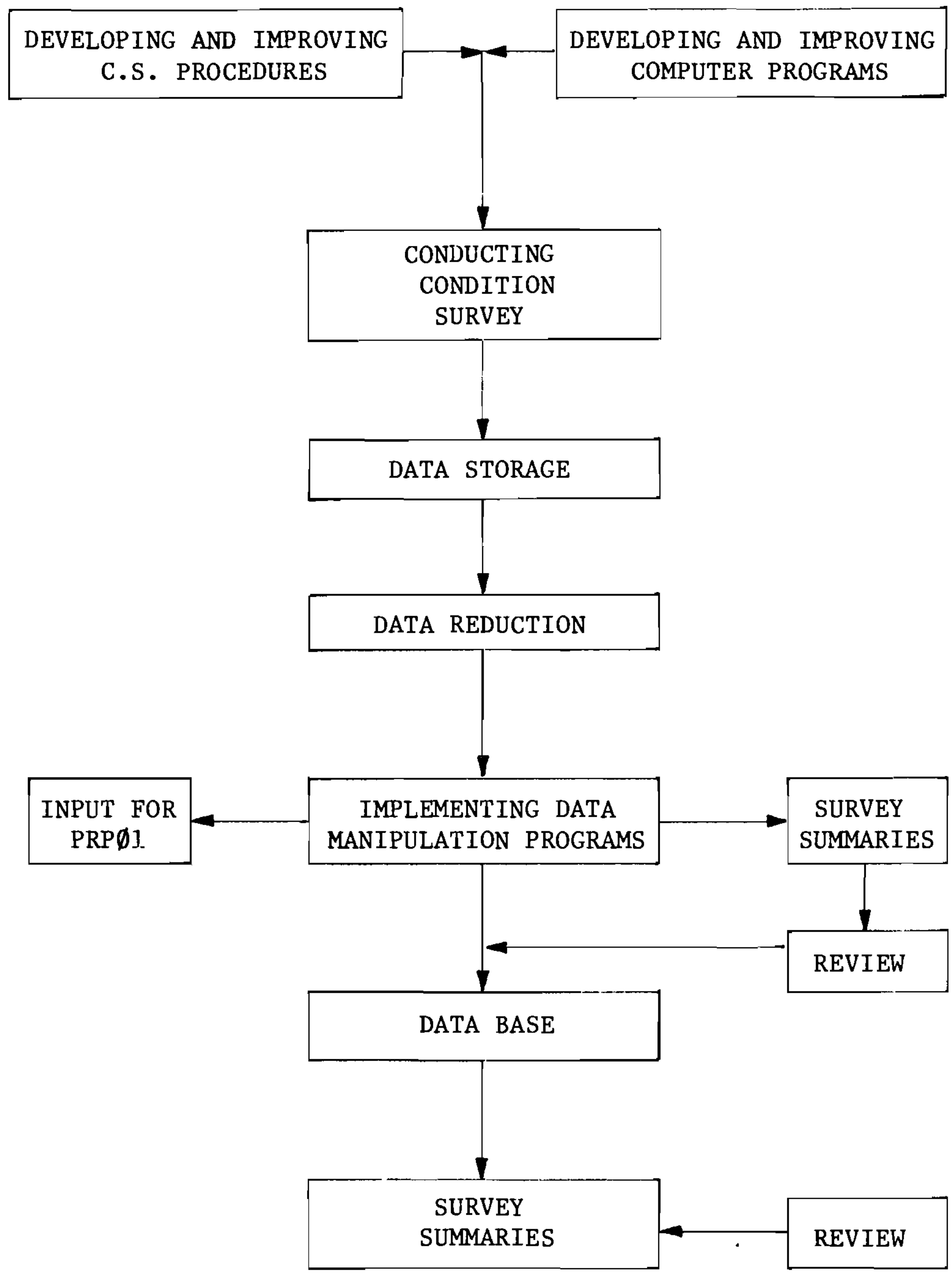


Fig 2.4. Flowchart of network level activities.

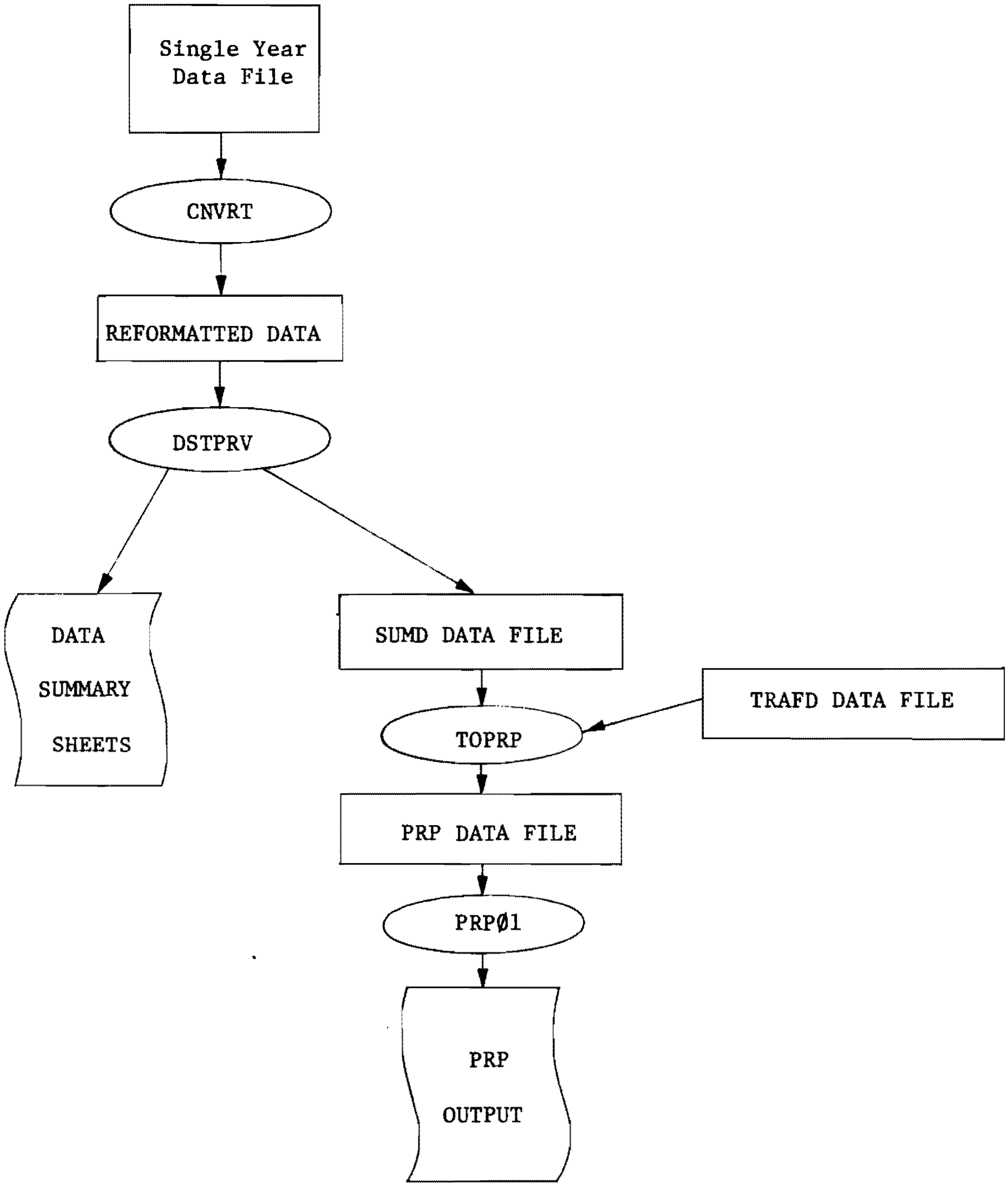


Fig 2.5. Steps needed to produce PRPØ1 output from CRCP data.

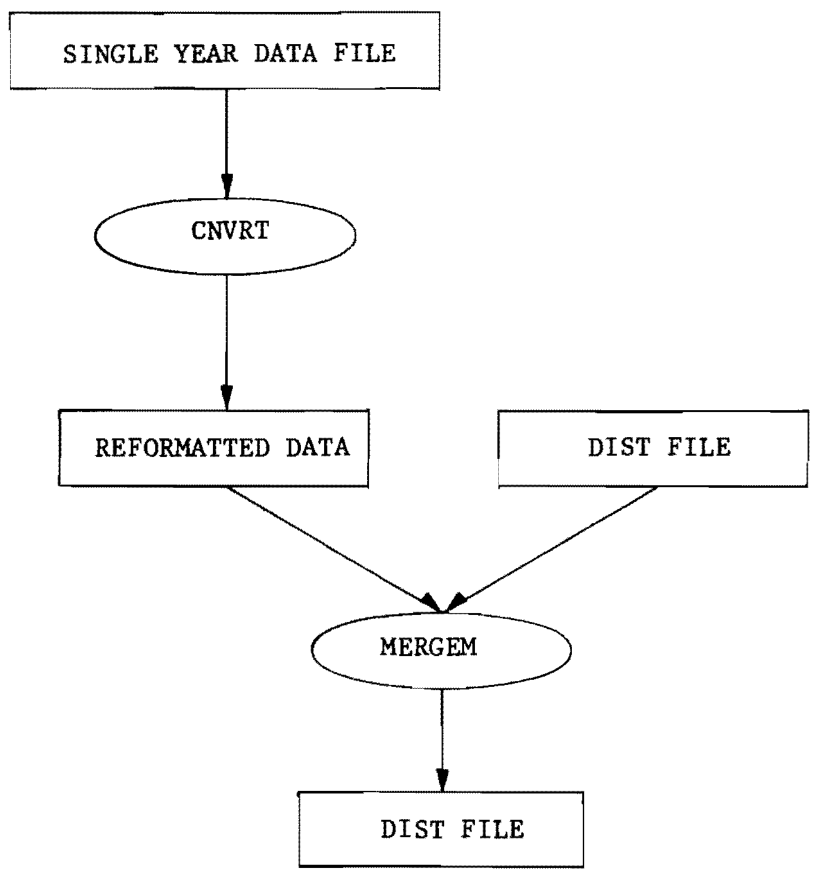


Fig 2.6. Steps needed to combine latest survey data with previous survey data for CRCP sections.

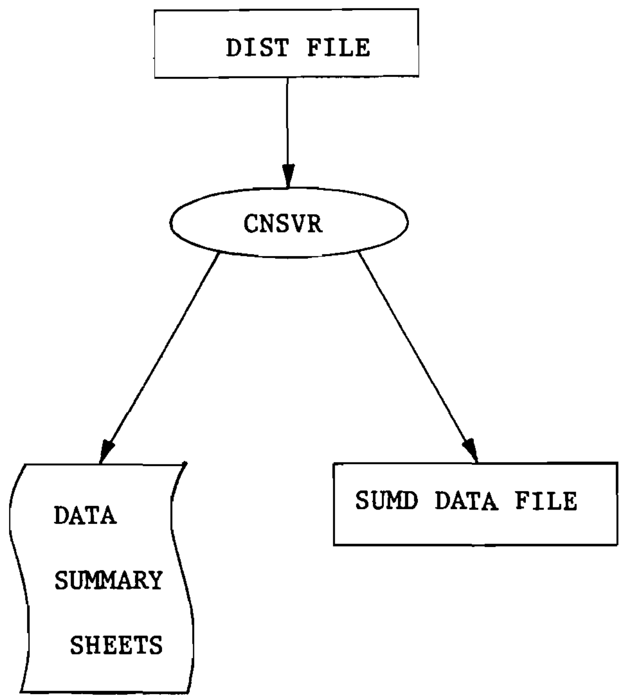


Fig 2.7. Steps needed to generate data summary sheets from all survey years of CRCP sections.

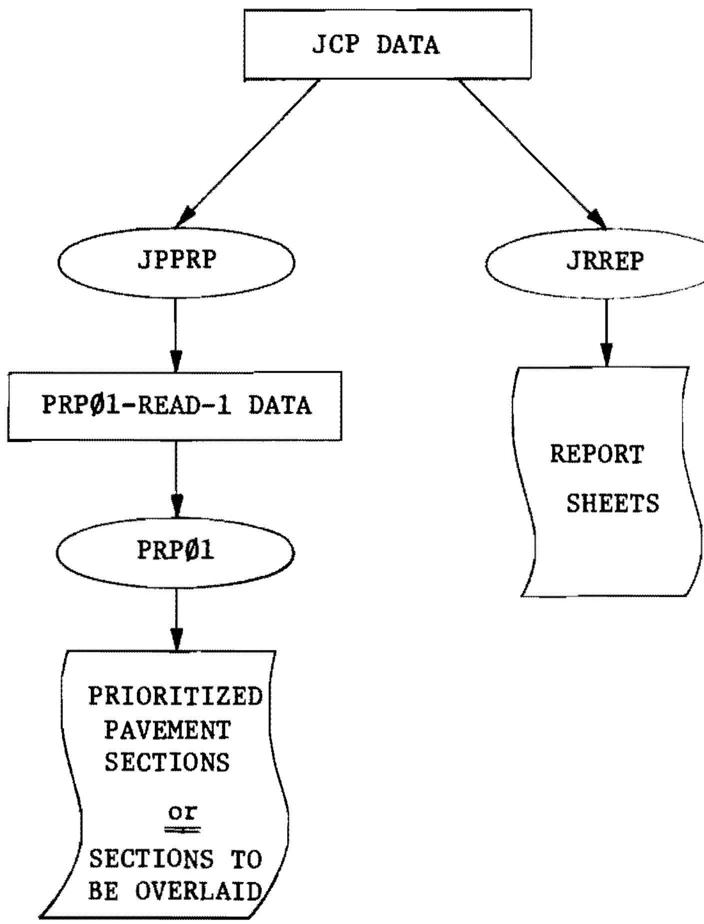


Fig 2.8. Steps needed to produce PRPØ1 ouput and data summary sheets from JCP sections.

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                         PROJECT SUMMARY SHEET
                              DISTRICT 25

*************************************************************
CNTR NO.25003   HIGHWAY IH-40   WB                 1982 SURVEY
*************************************************************

MILE POST:                        162.4     161.4     160.8

MILE POINT:                      16.240    15.260    14.640

*************************************************************

LENGTH (MILES):                        1.0       .6

LENGTH OVERLAYED:                       0         0

SERVICEABILITY INDEX (     ):           -         -

CRACK SPACING (FEET)

   MEAN:                                -         -

   STANDARD DEVIATION:                  -         -

PERCENT SPALLING

   MINOR:                               -         -

   SEVERE:                              -         -

PUMPING

   MINOR:                              NO        NO

   SEVERE:                             NO        NO

NUMBER OF SPALLING CRACKS

   MINOR:                             179       125

   SEVERE:                              1         0

NUMBER OF PUNCHOUTS

   MINOR  - L.T. 20 FT:                 4         0

          - G.T. 20 FT:                 0         0

   SEVERE - L.T. 20 FT:                 0         0

          - G.T. 20 FT:                 0         0

A.C. REPAIR PATCHES:                    0         0

P.C.C. REPAIR PATCHES:                  1         0

*************************************************************
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Fig 2.9. Example of CRCP Project Summary Sheet.

PROJECT IDENTIFICATION INFORMATION
DISTRICT 25

DETR NO.	HWY	COUNTY	CTRL	SEC	JOB	LENGTH	CONST DATE
25003	WB IH-40	WHEELER	275	12		1.6	1973
	(SHAMROCK(JCT US-83) TO 1 MI W OF FW &D R.R.)						
25003	EB IH-40	WHEELER	275	12		2.6	1973
	(1.0 MI W OF FW AND D R.R. TO SHAMROCK(JUNCTION US-83))						
25004	EB IH-40	WHEELER	275	13		1.4	1973
	(SHAMROCK(JCT. US-83) TO 1.0 MI EAST OF SHAMROCK)						
25004	WB IH-40	WHEELER	275	13		1.4	1973
	(1 MI E OF SHAMROCK TO SHAMROCK(JCT US-83))						
25005	EB IH-40	WHEELER	275	12		.7	1975
	(MILE POST 176 TO OKLAHOMA STATE LINE)						
25005	WB IH-40	WHEELER	275	12		.8	1975
	(TEXAS STATE LINE TO MILE POST 176)						
25002	EB IH-40	WHEELER	275	13		12.0	1970
	(1.0 MI EAST OF SHAMROCK TO MILE POST 176.0)						
25002	WB IH-40	WHEELER	275	13		12.2	1970
	(MILE POST 176.0 TO 1 MI E OF SHAMROCK)						
25001	EB IH-40	WHEELER	275	12		13.8	1968
	(GRAY COUNTY LINE TO .9 MI W OF FW AND D RR)						
25001	WB IH-40	WHEELER	275	12		14.8	1968
	(.9 MI W OF FW AND D RR TO GRAY COUNTY LINE)						

Fig 2.10. Example of CRCP Project Identification Sheet.

FAILURE SUMMARY FOR DISTRICT 25

CFTP NUMBER	CONST. DATE	SURVEY DATE	LENGTH TOTAL	LENGTH UNOVL	SPALLING (PER MILE) MINOR	SPALLING (PER MILE) SEVERE	PATCHES (PER MILE) A.C.	PATCHES (PER MILE) P.C.C.	PUNCHOUTS (PER MILE)	FAILURES PER MILE	FAILURES TOTAL
25003WB	1973	1982	1.6	1.6	190.0	.6	0	.6	0	.6	1
25003EB	1973	1982	2.6	2.6	228.1	.8	.4	.4	0	.8	2
25004EB	1973	1982	1.4	1.4	178.6	.7	0	.7	.7	1.4	2
25004WB	1973	1982	1.4	1.4	149.6	.7	0	.7	0	.7	1
25005EB	1975	1982	.7	.7	242.9	0	0	0	0	0	0
25005WB	1975	1982	.8	.8	162.5	0	0	0	0	0	0
25002EB	1970	1982	12.0	12.0	177.9	1.1	0	.2	0	.2	2
25002WB	1970	1982	12.2	12.2	193.5	.7	.2	.2	.1	.5	5
25001EB	1968	1982	13.8	13.8	256.7	2.8	.9	.7	.4	2.0	23
25001WB	1968	1982	14.8	14.8	255.4	1.4	.1	.7	2.2	3.1	45

DISTRICT MEANS (EXCLUDING TOTALLY OVERLAYED PROJECTS):

		1982	6.1	6.1	203.4	.9	.2	.4	.3	.9	3.3

Fig 2.11. Example of CRCP Failure Summary Sheet for latest survey year only.

rearranges the data so that they can be input into program MERGEM. The already stored survey data (stored in DIST data files) are also put into MERGEM. MERGEM combines the new survey data with the old survey data into a new DIST data file.

Inputting the DIST data file into program CNSUR creates summary sheets of the latest survey data (Fig 2.7). It also creates project identification sheets and failure summary sheets. The only difference between these sheets and the sheets created by DSTPRU is in the failure summary sheets. DSTPRU's failure summary sheets list only the latest year's data. Running CNSRU with the DIST file will list all the year's data on the failure summary sheet (Fig 2.12).

JCP data have been collected for only one year, and their storage is less complicated than that of CRCP data (Fig 2.8). Inputting the JCP data into program JPPRP creates a data file that can be input into program PRP01. Program JPREP reads the JCP data files and produces summary sheets similar to those created for CRCP data (Figs 2.13, 2.14, and 2.15).

SUMMARY

The two major application of the network-level analysis are to make a PRP01 run and to get data summary information. Step-by-step instructions FOR getting these results follow.

For PRP01 Runs:

<u>CRCP for One District</u>

(1) Input data into CNVRT to convert them to fixed format

(2) Input fixed-format district data into DSTPRV

(3) Input resulting SUMD file into TOPRP

(4) Input resulting INPRP file into PRP01*

<u>CRCP for More Than One District</u>

(1) Follow steps (1) and (2) above for each district

(2) Combine resulting SUMD files into one file

FAILURE SUMMARY FOR DISTRICT 25

CFTR NUMBER	CONST. DATE	SURVEY DATE	LENGTH TOTAL	LENGTH UNCVL	SPALLING (PER MILE) MINOR	SPALLING (PER MILE) SEVERE	PATCHES (PER MILE) A.C.	PATCHES (PER MILE) P.C.C.	PUNCHOUTS (PER MILE)	FAILURES PER MILE	FAILURES TOTAL
25003WB	1973	1982	1.6	1.6	190.0	.6	0	.6	0	.6	1
		1978	1.6	1.6	164.4	.6	0	0	0	0	0
		1974	1.6	1.6	0	0	0	0	0	0	0
25003EB	1973	1982	2.6	2.6	228.1	.8	.4	.4	0	.8	2
		1978	2.6	2.6	228.1	.8	0	0	.8	.8	2
		1974	2.6	2.6	0	0	0	0	0	0	0
25004EB	1973	1982	1.4	1.4	178.6	.7	0	.7	.7	1.4	2
		1978	1.4	1.4	178.6	.7	0	0	.7	.7	1
		1974	1.4	1.4	0	0	0	0	0	0	0
25004WB	1973	1982	1.4	1.4	148.6	.7	0	.7	0	.7	1
		1978	1.4	1.4	148.6	.7	0	.7	0	.7	1
		1974	1.4	1.4	0	0	0	0	0	0	0
25005EB	1975	1982	.7	.7	242.9	0	0	0	0	0	0
		1978	.8	.8	83.8	0	0	0	0	0	0
25005WB	1975	1982	.8	.8	162.5	0	0	0	0	0	0
		1978	.8	.8	107.5	0	0	0	0	0	0
25002EB	1970	1982	12.0	12.0	177.9	1.1	0	.2	0	.2	2
		1978	12.0	12.0	177.9	1.1	0	0	.1	.1	1
		1974	11.8	11.8	0	0	0	0	0	0	0
25002WB	1970	1982	12.2	12.2	193.5	.7	.2	.2	.1	.5	6
		1978	12.2	12.2	193.5	.7	0	.1	0	.1	1
		1974	12.2	12.2	0	0	0	0	0	0	0

Fig 2.12. Example of CRCP Failure Summary Sheet for all survey years.

PROJECT SUMMARY SHEET
DISTRICT 10

****

CFTR NO.10060 CONTROL NO. 205 SECTION NO. 13 JOB NO. 1

HIGHWAY SHL127 EB JOINT SPACING(FT) 60.0 YEAR OF SURVEY 1982

****

MILE POST:	0.0	1.0	1.6
MILE POINT:	0.000	0.000	0.000

****

LENGTH (MILES):	1.0	.6
LENGTH OVERLAYED:	0.0	.4
TRANSVERSE CRACKS (NO):	108	4
SPALLED JOINTS AND CRACKS (NO):	39	3
FAULTED JOINTS AND CRACKS (NO):	78	14
BAD JOINT SEALANTS (NO):	82	23
CORNER BREAKS (NO):	11	1
NUMBER OF SLABS WITH LONGITUDINAL CRACKS		
MINOR:	2	0
SEVERE:	0	0
PATCHES (NO):	12	6
COND. OF EDGE JOINTS		
MINOR:	YES	YES
SEVERE:	NO	NO
PUMPING:	NO	NO

****

Fig 2.13. Example of JCP Project Summary Sheet.

PROJECT IDENTIFICATION INFORMATION
DISTRICT 10

CFTR NO.	HWY	COUNTY	CTRL	SEC	JOB	LENGTH	CONST DATE
10060EB	SHL127	ANDERSON	205	13	1	1.6	6808
(FROM JCT LOOP256 TO JCT US84)							
10060WB	SHL127	ANDERSON	205	13	1	1.6	6808
(FROM JCT US84 TO JCT LOOP256)							
10063EB	FM13	RUSK	591	2	1	5.3	4207
(FROM 1.8MI W CHEROKEE C/L TO HENDERSON C/L)							
10061EB	13	RUSK	591	2	8	.8	6907
(FROM HENDERSON C/L TO 1MI PAST HEND C/L)							
10062EB	13	RUSK	591	2	9	1.4	6907
(FROM 1MI PAST HENDERSON C TO FRISCO ST)							
10062WB	FM13	RUSK	591	2	9	7.2	6907
(FROM FRISCO ST TO 1.8M OF CHEROKEE CO/)							
10064EB	FM850	RUSK	1163	2	2	3.2	5607
(FROM JCT SH135 TO W OF JCT SH42)							
10064WB	FM850	RUSK	1163	2	2	2.6	5607
(FROM W OF SH42 TO SH135)							

Fig 2.14. Example of JCP Project Identification Sheet.

FAILURE SUMMARY FOR DISTRICT 10

CFTR NO.	CONST DATE YYMM	SRVY DATE YYMM	LENGTH TOTAL (MI)	LENGTH UNOVL (MI)	TRANS. CRACKS (/MILE)	JOINTS AND CRACKS SPALLED (/MILE)	JOINTS AND CRACKS FAULTED (/MILE)	BAD JOINT SEALANTS (/MILE)	CORNER BREAKS (/MILE)	SLABS WITH LONG. CRACKS MINOR (/MI)	SLABS WITH LONG. CRACKS SEVERE (/MI)	PATCHES (/MILE)
10060EB	6808	8208	1.6	1.2	93.3	35.0	76.7	87.5	10.0	1.7	0.0	15.0
10060WB	6808	8208	1.6	1.4	78.6	31.4	54.3	71.4	2.1	7.9	9.3	16.4
10063EB	4207	8208	5.0	3.3	118.4	89.5	82.1	164.2	1.3	5.3	2.4	5.3
10061EB	6907	8208	.8	.4	157.5	127.5	137.5	200.0	2.5	2.5	2.5	0.0
10062EB	6907	8208	1.4	.9	50.0	45.0	28.8	177.5	2.5	0.0	2.5	0.0
10062WB	6907	8208	7.2	4.6	102.4	57.6	41.3	169.6	1.5	2.6	0.0	2.2
10064EB	5607	8208	3.2	2.4	115.4	90.4	80.4	167.5	4.5	2.1	1.7	11.7
10064WB	5607	8208	2.6	1.8	129.4	9.4	6.1	147.8	17.2	1.1	0.0	4.4

Fig 2.15. Example of JCP Failure Summary Sheet.

(3) Input combined SUMD file into TOPRP

(4) Input resulting INPRP file into PRP01*

JCP for One District

(1) Input District data into JPPRP

(2) Input resulting INPRP file into PRP01*

JCP for More Than One District

(1) Input data for each district into JPPRP

(2) Combine resulting INPRP files

(3) Input combined INPRP file into PRP01*

CRCP and JCP for One District

(1) Follow steps (1) through (3) in "CRCP for One District"

(2) Input JCP District data into JPPRP

(3) Combine resulting INPRP files

(4) Input combined INPR file into PRP01*

CRCP and JCP for More Than One District

(1) Follow steps (1) through (3) in "CRCP for More than One District"

(2) Follow steps (1) and (2) in "JCP for More than One District"

(3) Combine resulting INPRP files

(4) Input combined INPRP file into PRP01*

*The first seven cards required by PRP01 need to be added before the INPUT files can be input into PRP01.

For data summary sheets:

CRCP Latest-Year-Only Failure Summary

(1) Input data into CNVRT to convert to fixed format

(2) Input fixed-format district data into DSTPRV

(3) Print resulting OUTPUT, OUTFS, and OUTID files

CRCP All-Years Failure Summary

(1) If data are in free format, input them into CNVRT to convert them to fixed format

(2) INPUT single year fixed format data and DIST file into MERGEM

(3) INPUT resulting file into CNSRV 4

(4) Print resulting OUTPUT, OUTFS, and OUTID files

JCP

(1) Input district data into JPREP

(2) Print report

PROJECT-LEVEL ANALYSIS

The network-level analysis determines the road sections that are in the worst condition. It is the objective of the project-level analysis to provide information for use in overlay design or long-term monitoring. Computer program RPRDS-1 (described fully in Reference 3) is the major computer program used in the project-level analysis. The discussion of the project-level analysis is presented in Chapter 4 of this report.

CHAPTER 3. DEVELOPMENT OF A RIGID PAVEMENT REHABILITATION AND MAINTENANCE SCHEME AT THE NETWORK LEVEL

One phase of the project, reported in Research Report 249-5 (Ref 1), "Rigid Pavement Network Rehabilitation Scheduling Using Distress Quantities," concerned a working scheme for prioritizing and scheduling maintenance and rehabilitation in a rigid pavement network. Additionally, a computer program, PRP01, was developed to prioritize and schedule a set of rigid pavements for rehabilitation within specified time frame and budget constraints.

RIGID PAVEMENT NETWORK REHABILITATION SCHEDULING USING CONDITION SURVEY DATA

The development of a rigid pavement network rehabilitation scheduling program involved several steps, which are described in the following paragraphs.

The first step was the conceptual formulation of the problem, where the capabilities and limitations of the scheme to be developed were defined. Likewise, the availability of models for the scheme was studied, and, if new models were needed, data requirements were established. These developments are described in the first subsection of this chapter.

Second, models in the system were developed using field data collected from rigid pavements in Texas during the last decade. In addition, other models found in contemporary literature were incorporated into the scheme when there were no adequate data available. The distress models in the system were developed using standard statistical techniques. Discriminant analysis was employed to develop a distress index and to arrive at a terminal-condition criterion. For the distress prediction equations, regression analysis techniques were used. These analyses are briefly described in the second subsection.

The third step involved the preparation of a computer program that integrates the various distress models into the conceptual scheme of the Pavement Management Systems (PMS). Next, using condition survey data, sample runs were made to predict the rehabilitation requirements of the rigid-pavement network in the state of Texas.

Conceptual Formulation of the System

At the network level, the PMS provides information to assist decision makers in the development of agency-wide programs of new construction, maintenance, or rehabilitation which will optimize the use of available resources.

The basic inputs for a network level analysis are highway-need studies for new pavements and periodic evaluations of existing pavements.Additional information is required, such as traffic studies and cost records, depending on the application intended and the sophistication of the system. The results of the analysis are combined to program the construction, maintenance, and rehabilitation of pavements within available resources.

Figure 3.1 is a flow chart of the primary steps involved in a rehabilitation and maintenance system at the network level. The scheme uses field information on the group of projects composing the network under analysis; the input information required varies, depending on the models used within the program. The output is a prioritized list of projects requiring immediate rehabilitation and a list of predicted future rehabilitation needs.

The first step in the program is the computation of a prioritization index for each project that combines all the pavement responses into a single number, which facilitates comparison among projects. With the prioritization index, the projects can be sorted out to define the priorities for rehabilitation and maintenance. After the priorities for the first year are defined, the next step involves the prediction of the future condition of the pavement sections in order to repeat the prioritization cycle for the following years. This cycle is repeated until the time frame of the analysis is fully covered.

At the project level, detailed consideration is given to alternative design, construction, maintenance, or rehabilitation activities for a particular section or project within an overall program. The inputs for a project level analysis are load, environmental conditions, materials characteristics, construction and maintenance variables, and costs. The

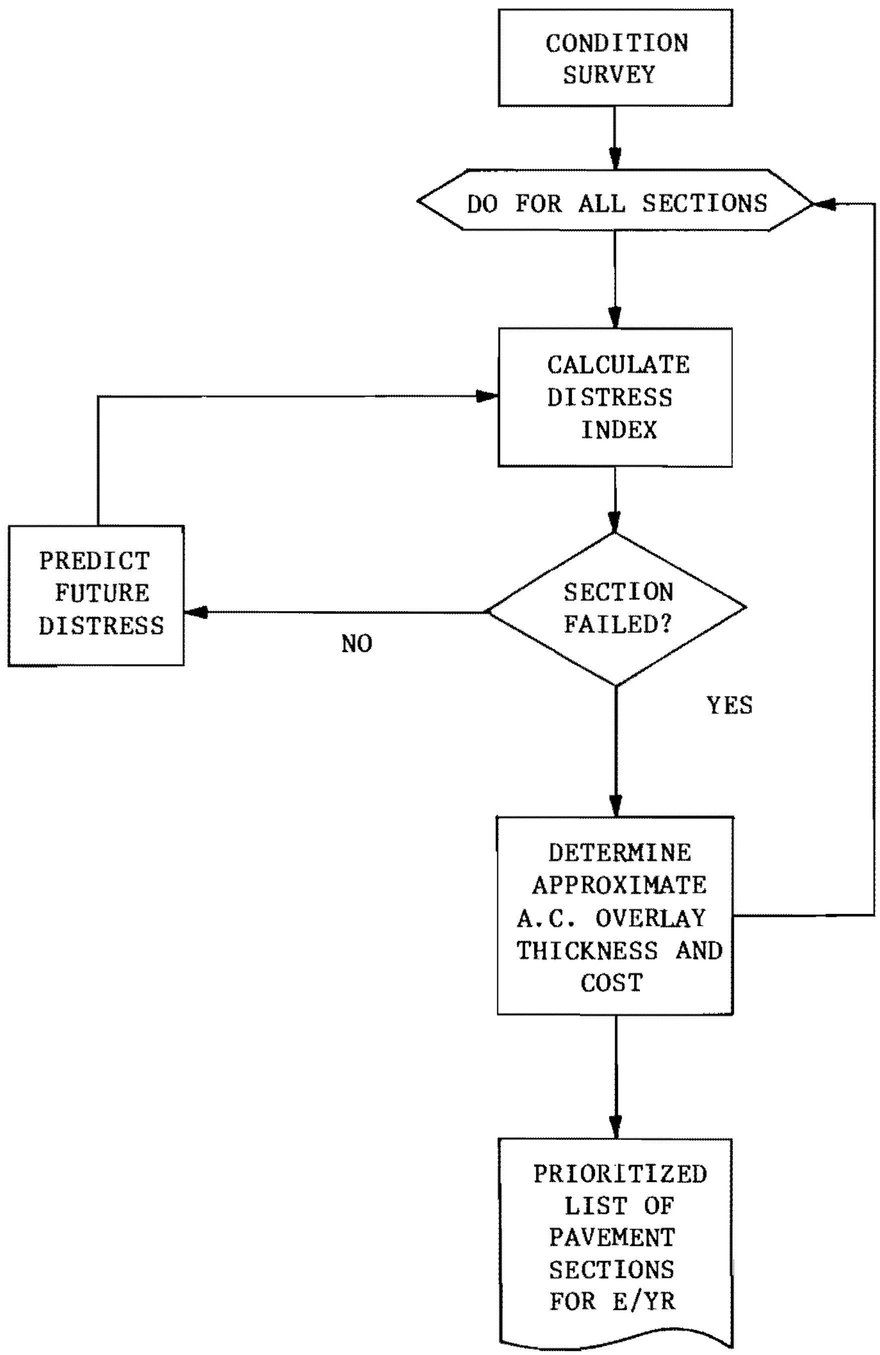

Fig 3.1. Basic steps in a network level rehabilitation and maintenance system (Ref 1).

output from the analysis consists of a set of the best possible strategies to provide, maintain, or rehabilitate a pavement structure. The generation of feasible alternatives is made from a detailed design, which includes the prediction of some or all of the pavement responses and an economic evaluation of the alternatives under consideration. A more detailed explanation of the project analysis is contained in the next chapter.

Distress Index and Decision Criteria Index

Discriminant analysis was selected for the development of the indices used in the rigid pavement rehabilitation and maintenance scheme, because of its appropriateness for analyzing the available condition survey data.

A distress manifestation is the visible consequence of carrying to a limit the response of the pavement to load and environmental stresses. Distress index is the combination of distress manifestations to ascertain with a single number the amount of pavement deterioration. A list of equations used for this purpose is included in Table 6.1, Ref 1 (page 128).

A decision criteria index, which reflects the combination of the distress manifestations, is considered to indicate the expected failure condition of a pavement section associated with age, traffic, and pavement structure. That is, the decision criteria index, when related to the distress index, will indicate if a pavement section has reached its terminal condition.

Discriminant analyses were performed on condition survey data of CRCP from the statewide monitoring conducted in Texas in 1974 and 1978. These analyses resulted in the equation that computes the discriminant score for CRC pavements (Table 6.1, Ref 1).

Equation for CRC Pavements. This equation requires as input data the number of failures per mile and the values corresponding to the percentages of minor spalling and severe spalling.

Equation for Jointed Pavements. The discriminant score for jointed pavements is obtained by multiplying by their corresponding equation coefficients the observed values of faulting in the wheel path, cracking, spalling, and patching of a given pavement section. This equation was derived from data used by Carey and Irick (Ref 11) to develop the serviceability-performance concept.

Distress Prediction Equations

Condition survey data were used to obtain models for CRCP and AC overlaid rigid pavements, whereas models for jointed pavements, were taken from the existing literature on the subject. In general, the models derived assume that information on the distress of a pavement was collected at some point in time, and that information is used to forecast the future condition of the pavement.

Equations for CRC Pavements. Five different types of data were considered in the development of the distress prediction models:

(1) environmental factors,
(2) materials,
(3) traffic,
(4) age, and
(5) pavement distress.

The distress prediction model obtained for failures requires that condition survey information be taken at some time in the life of a selected CRC pavement and that this information be used with the logarithmic equation for the prediction of failures at some future time during the pavement's life.

The percent of minor spalling is predicted by means of an exponentially asymptotic model and is a function of the percent of minor spalling and pavement age at the time of the condition survey, and pavement age at the time of the prediction.

The model for severe-spalling prediction is similar to that for minor spalling.

Equations for Jointed Pavements. In order to include jointed rigid pavements in the rehabilitation and maintenance scheme, and since field information had not been gathered by the Center for Transportation Research for this type of pavements, it was necessary to rely on the work done on the subject by other agencies.

Cracking is predicted by means of a very simple equation, which requires as input data the number of deteriorated transverse cracks, the equivalent 18-kip single axle loads, and the pavement age at the time of the condition survey, as well as the pavement age at the time of the prediction.

The model for prediction of faulting is an exponential equation that requires as input data the cumulative annual average number of daily one-way tractor-semitrailer combinations (TA) and pavement age at the time of the condition survey, and TA at the time of the prediction.

The input data necessary to use the spalling-prediction equation consist of pavement age at which prediction is required and percent of spalling and age of pavement section at the time the condition survey is conducted.

Equations for AC Overlaid Rigid Pavements. These equations were developed from analyses of field data collected in experimental sections of AC overlay on CRCP in Walker County, Texas.

The discriminant score for CRC pavements was modified so that it could be applied to AC overlays on rigid pavements. The resulting equation includes such terms as number of reflected failures per mile, number of patches per mile, and percent of reflected cracks. The following conclusions were also drawn from the analysis:

(1) distress increases with age,
(2) distress decreases with overlay thickness,
(3) rut depth increases with age, and
(4) rut depth increases with overlay thickness.

The equation for prediction of distress in new overlays was developed using percent distress as the dependent variable and age and overlay thickness as the independent variables.

The equation for prediction of distress in existing overlays was developed using percent distress as the dependent variable and overlay thickness, age and percent distress at the time of the condition survey, and time of prediction as the independent variables.

PROGRAM PRPO1

A program named PRPO1 was developed to schedule rehabilitation of rigid pavements (JCP, JRCP, and CRCP) within a certain design period. The input data are condition survey information on a set of rigid pavements for the same year. The solution is obtained using distress models: distress indices and distress prediction equations. All of the distress models were integrated as subroutines in program PRPO1 in order to facilitate future modifications.

The output from the program has several options:

(1) A prioritized list of pavement sections according to their distress condition at the time of the condition survey.

(2) A multi-period rehabilitation schedule of the pavement sections without considering budget constraints. The selection of candidates for each year is made on the basis of the magnitude of the distress index.

(3) A multi-period rehabilitation schedule of the pavement sections accounting for budget restrictions. The selection for each year depends on the magnitude of the distress index and the budget availability.

Figure 3.2 is a simplified flowchart of the computer program. Information on the distress condition of each project is required as an input. The program starts by calculating the distress index for each section. The sections are prioritized according to the magnitude of their distress indices. At this stage, a check is made of the design period. If the design period is set equal to zero years, the program prints the priority list and stops, but, if the design period is longer than zero years, the program continues. Next, a check is made for budget restrictions and two different criteria are followed, depending on the existence of budget constraints. If no budget constraints are imposed by the user, the rule for selecting the rehabilitation candidates is very simple: all the pavements which have

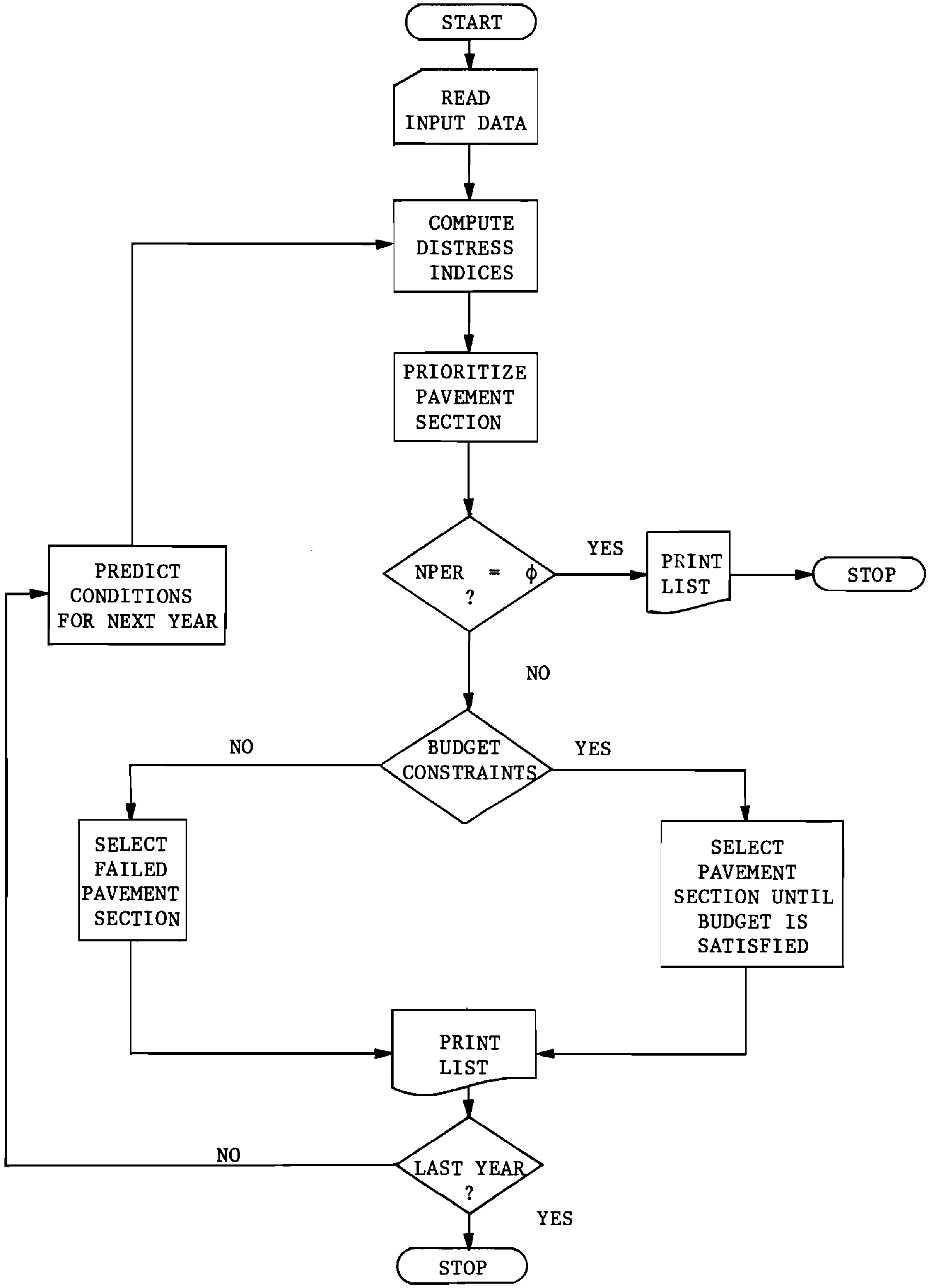

Fig 3.2. Simplified flowchart of the computer program (PRPØ1) developed in this project to prioritize and schedule rehabilitation (Ref 1).

reached terminal condition are included in the list for that year. If budget constraints are present, the selection of candidates is made on the basis of budget availability. The already prioritized sections are considered one by one, and the rehabilitation cost of each is calculated and accumulated until the budget is satisfied. A list of candidates is printed for each year of the design period. The program checks to see if the design period has been covered, in which case it exits; otherwise, conditions are predicted for the next year and the program returns to the step in which the distress indices are calculated.

Appendix A presents the input guide to program PRP01.

The following are among the applications of program PRP01:

(1) evaluation of the effect of various yearly budgets on the distress condition of the pavement network,

(2) estimation of the effect of time value of money on average overlay cost per mile for various budget levels, and

(3) computation of the additional cost incurred when postponing the recommended date of overlay.

Tables 3.1, 3.2, and 3.3, are partial outputs of sample runs made with the prioritization scheduling program, PRP01. Table 3.1 is a prioritization of the projects for the state, with the poorest condition pavement in the state given number one priority. It is a partial list of 261 identifiable projects on the system.

Table 3.2 presents the cost information for some of the projects requiring overlay for one year after the survey, using an unconstrained budget option. The overlay cost for each project is presented, and a total of $138 million will be required to upgrade the 330 miles of pavement that are in unacceptable distress condition. Table 3.3 is a summary of the output data for a 5-year period, using an unconstrained budget. Note that, for the five years, in excess of $200 million would be required to restore the pavement quality. This table also indicates the number of pavement miles that are to be restored each year, for a total of 539 roadway miles (269.5 centerline miles) over the 5-year period. Another interesting figure is the

TABLE 3.1. LIST OF PRIORITIZED SECTIONS DEVELOPED FROM 1982 CRCP CONDITION SURVEY OF SELECTED TEXAS DISTRICTS.

Section ID	Distress Index*	Rank
10-07 WB	- 3.25	1
9-04 SB	- 2.73	2
10-01 EB	- 2.66	3
10-06 WB	- 2.30	4
10-06 EB	- 2.09	5
10-07 EB	- 1.78	6
10-01 WB	- 1.51	7
13-03 WB	- 1.50	8
13-03 EB	- 1.39	9
13-06 WB	- 1.37	10
10-10 EB	- 1.02	11
17-06 SB	- 0.88	12
9-04 NB	- 0.85	13
...	...	...
24-15 EB	- 0.04	50
10-12 EB	- 0.04	51
13-07 EB	- 0.02	52
10-02 WB	- 0.00	53
17-10 SB	0.01	54
13-05 SB	0.01	55
1-02 WB	0.03	56
1-11 NB	0.03	57
...	...	...
1-15 WB	0.88	252
4-09 EB	0.91	253
20-02 SB	0.91	254
20-19 WB	0.92	255
1-15 EB	0.94	256
20-02 NB	0.94	257
20-23 NB	0.94	258
20-20 WB	0.98	259
20-13 SB	1.00	260
20-24 EB	1.00	261

*At the time of the condition survey

TABLE 3.2. LIST OF PAVEMENT SECTIONS REQUIRING OVERLAY DURING THE FIRST YEAR AFTER 1982 CONDITION SURVEY, UNCONSTRAINED BUDGET.

Section ID[1]	Distress Index[2]	Section Length, Miles	Overlay Cost, Dollars[3]	Rank
10-07 WB	- 3.95	5.00	3,509,000	1
9-04 SB	- 3.60	1.80	1,217,000	2
10-01 EB	- 3.20	4.00	2,561,000	3
10-06 WB	- 2.79	5.00	3,060,000	4
10-06 EB	- 2.64	5.20	3,129,000	5
10-07 EB	- 2.13	4.80	2,679,000	6
13-06 WB	- 1.91	5.00	2,690,000	7
10-01 WB	- 1.88	3.60	1,928,000	8
13-03 WB	- 1.82	12.10	6,407,000	9
13-03 EB	- 1.70	12.00	6,225,000	10
17-06 SB	- 1.33	2.30	1,107,000	11
10-10 EB	- 1.28	7.40	3,528,000	12
10-12 WB	- 0.17	6.40	2,185,000	49
13-07 EB	- 0.12	10.40	3,477,000	50
13-08 NB	- 0.12	3.40	1,133,000	51
1-11 NB	- 0.12	0.40	133,000	52
10-12 EB	- 0.11	6.40	2,124,000	53
13-05 SB	- 0.11	8.80	2,919,000	54
1-02 WB	- 0.09	1.80	591,000	55
24-15 EB	- 0.07	0.40	131,000	56
10-02 WB	- 0.03	6.60	2,118,000	67
3-07 WB	- 0.02	1.00	318,000	58
4-07 EB	- 0.01	5.60	1,771,000	59
	Total	336.70	138,014,500	

[1]Directional roadway of an Interstate, i.e., WB - westbound
[2]Predicted value of distress index at time of overlay which, is greater than at time of condition survey
[3]Based on asphalt concrete cost of $0.25/square yard/inch

TABLE 3.3. SUMMARY TABLE OF FIVE-YEAR BUDGET NEEDS DEVELOPED FROM SELECTED PORTIONS OF 1982 CONDITION SURVEY, UNCONSTRAINED BUDGET.

Year	Average Distress Index	Length, miles	Budget, dollars
1	0.19	336.70	138,014,500
2	0.62	74.90	24,866,100
3	0.61	48.70	15,990,600
4	0.60	42.00	13,638,000
5	0.60	36.60	11,822,200
	Average	Total	Total
	0.52	538.90	204,331,400

average distress index of all the pavements in the state. Note that a value of 0.19 is present in year one. The overall condition of the pavement is improved until the value of approximately 0.6 is reached.

Figure 3.3 shows average distress index for the network as a function of time for various yearly budgets using CRCP information from Texas. It can be noticed that the rate of deterioration, i. e., the slope of any of the lines in Fig 3.3 that occurs when a low budget is available can be diminished or even reversed if higher budgets are adopted.

The meaning of distress index can be easily visualized by examining Fig 3.4, which shows a 0.2-mile section with different stages of distress.

The program may also be used to determine the additional cost, on a per mile basis, that is incurred when the overlay of a pavement section is postponed. Table 3.4 presents information that was obtained by using the program in different modes. The year of overlay indicates the number of years that a decision is postponed after the pavement has reached terminal condition. If we look at the overall network average, we see it costs approximately $496,000 per mile, and this will increase if necessary action is postponed for 4 years. On severely deteriorated sections, the average cost goes from $956,000 per mile to $1,656,000, roughly a 75 percent increase for a 4-year delay. Thus, it may be noted that the overall cost of not facing up to a decision at the proper time is large, considering the network. Unfortunately, the chart does not include the additional rehabilitation cost of repairing the additional failures that will occur as described in a previous section, which adds to the cost shown.

Figure 3.5 shows that a minimum average cost per mile of overlay exists for the set of data analyzed. However, results do not include user costs. Furthermore, the yearly budget that produces the minimum cost per mile of overlay is not necessarily the budget resulting in the "ideal" average distress index (Fig 3.3).

SUMMARY

This chapter discusses a working scheme to prioritize and schedule rehabilitation and maintenance in a rigid pavement network. The scheme makes

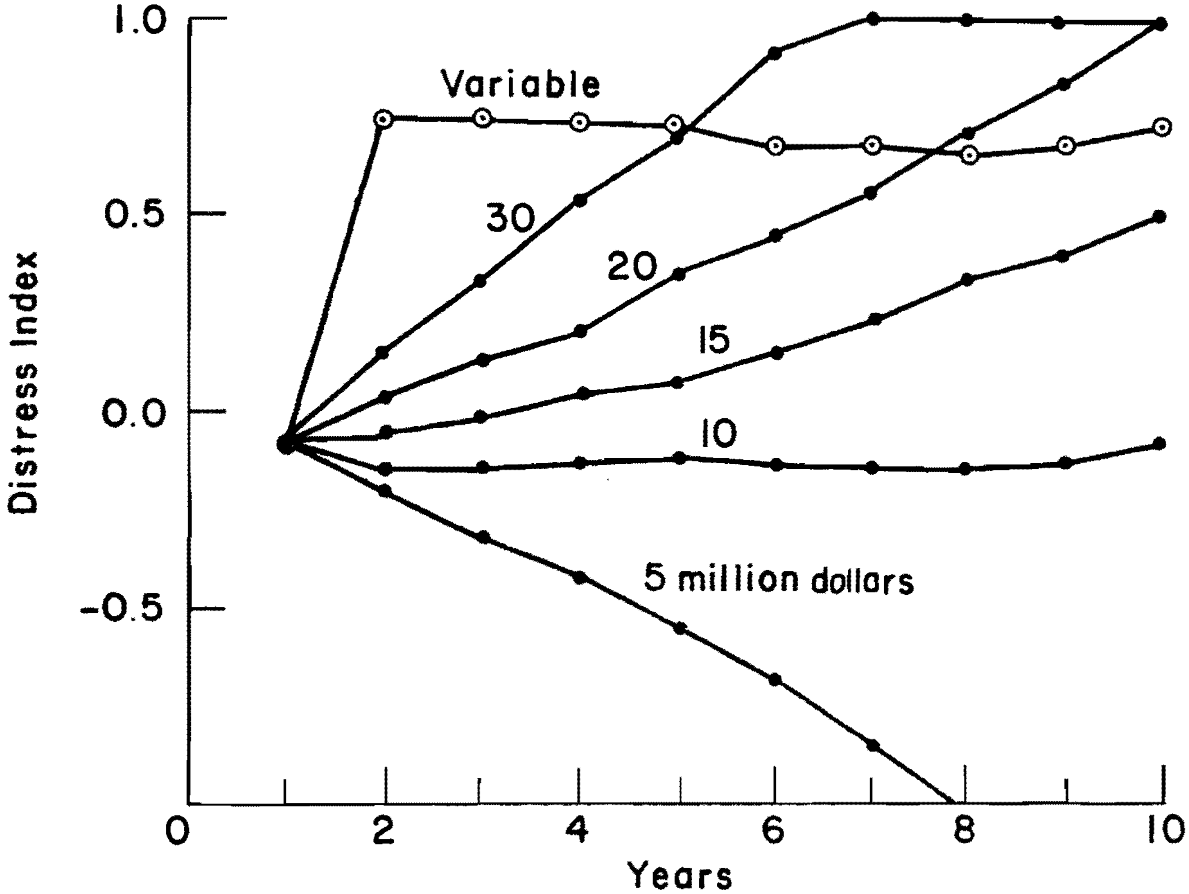

Fig 3.3. Average distress index for the network through time for various yearly budgets using Texas CRCP information (Ref 1).

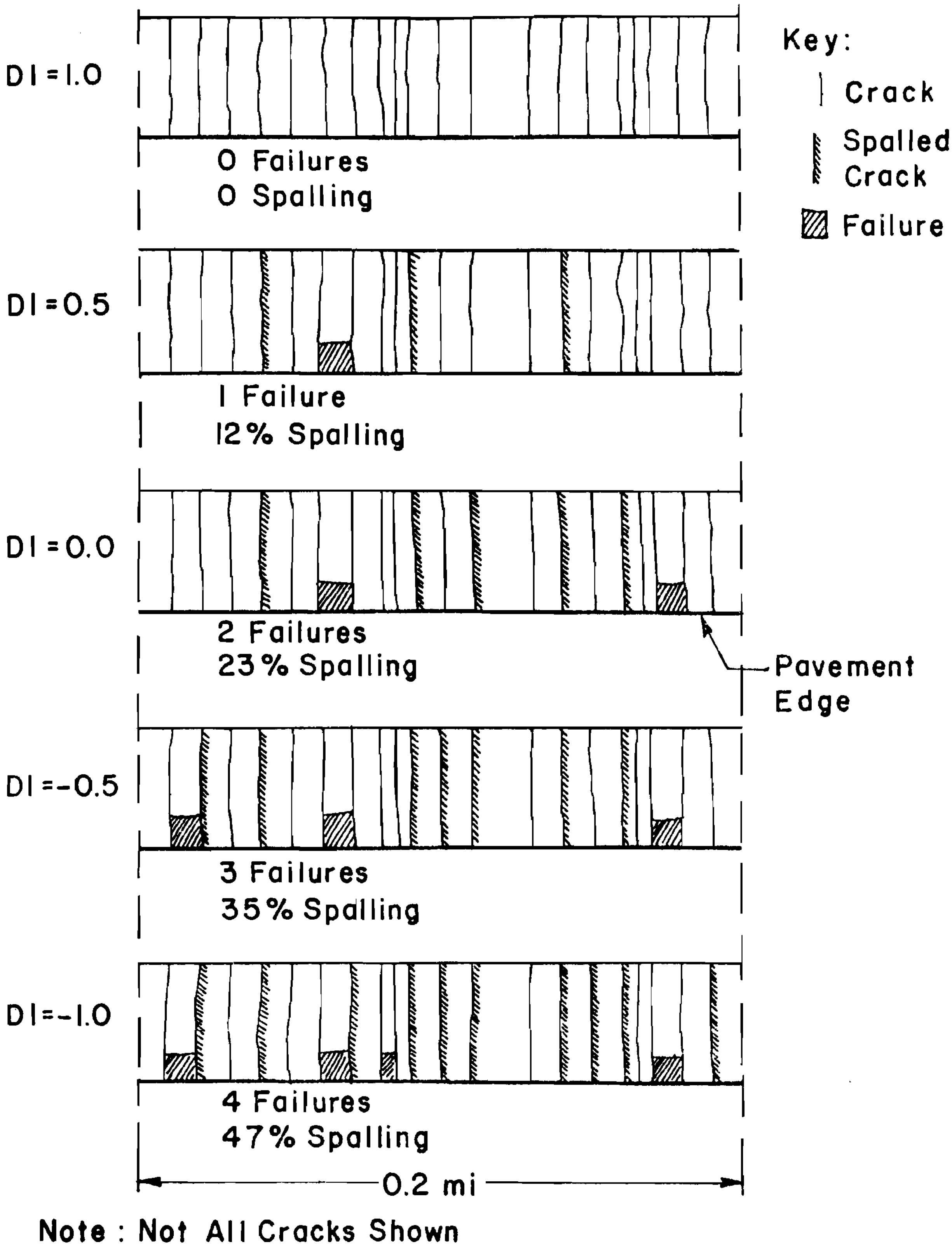

Fig 3.4. Sample distress condition of a 0.2-mile CRC pavement section with different values of the distress index (Ref 1).

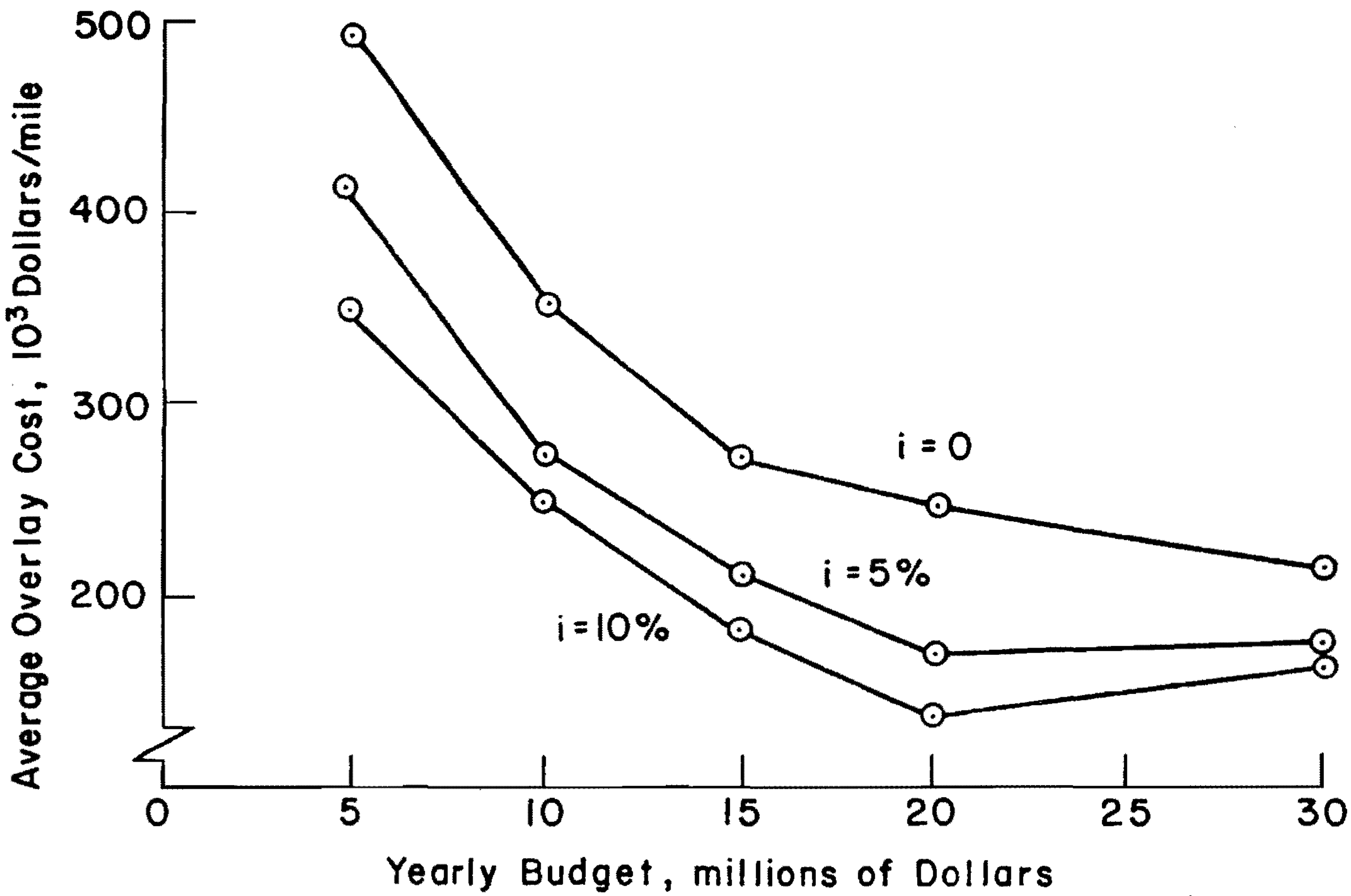

Fig 3.5. Average overlay cost per mile versus different yearly budgets for various interest rates using Texas CRCP information (Ref 1).

TABLE 3.4. ADDITIONAL CONSTRUCTION COST INCURRED WHEN THE OVERLAY OF A PAVEMENT SECTION IS POSTPONED - DEVELOPED FROM TEXAS CONCRETE PAVEMENT STUDIES BY THE CENTER FOR TRANSPORTATION RESEARCH (Ref 1)

	Network Average		Severely Deteriorated Section		Slightly Deteriorated Section	
Year of Overlay	Cost Per Mile, dollars	Percent Increase	Cost Per Mile, dollars	Percent Increase	Cost Per Mile, dollars	Percent Increase
1	496,000	--	956,000	--	361,000	--
2	531,000	7.0	1,090,000	14.0	364,000	1.0
3	569,000	14.8	1,249,000	30.6	368,000	2.1
4	612,000	23.5	1,436,000	50.2	372,000	3.1
5	661,000	33.3	1,656,000	73.2	376,000	4.2

use of a distress index as a decision criterion to determine when a pavement section has reached its terminal condition. The initial pavement condition is determined from condition surveys, and the future condition is estimated by means of prediction models.

CHAPTER 4. DEVELOPMENT OF A RIGID PAVEMENT DESIGN SYSTEM AT THE PROJECT LEVEL

INTRODUCTION

The main objective of this study was to improve and implement the overlay design method developed for the Texas SDHPT in Research Project 177. This chapter includes a brief summary of the improvements made to the materials characterization and fatigue life prediction methods used in the design procedure (see Ref 2 for details of this study).

The design procedure (improved) is also briefly summarized in this chapter. Research Report 249-1 (Ref 3) contains the complete details of this design procedure.

To minimize the development of reflection cracks in the overlay (AC), design charts were developed and the details were published in Research Report 249-6. A brief description of this method is included in this chapter.

Finally, a summary at the end of this chapter includes a discussion of the design procedure along with some recommendations for future improvement of the design procedure.

IMPROVEMENTS TO THE MATERIALS CHARACTERIZATION AND FATIGUE LIFE PREDICTION METHODS OF THE TEXAS RIGID PAVEMENT OVERLAY DESIGN PROCEDURE

During the implementation phase of the Texas State Department of Highways and Public Transportation (SDHPT) procedure for rigid pavement overlay design (RPOD2, Ref 4), certain difficulties and inaccuracies arising from its use suggested the need for improvements in the methods of materials characterization and fatigue life prediction.

The design procedure in RPOD2 outlined in Fig 4.1. All the steps are interdependent; the behavioral analysis depends on the materials properties characterized, and the fatigue life of the pavement is a function of the stresses and strains resulting from the behavioral analysis.

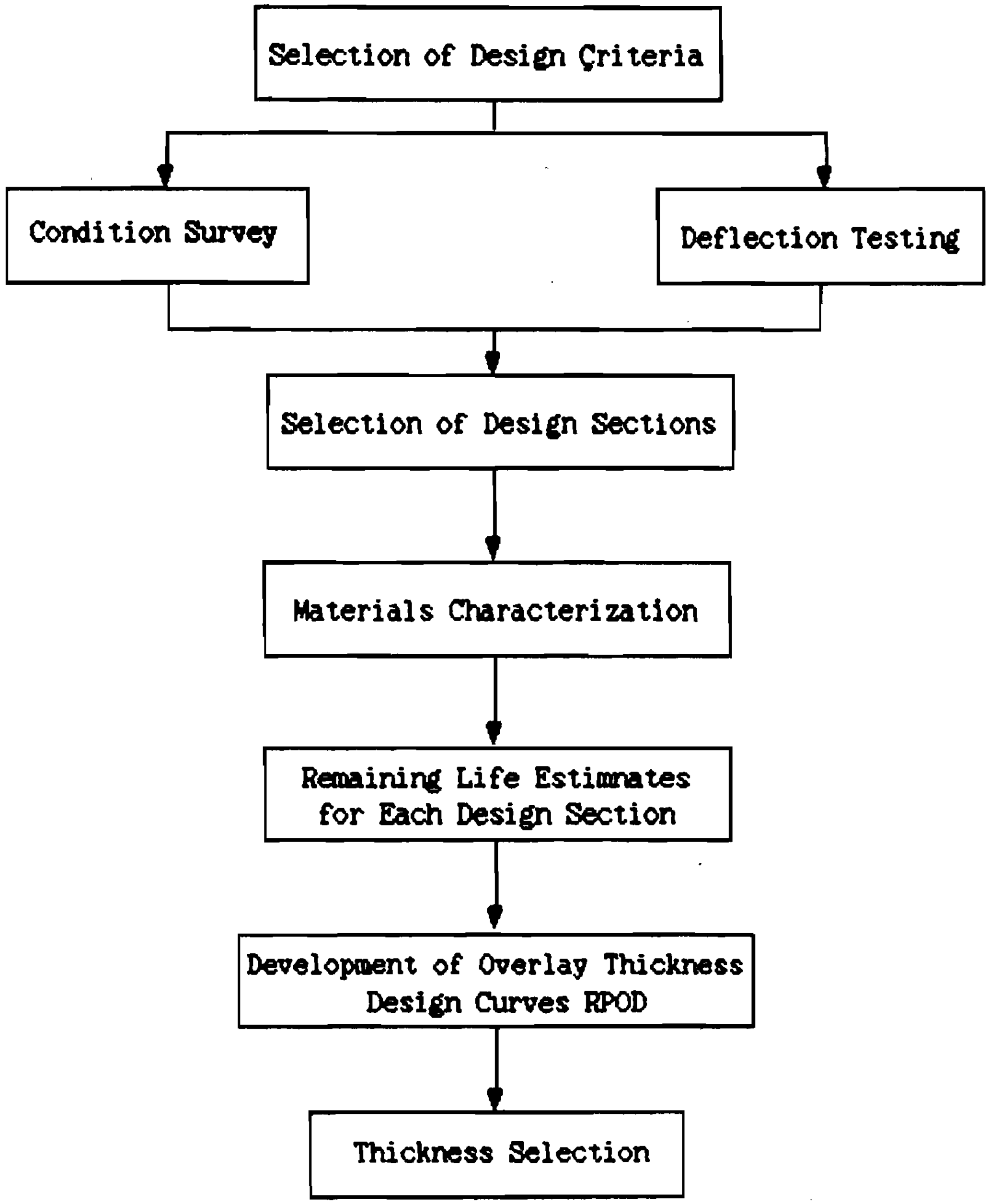

Fig 4.1. Flow diagram of RPOD2 design procedure (Ref 2).

The most important findings from Report 249-1 (Ref 2) are summarized in this chapter, and recommendations regarding their implementation on future overlay designs are made. Figure 4.8 shows the various options available for overlaying.

Materials Characterization

The existing pavement materials are characterized by using deflection measurements and laboratory testing. The Indirect Tensile test is used to obtain initial estimates of the moduli of the bound pavement layers and the Resilient Modulus test is used to obtain an indication of the stress sensitivity of the subgrade. Dynaflect deflections are used to improve these estimates of the bound layer moduli and are also used to calculate the effective subgrade modulus under the Dynaflect load. This is possible because the surface and subbase moduli have very little effect on the Dynaflect sensor 5 deflection. This deflection is, thus, indicative of the subgrade modulus. Figure 4.2 shows the subgrade modulus under the Dynaflect load from the sensor 5 deflection using elastic layered theory analysis.

The Dynaflect deflection basin slope, or sensor 1 minus sensor 5, is indicative of the moduli of the upper, bound, pavement layers. However, a number of combinations of layer moduli exist which will produce the same deflection basin slope and, thus, laboratory testing is required to obtain initial estimates of these moduli. Figure 4.3 has been prepared from elastic layered theory analysis to determine the subbase modulus of elasticity.

This nomograph can be used in conjunction with Fig 4.2, as follows: subgrade modulus is estimated from Dynaflect sensor 5 deflection, the Dynaflect deflection basin slope is entered in Fig 4.3, and, if the procedure indicated therein is followed, subbase modulus of elasticity is obtained.

The subgrade thickness has a significant effect on the deflections computed using layered theory. Figure 4.4 has been prepared from regression analysis of elastic layered theory results to indicate the reduction required in the subgrade modulus, calculated from the sensor 5 deflection, if a rigid foundation exists at some known depth.

D_1		Regression Equation	R^2	Std. Error
8" :	E_3' =	10 EXP (0.2072 - 1.156 Log W_5)	0.99	3%
9" :	E_3' =	10 EXP (0.0967 - 1.184 Log W_5)	0.99	3%
10" :	E_3' =	10 EXP (-0.0072 - 1.208 Log W_5)	0.99	3%
12" :	E_3' =	10 EXP (-0.1944 - 1.2507 Log W_5)	0.99	3%

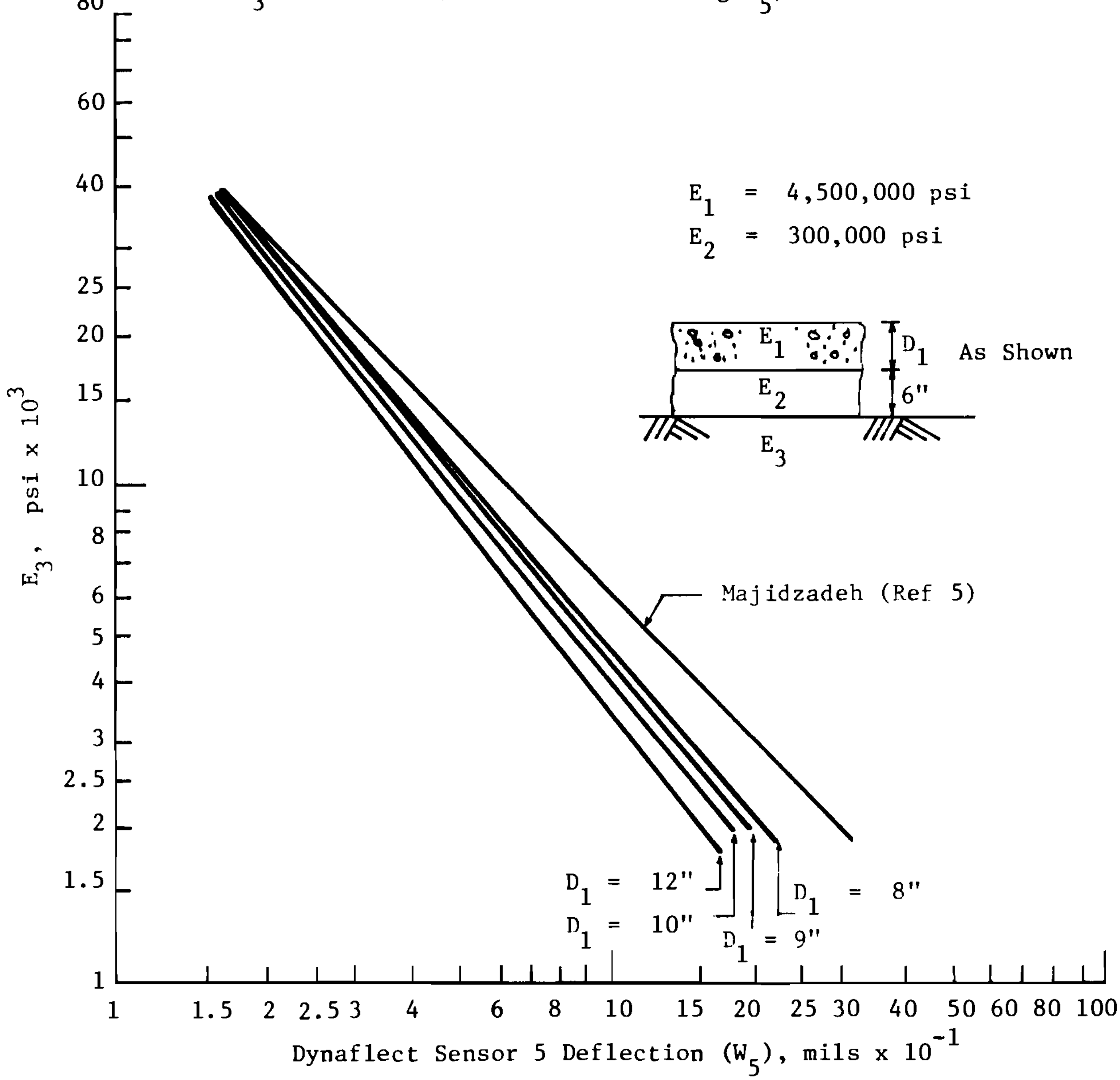

Fig 4.2. Subgrade modulus versus Dynaflect sensor 5 deflection for different pavement thicknesses (Ref 2).

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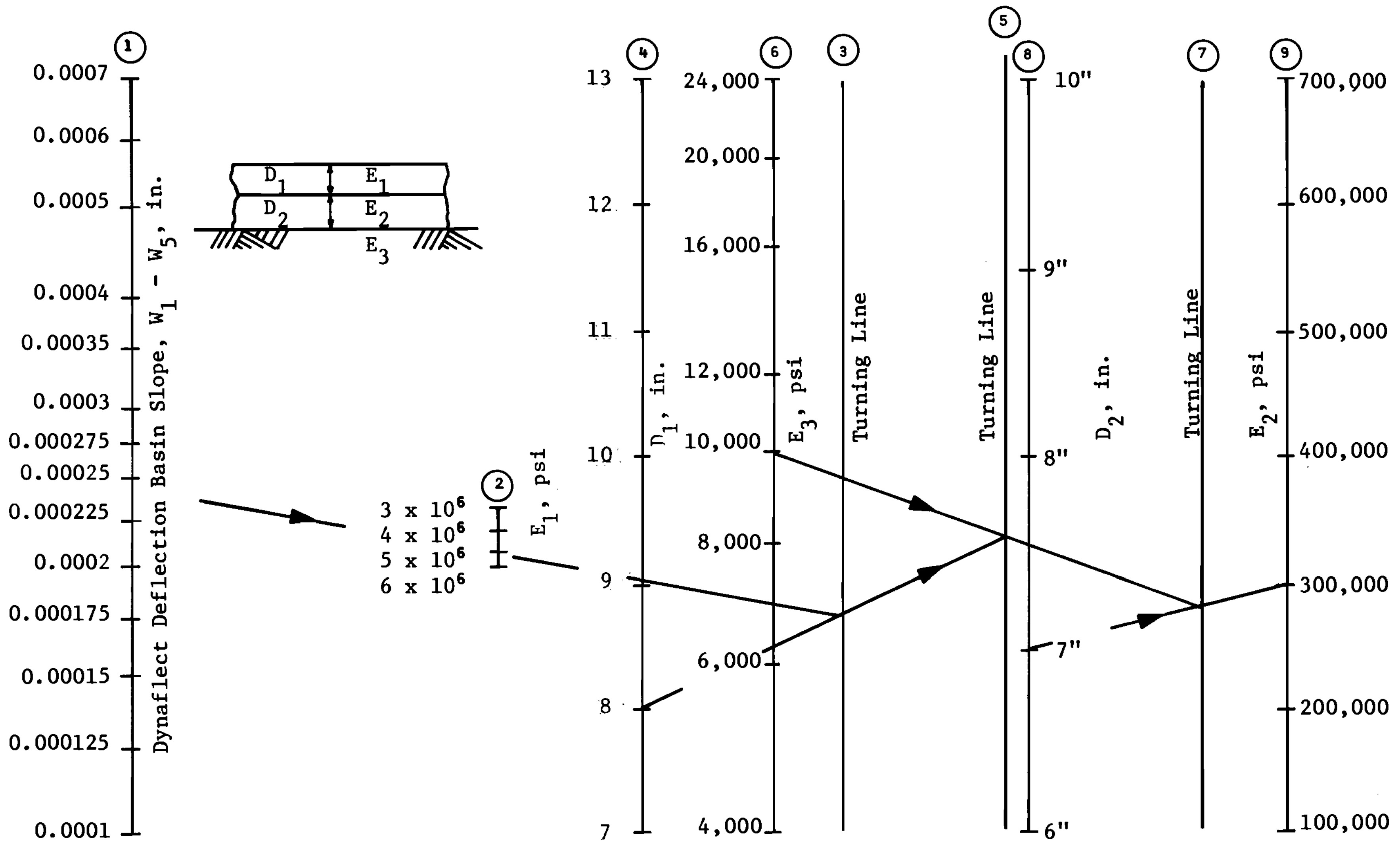

Fig 4.3. Nomograph for estimating subbase modulus of elasticity (E_2) for rigid pavements from Dynaflect deflections (Ref 2).

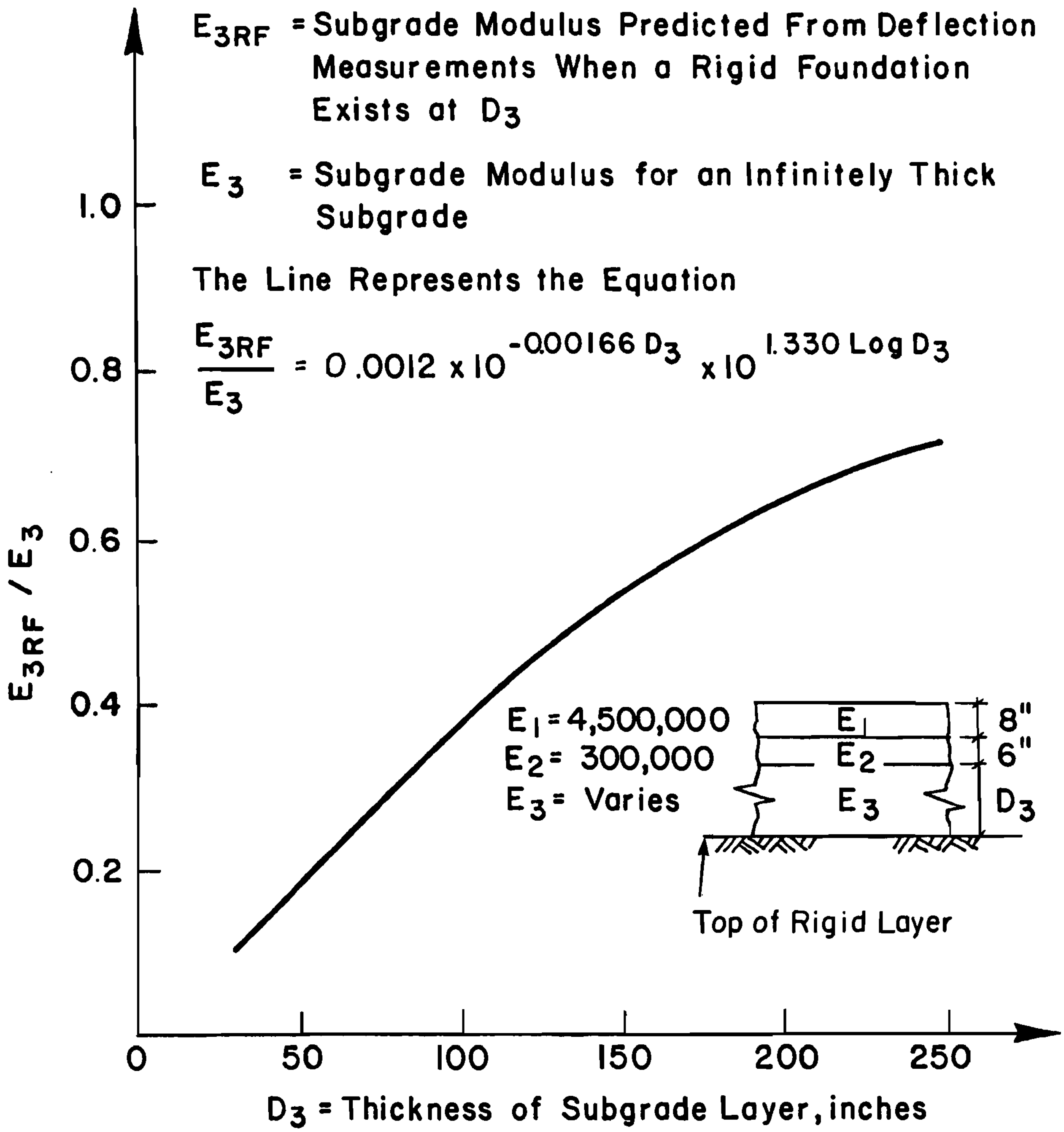

Fig 4.4. The reduction in subgrade modulus predicted using deflection measurements when the subgrade is supported by a rigid foundation at depth D_3 (Ref 2).

Deflection Measurements. Because of the increased reliance on deflection measurements for the materials characterization phase of the design procedure, it is recommended that deflections be taken at every 50 feet for CRC pavements and at the joint and midspan at every 100 feet along jointed concrete pavements. Wherever possible, approximately every second deflection measurement made along CRC pavements should be taken at a pavement discontinuity, such as a punch out or patch. This will facilitate the estimation of an effective pavement modulus for the CRC pavement layer with no remaining life and will give some indication of the measures to be taken to avoid reflection cracking in a subsequent overlay.

Selection of Pavement Design Sections. The pavement should then be divided into sections based on deflection measurements and condition survey data, and each section should be analyzed separately to provide the optimum overlay thickness. The deflection measurements used for this purpose depend on the condition of the existing pavement and on the type of overlay envisaged. If a pavement has some remaining life, or if an asphalt overlay is contemplated, the roadway is divided into sections based on the deflections taken at a midspan-type position.

Both the Dynaflect sensor 5 deflections and the deflection basin slopes are used to determine the section limits. These deflection parameters are plotted against the length of the road, using the PLOT4 program (Ref 2). Every section limit based on the sensor 5 deflection should also coincide with a section limit of the deflection basin slopes because of the effect which the sensor 5 deflection has on this parameter.

Because the deflections are not normally distributed, the modal deflection parameters in each section are used to determine the layer moduli for that section, as indicated earlier. To this end, program MODE (Ref 2), which will provide statistical information about the different deflection parameters, has been prepared.

After having characterized the upper layer moduli using the modal deflection parameters, the subgrade modulus should be reduced for design to that modulus which corresponds to the 90th percentile sensor 5 deflection within a section. The stress sensitivity of the subgrade modulus should then be taken into account, as indicated in Ref 4, by using the results of Resilient Modulus testing.

If the pavement has no remaining life and if a PCC overlay is planned the deflections taken at distress manifestations or at pavement discontinuities should be used to determine the section limits. The most severe stresses in the overlay will occur at these positions, and, thus, the existing pavement may be characterized as having an effective modulus, which would result in the same basin slope as obtained at these positions when analyzed using elastic layered theory. Basin fitting techniques may thus be used to calculate these effective moduli.

If the deflection basin slopes at some of the distress manifestations or pavement discontinuities are far greater than the design slopes used, it may be advisable to seek out these areas with deflection-measuring equipment and to repair them before overlaying.

This material characterization procedure should result in pavement layer moduli which are representative of the actual field conditions. However, in order to obtain an estimate of the seasonal variation and the long-term behavior of the different deflection parameters, it is recommended that some long-term deflection measurements be made at some selected locations. These sections should encompass the various distress manifestations and pavement discontinuities mentioned earlier.

Fatigue of Existing Concrete Pavements

Failure of rigid pavements was defined as that condition where additional heavy traffic applications would result in a rapid increase in distress. Examination of the AASHO Road Test data indicated that, for jointed pavements, this distress condition was reached when the cracking index was 50 feet per 1,000 square feet. Examination of condition survey data obtained from Texas CRC pavements indicated that this distress condition corresponded approximately to a rate of occurrence of three defects (punch outs and patches) per mile per year. Economic analysis confirmed that it was generally more economical to overlay before this rate of defect occurrence was exceeded.

Furthermore, this rate generally occurred when the number of defects per mile in the pavement equaled the pavement age in years. It is, therefore, recommended that this latter criterion be used to determine whether a pavement section has significant remaining life.

The fatigue equation developed from the AASHO Road Test data in Ref 6 was reevaluated using fewer simplifying assumptions. Deflection measurements were used to characterize the subgrade for the sections for different seasons, and the corresponding tensile stresses in the bottom of the rigid pavement layer were calculated using elastic layered theory. The transverse axle load distribution at the Road Test and finite element analysis were used to approximate the number of loads applied at an increased stress due to traffic close to the pavement edge. The seasonal interior and edge stresses were then converted to an equivalent stress, which would do the same amount of damage to the pavement with a number of applications equal to the total number of applications at the other stress levels. This was done using the fatigue equation developed in Ref 6.

Separate regression analyses were performed using the number of axles to failure (as defined earlier) against the equivalent tensile stresses in the rigid-pavement layer for single and tandem axles. From this it became apparent that the number of tandem axle applications had to be increased by 1.9 to achieve the same stress-applications-to-failure relationship as obtained with single axles. It is, therefore, recommended that this factor be used whenever Miner's hypothesis is used to compute the damage done to rigid pavements by tandem axle applications.

This process was repeated until the fatigue equation used to compute the equivalent stress was similar to the fatigue equation developed from the regression analysis. The final fatigue equation, which is recommended for use in rigid pavements, is given in Fig 4.5.

This fatigue equation correlates reasonably with failure of some selected CRC pavements in Texas, as shown in Fig 4.5, and can thus be used with reasonable confidence in further pavement designs.

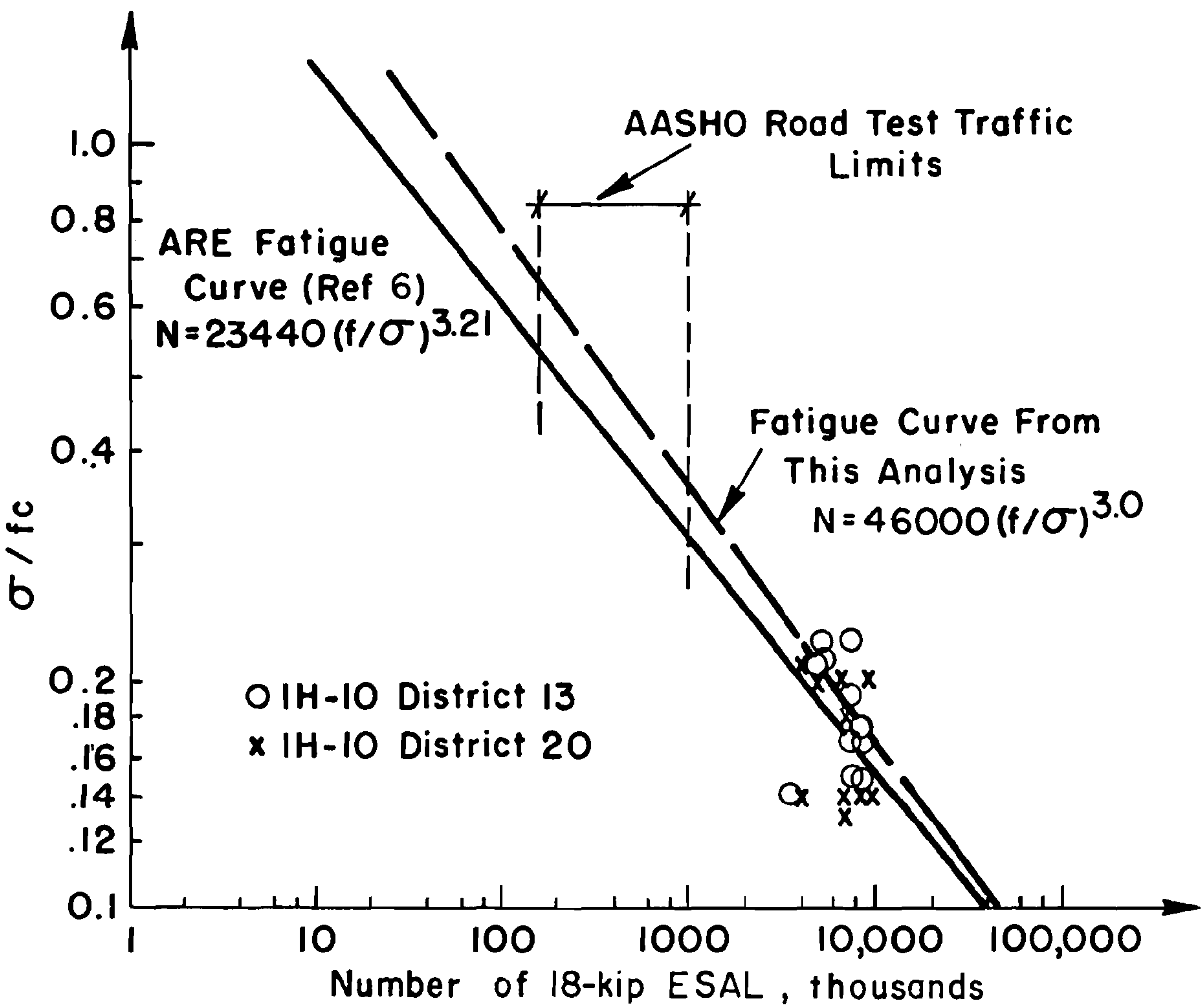

Fig 4.5. Correlation between fatigue curves developed from AASHO Road Test data and data from CRC pavements in Districts 13 and 20, Texas (Ref 2).

Fatigue of Overlaid Rigid Pavements

The analytical modeling of existing pavements by the RPOD2 design procedure was examined in the light of condition survey results of asphalt-overlaid CRC pavements and a recent PCC overlay design carried out on a jointed concrete pavement in Texas.

Condition surveys of asphalt overlaid CRC pavements indicate that relatively thin overlays (3 to 6 inches) may significantly extend the pavement's life. For example, CRC pavements which had already failed according to the condition survey criterion mentioned previously would carry traffic significantly in excess of the pavement life predictions made by RPOD2. This occurs primarily because RPOD2 models the existing pavement with no remaining life as an equivalent subgrade layer, based on the Dynaflect sensor 1 deflections.

This modeling is probably more severe than the field condition and hence the discrepancy. The recommended alternative to this form of modeling is to increase the remaining life of the overlaid pavement. This increase in remaining life can be explained by examining the differences between the fatigue curves developed from laboratory and field data. At low stress levels the laboratory data predict far more allowable applications than the field data. These differences may be ascribed to stress-concentrating factors which are present in the field. Many of these factors, such as moisture incursion and the resulting erosion of subgrade support, and warping stresses caused by vertical temperature differentials, are reduced considerably by overlaying.

A tentative fatigue equation for use with overlaid rigid pavements is presented in Fig 4.6. This curve has been estimated using the existing condition survey data on asphalt overlaid pavements and the subjective judgement that a new PCC pavement equal in thickness to the total overlaid pavement thickness will last longer than the overlaid pavement.

The RPOD2 design procedure assigns a modulus of 500,000 psi to a cracked rigid pavement layer with no remaining life. This value was obtained by analyzing the maximum deflections obtained on cracked pavements at the AASHO Road Test using plate theory. It is recommended that this modulus of the cracked pavement layer be estimated from deflection basin fitting procedures

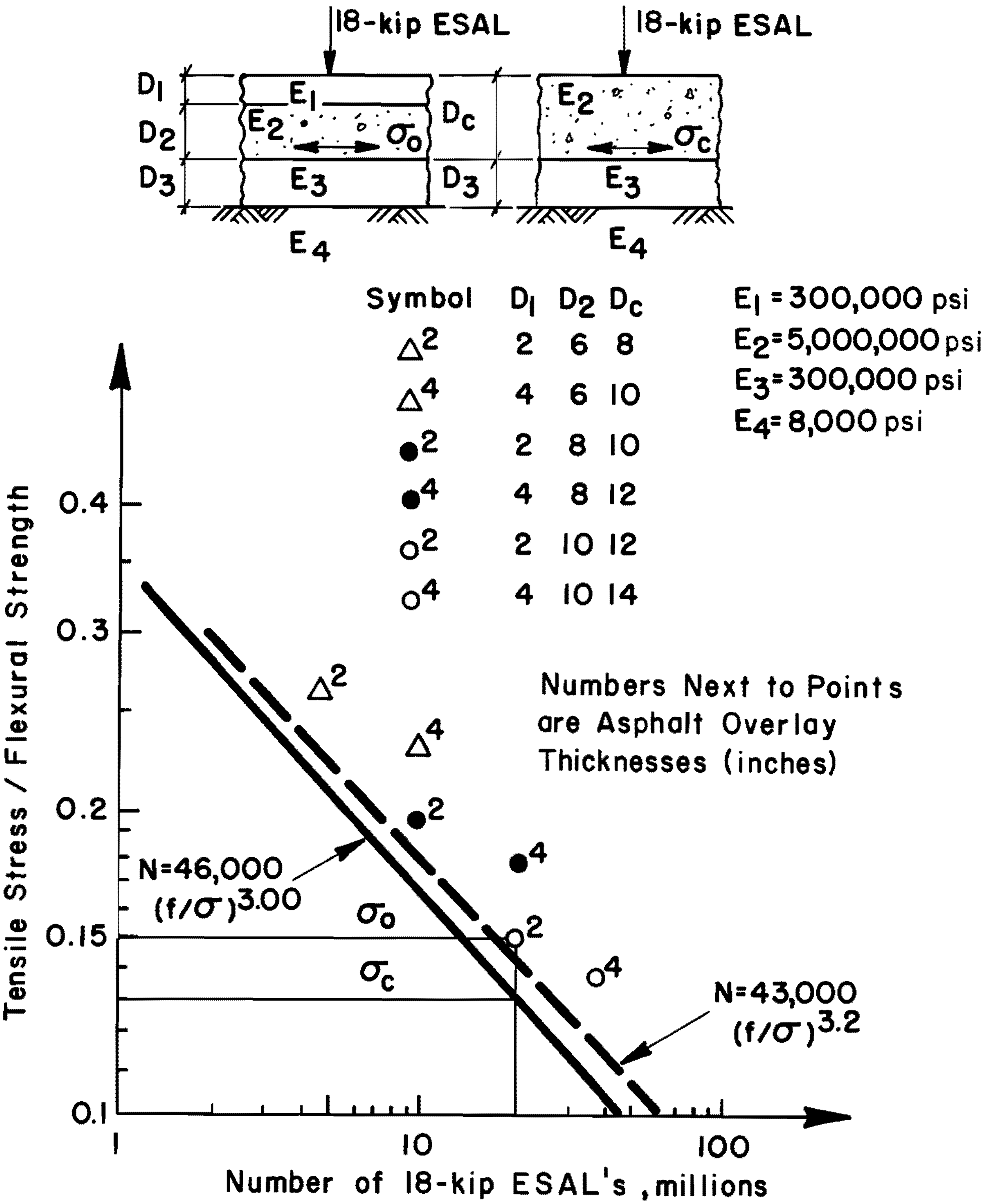

Fig 4.6. Figure showing the non-overlaid and overlaid rigid pavement fatigue curves and calculated points which provide the upper bounds for the position of the overlaid fatigue curve.

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instead. The deflection basin slopes at pavement distress manifestations and pavement discontinuities may be compared to those obtained from layered theory analysis. The surface and subbase moduli used in the analysis may then be varied until the measured and computed basin slopes are equal.

In order to avoid reflection cracking, PCC overlays are very often unbonded, and in this case the subgrade modulus has very little effect on the stresses in the overlay. Thus an estimated value of subgrade modulus may be used throughout this analysis.

The above improvements to the RPOD2 design procedure were incorporated in the RPRDS program, which was developed at The University of Texas at Austin (Ref 3). This program analyzes various alternate pavement rehabilitation strategies, using mechanistic procedures, in order to obtain an optimum strategy with regard to total costs. Continued collection of condition survey data and deflections, coupled with further implementation of the above procedures, should serve to provide continuous improvements to these methodologies.

A DESIGN SYSTEM FOR RIGID PAVEMENT REHABILITATION

A design system for rigid pavement rehabilitation using the systems methodology as a guide for the process of selecting, modifying, improving, and incorporating appropriate design and cost models into a comprehensive computer program (RPRDS-1) for the analysis of rigid pavement rehabilitation strategies was developed and is reported in Research Report 249-2, "A Design System for Rigid Pavement Rehabilitation."

The first version of the Rigid Pavement Rehabilitation Design System, RPRDS-1, begins at the project level. At this level, the problem or task is to select a pavement rehabilitation strategy for a given length of roadway which will provide the maximum service to the user over a given period of time and at a minimum overall cost.

Basically, RPRDS-1 attempts to solve this problem by analyzing a large number of rehabilitation strategies on a total cost basis where the primary method of rehabilitation considered is overlay construction. The methods that are considered in RPRDS-1 include a multitude of factors dealing with overlay construction, such as (1) concrete shoulder construction, (2) type of overlay (ACP, CRCP, JCP), (3) number of overlays (one or two during the analysis period), (4) aggregate type, (5) overlay thickness, and (6) flexural strength.

Figure 4.7 presents a general flowchart of RPRDS-1. Some of the equations and algorithms within the various routines of RPRDS-1 are discussed in the following subsections.

Prediction of Pavement Response

The procedure in RPRDS-1 uses a combination of elastic layered theory and finite element theory to predict pavement responses, i.e., stress, strain, and displacement.

RPRDS-1 can consider a variety of different overlays strategies. Since this combination of possible strategies requires an even larger number of pavement responses for predicting their corresponding lifetimes, it was not considered feasible to calculate or recalculate responses every time they are needed. Consequently, a computer routine, CONSRP (Fig 4.7), was developed for RPRDS-1 to generate the required responses. It is capable of (1) making the appropriate decisions as to which responses are required for each strategy, (2) preparing the necessary inputs to calculate the response, (3) calling the appropriate routine to calculate the response, and (4) storing the response for later use.

Both elastic layered theory and the finite element method have to be combined to predict the critical pavement response because (1) elastic layered theory cannot predict pavement response at a discontinuity, such as a pavement edge or crack, and (2) computer models based on finite element theory require too much data preparation and computer time for practical use in RPRDS-1.

The fusion of the two methods can be briefly described as follows. First, prediction models based on elastic layered theory are used to estimate the pavement response for an interior loading condition. Then, this interior response is adjusted for the other conditions using relationships developed from finite element theory in which the response at a discontinuity is correlated with the interior response. For example, if the stress near a

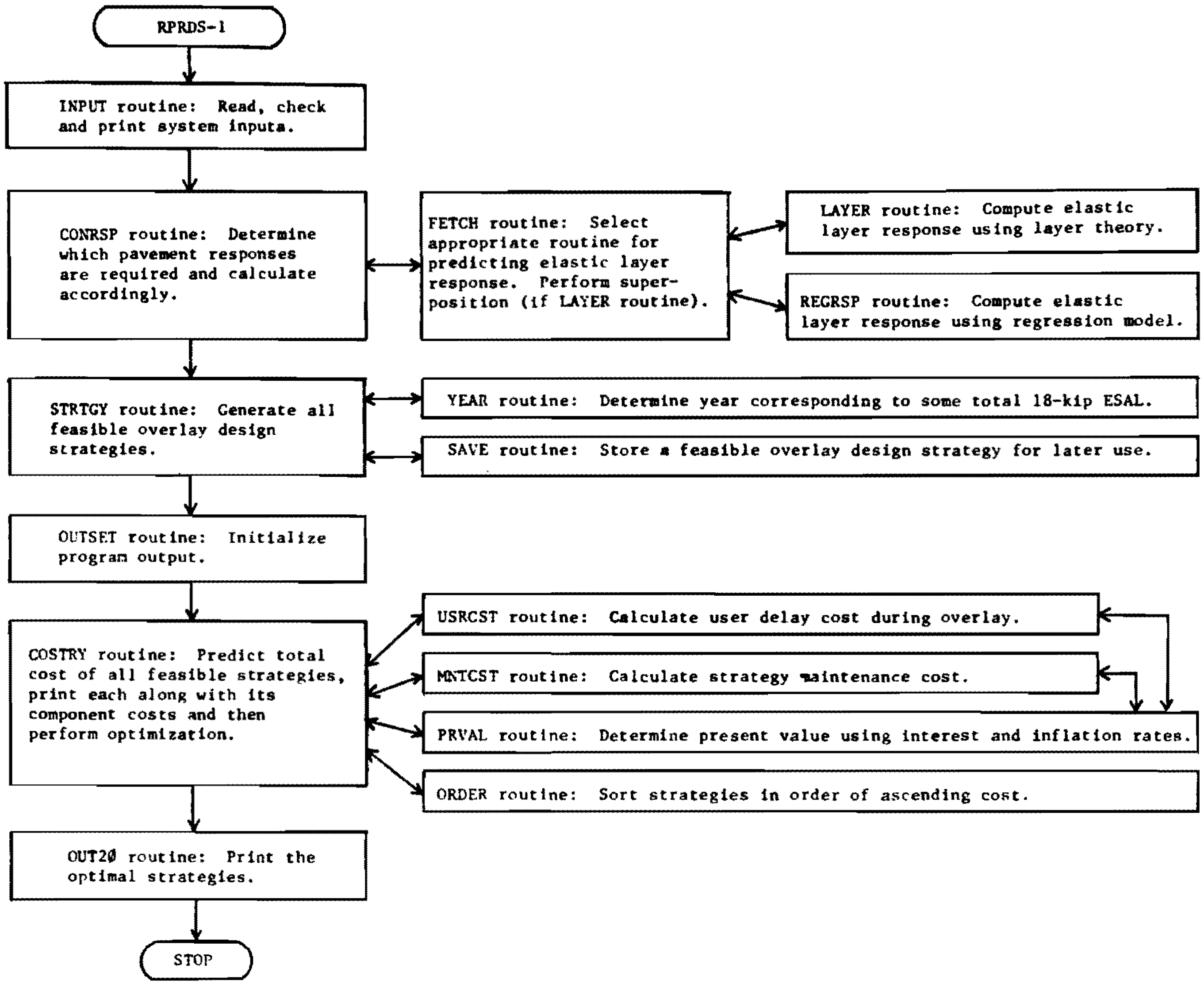

Fig 4.7. General flow diagram of the rigid pavement rehabilitation design system computer program, RPRDS-1 (Ref 3).

pavement edge were required, it would be determined by computing the interior stress using the elastic layered theory model and then multiplying by an edge stress factor developed from finite element theory.

Generation of Feasible Overlay Design Strategies

Design Constraints. Several types of constraints are considered within program RPRDS-1. The Rigid Pavement System, RPS (Ref 7), takes into account seven different types of design constraints. However, since RPRDS-1 is a design system for rehabilitation, only the following five types of design constraints that originally appear in program RPS are considered either directly or indirectly by RPRDS-1:

(1) minimum allowable time to first overlay,
(2) minimum allowable time between overlays,
(3) length of analysis period or minimum life of strategy,
(4) maximum ACP and PCC overlay thicknesses, and
(5) minimum ACP and PCC overlay thicknesses.

In most overlay design problems, the existing pavement is available for an "immediate" overlay, and, consequently, it does not matter how long ago it was constructed. The first constraint is still considered indirectly, however, since the program requires that the designer specify certain levels of pavement life at which the first overlay may be placed.

The second constraint is considered directly within RPRDS-1, the third constraint, minimum strategy life, is handled differently from RPS. Any strategy in which a second overlay is required too soon after the first overlay will be eliminated from further consideration.

Due to the type of maintenance cost model used in RPRDS-1, the third constraint, minimum strategy life, is handled differently from RPS. RPRDS-1 allows the user to specify some maximum period of heady maintenance, which, in effect, permits consideration of those strategies that do not quite last the analysis period without some period of heavy maintenance.

The fourth and fifth design constraints are also considered in RPRDS-1, but in a slightly different way. First of all, RPRDS-1 requires that the designer select the specific thicknesses of ACP and PCC overlay to be considered; therefore, infeasible thicknesses are eliminated immediately. Second, the program allows the designer to specify a maximum total overlay thickness.

Additionally, RPRDS-1 attempts to limit the number of thickness design alternatives by omitting those which provide excessive lifetimes. Once a feasible thickness design is generated, no further designs are considered in which only the overlay thickness is greater.

In summary, an RPRDS-1 strategy is constrained by how long it will last, the total allowable thickness of overlay, and the time at which a second overlay (if used) is placed.

Prediction of Fatigue Life. The basic method used in RPRDS-1 for predicting the fatigue life of an overlay design strategy is that developed by Austin Research Engineers, Inc. (ARE), for the Federal Highway Administration (Ref 6). That original method has experienced improvements made by Schnitter, Hudson, and McCullough (Ref 4), and by Taute et al (Ref 2).

Finally, several improvements resulted from the development of program RPRDS-1 (Ref 3). These include concrete shoulder construction, two overlays (instead of one) to provide the desired lifetime, and the consideration of the additional life left in an overlay after the original PCC loses its load-carrying capacity.

The method of prediction of fatigue life of an overlaid pavement assumes the Miner's linear damage hypothesis is valid for such applications and uses it to develop the concepts of pavement damage and remaining life.

Figure 4.8 illustrates the alternatives that are possible with regard to the type of the existing pavement and the type of overlay. Note that a two-overlay strategy can be considered but that at least one of the two must consist of asphaltic concrete.

Besides the type of overlay, the other variable components of an overlay strategy include

(1) remaining life of the existing surface layer at time of overlay placement,
(2) overlay thickness,

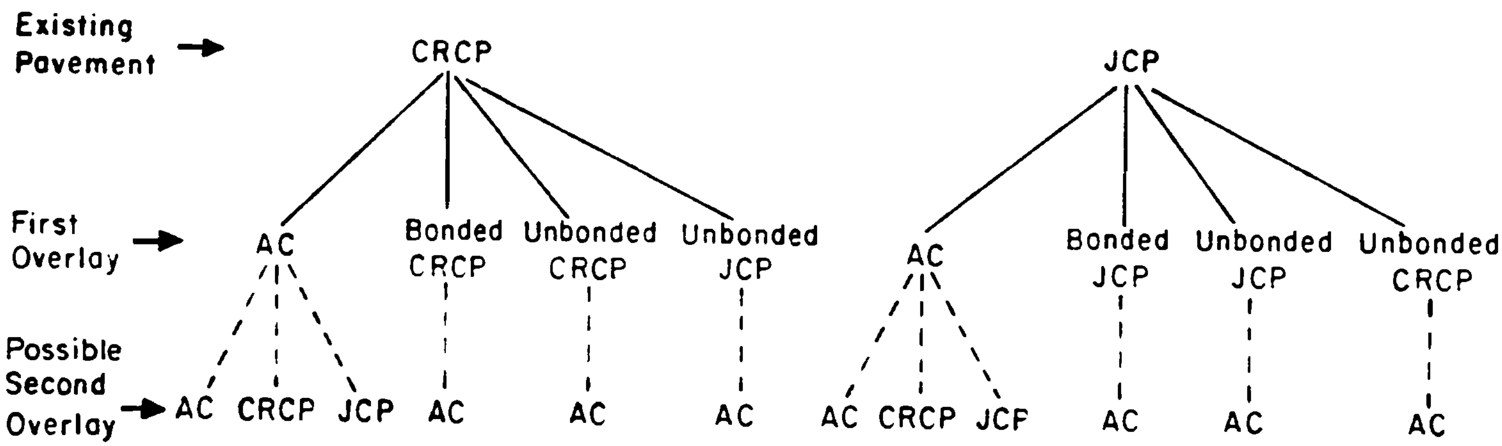

Fig 4.8. Illustration of the overlay design strategies available in RPRDS-1 with regard to existing pavement and overlay type (Ref 3).

(3) flexural strength of a PCC overlay, and

(4) concrete shoulder construction.

The two PCC fatigue equations used in RPRDS-1, along with the original ARE equation (Ref 6), are given in Fig 4.9.

The fatigue equation used in RPRDS-1 for the design of asphaltic concrete (AC) overlays is the original one developed by ARE, for the Federal Highway Administration (Ref 8). Figure 4.10 shows this fatigue equation.

In summary, feasible overlay strategies are generated in RPRDS-1 by considering some of the constraints in overlay thickness. In order to accomplish this, certain cumulative 18-kip ESAL applications must be obtained: (1) the traffic from year zero to the time of overlay placement and (2) the traffic from year zero to the time of overlay failure. These 18-kip ESAL traffic values are determined by first combining the results of elastic layered theory and the finite element method to predict the required critical responses. These critical responses are then used in conjunction with the fatigue equations and the fatigue life prediction models to obtain the 18-kip ESAL traffic values.

Next, the years corresponding to these 18-kip ESAL applications are determined, so that a check for feasibility can be made using the remaining time constraints. If the candidate strategy meets these remaining constraints, it is stored as a feasible strategy for later cost analysis and optimization.

Cost Analysis of Each Feasible Strategy

Traffic Delay Cost Submodel. The traffic delay cost routine in RPRDS-1 is basically the same as that used by Daniel (Ref 9).

The model first predicts the delay times incurred by each vehicle as it passes through the restricted overlay zone. Daily distributions of traffic for rural and urban areas of Texas, as well as the incremental user delay costs per unit time, are built into the routine. These, along with the user-specified traffic volumes and periods during which the delays will occur, are used to determine the total overall traffic delay cost. The cost is then

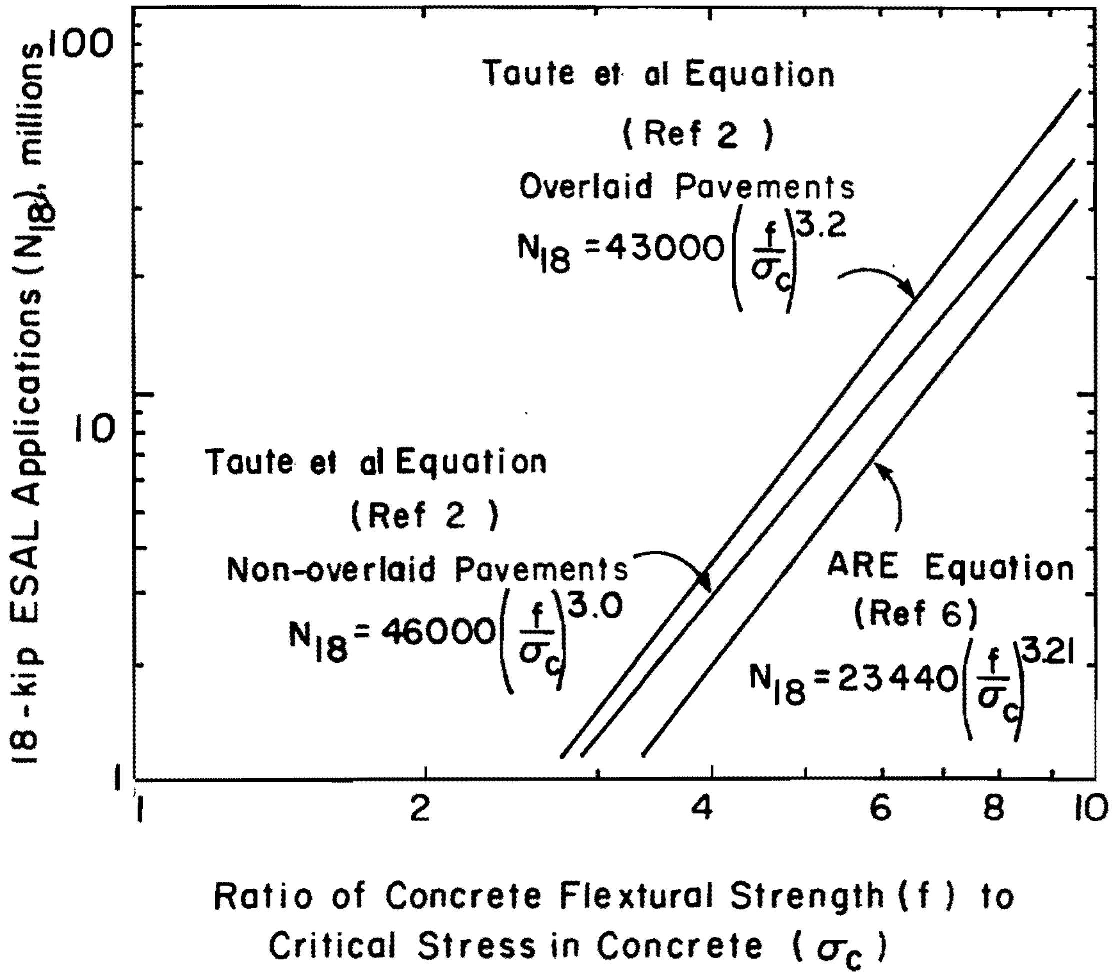

Fig 4.9. PCC fatigue equations (Ref 3).

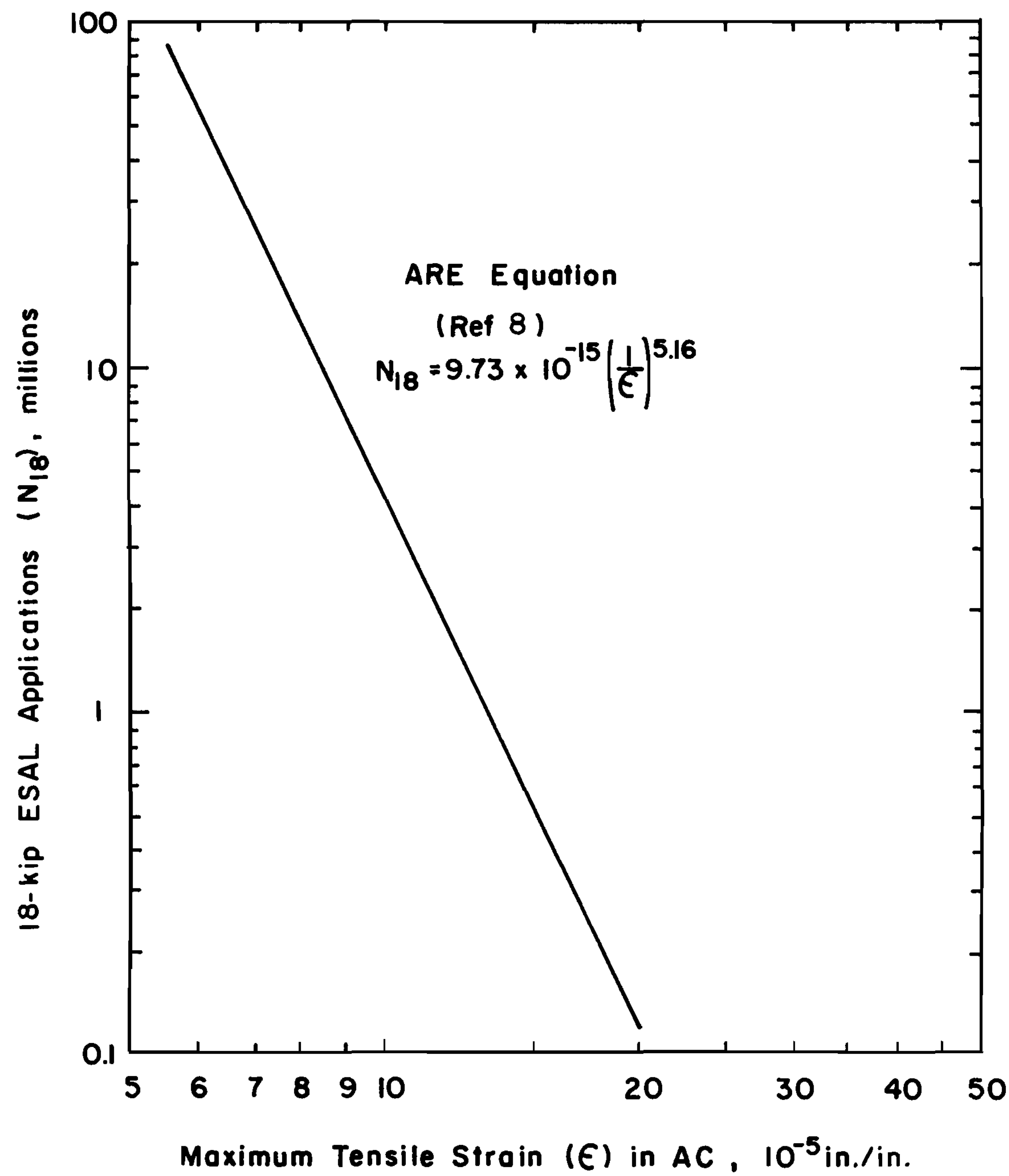

Fig 4.10. AC fatigue equation used in RPRDS-1 (Ref 3).

converted to a per square yard basis and is brought back to net present value.

There are five different models for handling traffic within RPRDS-1. Since the delay duration and the number of vehicles delayed are dependent upon the method in which traffic is detoured, it is necessary for the user to specify which method will be used. The choices available are shown in Fig 4.11.

Overlay Construction Cost Submodel. The cost of overlay construction can be broken down further into four categories.

(1) Site-Establishment Cost. This refers to the cost of mobilizing the men and equipment necessary to perform the overlay construction.

(2) Surface-Preparation Cost. This refers to the cost of any cleaning and milling which must be performed on an existing surface prior to overlaying.

(3) Overlay and Shoulder Thickness Cost. The calculation of the shoulder construction cost is handled in the same way as that of the overlay thickness cost; that is, the cost of a certain thickness of overlay (or shoulder) consists of a fixed cost (dollars per square yard) and a variable cost (dollars per square yard per inch of thickness). The fixed cost takes care of the cost of any traffic detour arrangement which needs to be made and the cost of machinery and manpower required to perform the actual construction.

The variable cost accounts for the differences in thickness between different overlay strategies.

In addition to the thickness cost, the construction cost submodel also considers the increased volume of material required for level-up and the cost of bond breaker placement for unbonded PCC overlay strategies.

(4) Steel Reinforcement Cost Submodel. RPRDS-1 does not use a sophisticated model for the prediction of the steel reinforcement percentages required by PCC pavements. Instead it must rely on the designer's empirical estimates of the steel percentages required

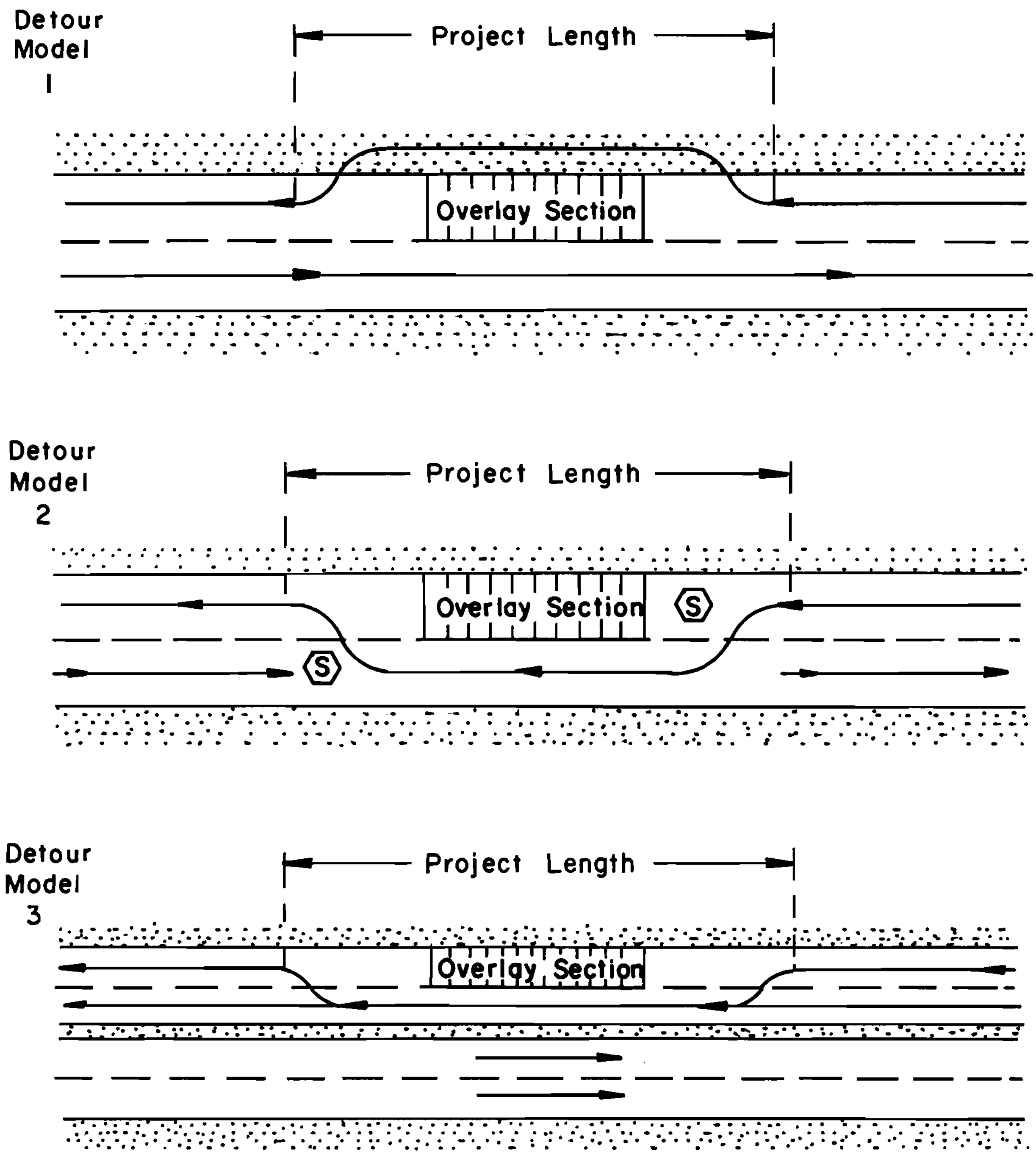

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Fig 4.11. Illustration of the detour models available in RPRDS-1 for use in estimating traffic delay cost (Ref 3).

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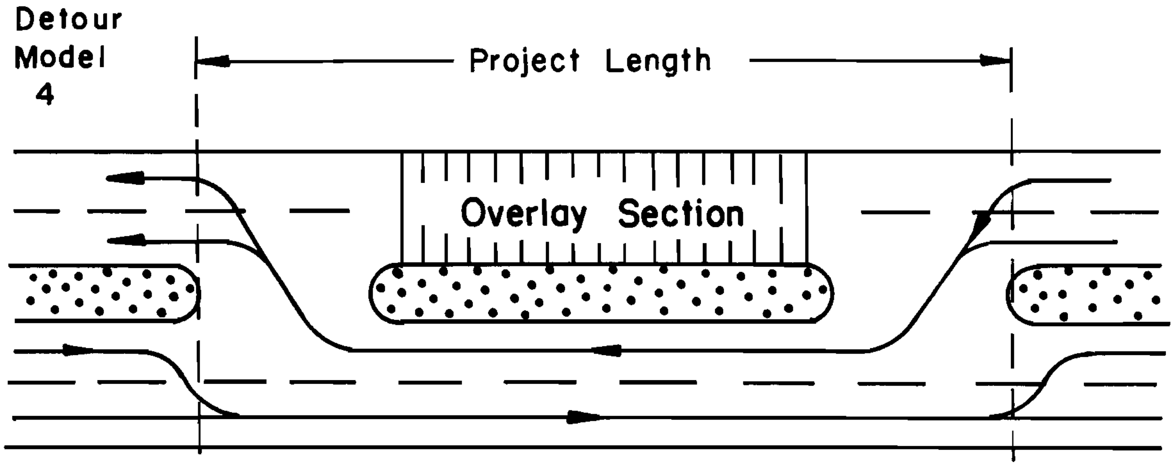

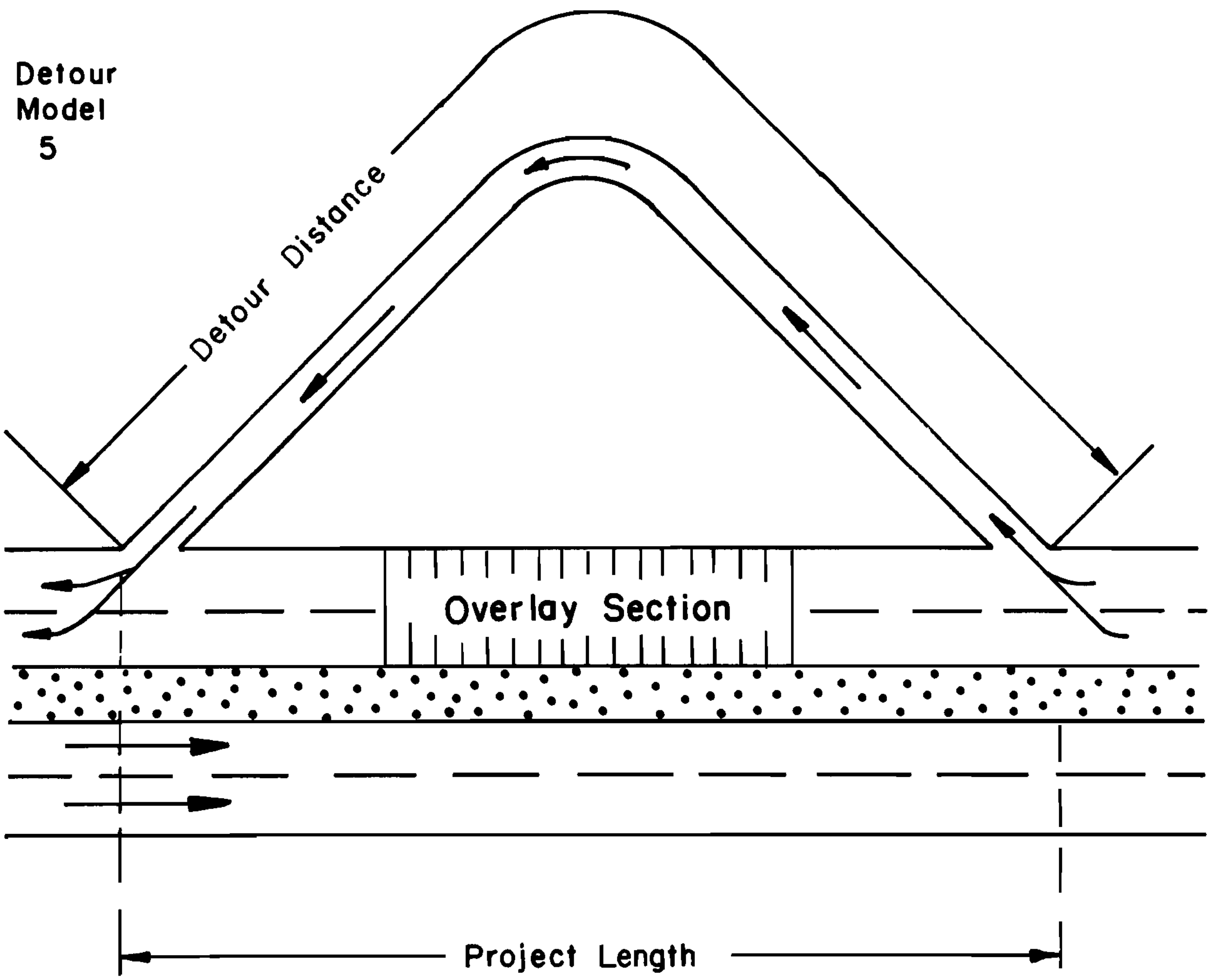

Fig 4.11. (Continued).

for the different overlay types. Basically, the steel percentages selected by the user are used to estimate the volume and weight of steel in a square yard of overlay.

Distress/Maintenance Cost Submodel. The mechanics of the model are simple. The user first defines the rate of distress occurrence and the cost for a single repair on the existing pavement. Then for each overlay type considered the user must specify (1) the cost of repairing the typical distress manifestation (or defect) which may occur, (2) the rates at which these defects occur during two stages of the fatigue life of the overlay, and (3) the rates of defect occurrence for any number of years (after the end of the fatigue life) the user wishes to consider to extend the life of a given overlay strategy (these additional years considered represent a period of heavy maintenance). With this information the program will increment its way through the life of a strategy, multiplying the number of defects which occur during a given year by the cost of repairing them and then bringing them back to net present value. Then, when the end of the analysis period is reached, these yearly costs are accumulated to give the maintenance costs for the existing pavement and overlay(s), as well as the total maintenance cost of the strategy.

The basis of the distress/maintenance cost submodel is a statewide condition survey of CRC pavements in Texas (Ref 10). In an analysis of these data performed by Taute et al (Ref 2), a pattern of distress development in the CRC pavements was observed. This pattern is illustrated in the graph shown in Fig 4.12. The geometric progression which was observed in the survey data is also shown in Fig 4.12. This section of the CRCP distress curve corresponds to a period of heavy maintenance which the user may want to consider to allow a certain design strategy to last the analysis period.

Value of Extended Life. This quantity represents a future return (negative cost) resulting from the additional years of service past the end of the analysis period that some strategies will provide due to the fact they are "over-designs." This is different from salvage value and comes about because of the nature of the input thicknesses in RPRDS-1. While one overlay thickness strategy may not last the analysis period, the next overlay

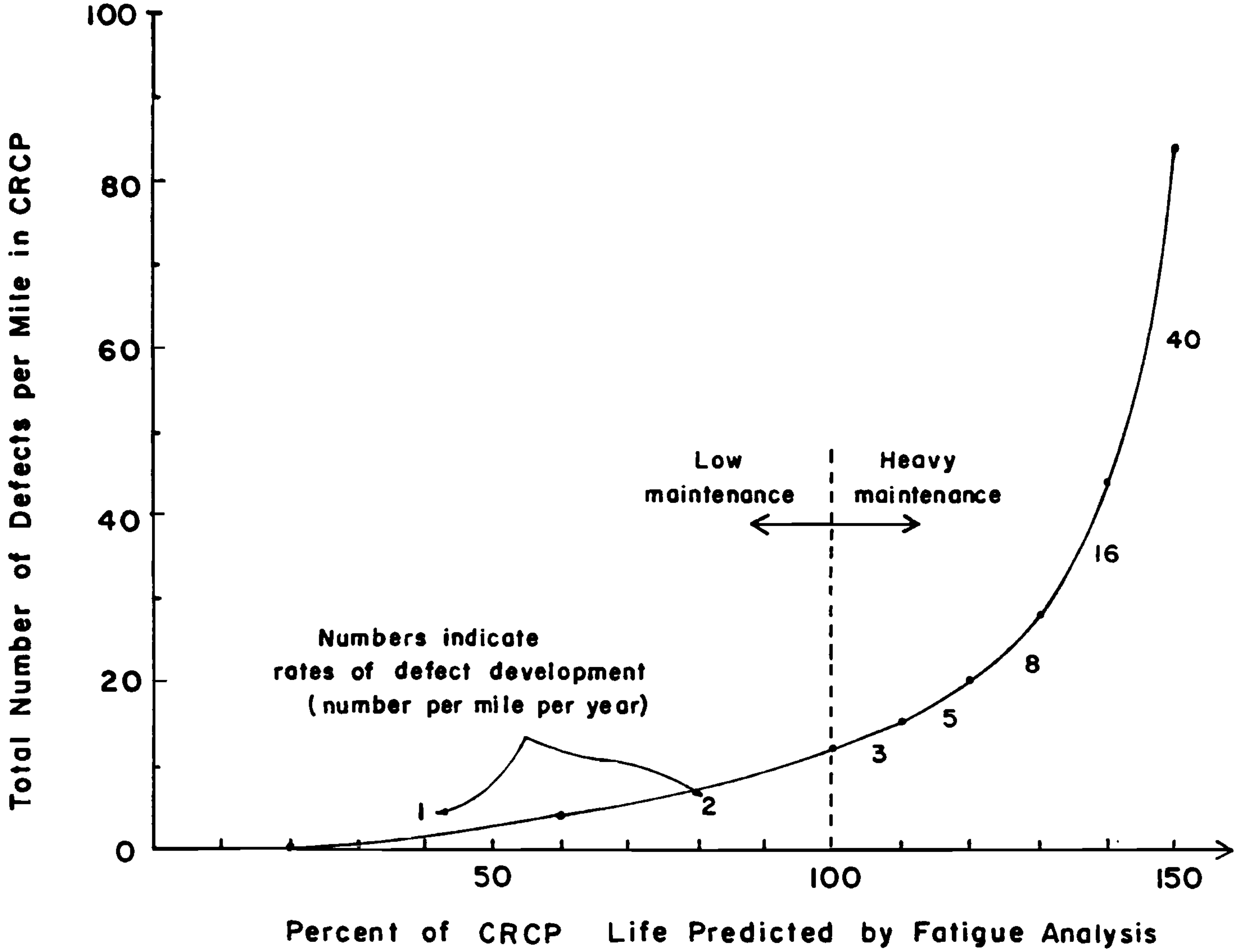

Fig 4.12. Normalized graph of the development of CRCP defects in Texas (Ref 3).

strategy, which may be only one inch thicker, may last an additional five to ten years, depending on the traffic. Consequently, provision is made in RPRDS-1 for the user to assign some value (on a per square yard basis) to each additional year of service. These values are brought back to present value using the combined interest and inflation model.

Salvage Value. This is another quantity that represents future return (negative cost). It accounts for the value of the overlay structure after it reaches the end of its life. Salvage value is computed by multiplying the total cost of overlay construction by a percentage specified by the user and once again returning this value to net present value.

Net Present Value. This model is used to account for the time value of money, namely, inflation, and the opportunity cost of capital (prime interest).

Method of Optimization. The method of optimization used in RPRDS-1 is very simple. Basically, RPRDS-1 will order the top 20 strategies in order of increasing net present value.

In summary, the cost analysis of each feasible strategy is performed by computing each individual cost on a per square yard basis and by bringing it back to net present value before summing to get total strategy cost.

A PROCEDURE TO ANALYZE THE DEVELOPMENT OF REFLECTION CRACKS IN AN AC OVERLAY

A detailed description of the procedure to analyze the development of reflection cracks in an AC overlay was published in Research Report 249-6 (see list of reports on page v). The report included a description of design procedure at three levels of details (see Chapter 6, of Research Report 249-6). Only the third level - hand solution is briefly summarized in this chapter. For further details, please refer to Research Report 249-6 (Ref 17).

THIRD LEVEL - HAND SOLUTION TO MINIMIZE REFLECTION CRACKING

This level consists of a hand solution based on a series of design charts, presented in Figs 6.6 to 6.14 of Ref 17, to predict overlay life and the design chart, presented in Fig 6.15 of Ref 17, to determine maximum deflection factor.

Before describing the application, the design chart's most limiting constraints are as follows:

(1) Figure 6.5 provides a map of Texas showing the six composite climatic zones. The charts presented in the report were developed only for Zones B, D, and F. Recognizing that Zone A has the mildest climate, then overlays in Zone A can be conservatively designed using the Zone B design chart. Furthermore, overlays in Zones C and E can be designed by interpolating between the results of designs for Zones B and D and D and F, respectively.

(2) The applicability of the design charts is limited to the range of values selected as typical in deriving the deterministic equations for the prevailing conditions in Texas. Since the model used in ARKRC-2 (see Research Report 249-6) is not very sensitive to the Portland Cement Concrete Properties, there was no use in deriving the different charts for different types of concretes; therefore, the values selected for creep modulus (4.5×10^6 psi) and thermal coefficient (4×10^{-6}) were based on the average properties of the Texas concrete pavements.

(3) The JCP/JRCP design charts were derived for a typical 10-inch thick jointed pavement, whereas the CRCP charts were developed for the standard CRCP cross-section used in Texas (8-inch slab with No. 5 bars at 6.25-inch centers).

(4) For cases where an intermediate layer is used, the design charts are only applicable to those which have the properties and characteristics of the standard Arkansas mix open-graded base course. For denser mixes, the results provided by the design charts will be conservative.

The design charts shown in Figs 6.6 to 6.15 of Research Report 249-6 to predict overlay life and maximum allowable deflection factor may be used in two possible ways:

(1) to determine the overlay substituting life and check how well it is performing in terms of reflection cracking (assuming adequate load transfer in cracks or joints of original PCC pavement) and

(2) to determine the most economical design alternative from the reflection cracking standpoint.

The step-by-step procedures for determining overlay subsisting life and selecting design alternatives are described in Research Report 249-6 (Ref 17), along with some application examples.

SUMMARY

Certain improvements to the Texas Rigid Pavement Overlay Design Procedure (RPOD2) regarding materials characterization and fatigue life predictions were made, based on data collected on Texas highways. They are presented in Research Report 249-1, "Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure," (Ref 2).

A large number of the improvements in Report 249-1 have been incorporated into Research Report 249-2, "A Design System for Rigid Pavement Rehabilitation" (Ref 3).

In Report 249-2 (Ref 3) a rigid pavement rehabilitation design system (RPRDS-1) was developed for the Texas State Department of Highways and Public Transportation as the next major phase in the implementation of tne department's rigid pavement overlay design (RPOD2) procedure. Unlike other pavement design systems, RPRDS-1 considers only structural rehabilitation, i.e., overlay construction. In addition, provision is made in RPRDS-1 for the consideration of other factors which affect pavement performance and accompany overlay construction. These include ACP, CRCP, and JCP type overlays; concrete shoulder construction; and variable concrete flexural strength; as well as variable overlay thickness. Unfortunately, some of the available methods of rigid pavement rehabilitation are not considered within RPRDS-1. These include under-sealing joints or cracks, pressure grouting, new overlay types (sulfur-asphalt, rubber asphalt, and sulflex), and replacement of worn-out sections by either cast-in-place or precast slabs.

It is recommended that an improved fatigue model be developed for ACP overlays since the existing model in RPRDS-1 is not based on observations of ACP overlays on rigid pavements. Likewise, data should be collected on the distress rates of JCP and ACP overlays to insure a congruent comparison with CRCP overlay strategies.

In order to identify the relative importance of each of the inputs to RPRDS-1 and to get an idea of their effect on the results, a sensitivity analysis of the program should be conducted.

CHAPTER 5. SUMMARY OF THE 1982 CRCP CONDITION SURVEY IN TEXAS

In order to obtain historical performance information to verify the established design criteria for CRC pavements and to help in planning and scheduling of maintenance and rehabilitation activities, a series of condition surveys of CRCP sections throughout the state were initiated in 1974. Continuing the 1974 initial condition survey, CRCP sections in the state were surveyed again in 1978, 1980, and 1982. In 1982, the jointed concrete pavements in the state were also surveyed. Most of the condition surveys were conducted at network as well as at Project level.

The technique used in these condition surveys involves the rating of specific pavement sections by two persons traveling on the shoulder in one vehicle, at very low speed. This distress condition and the riding quality of the facility were considered in the rating. The distress manifestations recorded were: transverse and localized cracks, spalling, pumping, punchouts and repaired patches directly in the CRC pavement, and reflected cracks in overlaid sections. These data, after being collected in the field, were stored, processed, and reported by a computer. The reports were distributed to the districts and the Texas SDHPT.

The primary objective of this chapter is to analyze the 1982 condition survey data and to compare it with past condition-survey data. The results are presented in a summary form consisting of charts, tables, and maps, with some statistical analyses performed.

The districts surveyed in 1974, 1978, and 1982 are shown in Fig 5.1.

Summary of Statewide Distress Condition in 1982

In the 1982 condition survey, the distress manifestations recorded were punchouts, patches, spalling, and pumping. In addition, the average crack spacing was determined for specific sections and extrapolated to all other projects.

In this section the distress types which define failures will be examined relative to state-wide historical trends between 1974 and 1982. In

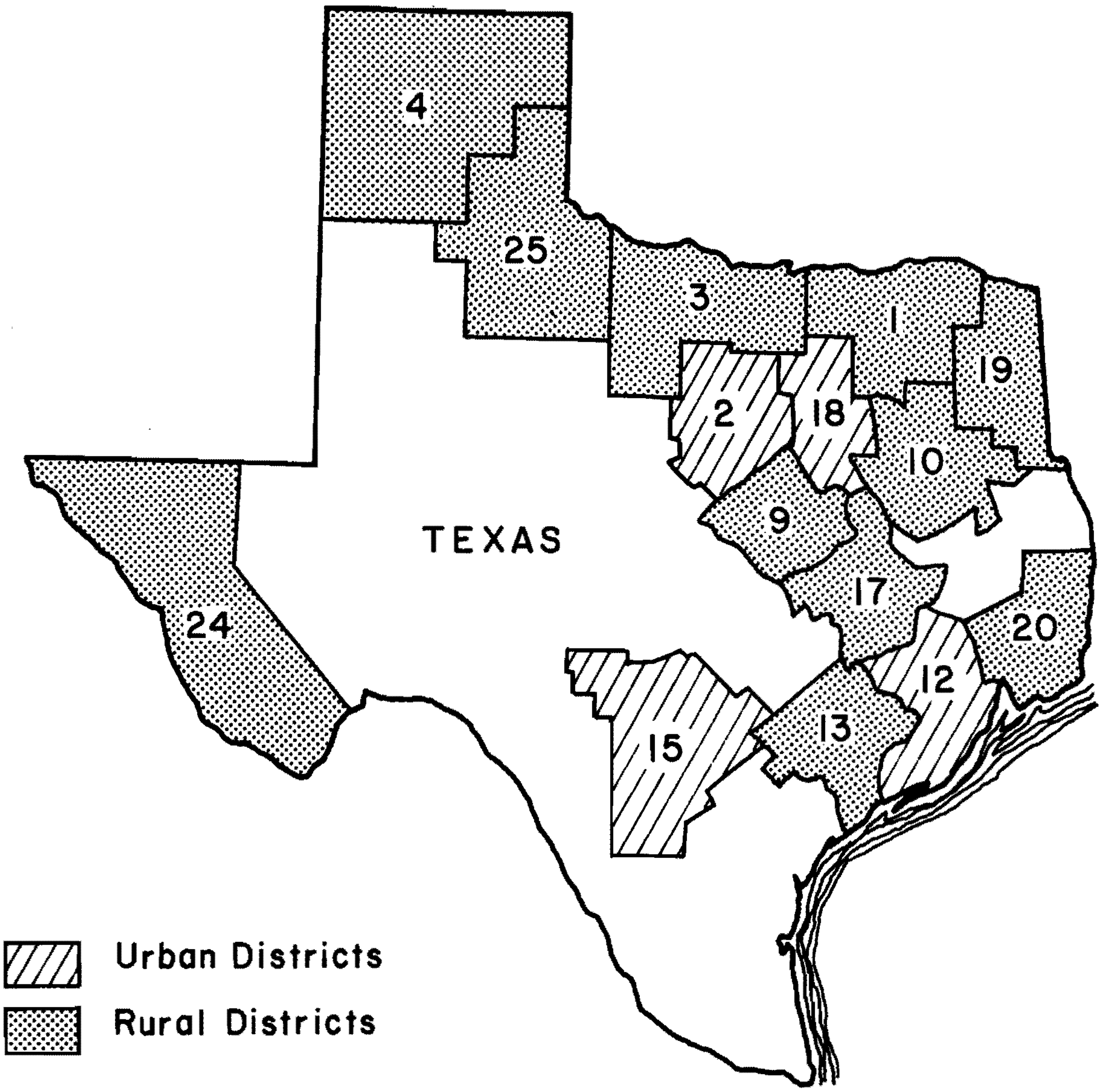

Fig 5.1. Location of Districts surveyed in 1974, 1978, and 1982.

general, the condition of the CRCP sections throughout the state is presented and some important comments, relative to each of the districts, are made.

Failures

Failures are considered as the sum of punchouts and repaired patches on the pavement. Punchouts are defined as rectangular shaped blocks formed by closely spaced transverse cracks linked by longitudinal cracks. Patches may be either portland cement concrete or asphalt concrete. During the survey, the condition of the repair patch was not recorded.

In Fig 5.2, the mean numbers of failures per mile in each district are shown for 1974, 1978, and 1982. The number of failures in each district would be expected to increase from 1974 to 1978 and subsequently from 1978 to 1982; in some cases this is not true because the highly distressed sections have been overlaid, reducing the observable number of failures per mile.

Table 5.1 provides further information for each district: the length reported, the length overlaid since 1974, the age range, failures per mile, and the mean failure rate. The mean failure rate values (FPM) presented in this report are based on the data recorded in 1978 and 1982.

To assist the reader in making relative comparisons, the survey data were used to prepare a series of maps that show the distress condition of the CRCP sections in some of the districts in 1982. Figures 5.3 and 5.4 show the distress condition of those projects monitored in 1974 and 1978, respectively. These figures illustrate the progressive deterioration of CRC pavements due to accumulation of traffic loads. It can be observed that in 1974, most of the pavement sections surveyed were in good condition and practically none had been overlaid. In contrast, several pavement sections had been already overlaid by the time the 1982 condition survey was conducted, and the number of projects in very poor condition increased considerably.

Observations by Districts

Some general observations, drawn from the data summarized in Table 5.1, for each of the districts surveyed are presented below.

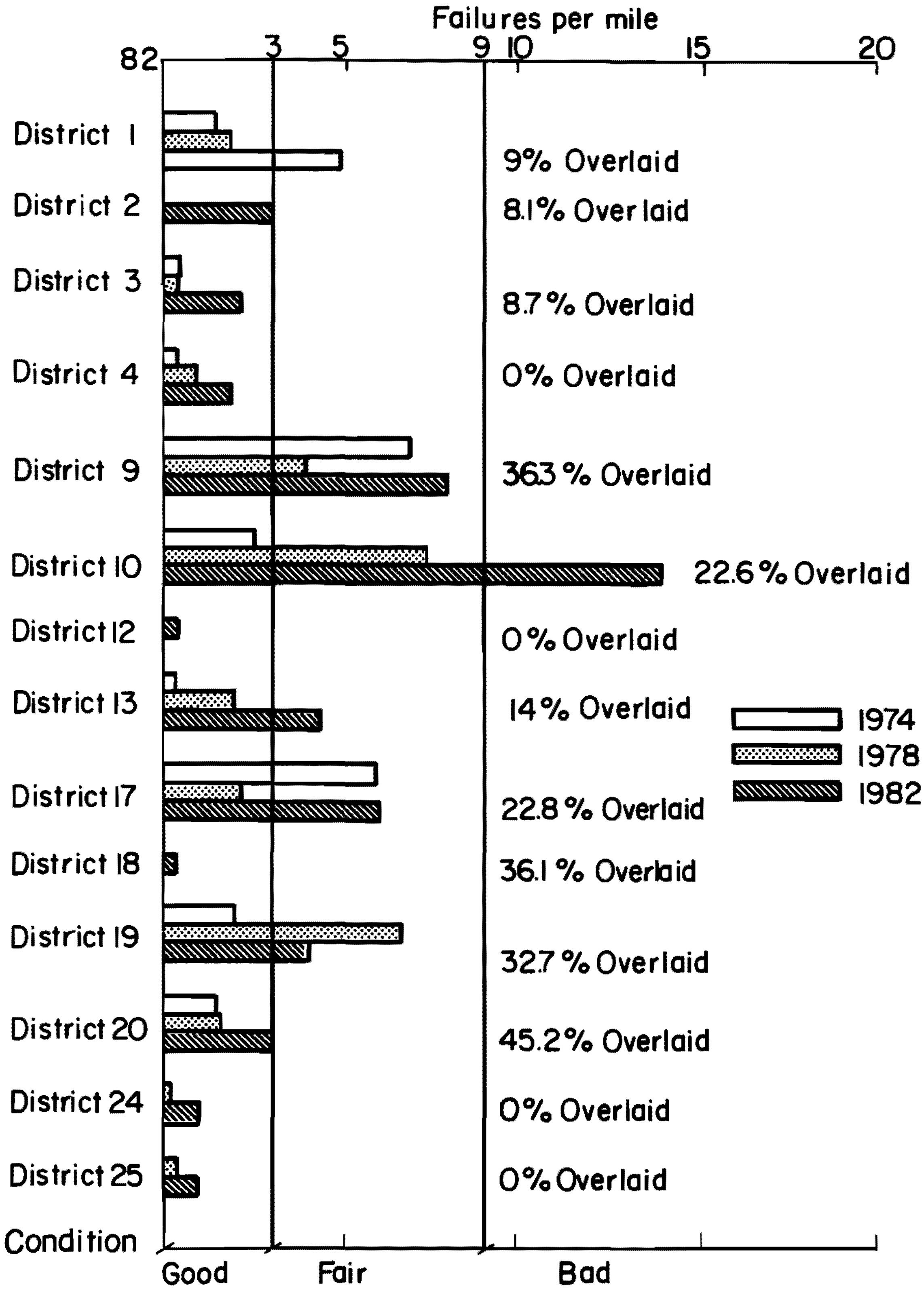

Fig 5.2. Mean failures per mile in each district.

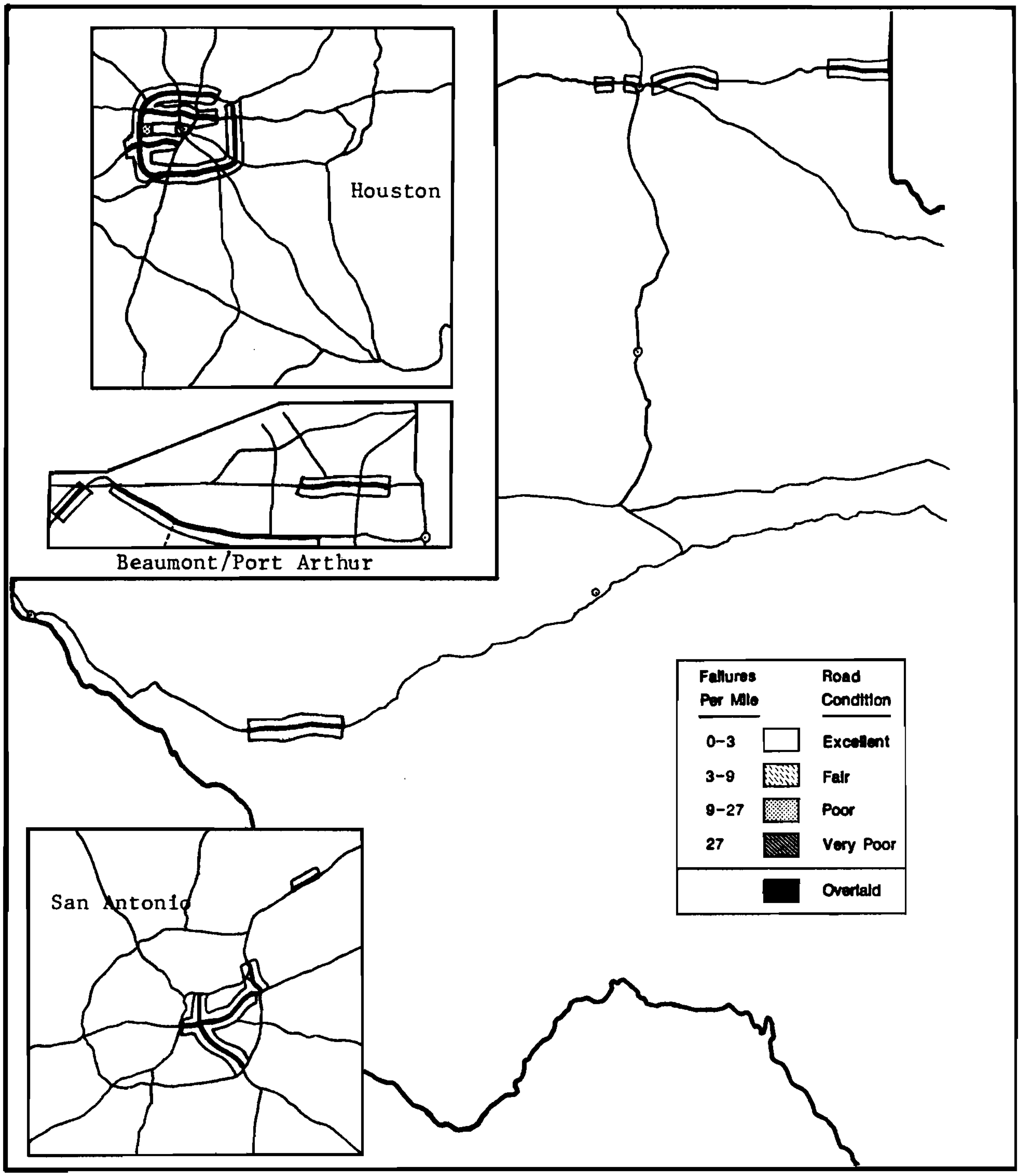

Fig 5.3. 1974 statewide condition survey of CRC pavements (see Table 5.2).

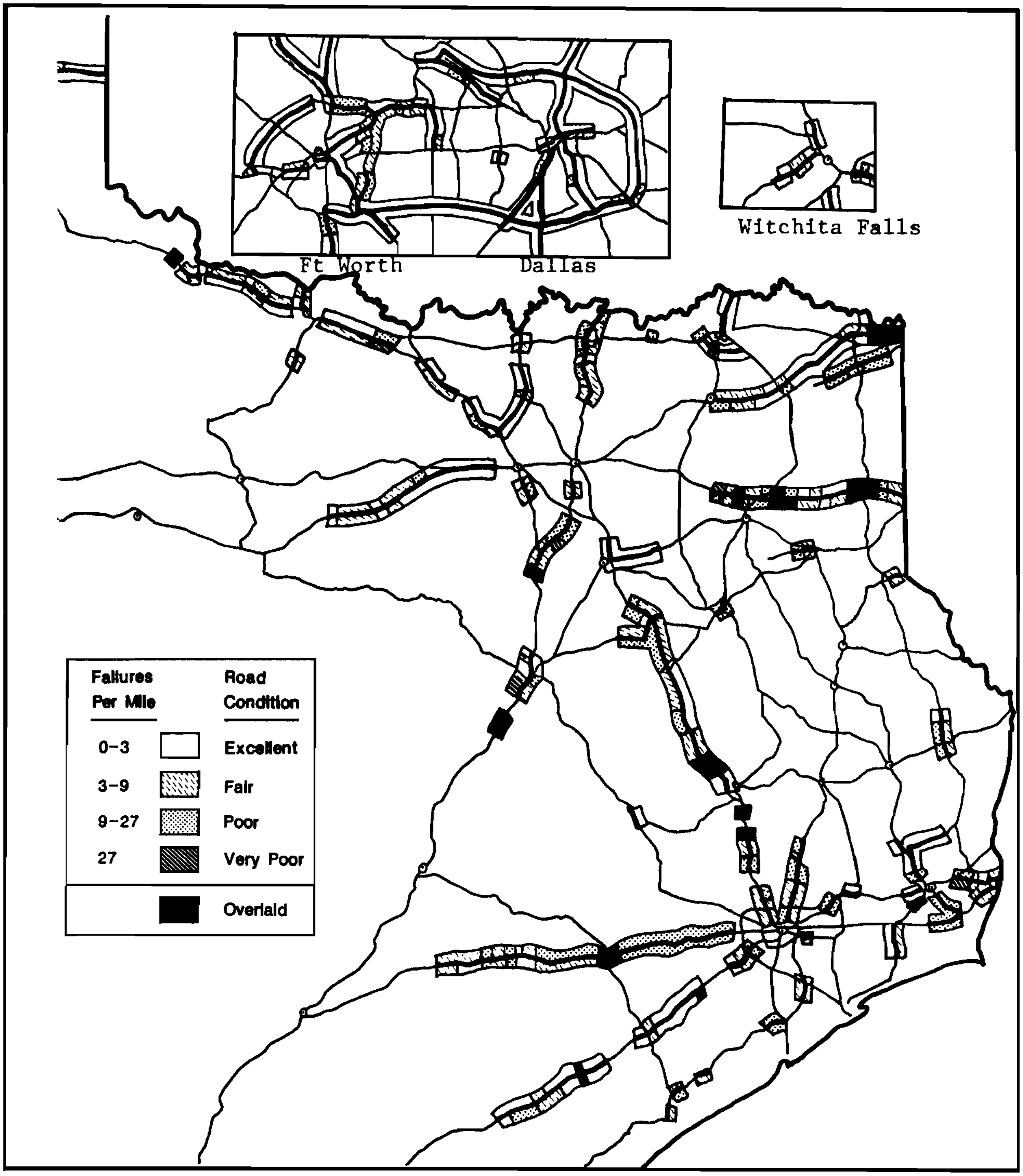

Fig 5.3. (continued).

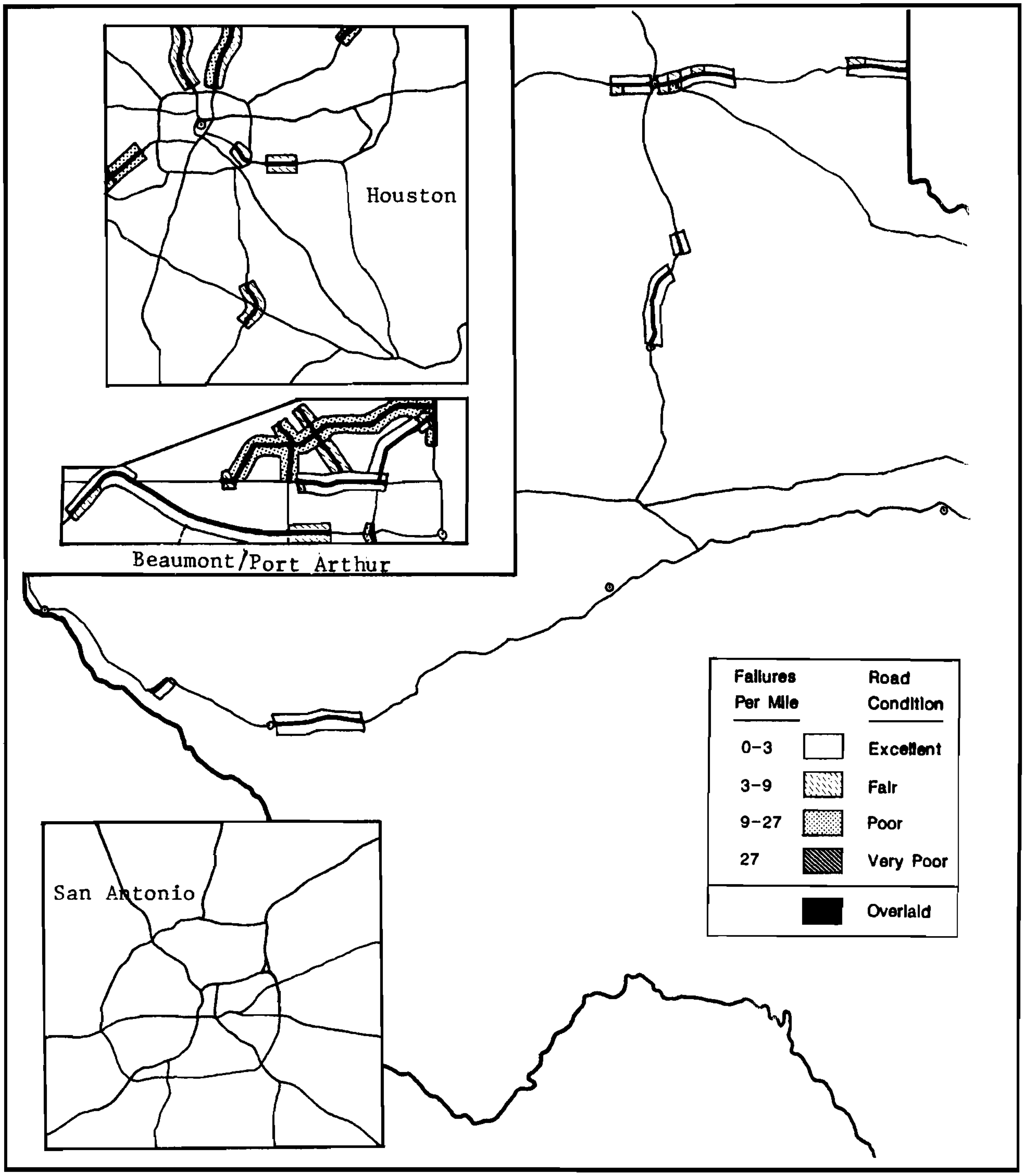

Fig 5.4. 1982 statewide condition survey of CRCP pavements (see Table 5.2).

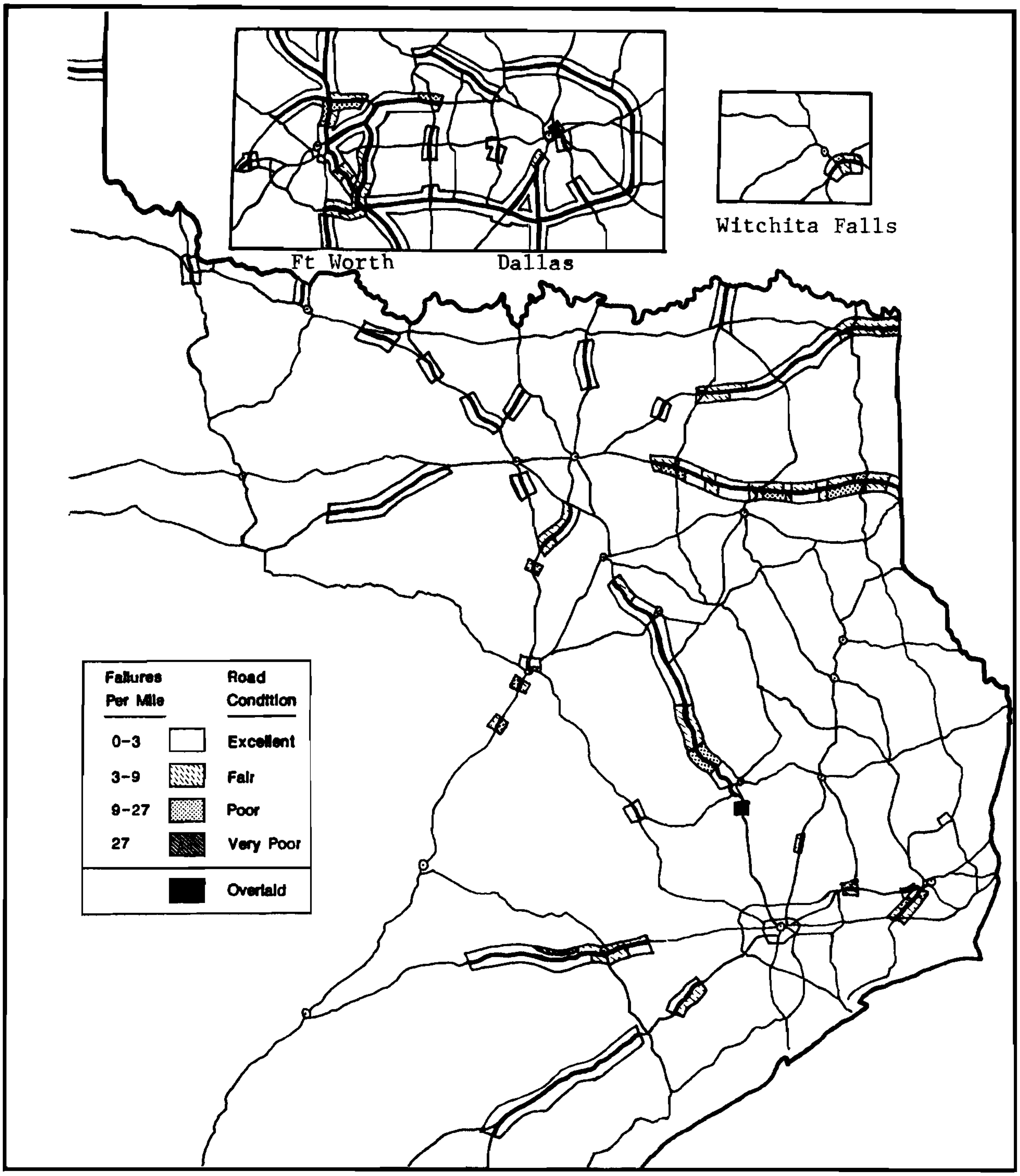

Fig 5.4. (continued).

TABLE 5.1. SUMMARY OF FAILURES FOR THE CRCP 1982 SURVEY.

District	Length Surveyed, miles	Length Overlaid Since 1974, miles	Percent of Overlaid Pavements	Age Range, years	Mean of Failures Per Mile			Mean Failure Rate ('78-'82) (FPM/Year)
					1974	1970	1982	
1	89.9	8.2	9.0	9-20	1.6	2.0	5.0	0.75
2	463.0	37.4	8.1	-	-	-	3.1	-
3	118.2	10.3	8.7	10-20	0.4	0.4	2.2	0.45
4	87.3	0.0	0.0	12-22	0.4	0.9	1.9	0.25
9	45.2	16.2	35.8	13-23	7.0	4.0	8.0	1.00
10	166.7	37.7	22.6	17-21	2.6	7.4	13.9	1.63
12	---	--	0.0	-	-	-	0.5	-
13	293.7	41.8	14.2	10-22	0.3	2.0	4.5	0.63
17	238.2	54.3	22.8	12-23	5.9	2.2	6.1	0.98
18	279.5	50.4	18.0	7-34	-	-	0.3	-
19	220.7	80.1	36.3	-	2.0	6.7	4.1	1.18
20	79.2	35.8	45.2	12-21	1.5	1.6	3.1	0.38
24	---	--	0.0	-	0.0	0.2	1.0	0.20
25	61.4	0.0	0.0	8-16	0.0	0.3	0.9	0.15

<u>District 1</u>. The 1974 condition survey indicated a mean failure-per-mile value of 1.6 and, at that time, no CRCP sections had been overlaid. Between 1980 and 1982 there was a significant increase in the number of overlaid CRCP sections, from 2 to 9 percent, as a result of the steady increase in the number of failures per mile during this period. Despite the overlay work, the mean of failures per mile encountered in the 1982 survey increased to 5. The mean failure rate computed for the 1978-1982 period resulted in the relatively high value of 0.75 failures per mile per year.

CRC pavements in District 1 range in age from 9 to 20 years, with 76 percent being at least 15 years old. Those CRCP projects which have aged 15 years or more by 1982 have a mean failure per mile value of 6.4, whereas those projects less than 15 years old have a mean failure per mile equal to 2.5.

<u>District 2</u>. This district was surveyed for the first time in 1982. The number of failures per mile encountered is, in general, small (3.1 failures/mile) and 8.1 percent of the total district CRC pavements have been overlaid.

<u>District 3</u>. The 1974 condition survey results indicate that there were no CRCP projects overlaid and that the mean of failures per mile was 0.4. Between 1978 and 1982 there was a sudden increase in overlaid CRC pavements, from 1.2 to approximately 8.7 percent, indicating a rapid deterioration of these pavements due to aging and traffic. The mean of failures per mile encountered in 1982 is small (2.2 failures/mile) and the mean failure rate for the 1978-1982 period is equal to 0.45 failures per mile per year.

District 3 CRC pavements range in age from 10 to 20 years. Currently, 51 percent of District 3 CRC pavements are over 15 years old. The construction dates of the completely overlaid projects in this district show a pavement age ranging from 10 to 15 years.

<u>District 4</u>. No major differences exist in the mean failures per mile obtained from the 1974, 1978, and 1982 surveys. The number of failures per mile recorded in 1982 is small (1.9 failures/mile) and no sections were overlaid during the eight-year interval. The mean failure rate for the 1978-1982 period is equal to 0.25 failures per mile per year, indicating a very low rate of deterioration.

District 4 range in age from 12 to 22 years. Currently, 83 percent of the CRC pavements are at least 15 years old.

District 9. This district contains some of the oldest CRCP sections in the state. The CRC pavements in this district range from 13 to 23 years in age. At this time, 86 percent of this district's CRCP sections are at least 15 years old. The 1982 condition survey indicated that there is an average of eight failures per mile, with various projects in this district falling in the range of the "poor" distress condition category. Since 1974, the distress condition of these projects has been improved by overlaying. By 1982, 35.8 percent of the district's CRC pavements had been overlaid. Rapid deterioration is characteristic of the CRCP in this district, with a mean failure rate during the 1978-1982 period of one failure per mile per year.

District 10. The CRC pavements in this district show distress similar to that in District 9. The age of the pavement sections ranges from 17 to 25 years. By 1982, the project sections shows a very high mean of failures per mile (approximately 14 failures/mile) and a very high mean failure rate (1.63 failures per mile/year) indicating a "poor" distress condition and a consistent increase in deterioration. The 1982 condition survey showed that 22.6 percent of the CRCP sections in this district were overlaid.

District 12. The only data available for the CRCP sections in this district in 1982 indicate very few failures per mile and no sections overlaid.

District 13. In general, the CRCP distress condition in this district is fair. The 1982 condition survey indicated an average of 4.5 failures per mile and a relatively low mean failure rate of 0.63 failures per mile per year. The age of the CRCP sections in this district varies from 10 to 22 years, but, even though the rate of deterioration is relatively low, the percent of overlaid sections is not very high (14.2 percent).

District 17. The 1982 condition survey indicates that, in general, the distress condition of the CRCP sections in this district is fair (6.1 mean failures/mile) but steadily deteriorating (approximately at a rate of one failure per mile/year rate during the 1978-1982 period). Since 1974 several projects have been overlaid (22.8 percent of the district). Some of the CRCP sections in this district are very old (around 23 years by 1982).

District 18. This district was surveyed in 1982 for the first time and showed some very old project sections (around 34 years) but very low number of mean failures per mile, basically due to overlaying of some of the projects (18 percent of total CRCP) and possibly low traffic volumes circulating in the facilities.

District 19. The distress condition of the CRC pavements in this district is fair and the high rate of failure increase (1.18 failures per mile/year) apparently has been controlled through overlaying (36.3 percent of all the CRC pavements in District 19 have been overlaid).

District 20. This district contains the highest percentage of CRCP projects overlaid in the state, with 45.2 percent. It is evident that the number of failures per mile and the growth rate, which is relatively low, have been controlled, basically through overlaying.

Districts 24 and 25. The numbers of failures in the different CRCP sections of these districts are small. The increase in the failures-per-mile increase rate is also very small. Most of the projects in these districts are relatively new and overlaying them was not required by 1982.

Analysis of Failure Data

This section presents a brief analysis of the failure data as related to some of the most important factors affecting failures. As stated before, failures are considered to be the sum of punchouts and repaired patches on the pavement.

First, a bar chart in Fig 5.5 presents, for comparison the mean yearly rates of the number of failures per mile and the percent of overlaid sections by 1982 for the CRCP projects in each district. From Fig 5.5, it is seen that CRCP projects in Districts 10, 19, 9, and 17 deteriorate more rapidly and that their distress condition in 1982 was, in general, poor. To compensate for the effect of rapid deterioration and to improve the riding quality of the sections in these districts , it has been necessary to overlay a high percentage of the total number of pavement sections.

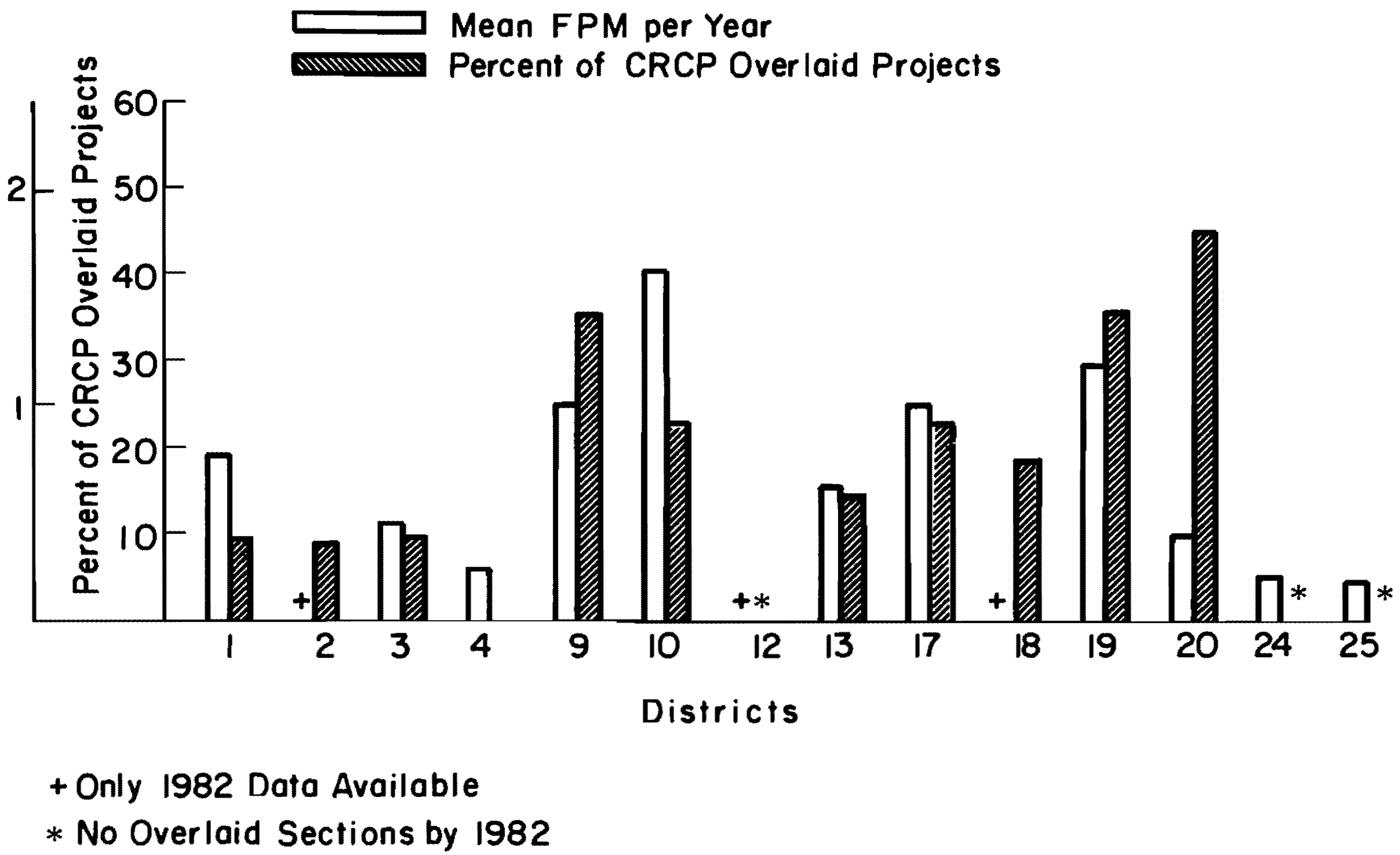

Fig 5.5. Mean rate of failures per mile (1978-1982 period) and percent of overlaid sections by 1982, for the CRCP projects of each district.

In District 20 the rate of deterioration has been well controlled by overlaying. This district has a very low mean failure rate, as well as the highest percentage of overlaid sections in the state.

Effect of Age

From Table 5.1 and Fig 5.5, it is obvious that the districts with older CRCP projects have higher mean failure rates and consequently more overlaid sections. The reason is that, in general, older pavements have been subjected to more applications of traffic- and environmentally-related stresses.

Figure 5.6 shows the probability curves for a CRCP project being overlaid, as a function of age, for a series of districts located in different regions of the state. The curves indicate that beyond 18 years of age, CRC pavements located in the eastern part of Texas (Districts 19 and 20) have a higher probability of being overlaid than those pavements in districts in the south-central (13 and 17) and northern regions (1 and 3). These differences can be explained in terms of the differences in traffic volumes and, mainly, environmental conditions prevailing in the regions. It is evident that the worse environmental conditions (rainfall, temperature, humidity and soil type) in the eastern districts influence the distress condition of a CRCP causing it to reach its terminal condition sooner and consequently requiring an overlay before a CRCP in any of the other locations. The following subsections below analyze some of the most significant environmental factors.

Effect of Rainfall

Table 5.2 presents the annual rainfall averages for the districts, computed from data recorded by the Weather and Climate Section of the Texas Department of Water Resources, for the years 1951 through 1980. Figure 5.7 was constructed from these data and from the failure data presented in Table 5.1 for the years 1974, 1978, and 1982.

Figure 5.7 shows a direct relationship between mean failures per mile and normal annual precipitation. The number of failures suddenly drops for districts with normal annual precipitation greater than 44, because most of the pavements in these districts have been overlaid.

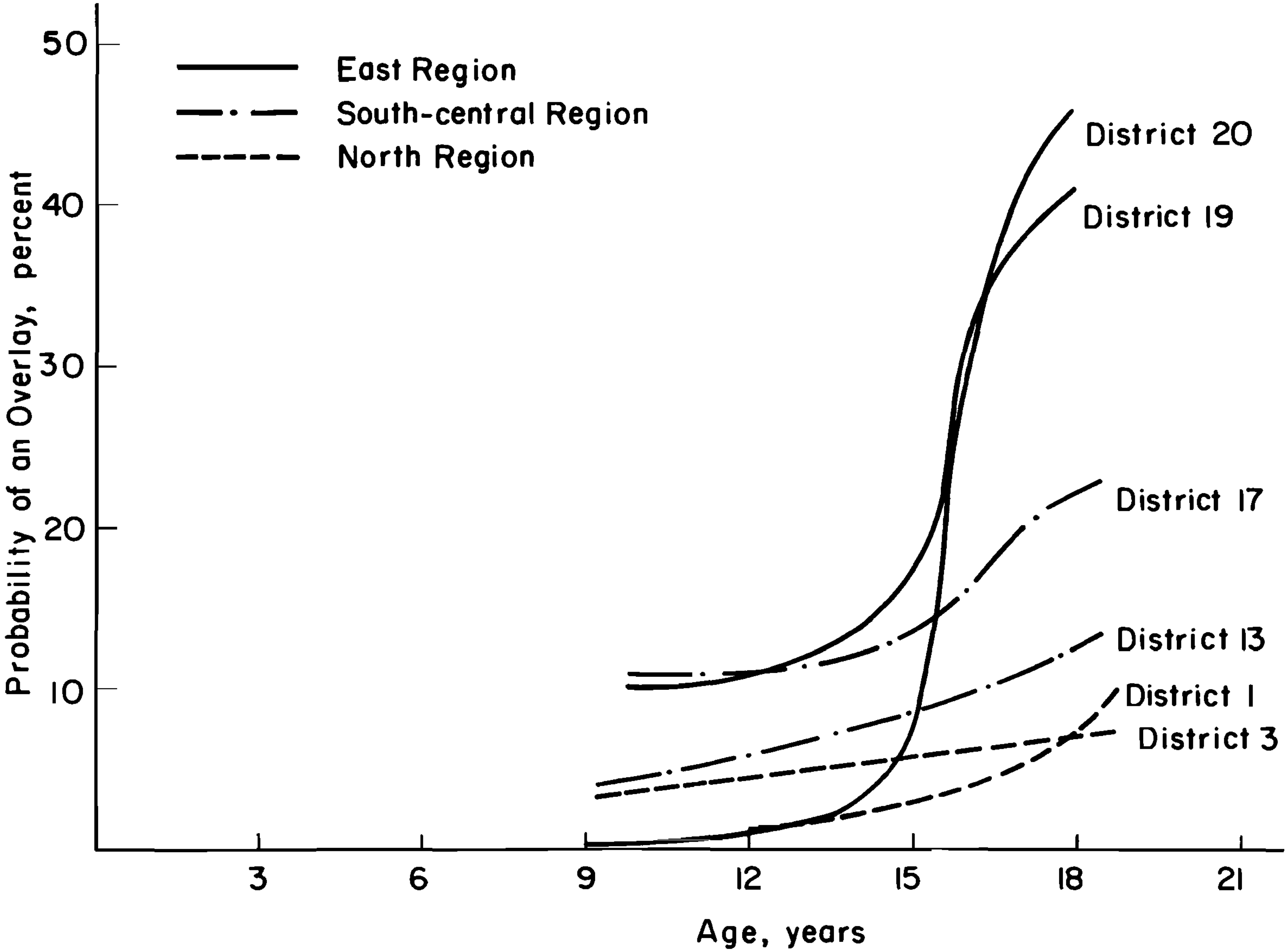

Fig 5.6. Probability of an overlay versus age for districts in different geographical locations of Texas.

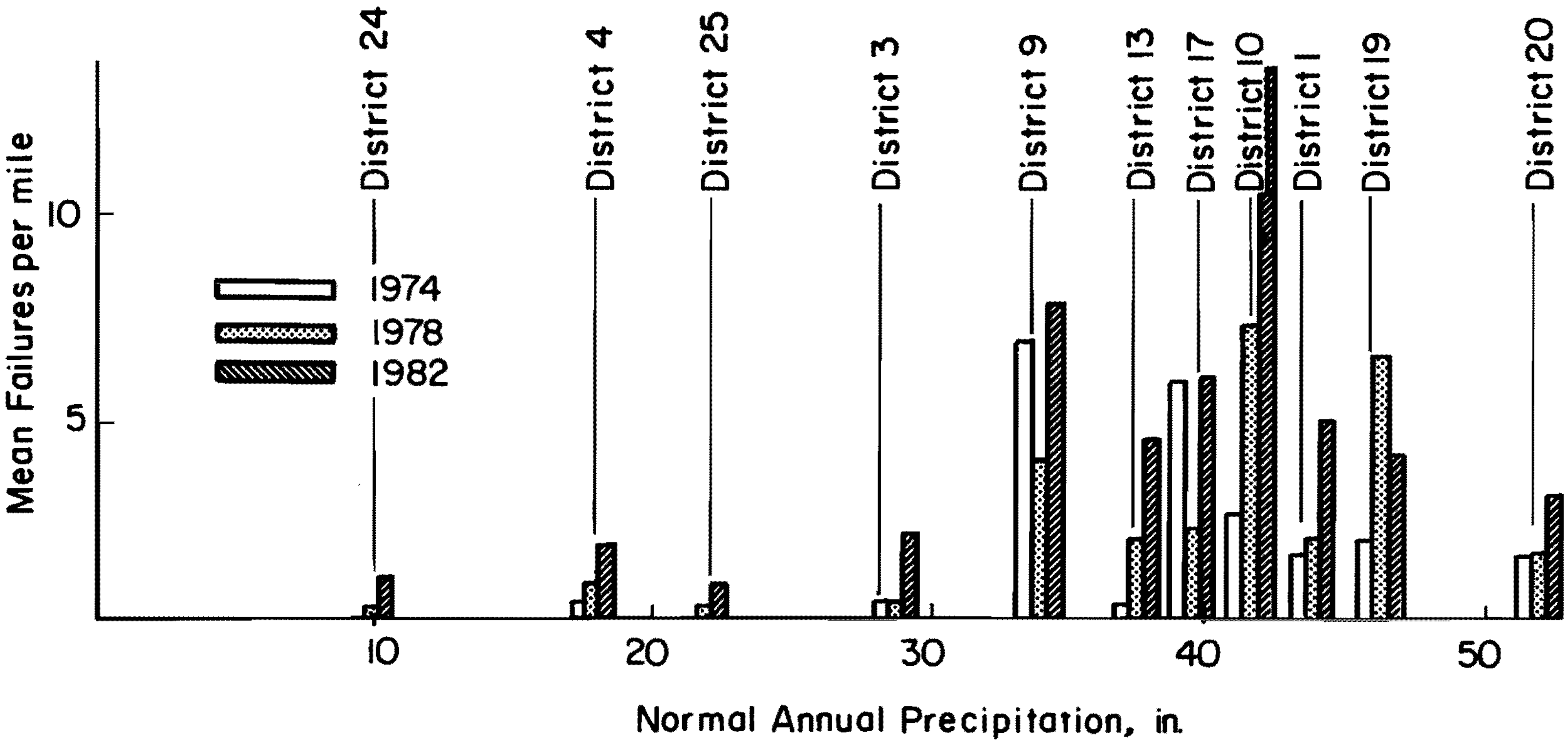

Fig 5.7. Mean failures per mile versus normal annual precipitation.

TABLE 5.2. ANNUAL RAINFALL AVERAGES BASED ON DATA FOR 1951 THROUGH 1980. (AFTER THE WEATHER AND CLIMATE SECTIONS OF THE TEXAS DEPARTMENT OF WATER RESOURCES)

District	Rainfall (in.)
1	43
3	29
4	18
9	34
10	42
13	38
17	40
19	46
20	52
24	10
25	22

A more meaningful relationship is obtained if the mean failures per mile rate is plotted versus normal annual precipitation, as shown in Fig 5.8. The best fit through the plotted points was obtained by a second order polynomial equation:

$$FR = 5.6239209 \times 10^{-2} + 5.700903 \times 10^{-4} P^2$$
$$(R^2 = 0.70)$$

where

FR = mean failures per mile rate for the 1978-1982 period (FPM/Year),

P = normal annual precipitation (in.), and

R^2 = coefficient of determination of the regression polynomial.

It can be assumed that this relationship will have a similar shape for subsequent years (the dashed line in Fig 5.8), when the pavement will be more deteriorated.

The final conclusion is that pavements located in districts with higher rainfall averages show higher rates of deterioration, following an approximately parabolic relationship.

Effect of Temperature and Traffic

Data about normal maximum and normal minimum temperatures were obtained from the National Climatic Center (Ref 16) for some climatological stations in the state. These data are shown in Table 5.3.

Mean failures per mile rates were plotted for each district versus their corresponding normal maximum and normal minimum temperatures and mean daily temperature drops.

The plot of mean failures per mile rate versus normal maximum temperature, shown in Fig 5.9, gave very significant results when the traffic parameter was included in the graph. It indicates that there is a very definite influence from high temperature together with traffic volumes on the rate of deterioration of a CRC pavement.

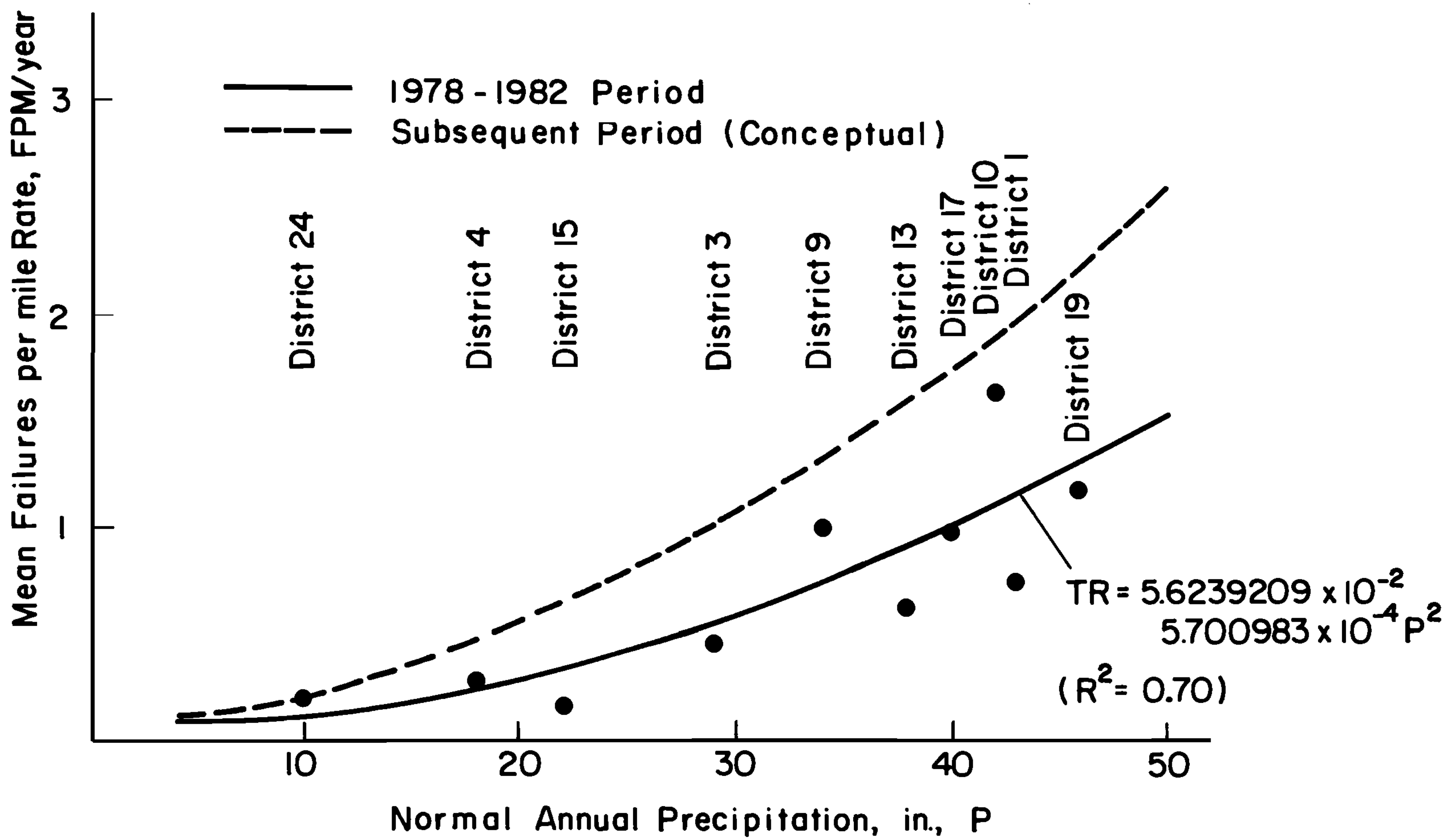

Fig 5.8. Mean failures per mile rate versus normal annual precipitation.

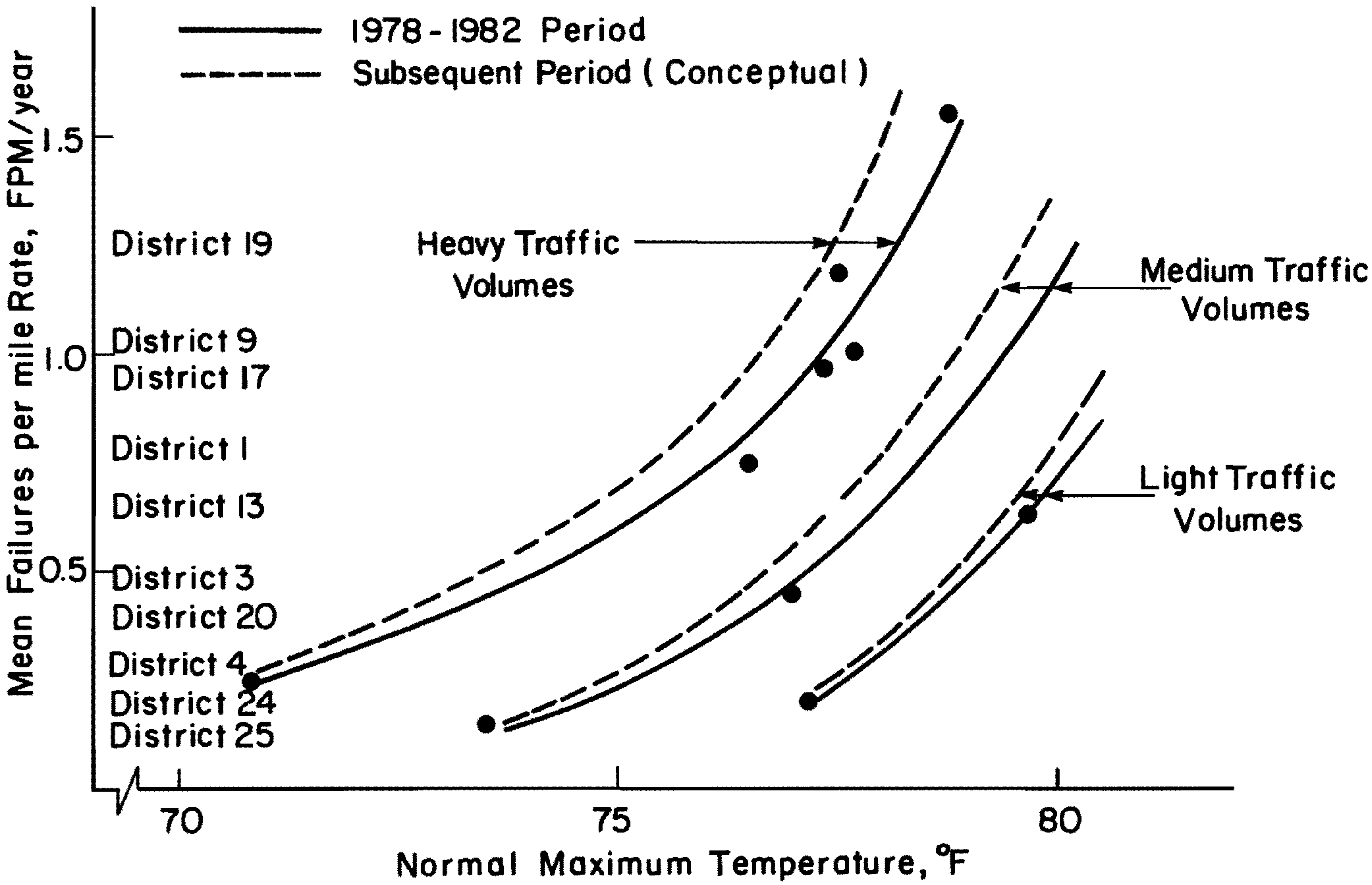

Fig 5.9. Mean failures per mile rate versus normal maximum temperature for different traffic volumes in districts surveyed.

TABLE 5.3. NORMAL MAXIMUM AND MINIMUM TEMPERATURES BASED ON DATA FOR 1940 THROUGH 1970. (AFTER THE NATIONAL CLIMATIC CENTER)

Station	Normal Temperature, °F	
	Maximum	Minimum
Amarillo	70.8	43.9
Dallas-Ft. Worth	76.5	54.4
El Paso	77.2	49.5
Galveston	74.5	65.0
Houston	79.8	58.0
Lubbock	73.6	45.8
Port Arthur	78.3	58.6
Victoria	79.7	60.5
Waco	77.8	56.4
Wichita Falls	77.0	51.2

The same relationships, as shown by the dashed lines in Fig 5.9, can be expected for subsequent years, when the pavement will be more deteriorated.

The final conclusion is that pavements located in districts with higher maximum daily temperatures and heavier traffic volumes are deteriorating more rapidly.

Analysis of Overlaid Sections

From the analyses in the previous sections, it can be emphasized that, in general, the CRCP in those districts having heavier traffic volumes and, mainly, adverse environmental conditions show a higher rate of deterioration and consequently more overlaid sections. The most severe environmental conditions are located in the eastern districts.

Reflection Cracking

Some time after an overlaid section is opened to traffic, the cracks in the original pavement start to propagate through the overlay leading to the appearance of the distress type known as reflection cracking.

Reflection cracking will be analyzed for the districts with more overlaid sections in the state. Table 5.4 summarizes the reflection cracking condition of the overlaid sections in some of the districts.

District 9. Figure 5.10 is a bar chart presenting the average number of reflection cracks per mile for the overlaid CRCP sections in District 9.

If it is assumed that all the sections are subjected to similar environmental conditions (rainfall, temperature, soil support, etc.), then, the differences in the levels of reflection cracking presented by the sections can be explained only by their differences in overlay thickness and traffic volumes . Analyzing the sections with different overlay thicknesses along their length (but the same traffic conditions), it is evident that thicker overlays present less reflection cracking. It is also apparent from Fig 5.10, that southbound lanes show more reflection cracking than northbound lanes; the reason is that southbound lanes carry heavier traffic volumes.

The mean number of reflection cracks per mile by 1982 and the rate of development of this distress type in this district are low (13 reflection cracks/mile and 2.2 reflection cracks per mile/year).

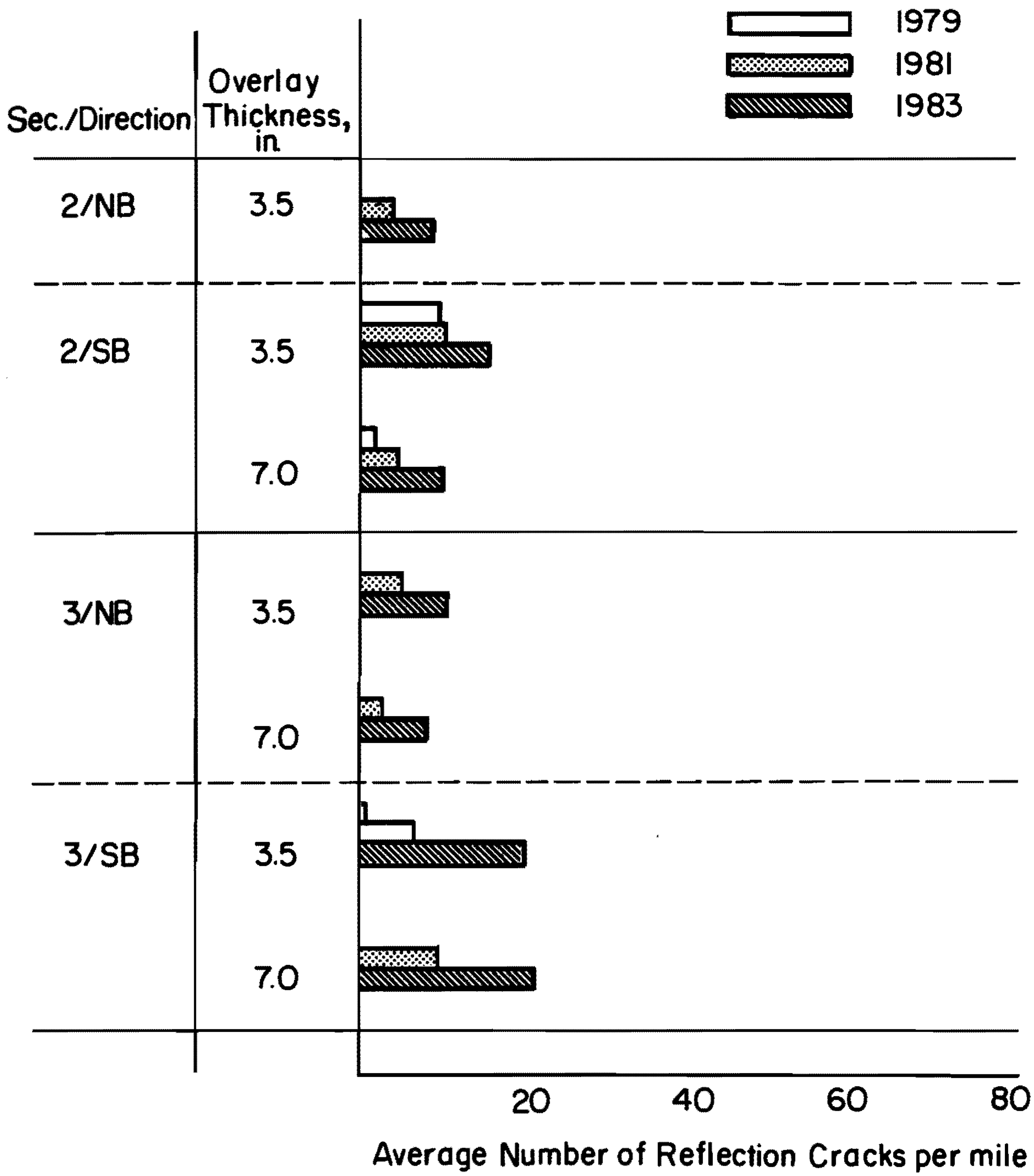

Fig 5.10. Average number of reflection cracks per mile for overlaid sections in District 9.

TABLE 5.4. SUMMARY OF REFLECTION CRACKING FOR THE OVERLAID CRCP SECTIONS IN DISTRICTS 9, 17, 19, AND 20

	Mean Reflection Cracks Per Mile					Mean Reflection Cracking Rate ('79-'81), RCPM/Year
District	1979	1980	1981	1982	1983	
9	1.6	--	6.0	--	13.0	2.2
17	25.0	44.0	54.0	--	--	14.5
19	16.0	--	46.0	--	--	15.0
20	4.0	12.7	14.0	30.8	--	5.0

District 17. Figure 5.11 is a bar chart for the average number of reflection cracks per mile for the overlaid sections in District 17. In this figure it is not very clear that thicker overlays result in less reflection cracking, probably because thicker overlays were required in those sections with more distress, which consequently developed reflection cracking sooner than those requiring thinner overlays.

This district shows very high numbers of mean reflection cracks per mile and rate of development of reflection cracking.

District 19. Figure 5.12 is a bar chart of reflection cracking in overlaid sections of District 19. Information about cut and fill sections was introduced in the chart, but no effect of this parameter on the average number of reflection cracks could be detected. In Fig 5.12, it is again evident that under the same traffic and environmental conditions thicker overlays exhibit less reflection cracking.

Overlaid sections in this district show a very high number of reflection cracks per mile and the highest computed rate of development of this type of distress, among all the districts.

District 20. The reflection cracking data for overlaid sections in District 20 are shown in Fig 5.13. This district shows a low mean of reflection cracks per mile and also a low rate of yearly development of reflection cracking.

Summary

In the light of a series of tables, maps, graphs, etc., the condition of CRCP sections (non-overlaid and overlaid) throughout the state, in 1982, is presented in this chapter. Also, the historical trend of the basic distress types (failures in non-overlaid sections and reflection cracking in overlaid) is shown. The eastern districts with more severe climatological conditions show more deteriorated sections.

The effects of some important factors, such as age, rainfall, temperature and traffic, on the occurrence of failures, are analyzed. All of them show a very direct relationship with the number of failures per mile recorded during the 1982 survey and the rate of deterioration of the sections surveyed.

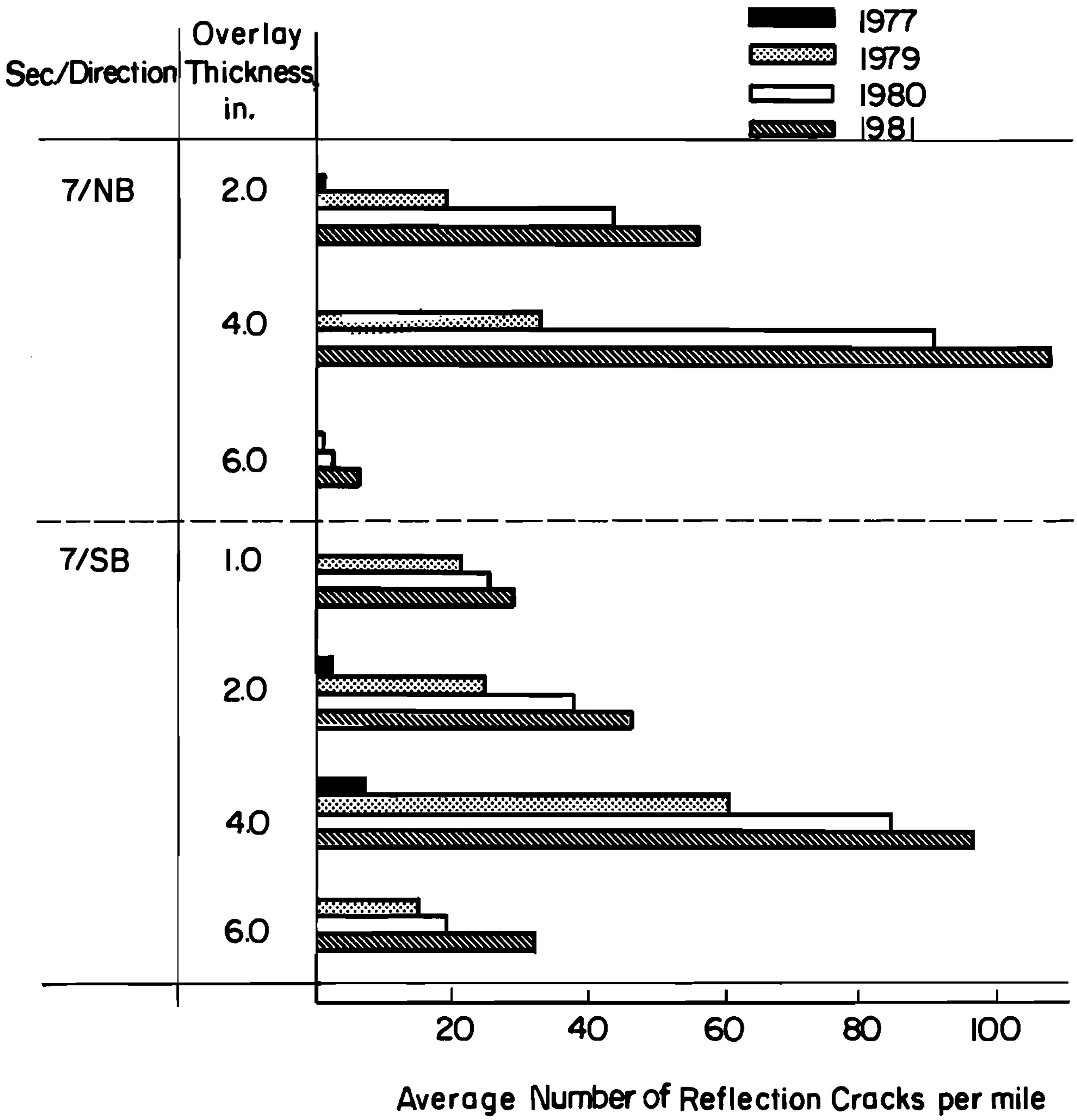

Fig 5.11. Average number of reflection cracks per mile for overlaid sections in District 17.

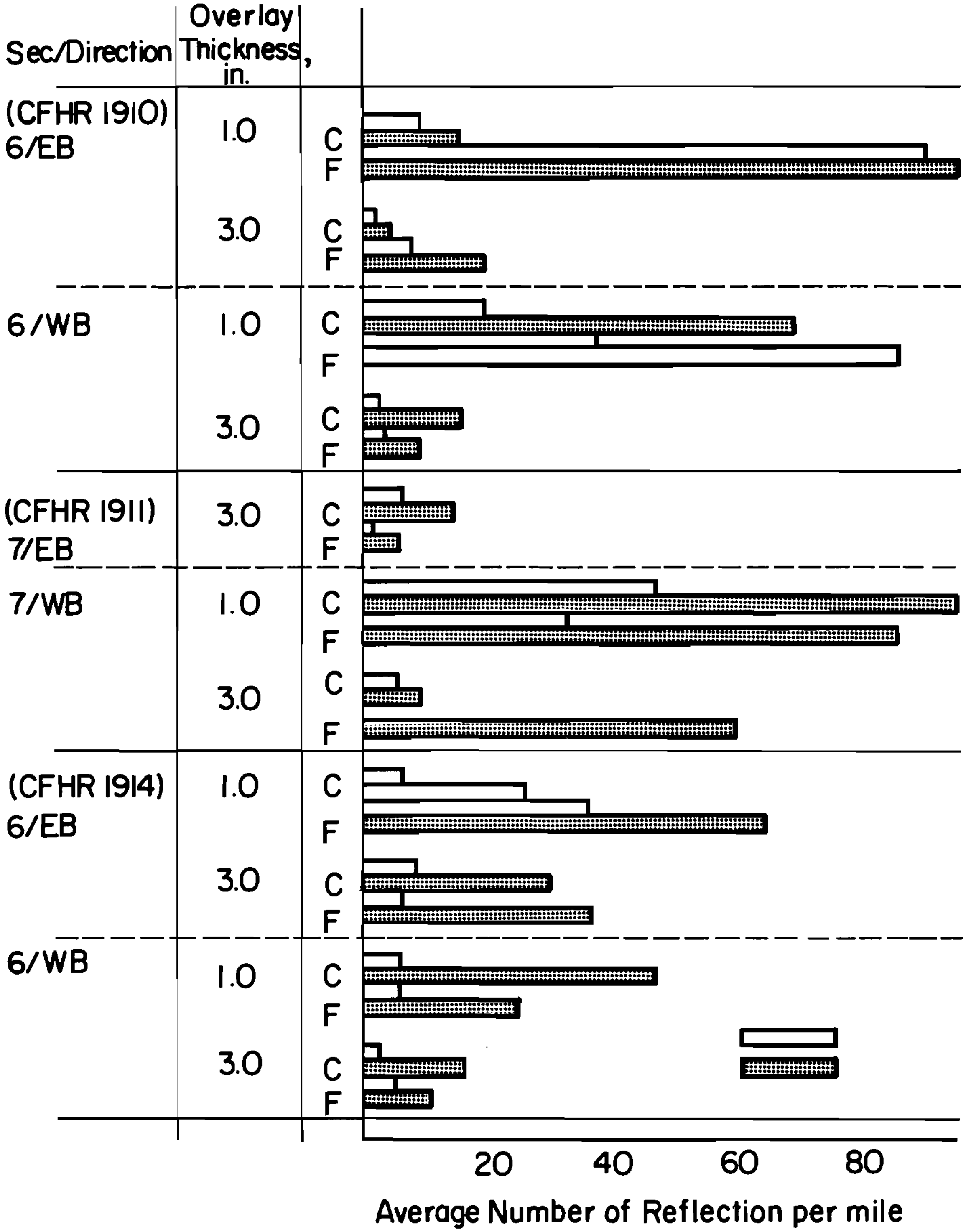

Fig 5.12. Average number of reflection cracks per mile for overlaid sections in District 19.

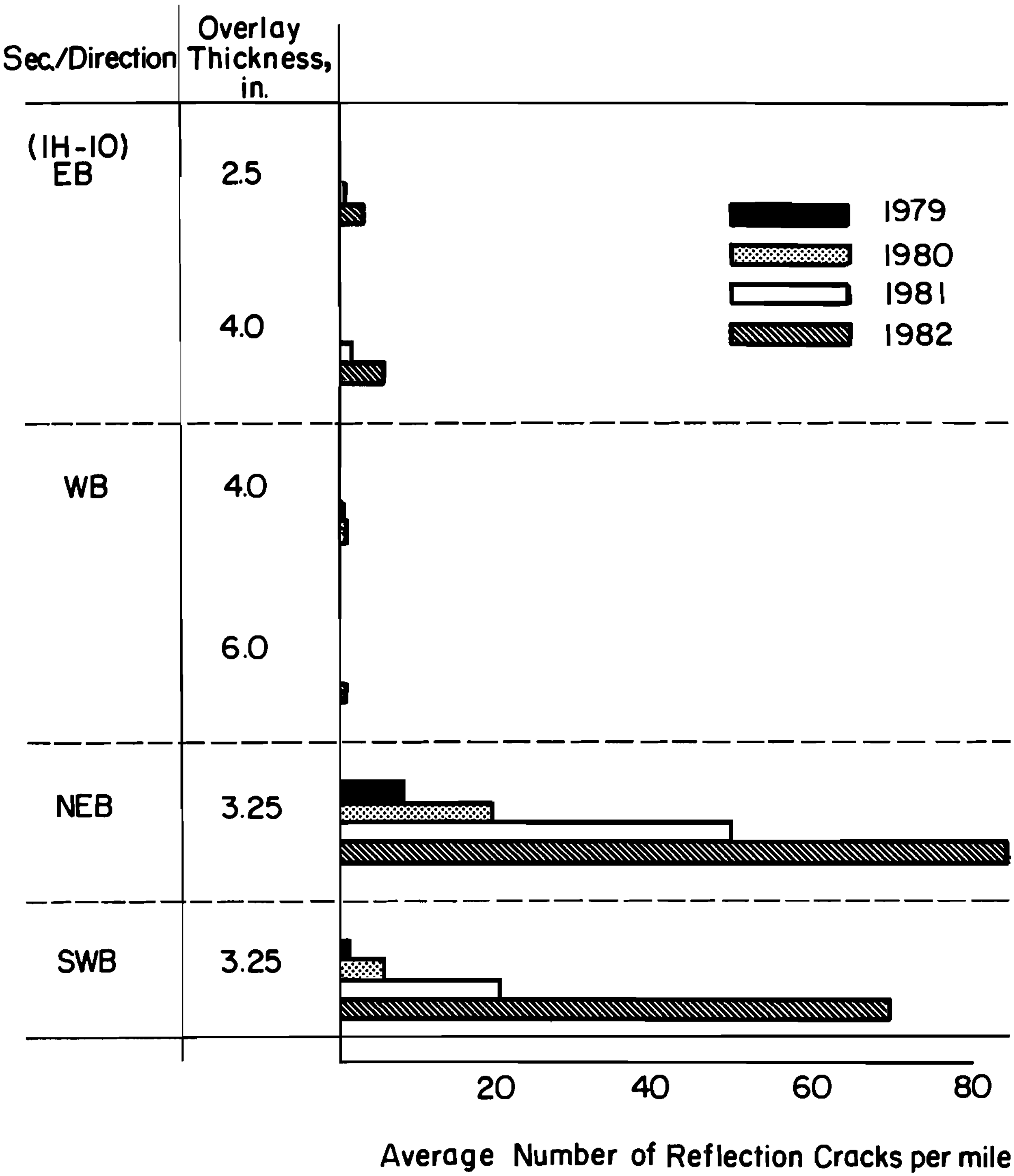

Fig 5.13. Average number of reflection cracks per mile for overlaid sections in District 20.

CHAPTER 6. SPECIAL STUDIES

The purpose of this chapter is to present a summary of various reports that are indirectly related to the objectives of Project 249, "Implementation of a Rigid Pavement Overlay and Design System."

EVALUATION OF VOID-DETECTION PROCEDURES AND GROUTING EXPERIMENT

Report 249-3 (Ref 12) describes an experiment performed in Victoria, Texas, in 1981, whose purpose was to evaluate the effectiveness of the grouting operation to fill voids underneath CRC pavements. In that experiment both condition survey data and Dynaflect deflections were used to locate areas in an experimental CRCP section in which the probability of presence of voids beneath the slab was estimated to be high.

A theoretical procedure to evaluate the effectiveness of the grouting operation was developed (Ref 13), and this procedure was used to analyze Dynaflect deflection data from the grouting experiment in Victoria, Texas, as well as from two other previous experiments carried out in Columbus and Fairfield, Texas.

Among the principal conclusions drawn from this study are the following:

(1) Voids beneath a continuously reinforced concrete pavement can be successfully detected by using the Dynaflect on those areas of the pavement in which pumping along the edge has been observed. Furthermore, grouting seems to be an adequate means to fill voids underneath a CRCP.

(2) The Dynaflect should be placed at about one foot from the pavement edge so that voids can be located more easily.

(3) Cost analyses using computer program RPRDS-1 (Ref 3) indicated the feasibility of injecting grout prior to an asphaltic concrete overlay.

EFFECT ON DYNAFLECT DEFLECTIONS OF VOIDS AND DISCONTINUITIES IN RIGID PAVEMENTS

Computer program Slab-49 (Ref 14) was used in Ref 13 by Torres-Verdin and McCullough to simulate voids of various sizes underneath a CRCP. Figure 6.1 shows deflections vs distance from the pavement edge for five different void conditions and a modulus of subgrade reaction of 100 psi/ in.

The effect of an inaccurate placement of the Dynaflect on deflections was also analyzed and compared with the effect due to voids of various sizes, as illustrated in Fig 6.2.

A procedure for estimating the required number of Dynaflect deflections for materials characterization was proposed; it is based on the assumption of normality for sensor 1 deflections. The allowable error in estimating sensor 1 mean deflection was expressed as a function of variation in slab thickness. This procedure has been improved in Ref 15 by investigators of Research Projects 249 and 256 ("The Study of New Technologies for Pavement Evaluation"). Now, it incorporates pavement-section length to determine the required number of Dynaflect deflections for materials characterization purposes.

Some of the most important conclusions that stemmed from Research Report 249-4 are:

(1) If the moduli of the distinct pavement layers are to be estimated from deflections, the Dynaflect should be placed between cracks (or joints), at 3 to 9 feet from the pavement edge.

(2) The Dynaflect placement error should be kept as small as possible. It is extremely important to record the distance from the pavement edge at which the Dynaflect is placed so that the deflections for a given pavement section taken at different times can be compared. For void detection and materials characterization purposes, the maximum placement errors are 5 and 10 inches, respectively.

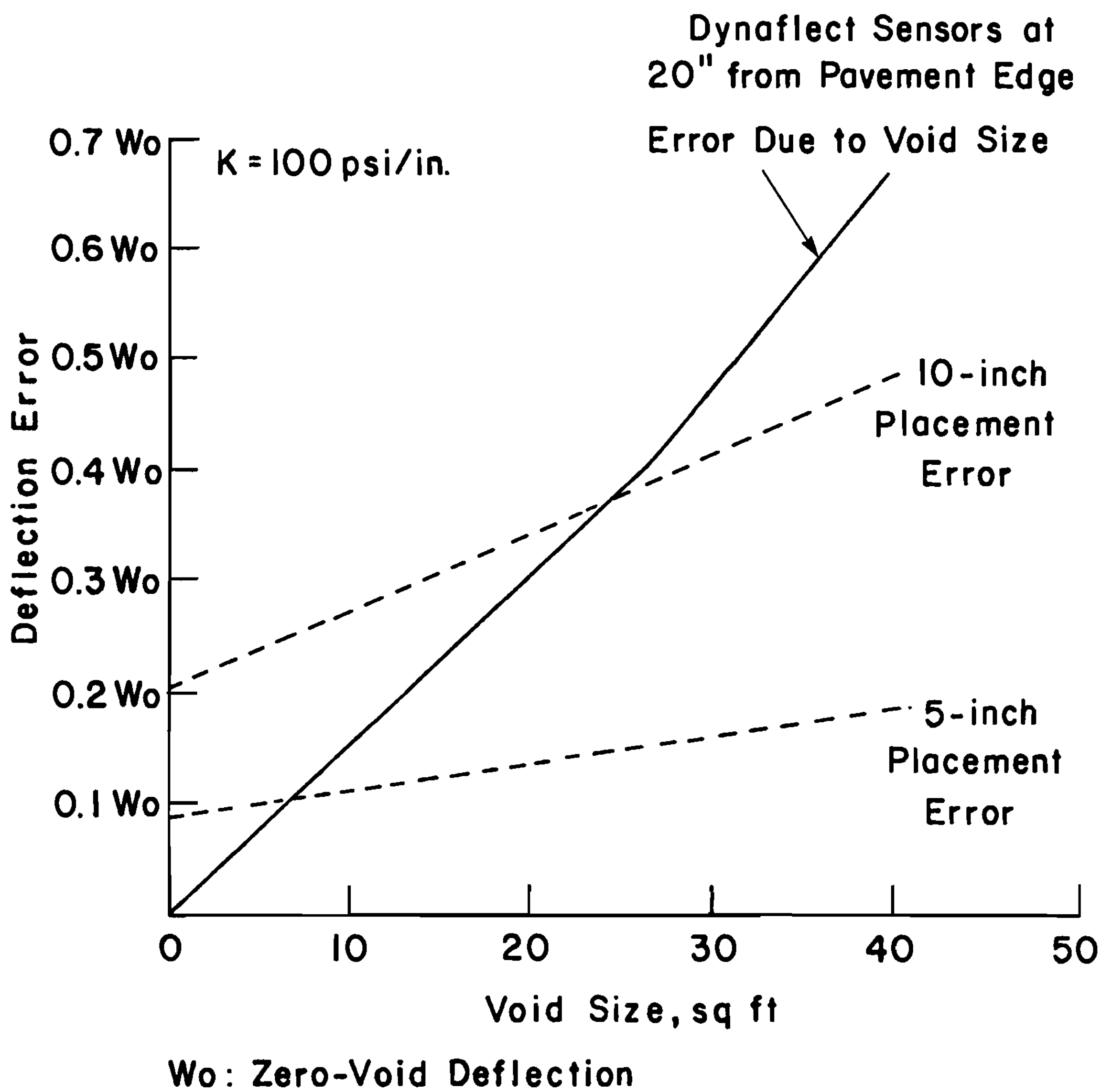

Fig 6.1. Deflection errors due to variations in Dynaflect placement as well as void size.

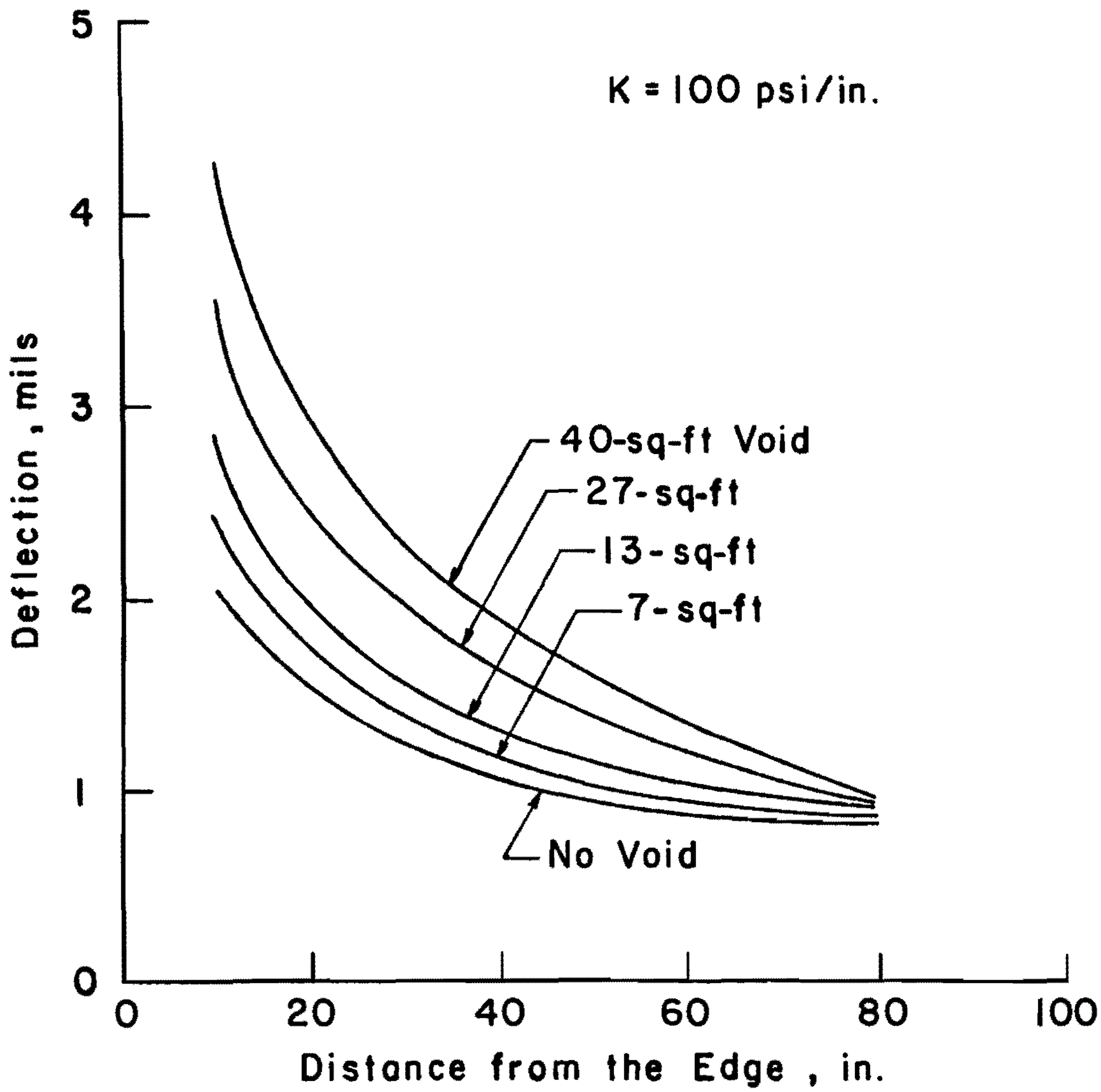

Fig 6.2. Deflection vs. distance from the pavement edge for five different void conditions.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS.

The main conclusions and recommendations that can be drawn from the findings of all the studies performed during the course of Research Project 249 are given below.

(1) The condition survey data base has been significantly augmented, and existing computer programs to analyze this information have been improved. Likewise, new computer programs have been developed to reduce and store data corresponding to the different pavement sections periodically monitored.

(2) Improved procedures for the collection of condition survey information have been developed and their use is recommended.

(3) The Texas SDHPT has been provided with a computer program, PRP01, that prioritizes the rehabilitation and maintenance needs of a series of rigid pavements in a given network (see Research Report 249-5). This program is capable of handling various budget levels to produce a list of the candidate sections. However, it is recommended that some research be directed towards the modification of PRP01 so that overlaid pavements can be included in the analysis.

(4) Certain improvements to the materials characterization and fatigue-life prediction method of the Texas Rigid Pavement Overlay Design Procedure (RPOD) have been suggested. These could be used in the development of an improved version of RPOD-2 (see Research Report 249-1).

(5) A new rigid-pavement design system at the project level has been completed (see Research Report 249-2). RPRDS-1 considers a cost analysis to determine feasible overlay strategies, and by using optimization techniques selects the optimal overlay strategy. This computer program is also capable of taking into account alternative and heavy maintenance prior to an overlay. However, RPRDS-1 has not been continuously and sufficiently employed in practical

applications; this has not made possible the verification of the fatigue-life models.

(6) The summary of CRCP condition survey information contained in Chapter 5 should help the reader to visualize the great importance of the condition survey data base. Furthermore, this information permits the verification of the different types of behavioral models considered in the mechanistic procedures for design of rigid pavements and overlays.

(7) Grouting injection proved to be a viable rehabilitation alternative prior to an overlay, as concluded in Research Report 249-3. Other rehabilitation measures include rigid-shoulder construction before overlay placement.

(8) Hand solution method to design against reflection cracking for various climatological regions in the state of Texas has been developed (see Research Report 249-6). This method can be used by design engineers where computer facilities are difficult to access or estimating phases of the planning process do not permit a detailed analysis.

Finally, it is believed that work under Research Project 388 should be compatible with the work previously done in Research Projects 177 and 249;the project should also consider the suggestions made in this report as well as those corresponding to Research Report 177-22F.

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APPENDIX A

STORAGE AND USE OF CONDITION SURVEY DATA

APPENDIX A. STORAGE AND USE OF CONDITION SURVEY DATA

INTRODUCTION

The Center for Transportation Research has been conducting road condition surveys for several years. This appendix will list what data are collected and the format that is used in storing the data in the computer. All of the programs used to handle the data are briefly described, and the data format required by each program is given.

DATA COLLECTION

The projects are surveyed in sections of 0.2-mile by two persons in a vehicle travelling on the shoulder at approximately five miles per hour. For each continuously reinforced concrete pavement (CRCP)section , the surveyors determine the number of minor and severe spalled cracks, whether minor and/or severe pumping is present, the size, number and severity of punchouts, and the number and type [i.e. asphaltic concrete (A/C) or portland cement (P/C)] of patches. For each jointed concrete pavement (JCP) the surveyors determine the number of cracks, spalled joints and cracks, faulted joints and cracks, bad joint sealants, corner breaks, slabs with minor longitudinal cracking, slabs with severe longitudinal cracking, and patches, as well as the edge joint condition and whether pumping exists. It is also noted for both types of pavements (CRCP and JCP) whether or not a section is overlaid or contains a bridge.

To help identify and site each surveyed road section, the following information is stored with the gathered data: the control number of the road, the section number, the highway identification (e.g., IH 35), the direction (eastbound - EB, westbound - WB, southbound - SB, or northbound - NB), the county, the job number, the survey date, the construction date, the starting location, the ending location, and the surveyors.

The control number of each project is a unique 5-digit identifying number. The first two digits designate the district the road is located in;

for example, the control number of a project in District 2 starts with "02". The next three digits are based on the order of construction. The control number of the road surveyed first in each district contains the digits "001". Newer roads are numbered sequentially based on their order of construction.

DESCRIPTION OF DATA FORMATS

This section describes the format of the data as they are stored in the computer. It details the formats the CRCP and JCP data are input with. It then describes the format that is used to store past and present condition survey data.

Latest Survey Data

The CRCP data and the JCP data are input into the computer in a "free" format. The free format does not place the restriction of specific columns for data input. It only requires a comma to separate data entries. This allows quicker, more accurate data input.

Each project consists of at least 4 lines of input data. The first 3 lines contain, basically, identification information, while the remaining line(s) contain the surveyed data, each line representing 0.2-mile.

For each CRCP project, the data should be entered as follows (Fig A.1):

Card 1 - control number, section number, highway, section age, crack spacing, direction, county, job number, CTR number.

Card 2 - starting mile post, ending mile post, starting location, ending location.

Card 3 - survey date (MMDDYY), surveyors.

Card 4+ - mile post, mile point, comment (e.g., overlay, bridge), number of minor spalled cracks, number of severe spalled cracks, minor pumping (1-yes, 0-no), severe pumping (1-yes,0-no), number of minor punchouts less than 20 feet, number of minor punchouts greater than 20 feet, number of severe punchouts less than 20 feet, number of severe punchouts greater than 20 feet, number of asphaltic concrete repair patches, number of portland cement repair patches, end of job indicator. (1-yes)

```
13,8,US287,12.3,7.2,NB,WISE,44,02044
31.1,20.3,JCT US81,2.7MI S OF DECATCR
072981,SDHPT
31.1,,,28,12
30.9,,,5,1,1
25.9,,,36,11
25.7,,,33,1
25.5,,,31,7
25.3,,,22,1
25.1,,,25
24.9,,,10,,,,,,,,,,,1
```

Fig A.1. CRCP data free format.

Each JCP project should be entered as follows (Fig A.2):

Card 1 - control number, section number, highway, section age, joint spacing, direction, county, job number, CTR number.

Card 2 - starting mile post, ending mile post, starting location, ending location.

Card 3 - survey date (MMDDYY), surveyors.

Card 4+ - mile post, mile point, comment (i.e. overlay, bridge), number of cracks, number of spalled joints and cracks, number of bad joint sealants, number of corner breaks, number of slabs with severe longitudinal cracking, edge joint condition (M-minor, S-severe), pumping (1-yes, 0-no), end of job indicator (1-yes).

It should be noted that zeroes and trailing commas (commas after the last significant entry) do not need to be entered.

Projects are stored in files based on the district in which they are located. Projects in the same district are stored together. Each district has one file with only projects in that district stored there. The first line of each district file contains the district number in columns 1 and 2.

Permanent Storage File

Condition surveys have been performed on CRCP sections for several years. All the surveys are stored in files called "DISTXX" where 'XX' represents the district the roads in a given file lay in. The format for the DIST files is as follows (Fig A.3):

Card 1 - Format (5X, A5, 5X, A5, A7, I4, 12X, A2, A12, A5, I5)

control number
section number
highway
date of construction (YYMM)
direction
county
job number
CTR number

```
196,3,IH35E,15,19.0,SB,DALLAS,47,18057
434.8,433.4,SOUTHWELL RD,ST114
081182,RR,RW,JS
434.8,0.0,,,8,,100
434.6,0.2,,,6,,100
434.4,0.4,,,3,,100
434.2,0.6,,,5,,100
434.0,0.8,,,,,100
433.8,1.0,,,2,,100
433.6,1.2,,,6,,100,1
433.4,1.4,,,2,,100,,,,,,,1
```

Fig A.2. JCP data.

249 8 050

```
2C    667        1     SH-347     6303           NBJEFFERSON     28    20002
  0.C0    1.20S. OF JCT. ST.73                      2.0 MI NW
                 SURV1982
   0.0   9.764             0    0    0    0    1    0    0    0        0         0
   0.2   9.564             C    0    0    0    1    0    0    0        0         0
   C.4   9.364             0    1    0    0    0    0    0    0        0         0
   0.6   9.164             0   11    0    0    1    0    0    0        0         0
   0.8   8.964             0    0    0    0    1    0    1    0        0         0
   1.0   8.764BRIDGE
   1.2   8.564             8    3    0    0    0    0    0    0        0         0
                 SURV1980
   0.0   9.764                                 1
   0.2   9.564
   0.4   9.364                  1              1
   0.6   9.164                 11
   0.8   8.964                                 1         1
   1.0   8.765            65    7
   1.2   8.564             8    3
                 SURV1978
   0.0   9.764                                                                   3.6
   C.2   9.564                                                                   3.8
   C.4   9.364                                                                   3.7
   0.6   9.164                                                                   3.1
   0.8   8.964                                                                   3.5
   1.0   8.765            65    7                                                3.3
   1.2   8.564             8    3                                                1.4
                 END
```

Fig A.3. Permanent storage file.

Card 2 - Format (F7.0, F8.0, A30, A25)

beginning mile post
ending mile post
starting location
ending location

Station Data Cards - Format (F5.1, F7.3, 2A4, 8I4, 2I8, F4.1, I1)

mile post
mile point
flag (1)
flag (2)
minor spalling - percent
severe spalling - percent
minor pumping - 1 = yes, 0 = no
severe pumping - 1 = yes, 0 = no
minor punchouts, L. T. 20 ft
minor punchouts G. T. 20 ft
severe punchouts, L. T. 20 ft
severe punchouts, G. T. 20 ft
AC patches
PCC patches
serviceability index
number of lanes

Flag (1) Values:

CRAC indicates crack data follows. (Rest of card is blank.)
SURV indicates new survey follows. Flag (2) contains year of survey. (Rest of card is blank.)
END indicates end of project. New project follows. (Rest of card is blank.)
OVER indicates station is overlayed. Data on rest of card ignored except for mile post and point.

Crack Data - format (16F5.1)

After a "crack" card appears, crack data are read in and processed line-by-line until a negative value appears in columns 1-5 of a card. This signals the end of the crack data, and the program resumes reading the normal station data. Any number of sets of crack data may be inserted within a single set of survey data.

PROGRAMS

The Center for Transportation Research maintains various computer programs that make use of the collected survey data. Included is the program PRP01 and its supporting programs.

Supporting Programs

The primary role of the support programs is to manipulate the data to reformat it so that it can be read by PRP01. Another function is to prepare summary sheets of the collected data.

CRCP Data Manipulation Programs

CN VRT. This program simply reads in a free format CRCP data file and reformats the data into a fixed format data file.

The fixed format requires that data be within certain columns on each line. For each project the data should be input as follows (Fig A.4):

Card 1 - Format (2I5, 5X, I5, A7, 16X, A2, A12, IX, 2I5, 2X, A8)

district number
control number
section number
highway
direction
county
job number
CTR number
survey date (MM-DD-YY)

1389 8 US-59 SBWHARTON 13026 06-08-1982
7203 0.2 MI SW OF SPRR U/P 0.2 MI NE OF AT,SF RR/FM1 JIM,LEON

7.0	8.0	BRIDGE	32	1	0	0	1	0	0	0	0	0
7.2	8.2		29	0	0	0	1	0	0	0	0	0
7.4	8.4		44	5	0	0	0	0	0	0	0	0
7.6	8.6		30	0	0	0	0	0	0	0	0	0
7.8	8.8		46	0	0	0	0	0	0	0	0	0
8.0	9.0		29	1	0	0	0	0	0	0	0	0
8.2	9.2		28	2	0	0	0	0	0	0	0	0
8.4	9.4		36	3	1	0	0	0	0	0	0	0
8.6	9.6		49	1	0	0	0	0	1	0	0	0
8.8	9.8		32	1	1	0	0	0	0	0	0	0
9.0	10.0		28	1	1	0	0	0	0	0	0	0
9.2	10.2		23	1	1	0	0	0	0	0	0	0
9.4	10.4		23	2	1	0	0	0	0	0	0	0
9.6	10.6		23	1	0	0	1	0	0	0	0	0
9.8	10.8		30	0	0	0	0	0	0	0	0	0
10.0	11.0	BRIDGE	11	0	1	0	0	0	0	0	0	0

Fig A.4. CRCP data-fixed format.

Card 2 - Format (I4, 11X, A30, A25, A10)

construction date (YYMM)
starting location
ending location
surveyors

Card 3 - Format [F5.1, F7.3, A10, 6X, 8I4, 2 (4X, I4)]

mile post
mile point
comment (i.e., overlay bridge)
number of minor spalled cracks
number of severe spalled cracks
minor pumping (1-yes, 0-no)
severe pumping (1-yes, 0-no)
number of minor punchouts less than 20 feet
number of minor punchouts greater than 20 feet
number of severe punchouts less than 20 feet
number of severe punchouts greater than 20 feet
number of asphaltic concrete repair patches
number of portland cement repair patches

There is one "card 3" for each 0.2-mile section. All projects in the same district are kept together and stored in the same computer file. The first line of each file contains the district number in columns 1 and 2.

DSTPRV. Reads a new (single year) fixed format data file and converts it into the format described previously under Permanent Storage file. DSTPRV then inputs the data into the CNSRV program, which creates data summary sheets and a data file which is read by TOPRP.

MERGEM. This program combines the latest year of survey data with the DIST files which contain data from surveys done in previous years.

CNSRV4. Reads data in the 'DIST' format. This program produces the following files:

OUTID - Project identification information

OUTFS - Failure summary

OUTPUT - Project summary (details of latest survey), and

SUMD - Project-by-project summary file

The OUTID, OUTFS, and OUTPUT files are formatted so that they can be printed out and cut to 8-1/2" x 11" to fit into reports.

TOPRP. Reformats SUMD files to a format which can be read by PRP01. The SUMD file is a project-by-project summary of the district in the following format (1 card per project per year) - (A5, A2, I4, 2F4.1, I5, 8I4, F5.1, 3F4.1, F5.1, I1) - with these data items: CTR number, direction, year of survey, total project length, unoverlaid project length, minor spalling, severe spalling, minor punchouts 20 ft, minor punchouts 20 ft, severe punchouts 20 ft, severe punchouts 20 ft, asphaltic concrete patches, portland cement patches, total failures, failures per unoverlaid mile, SI value, mean crack spacing, standard deviation of crack spacing, age of pavement at time of survey, and number of lanes.

JCP Data Manipulation Programs

JPPRP. Reads the free format JCP data and prepares a file for input into the PRP01 program.

JPREP. Reads the free format JCP data and prepares a 'REPORT' file which includes project identification information, failure summary, and project summary.

PRP01 Program

The PRP01 program prioritizes a set of rigid pavements (JCP and CRCP) for rehabilitation within a given time period. The prioritization procedure is performed using a distress index for each pavement type and several distress prediction equations.

The program is designed to give the results to one of three alternatives. These results are:

Alternative 1 - print a list of prioritized pavement sections at the time of the survey. This alternative is selected by setting the analysis period equal to zero years.

Alternative 2 - budget constraints are not considered. The selection of pavement sections to be overlaid is made depending on the magnitude of the distress index. If the distress index is less than or equal to zero, the section is overlaid.

Alternative 3 - budget constraints are considered. The selection of pavement sections to be overlaid is restricted by the allowable budget for a given year.

The PRP01 program requires data to be in the following format.

Card 1 - format (5X, 6A10)
description of problem

Card 2 - format (5X, 6A10)
description of problem

Card 3 - format (2I5)
switch to consider budget constraints (0 - budget constraints not considered, 1-budget constraints considered), analysis period in years

Card 4 - (optional - required only if budget constraints considered) - format (7 F10.0)
budget in dollars for each year

Card 5 - format (F10.0)
cost of overlay (dollars/inch/square feet)

Card 6 - format (3I5)
total number of sections of both types, number of JCP sections, number of CRCP sections

Card 7 - format (I5)
switch to print out input information
(0 - input not printed, 1 - input is printed)

Card 8 - (Requires one card per JCP section) - format (1X, A7, 8F7.0) CTR number, direction, cracking and patching (number per mile), spalled joints and cracks (percent) faulting (number per mile), age of pavement at time of condition, cumulative equivalent single axle load applications at the time of the condition survey, cumulative equivalent single axle load growth rate, section length, and number of lanes.

Card 9 - (Requires one card per CRCP section) - format (1X, A7, 8F7.0) CTR number, direction, cracking and patching (number per mile), percent minor spalling, percent severe spalling, section age at the time of the condition survey, cumulative equivalent single axle load applications at the time of the condition survey, equivalent single axle load growth rate, section length, number of lanes.