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NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **277**

PORTLAND CEMENT CONCRETE PAVEMENT EVALUATION SYSTEM

COPES

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REPLY TO: Robert J. Reilly
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October 22, 1985

TO: CHIEF ADMINISTRATIVE OFFICERS
STATE HIGHWAY AND TRANSPORTATION DEPARTMENTS

SUBJECT: National Cooperative Highway Research Program Report 277, "Portland Cement Concrete Pavement Evaluation System - COPES" the Final Report on Project 1-19 of the FY '78 & '80 Program

The final report resulting from research on Project 1-19, administered by the National Cooperative Highway Research Program, has been published in the document listed above. I am enclosing one copy of the document. The research was conducted by the University of Illinois, Urbana/Champaign, Illinois. In accordance with the selective distribution system of the Transportation Research Board, copies of this report will be directed to all persons having requested, together with the Highway Transportation mode, the subject areas of Maintenance and Pavement Design and Performance.

The NCHRP staff has provided a foreword that succinctly summarizes the scope of the work and indicates the personnel who will find the results of particular interest. This will aid in its distribution within your department and in practical application of the research findings. These findings add substantially to the body of knowledge concerning the evaluation of in-service portland cement concrete pavements. Evaluation forms and procedures are presented for the recommended concrete pavement evaluation system (COPES). The results of several demonstrations are also given to illustrate potential uses for COPES.

Sincerely yours,

Thomas B. Deen
Executive Director

Enclosures

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **277**

PORTLAND CEMENT CONCRETE PAVEMENT EVALUATION SYSTEM
COPES

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

PAVEMENT DESIGN AND PERFORMANCE
MAINTENANCE
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. SEPTEMBER 1985

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and enginees. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 277

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NOTICE

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation
Research Board

A Concrete Pavement Evaluation System (COPES) has been developed for direct use or as a guide for the creation of similar systems tailored to the specific needs of users. COPES provides a framework and procedures for collecting historical and field data on the characteristics and performance of in-service portland cement concrete pavements. As part of the research study, data were collected in six states using COPES. These data were subsequently analyzed to demonstrate the potential applications for such data analyses in examining the design, construction, maintenance, and rehabilitation of concrete pavements. The report will be of interest to engineers and researchers concerned with the performance and the evaluation of concrete pavements. COPES procedures and data items should also be of direct benefit to those involved in the development or execution of pavement management systems. Data collected during the study are available on request.

The great majority of portland cement concrete (PCC) pavements in the United States are providing satisfactory performance, but there is sufficient mileage of distressed pavement to necessitate a systematic approach to defining the causes and remedies of this distress. Many changes have been, and continue to be, made in the design and construction of PCC pavements. It is highly important to determine the effects of these changes to avoid the possibility of constructing additional miles of pavement that might fail prematurely. In many respects the pavements presently in service constitute a source of information on which to base future improvements in design and construction. Considering the mileage of PCC pavements built each year, any deficiency in their design and construction can result in continuing maintenance problems of significant proportions.

A general evaluation of the performance of in-service PCC pavements could provide guidance for design and construction in the future and develop information useful in planning the rehabilitation of these pavements. Recognizing that a nationwide survey and evaluation of the performance of all existing PCC pavements, or of those on the Interstate System alone, was beyond the realistic scope of an NCHRP project, the objectives of this research were (1) the development of a system for collection and analysis of information relevant to the performance of PCC pavements and to evaluation of the nature, extent, and cause of distress in such pavements; and (2) the demonstration of the system.

Researchers at the University of Illinois conducted the study under NCHRP Project 1-19, "Development of a System for Nationwide Evaluation of Portland Cement Concrete Pavements." The system that did evolve from this research is called COPES, Concrete Pavement Evaluation System. The system can be applied at several levels of government (national, regional, statewide, and local), and if desirable, COPES can be tailored to specific individual requirements. It could be used in conjunction with pavement management systems and research studies for continued collection and analysis of information and identification of methods for further improvements in the performance of PCC pavements.

The first part of the report provides a brief summary of the development of COPES and demonstrates the potential uses of data collected under COPES. Data collected from six states were analyzed to show the possible impact on the design, construction, maintenance, and rehabilitation of concrete pavements. The analyses took the form of regression equations and, although they were meant for demonstration purposes only, do provide insight into the performance of concrete pavements. However, interpretations of those regression analyses should be based on a full understanding of the methods and conditions on which the data were obtained.

The report contains the data analyses for all six states, collectively. Appendixes A through F include the individual data analyses for each of the six states that allowed data to be collected on their concrete pavements. Appendixes A through F are not published herein, but are contained in an agency submitted report titled, "Volume I, Concrete Pavement Evaluation System (COPES), Research Report." That report is available on a loan basis or for purchase at a cost of $10.00, on request to the NCHRP, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. Data collected under the study are also available on computer tape; for further information contact the NCHRP.

Appendix G, which constitutes a major part of the report, is a User's Manual. The User's Manual provides the framework and procedures for collecting and storing data from in-service portland cement concrete pavements. Of particular interest in the manual is a "Distress Identification Guide" that helps provide some degree of standardization in the otherwise highly subjective determination of the severity of concrete pavement distress. It should also be noted that the researchers chose to make use of a proprietary data base management system that was available to them. Although this system performed quite satisfactorily, other options could be used for data management.

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PART I

PART II

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 1-19 by the Department of Civil Engineering, University of Illinois at Urbana-Champaign. Dr. Michael I. Darter was the principal investigator and Dr. Samuel H. Carpenter was co-principal investigator for a portion of the work. The authors express much appreciation to the following persons who assisted in various phases of the work: Dr. Samuel H. Carpenter, Robert H. Beskow, Jeff Kirchbaum, Roger E. Smith, Steven L. Brandau, Jihad S. Sawan, Darlene Jessee, Susan Lewis, Margarita Zelaya-Nunez, and Amir Tabatabaie.

The Survey Research Laboratory, University of Illinois, is acknowledged for their assistance in preparing the field and historical data sheets and the development of the COPES computerized data management system.

Appreciation is also extended to many state DOT personnel, especially Emmitt Chastain, Wouter Gulden, Doug Anderson, Leo Warren, S. C. Shah, and Bill Neal from Illinois, Georgia, Utah, Minnesota, Louisiana and California, respectively, for their assistance in the collection of a massive amount of data.

PORTLAND CEMENT CONCRETE PAVEMENT EVALUATION SYSTEM (COPES)

SUMMARY

The primary objectives of this project were to develop a system for state and nationwide evaluation of concrete pavement performance, and to demonstrate and refine the system in cooperation with state highway departments.

The major finding of this project is that the *CO*ncrete *P*avement *E*valuation *S*ystem (COPES) developed under NCHRP Project 1-19 is capable of efficiently collecting, processing, and evaluating large amounts of pavement data to improve the design, construction, materials, and maintenance of concrete pavements. COPES is developed to include jointed plain (JPCP), jointed reinforced (JRCP), and continuously reinforced (CRCP) pavements. The COPES data bank also provides extensive information for the development of predictive models that can be used for pavement management purposes, including prediction of remaining life and future rehabilitation needs.

The system consists of three major components: data collection, storage and retrieval, and evaluation. Both inventory and monitoring data are obtained for each pavement section included in COPES. The data processing is computerized for maximum efficiency. The user can retrieve pavement information and perform many analyses and evaluations of the data almost instantaneously using a remote computer terminal.

State level demonstrations were conducted in six states: Illinois, Georgia, Utah, Minnesota, Louisiana, and California (a few sections were also included from Nebraska). Extensive data were collected from 418 uniform sections of pavement representing 1,305 miles of mostly heavily trafficked interstate highways. A number of demonstration analyses and evaluations were conducted, including the following:

- Network facility data summary.
- Network condition data summary.
- Prediction of future pavement deterioration (cracking, joint deterioration, faulting, PSR, pumping).
- Design evaluation.
- Construction and materials evaluation.
- Maintenance evaluation.
- Determination of causes of pavement deterioration.
- Recommendation of design improvements.
- Determination of rehabilitation needs.
- Determination of research needs and special studies.

Many interesting results relative to the foregoing were obtained from the state demonstrations and are presented in Appendixes A through F. The successful demonstration of COPES in six states shows that feedback performance data can be very useful in the improvement of concrete pavement technology. The "national" evaluation

demonstration shows that it is also possible to combine and evaluate data from several states to develop more broad-based findings on pavement deterioration and the effects of climate.

The following findings represent some preliminary indications from analyses of data collected with COPES on the performance of jointed concrete pavements in six states. A total of forty (40) regression models were developed to quantify the relationships between distress/serviceability and design, traffic, climate, and other variables.

1. *The following changes in design factors were determined to significantly increase pavement life for both JPCP and JRCP (except where noted):*

- Increased slab thickness.
- Decreased joint spacing (for JRCP).
- Increased dowel diameter.
- Use of tied PCC shoulders.
- Use of stabilized base materials.
- Increased slab reinforcement (over current requirements for JRCP).
- Provision of subdrainage through longitudinal edge drains or a granular foundation material beneath the base.
- Provision and maintenance of joint seals to resist infiltration of incompressibles.

2. *The following materials/soils factors were found to significantly increase pavement life for both JPCP and JRCP:*

- Prohibiting the use of "D" cracking or reactive aggregates at all costs.
- Provision of a granular subgrade.
- Increased PCC modulus of rupture.

3. *Climatic factors were found to affect pavement life greatly*:

- Annual precipitation.
- Average annual temperature.
- Freezing index.
- Annual temperature range.

4. *Evaluation of several maintenance-related factors revealed:*

- PCC full-depth patches were found to perform much better over time than AC full-depth patches.
- The condition of the transverse joint seals was found to greatly affect joint deterioration. Two to three times more deterioration was observed when transverse joint seals were allowed to deteriorate and fill with incompressibles.
- Subdrainage decreased visible pumping significantly. Pumping had a large negative effect on pavement life.

5. *The overall serviceability-performance of jointed plain concrete pavements (JPCP) was similar to that of conventional long-jointed reinforced concrete pavements (JRCP); however, JRCP exhibited significantly more joint deterioration which will require considerable maintenance for joint repairs.* One observed exception to this occurred where jointed reinforced concrete was constructed with a relatively short joint spacing (i.e., 27 ft) in Minnesota, which greatly improved its performance.

6. *Distress and serviceability models demonstrated how to develop "optimum" designs for JPCP and JRCP.*

Many of these findings were determined independently from analysis of data from each individual state, as well as from the analysis of the combined "nationwide" data from all six states.

The sample of data included in this demonstration (1,297 miles) represents approximately 6 percent of the total mileage of all Interstate concrete pavements. However, before any broad-based consensus of findings can be made, it will be necessary to expand the data base to include additional states with varying climates, soils, traffic, and other conditions. This will make it possible to conduct a truly nationwide evaluation of conventional concrete pavements.

One of the most important aspects of COPES is its potential for use in pavement management. Many states have expressed interest in this aspect of COPES in addition to its use as a research tool. The distress and other monitoring data obtained for an individual project can be used to help select candidate rehabilitation strategies. An adequate database with efficient storage and retrieval capabilities is a necessity for any pavement management system when many data items must be processed.

An example of the use of COPES for special studies was in the development of approximate truck lane distribution prediction models for multiple-lane controlled-access facilities.

COPES or its various components are already being used by several agencies. The highway distress identification manual (Ref. *1*) is being used by several states. Two states (Minnesota and Virginia) are implementing COPES presently, and Illinois has utilized the COPES database. Perhaps the most important use of COPES data collection procedures is in the FHWA Long-Term Monitoring Program. Two states have also extended COPES to include asphalt pavements (Illinois and Minnesota).

In summary, the results from the development and field demonstration of COPES show that the state and nationwide evaluations can be used to great advantage by AASHTO, the FHWA, and the individual states involved in developing improved design, construction, and maintenance procedures for concrete pavements.

The following report is organized in two parts. The first part presents an overview of the research approach and highlights of the findings, conclusions, and recommendations related to the development and field demonstration of COPES in the states of Illinois, Georgia, Utah, Minnesota, Louisiana, and California. The second part is composed of seven appendixes, the first six of which (A to F) discuss in greater depth the field tests in each of the six states. The final appendix (G) is a self-contained user-oriented manual. That section consists of three chapters and two appendixes. Two chapters cover, in detail, the field survey procedures recommended for collecting, storing, and retrieving COPES data. And one chapter is intended to be used as a standard guide for distress identification and measurement. Blank COPES data collection sheets and COPES data code sheets are provided in the two appendixes.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

Although the majority of portland cement concrete (PCC) pavements in the United States are providing satisfactory performance, there is sufficient mileage of prematurely distressed pavement to necessitate a systematic approach to defining the causes and remedies of this distress. Many changes have been and continue to be made in the design and construction of PCC pavements. It is highly important that the effects of these changes be determined in order to avoid the possibility of constructing additional miles of pavement that might fail prematurely. Considering the mileage of PCC pavement built each year, any deficiency in their design and construction can result in continuing maintenance problems of significant proportions.

It is believed that, in many respects, the pavements presently in service constitute a dependable source of information on which to base future improvements in design and construction. A comprehensive evaluation of the performance of existing PCC pavements can be used for a wide variety of purposes, including:

1. Improvement of paving materials and design, construction, maintenance, and rehabilitation procedures.
2. Provision of a database for pavement management in selecting and prioritizing rehabilitation needs and assisting in their design.
3. Generation of data and reports useful for pavement management and special studies.

The 4R program consisting of rehabilitation (including recycling), reconstruction, resurfacing, and restoration emphasizes the need for a continuous evaluation system from which information can be generated regarding the condition of a pavement network. Thus, a PCC evaluation system is needed to meet these objectives at both the state and national levels. The current interest and work in the development of FHWA's Long-Term Pavement Monitoring Program shows the great national interest and expectation in monitoring in-service pavements.

SCOPE OF STUDY

Recognizing that a nationwide survey and evaluation of the performance of all existing PCC pavements (or of those on the Interstate System alone) was beyond the resources available to this project, the scope was limited to: (1) the development of a system for collection, storage and retrieval, and evaluation of information relevant to the performance of PCC pavements, and the evaluation of the nature, extent, and cause of distress in such pavements; and (2) demonstration and refinement of the system. The system could then be used by many states and a large amount of data eventually collected so that a nationwide evaluation could be conducted as is currently being planned through the Long-Term Monitoring Program.

The system could also be used in conjunction with pavement management systems for continued collection and analysis of information and identification of methods for further improvements in the performance of PCC pavements.

RESEARCH APPROACH

In fulfillment of these objectives, the following tasks were accomplished:

1. *Development of a practical system for continuous evaluation of the performance of all types of conventional PCC pavements.* The *CO*ncrete *P*avement *E*valuation *S*ystem (COPES) is capable of efficiently processing large amounts of data in providing data collection, storage and retrieval, and analysis and evaluation.

The system is intended to: (a) be capable of considering all measurable physical factors that could affect PCC pavement performance, including structural design, environmental conditions, and traffic loadings; (b) be capable of considering distress in relation to such factors as drainage conditions, subgrade, subbase and design features, materials, construction methods, age, and maintenance activities; (c) be suitable for collection and analysis of information on an individual state basis as well as on a nationwide basis, so that it can be used for the planning, design, and formulation of maintenance and rehabilitation strategies; (d) permit correlations between such factors as design features, environment, traffic, pavement performance, and distress; and (e) provide a framework for implementation.

The initial system was developed based on University of Illinois staff experience and interviews with state DOT personnel.

2. *Demonstration of the system.* This task consisted of applying and refining COPES (as developed under task 1) in Illinois and Georgia, where extensive data were collected on over 150 pavement projects (Ref. *4*). COPES was then further demonstrated and refined in the states of Utah, Minnesota, Louisiana, and California.

The COPES system and state demonstrations are described in the following chapters and in Appendixes A to F. Appendix G is a user's manual for COPES including data collection, storage and retrieval, and the concrete highway pavement distress identification guide.

CHAPTER TWO

FINDINGS

COPES consists of the three major components illustrated in Figure 1—data collection, storage and retrieval, and evaluation/usage.

DATA COLLECTION

COPES is developed to include the three conventional concrete pavement types: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). The COPES data collection procedures specify what data to collect and how to collect it.

The concrete pavement network is divided into "uniform sections." A uniform section has uniform characteristics along its length including structural design, joint design and spacing, reinforcement, truck traffic, subgrade conditions, and distress. Uniform sections are frequently defined by original construction section boundaries.

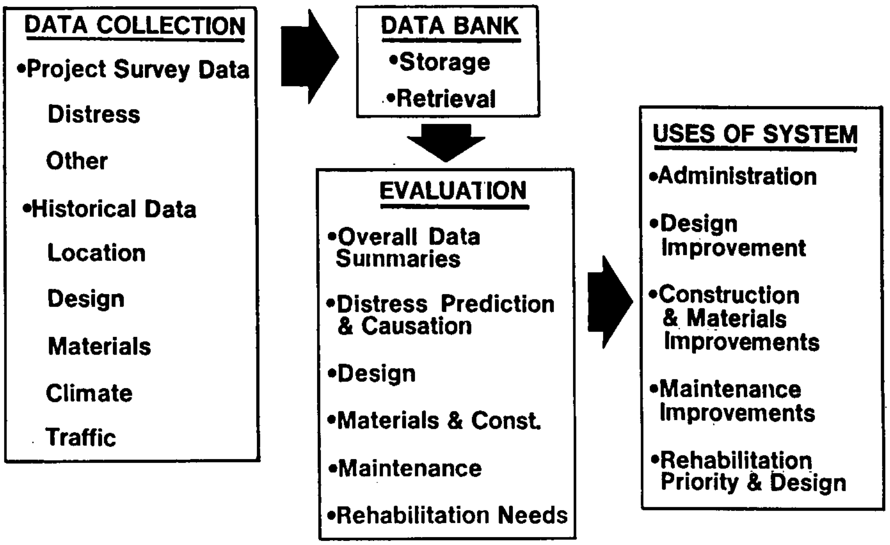

Figure 1. Concrete Pavement Evaluation System—COPES.

The number of uniform sections from which data are collected depends on the purpose of the pavement evaluation. If the data in COPES are to be used for network-level pavement management programming, all sections on a given highway system should be included. The COPES data can then be used to prioritize projects for maintenance or rehabilitation and to develop rehabilitation strategies.

If COPES is to be used basically for research purposes (e.g., design evaluation), only a "sample" of the entire network is required. This sample can be selected only after the agency determines the specific objectives of research. For example, the objective may be to evaluate and improve the performance of a given type of pavement that has been constructed in the state (or region). All available uniform sections for this design should be categorized in similar groupings based on similar climates, designs (e.g., similar joint spacings, base types, slab thicknesses) and any other major independent factors that are believed to strongly influence performance. A factorial type of arrangement is highly recommended. A sample of sections can then be selected from each of these similar groups.

Because of the highly variable performance of pavements, a sufficient number of sections must be selected from each similar group to provide a reasonable data base. The existing COPES data bank includes data that could be used to compute estimates of statistical performance variability to assist in the determination of the number of required sections for statistical reliability.

For nationwide evaluations, data for each pavement type and design will be required from each broad climatic zone. Nine such zones based on temperature and moisture factors were identified by Carpenter (*2*). Pavements of similar design built on similar subgrades should generally give similar performance in each of these zones.

The collection of inventory (or historical) and monitoring data is next. The inventory or historical data include over 325 variables relative to project identification, location, environment, structural design, joint design, reinforcing steel, concrete mix design and properties, base and subgrade properties, shoulder design, drainage, previous traffic, and previous maintenance and rehabilitation activities. The inventory data are recorded on 13 data collection sheets that are designed to facilitate direct data entry onto computer cards or other input media. The inventory data can normally be obtained directly from state departments of transportation as-built construction plans, standards, specifications, construction and materials reports, traffic studies, W-4 tables (truck axle-weight data), climatic records, and other sources.

COPES relies heavily on the use of existing pavement distress to conduct the many analyses and evaluations subsequently described. Because of this, a comprehensive distress identification manual (Chapter Two of Appendix G) was developed to provide for standardized uniform data collection. The manual describes each distress type, its general mechanism, and methods of measurement; defines levels of severity; and provides photographs of many typical distresses.

The field data collection procedures (Chapter One of Appendix G) describe how to obtain all needed data from a given highway construction project during a single visit to the project.

The survey procedure provides for the efficient collection of all existing distress data on seven field data collection sheets. No expensive equipment is needed to conduct the field survey. Only items such as a hand-held odometer, measuring tape, scale or pocket ruler, and faultmeter are required.

Field data collection times are highly dependent on the amount of distress present and the volume and characteristics of traffic present. The following survey time estimates show that the field data can be collected with relative expediency by a trained survey team:

COPES Field Data Collection Time Estimates for Interstate Pavements
(Time per two-lane mile)

Good pavement condition—rural (10 to 15 min), urban (15 to 25 min)
Fair pavement condition —rural (15 to 25 min), urban (25 to 35 min)
Poor pavement condition —rural (25 to 45 min), urban (35 to 50 min)

Not all of the data items were collected during the field demonstrations (some were never collected by the agency or were simply lost, such as material properties). *It is emphasized that not all of these data are required to use COPES.* COPES was designed to be able to accommodate the many unique pavement designs, material properties, construction procedures, distress types, and so on that might be encountered in nationwide uses. Considerable data collection and storage savings can be realized by eliminating the collection of any variables that are of constant value or of little use to the user agency. Some of the key data elements (or variables) are indicated by the symbol "*" on the user's manual (App. G) data sheets. *Thus, the user agency must first define the proposed objectives and applications of COPES and then select the data required to meet its needs.*

The development of the COPES data collection procedures was an iterative process. A comprehensive study was conducted at the beginning of the project to identify the variables that affect concrete pavement performance and cause all types of concrete pavement distress. Many discussions were held with various experienced pavement engineers and researchers (including highway department personnel) to identify the data that should be included, taking into consideration the difficulty in collecting certain types of data. After data collection and analysis in six states, a finalized set of historical (design) and field survey data was identified that could be reasonably collected within the resources of the agencies that would use COPES. *Again, it is not necessary to collect all of the identified data to be able to use COPES.* The specific data required depend on the type of analyses and evaluations desired by the user agency.

The data collection process has been made much more efficient by Minnesota through the use of hand-held computers. The distress data are simply coded into hand-held computers in the field and recorded on tape. The data are then transmitted over telephone lines each night to the main computer for verification and storage in the COPES data bank.

Deflection data are not currently included in COPES. This is not because deflections are unimportant in evaluating concrete pavement performance. Deflections measured with heavy load equipment have been shown to be very helpful in locating voids beneath slabs, "back-calculating" slab and foundation engineering properties (e.g., E, k-value), and measuring joint load transfer (Ref. *3*). However, the development of the required input, format, and analysis programs is a very complex task and was considered beyond the scope and funding limits of this study. Any future expansion of COPES, however, should consider the inclusion of deflection data.

DATA STORAGE AND RETRIEVAL

Large amounts of data must be collected and processed by COPES for a typical state highway network, and especially for nationwide or regional evaluations over many states. Thus, the use of automatic data processing (ADP) is essential for successful system operation. The data management system used in COPES is the *S*cientific *I*nformation *R*etrieval (or SIR) (Ref. *9*). SIR is a data base management system with the following major capabilities among others:

1. Efficient storage, retrieval, and manipulation of large amounts of data (input, modifications, deletions, and other means of controlling the data bank contents).
2. Simple and complex data retrievals in a straightforward manner.
3. Report-generating procedures for the production of simple or complex reports.
4. Direct interface with other computer programs to perform statistical and other analyses on the data.

The statistical analyses of the data can be performed using the SPSS (Statistical Package for the Social Sciences) (Refs. *8, 10, 11*), or the Bio-Med Computer Package, P-Series (BMDP) (Ref. *12*). These are among the most widely used statistical systems in existence.

Data retrieval and analyses are easily accomplished using SIR in either batch mode or interactive mode using a remote computer terminal. The terminal can be located in the user's office and connected to the computer with telephone lines. This allows the user to input and execute a set of SIR commands, retrieve data files in any desired format, and conduct many kinds of analyses of the data, without leaving the office.

It should be noted that the data collected on the inventory (or historical) and monitoring data collection sheets could be entered into other computerized data base managers (such as System 2000 with a rewrite of the data base schema) or even into statistical analysis systems (e.g., SPSS, SAS, BMDP) with rectangular-type files (where rows are pavement sections and columns are variables or data items). A separate file for each of the data collection sheets would probably be the best approach for this use. Some difficulties might be expected because of the large size of the database with the extensive file manipulation that would be required, and the cost of data storage, retrieval, and analysis would be greater. However, COPES can be used even if the SIR system is not available through rewriting the database definition.

The general data processing procedures used in COPES are shown in Figure 2. The first set of field and historical raw data are collected using standard data collection sheets that are then stored in a manual filing system. The raw data are extracted from these sheets and keypunched directly onto computer cards or other input media for ADP. The cards are read into a digital

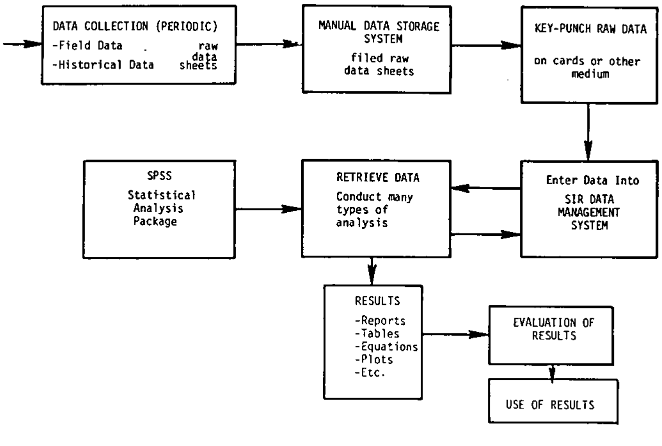

Figure 2. Basic COPES data processing procedures.

computer and the data are entered into the SIR database. At this point, the raw data are edited and cleaned to prepare them for analysis. The data may then be retrieved and analyzed using the many statistical procedures contained in SPSS or BMDP. The resulting summary tables, reports, predictive equations, plots, etc., may be evaluated to produce recommendations for design, construction, and materials improvements.

Additional data are collected at periodic intervals (e.g., every 1, 2, or 3 years). These data are input the same way as the initial data and are simply added to the existing database. Both the manual storage files and the computerized SIR data bank are easily updated with new data. Data analyses can be repeated, making time sequence analyses possible, since condition data are available at more than one point in time.

The development of automated reports is desirable for specific agency uses. The SIR database management system provides the user agency with flexible report generation facilities.

Details on data storage and retrievals are included in Appendix G.

DATA ANALYSIS AND EVALUATION

The information contained in the COPES data bank can be analyzed in many ways for many purposes. The analyses that can be conducted are limited only by the amount of data placed into the data bank and the needs of the engineer.

Demonstrations of different kinds of evaluations were performed in six states and the results are included in Appendixes A through F. These data were also analyzed as a group to demonstrate a "national" evaluation. It is recognized that a six-state analysis is not truly a national evaluation; thus, the results should not be extrapolated beyond the states involved. A summary of the findings from the state and national evaluations follows.

Network Facility Data Summary

Network facility information addresses the need to know the extent and design of pavement facilities. Overall summaries of pavement age, slab/base design, subgrade soil types, climate/drainage characteristics, traffic volumes, and 18-kip equivalent single-axle loadings (ESAL) can be developed. This information can be sorted and summarized by highway district, highway route, county, and pavement type. Facility data summaries for the six participant states are given in Appendixes A through F.

Pavement Condition Summary

Brief or comprehensive summaries of an agency's pavement condition can be generated. These can be sorted statewide by district, county, route, etc. Major JRCP and JPCP distress types identified in the six states included slab cracking, pumping, joint faulting, joint deterioration, and PSR (Present Serviceability Rating, which is essentially a measure of user-rated pavement roughness). Condition summaries for the six participant states are given in Appendixes A through F.

Distress Prediction and Causation

Regression models were developed for PSR and for the four major types of distress identified for either JRCP or JPCP in each of the six demonstration states (5 × 6 = 30 models). Regression models were also developed for the national database for each of these distress types and PSR for JRCP and for JPCP (5 × 2 = 10 models). These models provide a valuable source of information for determining which variables affect serviceability and distress occurrence. They can be used to identify the general mechanisms of these distresses and to estimate the relative effects of certain changes in design parameters on the occurrence of the distress. These results can then be used to assist in developing improved pavement design, construction, and maintenance procedures.

The following is a summary of the major findings. Further information is provided in Chapter Three and in Appendixes A through F.

Transverse Joint Faulting

Cumulative traffic loadings (18-kip ESAL) are the major cause of faulting. The general functional form identified for all joint faulting models is shown in Figure 3a. Faulting increases rapidly during the early stages of development, and then the rate of increase reduces considerably. The reason for this early rapid increase in faulting may be due to the looseness of the dowels caused by the layer of grease commonly applied to dowels just before paving.

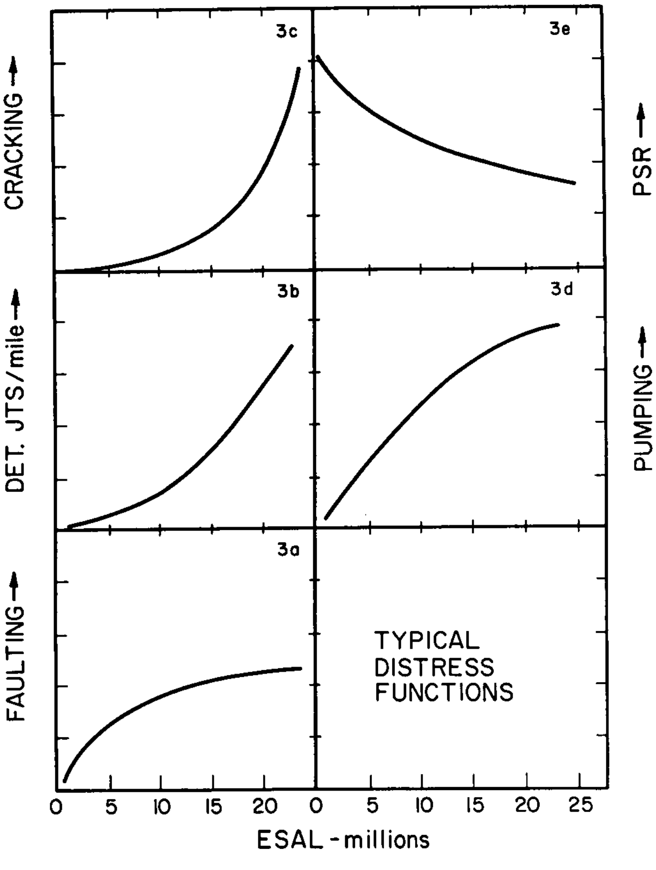

Figure 3. Typical PCC distress model functional forms.

The following variables were found to affect faulting as indicated:

CHANGE IN VARIABLE	RELATIVE EFFECT ON FAULTING
Increase ESAL	Large increase early
Increase slab thickness	Medium decrease
Decrease joint spacing	Small decrease
Use dowels or increase dowel diameter	Large decrease
Tied PCC shoulder (as opposed to AC shoulder)	Medium decrease
Stabilized base (as opposed to granular base)	Medium decrease
Increase foundation k-value	Medium decrease
Granular subgrade (as opposed to fine-grained)	Large decrease
Majority at-grade (as opposed to cut or fill)	Small decrease
Colder climate (increased freezing index)	Small decrease
Occurrence of visible pumping	Medium increase

Joint Deterioration

The age and type of pavement were the most significant variables affecting the deterioration of joints. Long-jointed JRCP exhibited far more serious joint deterioration than JPCP. Age represents annual cycles of large joint openings (during winter) and closings (during summer). Incompressibles infiltrate poorly sealed joints in the winter causing high compressive stresses to develop during hot weather. This contributes to joint deterioration through blowups and spalling for JRCP. The typical relationship between joint deterioration and age (in terms of cumulative traffic loadings) is shown in Figure 3b. A number of years (or climatic cycles) are required before any significant joint deterioration occurs, and then it develops rapidly for JRCP. JPCP did not exhibit much joint deterioration except where excessive incompressibles were allowed to infiltrate into the joints.

The following variables were determined to affect the amount of joint deterioration:

CHANGE IN VARIABLE	RELATIVE EFFECT ON JOINT DETERIORATION
Increase ESAL	Small increase
Increase pavement age (climatic cycles)	Large increase after time
Use of Unitube joint inserts (Georgia)	Large increase
Decrease joint spacing (JRCP)	Large decrease
Use of subdrains (on "D"-cracking susceptible pavements)	Large decrease
Use of "D"-cracking aggregates	Large increase
Use of reactive aggregates	Large increase
Increase annual precipitation	Small increase
Increase freeze-thaw cycles	Large increase
Increase January/July temperature difference	Medium increase
Joint seals in poor condition	Large increase

Slab Cracking

Cumulative traffic loading (18-kip ESAL) was the most significant variable affecting slab cracking in JPCP and in the deterioration of regular transverse shrinkage cracks in JRCP. Traffic loadings cause fatigue damage in the slab, which begins slowly and then accelerates rapidly. The typical relationship between slab cracking and ESAL is shown in Figure 3c. The following variables were determined to affect slab cracking:

CHANGE IN VARIABLE	RELATIVE EFFECT ON CRACKING
Increase ESAL	Large increase
Increase slab thickness	Large decrease
Increase reinforcement (JRCP)	Medium decrease
Decrease joint spacing (JRCP)	Large decrease
Use stabilized base	Medium decrease
Increase k-value	Medium decrease
Granular subgrade (as opposed to fine-grained)	Small decrease
Majority in cut or fill (as opposed to at-grade)	Medium increase
Increase PCC modulus of rupture	Large decrease
Increase pumping	Medium increase
Increase annual precipitation	Small increase
Increase freezing index	Small increase
Increase January/July temperature difference	Small increase

Pumping

Cumulative traffic loading (18-kip ESAL) was the variable found to most significantly affect pumping. The typical relationship between pumping severity and ESAL is shown in Figure 3d.

Pumping develops rapidly from none observed to medium severity and then takes longer to develop into a high-severity distress. Variables determined to significantly affect pumping are as follows:

CHANGE IN VARIABLE	RELATIVE EFFECT ON PUMPING
Increase ESAL	Large increase
Increase slab thickness	Large decrease
Provide subdrainage (longitudinal pipes)	Medium decrease
Granular subgrade (as opposed to fine-grained)	Large decrease
Increase in annual precipitation	Large increase
Increase in Thornthwaite moisture index	Medium increase
Increase freezing index	Small increase

Present Serviceability Rating (PSR)

The major factor causing loss of pavement serviceability was cumulative traffic loading (18-kip ESAL). The typical relationship between PSR and ESAL is shown in Figure 3e. The loss of serviceability appears to be rapid at first and then levels off somewhat for a long time/traffic period. The initial serviceability rating was assumed to be 4.5 whenever data were not available. It is known that some pavements are not constructed at this level of smoothness and perhaps this accounts for the apparent rapid early loss of serviceability. Another reason might be the typical rapid increase in faulting early in the pavement's life. The following variables were found to affect pavement serviceability:

CHANGE IN VARIABLE	RELATIVE EFFECT ON PSR
Increase ESAL	Large decrease
Increase slab thickness	Large increase (improvement)
Increase reinforcement content (JRCP)	Small increase
Decrease joint spacing (JRCP)	Medium increase
Skewed joints	Medium increase
Increase foundation k-value	Medium increase
Stabilize base course	Medium increase
Majority in cut (vs. majority in fill or at-grade)	Small decrease
Use "D"-cracking aggregate	Large decrease
Use reactive aggregate	Large decrease
Increase PCC modulus of rupture	Medium increase
Age (no. cumulative freeze-thaw cycles)	Medium decrease
Increase freezing index	Small decrease
Increase precipitation	Small decrease

Quantification of Variable Effects

The 40 regression models developed for this study can be used to predict the effects of changes in design, climate, traffic, and the like, on serviceability and the occurrence of key distresses. Examples of the estimation of the actual effects of the variables included in the regression models developed for this study are included in Chapter Three and Appendixes A through F.

Design Evaluation

Data from COPES can be used to conduct detailed evaluations of many different design variables. Some detailed examples are provided in the state demonstrations (Appendixes A through F) and national demonstration (Chapter Three). In brief, slab/foundation design, including thickness, reinforcement, joints, PCC durability (particularly aggregates), and base type, has a great effect on the performance of JPCP and JRCP pavements. The effects of the following design variables were determined in the COPES demonstration:

DESIGN VARIABLE	EFFECT ON DISTRESS
Increase slab thickness	Reduce cracking, faulting, pumping and PSR loss
Decrease joint spacing	Reduce faulting, joint deterioration, cracking and PSR loss
Increase dowel diameter	Reduce faulting, improve PSR
Increase reinforcement (JRCP)	Reduce crack deterioration
Use stabilized base	Reduce faulting and cracking
Use tied PCC shoulder	Reduce faulting
Use high-quality joint sealant (keep out incompressibles)	Reduce joint deterioration
Provide subdrainage (using either granular subgrade or longitudinal pipes)	Reduce pumping and PSR loss

One of the most interesting findings relative to design of JRCP was that the commonly recommended and used 40-ft JRCP joint spacing resulted in the highest number of deteriorated joints per mile compared to other joint spacings, as shown in Figure 4 (which was prepared using the JRCP joint and crack deterioration models). Reducing joint spacings to approximately 27 ft significantly reduced the rate of joint deterioration. Also, as the joint spacing increases, the amount of deteriorated cracks increases. Thus, these data indicate that a shorter joint spacing of approximately 27 ft may provide improved JRCP performance in terms of reduced joint deterioration and crack deterioration. Additional data are needed to verify this finding, however.

Another interesting finding for JRCP is that a considerable proportion of transverse cracks exhibited ruptured steel and were open working and faulted cracks. The amount of reinforcement for most of the JRCP was probably determined by the subgrade drag theory, which does not consider several factors (e.g., joint lockup, traffic loadings). It appears that this is generally not adequate reinforcement to hold the cracks tightly together. Consideration should be given into analyzing again the adequacy of current design procedures and standards regarding reinforcement requirements.

The surveyed pavements were generally heavily loaded. Truck traffic volumes had typically doubled or tripled between 1970 and 1980. Average applied ESAL/lane/year ranged from 500,000 to 1,000,000 in the most heavily traveled lane on many sections of JPCP and JRCP. A few sections were carrying about

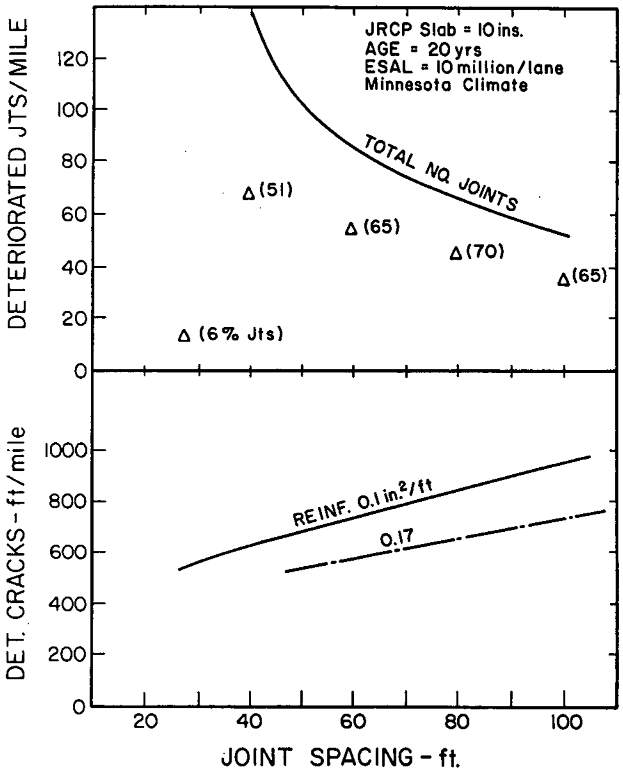

Figure 4. Sensitivity of JRCP joint and crack deterioration to joint spacing and slab reinforcement.

2,000,000 ESAL/lane/year at the time of the survey (e.g., I-5 in Los Angeles). Many pavements have carried more traffic than predicted by the AASHTO Interim Design Guide, yet still have considerable remaining life. In general, it was found that the surveyed JPCP and JRCP could be expected to exceed the AASHTO design traffic predictions, particularly in the drier climates. The major exception to this was the JRCP with 100-ft joint spacing located in Illinois. Actually, various design changes could be made to vary the design life of the pavement that could not be considered in the AASHTO Interim Design Guide (joint spacing, PCC shoulders, subdrainage).

The regression models developed for this study can be used to approximately quantify the effects of design variables for a given climate/traffic/foundation situation. The models were used to demonstrate the development of "improved" designs for heavily trafficked pavements in Chapter Three. A comparison of the performance of JPCP and JRCP is also given in Chapter Three.

Construction and Materials Evaluation

The major findings relative to construction and materials are as follows:

1. Overall, there were few obvious construction-related distresses on the JPCP or JRCP. However, there may be deterioration caused by construction that cannot be determined without cores and material samples or initial ride quality measurements.
2. Inadequate or improper sawing of joints was observed in three of the participating states. This resulted in considerable random slab cracking and can be expected to significantly reduce pavement life.
3. It is very important to use concrete with a reasonably high modulus of rupture to minimize slab cracking and loss of pavement serviceability (a modulus of rupture of less than 600 psi had a large negative effect on performance).
4. Use of either "D"-cracking or reactive susceptible aggregates was disasterous for a significant number of pavements. This single factor caused serious deterioration of PCC slabs in Illinois and Minnesota and must be prevented at all costs.
5. The rapid increase in faulting of doweled pavements after opening to traffic should be investigated. It may be related to looseness caused by greasing the dowels just prior to paving.
6. Other more detailed evaluations can be conducted as well, such as determining the effectiveness of plastic tape longitudinal joints as opposed to saw-cut joints. Both longitudinal joint spalling and longitudinal cracking data can be obtained from the COPES data bank.

Maintenance Evaluation

The data in COPES can be used to determine the effectiveness of certain pavement maintenance activities, such as full-depth patching, joint sealing, and subdrainage. Some of the results of the maintenance evaluation demonstrations are given as follows:

1. Analysis of full-depth patch performance showed that PCC patches exhibited much less deterioration over time/traffic than AC patches.
2. The extent of joint deterioration for effectively sealed joints was 2 to 3 times less than that for joints that were poorly sealed and contained incompressibles.
3. Pavements having longitudinal subdrains exhibited significantly less visible pumping than pavements that did not have drains. Most of the drains were placed as part of maintenance or rehabilitation work. For pavements that were "D"-cracked, less joint deterioration was observed when drains were present.

Rehabilitation Needs

The data in COPES provide an excellent source of information to assist in determining rehabilitation needs for individual projects, and for determining general rehabilitation strategies for an overall network of pavement sections. Detailed summaries of recommendations to reduce the development of major distress types before serious failure occurs are provided for each participating state in Appendixes A through F.

Figure 5 shows an example prediction of one state's rehabilitation needs for a 400-mile PCC pavement network. Regression models were developed from the COPES data and used to predict future performance.

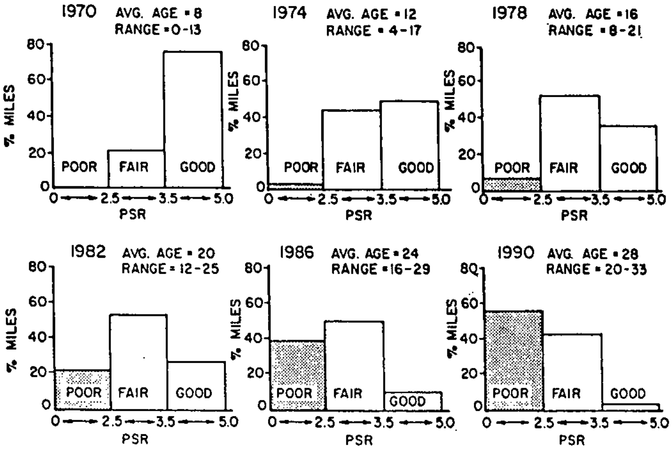

Figure 5. Predicted serviceability histograms for Illinois JRCP sections for 1970 to 1990.

Figure 6 shows an example of distress prediction for a single project using a set of regression models. This information can be used to help select the most cost-effective rehabilitation strategy.

Figure 7 shows an example report generated for a given pavement section. Location, design, materials, traffic, and condition data are provided in this report.

1. Project Design Data:

Age = 12 years (1982)
Traffic = 7.5 million accumulated
18-kip ESAL (outer lane)
Base = cement stabilized, 4 inches
Subgrade = A-6 AASHTO classification
k-Value = 375 pci (top of base)
Slab Thickness = 9 inches
Foundation Type = majority at grade
Edge Support = AC shoulder only
Modulus of Rupture = 517 psi (at 28 days)
Ratio = Stress/Modulus of Rupture = 0.379
Total Annual Precipitation = 31.0 cm
Summer Conc. Thermal Efficiency = 50.2
Joint Spacing = 12-19 feet
Load transfer = aggregate interlock only

2. Project Existing Condition Data (1982):

Pumping = low severity
Cracking = 343 ft/mile
Faulting = 0.05 inches/transverse joint (average)
Joint Deterioration = 4.4 joints/mile
(medium or high severity)
Joint Seal Damage = high severity,
incompressibles present
Present Serviceability Rating = 3.6

3. Traffic loadings (18-kip ESAL) for the past twelve years have averaged 0.625 million/year. It is assumed that the rate of loading will average 0.75 million/year in the future.

4. Future deterioration of the pavement (assuming no preventative maintenance or rehabilitation) is predicted using the distress prediction models as follows:

Year	Age (years)	ESAL	Pumping	Faulting	Cracking	Jt.Det.	PSR
1982*	12	7.5	0.3	0.05	343	4	3.6
1987**	17	11.3	1.4	0.06	841	12	3.4
1992**	22	15.0	1.8	0.07	1789	25	3.3
1997**	27	18.8	2.2	0.08	3441	45	3.2

Notes: * Measured condition data.
** The distress prediction models were "calibrated" to the existing amount of distress in the pavement so that future estimates for the pavement will be more accurate.

Figure 6. Example of distress prediction for a given JPCP project (using state models).

```
                      IDENTIFICATION/DESIGN/MATERIALS
                        Date of Report:  02/01/84

Identification
   Proj. Id.:  29946201
   Route:  I-94
   District:  3
   MP to MP:  142.3 to 149.1
   Const. Date:  1958

Design
   Reinforced Slab:  9 ins.
   Jt. Space:  40 ft.
   Load Transfer:  Dowels
   Dowel Dia.:  1.25 ins.
   Reinforcement:  0.10 sq. ins./ft.
   Base Type/Thick:  Gravel/6 ins.
   Edge Drains:  No
   Jt. Skew:  0
   Long. Jt. Type:  Weakened Plane Saw Cut

Rehabilitation
   None to Date

Materials:
   Modulus of Rupture:  722 psi (28-day)
   K-Value:  130 pci
   Subgrade Soil Class:  A-7-6
   Foundation:  Majority Fill (5 ft.)


                          TRAFFIC/CONDITION
                       Date of Report:  02/01/84


Traffic                         1965     1970      1975      1980
ADT (One-Way)                   5000     7060    12,000    17,000

ADTT (One-Way)                   400      600     1,200     1,800

Accumulated ESAL (million)       1.1      2.5       4.1       6.8

Condition
Pumping                         ----     ----      Med.      Med.
Cracking Long.  (ft/mile)       ----     ----       55        62
         Trans. (ft/mile)       ----     ----      175       250
Faulting (ins.)                 ----     ----      0.07      0.12
PSR                             ----     ----      3.7       3.4
Jt. Det. (no/mile)              ----     ----        5        15
Roughness (ins./mi.)            ----     ----       65        85
Jt. Saw Error (ft./mile)        ----     ----       30        30
Skid (SN)                       ----       45       41        38
```

Figure 7. Sample report generation for a selected project.

Research Needs and Special Studies

COPES provides an excellent source of distress data for determining research needs. For example, if the data show that joint deterioration is excessive, research studies can be initiated to develop improved joint spacing, load transfer methods, joint sealants and construction methods, etc., depending on the exact cause.

COPES can also be a valuable tool in conducting a number of special studies. For example, field data collected in the six participant states were used to develop regression models to estimate the lane distribution of trucks. Truck counts (129 in six states) were made in each lane of controlled-access highways with two to five lanes in each direction. Regression analysis of the data provided two models (see Appendix G) for estimating the percentage of trucks driving in the different lanes. The only variables in these models are one-way ADT and the number of lanes in the direction of travel. Table 1 gives the results of these models.

USES OF THE SYSTEM

The data collection, storage and retrieval, and evaluation results used in COPES have been briefly described. This extensive data source can be used by several offices of a state department of transportation, and also by the Federal Highway Administration in improving the design, construction, maintenance, and rehabilitation of concrete pavements. The results obtained from COPES can be used to: (1) improve overall pavement management, (2) improve design, construction and materials, and maintenance, and (3) determine rehabilitation strategies (Ref. *5*).

COPES provides efficient management of a pavement feedback database. Data can be collected and stored by individual states for concrete pavements in their highway networks. Thus, each state could have its own COPES data bank, and all of the evaluations previously discussed (and others) could be conducted.

A summary of expectations of how COPES will be used by the Minnesota DOT follows:

Table 1. Truck distribution for multiple-lane-controlled access highways (completed from models developed using 129 traffic counts in six states, 1982–1983; see Appendix G).

One-Way ADT	2 Lanes (One-Direction)		3+ Lanes (One-Direction)		
	Inner	Outer	Inner*	Center	Outer
2,000	6**	94	6	12	82
4,000	12	88	6	18	76
6,000	15	85	7	21	72
8,000	18	82	7	23	70
10,000	19	81	7	25	68
15,000	23	77	7	28	65
20,000	25	75	7	30	63
25,000	27	73	7	32	61
30,000	28	72	8	33	59
35,000	30	70	8	34	58
40,000	31	69	8	35	57
50,000	33	67	8	37	55
60,000	34	66	8	39	53
70,000	--	--	8	40	52
80,000	--	--	8	41	51
100,000	--	--	9	42	49

* Combined inner one or more lanes.
** Percent of all trucks in one direction.

Minnesota constantly needs answers to questions regarding the performance of their pavements. It is difficult to tell in advance what questions, to what detail and what the far reaching implications might be.

Considering the cost of our existing capital investment, the rate at which it is wearing out and the even higher costs of major rehabilitation or removal and replacement, we simply cannot afford to repeat design and construction techniques which will result in below optimum performance.

Therefore, we believe that COPES, with its vast amount of detailed information, coupled with SIR as a highly efficient data base manager and suitable statistical packages, will through simple and multiple regression analysis enable us to rapidly:

1. evaluate past pavement designs in detail;
2. evaluate past construction practices;
3. evaluate the effect of traffic on these pavements;
4. make predictions of remaining pavement life in existing pavements;
5. indicate the value of timely and appropriate rehabilitation techniques;
6. weed out elements in our concrete pavement philosophy which result in poorer performance;
7. emphasize elements in our concrete pavement philosophy which result in better performance;
8. support concept development which lowers annual road user costs; and
9. store this information in a readily retrievable format which through high tech equipment will make detailed information regarding a pavement available to our design, materials and maintenance engineers (Ref. *6*).

One of the most important uses of COPES is the evaluation of the data on a regional or nationwide basis. Each of the COPES data banks is *standardized* so that the data records from individual states can be sent to a central agency for processing on a regional or national basis. This evaluation will provide important results, because the range of variables will be much greater (e.g., climate, types of designs, soils, materials, etc.).

The distress identification manual has been used by the FHWA and several states for their condition survey procedures (Appendix G). COPES data collection procedures and distress identification have been used extensively in the FHWA Long-Term Monitoring Program (Ref. *7*). COPES has been adopted by Minnesota and Virginia for monitoring their concrete pavements. The system has also been extended to include asphalt pavements and overlays by the Illinois DOT. Thus, portions of COPES have already found practical application.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION—NATIONAL AND STATE DEMONSTRATIONS

This chapter describes demonstrations of the use of the COPES in-service pavement feedback data on an overall or national level to improve design, construction, materials and maintenance practices. The significance of the results obtained from the combined data from the six participating states is discussed, along with results from the individual state analyses.

It is emphasized that the results described herein are based on a sample of data (6 percent of the Interstate highway concrete pavement mileage) and that it is an initial effort in the development of predictive models. Further work is needed to produce reliable results that can be used to develop improved mechanistic-empirical models for use in design and analysis. In fact, an entire research project could easily be devoted to the development of each of the predictive models.

NATIONWIDE FACILITY SUMMARY

The combined data from the six states include a fairly large variety of designs, traffic levels, climates, and subgrades. In addition, data from eight JRCP sections from Nebraska, which were collected under another research study (using the COPES data collection procedures), were included in the COPES database to expand the climatic coverage. A total of 418 individual sections and 1,305 miles of primarily Interstate highway is included, as summarized in Table 2. Overall summaries of the major design variables and climates included in the combined data are presented in Tables 3, 4, and 5. Details of the designs and climates are provided in Appendixes A through F.

Table 2. Data collected for NCHRP Project 1-19 from six states (plus a few sections from Nebraska).

State	J P C P Unif.Sec.	J P C P Miles	J R C P Unif.Sec.	J R C P Miles
California	45	141	0	0
Utah	33	98	0	0
Georgia	28	263	0	0
Illinois	38	2	184	409
Minnesota	1	7	52	233
Louisiana	5	22	24	122
(Nebraska)	(0)	(0)	(8)	(8)
Totals	150	533	268	772

Table 3. Summary of slab thickness designs and climates for data from all states.

Climatic Zone	J P C P 8	9	10	11-13 ins.	J R C P 8	9	10	11-13 ins.
Wet-Freeze	X	X	X	X	X	X	X	X
Dry-Freeze	---	X	X	X	X	X	X	---
Wet-Non Freeze	---	X	X	---	---	X	X	---
Dry-Non Freeze	X	X	---	X	---	---	---	---

X Denotes the existence of pavement sections of particular design/climate in data bank.
- Denotes no pavement sections in data bank with given design/climate.

Table 4. Summary of major joint designs and climates for data from all states.

Climatic Zone	J P C P Joint Spacing (ft)/LT* <11	12-20	21-30	J R C P Joint Spacing (ft)/LT 27	40-50	51-80	100
Wet-Freeze	----	X/YES	----	X/YES	X/YES	----	X/YES
Dry-Freeze	----	X/NO	----	X/YES	X/YES	----	----
Wet-Non Freeze	----	X/YES	X/NO	----	----	X/YES	----
Dry-Non Freeze	X/NO	X/NO	----	----	----	----	----

LT denotes presence of mechanical load transfer.
X denotes the existence of pavement sections of given design/joint spacing in data bank.
NO/YES denotes the nonexistence (or existence) of mechanical load transfer.
---- denotes no pavement sections in data bank with given design/joint spacing.

Table 5. Summary of base, subgrade, and subdrainage data from all states for both JPCP and JRCP.

Climatic Zone	Base Type Non-Stab.	Base Type Stab.*	Subgrade Fine Grained	Subgrade Coarse Grained	Subdrainage No	Subdrainage Yes
Wet-Freeze	X	X	X	X	X	X
Dry-Freeze	X	X	X	X	X	X
Wet-Non Freeze	X	X	X	X	X	X
Dry-Non Freeze	----	X	X	X	X	----

* Stabilized with cement or asphalt.

X denotes the existence of pavement sections of particular climate/base/subgrade/subdrainage designs in data base.

---- denotes no pavement sections in data bank with given climate/base/subgrade/subdrainage.

FACTORS CAUSING DISTRESS—NATIONWIDE REGRESSION MODELS

Regression models were developed independently for each of the six states for each distress and PSR (30 models). The analysis of the combined data from the six states provides an opportunity to determine which variables most affect pavement deterioration over the states involved. "Nationwide" regression models were then developed for both JPCP and JRCP for each of the four major distresses and PSR. These models were developed using a combination of multiple linear regression and nonlinear regression techniques as included in the SPSS statistical package (*8*). Multiple linear regression was used to determine which independent variables were significantly affecting the dependent variables. The nonlinear regression was then used to compute the coefficients and exponents for the final predictive model.

The general functional form used for most of the models is as follows:

$$\text{DISTRESS} = (\text{TRAFFIC OR AGE})^{a}\,(\text{b DESIGN}^{c} + \text{d SUBGRADE}^{e} + \text{f CLIMATE}^{g} + \text{h MATERIALS}^{i})$$

where: a, b, c, d, e, f, g, h, and i are constants determined from regression. TRAFFIC, AGE, DESIGN, and the remainder of the terms in the equation are major variables included in the model.

This form allowed either traffic (as represented by the number of equivalent 18-kip single-axle loads, ESAL) or age or both to enter the model plus any number of design, subgrade, climate, and materials variables plus other distresses (such as pumping and incompressibles in joints). This form then used age or traffic as a multiplier for each other variable so that boundary conditions of zero traffic/age and zero distress would occur. The form of model is rational and could fit the various functional forms of the distress and PSR fairly well within the range of data available.

Although the following "national" models required an extensive amount of development time, they still should be considered "initial" models. With more time and effort, they could be expanded to include additional terms, more mechanistic variables and improved functional forms. This point becomes evident on examination of some of the individual models where it is evident that certain important variables are missing. In these cases, it is not that they were intentionally excluded, but that they did not enter the models either because they were not significant or because the data bank did not include a sufficient set of pavement sections to show their true effect.

Each of these regression models is based on available data. Anyone using the models must not extend them beyond the ranges of the data from which they were developed. The ranges of available data from each state are described in Appendixes A through F.

The following is a list of some of the more obvious deficiencies in the data bank:

1. JPCP with dowels were not available in dry-nonfreeze or dry-freeze climates.
2. JPCP with subdrains were only available in a wet-nonfreeze climate.
3. JRCP could not be located in a dry-nonfreeze climate and thus were not included in the data bank.
4. Concrete shoulders were only included in dry-freeze climates for JPCP. No concrete shoulders were available for JRCP.
5. A variety of other situations in which there was not a sufficient range of some of the variables (e.g., slab thickness, base type, reinforcement content) existed.

The national models for JPCP and JRCP are available on personal computer software for the IBM Personal Computer (*14*).

Pumping

The final national model for pumping of JPCP is as follows:

$$\begin{aligned}\text{PUMP} = {} & \text{ESAL}\ 0.443[-1.479 + 0.255(1 - \text{SOILCRS}) \\ & + 0.0605\ \text{SUMPREC}^{0.5} + 52.65/\text{THICK}^{1.747} \\ & + 0.0002269\ \text{FI}^{1.205}]\end{aligned}$$

where:

PUMP = 0, no pumping; 1, low severity; 2, medium severity; 3, high severity;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
SOILCRS = 0, fine-grained subgrade soil; 1, coarse-grained subgrade soil;
SUMPREC = average annual precipitation, cm;
THICK = slab thickness, in.; and
FI = freezing index.

Statistics: $R^2 = 0.68$
SEE (standard error of the estimate) = 0.42
n (no. of data points) = 289

The final national model for pumping of JRCP is as follows:

$$\begin{aligned}\text{PUMP} = {} & \text{ESAL}^{0.670}\,[-22.82 + 26102.2/\text{THICK}^{5.0} \\ & - 0.129\ \text{DRAIN} - 0.118\ \text{SOILCRS} \\ & + 13.224\ \text{SUMPREC}^{0.0395} + 6.834(\text{FI}+1)^{0.00805}]\end{aligned}$$

where

PUMP = 0, no pumping; 1, low severity; 2, medium severity; 3, high severity;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
THICK = slab thickness, in.;
DRAIN = 0, if no subdrainage (longitudinal pipes) exists; 1, if subdrainage exists;
SOILCRS = 0, fine-grained subgrade soil; 1, coarse-grained subgrade soil;
SUMPREC = average annual precipitation, cm; and
FI = freezing index.

Statistics: $R^2 = 0.57$
SEE = 0.52
n = 481

Pumping entered into several state distress models, indicating a strong influence on the rate of concrete pavement deterioration irrespective of geographic or climatic region. Pumping of fines beneath the slab and or subbase rapidly leads to faulting and slab cracking. Figures 8 and 9 show the relative effect of different variables on pumping.

Slab thickness has a very significant effect on pumping. This is probably because of the close relationship between slab thickness and pavement deflections, which are part of the pumping mechanism. The effect of coarse-grained subgrade soils on reducing pumping reflects the ability of a granular foundation to drain free moisture from the pavement structure. The use of

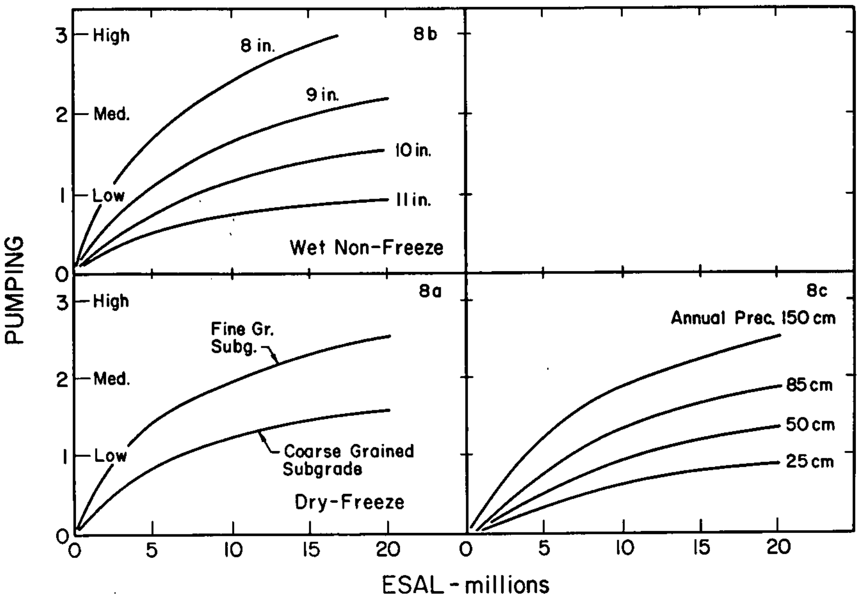

Figure 8. Sensitivity of the national JPCP pumping model to slab thickness, subgrade type, and annual average precipitation.

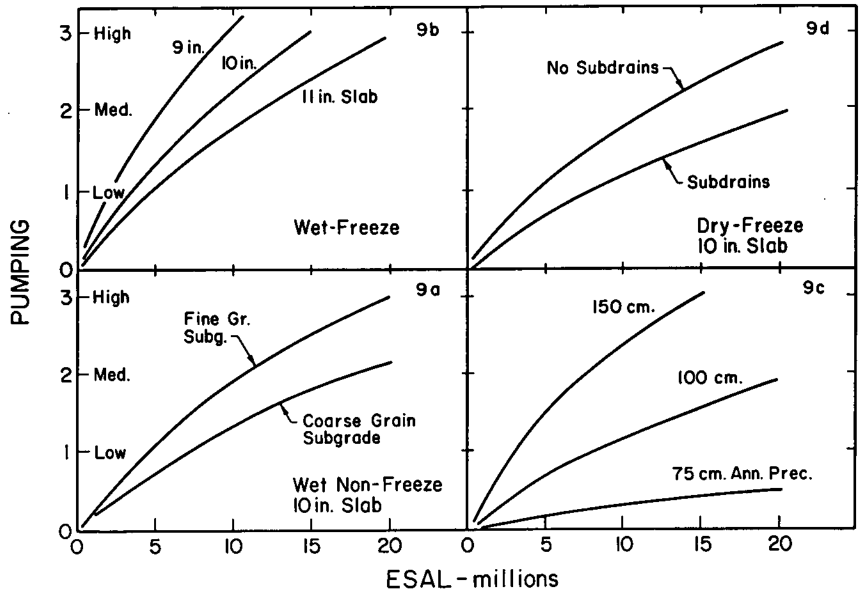

Figure 9. Sensitivity of the national JRCP pumping model to slab thickness, subgrade type, annual average precipitation, and subdrainage.

subdrains similarly reduces visible pumping. Increased precipitation generally results in increased pumping.

All of the variables determined to significantly affect pumping in both state and national models are given in Table 6. The effect (+ or − correlation) and the states in which the variable was significant are also included.

Table 6. Variables significantly affecting the occurrence of pumping.

		Regression Models	
Variables	Effect*	States	National**
Traffic			
ESAL	+	IL,MN,LA,GA,UT,CA	YES
Design/Foundation			
Slab Thickness	-	MN,GA,CA	YES
Subdrainage	-	IL,LA,GA	YES (JRCP)
Granular Subgrade	-	LA,CA	YES
Climate			
Age*Thorn.Moist. Index	+	GA	---
Age*Annual Prec.	+	CA	---
Freezing Index	+	--	YES
Annual Precipitation	+	IL	YES

* + indicates positive correlation between pumping and the variable.
\- indicates negative correlation.

** YES indicates that the variable was included in both the JRCP and the JPCP models. YES (JRCP) indicates that variable included in only the JRCP model, etc.

Joint Faulting

The final national model for faulting of JPCP is as follows:

$$
\begin{aligned}
\text{FAULT} = {} & \text{ESAL}\,0.144\,[-0.2980 + 0.2671/\text{THICK}\,0.3184 \\
& - 0.0285\ \text{BASETYP} + 0.00406(\text{FI}+1)^{0.3598} \\
& - 0.0462\ \text{EDGESUP} + 0.2384(\text{PUMP}+1)^{0.0109} \\
& - 0.0340\ \text{DOW}^{2.0587}]
\end{aligned}
$$

where:

FAULT = mean transverse joint faulting, in.;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
THICK = slab thickness, in.;
BASETYP = 0, if granular base; 1, if stabilized base (asphalt, cement, etc.);
FI = freezing index;
EDGESUP = 0, if AC shoulder; 1, if tied PCC shoulder;
PUMP = 0, if no pumping; 1, if low severity; 2, if medium severity; 3, if high severity;
DOW = diameter of dowel bar, in.
= 0 if no dowel bars exist

Statistics: $R^2 = 0.79$
SEE = 0.02 in.
n = 259

The final national model for faulting of JRCP is as follows:

$$
\begin{aligned}
\text{FAULT} = {} & \text{ESAL}^{0.4731}\,[-3.8536 - 1.5355\ \text{SOILCRS} \\
& + 197.124(\text{THICK} * \text{DOW}^{2.0})^{-1.7842} \\
& + 0.00024\ \text{FI} + 0.09858\ \text{JSPACE} \\
& + 0.24115\ \text{PUMP}^{2.0}]
\end{aligned}
$$

where:

FAULT = mean transverse joint faulting, in.;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
SOILCRS = 0, if subgrade is fine-grained soil; 1, if subgrade is coarse-grained soil;
THICK = slab thickness, in.;
DOW = diameter of dowel bar, in.;
= 0 if no dowel bars exist;
Note: dowel bar spacing is 12 in.;
FI = freezing index;
JSPACE = transverse joint spacing, ft;
PUMP = 0, if no pumping; 1, if low severity; 2, if medium severity; 3, if high severity.

Statistics: $R^2 = 0.69$
SEE = 0.06 in.
n = 384

Plots of faulting versus ESAL illustrating the effects of several variables are shown in Figures 10 and 11. The results show several very important design implications. Dowel bar diameter probably has the greatest effect on faulting. This is because bearing stress increases rapidly with smaller dowel bars, resulting in a wearing away of the concrete surrounding the dowel and creating looseness. Figure 11 illustrates the effects of different combinations of granular and stabilized bases, with and without dowels, on JPCP faulting.

The effect of subgrade soil classification (i.e., AASHTO coarse grained vs. fine grained) on faulting reflects its effect on pumping, as previously shown. Faulting is a direct result of fines pumping beneath the slab. A coarse-grained subgrade results in more rapid removal of free moisture beneath the slab, and thus, less pumping and faulting.

One important result is the observed effect of joint spacing. A slab with 27-ft joint spacing typically exhibits much less faulting than a slab with 40-ft joint spacing, all other parameters being equal. This is because longer joint spacings result in wider seasonal joint openings, which in turn result in higher dowel bearing stresses. Thicker slabs were also observed to result in less joint faulting, which may be due to less bending or deflection and reduced pumping potential.

Another interesting finding is that the use of tied PCC shoulders was determined to reduce faulting by about one-half (only limited data were available, however). Tied shoulders reduce slab corner deflection, and thus pumping potential. They also reduce the infiltration of water into the pavement structure because they maintain a tighter seal.

A summary of all variables entering into the state and national faulting models is given in Table 7.

Joint Deterioration

The national model for JPCP joint deterioration is as follows:

$$
\begin{aligned}
\text{DETJT} = {} & \text{AGE}1.695\ (0.9754\ \text{DCRACK}) \\
& + \text{AGE}^{2.841}\ (0.01247\ \text{UNITUBE}) \\
& + \text{AGE}^{3.038}\ (0.001346\ \text{INCOMP})
\end{aligned}
$$

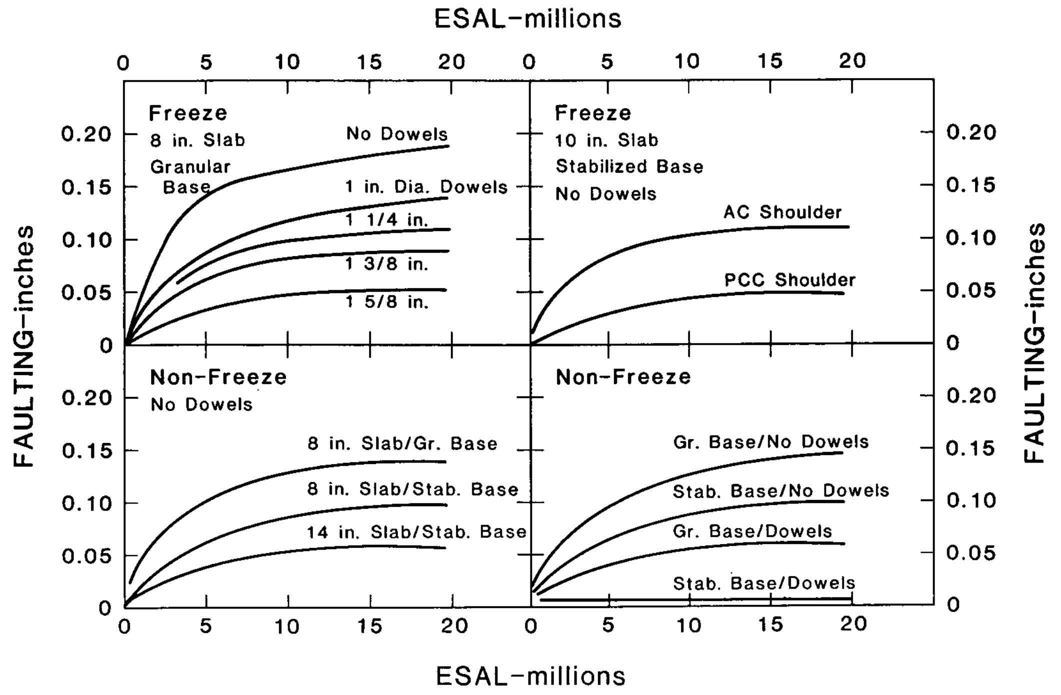

Figure 10. Sensitivity of the national JPCP faulting model to dowel size, shoulder type, slab thickness, and base type.

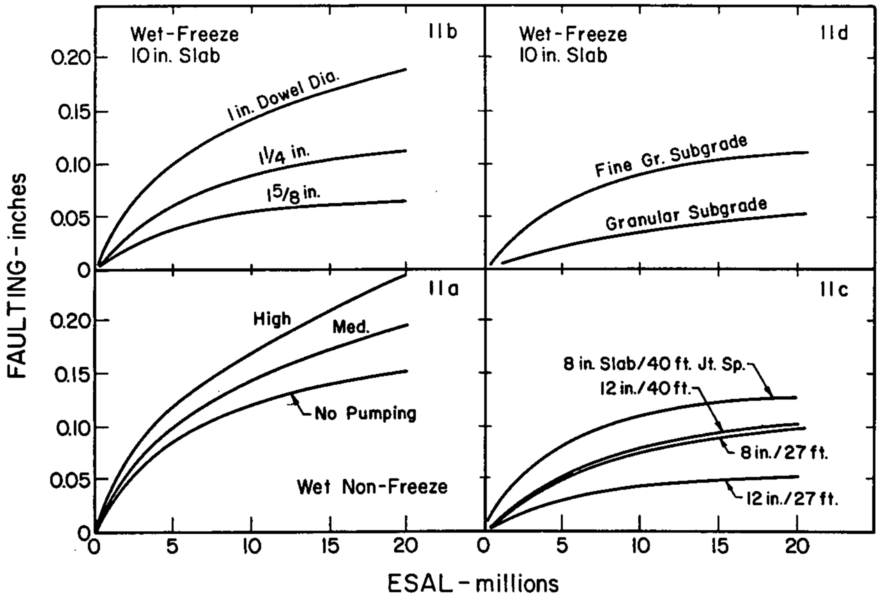

Figure 11. Sensitivity of the national JRCP faulting model to dowel size, slab thickness, joint spacing, subgrade type, and pumping.

where:

DETJT = number of deteriorated joints/mile (medium and high severity only);

AGE = time since construction, years (represents annual cycles of joint opening and closing);

UNITUBE = 0, if no Unitube joint inserts exist; 1, if Unitube joint inserts exist;

INCOMP = 0, if no incompressibles are visible in joint; 1, if incompressibles are visible in joint.

Table 7. Variables significantly affecting faulting.

Variables	Effect*	Regression Models States	 National**
Traffic			
ESAL	+	IL,MN,LA,GA,UT,CA	YES
Design/Foundation			
Slab Thickness	-	IL,MN,GA,CA	YES
Joint Spacing	+	IL	YES (JRCP)
Dowel Diameter	-	IL	YES (JPCP)
PCC Shoulder	-	UT	YES (JPCP)
Stabilized Base	-	GA	YES (JPCP)
K-value	-	GA,CA	---
Granular Subgrade	-	--	YES (JRCP)
Majority in Cut	+	GA	---
Majority in Fill	+	GA	---
Climate			
Freezing Index	+	--	YES
Maintenance			
Occurrence of Pumping	+	--	YES

* + indicates positive correlation between joint faulting and the given variable.
  - indicates negative correlation between joint faulting and the given variable.

** YES indicates that the given variable was included in both the JRCP and JPCP national models. YES (JPCP) and YES (JRCP) indicate that the given variable was included in the parenthesized national model only.

Statistics: $R^2 = 0.59$
SEE = 16 joints/mile
n = 252

The national model for JRCP joint deterioration is as follows:

$$\begin{aligned} \text{DETJT} = {} & \text{AGE}^{0.756} (2.4367\ \text{DCRACK} + 2.744\ \text{REACTAG}) \\ & + \text{AGE}^{2.1521}\ \text{ESAL}^{0.1419} (0.05202 + 0.0000254\ \text{FI} \\ & + 0.01109\ \text{TJSD} - 0.003384 * \text{K1} * \text{JTSPACE} \\ & - 0.0006446 * \text{K2} * \text{JTSPACE}) \end{aligned}$$

where:

JTSPACE = transverse joint spacing, ft;
DCRACK = 0, if no "D" cracking exists; 1, if "D" cracking exists
REACTAG = 0, if no reactive aggregate exists; 1, if reactive aggregate exists;
FI = freezing index;
TJSD = transverse joint seal damage;
= 0, none or low severity; 1, medium or high severity;
K1 = 1, if JTSPACE = 27 ft; 0, if JTSPACE is not equal to 27 ft;
K2 = 1, if JTSPACE 39 to 100 ft; 0, if JTSPACE is less than 39 ft;
Note: Do not use model out of these ranges.

Statistics: $R^2 = 0.61$
SEE = 15 joints/mile
n = 319

The relative effects of various design and climatic variables on joint deterioration are shown on Figures 12 and 13. The factors with the most devastating effect on joint deterioration are the presence of either "D" cracking or reactive aggregates.

The deterioration of short-jointed JPCP is generally very minor when no deterioration exists in the PCC (e.g., "D" cracking). However, it was shown that the use of potentially corrosive joint inserts (such as the Unitube) can produce disastrous results.

One of the most important findings is the observed effect of joint spacing on the number of deteriorated joints per mile of JRCP pavement. A spacing of 40 ft (currently recommended by many agencies) results in more severely deteriorated joints per mile than any other spacing. The data indicate that a joint spacing of approximately 27 ft may produce the best long-term joint performance in JRCP. More data are needed to verify this finding.

The effect of failing to provide and maintain good joint seals is quite significant. JRCP pavements with deteriorated joint seals typically exhibited about twice the amount of joint deterioration as pavements with good seals. Some of the state models showed an even more pronounced effect.

All of the variables determined to significantly affect joint deterioration in either the state or national models are summarized in Table 8.

Table 8. Variables significantly affecting joint deterioration.

Variables	Effect*	Regression Models States	 National**
Traffic			
ESAL	+	IL,MN,GA	---
Design/Foundation			
Unitube Joint Insert	+	GA	YES
Joint Spacing	+/-	MN	YES (JRCP)
Subdrains	-	IL	---
Materials			
"D" Cracking	+	IL,MN	YES
Reactive Aggregate	+	NEB	YES
Climate			
Age (open/close cycles)	+	IL,MN,LA,GA,UT,CA	YES
Annual Precipitation	+	IL	---
Freezing Index	+	IL	YES (JRCP)
Freeze-Thaw Cycles	+	IL	---
Max. Temp. Diff. (Jan-Jul)	+	IL	---
Maintenance			
Joint Seal Deterioration (or incompressibles in joint)	+	IL,MN,LA,GA,UT,CA	YES

* + indicates positive correlation between joint deterioration and the given variable.
  - indicates negative correlation between joint deterioration and the given variable.

** YES indicates that the variable was included in both the JRCP and the JPCP national models. A YES (JPCP) indicates that the variable is included in only the JPCP model, etc.

Slab Cracking

The national model for slab cracking of JPCP is as follows:

$$\begin{aligned} \text{CRACKS} = {} & \text{ESAL } 2.755\ [3092.4(1 - \text{SOILCRS})\ \text{RATIO } 10.0 \\ & + \text{ESAL}^{0.5} (1.233\ \text{TRANGE}^{2.0}\ \text{RATIO}^{2.868}) \\ & + \text{ESAL}^{2.416} (0.2296\ \text{FI}^{1.53}\ \text{RATIO}^{7.31}) \end{aligned}$$

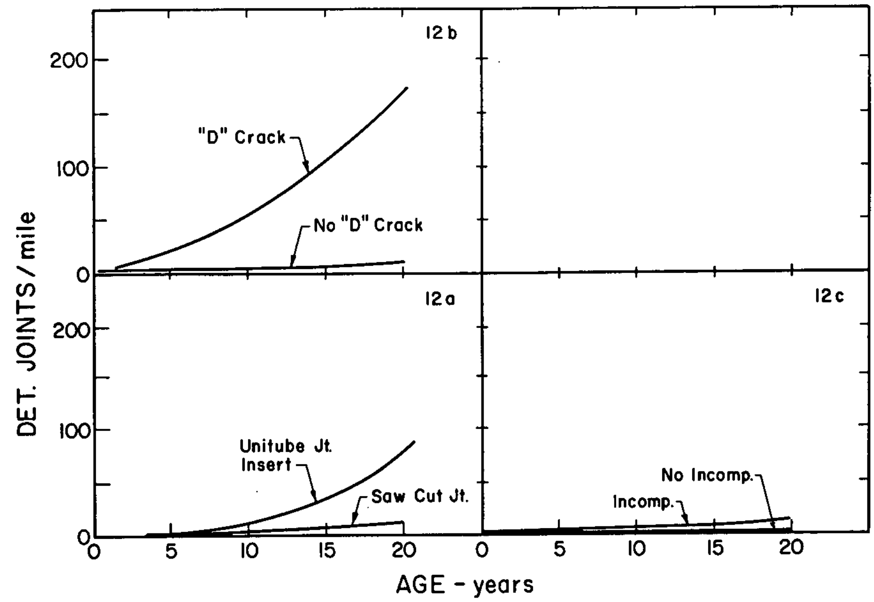

Figure 12. Sensitivity of the national JPCP joint deterioration model to "D" cracking aggregates, joint forming method, and infiltration of incompressibles.

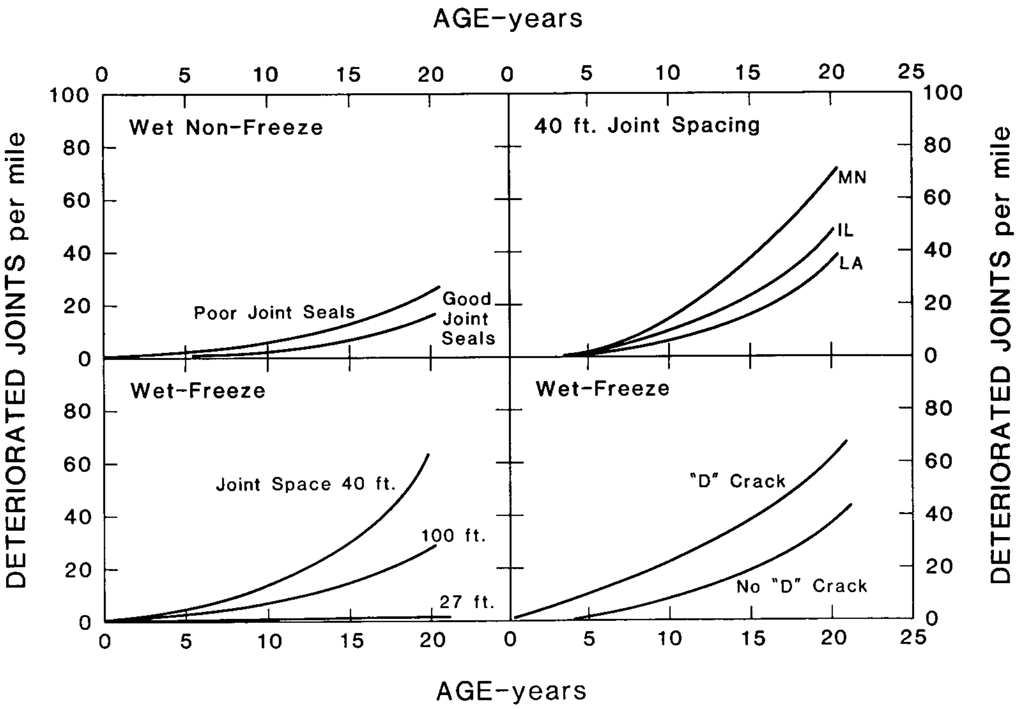

Figure 13. Sensitivity of the national JRCP joint deterioration model to joint seal quality, climate, "D" cracking, and joint spacing.

where:

CRACKS = total length of cracking of all severities, ft/lane mile;

ESAL = accumulated 18-kip equivalent single-axle loads, millions;

SOILCRS = 0, if subgrade is fine-grained; 1, if subgrade is coarse-grained;

RATIO = Westergaard's edge stress/modulus of rupture (stress computed under a 9-kip wheel load);

FI = freezing index;

TRANGE = difference between average maximum temperature in July and average minimum temperature in January;

Statistics: $R^2 = 0.69$

SEE = 176 ft/mile

n = 303

The national model of JRCP crack deterioration is as follows:

$$\text{CRACKS} = \text{ESAL } 0.897\ [7130.0\ \text{JTSPACE}/(\text{ASTEEL} * \text{THICK } 5.0)]$$
$$+ \text{ESAL}^{0.10}\ (2.281\ \text{PUMP}^{5.0})$$
$$+ \text{ESAL}^{2.16}\ [1.81/(\text{BASETYP} + 1)]$$
$$+ \text{AGE}^{1.3}\ [0.0036\ (\text{FI} + 1)^{0.36}]$$

where:

CRACKS = total length of medium- and high-severity deteriorated temperature and shrinkage cracks, ft/mile;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
JTSPACE = transverse joint spacing, ft;
ASTEEL = area of reinforcing steel, in^2/ft width;
THICK = slab thickness, in.;
PUMP = 0, if no pumping exists; 1, low severity; 2, medium severity; 3, high severity;
BASETYP = 0, if granular base; 1, if stabilized base (cement, asphalt, etc.);
AGE = time since construction, years (indicator of cycles of cold and warm temperatures stressing reinforcing steel);
FI = freezing index.

Statistics: $R^2 = 0.41$
SEE = 280 ft/mile
n = 314

The relatively low value of R^2 indicates that this model does not explain much of the variability in data. It must be noted that the cracking predicted by each model is different in that the JPCP model includes all cracking of the slab (low, medium, and high severity). The cracking in the JRCP model includes only the deteriorated cracks that occur when the reinforcement cannot hold a temperature/shrinkage crack tightly (medium and high severity).

The sensitivity of some of the factors in the cracking models is shown on Figures 14 and 15. Slab thickness is the most significant design variable affecting slab cracking. This is because slab thickness has the most significant effect on stress, which was modeled using Westergaard's edge stress. For JPCP, a typical 8-in. slab will deteriorate rapidly after only 5 million ESAL, while an 11-in. slab will not crack significantly until well beyond 20 million ESAL, which is very heavy traffic. The same is not true for typical long-jointed JRCP (e.g., 40 ft), where existing cracks in an 11-in. slab will break down under such heavy traffic. This probably occurs because JRCP of any thickness develops transverse cracks from shrinkage and curling early in its life. The corrosion of dowels causing locked joints forces some of the cracks open, and the heavy traffic loadings then deteriorate the cracks into working cracks where the reinforcement has ruptured. Thus, the impact of increased slab thickness on JRCP may not be as great as on JPCP.

The effects of reductions in PCC modulus of rupture are very severe, particularly after critical levels of stress/modulus of rupture are reached. For many pavements, this occurs when the PCC modulus of rupture falls below 600 psi. This reflects fatigue damage that occurs once a critical level of stress/strength is reached.

Coarse-grained subgrade soils permit better bottom drainage

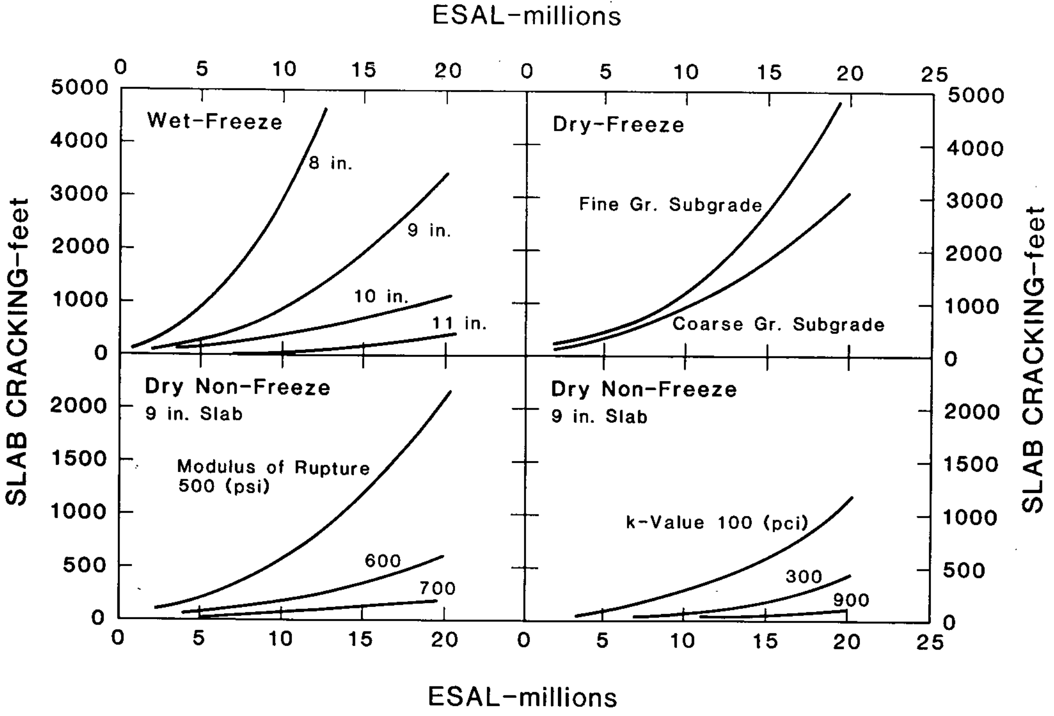

Figure 14. Sensitivity of the national JPCP slab cracking model to slab thickness, subgrade type and support, and modulus of rupture.

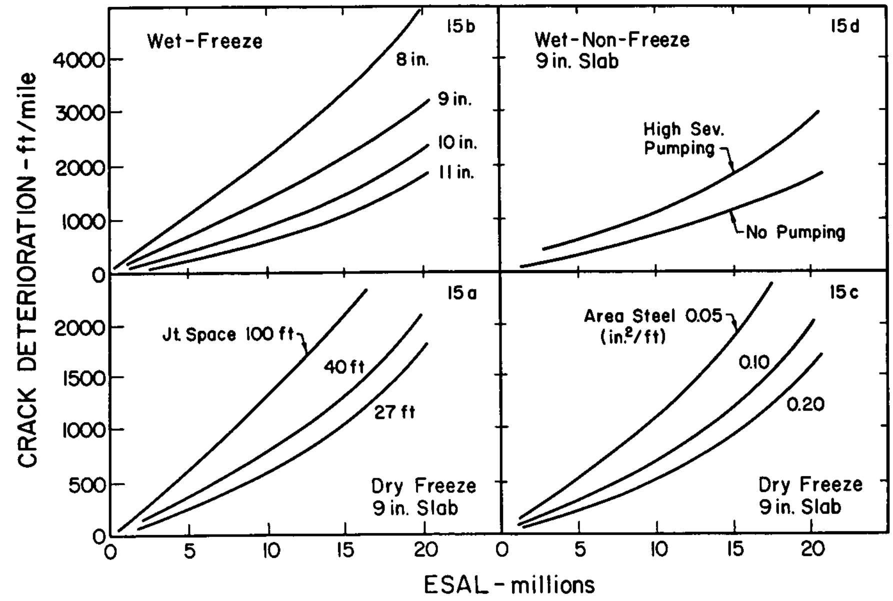

Figure 15. Sensitivity of the national JRCP crack deterioration model to slab thickness and reinforcement, joint spacing, and pumping.

than fine-grained soils and thus result in less pumping, less loss of support, and subsequently less cracking.

The model also indicates that as JRCP joint spacing increases, the amount of crack deterioration increases as well. Also, as the amount of reinforcement decreases, the amount of deteriorated cracking increases, as one would expect (see Fig. 4 for a similar plot).

A summary of all variables entering into the state and national models is given in Table 9.

Present Serviceability Rating

The national model for present serviceability rating (PSR) for JPCP is as follows:

$$PSR = 4.5 - 1.486\ ESAL\ 0.1467$$
$$+ 0.4963\ ESAL^{0.265}\ RATIO^{-0.5}$$
$$- 0.01082\ ESAL^{0.644}\ (SUMPREC^{0.91} / AVGMT^{1.07}) * AGE^{0.525}$$

where:

PSR = present serviceability rating;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
RATIO = Westergaard's edge stress/modulus of rupture;
SUMPREC = average annual precipitation, cm;
AVGMT = average monthly temperature, degrees C;
AGE = time since construction, years.

Statistics: $R^2 = 0.69$
SEE = 0.25
n = 316

Table 9. Variables significantly affecting slab cracking.

Variables	Effect*	Regression Models States	National**
Traffic			
ESAL	+	IL,MN,LA,GA,UT,CA	YES
Design/Foundation			
Slab Thickness	-	IL,CA	YES
Area of Steel/Ft Width	-	IL,	YES (JRCP)
Joint Spacing	+	IL	YES (JRCP)
Stabilized Subbase	-	IL	YES (JRCP)
K-value Of Foundation	-	CA	---
Granular Subgrade	-	UT,CA	YES (JPCP)
Majority in Cut	+	GA	---
Majority in Fill	+	LA,UT	---
Materials			
PCC Modulus of Rupture	-	CA	YES (JPCP)
Climate			
Age*Annual Precipitation	+	IL,MN	---
Age*Freezing Index	+	--	YES (JRCP)
Freezing Index	+	--	YES (JPCP)
Age*Temp. Diff.(Jul.-Jan.)	+	GA	---
Temp. Range(Highest Jul. - Lowest Jan.)	+	--	YES (JPCP)

* + indicates positive correlation between cracking and the given variable.
 - indicates negative correlation.

** YES indicates that the given variable was included in both the JRCP and JPCP national models. YES (JPCP) indicates that the given variable was included in only the JPCP model, etc.

The national model for present serviceability rating for JRCP is as follows:

$$PSR = 4.5 - ESAL\ 0.424\ (-1.88\ E-3 + 14.417\ RATIO\ 3.58$$
$$+ 0.0399\ PUMP + 0.0021528\ JTSPACE + 0.1146$$
$$DCRACK + 0.05903\ REACT$$
$$+ 4.156\ E-5\ FI + 0.00163\ SUMPREC$$
$$- 0.070535\ BASETYP)$$

where:

PSR = present serviceability rating;
ESAL = accumulated 18-kip equivalent single-axle loads, millions;
RATIO = Westergaard's edge stress/modulus of rupture;
PUMP = 0, is none or low pumping; 1, if medium or high pumping;
JTSPACE = transverse joint spacing, ft;
DRACK = 0, if no "D" cracking exists; 1, if "D" cracking exists;
REACTAG = 0, if no reactive aggregate exists; 1, if reactive aggregate exists;
FI = freezing index;
SUMPREC = average annual precipitation, cm;
BASETYP = 0, if granular base; 1, if stabilized base (asphalt, cement, etc.).

Statistics: $R^2 = 0.78$
$SEE = 0.30$
$n = 377$

The PSR is actually a measurement of the effects of a combination of several different distress types and other factors on pavement roughness. Even though the PSR was estimated by only a small rating panel, it was possible to develop some interesting regression models that quantify the effects of several variables on pavement serviceability. The results from the PSR models should be expected to follow those of the other distresses. Some of the national model results are as follows:

1. The models indicate that slab thickness has a significant effect on the rate of loss of pavement serviceability. The JRCP model shows a greater loss of PSR for the same range of thickness than JPCP.
2. "D" cracking causes severe and rapid loss of pavement serviceability.
3. Pumping causes significant loss of pavement serviceability over time.

Figure 16 shows the predicted PSR curves for different JPCP designs. Included in Figure 16c are four identical designs of JPCP (e.g., same slab thickness, joints, base, concrete strength) located in four states. Figure 16 indicates that a JPCP located in California will last much longer than the same pavement in Illinois. This difference in performance is attributed primarily to the difference in thermal and moisture conditions. Similarly, a pavement located in Georgia will not last as long as the same pavement in California, probably because of the greatly increased moisture conditions in Georgia. This illustrates the danger of using the same design in different climatic areas.

Figure 17 shows similar results for different JRCP designs. Figure 17c shows typically designed JRCP pavements located

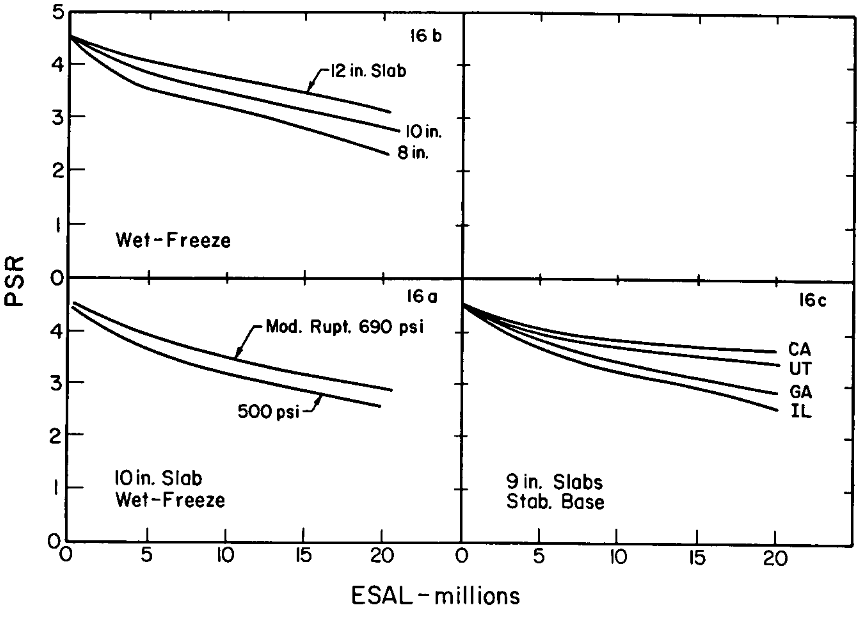

Figure 16. Sensitivity of the national JPCP serviceability model to slab thickness, modulus of rupture, and climate.

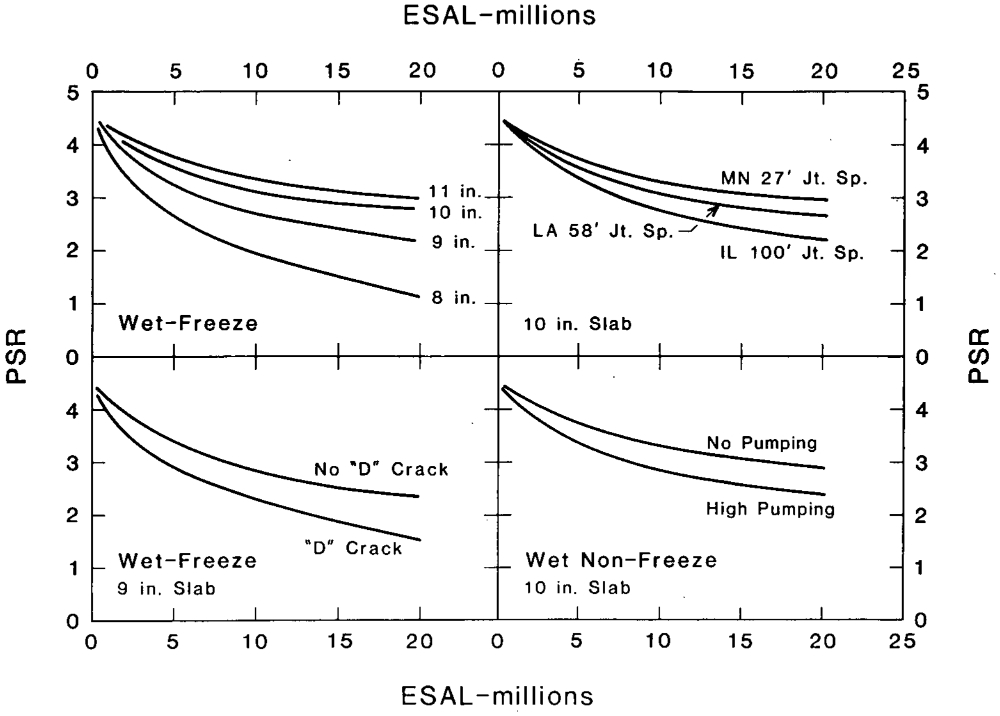

Figure 17. Sensitivity of the national JRCP serviceability model to slab thickness, joint spacing, "D" cracking, and pumping.

in three states. The models indicate that Minnesota's 27-ft JRCP will last much longer than Illinois' 100-ft JRCP and will carry more traffic than the 58-ft JRCP in Louisiana. The Minnesota 27-ft pavement will carry much more traffic than the pavement with 40-ft joint spacing.

A summary of all variables entering into the state and national PSR models is given in Table 10.

APPLICATION OF RESULTS

COPES has been field tested in six states and can now be used to collect, process, store, retrieve, and evaluate data from in-service concrete highway pavements. This section demonstrates some of the potential applications of results obtained from the state and national evaluations for improving concrete pavement design, construction, materials selection, and maintenance. The results shown should be considered only as tentative, for illustration purposes only.

Comparison of JRCP vs. JPCP

A comparison of the predicted performance of JRCP vs. JPCP was conducted using the national models presented earlier in this chapter and typical data from a wet-freeze Midwest climate. The design inputs are summarized in Table 11. All input factors entered into each model were the same except for joint spacing. The JPCP slabs were assumed to be 15 ft long, and the JRCP slabs were assumed to be 40 ft long.

The expected performance of these pavements over a 30-year time period can be observed in Table 12 where cracking, joint deterioration, faulting, pumping, and PSR are predicted.

Table 10. Variables significantly affecting loss of pavement serviceability (PSR).

		Regression Models	
Variables	Effect*	States	National**
Traffic			
ESAL	+	IL,MN,LA,GA,UT,CA	YES
Design/Foundation			
Slab Thickness	-	IL,MN,LA,GA,UT,CA	YES
Area of Steel/Ft. Width	-	IL	---
Joint Spacing	+	IL,MN,CA	---
Skewness of Joints	-	CA	---
K-value of Subgrade	-	LA,GA,UT,CA	YES
Stabilized Base	-	IL	YES (JRCP)
Majority in Cut	+	LA	---
Materials			
"D" Cracking Aggregates	+	IL,MN	YES (JRCP)
Reactive Aggregates	+	NEB	YES (JRCP)
PCC Modulus of Rupture	-	LA,GA,UT,CA	YES
Climate			
Age (annual cycles of joint movement)	+	IL	---
Freezing Index	+	--	YES (JRCP)
Annual Precipitation	+	--	YES (JRCP)

* + indicates positive correlation between PSR loss and the given variable.
 - indicates negative correlation between PSR loss and the given variable.

** YES indicates that the given variable was included in both the JRCP and the JPCP national models. A YES (JPCP) indicates that the variable included in only the JPCP model, etc.

Some interesting differences can be seen in comparing the two pavement types that are performing under the same conditions. The predicted serviceability and pumping of these two

Table 11. Variable inputs used in the JRCP and JPCP national model demonstration evaluations.

DESIGN FACTORS	INPUTS (Typical Illinois Values)
Cumulative Traffic (ESAL)	0.5 MILLION/YEAR
AGE	0 to 30 years
Slab Thickness (THICK)	9 inches
PCC Modulus (MR)	650 psi
Dowel Diameter (DOWEL)	1.2555 inches
Joint Spacing (JSPACE)	JRCP = 40 ft., JPCP = 15 ft.
Unitube Inserts (UNITUBE)	No (0)
Area of Reinf. Steel (ASTEEL)	0.10 in^2/ft width
Base Type (BASETYP)	Granular (0)
Edge Support (EDGESUP)	No (AC Shoulders)
INCOMPR-TJSD*	Yes (1)
Subgrade Type (SOILCRS)	Fine-grained (1)
Subdrainage (DRAIN)	No (0)
Slab Support Top Base(KVALUE)	200 psi/inch
"D" Cracking (DCRACK)	No (0)
Reactive Aggregate (REACTAG)	No (0)
TRANGE (C^o)**	40
Avg. Mean Temp (AVGMT) (^oC)	10
COE Freezing Index (FI)	625
Avg. Ann. Pptn. (SUMPREC)	85 cm

* Either incompressibles visible in joint or joint seal has medium- to high-severity deterioration.

** Difference between average maximum temperature in July and average minimum temperature in January.

types of pavements are approximately the same. However, the JRCP exhibits a greater amount of cracking throughout most of the 30 years. The JRCP also has significantly more joint deterioration, resulting in a need for joint repairs after about 15 to 20 years. Faulting is also greater for the JRCP, except that the impact is less due to the greater joint spacing. Thus, this specific JRCP design (which is a common design) does not perform as well as the JPCP.

However, by modifying the design of the JRCP, a considerable difference in performance can be expected. Table 13 shows the predicted performance after changing the joint spacing from 40 to 27 ft for the JRCP. Joint deterioration will apparently be minor for the 27-ft JRCP. Faulting and cracking are also reduced. One might conclude from these results that 27-ft JRCP would perform significantly better than the 40-ft JRCP and about the same as the 15-ft JPCP.

The national models suggest that it should be possible to improve the predicted performance of the JRCP by changing certain design factors. Some previous findings are listed as follows:

1. Subdrainage significantly reduces pumping.
2. Increasing the thickness of the 27-ft JRCP pavement from 9 to 10 in. increases the expected life of the pavement.
3. Increasing the thickness of the pavement decreases the amount of cracking, as well as the amount of pumping (reduced pumping because of reduced deflections).
4. A dowel diameter of 1.25 in. is recommended to reduce faulting. (Thicker dowels have no impact on faulting, whereas decreasing the dowel diameter to 1.00 in. increases the predicted faulting greatly.) However, it is very important to note that other design situations may show that a larger diameter dowel bar may be well worth the increase in cost.
5. Stabilizing the base decreases cracking somewhat, but has little effect on the serviceability.
6. Increasing the amount of reinforcement reduces the number of deteriorated cracks in JRCP.

Table 12. Comparison of the performance of 40-ft JRCP and 15-ft JPCP using the national models (see Table 11 for design inputs).

		PSR		CRACKING		JT. DETER		FAULTING		PUMPING	
AGE	ESAL	JRCP	JPCP	JRCP	JPCP	JRCP	JPCP	JRCP	JPCP	JRCP	JPCP
0	0	4.5	4.5	0	0	0	0	0	0	0	0
5	2.5	3.7	3.7	127	140	2	0	.04	.07	1.1	1.5
10	5	3.3	3.5	303	248	9	1	.06	.08	1.7	2.0
15	7.5	3.1	3.2	593	400	24	5	.08	.08	2.2	2.4
20	10	2.8	2.9	1068	615	47	12	.11	.08	2.7	2.8
25	12.5	2.7	2.6	1550	840	77	24	.14	.09	3.0	3.0
30	15	2.5	2.3	1906	1279	118	41	.15	.09	3.0	3.0

Units:
Cracking: linear feet/lane mile
Jt. Deterioration: number of deteriorated joints/mile
Faulting: average, in inches
Pumping: 1 = low, 2 = medium, 3 = high

Table 13. Predicted performance of 27-ft JRCP using the national model (see Table 11 for design inputs).

AGE	ESAL	PSR	CRACK	DET JT	FAULT	PUMP
0	0	4.5	0	0	0	0
5	2.5	3.7	91	0	0.02	1.1
10	5	3.4	236	0	0.03	1.7
15	7.5	3.1	497	0	0.05	2.2
20	10	2.9	944	0	0.07	2.7
25	12.5	2.8	1404	0	0.09	3.0
30	15	2.6	1728	0	0.10	3.0

Note: Slab Thickness = 9 inches.

Units:
Cracking: linear feet/lane mile
Jt. Deterioration: Number of deteriorated joints/mile
Faulting: average, in inches
Pumping: 1 = low, 2 = medium, 3 = high

The JRCP design was changed to include a stabilized base, 10-in. slab thickness, increased reinforcement, and installation of subdrains to illustrate the impact these changes might have on the predicted performance of 27-ft JRCP. Table 14 shows the predicted performance of a 27-ft JRCP pavement with improved design for a wet-freeze climate, which can be compared to Table 13. This improved performance indicates that such a pavement design would perform satisfactorily over a 30-year life with 15 million ESAL under these climatic conditions.

Improved Design for JPCP

The overall results of the COPES demonstration can be used to show how improved pavement designs can be developed. The following design factors were found to increase the life of a JPCP:

- Stabilized base
- PCC shoulder
- Increased k-value
- Increased modulus of rupture
- Large diameter dowels (≥ 1.25 in.)
- Thicker slab
- Increased PCC strength
- Sawed, sealed trans. joints
- High quality joint seals
- Use of sound, non-"D" cracking aggregates

Regression models can be used to estimate the required slab thickness for a given design and climate. A wet-nonfreeze climate, 40-year design life, and heavy traffic conditions will be used for this example. The following inputs are required to estimate joint deterioration, cracking, pumping, faulting, and PSR.

Design Factor	Example Input
ESAL (millions)	20
AGE (years)	40
SOILCRS	fine-grained
Base Type	stabilized
Edge Support	PCC shoulders
Dowel Diameter (in.)	1.25
PCC Modulus of Rupture (psi)	600
k-value (psi/in.)	300
Incompessibles in transverse joints	no
Unitube joint inserts used	no
"D" Cracking observed	no
SUMPREC (cm annual precipitation)	120
Freezing Index	0
Jan.–July temperature range (°C)	30
Mean Annual Temperature (°C)	17

Note that subdrainage should also be provided. It is not included in these inputs because it is not included in the models (because there were no JPCP sections with subdrainage in the database).

The following distress predictions were obtained for different slab thicknesses:

Slab Thickness (in.)	PSR	Cracking (ft/lane mile)	Det. Joints (no./mile)	Faulting (in.-avg.)	Pumping (avg. level)
9	2.2	447	0	0	2.2
10	2.3	172	0	0	1.4
11	2.5	91	0	0	0.9
12	2.8	55	0	0	0.5
13	3.0	36	0	0	0.1

Given the design inputs, a 13-in. slab is required to produce a pavement with a minimum PSR of 3.0. If a minimum PSR of 2.5 is acceptable, an 11-in. slab will be adequate for 20 million 18-kip ESAL applied over a 40-year design period.

Other design inputs could be selected and the distress predictions obtained would aid in the selection of an appropriate slab thickenss.

Table 14. Summary of predicted performance of 27-ft improved design JRCP (see Table 11 for design inputs and modification shown in Table 14).

AGE	ESAL	PSR	CRACK	DET JT	FAULT	PUMP
0	0	4.5	0	0	0	0
5	2.5	4.1	36	0	0.01	0.5
10	5	3.9	85	0	0.01	0.8
15	7.5	3.8	153	0	0.02	1.0
20	10	3.7	243	0	0.02	1.3
25	12.5	3.6	333	0	0.03	1.4
30	15	3.5	500	0	0.04	1.7

Note: Slab Thickness = 10 inches
Stabilized base course
Subdrainage pipes along slab edge
Increased reinforcement = 0.15 in^2/foot width
Joint spacing = 27 feet

Units: Cracking: linear feet/lane mile
Jt. Deterioration: number of deteriorated joints/mile
Faulting: average, in inches
Pumping: 1 = low, 2 = medium, 3 = high

Choosing Rehabilitation Alternatives Using COPES

The detailed data from COPES and the prediction models can be used to help select general rehabilitation strategies for individual projects. For example, the projects can be sorted into groups exhibiting significant pumping, joint deterioration, low PSR, faulting, and slab cracking. They could then be further sorted into groups based on other factors (e.g., other distress, design) and general rehabilitation strategies could be assigned. An example of the assignment of rehabilitation strategies to various pavement groupings is as follows:

1. *Pumping with other minor distresses.*
   Recommendations: Subseal, subdrainage, seal joints, restore joint load transfer, tied PCC shoulder.
2. *Pumping and faulting with other minor distresses.*
   Recommendations: Same as (1), plus grinding.
3. *Joint deterioration with minor slab cracking.*
   Recommendations: Full-depth patching of cracks (create working joints at patches).
4. *Transverse slab crack deterioration (JRCP) with other minor distresses.*
   Recommendations: Full-depth patching.
5. *Major joint and crack deterioration and "D" cracking.*
   Recommendations: Major rehabilitation with patching and overlay, or reconstruction of lane.

The models could also be used to predict future deterioration for individual pavements as illustrated in Figure 6. Then, the cost to rehabilitate the pavement after 5, 10, or 15 years into the future could be estimated. These results can help the design engineer decide when is the best time to rehabilitate the pavement.

Developing Design Models

The various state and national models developed in this project show that it is possible to reasonably model major distress types in concrete pavements. These models represent far greater ranges in design, climate, traffic, and soils variables than any existing empirical or mechanistic design models. However, it is believed that models used for design should include more mechanistic variables than were used in the models developed in this study. For example, concrete stresses, deflections, annual joint movements, dowel bearing stresses, and Miner's fatigue damage can be computed and used as independent variables in developing mechanistic-empirical models (along with other variables) to predict more accurately cracking, faulting, joint deterioration, pumping, and PSR loss. These improved models could then be tested and considered for design applications.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDED RESEARCH

CONCLUSIONS

The primary conclusion from this research study is that valuable information can be obtained through the evaluation of in-service concrete pavements to improve design, construction, material quality, and maintenance procedures. The information is also very useful in pavement management for determining the condition of an overall pavement network and its existing and future rehabilitation needs. This conclusion is true for data from a given state and from combining data from several states located in diverse climates.

The collection, processing, and analysis of large amounts of data from in-service pavements require an efficient and comprehensive system. The *CO*ncrete *P*avement *E*valuation *S*ystem (or COPES) developed in this study was field demonstrated in six states and on a "national" basis (by combining all of the data). COPES is designed for use at the state level, as well as the national or regional levels, to periodically *collect, store and retrieve (or process),* and *evaluate* in-service concrete pavement data. Both inventory (e.g., design, construction, traffic, climate, etc.) and monitoring condition data are collected using specified procedures on data collection sheets prepared for immediate computerized data processing. COPES can handle the three conventional concrete pavement types: jointed plain, jointed reinforced, and continuously reinforced.

The data are entered into an efficient computerized database management system. Data retrieval and analysis are easily accomplished using a computer terminal and statistical analysis packages.

It is very important to realize that not all of the data items included in COPES need be collected by an agency. Each agency must first determine what functions COPES is to serve, and then select the data items and pavement sections required to meet these needs.

Many analyses and evaluations can be made using the COPES data bank on a state or national level, including the following:

1. *Network facility data summary*—A complete summary of information important to pavement management and research can be obtained from the data bank for all sections in a state, district, route, and so on.
2. *Network condition data summary*—A complete summary of pavement condition (distress, roughness, PSR or PSI, skid) can be obtained from the data bank for all sections in a state, district, route, etc.
3. *Future pavement condition prediction*—Regression models can be developed using the data collected to predict slab cracking, pumping, joint deterioration, joint faulting, and PSR. These models can be used for predicting remaining life of a given project by (1) collection of all data needed to input to the models and the existing distress and PSR, (2) calibrating the models to the existing conditions, and (3) project distress and PSR into the future for an assumed traffic loading. Thus, a knowledge of the future development of distress for the project could be used to help program when pavement rehabilitation should be performed. The individual distress types can also help to determine the general causes of pavement deterioration.
4. *Design evaluation*—The COPES data provide an excellent source of information to continually monitor the performance of past designs. The adequacy of the design procedures can be evaluated by comparing field performance with predicted performance. The regression models provide a useful source of information on the effects of many different design, traffic, subgrade, and climatic effects.
5. *Construction and materials evaluation*—The detailed data in COPES provide information to determine if construction procedures or materials used are contributing to pavement deterioration.
6. *Maintenance evaluation*—Several aspects of pavement maintenance and rehabilitation can be evaluated, including full depth patching, joint sealing, subdrainage, among others. For example, the impact of joint sealing on joint deterioration was shown to reduce joint deterioration by a factor of 2 to 3 times.
7. *Causes of pavement deterioration*—The distress prediction models provide an excellent source of information for identifying the general causes of pavement deterioration and determining what design, construction, or materials selection procedures can be changed to reduce deterioration.
8. *Development of recommended design, construction, and maintenance improvements*—The demonstrations in six states and the national demonstration showed that it is possible to develop many recommendations to improve pavement design,

construction, and maintenance practices. A number of such tentative recommendations are provided in Chapters 2 and 3.

9. *Determination of rehabilitation needs and selection of strategies for projects*—The distress, roughness, skid, and PSR/PSI information contained in COPES can be used by the engineer to select rational rehabilitation alternatives that repair existing deterioration and prevent future deterioration.

10. *Research needs and special studies*—Information in the COPES data bank can be used to determine the most important needs for further research by indicating which major types of deterioration occur for specific designs. A host of special studies can be conducted using the detailed data bank. An example of development of a truck lane distribution prediction model was provided in Chapter 2, Figure 1.

RECOMMENDED RESEARCH

The following recommendations are made based on the results of this project:

1. COPES should be extended to include all types of pavements. It is believed that similar concepts can be applied to asphalt pavements and that significant results can be obtained. Such an effort has been completed at the University of Illinois for the Illinois DOT. A similar effort has also been accomplished for the FHWA Long Term Monitoring Program (*15*). The results obtained from COPES will be valuable to the planning and design of the Long Term Pavement (Performance) Monitoring Program of SHRP.

2. Many of the findings from the individual state and national evaluations should be studied further to determine if they should be recommended as design improvements. The effect of joint spacing is a prime example of a topic that requires further research. The data collected in this study indicated that current JRCP joint spacing recommendations of approximately 40 ft result in a much higher rate of joint deterioration per mile than a shorter 27-ft joint spacing.

3. Automated reports can be developed for COPES that can provide preformatted information more rapidly. Minnesota has developed an automated report for project level data summaries (see Appendix G). The addition of automated reports will make COPES much more "user-friendly".

4. The models developed for state and national demonstrations represent a "first cut" at pavement distress prediction. Further work could produce much improved mechanistic-empirical models that would be more reliable for use in design/analyses.

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APPENDIXES A THROUGH F

Appendixes A through F describe the demonstration of COPES in each of the participating states (Illinois, Minnesota, Louisiana, Georgia, Utah, and California). Each appendix provides an Introduction, Facility Data Summary, Pavement Condition Summary, Future Pavement Condition, References, and varying other sections to demonstrate the potential uses of collecting and evaluating data to influence the design, construction, maintenance, and rehabilitation of jointed concrete pavements with and without reinforcement.

Appendixes A through F are not published herewith but are contained under separate binding titled, "Volume I, Concrete Pavement Evaluation System (COPES), Research Report," as submitted by the research agency to sponsors. That report is available on a loan basis or for purchase at a cost of $10.00 on request to the NCHRP, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

APPENDIX G

CONCRETE PAVEMENT EVALUATION SYSTEM—COPES USER'S MANUAL

CONTENTS

CHAPTER ONE

COPES Data Collection Procedures

INTRODUCTION

The overall objective of the *CO*ncrete *P*avement *E*valuation *S*ystem (COPES) is to provide a *system* to periodically collect and evaluate data from in-service concrete pavements. These data can be used for a wide variety of pavement management purposes, including: improvement of design, construction (including materials) and maintenance procedures; provision of a data base for planning rehabilitation needs and assisting in their design; provision of data collection procedures for the long-term monitoring of pavement performance; and generation of reports useful for administration and many other purposes. COPES is developed to meet these objectives at the state level and eventually at the national level after collection of data from a number of states.

COPES consists of procedures for (1) data collection, (2) data storage and retrieval, and (3) data evaluation. This chapter describes the *data collection procedures.* Three conventional pavement types are included: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP).

The overall data are divided into seven general categories or *records:* Design, Roughness, Axle Load, Traffic Volume, Maintenance, Uniform Section Field Data, and Sample Unit Field Data. A description of each required data item, including instructions on how to conduct the field data survey, is provided in this chapter. (Chapter Two, the distress identification guide, supplements the field data collection procedures.) Data are recorded on the COPES data sheets in this chapter (blank data sheets are provided in Appendix A of this manual), which are prepared for direct keypunching into a computer data file either by filling in the appropriate space(s) or by circling the appropriate code number. Completed samples of the data sheets are included in Exhibits 1 through 15 of this chapter. The code identification used for many of the variables is provided in Appendix B.

It is emphasized that an agency does not need to collect all of the data included in the data bank. The variables included are intended to cover a wide variety of needs nationwide. An individual agency should review the data items carefully and collect only those that are of importance for their pavements and objectives in pavement management. During the demonstration of COPES, certain variables were found to be essential to perform a number of valuable analyses. These variables are denoted by a star (*), and every effort should be made to obtain at least this minimal amount of data for each pavement section included in COPES.

DESIGN DATA COLLECTION PROCEDURES

More than 150 variables are entered on the design data sheets. These variables are defined in the following paragraphs, and instructions for the calculation of some variables are included where appropriate. Most of these variables can be obtained from Department of Transportation standards, original plans, specification manuals, field data collection sheets, and other available plans and reports. The design data constitute Record Number 1.

Project and Uniform Section Idntification (Sheet 1—see Exhibit 1)

*******Record Number:* This uniquely identifies the data record in the COPES data bank. Equal to 1, it identifies the design data record.

**State Code:* A two-digit code number is used to identify the state in which the pavement section is located (see the appropriate code sheet in Appendix B).

**Project ID:* A four-digit identification number is assigned to each project by the agency. This number is used solely to facilitate computer filing of the projects, and can be cross-referenced with the construction project section number.

**Uniform Section:* Each construction project is divided into uniform sections, which are defined in detail in the Field Data Collection Procedures section of this chapter. The uniform sections are numbered as shown in Figure 1. Note that it may be helpful to complete the collection of as much of the design data as possible *before* sending a survey crew into the field, because nonuniform conditions (such as different subgrade types) may dictate that the project be divided into two or more uniform sections.

D1. *State Highway Department (SHD) district number:* A two-digit number is used to identify the SHD district where the pavement section is located.

D2. *County:* A five-digit code number is used to identify the state (first 2 digits) and the county (last 3 digits) where the pavement section is located (see the appropriate code sheet in Appendix B for an Illinois example).

* **D3.** *Type of highway:* This is the Federal-Aid Highway Classification. The number corresponding to the appropriate type of highway is circled on Sheet 1.

* **D4.** *Highway letter designation:* This is the letter designation that precedes the number of the highway where the SHD project is located. The appropriate letter designation is circled on Sheet 1 (e.g., circle number 1 for Interstate Highway I-15).

* **D5.** *Highway number:* This is the route number assigned to the highway where the SHD project is located (e.g., 015 for I-15).

* **D6.** *Direction of survey:* This identifies the set of lanes in which the field survey was conducted. The field survey proceeds in one direction of traffic flow along the uniform section. This general direction is circled on the sheet.

* **D7.** *Beginning milepost of SHD project:* This is the mile post where the SHD project begins (e.g., 332.25).

* **D8.** *Ending milepost of SHD project:* This is the milepost where the SHD project ends (e.g., 344.44).

D9. *Beginning station number of SHD project:* This is the station at which the SHD project begins, as determined from the project layout plans (e.g., 11782 + 63).

D10. *Ending station number of SHD project:* This is the station at which the SHD project ends, as determined from the project layout plans (e.g., 11810 + 86).

D11. *Number of uniform sections in project:* The SHD project is divided into one or more uniform sections as shown in Figure 1. The definition of a uniform section, as given in the Field Data Collection section, will determine the number of those sections and their locations. This item cannot be completed until the field survey is completed. This value should include *all* uniform sections in the SHD project (uniform sections both surveyed and not surveyed) so that a uniform section not initially surveyed can be added to the data bank at a later date if so desired.

* **D12A.** *Beginning milepost of uniform section:* This is the milepost where the uniform section begins (e.g., 332.25).

* **D12B.** *End milepost of uniform section:* This is the milepost where the uniform section ends (e.g., 338.61).

D12C. *Beginning station number of uniform section:* This is the station at which the uniform section starts, as determined from the project layout plans or the field survey (e.g., 11782 + 63).

D12D. *Ending station number of uniform section:* This is the station at which the uniform section ends, as determined from the project plans or the field survey (e.g., 11810 + 86).

* **D13.** *Number of lanes in uniform section:* Each uniform section contains either one or two lanes. If the total number of lanes in one direction is an odd number, the innermost uniform section will consist of only one lane. If the total

Exhibit 1

SHEET 1
DESIGN DATA
-COPES-

NCHRP Project 1-19
Concrete Pavement
Evaluation System-COPES

University of Illinois
Dept. of Civil Engineering

*Record No. 1. — 1
*State Code 44 — 2-3
*Proj. ID 1511. — 4-7
*Unif. Sect. 01. — 8-9

PROJECT AND UNIFORM SECTION IDENTIFICATION

D 1. State Highway Department (SHD) District Number .. 01. — 10-11
D 2. County (See County Code Sheet) .... 44057. — 12-16
*D 3. Type of Highway .... [✓ Interstate .... 1] Primary Non-Interstate... 2 Secondary .... 3 Other (specify)________ 4 — 17
*D 4. Highway letter designation .... [✓ Interstate .... 1] U.S. .... 2 State .... 3 Other (specify)________ 4 — 18
*D 5. Highway number .... 015. — 19-21
*D 6. Direction of survey .... East .... 1 West .... 2 [✓ North .... 3] South .... 4 — 22
*D 7. Beginning mile marker of SHD project .... 332.25 — 23-27
*D 8. Ending mile marker of SHD project .... 344.44 — 28-32
D 9. Beginning station number of SHD project .... _ _ _ _ _._ _ — 33-39
D10. Ending station number of SHD project .... _ _ _ _ _._ _ — 40-46
D11. Number of uniform sections in project .... 04. — 47-48
D12. Uniform section
*A. Start point-mile mark .... 332.25 — 49-53
*B. End point-mile mark .... 338.61 — 54-58
C. Start point station no. .... _ _ _ _ _._ _ — 59-65
D. End point station no. .... _ _ _ _ _._ _ — 66-72
*D13. Number of lanes in uniform section ..... 1 lane .... 1 [✓ 2 lanes .... 2] — 73
*D14. Type of original concrete slab .... [✓ JPCP .... 1] JRCP .... 2 CRCP .... 3 Other (specify) ________________ 4 — 74

State Highway Department
Construction Project No.
259,261 — 75-78/BK — 79-80/01

*Variables that were found to be highly important.

number of lanes in one direction is an even number, the innermost uniform section will consist of two lanes, as shown on Figure 1. All remaining uniform sections will have two lanes. The number corresponding to the applicable number of lanes is circled on Sheet 1.

*** D14.** *Type of original concrete slab:* The types of original concrete pavement normally constructed are jointed plain concrete (JPCP), jointed reinforced concrete (JRCP), and continuously reinforced concrete (CRCP). The number corresponding to the appropriate pavement type is circled on Sheet 1.

State Highway Department Construction Project Number: This is the section number assigned to a given project at the time of its conception by the State Highway Department (e.g., 259.261). This variable is not entered into the computer data bank, but can be cross-referenced to the Project ID number.

Environmental Data (Sheet 2—see Exhibit 2)

*** D21A–D32A.** *Average monthly temperature (°C):* This is the average air temperature at the site of the uniform section during the given month (e.g., 15°C). All environmental data can be obtained from published climatic information. Use data from the weather station located closest to the project, or interpolate using data from the nearest stations.

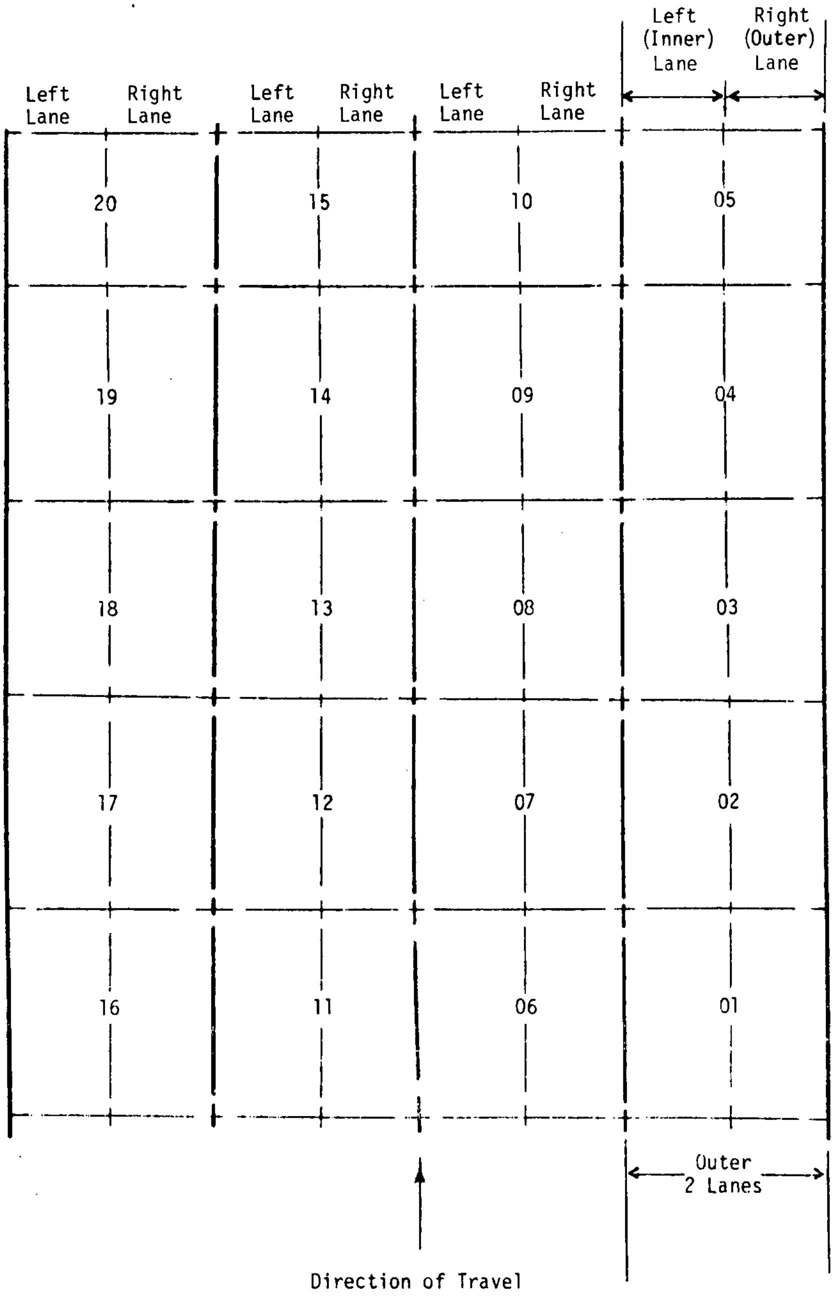


Figure 1. Standard uniform section layout.(Note: This numbering system for uniform sections shall be used for all situations.)

- * **D21B–D32B.** *Average monthly daily maximum temperature (°C):* This is the average of the maximum daily air temperatures for the given month at the site of the uniform section (e.g., 32°C).
- * **D21C–D32C.** *Average monthly daily minimum temperature (°C):* This is the average of the minimum daily air temperatures for the given month at the site of the uniform section (e.g., −02°C).
- * **D21D–D32D.** *Average monthly precipitation (cm of water):* This is the average amount of precipitation that falls at the site of the uniform section over the entire given month (e.g., 04.6 cm). If part of the precipitation is in the form of snow, it should be converted to equivalent centimeters of water and added to the rainfall data to obtain the average total monthly precipitation.
- * **D36.** *Latitude (degrees):* The latitude of the project can be obtained from appropriate geographical maps. The latitude is expressed to the nearest whole degree (e.g., 41 degrees).
- * **D37.** *Freezing index (32°F—Corps of Engineers method):* The accumulation of depressed air temperature over a period of time is referred to as the freezing index of that period. It is customary to measure the freezing index in degree-days over a one-year period. One degree-day represents one day with a mean air temperature one Fahrenheit degree

Exhibit 2

SHEET 2

DESIGN DATA
-COPES-

Record No. 1. 1-9/Dup.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

ENVIRONMENTAL DATA

		Avg. Monthly Temp., °C (A)	Avg. Max. Daily Temp., °C (B)	Avg. Min. Daily Temp., °C (C)	Avg. Monthly Precip., CMS of Water (D)	
* D 21	January	-03.	002.	-08.	03.1	10-21
* D 22	February	001.	006.	-04.	03.0	22-33
* D 23	March	005.	011.	-01.	04.3	34-45
* D 24	April	010.	017.	003.	04.6	46-57
* D 25	May	015.	023.	007.	04.1	58-69
* D 26	June	19.	28.	11.	02.3	70-78
						79-80/02 1-9 /Dup.
* D 27	July	24.	33.	16.	01.5	10-18
* D 28	August	23.	32.	15.	02.5	19-27
* D 29	September	18.	26.	09.	01.8	28-36
* D 30	October	012.	019.	004.	03.3	37-48
* D 31	November	004.	010.	-02.	03.6	49-60
* D 32	December	000.	004.	-05.	03.3	61-72

73-78/BK
79-80/03
1-9 /Dup.

* D 36. Latitude (degrees) 41. 10-11

* D 37. Freezing Index (32°F -- CE Method) 0250. 12-15

D 38. Average No. of Annual Freeze-Thaw Cycles 003. 16-18

D 39. Elevation (feet above sea level) 04215. 19-23

D 40. Avg. Annual Deicing Salt ($CaCl_2$) Application (ton/lane mile/year) 1.0. 24-25

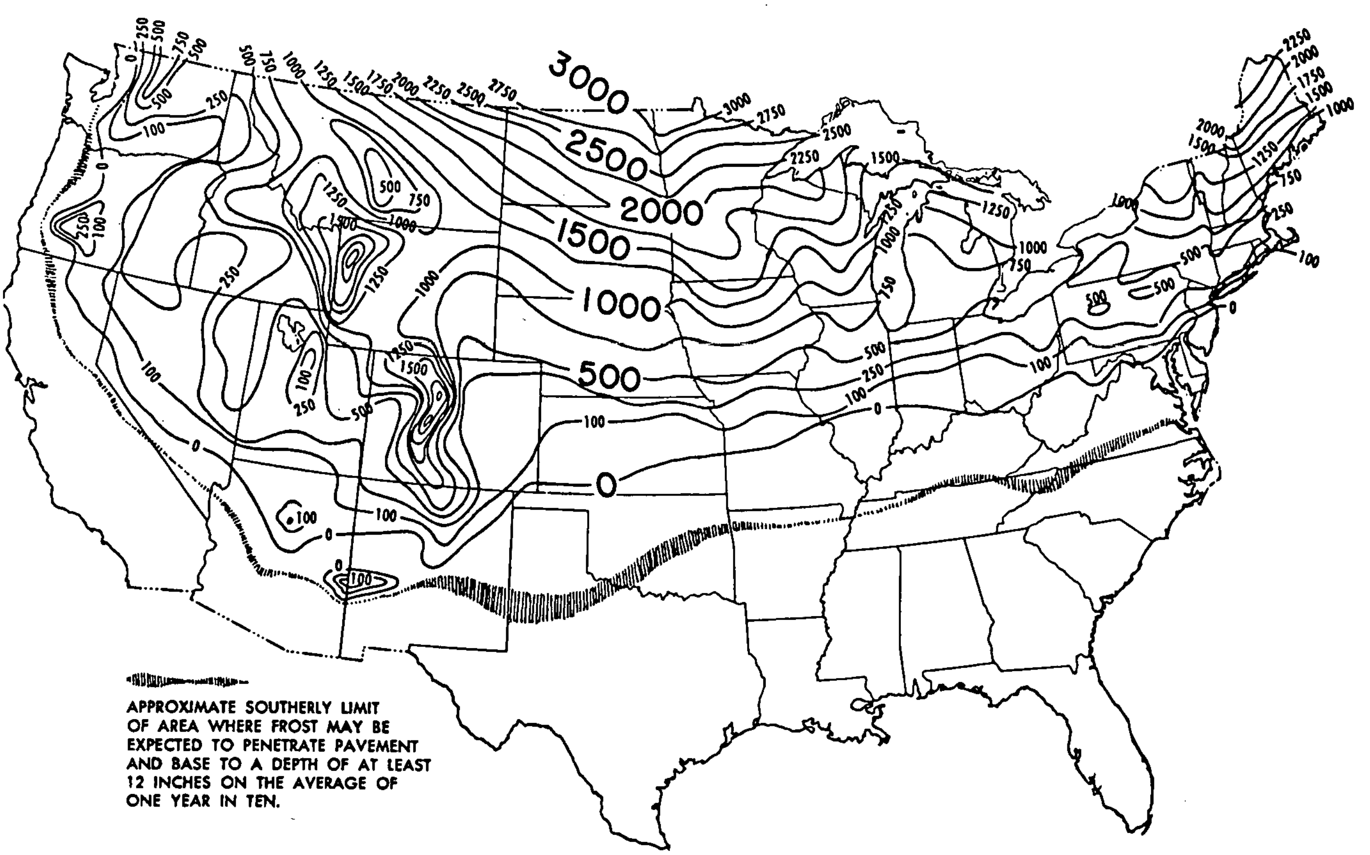
*Variables that were found to be highly important.

below freezing. Thus, 10 degree-days may accumulate when the air temperature is 31°F for 10 days or when the air temperature is 22°F for one day. A distribution of mean freezing index values in the continental United States is shown with contour lines in Figure 2.

D38. *Average number of annual freeze-thaw cycles:* This is the average annual number of freeze-thaw cycles that occur at the project site at the bottom of the pavement slab. This information is difficult to obtain and may need to be estimated by experienced personnel. It is noted that temperature and precipitation information for any state or any location within the state may be obtained from various state climatic reports or by obtaining the appropriate climatological publications for the area under survey by writing or calling: National Climatic Center, Federal Building, Asheville, N.C. 28801, Telephone: (704) 258-2850, Ext. 683.

D39. *Elevation (ft):* This is the mean elevation of the uniform section in feet above sea level.

D40. *Mean deicing salt ($CaCl_2$) application:* This is the average amount of salt ($CaCl_2$) used as a deicing agent on the pavement in tons per lane mile per year. This information



APPROXIMATE SOUTHERLY LIMIT OF AREA WHERE FROST MAY BE EXPECTED TO PENETRATE PAVEMENT AND BASE TO A DEPTH OF AT LEAST 12 INCHES ON THE AVERAGE OF ONE YEAR IN TEN.

Figure 2. Freezing index map of the United States.

may be obtained from maintenance records in the district where the project under survey is located.

Slab Structural Design Data (Sheet 3—see Exhibit 3)

- * **D41.** *Slab thickness (in.):* This is the thickness of the concrete pavement slab for the uniform section (e.g., slab thickness = 9.0 in.). The thickness may be obtained from the original or as-built project plans.
- * **D42.** *Lane width (ft):* This is the width of the traffic lane for the uniform section (e.g., lane width = 12 ft). The width may be obtained from the original or as-built project plans.
- * **D43.** *Date slab construction completed (month/year):* This is the date (month/year) during which the slab was constructed (e.g., 09/76). The construction date of the project is normally stamped in the pavement, and should be verified with the construction date shown on the as-built plans.
- * **D44.** *Date opened to traffic (month/year):* This is the date (month/year) during which the project was opened to traffic (e.g., 11/76). Normally this date is shown on maps or other sources published for this purpose.

Joint Data (Sheets 3 and 4—see Exhibits 3 and 4)

- * **D51.** *Average contraction joint spacing (ft):* This is the average spacing in feet between consecutive contraction joints (length of the concrete slab) within the uniform section (e.g., L_c = 100 ft). The contraction joint spacing may be obtained from the original or as-built plans or standards for the type of pavement constructed. Random spacing of joints (e.g., 13, 12, 19, 18, average L_c = 15.5 ft) should also be recorded.
- * **D52.** *Built-in expansion joint spacing (ft):* This is the average spacing, in feet, between consecutive expansion joints within the uniform section (e.g., L = 1000 ft). The expansion joint spacing may be obtained from the original or as-built plans or standards for the type of pavement constructed. If no expansion joints were placed in the original construction, this item should be left blank. Expansion joints cut after initial construction are recorded only in the field data collection sheets.
- * **D53.** *Skewness of joint (ft/lane):* The deviation of the contraction joint across the slab from the perpendicular to the pavement edge is called the skewness of the joint (e.g., skewness = 2.0 ft/lane).
- * **D54.** *Transverse contraction joint load transfer system:* The mechanism by which a portion of the moving load is transferred across the transverse contraction joint to the adjacent slab is referred to as the load transfer system. The system could be either dowel bars, nonmechanical load transfer (e.g., aggregate interlock), or some other system (e.g., angle iron). The number corresponding to the applicable transfer system is circled on Sheet 3.

* **D55.** *Dowel diameter (in.):* This is the outer diameter, in inches, of the dowel bar used as the load transfer device across the contraction joint of the pavement (e.g., dowel diameter = 1.25 in.). The dowel bar diameter may be obtained from the original or as-built project plans or standards for the type of pavement constructed.

* **D56.** *Dowel spacing (in.):* This is the center-to-center distance, in inches, between adjacent dowel bars across the contraction joint of the pavement (e.g., dowel spacing = 18 in.). The dowel bar spacing may be obtained from the original or as-built project plans or standards for the type of pavement constructed.

* **D57.** *Dowel length (in.):* This is the length, in inches, of the dowel bars across the project contraction joint (e.g., dowel length = 18 in.). The dowel bar length may be obtained from the original or as-built project plans or standards for the type of pavement constructed.

D58. *Dowel coating:* The material (paint, grease, etc.) that covers the dowel surface during construction is referred to as the dowel coating. The dowel bar could also have a special type of surface such as stainless steel. This information may be obtained from original or as-built project plans or standards for the type of pavement constructed. The number corresponding to the appropriate type of dowel coating is circled on Sheet 3.

D59. *Method used to install dowels:* Dowel bars can be installed during pavement construction by either preplacing them on baskets, installing them mechanically with special equipment, or by other means. This information may be obtained from the original or as-built project plans or standards for the type of pavement constructed. The number corresponding to the appropriate method is circled on Sheet 3.

* **D70.** *Method used to form transverse joints:* Contraction joints can be constructed by sawing the hardened slab at the proper time, placing an insert in the slab surface while the concrete is plastic, or by another construction method. This information may be obtained from project reports, plans, and specifications. The number corresponding to the applicable method is circled on Sheet 4.

D71. *Joint sealant type used in transverse joints (as built):* Types of transverse joint sealant commonly used are listed on Sheet 4. This information may be obtained from project plans, specifications, or reports. The number corresponding to the sealant type used is circled on Sheet 4. Circle "0" if no joint sealant was incorporated at the time of construction.

D72. *Transverse joint sealant reservoir (as built):* The width and the depth of the transverse joint sealant reservoir may be obtained from the original or as-built project plans or specifications for the type of pavement constructed (e.g., width = 0.37 in., depth = 1.6 in.).

D73. *Type of longitudinal joint (between lanes):* The longitudinal joint between the lanes can be formed as a butt, keyway, or weakened plane (by sawing hardened concrete or by inserting a plastic tape or premolded insert while the concrete is still plastic). Types of longitudinal joints commonly used are listed on Sheet 4. This information may be obtained from project plans, specifications, and reports. The number corresponding to the appropriate joint type is circled on Sheet 4.

D74. *Tie bar diameter (in.):* This is the outer diameter, in inches, of the tie bar used across the longitudinal joint between lanes to keep the joints closed (e.g., tie bar diameter = 0.62 in.). The tie bar diameter may be obtained from the project plans or standard specificatons for the type of pavement constructed. If no tie bars were placed, enter "0" for item D74.

D75. *Tie bar length (in.):* This is the length, in inches, of the tie bar used across the longitudinal joint between the lanes of the project (e.g., tie bar length = 30 in.). The tie bar length may be obtained from the project plans or standard specifications for the type of pavement constructed.

D76. *Tie bar spacing (in.):* This is the center-to-center distance, in inches, between tie bars used across the longitudinal joint between the lanes of the project (e.g., tie bar spacing = 36 in.). The tie bar spacing may be obtained from the project plans or standard specifications for the type of pavement constructed.

D77. *Type of shoulder-traffic lane joint (for concrete shoulder only):* The type of longitudinal joint between the concrete shoulder and the outer traffic lane may be a butt, keyed, sawed weakened plane, insert weakened plane, or some other type. The types of concrete shoulder-traffic lane joints normally used are listed on Sheet 4 under Item D77. This information may be obtained from reports or plans pertinent to the project. The number corresponding to the applicable type is circled on Sheet 4. If no concrete shoulder exists, leave this item blank and proceed to Item D81.

D78. *Shoulder-traffic lane joint tie bar diameter (for concrete shoulder only) (in.):* This is the outer diameter, in inches, of the tie bars used across the concrete shoulder-traffic lane joint of the project (e.g., tie bar diameter = 0.75 in.). The tie bar diameter may be obtained from reports, plans, or specifications pertinent to the project. If no concrete shoulder exists, leave this item blank.

D79 *Shoulder-traffic lane joint tie bar length (for concrete shoulder only) (in.):* This is the length, in inches, of the tie bar used across the concrete-shoulder traffic lane joint of the project (e.g., tie bar length = 30 in.). The tie bar length may be obtained from the reports, plans or specifications pertinent to the project. If no concrete shoulder exists, leave this item blank.

D80. *Shoulder-traffic lane joint tie bar spacing (for concrete shoulder only) (in.):* This is the center-to-center distance, in inches, between tie bars used across the concrete shoulder-traffic lane joint of the project (e.g., tie bar spacing = 30 in.). The tie bar spacing may be obtained from reports, plans, or specifications pertinent to the project. If no concrete shoulder exists, leave this item blank.

Reinforcing Steel Data (Sheet 5—see Exhibit 5)

* **D81.** *Type of reinforcing:* The types of reinforcing bars, if any, that are used in the pavement may be deformed bars, welded wire fabric, or some other type. The type of reinforcing used may be obtained from reports, plans, or specifications pertinent to the project. The number corresponding to the applicable type is circled on Sheet 5. If no reinforcing is used (e.g., in JPCP), circle "0" and proceed to Item D101.

D82. *Transverse bar diameter (in.):* This is the outer diameter, in inches, of the reinforcing bar or wire provided in the transverse direction (e.g., transverse bar diameter = 1.25

SHEET 3

Exhibit 3

DESIGN DATA
-COPES-

Record No. 1.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

SLAB STRUCTURAL DESIGN

* D 41. Slab thickness (in.) 09.0 26-28
* D 42. Lane width (ft) 12. 29-30
* D 43. Date slab construction completed (month/year) 09/76 31-34
* D 44. Date opened to traffic (month/year) 11/76 35-38
39-44/BK

JOINT DATA

* D 51. Average contraction joint spacing (ft) 015.5 45-48
(Random joint spacing, if any: 13,12,19,18)
* D 52. Built-in expansion joint spacing (ft)...... 1000. 49-52
* D 53. Skewness of joint in (ft/lane) 2.0 53-54
* D 54. Transverse contraction joint load transfer system 55
Dowels 1
Nonmechanical load transfer device .....[✓ 2]
Other (specify) ____________________ 3
* D 55. Dowel diameter (in.) 1.25 56-58
* D 56. Dowel spacing (in.) 18. 59-60
* D 57. Dowel length (in.)........................ 18. 61-62
D 58. Dowel coating 63
Paint and/or grease 1
Plastic 2
Monel 3
Stainless steel 4
Epoxy 5
Other (specify) ____________________ 6
D 59. Method used to install dowels 64
Preplaced on baskets ...1
Mechanically installed .2
Other (specify) ____________________ 3
65-78/BK
79-80/04

*Variables that were found to be highly important.

in.). The transverse bar diameter may be obtained from reports, plans, or specifications pertinent to the project.

D83. *Transverse bar spacing (in.):* This is the center-to-center distance, in inches, between transverse reinforcing bars or wires used in the slab (e.g., transverse bar spacing = 12.5 in.). The transverse bar spacing may be obtained from reports, plans, or specifications pertinent to the project.

*** D84.** *Longitudinal bar diameter (in.):* This is the outer diameter, in inches, of the reinforcing bar or wire provided in the longitudinal direction (e.g., longitudinal bar diameter = 1.25 in.). The longitudinal bar diameter may be obtained from reports, plans, or specifications pertinent to the project.

*** D85.** *Longitudinal bar spacing (in.):* This is the center-to-center distance, in inches, between longitudinal reinforcing bars or wires used in the slab (e.g., longitudinal bar spacing = 12.5 in.). The longitudinal bar spacing may be obtained from reports, plans, or specifications pertinent to the project.

D86. *Yield strength of reinforcing:* In simple terms, the yield strength is the load limit below which the steel can be stretched and still return closely to its original length when the load is released (e.g., yield strength of reinforcing = 62.5 ksi). Reinforced concrete pavement design requires that the loads carried by the reinforcement not exceed the yield strength of steel. The yield strength (in ksi) of rein-

SHEET 4

Exhibit 4

DESIGN DATA

-COPES-

Record No. 1. 1-9/Dup.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

JOINT DATA

(continued from sheet 3)

* D 70. Method used to form transverse joints — 10
- [✓ Sawed .... 1]
- Plastic insert 2
- Metal insert (i.e., Uni-tube) 3
- Other (specify) ________ 4

D 71. Joint sealant type used in transverse joints (as built) — 11
- No joint sealant 0
- Preformed (open web) 1
- [✓ Asphalt .... 2]
- Rubberized asphalt (old type) 3
- Rubberized asphalt (new type) 4
- Silicone 5
- Other (e.g., closed neoprene) (specify) ________ 6

D 72. Transverse joint sealant reservoir (as built)
- (A) Width (in.) 0.37 — 12-14
- (B) Depth (in.) 1.6 — 15-16

D 73. Type of longitudinal joint (between lanes) — 17
- Butt 1
- Keyed 2
- [✓ Sawed weakened plane ..... 3]
- Insert weakened plane 4
- Other (specify) ________ 5

D 74. Tie bar diameter (in.) .... 0.62 — 18-20

D 75. Tie bar length (in.) .... 30. — 21-22

D 76. Tie bar spacing (in.) .... 36. — 23-24

D 77. Type of shoulder-traffic lane joint (for concrete shoulder) — 25
- [✓ Butt .... 1]
- Keyed 2
- Sawed weakened plane 3
- Insert weakened plane 4
- Tied concrete curb 5
- Other (specify) ________ 6

D 78. Shoulder-traffic lane joint tie bar diameter (for concrete shoulder)(in.) .... _._ _ — 26-28

D 79. Shoulder-traffic lane joint tie bar length in inches (for concrete shoulder) .... _ _. — 29-30

D 80. Shoulder-traffic lane joint tie bar spacing (for concrete shoulder) (in.)................ _ _. — 31-32

forcing bars used in the slab may be obtained from reports, plans, or specifications pertinent to the project.

D87. *Depth to reinforcement from slab surface (in.):* This is the thickness, in inches, of the concrete cover over the reinforcing steel in the concrete pavement (e.g., reinforcement depth = 3.5 in.). The depth to reinforcement from the slab surface may be obtained from reports, plans, or specifications pertinent to the project.

D88. *Method used to place rebar:* Steel bar or wire fabric reinforcing may be installed during pavement construction by presetting the reinforcement on chairs, placing it mechanically by means of special equipment, placing it between layers of concrete, or by some other method. This information may be obtained from construction reports related to the project. The number corresponding to the appropriate placement method is circled on Sheet 5.

D89. *Length of steel lap at construction joint (CRCP only) (in.):* This is the length, in inches, of the longitudinal reinforcing steel overlap at the CRCP construction joint (e.g., length of steel lap at construction joint = 60 in.). This information may be obtained from reports, plans, or specifications pertinent to the project.

SHEET 5

Exhibit 5

DESIGN DATA

-COPES-

Record No. 1.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

REINFORCING STEEL DATA

* D 81. Type of reinforcing .... No reinforcing .... [✓ 0] 33
Deformed bars 1
Welded wire fabric 2
Other (specify) ____________ 3

D 82. Transverse bar diameter (in.) .... _.__ __ 34-36

D 83. Transverse bar spacing (in.) .... __ __.__ 37-39

* D 84. Longitudinal bar diameter (in.) .... _.__ __ 40-42

* D 85. Longitudinal bar spacing (in.) .... __ __.__ 43-45

D 86. Yield strength of reinforcing (ksi) .... __ __.__ 46-48

D 87. Depth to reinforcement from slab surface .... (in.) __.__ 49-50

D 88. Method used to place rebar .... Preset on chairs 1 51
Mechanically 2
Between layers of concrete. 3
Other (specify) ____________ 4

D 89. Length of steel lap at construction .... joint (CRCP only) (in.): __ __. 52-53

54-78/BK

79-80/05

*Variables that were found to be highly important.

Concrete Data (Sheets 6 through 8—see Exhibits 6, 7, and 8)

D101. *Mix design (lb/yd^3):* The concrete mix design is specified by the weight in pounds of coarse aggregate, fine aggregate (sand), cement, and water used per cubic yard of concrete mix. This information may be obtained from concentration reports related to the project.

*** D102A. and D102B.** *Strength (28-day modulus of rupture) (psi):* The modulus of rupture is defined as the extreme fiber stress in a simply supported beam under the breaking load. Beam specimens are generally tested using simple third-point loading as described in ASTM C78 or AASHTO T97 specifications, although center-point loading is also used by some agencies. The concrete beams are cast from the concrete used in the slab and the modulus of rupture is determined at various times, such as 7, 14, or 28 days. The mean and the range of the modulus of rupture tests are recorded. This information may be obtained from construction reports. If the 28-day, third-point loading information is not available for the project, any available information related to the strength of the concrete should be provided inside the box on Sheet 6 under Item D102. For example, if only compressive strength at 7 days is available, this data should be entered in the box, and the 28-day, third-point data (columns 26–33) should be left blank. The data in the box must be converted to an approximate third-point, 28-day modulus of rupture using standard relationships prior to keypunching.

D104. *Slump (in.):* The slump test is used to measure the workability and consistency of concrete. Details of the slump test are given in ASTM Standard Specification C143. The mean and range of the slump tests can be obtained from construction records.

D105. *Type cement used:* The different types of cement normally used in concrete mix design are listed in the "Cement Type

SHEET 6

Exhibit 6

DESIGN DATA

-COPES-

Record No. 1. 1-9/Dup.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

CONCRETE DATA

D101. Mix design (lb/yd^3).............. (A) Coarse aggregate 2028. 10-13
(B) Fine aggregate 1352. 14-17
(C) Cement 0423. 18-21
(D) Water 0187. 22-25

* D102. Strength (28-day modulus of rupture) (psi)(based on 3rd point loading) (A) Mean 0668. 26-29
(B) Range 0200. 30-33

Note: If data specified above is not available, please provide any available data below:
Type of Test ____________ 34-42/BK
(see Test Type Code)
Age of Concrete (days) ____________
Mean ____________
Range ____________

D104. Slump (in.) .... (A) Mean 2.0 43-44
(B) Range 3.0 45-46

D105. Type cement used (see Cement Type Codes) 01. 47-48

D106. Alkali content of cement,(%)......................... 00.5 49-51

D107. Entrained air,(%)................ (A) Mean 4.0 52-53
(B) Range 5.0 54-55

D108. Additives other than air-entrainers .... __ __. 56-57
(see Cement Additive Code)

D109. Maximum size of coarse aggregate (in.) 2.0 58-59

*D110. Type of coarse aggregate 60
Crushed stone 1
Gravel or crushed gravel ...... [✓ 2]
Crushed slag 3
Blend crushed stone/gravel 4
Blend crushed stone/slag 5
Blend Gravel/slag 6
Other (specify) ____________ 7

*Variables that were found to be highly important.

Code" sheet included in Appendix B. The code number corresponding to the type of cement used is entered under this item. This information may be obtained from construction records.

D106. *Alkali content of cement (percent):* Alkalies, such as Na_2O and K_2O, are important minor constituents because they can cause very rapid expansive deterioration of concrete when certain types of siliceous aggregates are used. Therefore, obtaining the alkali content of the cement type used is important in predicting characteristics such as the durability of the concrete pavement. The alkali content of the cement used, in percent by weight, may be obtained from construction records (e.g., alkali content = 0.5 percent).

D107. *Entrained air (percent):* Air entraining agents increase the resistance of concrete to frost action by introducing millions of tiny air bubbles into the cement paste. Air entraining agents are usually composed of natural or synthetic soaps. The entrained air percentage of the concrete mix and its range may be obtained from construction records (e.g., mean entrained air = 4.0 percent, range = 5.0 percent).

D108. *Other additives:* An additive or admixture is any material other than aggregates, portland cement, or water that is added as an ingredient of concrete immediately before or during mixing. Additives are used to modify, improve, or give special properties to concrete mixtures. The different types of cement additives normally used in portland cement concrete mix design are listed and coded in the "Cement Additive Code" sheet in Appendix B. The additives used, other than air entrainers, may be obtained from construction records. The code number(s) corresponding to the additives used are entered under this item.

D109. *Maximum size of coarse aggregate (in.):* The maximum size of coarse aggregate is an important factor in mix design and on durability characteristics of the concrete. The maximum size of coarse aggregate, in inches, may be obtained from construction records (e.g., maximum size of coarse aggregate = 2.0 in.).

*** D110.** *Type of coarse aggregate:* Coarse aggregate is that portion of an aggregate retained on the No. 4 (4.75 mm) sieve. The types of coarse aggregate normally used in concrete pavement mixes are listed on Sheet 6. The type of coarse aggregate used in the paving concrete may be obtained from construction records. The number corresponding to the type of coarse aggregate used is circled on Sheet 6.

D111. *Sources of coarse aggregate:* A list of sources of coarse aggregate for a given state is typically tabulated in booklet form. For example, in Illinois it is entitled "Sources and Producers of Aggregates for Highway Construction." This bulletin includes a number for each source where state contractors obtain their aggregates. The source number can contain up to six digits (e.g., Illinois source number 113145).

D112. *Type of fine aggregate:* Fine aggregate is that portion of an aggregate passing the No. 4 (4.75 mm) sieve and retained on the No. 200 (75 mm) sieve. The types of fine aggregate normally used in concrete pavement mixes are listed on Sheet 7. The type of fine aggregate used in the pavement concrete may be obtained from construction records. The number corresponding to the type of fine aggregate is circled on Sheet 7.

D113. *Sources of fine aggregate:* A list of sources of fine aggregate for a given state is typically tabulated in booklet form similar to the listing for coarse aggregates. The source number can contain up to six digits (e.g., Illinois source number 113145).

D114. *Type of aggregate durability test used:* The durability test is conducted to determine if the aggregate is durable enough to withstand the action of rolling during construction, the action of traffic, and the action of the weather during freeze-thaw and wet-dry cycles. Aggregate durability tests normally used are listed and coded on the "Aggregate Durability Test Type Code" sheet in Appendix B. The code corresponding to the test used for a given project should be entered on Sheet 7. Information about the type of aggregate durability test used may be obtained from construction records.

D115. *Result of durability test:* The results of the durability test referred to under Item D114 are recorded under this item in the units specified for the test.

D116. *Type of paver used:* Two types of pavers are normally used for placement of concrete. The *slip-form* paver consists of equipment mounted on crawler tracks with moving side forms that typically incorporates the spreading, consolidation, finishing, and floating operations all in one piece of equipment. The *side-form* method of paving consists of setting fixed forms to line and grade. A paving train, which may consist of either one or two spreaders, is used to distribute the concrete between the forms, and consolidation and finishing of the concrete is accomplished using vibrating pans or tubes. Information about the type of paver used may be obtained from construction records or specifications of the project. The number corresponding to the type of paver used is circled on Sheet 7.

D117. *Method used to cure concrete:* Curing is the procedure used to ensure that there is enough water present in the concrete to provide for continuous hydration of the cement. Several methods that have been used to cure freshly finished concrete pavement slabs are listed on Sheet 7. The method used for curing may be obtained from construction records. The number corresponding to the method used to cure the concrete is circled on Sheet 7.

*** D118.** *Method used to finish concrete:* The texture of the surface depends on the manner in which the concrete was finished. The plans and specifications for the project should describe the procedure followed to secure the desired finish or surface texture. The number corresponding to the method used to finish the concrete is circled on Sheet 8.

D119. *Geologic classification of coarse crushed stone concrete aggregate:* All coarse aggregate types exhibit certain inherent properties that depend on the mineral constituents present in their original rock formation. Rocks may embrace a great number of *types* according to their mineral constituents, but only three major *classes,* according to origin. These classes are igneous, sedimentary, and metamorphic. The three major classes and types of rock most commonly used for highway purposes are listed on the "Geologic Classification Code" sheet in Appendix B. The predominant rock type used as a coarse aggregate in the concrete mix may be obtained from construction records, or it may be obtained from information about the source(s) where the aggregate was obtained. Definitions and explanations of most of the rock types listed in Appendix B are as follows:

- *Basalt:* An igneous, fine-grained, dense, volcanic rock, dark-colored or black. Commonly found in Northwestern states, but occasionally found in other areas of former volcanic activity. Also called "traprock." Some varieties have given trouble in gravel base courses.
- *Breccia:* A rock formed of angular fragments of preexisting rock cemented together with bonding material such as silica or calcite compounds.
- *Chert:* Very fine-grained siliceous rock containing cryptocrystalline quartz, chalcedony, opal, or a combination thereof. Porous varieties are usually light-colored and have splintery fractures. Dense varieties are hard, have conchoidal fracture, greasy luster, and occur in many colors including white, yellow, brownish stained, or green. The colored varieties are sometimes designated "jasper." Dense, gray varieties are called "flint." All varieties will scratch glass and not be scratched by a knife blade. Some of its constituents may be reactive with cement alkalies, and it should be considered a poor choice for concrete aggregate, especially for exposed concrete in northern climates.

Exhibit 7

SHEET 7

DESIGN DATA

-COPES-

Record No. 1.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

CONCRETE DATA
(continued from Sheet 6)

D111. Source of coarse aggregate (Source code number obtained from a State list of sources and producers of aggregates for highway construction)
(A) Source I ______. 61-66
(B) Source II ______. 67-72
(C) Source III______. 73-78

D112. Type of fine aggregate ....
Natural or crushed sand 1 79-80/06
Manufactured sand (from crushed gravel or stone) ... 2 1-9 /Dup. 10
Other (specify)
Both 1 & 2 [✓ 3]

D113. Source of fine aggregate (Source code number obtained from a State list of sources and producers of aggregates for highway construction)
(A) Source I ______. 11-16
(B) Source II ______. 17-22
(C) Source III______. 23-28

D114. Type of aggregate durability test used (see Durability Test Type Code) .... __. 29-30

D115. Result of durability test in item D114 .... __.__ 31-33

D116. Type of paver used 34
Slip form .... [✓ 1]
Side form 2

D117. Method used to cure concrete 35
Membrane curing compound .... [✓ 1]
Burlap curing blankets 2
Waterproof paper blankets 3
White Polyethylene sheeting .. 4
Burlap-polyethylene blanket .. 5
Cotton mat curing 6
Hay 7
Other (specify)
______ 8

- *Conglomerate:* Rock consisting of rounded pebbles cemented together with finer material.
- *Diabase:* Same material composition as basalt, but crystals slightly larger—just visible to the unaided eye. Also called "traprock."
- *Diorite:* Medium- to coarse-grained rock composed essentially of plagioclase feldspar and ferromagnesium minerals.
- *Dolomite:* The mineral calcium magnesium carbonate $CaMg(CO_3)_2$.
- *Gabbro:* Igneous rock similar to diorite, predominantly composed of ferromagnesium minerals with crystals visible to the eye. Same mineral composition as basalt.
- *Gneiss:* A banded or foliated metamorphic rock (e.g., granite gneiss, diorite gneiss).
- *Granite:* Rock with large grains easily visible to the eye and consisting predominantly of quartz and alkali feldspars.
- *Limestone:* Of sedimentary origin and containing a predominance of the mineral calcite (calcium carbonate).
- *Quartzite:* Extremely hard, tough, and stable metamorphosed sandstone. Sand grains have been cemented together with secondary quartz. Excellent concrete aggregate but may crush to thin or elongated pieces.
- *Schist:* May be formed from a number of igneous or sedimentary rocks. Characterized by crushing to thin, platy, flat fragments or crumbling to prismatic shapes. Weak parallel to plane of foliation.
- *Shale:* Argillaceous sedimentary rock derived

from silts or clays. Typically thinly laminated and weak along planes. Should be considered a poor choice for concrete aggregate unless proven otherwise.

- *Slate:* Fine-grained metamorphic rock, stratified and breaks easily, not necessarily parallel to laminations. Less suspect as concrete aggregate than shale.

The code number corresponding to the applicable geologic classification of coarse aggregate type is entered under item D119.

Base Data (Sheet 8—see Exhibit 8):

* **D131.** *Type of base:* A base course is defined as the layer of material that lies immediately below the portland cement concrete slab (sometimes the material under the slab is called a subbase). Base courses may consist of stone fragments, slag, soil-aggregate mixtures, cement-treated granular materials or bituminous-aggregate mixtures of several types. The base types normally used in concrete pavements are listed along with their code numbers on the "Base Type Code" sheet in Appendix B. Information about the type of base used in the project may be obtained from construction records or other reports and plans pertinent to the project. The code number corresponding to the type of base used is entered under this item.

* **D132.** *Stabilized base layer thickness (in.):* If a stabilized base was constructed, the thickness of this layer, in inches, is recorded. The thickness may be obtained from the construction records or other reports and plans pertinent to

Exhibit 8

SHEET 8

DESIGN DATA

-COPES-

Record No. 1.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

CONCRETE DATA
(continued from Sheet 7)

*D118. Method used to finish concrete .... Tine .... [✓ 1] 36
Broom 2
Burlap drag 3
Grooved float 4
Astro turf 5
Other (specify)
____________________ 6

D119. Geologic classification of coarse crushed stone concrete aggregate (see Geologic Classification Code) 01. 37-38

39-46/BK

BASE DATA

*D131. Type of base (see Base Type Code) 13. 47-48

*D132. Stabilized base layer thickness (in.) 8.0 49-50

D133. Type strength test used for stabilized base layer (see Test Type Code) 20. 51-52

D134. Result of strength test in Item D133 .... __ __ __ __. 53-56

D135. Percent material passing No. 200 sieve (for granular base only) .... __ __. 57-58

*D136. Nonstabilized (granular) base layer thickness (in.) .... __.__ 59-60

D137. Type strength test used for nonstabilized base layer thickness (see Test Type Code) .... __ __. 61-62

D138. Result of strength test in Item D137 .... __ __. 63-64

65-78/BK

79-80/07

*Variables that were found to be highly important.

the project. If an unstabilized base was constructed, this item is left blank.

D133. *Type strength test used for stabilized base layer:* The strength test is conducted to determine if the stabilized base layer is strong and durable enough to withstand the traffic and environmental loadings. The strength tests normally used are listed on the "Test Type Codes" sheet in Appendix B. Information about the type of strength test used on the stabilized base layer may be obtained from construction records. The code number corresponding to the strength test used is entered under this item.

D134. *Result of strength test:* The result of the strength test identified under item D133 is recorded under this item in the units specified for the test method used.

D135. *Percent material passing No. 200 sieve:* If a granular base is used, the percentage of base material passing a No. 200 sieve is recorded. This information may be obtained from construction reports.

* **D136.** *Unstabilized (granular) base layer thickness (in.):* If an unstabilized (granular) base is used, the thickness of this layer, in inches, is recorded. The thickness of the base may be obtained from the construction records or other reports pertinent to the project. If a stabilized base is used, this item is left blank.

D137. *Type of strength test used for unstabilized base layer:* The strength test is conducted to determine if the unstabilized base layer is strong enough to withstand the traffic and environmental loadings. The strength tests normally used are listed on the "Test Type Codes" sheet in Appendix B. Information about the type of strength test used on the unstabilized base layer may be obtained from construction records. The code number corresponding to the strength test used is entered under this item.

D138. *Result of strength test:* The result of the strength test identified in item D137 is recorded under this item in the units specified for the test method used.

Subgrade Data (Sheet 9—see Exhibit 9)

* **D151.** *AASHTO soil classification:* This system is the most widely known and used method of classifying soils for highway purposes. The groups into which soils are classified are listed on the "Soil Type Code" sheet in Appendix B. Information about the natural subgrade soil classification may be obtained from material reports. The code number corresponding to the appropriate classification is entered under this item.

* **D152.** *Strength test used on subgrade:* The strength tests normally used on the subgrade are listed on the "Test Type Code" sheet in Appendix B. Information about the type of strength test used on the subgrade may be obtained from materials reports. The code number corresponding to the strength test used is entered under this item.

* **D153.** *Test results from item D152:* The result of the strength test identified in item D152 is recorded under this item in the units specified for the test used.

D154. *Test used to predict swell potential:* This test is used to evaluate the swell characteristics of the subgrade soil when moisture is added. Tests used to predict the subgrade swell potential are listed on the "Test Type Code" sheet in Appendix B. Information about the test used to predict swell potential of the subgrade may be obtained from materials reports. The code number corresponding to the test used is entered under this item.

D155. *Test value from item D154:* The result of the swell potential test identified in D154 is recorded under this item in the units specified for the test used.

D156. *Test used to predict frost susceptibility:* This test is used to evaluate the susceptibility of the subgrade to frost action. Tests used to determine the frost susceptibility of the subgrade are listed on the "Test Type Code" sheet in Appendix B. Information about the test used may be obtained from materials reports. The code number corresponding to the test used is entered under this item.

D157. *Test value from item D156:* The result of the frost susceptibility test identified in item D156 is recorded under this item in the units specified for the test used.

D158. *Optimum lab dry density (pcf):* This is the laboratory-determined optimum dry density of the subgrade soil, in pcf. This value may be obtained from materials reports.

D159. *Optimum lab moisture content (percent):* This is the moisture content, in percent, that corresponds to the optimum dry density of the subgrade soil. The moisture content may be found according to *ASTM* Standard D2216 or other ASTM or AASHTO available methods. This value may be obtained from materials reports.

D160. *Test used to measure dry density:* The test used to measure the dry density obtained under item D158 could be either the Standard Proctor test (AASHTO T99), the Modified Proctor test (AASHTO T180), or another accepted test. The type of test used may be obtained from material reports. The number corresponding to the test used is circled on Sheet 9.

D161. *Mean measured dry density in situ (percent of optimum):* The mean dry density of the compacted layer can be measured in situ according to most of the standard AASHTO and ASTM volumetric or sand cone methods, or with a nuclear density gauge (e.g., ASTM Standard D2937, D2167, D1556, etc.). The percentage of the mean measured dry density relative to the laboratory-determined optimum dry density can then be calculated. These data may be obtained from material reports.

D162. *Mean measured moisture content in situ (percent of optimum):* The mean moisture content of the compacted layer can be measured in situ as described in ASTM Standards (e.g., D3017, etc.) and the percentage relative to the laboratory-determined optimum mositure content can be computed. This value may be obtained from material reports.

D163. *Plasticity Index (PI):* This is the difference between the liquid limit and the plastic limit of the fine-grained soil. The plastic limit and plasticity index are found according to ASTM Standard D424. The PI may be obtained from material reports.

D164. *Liquid Limit (LL):* This is the moisture content representing the boundary between the semiliquid and the plastic states. The liquid limit is found according to the ASTM Standard D423 procedures. The LL may be obtained from material reports.

Shoulder Data (Sheet 10—see Exhibit 10)

* **D181.** *Shoulder surface type:* Types of shoulder surface commonly used are turf, granular, asphalt, and concrete. In-

Exhibit 9

SHEET 9

DESIGN DATA

-COPES-

Record No. 1.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.
1-9/Dup.

SUBGRADE DATA

*D151. AASHTO soil classification 05. 10-11
(see Soil Type Code)

*D152. Strength test used on subgrade 02. 12-13
(see Test Type Code)

*D153. Test result from Item D152 .... 015. 14-16

D154. Test used to predict swell potential .... __ __. 17-18
(see Test Type Code)

D155. Test value from Item D154 .... __ __ __.__ 19-22

D156. Test used to predict frost susceptibility .... __ __. 23-24
(see Test Type Code)

D157. Test value from Item D156 .... __ __ __.__ 25-28

D158. Optimum lab dry density (pcf) .... __ __ __. 29-31

D159. Optimum lab moisture content (%) .... __ __. 32-33

D160. Test used to measure dry density 34

No test performed 0
Standard Proctor (T-99) 1
Modified Proctor (T-180)..... 2
Other (specify)
____________________________ 3

D161. Mean measured dry density insitu (% optimum) .... __ __ __. 35-37

D162. Mean measured moisture content in situ .... __ __ __. 38-40
(% optimum)

D163. Plasticity index .... __ __. 41-42

D164. Liquid limit .... __ __. 43-44

45-59/BK

*Variables that were found to be highly important.

formation about the shoulder surface type may be obtained from the construction plans. The number corresponding to the shoulder surface type originally constructed is circled on Sheet 10.

*** D182.** *Shoulder base type:* Types of bases that are commonly used under the shoulder surface are included on the "Base Type Code" sheet in Appendix B. Information about the shoulder base type may be obtained from the construction plans. The code number corresponding to the type of shoulder base constructed is entered under this item.

*** D183.** *Shoulder width (ft):* This is the width, in feet, of the *outside* paved shoulder. This width may be obtained from plans and specifications pertaining to the project.

D184. *Shoulder surface thickness (in.):* This is the thickness of the shoulder surface layer in inches. This information may be obtained plans and specifications pertaining to the project.

D185. *Shoulder base thickness (in.):* This is the thickness of the shoulder base layer in inches. This information may be obtained from any plans or specifications pertaining to the project.

Drainage Data (Sheet 10—see Exhibit 10)

*** D186.** *Subsurface drainage type:* Subsurface drainage systems commonly used in pavements are listed on Sheet 10 under this item. The number that corresponds to the drainage facilities constructed is circled on Sheet 10. If no subsurface drainage is present, circle 1 and ignore items D187 and D188. Information about the subsurface drainage type may be obtained from construction plans or reports related to the project.

D187. *Diameter of longitudinal drain pipes (in.):* This is the inner diameter, in inches, of the longitudinal pipes used in the subsurface drainage system. This information may be obtained from state standard plans, or plans or reports related to the project.

D188. *Subsurface drainage location:* The subsurface drainage system, as listed on Sheet 10 under item D186, is either continuous along the entire length of the project or is intermittent. This information may be obtained from the construction plans or other plans or reports related to the project. The number corresponding to the location of subsurface drains along the project is circled on Sheet 10. If there is no subsurface drainage system, leave this item blank.

ROUGHNESS DATA COLLECTION PROCEDURES

The "roughness" data (Record Number 2) includes Present Serviceability Index (PSI), Skid Number (SN), and Roughness Index (RI) measurements. Data are collected on the uniform section level and are recorded on Sheet 11. The data bank is structured to allow for multiple entries on the "year" variable (up to 99 entries per uniform section) and "roughness sequence" variable (up to 99 entries per "year"). For analysis purposes, the "year" variable in the roughness record must match the "year" variable in the field survey. When roughness measurements are not taken during the same years that the field surveys are conducted, this match can be obtained by plotting the rough-

Exhibit 10

SHEET 10

DESIGN DATA

-COPES-

Record No. 1.
State Code 44.
Proj. ID 1511.
Unif. Sect. 01.

SHOULDER DATA

* D181. Shoulder surface type .... Turf 1 60
Granular 2
Asphalt concrete .... [✓ 3]
Concrete 4
Other (specify) ____________________ 5

* D182. Shoulder base type (see Base Type Code) 13. 61-62

* D183. Shoulder width (ft) 10. 63-64

D184. Shoulder surface thickness (in.) 3.0 65-66

D185. Shoulder base thickness (in.) 08.0 67-69

DRAINAGE DATA

* D186. Subsurface drainage type .... No subsurface drainage ..... [✓ 1] 70
Longitudinal drains 2
Transverse drains 3
Drainage blanket 4
Well system 5
Drainage blanket with longitudinal drains 6
Other (specify) ____________________ 7

D187. Diameter of longitudinal drainpipes .... (in.) __.__ 71-72

D188. Subsurface drainage location .... Continuous along project ... 1 73
Intermittent 2

74-78/BK

79-80/08

*Variables that were found to be highly important.

ness data versus time, drawing a best-fit curve, and obtaining the roughness values for the desired years. Note that each roughness sequence input requires a Sheet 11.

Roughness Data (Sheet 11—see Exhibit 11)

Record Number: This variable identifies the data record in the COPES data bank. Equal to 2, it identifies the roughness data record.

State Code: (same as for Design data)

Project ID: (same as for Design data)

Uniform Section: (same as for Design data)

Year: This is a two-digit entry containing the last two digits of the year in which the roughness survey was performed (e.g., 81).

Roughness Sequence: A two-digit number is used to identify multiple occurrences of roughness surveys in a given year. If only one survey was performed in a given year, this variable is entered as 01. Up to 99 surveys can be entered for a given year.

R1. *Calculated PSI from roughness/distress measurements:* The Present Serviceability Index (PSI) is calculated from a mathematical combination of measurements of road roughness, cracking, and patching. The serviceability equation for jointed concrete pavement developed during the AASHO Road Test is as follows

$$PSI = 5.41 - 1.80 \log (1 + SV) - 0.09 [(C + P)^{0.5}]$$

where:

PSI = present serviceability index (value ranges from 0 to 5);

SV = slope variance (10);

C = linear feet of major cracking per 1,000-sq ft lane area; and

P = patching in sq ft per 1,000-sq ft lane area.

Various agencies have modified this equation by correlating slope variance with other roughness measurement devices and some have eliminated the use of distress measurement. The calculated PSI of the inner and outer lanes may be available from research reports. Only one value of PSI at a given date can be entered for a given lane.

R2. *Inspection date for PSI:* This is the date in day/month/year on which the measurements of road roughness, cracking, and patching for the determination of PSI took place.

*** R3.** *Skid number (SN) (wet):* The skid number, which represents the skid resistance of the pavement, is calculated as follows:

$$SN = 100 \times F/L$$

where F is the maximum frictional force developed by a wheel load, L. Several methods for measuring the skid resistance of a pavement are listed under item R5 on Sheet 11.

*** R4.** *Inspection date for SN:* This is the date in day/month/year on which the skid number measurement for the given lane took place.

*** R5.** *Equipment used to measure SN:* The skid number may

Exhibit 11

SHEET 11

ROUGHNESS, SKID, AND PSI DATA

-COPES-

Record	2.	1
State Code	37.	2-3
Proj. ID	1007.	4-7
Unif. Sect.	01.	8-9
Year	81.	10-11
Roughness Seq.	01.	12-13

	Left Lane (L).	Right Lane (R).	
R 1. Calculated PSI from roughness/distress measurements ...	3.4	3.5	14-17
R 2. Inspection date (day/month/year) for PSI	15/10/81	15/10/81	18-29
*R 3. Skid number (S N) (wet)	38.	38.	30-33
*R 4. Inspection date (day/month/year) for S N	15/10/81	15/10/81	34-45
*R 5. Equipment used to measure S N (left and right lanes)			
- Trailer (locked wheel with ASTM E274 standard tire)	....	.... [✓ 1]	46
- Mu meter	....	 2	
- Other (specify) ________	....	 3	
*R 6. Roughness Index (R I)	98.	102.	47-52
*R 7. Inspection date (day/month/year) for R I)	15/10/81	15/10/81	53-64
*R 8. Equipment used to measure R I (left and right lanes)			
- BPR Roughometer (in/mile)	....	 1	65
- May's Ride Meter (in/mile)	....	.... [✓ 2]	
- PCA Roughometer (in^2/mile)	....	 3	
- Profilograph (in/mile)	....	 4	
- GM Profilometer	....	 5	
- Other (specify) ________	....	 6	

*Variables that were found to be highly important.

66-78/BK
79-80/01

be measured using trailers with locked wheels, trailers with unlocked wheels making a yaw angle with the direction of travel (Mu meter), trailers with rolling wheels in the slip mode, and various other devices. Skid resistance should be measured in the outer wheel path. Devices commonly used for determining SN are listed on Sheet 11. The number corresponding to the device used on the project is circled.

- * **R6.** *Roughness Index (RI):* The term "roughness index" (RI) has been applied to both the sum of vertical deviations of a pavement surface profile over a specified distance, and the sum of vertical deviations between a vehicle body and axle. The devices used to measure RI are listed on Sheet 11.
- * **R7.** *Inspection date.* This is the date in day/month/year on which the roughness index measurement for the given lane took place.
- * **R8.** *Equipment used to measure RI:* Several different types of measuring devices are commercially available. Because these devices actually measure different parameters, each generally gives a different roughness index for the same pavement profile. Devices commonly used for measuring RI are the BPR roughometer, ride meter, PCA roughometer, profilograph, GM profilometer, and other devices. Devices commonly used to measure RI are listed on Sheet 11. The number corresponding to the equipment used on the project is circled.

AXLE LOAD DATA COLLECTION PROCEDURES

The axle load data (Record Number 3) are collected on the uniform section level and are recorded on Sheet 12. The data needed for this sheet can be calculated from W-4 loadometer sheets and should be provided for every 2 to 4 years of the life of the pavement. The data may be obtained from a loadometer or weigh-in-motion station near the project, a station representative of the project traffic, or statewide average figures for the highway type under consideration (e.g., rural Interstate). Each Sheet 12 pertains to data collected for one year for a given uniform section.

A sample W-4 table (1974 Utah Interstate Rural for Single-Unit Trucks) is shown in Figure 3(a). The "total probable number" of axles within a given weight range can be obtained directly from the W-4 tables for (1) tractor, semitrailer combinations; (2) semitrailer, trailer combinations; and (3) truck and trailer combinations. However, because the W-4 tables include axles from pickup, panel, and 2-axle, 4-tire trucks in the single-unit truck category, data from the W-4 tables must be corrected, as illustrated in the examples that follow.

Example 1. Calculate the probable number of single axles (excluding pickup and panel trucks and 2-axle, 4-tire trucks) in the range of 8,000 to 12,000 pounds which would be expected during the period in which single-unit trucks and axles on single-unit trucks are counted. Refer to Figure 3(a).

Exhibit 12

SHEET 12
* AXLE LOAD DATA
-COPES-

Record No.	3.	1
State Code	44.	2-3
Proj. ID	2151.	4-7
Unif. Sect.	02.	8-9
Year	74.	10-11

	SINGLE AXLE LOAD	%	
A 1.	Under 3,000	01.13	12-15
A 2.	3,000 - 6,999	09.17	16-19
A 3.	7,000 - 7,999	03.67	20-23
A 4.	8,000 - 11,999	33.13	24-27
A 5.	12,000 - 15,999	12.22	28-31
A 6.	16,000 - 17,999	06.23	32-35
A 7.	18,000 - 18,499	00.29	36-39
A 8.	18,500 - 19,999	0027	40-43
A 9.	20,000 - 21,999	00.00	44-47
A10.	22,000 - 23,999	0027	48-51
A11.	24,000 - 25,999	00.00	52-55
A12.	26,000 - 29,999	00.00	56-59
A13.	30,000 or over	00.00	60-63
	* Total SA =	66.39	
A14.	Average No. of Axles per Truck .... (single and tandem)	3.138	64-67 68-78/BK

*Variables that were found to be highly important. 79-80/01

	TANDEM AXLE LOAD	%	1-11/Dup.
A21.	Under 6,000	00.14	12-15
A22.	6,000 - 11,999	04.78	16-19
A23.	12,000 - 17,999	04.27	20-23
A24.	18,000 - 23,999	03.16	24-27
A25.	24,000 - 29,999	04.19	28-31
A26.	30,000 - 31,999	02.95	32-35
A27.	32,000 - 32,499	01.03	36-39
A28.	32,500 - 33,999	03.36	40-43
A29.	34,000 - 35,999	03.88	44-47
A30.	36,000 - 37,999	0349	48-51
A31.	38,000 - 39,999	01.19	52-55
A32.	40,000 - 41,999	00.84	56-59
A33.	42,000 - 43,999	00.16	60-63
A34.	44,000 - 45,999	00.00	64-67
A35.	46,000 - 49,999	00.16	68-71
A36.	50,000 or over	00.00	72-75
	* Total TA =	33.61	

* Note: % SA + % TA = 100.00

76-78/BK
79-80/02

STATE OF UTAH
FINAL IR
INCLUDES 1 STATIONS

PART 1 OF 5

TABLE W-4

STATE OF UTAH
FINAL IR
INCLUDES 1 STATIONS

NUMBER OF AXLE LOADS OF VARIOUS MAGNITUDES OF LOADED AND EMPTY TRUCKS AND TRUCK COMBINATIONS OF EACH TYPE WEIGHED. THE PROBABLE NUMBER OF SUCH LOADS AND THE EIGHTEEN KIP AXLE EQUIVALENTS OF EACH GENERAL TYPE AND OF ALL TYPES COUNTED DURING 1974 COMPARED TO CORRESPONDING DATA FOR 1972

	18 KIP AXLE EQUIVALENCY FACTOR		SINGLE-UNIT TRUCKS									
AXLE LOADS IN POUNDS AND EIGHTEEN KIP AXLE EQUIVALENCY ITEMS	RIGID PAVEMENT	FLEXIBLE PAVEMENT	PANEL AND PICKUP (UNDER 1 TON)		2 AXLE 4 TIRE		2 AXLE 6 TIRE		3 AXLE		SINGLE-UNIT TRUCKS PROBABLE NO.	
	P=2.5, C=9''	P=2.5, SN=5	1974	1972	1974	1972	1974	1972	1974	1972	1974	1972
							SINGLE AXLES					
UNDER 3,000	0.0002	0.0002	8	1	1	1	3	4	0	0	2361	1824
3,000 - 6,999	0.0050	0.0050	3	1	5	1	22	26	0	0	2335	2048
7,000 - 7,999	0.0260	0.0320	0	0	0	0	1	4	0	1	16	64
8,000 - 11,999	0.0820	0.0870	1	0	0	0	13	7	2	0	508	71
12,000 - 15,999	0.3410	0.3600	0	0	0	0	1	3	0	0	16	30
16,000 - 18,000	0.7830	0.7960	0	0	0	0	4	0	0	0	64	0
18,001 - 18,500	1.0650	1.0600	0	0	0	0	0	0	0	0	0	0
18,501 - 20,000	1.3360	1.3070	0	0	0	0	0	0	0	0	0	0
20,001 - 21,999	1.9260	1.8260	0	0	0	0	0	0	0	0	0	0
22,000 - 23,999	2.8180	2.5830	0	0	0	0	0	0	0	0	0	0
24,000 - 25,999	3.9760	3.5330	0	0	0	0	0	0	0	0	0	0
26,000 - 29,999	6.2890	5.3890	0	0	0	0	0	0	0	0	0	0
30,000 OR OVER	11.3950	9.4320	0	0	0	0	0	0	0	0	0	0
TOTAL SINGLE AXLES WEIGHED			12	2	6	2	44	44	2	1		
TOTAL SINGLE AXLES COUNTED			3110	2706	1448	862	700	446	42	23	5300	4037
							TANDEM AXLE GROUPS					
UNDER 6,000	0.0100	0.0100	0	0	0	0	0	0	0	0	0	0
6,000 - 11,999	0.0100	0.0100	0	0	0	0	0	0	1	1	21	23
12,000 - 17,999	0.0620	0.0440	0	0	0	0	0	0	1	0	21	0
18,000 - 23,999	0.2530	0.1480	0	0	0	0	0	0	0	0	0	0
24,000 - 29,999	0.7290	0.4260	0	0	0	0	0	0	0	0	0	0
30,000 - 32,000	1.3050	0.7580	0	0	0	0	0	0	0	0	0	0
32,001 - 32,500	1.5425	0.8850	0	0	0	0	0	0	0	0	0	0
32,501 - 33,999	1.7510	1.0026	0	0	0	0	0	0	0	0	0	0
34,000 - 35,999	2.1656	1.2300	0	0	0	0	0	0	0	0	0	0
36,000 - 37,999	2.7210	1.5330	0	0	0	0	0	0	0	0	0	0
38,000 - 39,999	3.3730	1.8850	0	0	0	0	0	0	0	0	0	0
40,000 - 41,999	4.1290	2.2890	0	0	0	0	0	0	0	0	0	0
42,000 - 43,999	4.9970	2.7490	0	0	0	0	0	0	0	0	0	0
44,000 - 45,999	5.9870	3.2690	0	0	0	0	0	0	0	0	0	0
46,000 - 49,999	7.7250	4.1700	0	0	0	0	0	0	0	0	0	0
50,000 OR OVER	10.1600	5.1000	0	0	0	0	0	0	0	0	0	0
TOTAL TANDEM AXLES WEIGHED			0	0	0	0	0	0	2	1		

Figure 3(a). Sample W-4 table.

2-axle/6-tire trucks

13 axles weighed between 8,000 and 12,000 pounds
44 *total* axles weighed with given axle configuration
700 *total* axles counted

3-axle trucks

2 axles weighed between 8,000 and 12,000 pounds
2 *total* axles weighed with given axle configuration
42 *total* axles counted

The probable number of single axles on single-unit trucks weighing between 8,000 and 12,000 pounds during the period in which single-unit trucks and axles on single-unit trucks were counted is:

$$(13/44 \times 700) + (2/2 \times 42) = 248.8, \text{ say 249 single axles}$$

This value is then entered on the Axle Load Distribution Analysis—Sheet 1 of 2 worksheet, shown in Figure 3(b), and used for obtaining the percentage of axles within each given weight range.

Example 2. Example 2 considers the 8,000- to 12,000-pound single-axle load range.

1,698 axles expected to weigh between 8,000 and 12,000 pounds
5,124 total axles (probable number)
Percent of all axles = 1698/5124 × 100 percent
= 33.13 percent

This value is entered for item A4 on Sheet 12. The axle load data are required to calculate the load distribution factor (LDF), which is the mean number of equivalent 18-kip single-axle loads per truck for a given year. The LDF is required data for the traffic volume data (Sheet 13) and can be either calculated by hand using the "Axle Load Distribution Analysis Sheet 2 of 2" shown in Figure 3(c), or generated by computer using the data entered on Sheet 12.

Axle Load Data (Sheet 12—see Exhibit 12)

- *Record Number:* This variable identifies the data record in the COPES data bank. Equal to 3, it identifies the axle load data record.
- *State Code:* (same as for Design data)
- *Project ID:* (same as for Design data)
- *Uniform Section:* (same as for Design data)
- *Year:* This is the last two digits of the year for which the W-4 table applies (e.g., 84).
- **A1 through A13.** *Single-axle load percentages:* These are the percentages of single axles (trucks only) in the given weight ranges, as calculated using W-4 tables. Note that pickup, panel, and 2-axle, 4-tire trucks are excluded.

A14. *Average number of axles per truck:* This is the average total number of single and tandem axles counted on all trucks observed. Again, pickup, panel, and 2-axle, 4-tire trucks are excluded.

- **A21 through A36.** *Tandem axle load percentages:* These are the percentages of tandem axles in the given weight ranges, as calculated using W-4 tables. Pickup, panel, and 2-axle, 4-tire trucks are excluded. Also note that the single and tandem axle percentages must sum to 100.00.

TRAFFIC VOLUME DATA COLLECTION PROCEDURES

The traffic volume data (Record Number 4) are collected on the uniform section level and are recorded on Sheet 13. *All data on Sheet 13 are essential and must be collected.*

There are many ways to analyze traffic data, but for the sake of uniformity the following basic procedure is used in COPES:

1. Information about average daily traffic (one way) and average daily truck traffic (one way, excluding pickup, panel, and 2-axle, 4-tire trucks) is obtained from an appropriate state highway agency. State highway agencies have maintained traffic counts at various locations for many years. Thus, several years of traffic data can be obtained for a point on or near the given project. These data should be plotted versus time to obtain approximate traffic figures for years when traffic counts were

AXLE LOAD DISTRIBUTION ANALYSIS - SHEET 1 of 2

State UTAH Year 74 Highway System I-R

GROUP NO.	GROUP WT. (kips)	SINGLE UNIT TRUCKS*	TRACTOR SEMI-TRAIL COMB.	SEMI-TRAILER TRAIL.C	TRUCK & TRAILER COMB.	ALL TRUCKS	PERCENT OF ALL AXLES
Single Axles							
1	under 3	48	6	0	4	58	1.13
2	3 to 7	350	60	19	41	470	9.17
3	7 to 8	16	81	82	9	188	3.67
4	8 to 12	249	784	600	65	1698	33.13
5	12 to 16	16	79	531	0	626	12.22
6	16 to 18	64	46	186	23	319	6.23
7	18 to 18.5	0	8	7	0	15	0.29
8	18.5 to 20	0	0	0	14	14	0.27
9	20 to 22	0	0	0	0	0	0
10	22 to 24	0	0	14	0	14	0.27
11	24 to 26	0	0	0	0	0	0
12	26 to 30	0	0	0	0	0	0
13	30 or over	0	0	0	0	0	0
		743	1064	1439	156	3402	66.38
Tandem Axles							
14	under 6	0	7	0	0	7	0.14
15	6 to 12	21	212	0	12	245	4.78
16	12 to 18	21	154	0	44	219	4.27
17	18 to 24	0	162	0	0	162	3.16
18	24 to 30	0	198	0	17	215	4.19
19	30 to 32	0	144	7	0	151	2.95
20	32 to 32.5	0	53	0	0	53	1.03
21	32.5 to 34	0	136	27	9	172	3.36
22	34 to 36	0	190	0	9	199	3.88
23	36 to 38	0	174	0	5	179	3.49
24	38 to 40	0	61	0	0	61	1.19
25	40 to 42	0	38	0	5	43	0.84
26	42 to 44	0	8	0	0	8	0.16
27	44 to 46	0	0	0	0	0	0.00
28	46 to 50	0	8	0	0	8	0.16
29	50 or over	0	0	0	0	0	0.00
		42	1575	34	71	1722	100.00
Total Single Axles (Probable No.)		743	1064	1439	156	3402	5124
Total Tandem Axles (Probable No.)		42	1575	34	71	1722	
Total Vehicles Counted*		392	867	296	78	1633	

* Exclude pickup, panel, and 2 axle/4 tire trucks.

Figure 3(b). Sample worksheet, axle load distribution analysis, sheet 1 of 2.

AXLE LOAD DISTRIBUTION ANALYSIS - SHEET 2 of 2

State UTAH Year 74 Highway System I-R

GROUP NO.	GROUP WT. (kips)	PERCENTAGE OF AXLES (p_i)	EQUIVALENCY FACTOR(EF_i) (rigid pvt.)	PERCENT X EQUIV. FACTOR
Single Axles				
1	under 3	1.13	0.0002	0.0002
2	3 to 7	9.17	0.0050	0.0459
3	7 to 8	3.67	0.0260	0.0954
4	8 to 12	33.13	0.0820	2.717
5	12 to 16	12.22	0.3410	4.167
6	16 to 18	6.23	0.7830	4.878
7	18 to 18.5	0.29	1.0650	0.3089
8	18.5 to 20	0.27	1.3360	0.3607
9	20 to 22	0.00	1.9260	0.0000
10	22 to 24	0.27	2.8180	0.7609
11	24 to 26	0.00	3.9760	0.0000
12	26 to 30	0.00	6.2890	0.0000
13	30 or over	0.00	11.395	0.0000
Tandem Axles				
14	under 6	0.14	0.0100	0.0196
15	6 to 12	4.78	0.0100	0.0478
16	12 to 18	4.27	0.0620	0.2647
17	18 to 24	3.16	0.2530	0.7995
18	24 to 30	4.19	0.7290	3.055
19	30 to 32	2.95	1.3050	3.850
20	32 to 32.5	1.03	1.5420	1.586
21	32.5 to 34	3.36	1.7510	5.883
22	34 to 36	3.88	2.1650	8.400
23	36 to 38	3.49	2.7210	9.496
24	38 to 40	1.19	3.3730	4.014
25	40 to 42	0.84	4.1290	3.468
26	42 to 44	0.16	4.9970	0.800
27	44 to 46	0.00	5.9870	0.000
28	46 to 50	0.16	7.7250	1.236
29	50 or over	0.00	10.1600	0.000
		100.00	Σp_i EF_i =	56.254%

Calculation of Load Distribution Factor (LDF):

ESAL/Axle = Σp_i EF_i = 56.254%

Ave. Axles/Truck = $\frac{\text{Total S.A. + Total T.A.}}{\text{Total Vehicles Counted*}} = \frac{3402+1722}{1633} = 3.138$

LDF = Axles/Truck * ESAL/Axle = 3.138 * 0.56254

LDF = 1.765 ESAL/truck

* Excluding pickup, panel, and 2 axle/4 tire trucks.

Figure 3(c). Sample worksheet, axle load distribution analysis, sheet 2 of 2.

not obtained and to identify possible inconsistencies in the data (see Fig. 4).

2. The one-way load distribution factor is calculated using the axle load data (from W-4 tables). These data are also plotted versus time (see Fig. 5).

3. The lane distribution factor for trucks (excluding pickup, panel, and 2-axle, 4-tire trucks) can be obtained by using empirical equations presented on succeeding pages. These were developed using data obtained from several states using Sheet 7F, which is shown in Exhibit 15(h). Since most states have very little truck lane distribution data available, these equations may be the best way to estimate truck lane distributions. They can be used to easily obtain the required lane distribution factors over time. It is *not* recommended that the raw data obtained from Sheet 7F be used for estimating lane distribution factors. Lane distribution is *highly* variable with time and a small sample may not be as accurate as the predictive equations, which were developed using over 100 data points.

4. For analysis purposes, (e.g., to easily calculate cumulative equivalent single-axle loads on the pavement to a particular date), data on ADT, ADTT, load distribution factors, and lane distribution must be entered for every year during the life of the pavement, beginning with the year the pavement was opened to traffic. This is accomplished by reading values from the plots prepared in the previous steps, as shown on Figures 4 and 5.

5. Future traffic data can be easily entered into the data bank at any time.

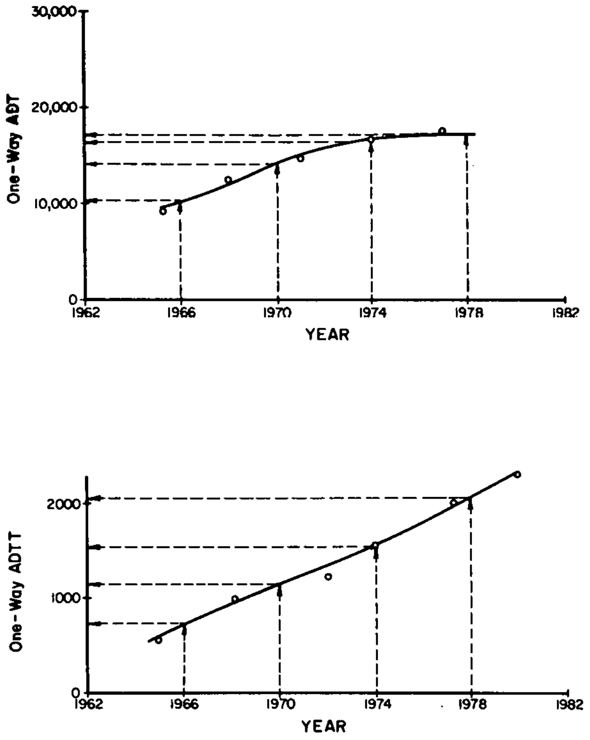


Figure 4. Illustration of plots used to obtain ADT and ADTT over time for a given project.

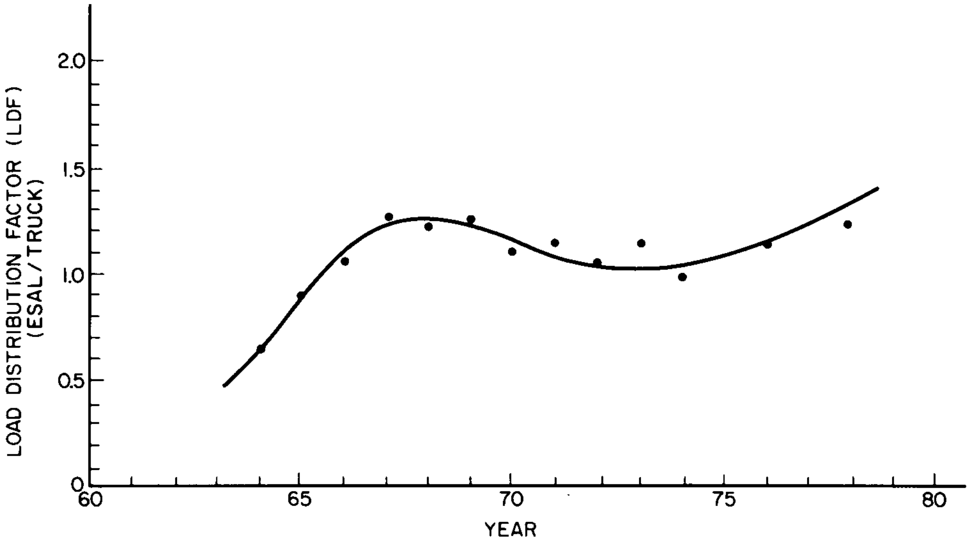


Figure 5. Illustration of the variability and trend of the average equivalent single-axle load per truck versus time.

Traffic Volume Data (Sheet 13—see Exhibit 13)

- * *Record Number:* This variable identifies the data record in the COPES data bank. Equal to 4, it identifies the traffic volume data record.
- * *State Code:* (same as for Design data)
- * *Project ID:* (same as for Design data)
- * *Uniform Section:* (same as for Design data)
- * *Year:* This is the last two digits of the year. Data should be entered for every year, beginning with the year that the pavement was opened to traffic (item D44) and continuing through the last year in which a field survey was conducted.
- * **T1.** *One-way average daily traffic (ADT):* This is the one-way average traffic volume which includes *all* vehicles. ADT values can be plotted versus time to obtain approximate volumes for intermediate years (see Fig. 4).
- * **T2.** *One-way average daily truck traffic (ADTT):* This is the one-way average daily truck traffic across *all* traffic lanes, excluding pickup, panel, and 2-axle, 4-tire trucks. ADTT values can be plotted versus time to obtain approximate values for intermediate years (see Fig. 4).
- * **T3L,** * **T3R.** *One-way lane distribution, trucks:* This is the proportion of trucks (with respect to the total number of trucks traveling in one direction) which travel in the given lane. In all cases, pickup, panel, and 2-axle, 4-tire trucks are excluded.

For example, consider a divided highway with two lanes in one direction. Of all the trucks traveling in these two lanes, 90 percent may be in the right lane and 10 percent in the left lane. Thus, T3L = 0.10 and T3R = 0.90. If there were three lanes in the same direction and trucks were distributed from left to right as 8, 39, and 53 percent, then T3L = 0.39 and T3R = 0.53.

The lane distribution of trucks is obtained using the COPES lane distribution equations given below:

1. *Proportion of all one-directional trucks in outermost right lane:*

$$T3R = [1.567 - 0.0826 * \text{Ln (One-Way ADTT)} - 0.12368 * LV]/100$$

where:

LV = 0 if the number of lanes in one direction is 1 or 2;
LV = 1 if the number of lanes in one direction is 3 or more; and
Ln = natural logarithm (base = 2.71).

Statistics: R-squared = 0.52
Std. Dev. = 13.0
n = 129 cases from six states

2. *Proportion of all one-directional trucks in lane adjacent to (to the left of) outermost lane:*

$$T3L = [0.520 + 0.0772 * \text{Ln (One-Way ADTT)} + 0.0564 * LV]/100$$

where:

LV = 0 if the number of lanes in one direction is 1 or 2;

Exhibit 13

SHEET 13

TRAFFIC VOLUME DATA

-COPES-

Record No. 4. 1
State Code 44. 2-3
Proj. ID 1511. 4-7
Unif. Sect. 01. 8-9

	YEAR (YEAR)	ONE-WAY ADT (*T1)	ONE-WAY ADTT[a] (*T2)	ONE-WAY LANE DISTRIBUTION[b] (TRUCKS[a]) LEFT LANE (*T3L)	RIGHT LANE (*T3R)	ONE-WAY LOAD DISTRIBUTION FACTOR[a] (* T4)	ONE-WAY NUMBER OF LANES ACROSS HIGHWAY (* T5)	
	76.	14800.	01510.	.28	0.65	1.230	3.	10-31 32-78/BK 79-80/01
1-9/Dup.	77.	15750.	01630.	.28	0.65	1.180	3.	10-31 32-78/BK 79-80/01
1-9/Dup.	78.	16500.	01740.	.29	0.64	1.180	3.	10-31 32-78/BK 79-80/01
1-9/Dup.	79.	17000.	01790.	.29	0.64	1.240	3.	10-31 32-78/BK 79-80/01
1-9/Dup.	80.	17200.	01800.	.29	0.64	1.300	3.	10-31 32-78/BK 79-80/01
1-9/Dup.	81.	17400.	01825.	.29	0.64	1.345	3.	10-31 32-78/BK 79-80/01

[a] Excluding Pickup and Panel Trucks, and 2 axle/4 tire Trucks.

[b] Distribution across lanes must sum to 1.00 for 2 lane highways in one direction, and must sum to less than 1 for highways of 3 lanes or more in one direction. Right Lane Distribution factor must equal 1.00 for highways of one lane in one direction.

*Variables that were found to be highly important.

LV = 1 if the number of lanes in one direction is 3 or more; and
Ln = natural logarithm (base = 2.71).

Statistics: R-squared = 0.47
Std. Dev. = 11.0
n = 129 cases from six states

NOTE: (1) If there are only two lanes in one direction, the T3L is calculated as 1.00 − T3R. (2) If there are three or more lanes in one direction, the proportion of trucks in the inner lane(s) is calculated as 1.00 − T3R − T3L. This proportion applies to all lanes inside of the outermost two lanes regardless of the number.

Figure 6 has been prepared using these equations to show the typical values obtained.

- * **T4.** *One-way load distribution factor:* This is the mean 18-kip equivalent single-axle load (ESAL) applied per truck (excluding pickup, panel, and 2-axle, 4-tire trucks). It is obtained from the axle load data, and should be plotted versus time to obtain approximate values for every year (see Fig. 5). The LDF typically ranges from 0.75 to 1.50 or higher.
- * **T5.** *Total number of lanes across entire highway (one-way):* This is the total number of lanes on the highway in one direction of travel. This variable must remain constant within a uniform section. It can, however, vary with time (e.g., a lane may be added 10 years after the original pavement was constructed).

One-Way ADT	2 Lanes (One-Direction)		3+ Lanes (One-Direction)		
	Inner	Outer	Inner*	Center	Outer
2,000	6**	94	6	12	82
4,000	12	88	6	18	76
6,000	15	85	7	21	72
8,000	18	82	7	23	70
10,000	19	81	7	25	68
15,000	23	77	7	28	65
20,000	25	75	7	30	63
25,000	27	73	7	32	61
30,000	28	72	8	33	59
35,000	30	70	8	34	58
40,000	31	69	8	35	57
50,000	33	67	8	37	55
60,000	34	66	8	39	53
70,000	--	--	8	40	52
80,000	--	--	8	41	51
100,000	--	--	9	42	49

* Combined inner one or more lanes.
** Percent of all trucks in one direction (note that the proportion of trucks in one direction sums to 100 percent).

Figure 6. Truck distribution for multiple-lane controlled-access highways (computed from models developed using 129 traffic counts in six states 1982–1983).

NOTE: There are other variables which can be generated using the COPES data bank that have been allocated space in the COPES data bank. Traffic variables include the following:

- * **TESALL,** * **TESALR.** *One-way equivalent single-axle loads per year in left or right lanes:* These are the cumulative number of 18-kip equivalent single-axle loads in the left and right lanes, respectively, applied during a given year. It is calculated using the following equation:

One-Way ESAL (year i) = One-way ADTT$_i$ * Lane Distribution$_i$ * Load Distribution Factor$_i$ * 365
(For left lane): TESALL = T2 * T3L * T4 * 365
(For right lane): TESALR = T2 * T3R * T4 * 365

Examples 3, 4, and 5 illustrate how the traffic volume data are used to generate the ESAL's:

Example 3.

Two-lane highway (one direction)
ADT (one direction) = 5,000 vehicles/day
ADTT (one direction) = 1,000 trucks/day
Load Distribution Factor = 1.350 18-kip ESAL/truck

Uniform Section 01, Left Lane: 14 percent trucks
Uniform Section 01, Right Lane: 86 percent trucks
Total = 100 percent

ADTT, Left Lane, one way = 0.14 * 1,000 = 140 trucks/day
TESALL = 0.14 * 1,000 * 1.350 * 365
= 68,985 18-kip ESAL/year

ADTT, Right Lane, one way = 0.86 * 1,000 = 860 trucks/day
TESALR = 0.86 * 1,000 * 1.350 * 365
= 423,765 18-kip ESAL/year

Example 4.

Three-lane highway (one direction)
ADT (one direction) = 5,000 vehicles/day
ADTT (one direction) = 1,000 trucks/day
Load Distribution Factor = 1.650 18-kip ESAL/truck

Uniform Section 07, Right Lane:	7 percent trucks
Uniform Section 02, Left Lane:	19 percent trucks
Uniform Section 02, Right Lane:	74 percent trucks,
Total =	100 percent

For Uniform Section 02
ADTT, Left Lane, one way = 0.19 * 1,000 = 190 trucks/day
TESALL = 0.19 * 1,000 * 1.650 * 365
= 114,427 18-kip ESAL/year

ADTT, Right Lane, one way = 0.74 * 1,000 = 740 trucks/day
TESALR = 0.74 * 1,000 * 1,650 * 365
= 5,665 18-kip ESAL/year

Example 5.

One-lane highway (one direction)
ADT (one direction) = 5,000 vehicles/day
ADTT (one direction) = 1,000 trucks/day
Load Distribution Factor = 1.500 18-kip ESAL/truck

Uniform Section 03, Left Lane: 0 percent trucks
Uniform Section 03, Right Lane: 100 percent trucks

TESALR = 1,000 * 1.00 * 1.500 * 365
= 547,500 18-kip ESAL/year

*** TCUML, * TCUMR.** *One-way cumulative single-axle loads in right or left lane over life of pavement to date of survey:* Assuming that traffic data have been entered each year for the entire life of the pavement, this variable is the number of cumulative 18-kip equivalent single-axle loads applied to the left and right lanes, respectively, from the date of opening to the desired year (e.g., the year of a field survey).

MAINTENANCE DATA COLLECTION PROCEDURES

The maintenance and rehabilitation data (Record Number 5) are collected on the uniform section level and are recorded on Sheet 14. Because there can be multiple occurrences of maintenance activities in a given year, the data bank is structured to allow for 99 entries in the "maintenance sequence" variable per "year." Also, up to 99 "years" of maintenance data per uniform section are allowed.

Maintenance Data (Sheet 14—see Exhibit 14)

Record Number: This variable uniquely identifies the data record in the COPES data bank. Equal to 5, it identifies the Maintenance Data record.

State Code: (same as for Design Data)

Project ID: (same as for Design data)

Uniform Section: (same as for Design data)

Year: (same as for Roughness data)

Maintenance Sequence: A two-digit number is used to identify multiple occurrences of any maintenance activity in a given year. Up to 99 activities are allowed for a given project in a given year.

M1. *Work type*: The maintenance and rehabilitation record of a pavement is important because it enables the investigator to more accurately evaluate the performance of the pavement. Many types of maintenance and rehabilitation work are listed on the "Maintenance and Rehabilitation Work Codes" sheet in Appendix B. The code numbers corresponding to the maintenance activities performed are entered in this column. This information, if available, may be obtained from maintenance records and rehabilitation construction reports. Note that patches are recorded during the field survey, but it is also desirable to find out when they were placed if possible.

M2. *Location on pavement:* Locations where maintenance and/or rehabilitation work are commonly performed are listed on the "Maintenance Location on Pavement Code" sheet in Appendix B. The code number corresponding to the location on the pavement where work has been done is entered in this column.

M3. *Maintenance material:* Commonly used maintenance materials are listed on the "Maintenance Materials Type Codes" sheet in Appendix B. The code number corresponding to the material used for maintenance is entered in this column. This information may be obtained from maintenance and rehabilitation records.

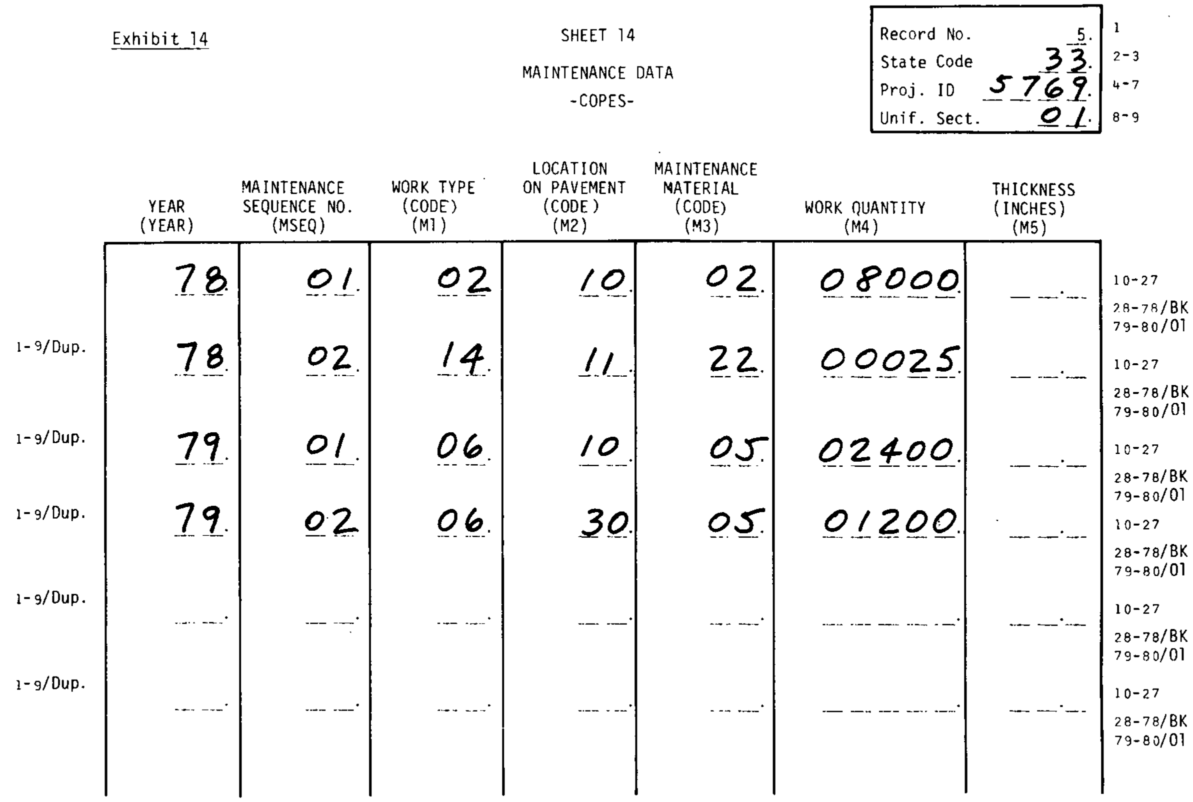


Exhibit 14

SHEET 14
MAINTENANCE DATA
-COPES-

Record No.	5	1
State Code	33	2-3
Proj. ID	5769	4-7
Unif. Sect.	01	8-9

	YEAR (YEAR)	MAINTENANCE SEQUENCE NO. (MSEQ)	WORK TYPE (CODE) (M1)	LOCATION ON PAVEMENT (CODE) (M2)	MAINTENANCE MATERIAL (CODE) (M3)	WORK QUANTITY (M4)	THICKNESS (INCHES) (M5)	
	78	01	02	10	02	08000		10-27 28-78/BK 79-80/01
1-9/Dup.	78	02	14	11	22	00025		10-27 28-78/BK 79-80/01
1-9/Dup.	79	01	06	10	05	02400		10-27 28-78/BK 79-80/01
1-9/Dup.	79	02	06	30	05	01200		10-27 28-78/BK 79-80/01
1-9/Dup.								10-27 28-78/BK 79-80/01
1-9/Dup.								10-27 28-78/BK 79-80/01

M4. *Work quantity:* The quantity of maintenance and rehabilitation work performed on the pavement is entered under this column. This information may be obtained from maintenance and rehabilitation records. The units normally used for certain work types are already written next to the work types on the "Maintenance and Rehabilitation Work Codes" sheet.

M5. *Thickness (in.):* This is the thickness, in inches, of any extra layer that may have resulted from the maintenance or rehabilitation work performed on the pavement.

FIELD DATA COLLECTION PROCEDURES

The field data collection procedures are used to obtain all needed field data from a given highway construction project during a single visit to that project. The procedures are subdivided into four areas: (1) sampling plan; (2) organization of the survey team; (3) description of the field data collection procedures; and (4) suggestions and notes, checklist, and flow chart of the duties of each member of the survey team. In addition, samples of the data sheets, shown in Exhibits 15(a) through 15(i), are included for easy reference. Every attempt has been made to produce a uniform set of data sheets and procedures for use on JRCP, CRCP, and JPCP. There are slight differences in the procedures for each type of pavement, so it is important that the user thoroughly familiarize himself with the data collection procedures, the data sheets, the distress identification guidelines in Chapter Two, and the instructions printed on the data sheets.

Project Sampling Plan

The objective of the sampling plan is to obtain the required data with an acceptable degree of precision with the minimum expenditure of resources and within acceptable time constraints. The field data required mainly consist of pavement distress measurements.

Portland cement concrete (PCC) pavement projects are not always uniform along their entire length. Changes in characteristics such as structural design, construction, materials, traffic volume, and foundation soil conditions result in nonuniformity and cause variations in distress occurrence along the concrete pavement.

If a significant change in these conditions exists along a project, the project should be divided into two or more uniform sections. A uniform section has the following *uniform* characteristics along its length:

- Structural design.
- Joint and reinforcement design.
- Truck traffic.
- Number of lanes across entire highway (one direction).
- Subgrade conditions (shallow cuts and low fills should normally not be considered as nonuniform).
- Construction by same contractor.
- Opened to traffic same year.
- Pavement materials (such as coarse aggregate source where one aggregate source has caused deterioration of the concrete).
- General distress occurrence (type, severity, and quantity).
- Maintenance applied.
- Same local governmental jurisdiction.

In most cases, the entire construction project length may be considered a uniform section. The standard uniform section layout is shown on Figure 1, and some examples are shown on Figure 7.

Each uniform section may vary in length from less than a mile to several miles. The maximum allowable length for a uniform section is 10 miles; only rarely will a pavement have the same uniform characteristics for greater distances.

A condition survey inspection of an *entire uniform section,* especially for some distress types (such as joint faulting or joint spalling), requires a large amount of effort and time. Therefore, a sampling plan should be used to allow for the inspection of only a portion of the uniform section for most distresses. Swells and depressions are the only distresses measured over the entire uniform section.

Use of a statistical sampling plan can reduce inspection time considerably without resulting in a significant loss of accuracy. Several commonly used sampling methods are available. The stratified random sampling procedure was selected for COPES because it is easy to apply and gives excellent results. This procedure has been used extensively to survey pavements and is used in many applications in industry.

Each uniform section is divided into *sample units,* which should be approximately 0.1 mile in length so that the car odometer or mile markers can be used to locate the sample unit if no stations are stamped in the slab. Thus, for a JRCP with a joint spacing of 100 ft, 5 or 6 slabs would be included in each sample unit. The 0.1-mile length would also be used for JPCP and CRCP.

One problem with sampling procedures is determining how many sample units must be measured, so that a reasonable estimate can be made of the mean of each distress type in the uniform section. Analysis has shown that normally *one sample unit must be surveyed for every ten* in the uniform section to obtain a reasonable degree of accuracy in the pavement survey.

The next step is to determine which sample units should be measured. This is accomplished using stratified random sampling techniques. The uniform section is divided into a number of "strata," each consisting of a series of sample units. Sample units are selected for survey from each stratum according to the sampling rate (e.g., one surveyed sample for every ten sample units in the uniform section or stratum).

Two techniques have been used by COPES survey crews to select survey sample units. The simpler and much preferred technique is to survey sample units at each milepost marker. This greatly simplifies the selection of sample units to be surveyed and allows the survey team to easily and quickly find the sample unit when resurveying the pavement in future years. An example of this technique is as follows:

Example 6.

3.69-mile project, 20-ft slabs, one uniform section.
Project begins at milepost 258.20 and ends at milepost 261.89.

Sample unit length = 600 ft/sample unit (which is approximately 0.1 mile, a convenient length to use).

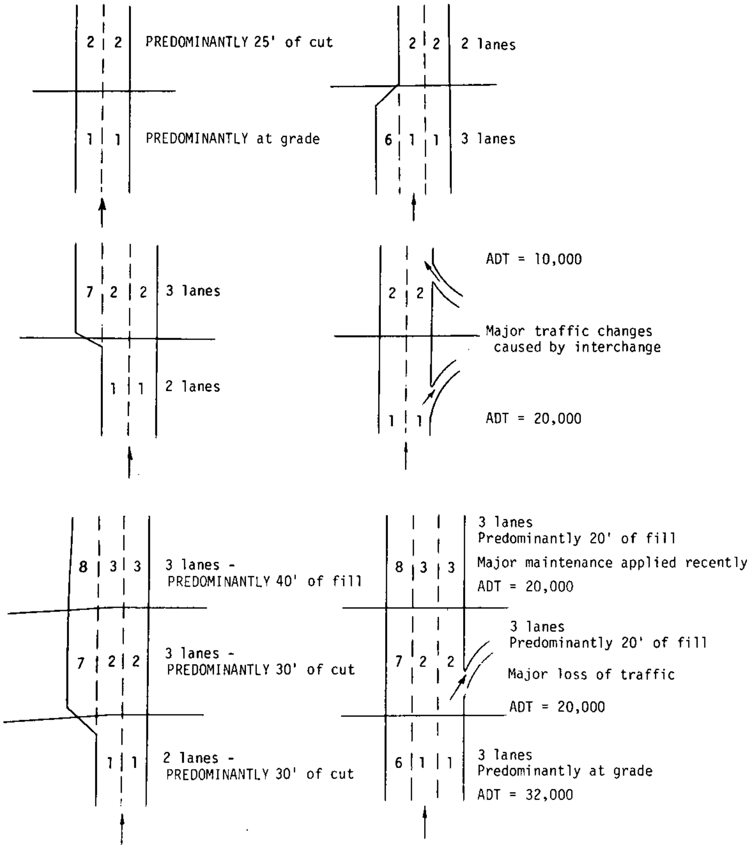


Figure 7. Example of uniform section assignment (all traffic is one-directional).

Uniform section length = 3.69 miles × 5,280 ft/mile
= 19,483 ft

19,483 ft/600 ft/sample unit = 32.5 sample units

A 10 percent sample requires surveying three or four sample units. Simplified, because a 10 percent sample is desired and the sample units are approximately 0.1 mile long, one sample unit per mile is needed.

Three sample units can easily be selected by surveying at mileposts 259, 260, and 261. If four sample units are desired, the remaining sample unit is selected near either the beginning or end of the uniform section, using an alternate technique (explained later) for selecting sample units.

By surveying a sample unit near each milepost, a stratified sample is assured. If one of the sample units contains a secondary structure or is located in an interchange, begin the sample unit survey in the immediate vicinity to avoid the structure of interchange.

The alternate technique for selecting survey sample units is as follows:

1. Determine the length of the sample unit (e.g., 600 ft or 6 slabs for 100-ft joint spacing, and 540 ft or 36 slabs for 15-ft joint spacing).
2. Determine the length of the uniform section in feet.
3. Divide the length of the uniform section by the length of the sample unit to obtain the total number of sample units in the uniform section.
4. These sample units are then consecutively numbered from one end of the uniform section (see Exhibit 15(i), Sheet 8F), and "stratified" into groups of 10 sample units.
5. A stratified sampling plan can then be implemented by selecting survey sample units using a random number table or random number-generating calculator.

A typical stratified sample is shown in the following example.

Example 7.

3.29-mile project, 100-ft slabs, one uniform section.
Sample unit length = 600 ft/sample unit.
Uniform section length = 3.29 miles × 5,280 ft/mile
= 17,371 ft
17,371 ft/600 ft/sample unit = 29 sample units in the uniform section.

Strata	Sample Unit No.	Selected Sample Unit No. Using Random Number Table
1	1–10	4
2	11–20	11
3	21–29	26

If one of the sample units contains a secondary structure (e.g., a bridge) that prevents surveying the complete sample unit, it should be deleted. A different sample unit in the stratum should be selected using a random number table or random number-generating calculator.

For projects located in urban areas where many interchanges exist, it will be necessary to select sample units that can most safely be surveyed (e.g., between interchanges).

Survey Team Organization

Experience has shown that a three-person crew is required to efficiently conduct the condition survey; however, it can be conducted by a two-person crew if necessary. The three-person crew consists of a supervisor, a technician, and a driver.

During each condition survey, data are collected in two passes of each lane of the construction project in two different steps. In step 1, one pass is made in a mid- to full-size sedan over each lane of the uniform section at the posted speed limit. In step 2, another pass is made, stopping to survey each selected sample unit in detail. All distress types and severity levels are measured and counted in accordance with the concrete pavement distress identification guide for highways (Chapter Two).

In step 1, the Supervisor's first job is to locate the boundaries of the construction project to be surveyed. He/she also decides whether the project will be surveyed in only one direction or in both directions based on the existing condition. The Supervisor determines the number of sample units within each uniform section and selects the required number of sample units to be surveyed in detail. The Driver then drives over all lanes in the direction to be surveyed at normal driving speeds. The Supervisor or Technician records the number of severity of depressions and swells in each lane during the normal-speed passes.

All crew members rate the ride quality of the pavement according to the standard present serviceability rating (PSR) procedure. A rating of 5 to 4 = very good, 4 to 3 = good, 3 to 2 = fair, 2 to 1 = poor, and 1 to 0 = very poor. They should rate the pavement condition as *users* of the highway pavement, *not* as *engineers.* The rating should be based on how well they feel the pavement is serving the existing traffic. It is mostly a rating of pavement roughness. The mean PSR of the crew is determined and recorded at the end of the first trip over each lane.

In step 2, after reaching a sample unit to be surveyed in detail, the Supervisor and Technician leave the car and walk the length of the sample unit. The Technician measures joint faulting and lane/shoulder separation. The Supervisor records these measurements and sketches all patches and cracks, labeling the medium- and high-severity cracks. The Supervisor and Technician also complete other data collection sheets as required. The Driver follows the other two members of the team, driving the automobile on the shoulder. At the discretion of the Supervisor, he/she completes data collection sheets while the Supervisor and Technician are out of the car.

It is important that all members of the crew familiarize themselves with all of the data sheets and also with the definitions of each type and severity level of distress.

Subject to certain contingencies (discussed below), the following survey time estimates based on extensive field experience are given for a uniform section mile (two lanes) with one sample unit:

Pavement Condition	Rural	Urban
Good	10–15 min	15–25 min
Fair	15–25 min	25–35 min
Poor	25–45 min	35–50 min

These estimates were obtained from a crew experienced with the data sheets and field techniques working on 2- to 5-lane (one direction) JPCP and JRCP, slab lengths from 15 to 100 ft, and traffic volumes of 1,000 to 75,000 ADT (one direction). Higher traffic levels and inexperienced crews will require longer survey times.

If a manpower shortage exists, a two-person crew can be used. The crew would consist of a Supervisor and a Technician, with the Technician performing the duties of the Driver. A two-person crew has many disadvantages, including a smaller PSR panel and a rather heavy work load falling on both crew members. The greatest disadvantages, however, are the decreases in safety and efficiency. With no Driver in the car while the Supervisor and Technician are walking along the sample unit, no barrier exists between the crew and traffic, because the car is at the beginning of the sample unit. Also, after a sample unit has been surveyed, the crew must walk 600 ft to return to the car, a considerable waste of time if many sample units need to be surveyed.

Duties and Responsibilities of the Supervisor

Before going into the field, it is the responsibility of the Supervisor to be certain that all materials and tools required for the day are in the possession of the crew. This includes safety vests and lights, an ample supply of all data sheets, strip maps, road maps, faultmeters and rulers, camera, film, pencils, and clipboards. He/she may enlist the help of the Technician and the Driver.

Prior to working on each project, the Supervisor locates the project on the strip map and highway map and fills out Sheet No. 1F (see Exhibit 15(a)). The Supervisor calculates the length of the project to help the Driver locate the end of the project more easily using the car odometer. The project may be divided into one or more uniform sections at this time based on traffic volume, time of construction, etc. The Supervisor must then prepare a set of blank data sheets by filling in the state, project number, etc., for each uniform section and each sample unit which will be surveyed.

The Supervisor should also designate a *Time Sequence* number to the survey which will be performed. The Time Sequence number is the numerical sequence of this survey with respect to all other surveys previously performed on this uniform section using the COPES data collection procedures. If no previous surveys have been performed, the Time Sequence should read 01. Alternatively, the last two digits of the year of survey may be used (e.g., 84) if surveys will be performed no more than once a year. The Time Sequence number must be the same on all the Field Data Collection Sheets (Nos. 2F, 3F, 4F, 5F, and 6FR or 6FP) for a given survey.

During the first pass, the Supervisor should check and record the milepost (and station) of the beginning and end of the project on Sheet No. 1F. A picture of that sheet should be taken so that it is clear that all subsequent pictures belong to that particular project. During the first pass in each lane the Supervisor (or Technician) completes a Sheet 2F (see Exhibit 15b) for each uniform section, recording all swells and depressions and noting the severity of each occurrence (i.e., low, medium, high). Minor roughness of the ride associated with joint faulting or patches should not be counted with depressions and swells. If the rater is not sure of whether or not to count a particular depression or swell, he/she probably should not count it. After each first pass, the Supervisor immediately obtains the PSR from the Technician and the Driver.

The Supervisor should also note the prevailing foundation conditions and complete Sheet 2F accordingly. At this time it may be decided to divide the project into two or more uniform sections based on nonuniform foundation conditions. (For example, if the first 4 miles of the project are predominantly in 40 ft of fill and the last 2 miles are at grade, two uniform sections would probably be required. See Figure 7). As the team approaches the end of the uniform section, the Supervisor should watch for some indication of the end (e.g., a construction joint or a shoulder change) and should note an appropriate landmark for reference on future passes.

During the return trips from the first passes, the Supervisor must select the sample units that will be surveyed in detail and prepare a set of sample unit data collection sheets for each sample unit to be surveyed. He/she should also watch for the sample unit to be surveyed and alert the Driver to the milepost of the beginning of the sample unit. The Supervisor also assigns each sample unit to be surveyed in detail a sequence number. This number is entered on Sheets 3F through 6F (-R or -P) (see Exhibits 15c through 15g).

The *sample unit sequence number* is defined as the numerical position of the sample unit being surveyed with respect to the other sample units that are to be surveyed in detail within the uniform section. For example, if sample units 8, 17, and 23 in a given uniform section are to be surveyed in detail (see Sheet 8F), sample unit 8 would be assigned sample unit sequence number 1, sample unit 17 would be assigned sequence number 2, and sample unit 23 would be assigned sequence number 3.

In the second pass, during the sample unit survey, the Supervisor gives Sheet 7F (see Exhibit 15h) to the Driver for completion by the end of the project. If traffic is very heavy, or if the view of the opposing traffic is obstructed, the Supervisor may choose to have this sheet completed at a later time or to neglect it. The Technician and the Supervisor then don safety vests (and hard hats if required) and leave the car to perform the sample unit survey. At this time the Supervisor records all measurements given him/her by the Technician and sketches the sample unit on Sheet 4F. This sketch includes all cracks, "D" cracking, expansion and construction joints, and permanent patches. These values will be tabulated on Sheet 5F at a later time. Typical joint spacings may be drawn in and copied in the office. All cracking is labeled by placing the letters "L," "M," or "H" over the affected area to indicate low-, medium-, or high-severity distress. "D"-cracked areas are noted using "DL," "DM," and "DH." It may be preferable to leave all low-severity areas unlabeled to reduce cluttering of the sketch. A low-severity crack then has no label, and a low-severity "D" crack is labeled "D." If it is impossible to obtain a particular reading, the recorder enters an "X" in that space so that it is clear that the reading was unobtainable and not forgotten.

Sheets 3F and 6F (-R or -P) should also be completed at this time, tallying all types and severities of distress identified on these data collection sheets (e.g., blowups, corner breaks, etc.).

If few permanent patches exist, it is often easy for the Supervisor to carry two clipboards, one with Sheet 4F and the other with Sheet 3F over Sheet 6F (-R or -P). Otherwise, the Supervisor may choose to have the Driver fill out Sheet 6F (-R or -P). Note that either Sheet 6F-R or Sheet 6F-P will be used in any given uniform section/sample unit, not both.

The Supervisor should also take many pictures of each sample unit. The first picture in each sample unit should be taken down the road to obtain a general overview of the sample unit for future reference. Subsequent pictures should be taken to provide documentation of typical distress types, severities, and quantities.

At the end of the project the Supervisor collects Sheet 7F from the Driver. This completes the duties of the Supervisor for a given project.

Duties and Responsibilities of the Technician

Before leaving the office the Technician assists in gathering all of the necessary materials for the day. These include safety vests, safety lights, faultmeters, rulers, and maps.

During each first pass, the Technician (or Supervisor) completes a Sheet 2F for each uniform section, recording all swells and depressions and noting the severity of each occurrence. Minor roughness of the ride associated with joint faulting or patches should not be counted with depressions and swells. If the rater is not sure of whether or not to count a particular depression or swell, he/she probably should not count it. After each first pass, he/she immediately obtains the PSR from the Supervisor and Driver, completes Sheet 2F, and returns it to the Supervisor.

On each first pass the Technician should keep the strip map handy for the Driver's reference to help the Driver locate the end of the project.

In the second pass, upon reaching the sample unit, the Supervisor and the Technician leave the vehicle, and the Technician measures all transverse joint faulting and mean lane/shoulder separation. For consistency, the readings taken with the faultmeter should be taken 1 ft from the pavement edge. This is illustrated in Figure 8. If slab 2 (Fig. 8) is lower than slab 1, the reading from the faultmeter is recorded as positive; otherwise, the readings are recorded as negative.

The measurement of transverse joint faulting is time consuming and relatively *dangerous*. Thus, only the minimum number of joints should be measured to provide a sufficiently accurate estimate of the mean faulting for the uniform section. The following number of joints are recommended for measurement:

Joint Spacing (ft)	Number of Joints Measured in Sample Unit
50–100	All joints
less than 50	7 to 10
Random Spacing (repeated every four slabs)	Two sets of 4 readings (one near the beginning and one near the end of the sample unit)

Exhibit 15(a)

SHEET 1F

FIELD DATA

-COPES-

NCHRP Project 1-19
Concrete Pavement
Evaluation System-COPES

Dept. of Civil Engineering
University of Illinois

State Code 37.
Proj. ID 1207.

CONSTRUCTION PROJECT REFERENCE DATA

Construction Project Locations:

Start Pt. Mile Mark 23.9

End Pt. Mile Mark 28.9

Start Pt. Station No. 625+00

End Pt. Station No. 2562+25

Construction Project Length (Miles)____ .

Highway No. US 120

Direction of Survey:

East .... [✓ 1]
West 2
North 3
South 4

Surveyor Initials m/A

Uniform Section Locations:

Uniform Section No.	Uniform Section Start Point		Number of Lanes	Location of Lanes
	Mile Marker	Station Number		
01	23.9	625+00	1 [✓ 2]	Outer 2
02				Outer 2
03				Outer 2
04				Outer 2
05				Outer 2
06				1st Inner 2
07				1st Inner 2
08				1st Inner 2
09				1st Inner 2
10				1st Inner 2
11				2nd Inner 2
12				2nd Inner 2
13				2nd Inner 2
14				2nd Inner 2
15				2nd Inner 2

SHEET 2F

Exhibit 15(b)

UNIFORM SECTION FIELD DATA

-COPES-

Record No. 6. 1
State Code 37. 2-3
Proj. ID 1207. 4-7
Unif. Sect. 01. 8-9
Time Sequence 01. 10-11

UNIFORM SECTION SURVEY

Uniform Section Location:

Start Pt. Mile Mark 23.9

End Pt. Mile Mark 28.9

Start Pt. Station No. ________

End Pt. Station No. ________

*U 1. Date Surveyed (day/month/year):

14/06/82 12-17

*U 2. Foundation:

Majority at grade .... [✓ 1] 18
Majority in cut 2
Majority in fill 3

*U 3. Depth of Typical Cut:

5 ft. or less .... [✓ 1] 19
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. 4

*U 4. Typical surface drainage in cut or at grade:

H* less than 2 ft. ..1 34
H between 2-5 ft. ...2
H greater than 5 ft. [✓ 3]
Tied Concrete Curb ..4

Other ____________5

*H=Distance from top of slab to bottom of side ditch or natural ground if no ditch.

*U 5. Height of typical fill:

5 ft. or less 1 35
6-15 ft. .... [✓ 2]
16-40 ft. 3
Greater than 40 ft. .4

36/BK

Record the number of occurances for each lane at each severity level.

	Distress Type/ Location	Left Lane Severity			
		L	M	H	
U6L.	Depressions	09.	02.	00.	20-25
U7L.	Swells	04.	00.	00.	26-31

	Right Lane Severity			
	L	M	H	
U6R.	10.	03.	00.	37-42
U7R.	04.	00.	00.	43-48

		Left Lane	
* U8L.	Mean Panel PSR	3.6	32-33

	Right Lane	
* U8R.	3.4	49-50

51-78/BK
79-80/01

*Variables that were found to be highly important.

Exhibit 15(c)

SHEET 3F

SAMPLE UNIT FIELD DATA

-COPES-

Record No. 7 — 1
State Code 37 — 2-3
Proj. ID 1207 — 4-7
Unif. Sect. 01 — 8-9
Time Sequence 01 — 10-11
Sample Unit Seq. 1 — 12

DISTRESS IDENTIFICATION

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	
	Distress type									1-12/Dup.
S 1L.	Blowup (No.)	00	00	00	13-18	S 1R.	00	00	00	13-18
S 2L.	Transverse Joint Spall (No. of Joints) (JPCP and JRCP only)	00	00	00	19-24	S 2R.	02	01	00	19-24
S 3L.	Longitudinal Joint Spalling (No. of Joints) (JPCP and JRCP only)	03	01	01	25-30	S 3R.	01	01	00	25-30
S 4L.	Reactive Aggregate Distress (% Area of Sample Unit)	000	000	000	31-39	S 4R.	000	000	000	31-39
S 5L.	Pumping (circle highest severity found)	0 [✓ 1]	2	3	40	S 5R.	0 1	[✓ 2]	3	40
S 6L.	Scaling, Map Cracking, or Crazing (circle highest severity found)	[✓ 0] 1	2	3	41	S 6R.	[✓ 0] 1	2	3	41
S 7L.	Longitudinal Joint Spalling (linear feet) (CRCP only)				42-50	S 7R.				42-50
S 8L.	Localized Distress (No. of Areas) (CRCP only)				51-56	S 8R.				51-56
S 9L	Edge Punchout (No.) (CRCP only)				57-62	S 9R.				57-62
S10L.	Construction Joint Deterioration (CRCP only)				63-68	S10R.				63-68

S11. Outer Shoulder Condition: — 69

- Very good 1
- Good 2
- Fair .... [✓ 3]
- Poor 4
- Very poor 5

S12. Foundation of Sample Unit: — 70

- Fill Greater than 40 Ft. 1
- Fill 16-40 ft. 2
- Fill 6-15 ft. .... [✓ 3]
- At Grade (5' fill to 5' cut) 4
- Cut 6-15 ft. 5
- Cut 16-40 ft. 6
- Cut Greater than 40' 7

S13. Expansion Joints (No.) .... 00 — 71-72

S14. Studded Tire Damage (Right Lane) — 73

- Yes 1
- No .... [✓ 2]

74-78/BK

79-80/01

S21. Transverse Joint Seal Damage (JRCP and JPCP) (Right Lane) — 69

- Low 1
- Medium .... [✓ 2]
- High 3

S22. Incompressibles in Transverse Joint (JRCP and JPCP) (Right Lane) — 70

- Yes .... [✓ 1]
- No 2

S23. Temporary Patching Present (Both Lanes) — 71

- None or Very Minor .... [✓ 1]
- Less than One-Half of the Joints 2
- Half or More of the Joints 3

72-78/BK

79-80/02

Exhibit 15(d)

SHEET 4F

SAMPLE UNIT FIELD DATA

-COPES-

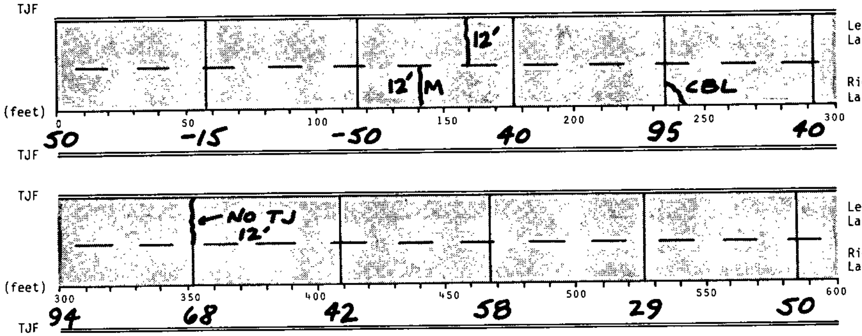
(58.5' Jt. Spacing)

State Code 37
Proj. ID 1207
Unif. Sect. 01
Time Sequence 01
Sample Unit Seq. 1

CRACKING AND FAULTING DATA

Start Pt. Mile Mark 24.00

Start Pt. Station No. ____________



1. Record crack pattern (indicate Medium (M) and High (H) severity; "D" Cracking severity as D_L, D_M, D_H
2. Measure Transverse Joint Faulting (TJF) at 1 foot in from pavement edge.
3. Also record corner breaks and cracking from improper joint construction.
4. Data from this sheet to be tabulated on Sheet 5F.
5. Mean Lane Shoulder Separation (inches) 0.10.

Exhibit 15(e)

SHEET 5F
SAMPLE UNIT FIELD DATA
-COPES-

Record No. 7.
State Code 37
Proj. ID 1207
Unif. Sect. 01
Time Sequence 01
Sample Unit Seq. 1

1-12/Dup.

CRACKING AND FAULTING DATA
(Tabulated from Sheet 4F)

*S31. Sample Unit Length (feet) 0585 13-16

*S32. Sample Unit Start Pt. - Mile Mark 024.00 17-21

S33. Sample Unit Start Pt. - Station No. 22-26

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	
	Distress Type									
S34L.	Longitudinal "D" Cracking (linear ft.)	0000	0000	0000	29-40	S34R.	0000	0000	0000	32-43
S35L.	Transverse "D" Cracking (linear ft.)	000	000	000	41-49	S35R.	000	000	000	44-52
S36L.	Longitudinal Cracking (linear ft.)	0000	0000	0000	50-61	S36R.	0000	0000	0000	53-64
S37L.	Transverse Cracking (linear ft.)	0012	0000	0000	62-73	S37R.	0000	0012	0000	65-76
S38L.	Corner Breaks (No.) (low, medium and high)			00	74-75	S38R.			01	77-78

76-78 /BK
79-80 /03
1-12/Dup

79-80 /04
1-12 /Dup

S39L.	Cracking from Improper Joint Construction (linear ft.)(low, med. & high)	0012	13-16	S39R			0000	13-16
S40L.	Transverse Joint Faulting (mean, inches) (JRCP/JPCP only)	.	17-19	S40R			0.05	17-19
S41L.	No. of Longitudinal Joint Faulting Areas	0	20	S41R			0	20
	Lane/Shoulder Separation (Circle Mean Severity Found)			S42R	[✓ 1]	2	3	21

21-71 /BK

22-78 /BK
79-80 /05

Exhibit 15(f)

SHEET 6F-R
SAMPLE UNIT FIELD DATA
-COPES-

Record No. 7.
State Code 37
Proj. ID 1207
Unif. Sect. 01
Time Sequence 01
Sample Unit Seq. 1

1-12/Dup

PERMANENT PATCH DETERIORATION
(Reinforced Pavements)

JRCP Permanent Patch at each Transverse Joint (slab replacement excluded)

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	
	Total Asphalt Patch Area at a Joint ** (square feet)									
S61L.	Total Asphalt Patch (sq. feet)	0000	0000	0000	13-24	S61R.	0000	0000	0000	37-48
S62L.	No. of Joints Patched (asphalt)	00	00	00	25-30	S62R.	00	00	00	49-54
	Total PCC Patch Area at a Joint ** (square feet)									
S63L.	Total PCC Patch (sq. feet)	0000	0000	0000	31-42	S63R.	0000	0000	0000	55-66
S64L.	No. of Joints Patched (PCC)	00	00	00	43-48	S64R.	00	00	00	67-72

** Each cell represents one joint.

73-78/BK
79-80/07
1-12/Dup

JRCP Permanent Patch Not at a transverse joint, including slab replacement or CRCP Permanent Patch at any location.

		L	M	H			L	M	H	
	Asphalt Patch(es)* (square feet)									
S65L.	Total Asphalt Patch (sq. feet)	0000	0000	0000	49-60	S65R.	0000	0000	0000	13-24
S66L.	Asphalt Patch (No.)	00	00	00	61-66	S66R.	00	00	00	25-30
	PCC Patch(es)* (square feet)				67-78/BK 79-80/08 1-12/Dup					
S67L.	Total PCC Patch (sq. feet)	0000	0000	0000	13-24	S67R.	0000	0000	0000	31-42
S68L.	PCC Patches (No.)	00	00	00	25-30	S68R.	00	00	00	43-48

* Each cell represents one patch.

No. of Patches with Patch Adjacent Slab Deterioration (JRCP and CRCP)

S69L.	Corner Break	00	31-32	S69R.	00	49-50
S70L.	"D" Cracking	00	33-34	S70R.	00	51-52
S71L.	Spalling	00	35-36	S71R.	00	53-54

55-78/BK
79-80/ 08

Exhibit 15(g)

SHEET 6F-P

SAMPLE UNIT FIELD DATA

-COPES-

Record No.	7.
State Code	
Proj. ID	
Unif. Sect.	
Time Sequence	
Sample Unit Seq.	

1-12/Dup.

PERMANENT PATCH DETERIORATION

(Plain Jointed Pavements)

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	

JPCP Permanent Small Patches (entire patch within 3 ft. of original joint) placed at a joint to repair joint deterioration.

	Total Asphalt Patch Area at a Joint * (square feet)									
S61L.	Total Asphalt Patch (square feet)				13-24	S61R.				37-48
S62L.	No. of Joints Patched (asphalt)				25-30	S62R.				49-54
	Total PCC Patch Area at a Joint* (square feet)									
S63L.	Total PCC Patch (square feet)				31-42	S63R.				55-66
S64L.	No. of Joints Patched (PCC)				43-48	S64R.				67-72

73-78/BK
79-80/07
1-12/Dup.

JPCP Permanent Large Patches and Slab Replacements placed to repair slab failure.

	Asphalt Patch(es)* (square feet)									
S65L.	Total Asphalt Patch (square feet)				49-60	S65R.				13-24
S66L.	Asphalt Patch (No.)				61-66	S66R.				25-30
	PCC Patch(es)* (square feet)				67-78/BK 79-80/06 1-12/Dup.					
S67L.	Total PCC Patch (square feet)				13-24	S67R.				31-42
S68L.	PCC Patch (No.)				25-30	S68R.				43-48

*Each cell represents one patch.

31-36/BK

49-76/BK
79-80/08

Exhibit 15(h)

SHEET 7F

FIELD DATA

-COPES-

State Code 37

Proj. ID 1207

TRUCK LANE DISTRIBUTION DATA

	Mile-Post (approximate) [✓ E] W, N, S	TIME			TRUCK DISTRIBUTION* (excluding pick-up, panel, and 2 axle/4 tire trucks)	
		Begin Count t_0	End Count t_1	Δt $t_1 - t_0$ (min)	Far Right Lane	Far Left Lane
	24.0	7:08	7:13	5	////	/
	25.0	7:15	7:20	5	𝍸 /	//
	26.0	7:23	7:27	4	𝍸 ///	//
	27.0	7:29	7:34	5	𝍸 /	////
	28.0	7:40	7:45	5	////	/
Σ				24	28	10
%					0.74	0.26**

APPROX. ADTT = 1440 * (Σ trucks ÷ ΣΔt) = 2280

*Data to be taken for trucks traveling in direction opposite that of the direction of the pavement survey.
**Distribution across lanes must sum to 100%.

Exhibit 15(i)

SHEET 8F
UNIFORM SECTION FIELD DATA
-COPES-

State Code 37
Proj. ID 1207
Unif. Sect. 01

SAMPLE UNIT LAYOUT DATA

210	180	150	120	90	60	30	Sample Unit No.
209	179	149	119	89	59	29	
208	178	148	118	88	58	28	
207	177	147	117	87	57	27	
206	176	146	116	86	56	26	
205	175	145	115	85	55	25	
204	174	144	114	84	54	24	
203	173	143	113	83	53	23	
202	172	142	112	82	52	22	
201	171	141	111	81	51	21	
200	170	140	110	80	50	20	
199	169	139	109	79	49	19	
198	168	138	108	78	48	18	
197	167	137	107	77	47	17	
196	166	136	106	76	46	16	
195	165	135	105	75	45	15	
194	164	134	104	74	44	14	
193	163	133	103	73	43	13	
192	162	132	102	72	42	12	
191	161	131	101	71	41	11	
190	160	130	100	70	40	10	
189	159	129	99	69	39	9	
188	158	128	98	68	38	8	
187	157	127	97	67	37	7	
186	156	126	96	66	36	6	
185	155	125	95	65	35	5	
184	154	124	94	64	34	4	
183	153	123	93	63	33	3	
182	152	122	92	62	32	2	
181	151	121	91	61	31	1	Start

Instructions: Identify start and end of uniform section, and also start of each sample unit to be surveyed with a station no. or milepost. Circle each sample unit to be surveyed. Sample Unit to consist of a 10% sample, i.e. 0.1 mile sample unit per 1 mile of uniform section.

The Technician should also bring to the attention of the Supervisor the highest severity of pumping, crazing and/or scaling that occurs in the sample unit. This completes the Technician's duties for a given project.

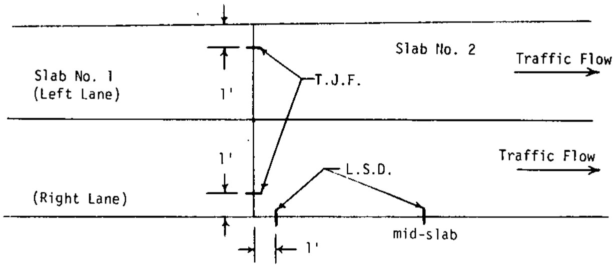


Figure 8. Suggested locations for transverse joint faulting and lane-shoulder dropoff measurements.

Duties and Responsibilities of the Driver

The duties of the Driver begin before he/she enters the car. He/she first assists the Supervisor and the Technician in gathering all of the necessary materials for the day.

Before making any first passes on the project at the posted speed limit, the Driver should note the length of the project in miles and calculate the mileage that will appear on the odometer at the end of the project. This may assist the Driver in locating the end of the project if there are no immediately visible construction joints, shoulder changes, or color changes in the concrete.

During these passes (one over each lane as directed by the Supervisor), it is important that the car be driven at a constant speed and without undue transverse motion within the lane, as this might adversely affect the mean panel PSR. The Driver should also pay attention to the ride quality so that he/she can readily give his PSR to the Supervisor at the end of the pass.

As the crew approaches the end of the project, the Driver should note a landmark of some type to assist him/her in knowing where the end of the project is on subsequent passes. This landmark may be a construction joint, change in pavement color or shoulder quality, or even a power pole or the end of a bridge. If he/she is relying solely on the odometer, the Driver should alert the Supervisor to the fact that the end of the job is near. He/she should also watch for turnarounds for future use, as they will save considerable time.

At the end of each first pass the Driver should give his PSR to the supervisor and immediately begin to look for a turnaround.

After covering all lanes with the first runs, the Driver should return to the beginning of the project for the sample unit surveys. When the Supervisor is ready and all emergency and warning lights on the car have been turned on, the Driver should proceed down the project to the beginning of the first sample unit. He/she should be aware of the beginning station or milepost of the sample unit so that he does not pass it by. Noting the station at a construction joint and counting slabs to the sample unit may save time and help avoid the need to back up on the shoulder in order to look for the correct joint.

During the survey of the sample unit, the Driver should bear in mind that the *safety of the crew is the top priority.* The car should always have its flashers and emergency lights on during the slow passes and the car should be kept between the oncoming traffic and the survey crew at all times. Note that if a two-person survey crew is used, no barrier will exist between the crew and traffic since the auto is left at the beginning of the sample unit. The Driver should continue to drive slowly down the shoulder, staying between the traffic and the crew, filling out Sheet No. 7F at the discretion of the Supervisor. At the end of the sample unit, the Driver temporarily stops filling out Sheet 7F, picks up the Supervisor and Technician, and resumes full speed to the beginning of the next sample unit. He/she then continues as before until all selected sample units are surveyed and the entire project completed. The Driver then proceeds to the next project which will be surveyed. This completes the Driver's duties for a given project. A flowchart illustrating the sequence of operations of the COPES field data collection survey crew is shown in Figure 9.

Suggestions and Notes

During the Illinois, Georgia, Utah, Minnesota, Louisiana, and California surveys, a few procedures and techniques were developed which may be helpful in reducing time and cost.

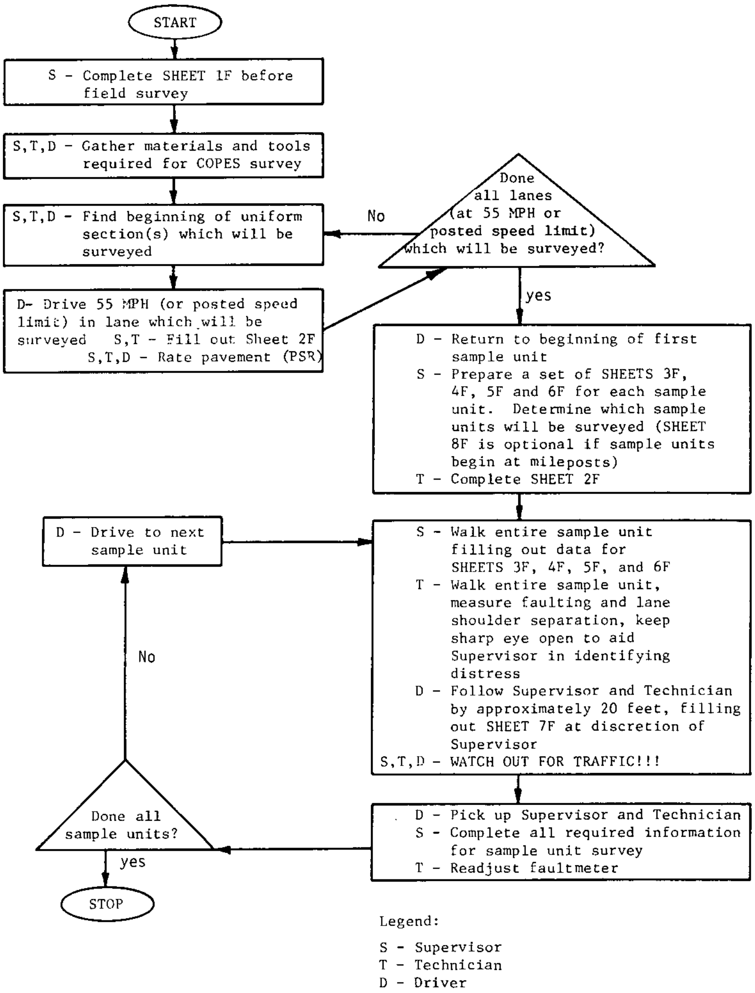


Figure 9. Flowchart illustrating COPES field data collection for survey crew.

1. When setting up a timetable for surveying projects, it is recommended to survey those projects closest to the base of operations first, particularly if the crew is inexperienced. Thus, if anything is forgotten, it can be easily obtained. If there are any changes in the survey format, additional information can be easily obtained before proceeding to more distant projects.

2. Considerable time can be saved by doing two or three projects at one time. Turnarounds are frequently several miles from either end of a project. By simply preparing data collection sheets for several projects, the first passes (55-mph or speed limit) could be performed on consecutive sections while keeping an eye out for a turnaround.

3. If one lane of a section is undergoing repairs (e.g., patchwork), it is easy to skip that section and return early the next morning or later that evening when the maintenance crews are gone and the delineating cones have been removed. Otherwise the section should be skipped until a more suitable time.

4. In urban areas the volume of traffic may be extremely high at certain times of the day. During these times it is best to avoid sample unit surveys. While the 55-mph passes are usually possible, the sample unit surveys should usually be performed at nonpeak times.

5. Crew safety should always be the prime consideration in selecting sample units. Therefore, if a project is almost entirely in an urban area and consists mainly of merging lanes, overpasses, curves, and other dangerous conditions, either select the sample unit in an acceptably safe area or *skip it.* The crew should always adhere to proper traffic control requirements and laws.

6. The Supervisor and Technician may total the tally marks on Sheets 3F and 6F while returning to the base of operations. This will save office time later. Information from Sheet 4F can be transferred to Sheet 5F at this time.

7. Good organization and teamwork are the keys to speedy, efficient, and *safe* field work.

Check List

The following includes the basic materials that are required on the field surveys.

1. Data Sheets

Sheet No. 1F.	One for each project
Sheet No. 2F.	One for each uniform section
Sheet No. 3F.	One per sample unit (prepare at least one sheet per mile)
Sheet No. 4F.	One per sample unit (prepare at least one sheet per mile)
Sheet No. 5F.	One per sample unit (prepare at least one sheet per mile)
Sheet No. 6F-R.	One per sample unit (prepare at least one sheet per mile of reinforced pavement)
Sheet No. 6F-P.	One per sample unit (prepare at least one sheet per mile of plain jointed pavement)
Sheet No. 7F.	One per uniform section or project
Sheet No. 8F.	One per uniform section

2. Strip maps of projects to be surveyed
3. State highway map
4. Fault meter
5. Mason's level (to calibrate fault meter)
6. Twelve (12) inch ruler
7. Distance meter or odometer wheel
8. Camera and accessories (film for at least 10 pictures for each project)
9. Flashing warning light for the car top (with spare light bulb)
10. Reflective vests (and hard hats if required)
11. Spray paint (preferably a bright color, for making marks on the pavement)
12. Clip boards
13. Paper clips
14. Pencils and eraser
15. Distress Identification Manual and the Data Collection Procedures for Concrete Pavement Evaluation System
16. Emergency telephone numbers (e.g., county police, phone number of immediate supervisor, etc.)

CHAPTER TWO

COPES CONCRETE HIGHWAY PAVEMENT DISTRESS IDENTIFICATION GUIDE

INTRODUCTION

This chapter has been developed for three basic types of pavements: (1) jointed plain concrete, (2) jointed reinforced concrete, and (3) continuously reinforced concrete. Each distress type and its general mechanisms are described, levels of distress are defined, and typical photographs of each type and severity are provided.

The distress definitions are based on the results of many previous studies on the causes of pavement distress. This guide is patterned after the U. S. Air Force distress identification manual for airfields developed by Shahin, Darter, and Kohn. (Shahin, M. Y., Darter, M. I., and Kohn, S. D., "Development of a Pavement Maintenance Management System, Volume V, Proposed Revision of Chapter 3, AFR 93-5," *Report No. CEE-DO-TR-77-44,* U. S. Air Force, U. S. Army Construction Engineering Research Laboratory, 1977.) The definitions, severity levels, and measurement methods were further developed through extensive field surveys and discussions with state highway engineers. The photographs were obtained during many field trips and surveys conducted on highways located throughout the United States. (Figures 10 through 56 show jointed plain concrete distress; 57 through 108, jointed reinforced concrete distress; and 109 through 166, continuously reinforced concrete distress.)

This chapter is intended to be used as a standard guide for distress identification and measurement for concrete highway pavements for collecting field data for the "Concrete Pavement Evaluation System—COPES." Recommended field survey procedures are described in Chapter One, "COPES Data Collection Procedures." It is noted that to expedite publication, the remainder of Chapter Two is reproduced as submitted by the research agency.

JOINTED PLAIN CONCRETE DISTRESS

Name of Distress: Blow-up

Description: Most blow-ups occur during the spring and hot summer at a transverse joint or wide crack. Infiltration of incompressible materials into the joint or crack during cold periods results in high compressive stresses in hot periods. When this compressive pressure becomes too great, a localized upward movement of the slab or shattering occurs at the joint or crack. Blow-ups are accelerated due to a spalling away of the slab at the bottom creating reduced joint contact area. The presence of "D" cracking or freeze-thaw damage also weakens the concrete near the joint resulting in increased spalling and blow-up potential.

Severity Levels: *L - Blow-up has occurred, but only causes some bounce of the vehicle which creates no discomfort.

*M - Blow-up causes a significant bounce of the vehicle which creates some discomfort. Temporary patching may have been placed beacuse of the blow-up.

*H - Blow-up causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure:. Blow-ups are measured by counting the number existing in each sample unit. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lbs. (13.3-16.9 kN) over the uniform section at the posted speed limit.

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*L = Low severity level
*M = Medium severity level
*H = High severity level

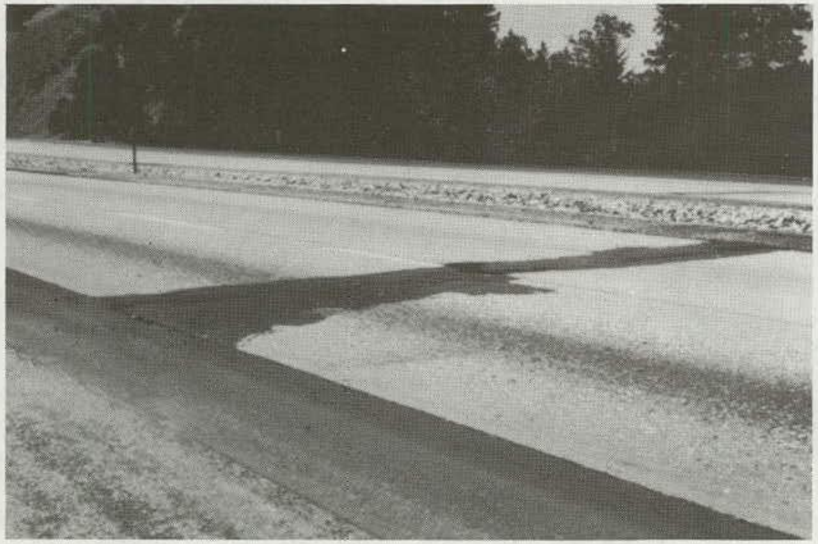

Figure 10. Medium-Severity Blow-up (temporary patch).

Name of Distress: Corner Break

Description: A corner break is a crack that intersects the joints at a distance less than 6 ft (1.8 m) on each side measured from the corner of the slab. A corner break extends vertically through the entire slab thickness. It should not be confused with a corner spall which intersects the joint at an angle through the slab and is typically within 1 ft (0.3 m) from the slab corner. Heavy repeated loads combined with pumping, poor load transfer across the joint, and thermal curling and moisture warping stresses result in corner breaks.

Severity Level: No levels of severity are defined.

How to Measure: Corner breaks are measured by counting the total number that exists in the sample unit. Corner breaks adjacent to a patch will not be recorded.

Figure 11. Corner Break.

Figure 12. Corner Break.

Name of Distress: Cracking from Improper Joint Construction

Description: The lack of proper joint construction due to late sawing, inadequate depth of sawing, inadequate placement of inserts, etc. may result in random cracks developing in the slab. These cracks may occur very close to where the joint was supposed to be located, or they may meander a substantial distance from the intended joint. These cracks may lead to a major structural distress with heavy load repetitions.

Severity Levels: Only one level of severity is defined. If cracking from improper joint construction occurs anywhere in the long slab, it is counted.

How to Measure: Cracking from improper joint construction is measured in linear feet (or meters).

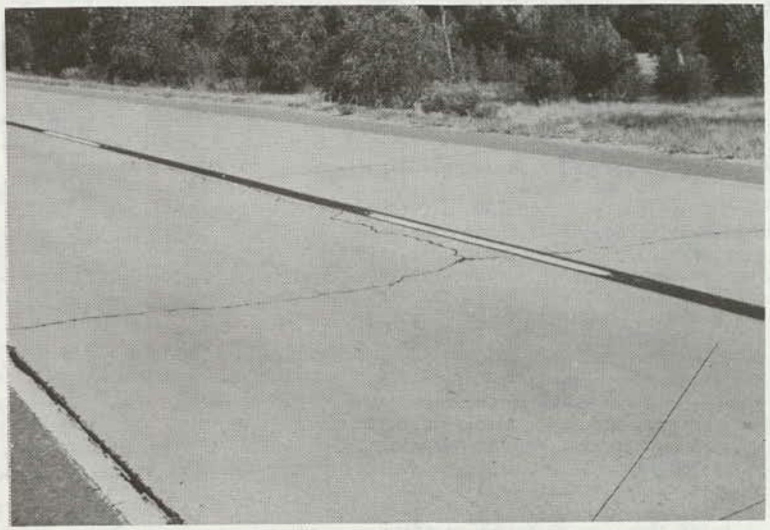

Figure 13. Cracking from Improper Joint Construction (cracking is at a location where a joint should have been saw-cut).

Name of Distress: Depression

Description: Depressions in concrete pavements are localized settled areas. There is generally significant slab cracking in these areas due to uneven settlement. The depressions can be located by stains caused by oil droppings from vehicles, and by riding over the pavement. Depressions can be caused by settlement or consolidation of the foundation soil or can be "built in" during construction. They are frequently found near culverts. This is usually caused by poor compaction of soil around the culvert during construction. Depressions cause slab cracking, roughness, and hydroplaning when filled with water of sufficient depth.

Severity Levels:

L - Depression causes a distinct bounce of vehicle which creates no discomfort.

M - Depression causes significant bounce of the vehicle which creates some discomfort.

H - Depression causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Depressions are measured by counting the number that exists in each uniform section. Each depression is rated according to its level of severity. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Name of Distress: Durability ("D") Cracking

Description: "D" cracking is a series of closely spaced crescent-shaped hairline cracks that appear at a PCC pavement slab surface adjacent and roughly parallel to transverse and longitudinal joints, transverse and longitudinal cracks, and the free edges of pavement slab. The fine surface cracks often curve around the intersection of longitudinal joints/cracks and transverse joints/cracks. These surface cracks often contain calcium hydroxide residue which causes a dark coloring of the crack and immediate surrounding area. This may eventually lead to disintegration of the concrete within 1-2 ft. (0.30-0.6 m) or more of the joint or crack, particularly in the wheelpaths. "D" cracking is caused by freeze-thaw expansive pressures of certain types of coarse aggregates and typically begins at the bottom of the slab which disintegrates first. Concrete durability problems caused by reactive aggregates are rated under "Reactive Aggregate Distress."

Severity Levels:

L - The characteristic pattern of closely spaced fine cracks has developed near joints, cracks, and/or free edges; however, the width of the affected area is generally <12 in. (30 cm) wide at the center of the lane in transverse cracks and joints. The crack pattern may fan out at the intersection of transverse cracks/joints with longitudinal cracks/joints. No joint/crack spalling has occurred, and no patches have been placed for "D" cracking.

M - The characteristic pattern of closely spaced cracks has developed near the crack, joint or free edge and: (1) is generally wider than 12 in. (30 cm) at the center of the lane in transverse cracks and/or joints; or (2) low or medium severity joint/crack or corner spalling has developed in the affected area; or (3) temporary patches have been placed due to "D" cracking induced spalling.

H - The pattern of fine cracks has developed near joints or cracks and (1) a high severity level of spalling at joints/cracks exists and considerable material is loose in the affected area; or (2) the crack pattern has developed generally over the entire slab area between cracks and/or joints.

How to Measure: "D" cracking is measured and recorded in linear feet of joints, cracks, and free edges affected. Different severity levels are counted and recorded separately. "D" cracking adjacent to a patch is rated as patch-adjacent slab deterioration. "D" cracking should not be counted if the fine crack pattern has not developed near cracks, joints and free edges. Popouts and discoloration of joints, cracks and free edges may occur without "D" cracking.

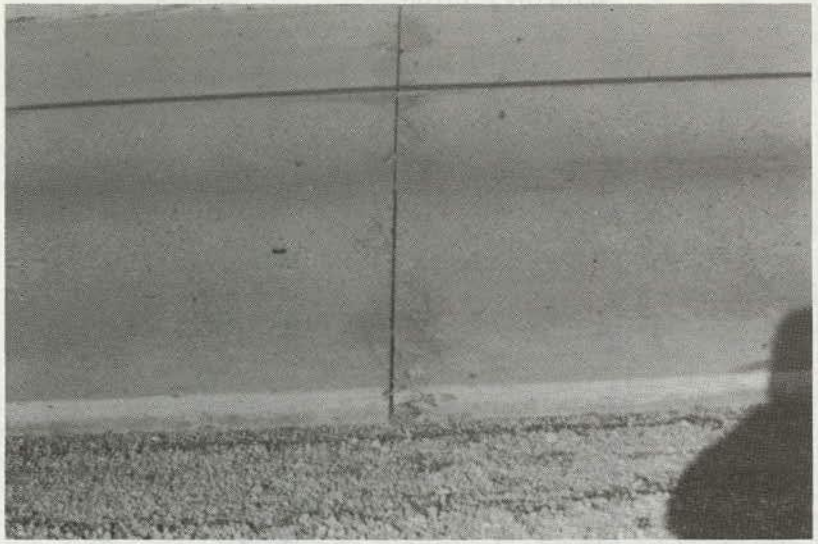

Figure 14. Low-Severity "D" Cracking.

Figure 15. Medium-Severity "D" Cracking.

Figure 16. High-Severity "D" Cracking.

Name of Distress:	Faulting of Transverse Joints and Cracks
Description:	Faulting is the difference of elevation across a joint or crack. Faulting is caused in part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping from under the leave slab and shoulder (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of load transfer contributes greatly to faulting.
Severity Levels:	Severity is determined by the average faulting over the joints within the sample unit.
How to Measure:	Faulting is determined by measuring the difference in elevation of slabs at transverse joints for the slabs in the sample unit. Faulting of cracks are measured as a guide to determine the distress level of the crack. Faulting is measured one foot in from the outside (right) slab edge on all lanes except the inner-most passing lane. Faulting is measured one foot in from the inside (left) slab edge on the inner passing lane. If temporary patching prevents measurement, proceed on to the next joint. Sign convention: + when approach slab is higher than departure slab, - when the opposite occurs.

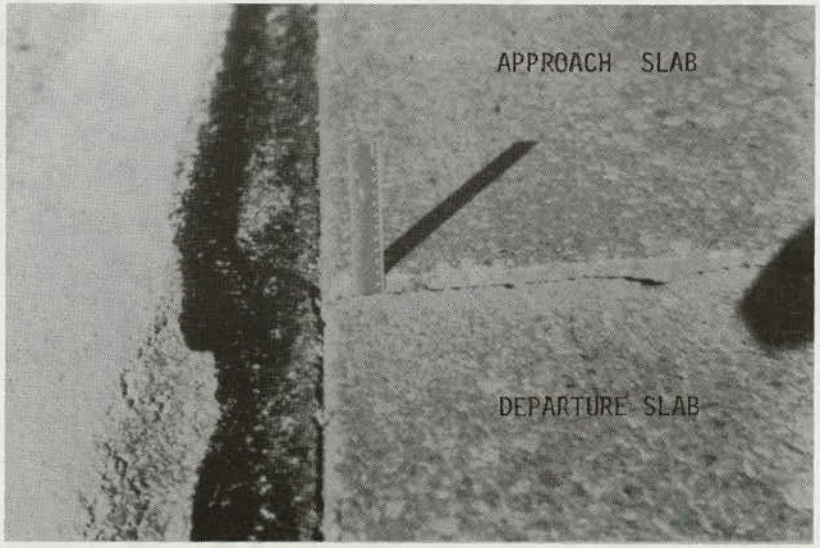

Figure 17. Joint Faulting

Figure 18. Joint Faulting.

Figure 19. Joint Faulting.

Name of Distress: Joint Seal Damage of Transverse Joints

Description: Joint seal damage exists when incompressible materials and/or water can infiltrate into the joints. This infiltration can result in pumping, spalling, and blow-ups. A joint sealant bonded to the edges of the slabs protects the joints from accumulation of incompressible materials, and also reduces the amount of water seeping into the pavement structure. Typical types of joint seal damage are: (1) stripping of joint sealant, (2) extrusion of joint sealant, (3) weed growth, (4) hardening of the filler (oxidation), (5) loss of bond to the slab edges, and (6) lack or absence of sealant in the joint.

Severity Levels:

L - Joint sealant is in good condition throughout the section with only a minor amount of any of the above types of damage present. Little water and no incompressibles can infiltrate through the joint.

M - Joint sealant is in fair condition over the entire surveyed section, with one or more of the above types of damage occuring to a moderate degree. Water can infiltrate the joint fairly easily; some incompressibles can infiltrate the joint. Sealant needs replacement within 1-3 years.

H - Joint sealant is in poor condition over most of the sample unit, with one or more of the above types of damage occurring to a severe degree. Water and incompressibles can freely infiltrate the joint. Sealant needs immediate replacement.

How to Measure: Joint sealant damage of transverse joints is rated based on the overall condition of the sealant over the entire sample unit.

Figure 20. **Low-Severity Joint Sealant Damage.**

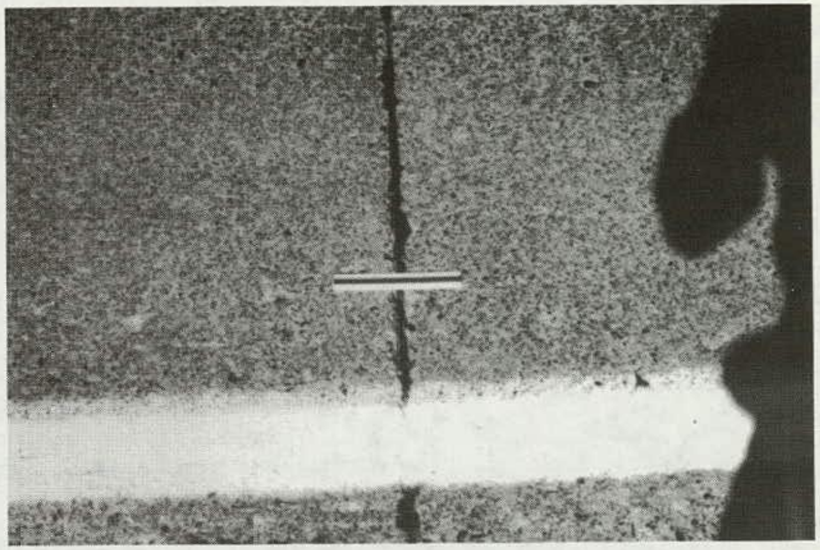

Figure 21. **Medium-Severity Joint Sealant Damage.**

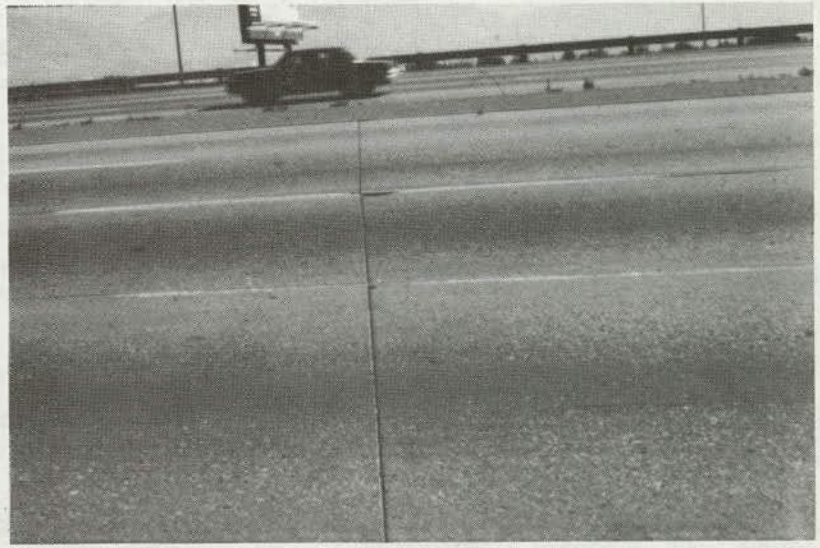

Figure 22. High-Severity Joint Sealant Damage (sealant generally missing).

Name of Distress: Lane/Shoulder Joint Separation

Description: Lane/shoulder joint separation is the widening of the joint between the traffic lane and the shoulder generally due to movement in the shoulder. If the joint is tightly closed or well sealed so that water cannot easily infiltrate, then lane/shoulder joint separation is not considered a distress.

Severity Level:

L - A tight joint (sealed) with a mean opening up to 0.12 inch (3 mm).

M - More than 0.12 inch (3 mm) but equal to or less than 0.4 inch (10 mm) opening.

H - More than 0.4 (10 mm) opening. Gravel or sod shoulders are rated as high.

How to Measure: Lane/shoulder joint separation is measured and recorded in inches (or mm) near transverse joints and at mid-slab. The mean separation is used to determine the severity level.

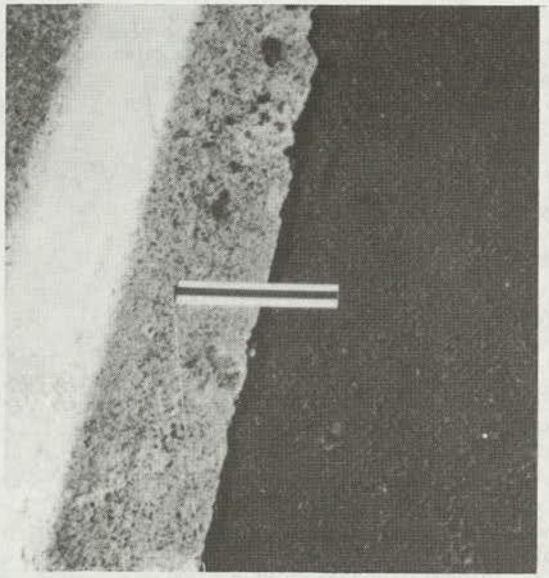

Figure 23. Low-Severity Lane/Shoulder Separation.

Figure 24. High-Severity Lane / Shoulder Separation.

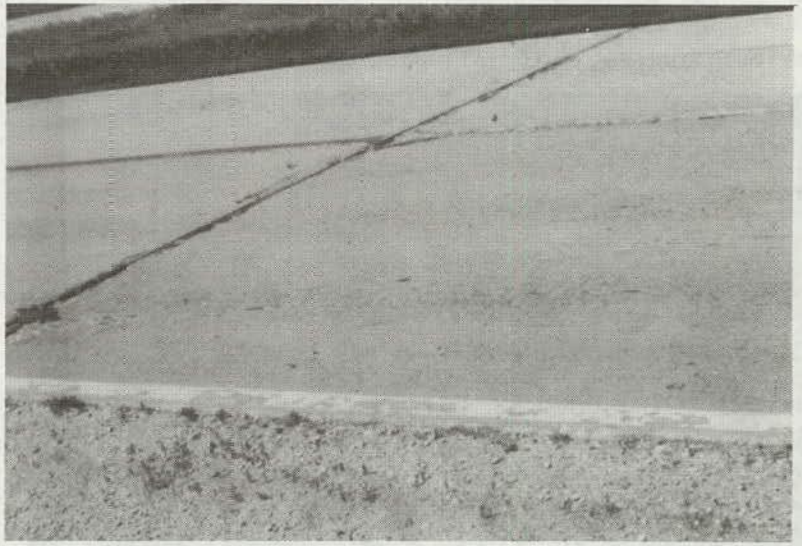

Figure 25. Gravel Shoulder Recorded as High-Severity Lane/ Shoulder Separation.

Name of Distress: Longitudinal Cracks

Description: Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints, or by a combination of heavy load repetition, loss of foundation support, and thermal and moisture gradient stresses.

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting, or a well sealed crack with no visible faulting or spalling.

M - Working crack with a moderate or less severity spalling and/or faulting less than 1/2 inch (13 mm).

H - A crack with width greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.

How to Measure: Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded.

Figure 26. Low-Severity Longitudinal Crack.

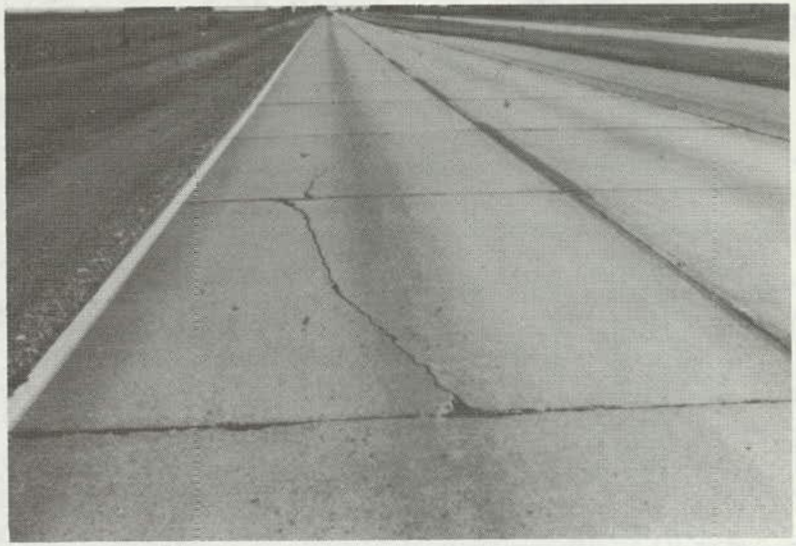

Figure 27. Medium-Severity Longitudinal Crack.

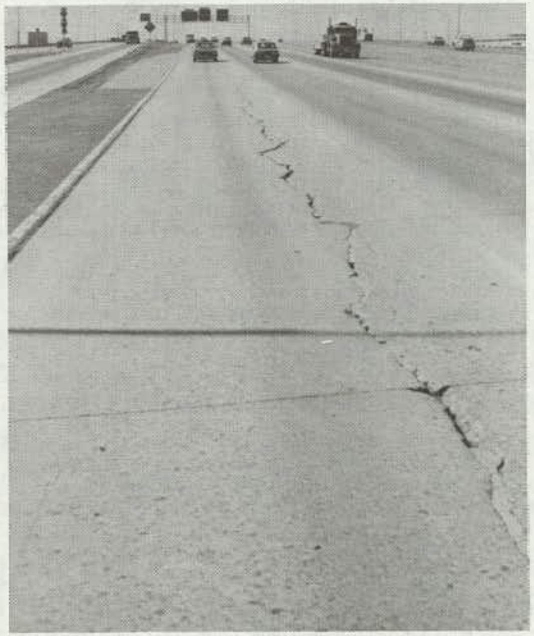

Figure 28. High-Severity Longitudinal Crack.

Name of Distress: Longitudinal Joint Faulting

Description: Longitudinal joint faulting is a difference in elevation of two traffic lanes measured at the longitudinal joint. It is caused primarily by heavy truck traffic and settlement of the foundation.

Severity Levels: No levels of severity are defined.

How to Measure: If the maximum longitudinal joint faulting is greater than 1/2 inch (13 mm), it is recorded as a distressed area.

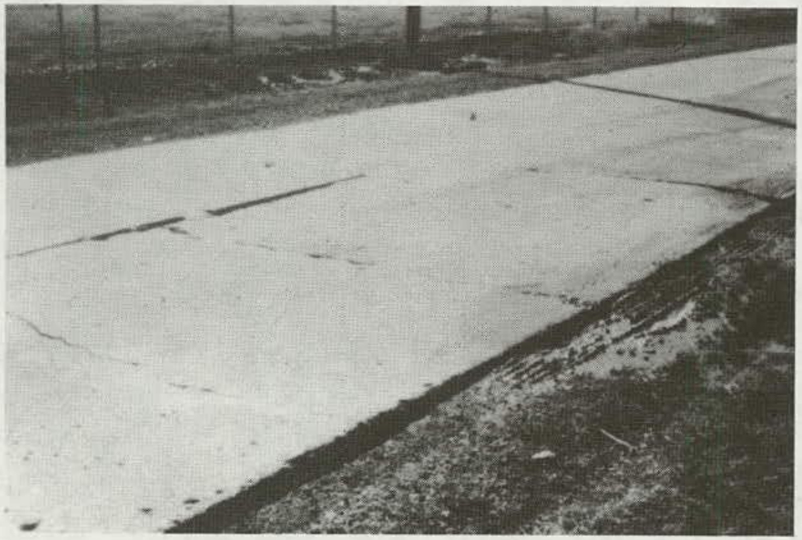

Figure 29. Longitudinal Joint Faulting.

Name of Distress: Patch Deterioration (including replaced slabs)

Description: A patch is an area where a portion or all of the original concrete slab has been removed and replaced with a permanent type of material (e.g., concrete, epoxy, hot mix asphalt/aggregate mixture). Only permanent patches should be considered.

Patches which lie entirely within 3 feet (1 meter) of the original joint are considered joint repairs, whereas all other patches (including replaced slabs) are considered slab repairs.

Severity Levels:

L - Patch has little or no deterioration. Some low severity spalling or ravelling of the patch edges may exist. Faulting (concrete) patch or settlement (asphalt) patch across the slab-patch joint must be less than 1/4 inch (6 mm). Patch is rated low severity even if it is in excellent condition.

M - Patch has cracked (low severity level and/or some spalling of medium severity level exists around the edges. Minor ravelling, rutting, or shoving may be present. Faulting or settlement of 1/4 to 1/2 inch (6-13 mm) exists. Temporary patches may have been placed because of permanent patch deterioration.

H - Patch is badly deteriorated either by cracking, faulting, spalling, rutting or shoving to a condition which requires replacement. Patch may present tire damage potential.

How to Measure: Patches placed to repair slab distress are recorded separately from those placed to repair joint distress. For patches which lie entirely within 3' of the original transverse joint, the number of joints with permanent patching within each sample unit is recorded. The approximate total square footage (or meters) of patches within the 3' area is recorded under the mean level of severity of the patch(es) and type (e.g., PCC or asphalt). All patches are rated either L, M, or H. For large patches (patches extending past 3' of the original joint) and slab replacements, the number of patches within each sample unit is recorded. Patches at different severity levels within a slab are counted and recorded separately, as are the approximate square footage (or meters) of each patch and type (e.g., PCC or asphalt). Again, all patches are rated either L, M, or H.

Figure 30. Low-Severity PCC Patch Deterioration.

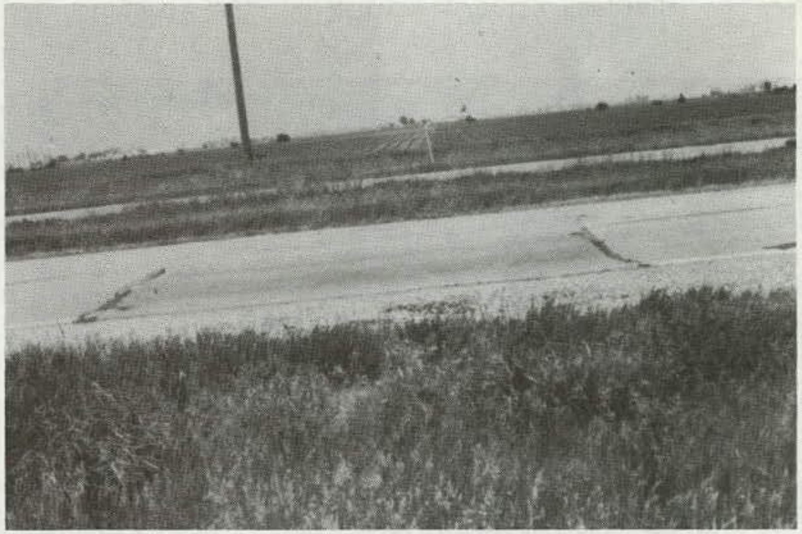

Figure 32. Low-Severity Asphalt Patch Deterioration.

Figure 31. Medium-Severity PCC Patch Deterioration.

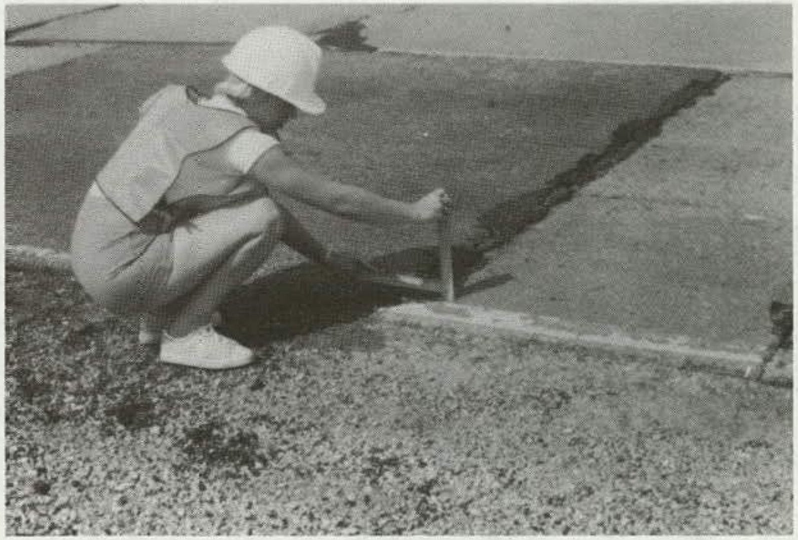

Figure 33. Medium-Severity Asphalt Patch Deterioration.

Name of Distress: Pumping and Water Bleeding

Description: Pumping is the movement of material by water pressure beneath the slab when it is deflected under a heavy moving wheel load. Sometimes the pumped material moves around beneath the slab, but often it is ejected through joints and/or cracks (particularly along the longitudinal lane/shoulder joint with an asphalt shoulder). Beneath the slab there is typically particle movement counter to the direction of traffic across a joint or crack that results in a buildup of loose materials under the approach slab near the joint or crack. Many times some fine materials (silt, clay, sand) are pumped out leaving a thin layer of relatively loose clean sand and gravel beneath the slab, along with voids causing loss of support. Pumping occurs even in pavement sections containing stabilized subbases. The erosion of the top of the stabilized subbase often occurs, and also a pumping of the foundation material from beneath the stabilized subbase is common.

Water bleeding occurs when water seeps out of joints and/or cracks. It many times drains out over the shoulder in low areas.

Severity Levels:

L - No fines can be seen on the surface of the traffic lanes or shoulder. However, there is evidence that water is forced out of a joint or crack when trucks pass over the joints or cracks. One evidence of water pumping is the existance of small "blowholes" in the asphalt shoulder adjacent to a transverse joint. The asphalt surface may have settled some indicating a loss of material beneath the surface. Another evidence of low severity pumping is the bleeding of water from the longitudinal lane/shoulder joint.

M - A small amount of pumped material can be observed near some of the joints or cracks on the surface of the traffic lane or shoulder. Blow holes may exist.

H - A significant amount of pumped materials exist on the pavement surface of the traffic lane or shoulder along the joints or cracks.

How to Measure: If pumping or water bleeding exists anywhere in the sample unit it is counted as occurring at highest severity level as defined above.

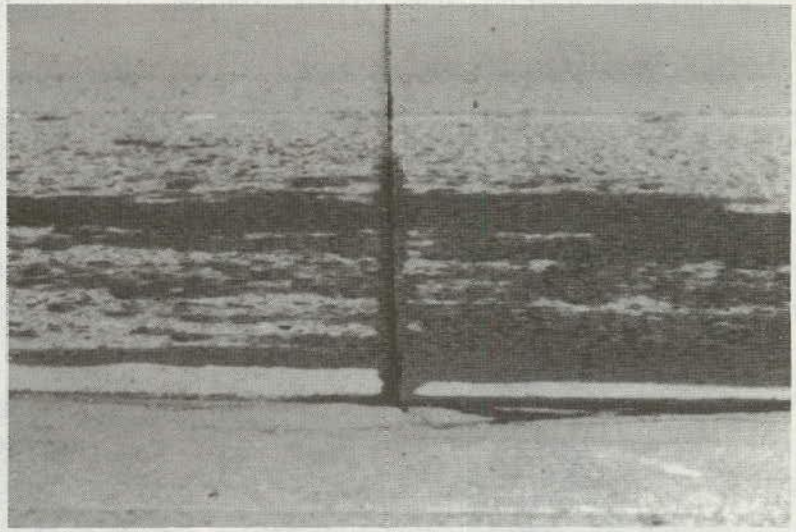

Figure 34. Low-Severity Pumping.

Figure 35. Medium-Severity Pumping.

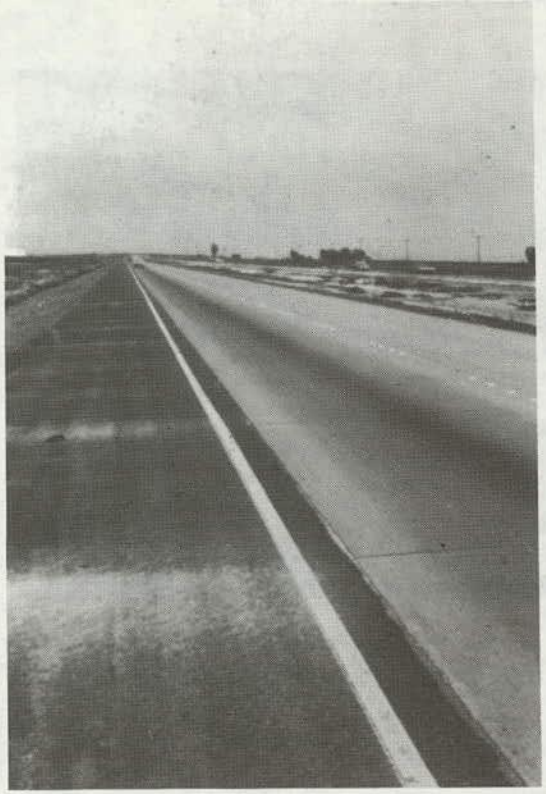

Figure 36. High-Severity Pumping.

Name of Distress: Reactive Aggregate Distress

Description: Reactive aggregates either expand in alkaline environments or develop prominent siliceous reaction rims in concrete. It may be an alkali-silica reaction or an alkali-carbonate reaction. As expansion occurs, the cement matrix is disrupted and cracks. It appears as a map cracked area; however, the cracks may go deeper into the concrete than in normal map cracking. It may affect most of the slab or it may first appear at joints and cracks.

Severity Levels:

L - Joint and or slab shows pressure and map cracking. Pavement may be discolored, but scaling and spalling of joints does not exist.

M - Joints are spalled and or scaling exists. White fines may exist along cracks and joints.

H - Joint spalling and or scalling exists to the extent that a tire damage or safety hazard exists. A significant amount of white fines may exist on the pavement surface.

How to Measure: Reactive aggregate distress is measured as the percent of area of the sample unit which exhibits this distress at each severity level.

Figure 37. Medium-Severity Reactive Aggregate Distress.

Name of Distress: Scaling and Map Cracking or Crazing

Discription: Scaling is the deterioration of the upper 1/8-1/2 inch (3-13 mm) of the concrete slab surface. Map cracking or crazing is a series of fine cracks that extend only into the upper surface ot the slab surface. Map cracking or crazing is usually caused by over-finishing of the slab and may lead to scaling of the surface. Scaling can also be caused by reinforcing steel being too close to the surface.

Severity Levels:

L - Crazing or map cracking exists over a majority of the slab area; the surface is in good condition with no scaling.

M - Less than 10% of any slab exhibits scaling.

H - More than 10% of any slab exhibits scaling.

How to Measure: Scaling and map cracking or crazing are rated according to the highest severity level found in a sample unit.

Figure 39. Scaling Near Transverse Joint.

Figure 38. Scaling.

Figure 40. Map Cracking or Crazing.

Name of Distress: Spalling (Transverse and Longitudinal Joint/Crack)

Description: Spalling of cracks and joints is the cracking, breaking, or chipping (or fraying) of the slab edges within 2 ft. (0.6 m) of the joint/crack. A spall usually does not extend vertically through the whole slab thickness, but extends to intersect the joint at an angle. Spalling usually results from (1) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion, (2) disintegration of the concrete from freeze-thaw action of "D" cracking, (3) weak concrete at the joint (caused by honeycombing), (4) poorly designed or constructed load transfer device (misalignment, corrosion), and/or (5) heavy repeated traffic loads.

Severity Levels:

L - The spall or fray does not extend more than 3 ins. (8 cm) on either side of the joint or crack. No temporary patching has been placed to repair the spall.

M - The spall or fray extends more than 3 ins. (8 cm) on either side of the joint or crack. Some pieces may be loose and/or missing but the spalled area does not present a tire damage or safety hazard. Temporary patching may have been placed because of spalling.

H - The joint is severly spalled or frayed to the extent that a tire damage or safety hazard exists.

How to Measure: Spalling is measured by counting and recording separately the number of joints with each severity level. If more than one level of severity exists along a joint, it well be recorded as containing the highest severity level present. Although the definition and severity levels are the same, spalling of cracks should not be recorded. The spalling of cracks is included in rating severity levels of cracks. Spalling of transverse and longitudinal joints will be recorded separately. Spalling of the slab edge adjacent to a permanent patch will be recorded as patch adjacent slab deterioration. If spalling is caused by "D" cracking, it is counted as both spalling and "D" cracking at appropriate severity levels.

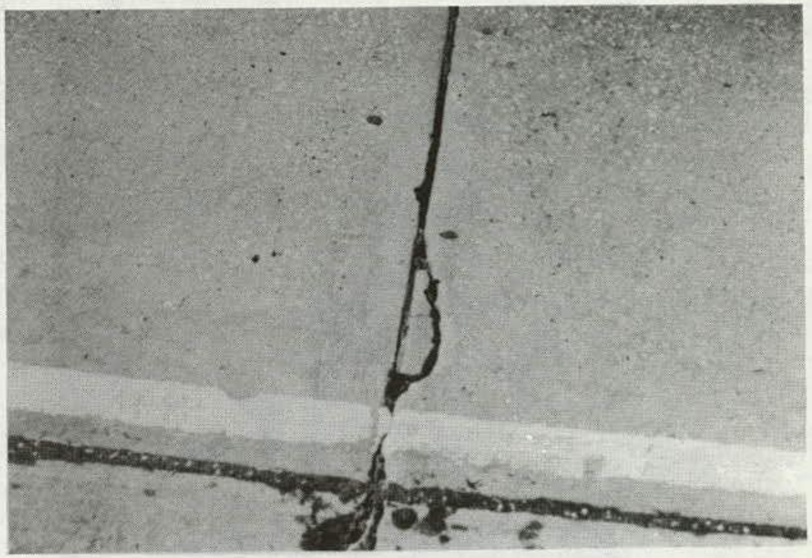

Figure 41. Low-Severity Spalling (Transverse Joint).

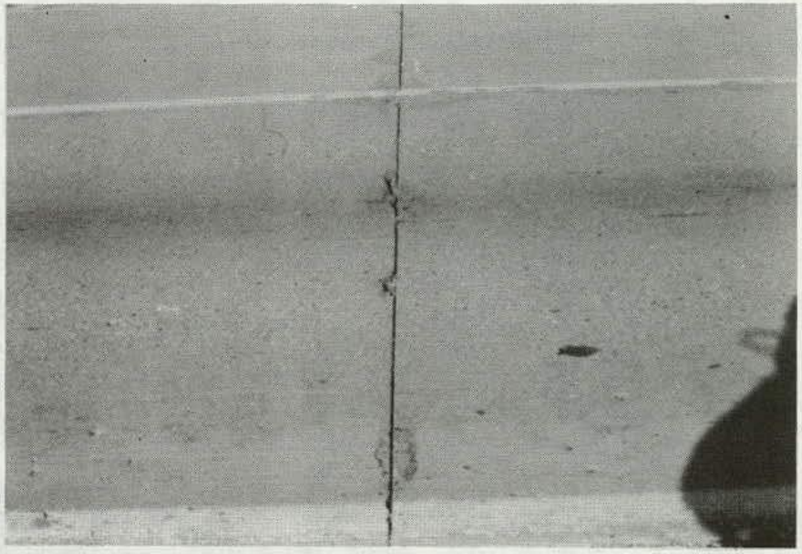

Figure 42. Low-Severity Spalling (Transverse Joint).

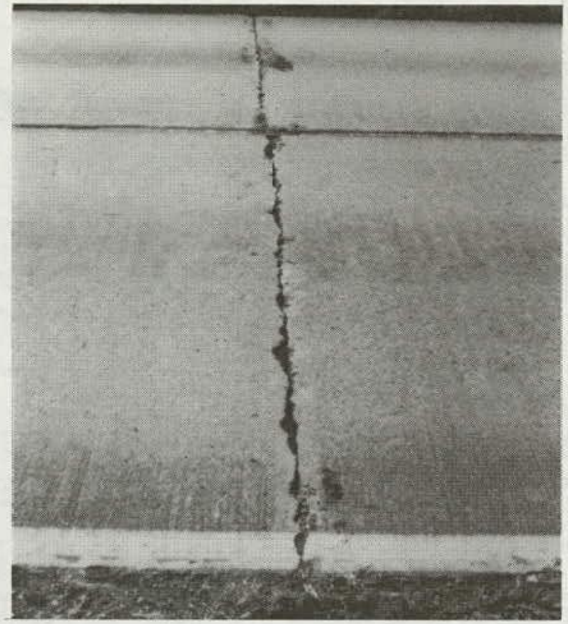

Figure 43. Low-Severity Spalling (Transverse Joint).

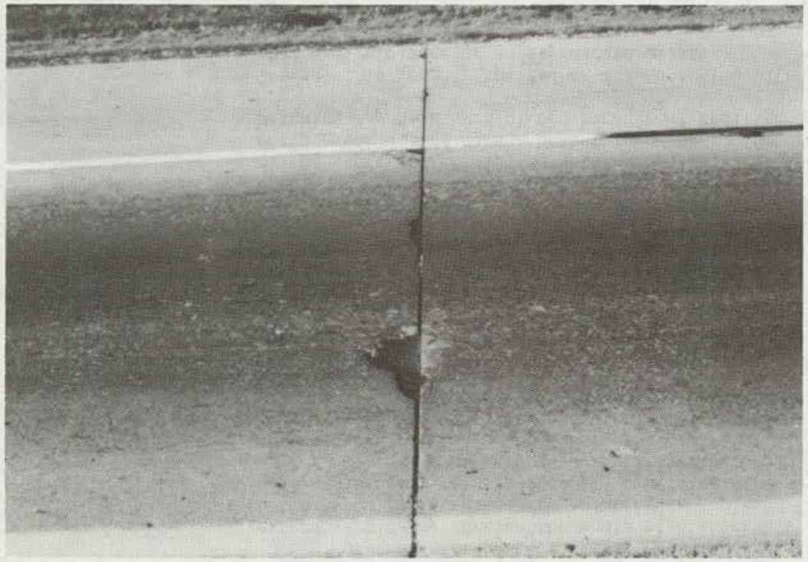

Figure 44. Medium-Severity Spalling (Transverse Joint).

Figure 45. Medium-Severity Spalling (Transverse Joint).

Figure 46. Medium-Severity Spalling (Transverse Joint).

Figure 47. High-Severity Spalling (Transverse Joint).

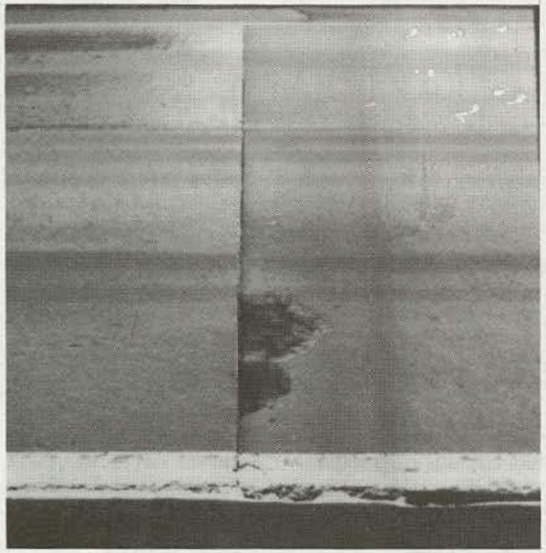

Figure 48. High-Severity Spalling (Transverse Joint) (safety hazard).

Name of Distress:	Studded Tire Damage
Description:	Studded tire damage is a pavement wear caused or aggravated by the initial action of studded tires. Removal of or damage to the surface of the pavement exposing coarse aggregate can be observed in the wheel paths. Studded tire damage is not to be confused with scaling and crazing which can occur anywhere on the pavement.
Severity Levels:	No level of severity is defined. If studded tire damage occurs anywhere in the sample unit it is counted.
How to Measure:	If studded tire damage occurs anywhere in the sample unit, it is counted.

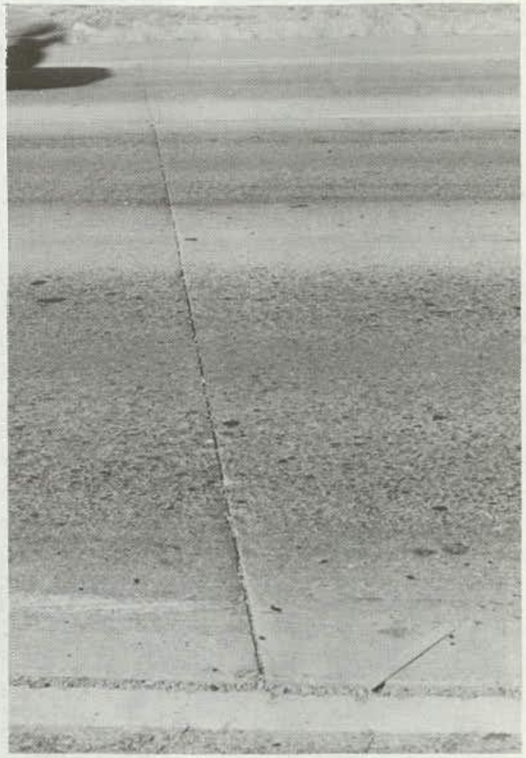

Figure 49. Studded Tire Damage.

Name of Distress: Swell

Description: A swell is an upward movement or heave of the slab surface resulting in a sometimes sharp wave. The swell is usually accompanied by slab cracking. It is usually caused by frost heave in the subgrade or by an expansive soil. Swells can often be identified by oil droppings on the surface as well as riding over the pavement in a vehicle.

Severity Levels:

L - Swell causes a distinct bounce of the vehicle which creates no discomfort.

M - Swell causes significant bounce of the vehicle which creates some discomfort.

H - Swell causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: The number of swells within the uniform section are counted and recorded by severity level. Severity levels are determined by riding in a mid- to full-sized sedan weighing approximately 3000-38000 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Figure 50. Swell due to Frost Heave (observe cracking).

Figure 51. Swell Due to Frost Heave (observe cracking of slab).

Name of Distress: Transverse and Diagonal Cracks

Description: Linear cracks are caused by one or a combination of the following: heavy load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high severity cracks are working cracks and are considered major structural distresses. (Note: hairline cracks that are less than 6 feet (1.8 m) long are not rated).

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting, a well sealed crack with no visible faulting or spalling.

M - Working crack with low to medium severity level of spalling, and/or faulting less than 1/2 inch (13 mm). Temporary patching may be present.

H - A crack with width of greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.

How to Measure: Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded. Cracks in patches are recorded under patch deterioration.

Figure 52. Low-Severity Transverse Crack.

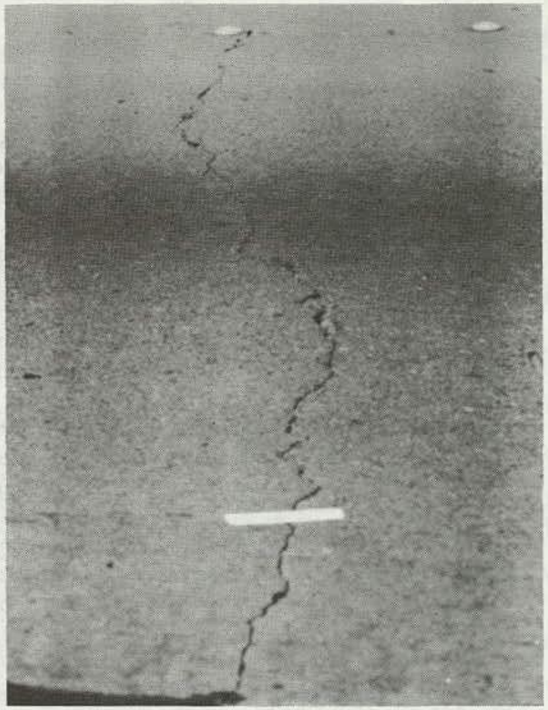

Figure 53. Low-Approaching-Medium-Severity Transverse Crack.

Figure 54. Medium-Severity Transverse Crack.

Figure 55. Medium-Severity Transverse Crack.

Figure 56. High-Severity Transverse Crack.

JOINTED REINFORCED CONCRETE DISTRESS

Name of Distress: Blow-up

Description: Most blow-ups occur during the spring and hot summer at a transverse joint or wide crack. Infiltration of incompressible materials into the joint or crack during cold periods results in high compressive stresses in hot periods. When this compressive pressure becomes too great, a localized upward movement of the slab or shattering occurs at the joint or crack. Blow-ups are accelerated due to a spalling away of the slab at the bottom creating reduced joint contact area. The presence of "D" cracking or freeze-thaw damage also weakens the concrete near the joint resulting in increased spalling and blow-up potential.

Severity Levels:

*L - Blow-up has occurred, but only causes some bounce of the vehicle which creates no discomfort.

*M - Blow-up cuases a significant bounce of the vehicle which creates some discomfort. Temporary patching may have been placed beacuse of the blow-up.

*H - Blow-up causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Blow-ups are measured by counting the number existing in each sample unit. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lbs. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Figure 57. High-Severity Buckling Type Blow-up.

Figure 58. High-Severity Shattering Type Blow-up.

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*L = Low severity level
*M = Medium severity level
*H = High severity level

Name of Distress: Corner Break

Description: A corner break is a crack that intersects the joints at a distance less than 6 ft (1.8 m) on each side measured from the corner of the slab. A corner break extends vertically through the entire slab thickness. It should not be confused with a corner spall which intersects the joint at an angle through the slab and is typically within 1 ft (0.3 m) from the slab corner. Heavy repeated loads combined with pumping, poor load transfer across the joint, and thermal curling and moisture warping stresses result in corner breaks.

Severity Level: No levels of severity are defined.

How to Measure: Corner breaks are measured by counting the total number that exists in the sample unit. Corner breaks adjacent to a patch will be counted as "patch adjacent slab deterioration."

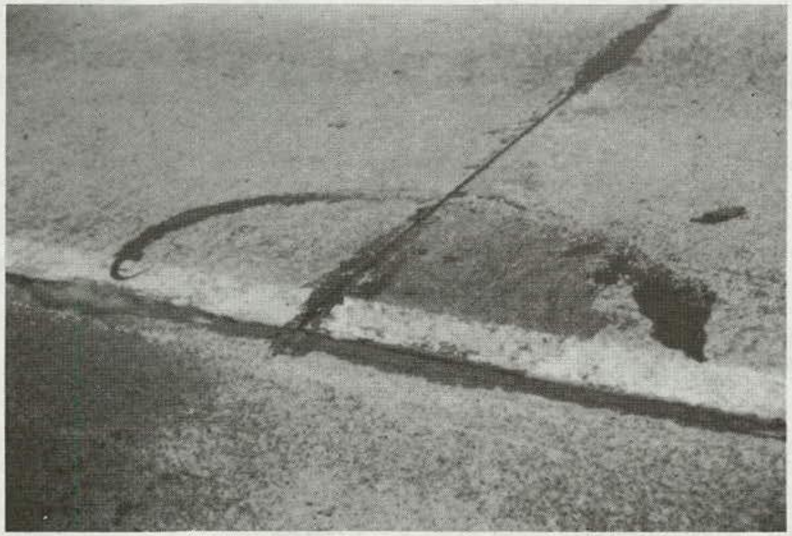


Figure 59. Corner Break.

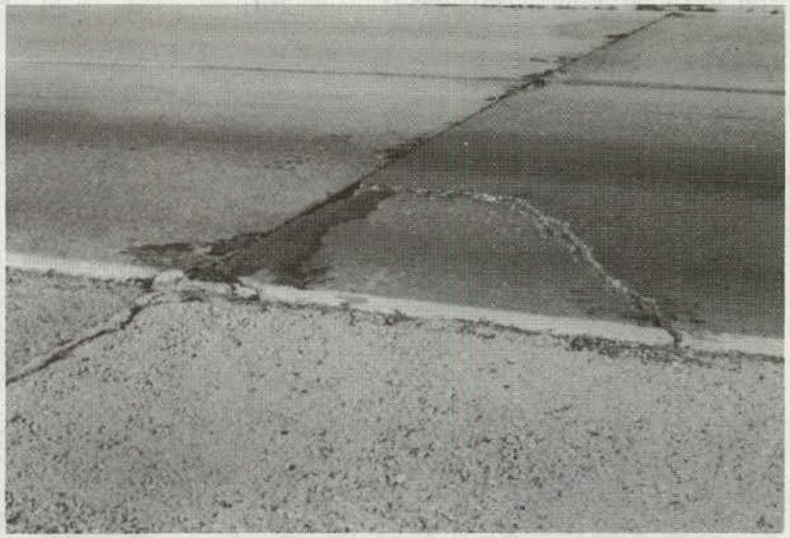


Figure 60. Corner Break.

Name of Distress: Cracking from Improper Joint Construction

Description: The lack of proper joint construction due to late sawing, inadequate depth of sawing, inadequate placement of inserts, etc. may result in random cracks developing in the slab. These cracks may occur very close to where the joint was supposed to be located, or they may meander a substantial distance from the intended joint. These cracks may lead to a major structural distress with heavy load repetitions.

Severity Levels: Only one level of severity is defined. If cracking from improper joint construction occurs anywhere in the long slab, it is counted.

How to Measure: Cracking from improper joint construction is measured in linear feet (or meters).

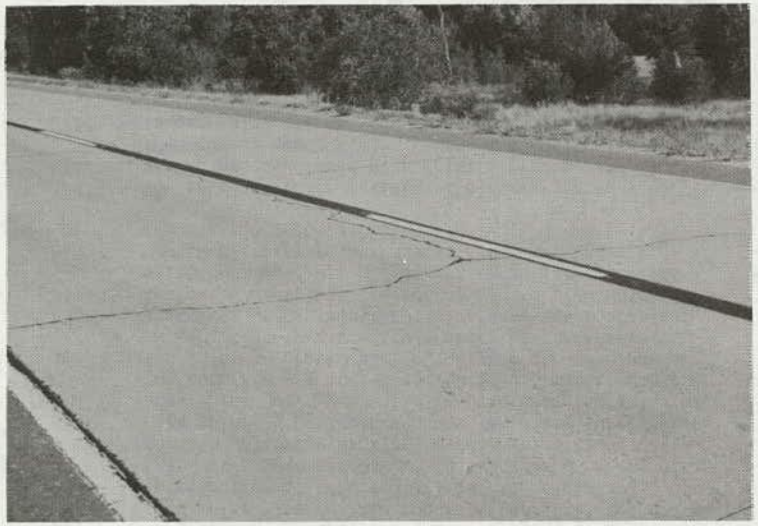


Figure 61. Cracking from Improper Joint Construction (Cracking is at a location where a joint should have been saw cut.) (Picture is of a jointed-plain concrete pavement.)

Name of Distress: Depression

Description: Depressions in concrete pavements are localized settled areas. There is generally significant slab cracking in these areas due to uneven settlement. The depressions can be located by stains caused by oil droppings from vehicles, and by riding over the pavement. Depressions can be caused by settlement or consolidation of the foundation soil or can be "built in" during construction. They are frequently found near culverts. This is usually caused by poor compaction of soil around the culvert during construction. Depressions cause slab cracking, roughness, and hydroplaning when filled with water of sufficient depth.

Severity Levels:

L - Depression causes a distinct bounce of vehicle which creates no discomfort.

M - Depression causes significant bounce of the vehicle which creates some discomfort.

H - Depression causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Depressions are measured by counting the number that exists in each uniform section. Each depression is rated according to its level of severity. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Name of Distress: Durability ("D") Cracking

Description: "D" cracking is a series of closely spaced crescent-shaped hairline cracks that appear at a PCC pavement slab surface adjacent and roughly parallel to transverse and longitudinal joints, transverse and longitudinal cracks, and the free edges of pavement slab. The fine surface cracks often curve around the intersection of longitudinal joints/cracks and transverse joints/cracks. These surface cracks often contain calcium hydroxide residue which causes a dark coloring of the crack and immediate surrounding area. This may eventually lead to disintegration of the concrete within 1-2 ft. (0.30-0.6 m) or more of the joint or crack, particularly in the wheelpaths. "D" cracking is caused by freeze-thaw expansive pressures of certain types of coarse aggregates and typically begins at the bottom of the slab which disintegrates first. Concrete durability problems caused by reactive aggregates are rated under "Reactive Aggregate Distress."

Severity Levels:

L - The characteristic pattern of closely spaced fine cracks has developed near joints, cracks, and/or free edges; however, the width of the affected area is generally <12 in. (30 cm) wide at the center of the lane in transverse cracks and joints. The crack pattern may fan out at the intersection of transverse cracks/joints with longitudinal cracks/joints. No joint/crack spalling has occurred, and no patches have been placed for "D" cracking.

M - The characteristic pattern of closely spaced cracks has developed near the crack, joint or free edge and: (1) is generally wider than 12 in. (30 cm) at the center of the lane in transverse cracks and/or joints; or (2) low or medium severity joint/crack or corner spalling has developed in the affected area; or (3) temporary patches have been placed due to "D" cracking induced spalling.

H - The pattern of fine cracks has developed near joints or cracks and (1) a high severity level of spalling at joints/cracks exists and considerable material is loose in the affected area; or (2) the crack pattern has developed generally over the entire slab area between cracks and/or joints.

How to Measure: "D" cracking is measured and recorded in linear feet (or meters) of free edges, cracks and joints affected. Different severity levels are counted and recorded separately. "D" cracking adjacent to a patch is rated as patch-adjacent slab deterioration. "D" cracking should not be counted if the fine crack pattern has not developed near cracks, joints and free edges. Popouts and discoloration of joints, cracks and free edges may occur without "D" cracking.

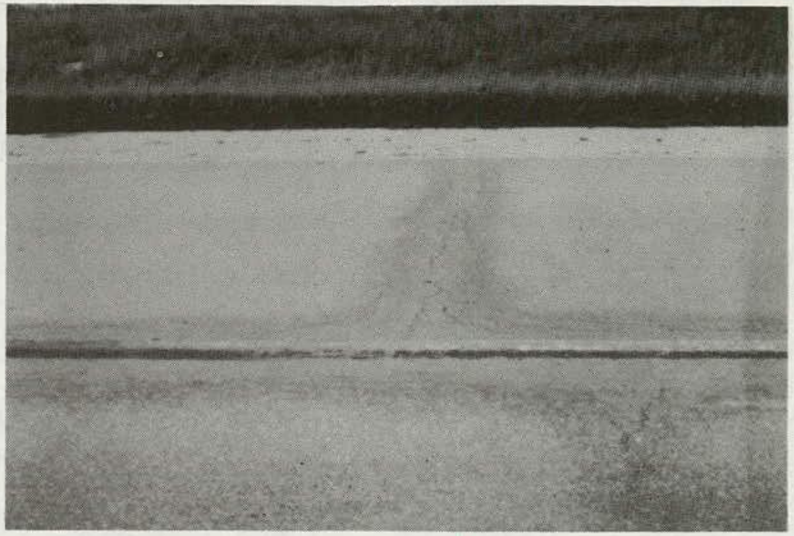


Figure 62. Low-Severity "D" Cracking.

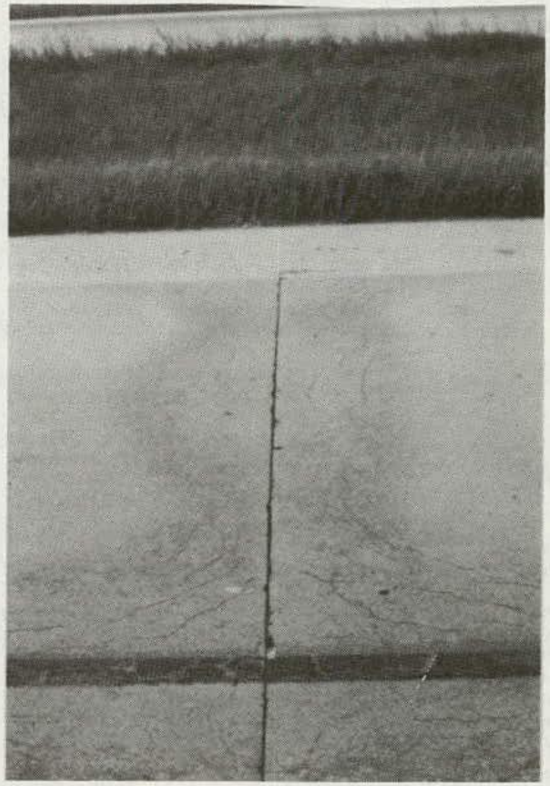


Figure 63. Medium-Severity "D" Cracking.

Figure 64. Medium-Severity "D" Cracking.

Figure 65. High-Severity "D" Cracking.

Figure 66. High-Severity "D" Cracking.

Name of Distress:	Faulting of Transverse Joints and Cracks
Description:	Faulting is the difference of elevation across a joint or crack. Faulting is caused in part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping from under the leave slab and shoulder (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of load transfer contributes greatly to faulting.
Severity Levels:	Severity is determined by the average faulting over the joints within the sample unit.
How to Measure:	Faulting is determined by measuring the difference in elevation of slabs at transverse joints for the slabs in the sample unit. Faulting of cracks are measured as a guide to determine the distress level of the crack. Faulting is measured one foot in from the outside (right) slab edge on all lanes except the inner-most passing lane. Faulting is measured one foot in from the inside (left) slab edge on the inner passing lane. If temporary patching prevents measurement, proceed on to the next joint. Sign convention: + when approach slab is higher than departure slab, - when the opposite occurs.

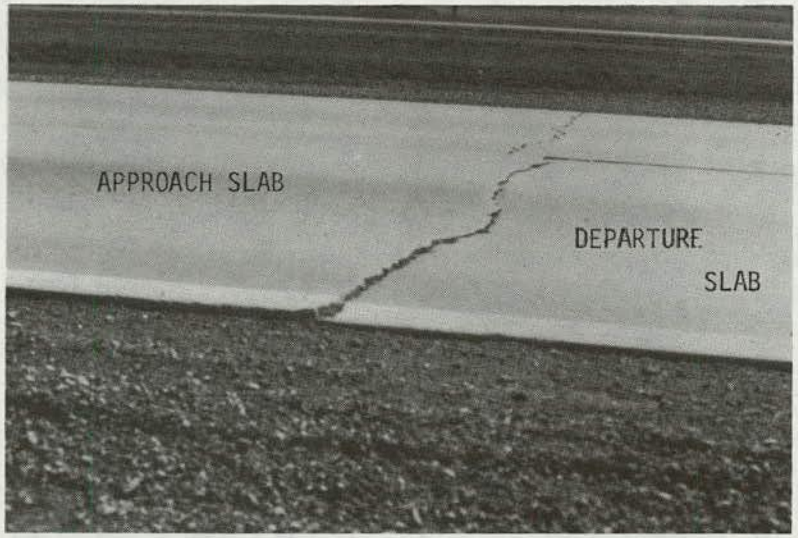


Figure 67. Crack Faulting.

Figure 68. Joint Faulting.

Name of Distress: Joint Seal Damage of Transverse Joints

Description: Joint seal damage exists when incompressible materials and/or water can infiltrate into the joints. This infiltration can result in pumping, spalling, and blowups. A joint sealant bonded to the edges of the slabs protects the joints from accumulation of incompressible materials, and also reduces the amount of water seeping into the pavement structure. Typical types of joint seal damage are: (1) stripping of joint sealant, (2) extrusion of joint sealant, (3) weed growth, (4) hardening of the filler (oxidation), (5) loss of bond to the slab edges, and (6) lack or absence of sealant in the joint.

Severity Levels:

L - Joint sealant is in good condition throughout the section with only a minor amount of any of the above types of damage present. Little water and no incompressibles can infiltrate through the joint.

M - Joint sealant is in fair condition over the entire surveyed section, with one or more of the above types of damage occuring to a moderate degree. Water can infiltrate the joint fairly easily; some incompressibles can infiltrate the joint. Sealant needs replacement within 1-3 years.

H - Joint sealant is in poor condition over most of the sample unit, with one or more of the above types of damage occurring to a severe degree. Water and incompressibles can freely infiltrate the joint. Sealant needs immediate replacement.

How to Measure: Joint sealant damage of transverse joints is rated based on the overall condition of the sealant over the entire sample unit.

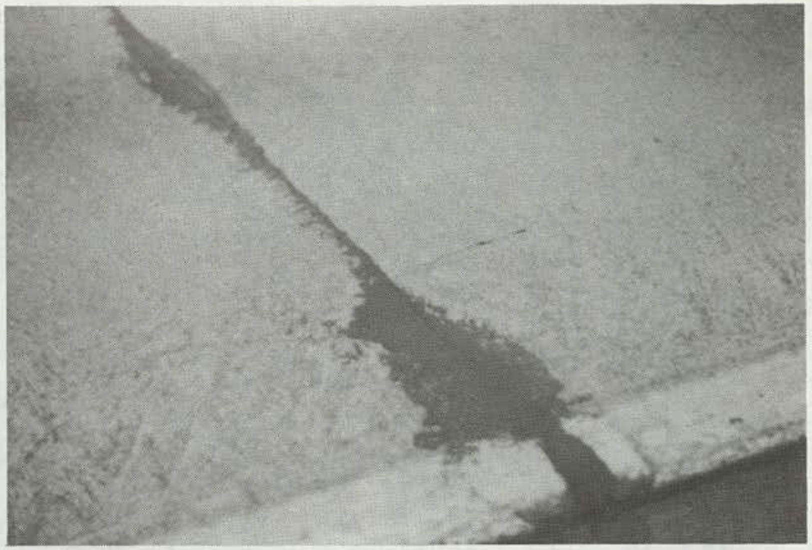


Figure 69. Low-Severity Joint Seal Damage.

Figure 70. Medium-Severity Joint Seal Damage.

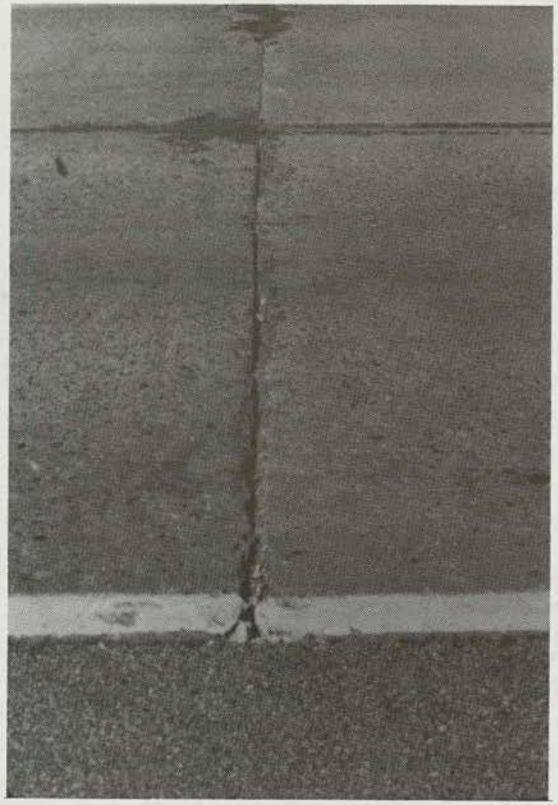


Figure 71. High-Severity Joint Seal Damage.

Name of Distress: Lane/Shoulder Joint Separation

Description: Lane/shoulder joint separation is the widening of the joint between the traffic lane and the shoulder generally due to movement in the shoulder. If the joint is tightly closed or well sealed so that water cannot easily infiltrate, then lane/shoulder joint separation is not considered a distress.

Severity Level:

L - A tight joint (sealed) with a mean opening up to 0.12 inch (3 mm).

M - More than 0.12 inch (3 mm) but equal to or less than 0.4 inch (10 mm) opening.

H - More than 0.4 (10 mm) opening. Gravel or sod shoulders are rated as high.

How to Measure: Lane/shoulder joint separation is measured and recorded in inches (or mm) near transverse joints and at mid-slab. The mean separation is used to determine the severity level.

Figure 72. Lane/Shoulder Separation (Asphalt Shoulder).

Figure 73. Lane/Shoulder Separation (PCC Shoulder).

Figure 74. Lane/Shoulder Separation (high severity due to gravel shoulder).

Name of Distress: Longitudinal Cracks

Description: Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints, or by a combination of heavy load repetition, loss of foundation support, and thermal and moisture gradient stresses.

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting, or a well sealed crack with no visible faulting or spalling.

M - Working crack with a moderate or less severity spalling and/or faulting less than 1/2 inch (13 mm).

H - A crack with width greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.

How to Measure: Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded.

Figure 75. Low-Severity Longitudinal Crack.

Figure 76. High-Severity Longitudinal Crack in Center Lane.

Name of Distress:	Longitudinal Joint Faulting
Description:	Longitudinal joint faulting is a difference in elevation of two traffic lanes measured at the longitudinal joint. It is caused primarily by heavy truck traffic and settlement of the foundation.
Severity Levels:	No levels of severity are defined.
How to Measure:	If the maximum longitudinal joint faulting is greater than 1/2 inch (13 mm), it is recorded as a distressed area.

Figure 77. Longitudinal Joint Faulting.

Name of Distress: Patch Deterioration (including replaced slabs)

Description: A patch is an area where a portion or all of the original concrete slab has been removed and replaced with a permanent type of material (e.g., concrete, epoxy, hot mix asphalt/aggregate mixture). Only permanent patches should be considered.

Patches which lie at a transverse joint (excluding slab replacement) are considered joint repairs, whereas patches NOT at a transverse joint and replaced slabs are considered slab repairs.

Severity Levels:

L - Patch has little or no deterioration. Some low severity spalling or ravelling of the patch edges may exist. Faulting (concrete) patch or settlement (asphalt) patch across the slab-patch joint must be less than 1/4 inch (6 mm). Patch is rated low severity even if it is in excellent condition.

M - Patch has cracked (low severity level and/or some spalling of medium severity level exists around the edges. Minor ravelling, rutting, or shoving may be present. Faulting or settlement of 1/4 to 1/2 inch (6-13 mm) exists. Temporary patches may have been placed because of permanent patch deterioration.

H - Patch is badly deteriorated either by cracking, faulting, spalling, rutting or shoving to a condition which requires replacement. Patch may present tire damage potential.

How to Measure: Patches placed to repair slab distress are recorded separately from those placed to repair joint distress. For patches at a transverse joint, the number of joints with permanent patching within each sample unit is recorded. The approximate total square footage (or meters) of patches at a joint are recorded under the mean level of severity of the patch(es) and type (e.g., PCC or asphalt). All patches are rated either L, M, or H. For patches not at a transverse joint and slab replacements, the number of patches within each sample unit is recorded. Patches at different severity levels within a slab are counted and recorded separately, as are the approximate square footage (or meters) of each patch and type (i.e., PCC or asphalt). Again, all patches are rated either L, M or H.

Figure 78. High-Severity Asphalt Patch Deterioration.

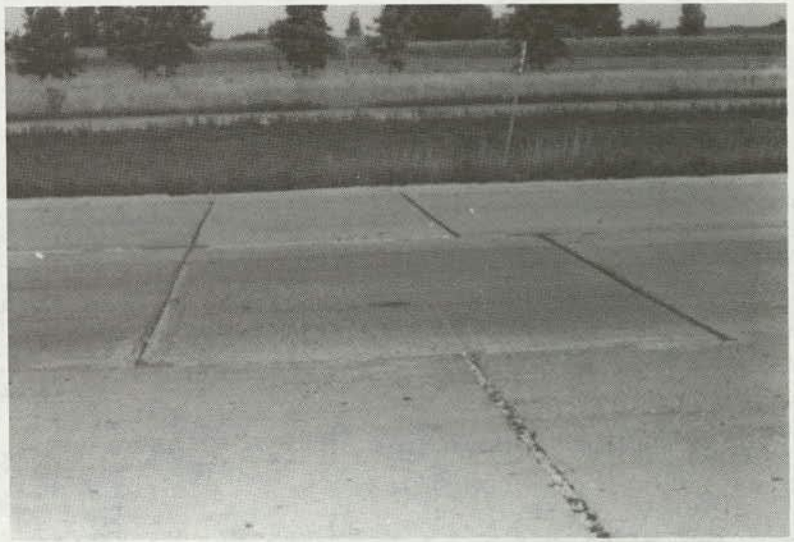


Figure 79. Low-Severity Concrete Patch Deterioration.

Figure 80. Medium-Severity Concrete Patch Deterioration.

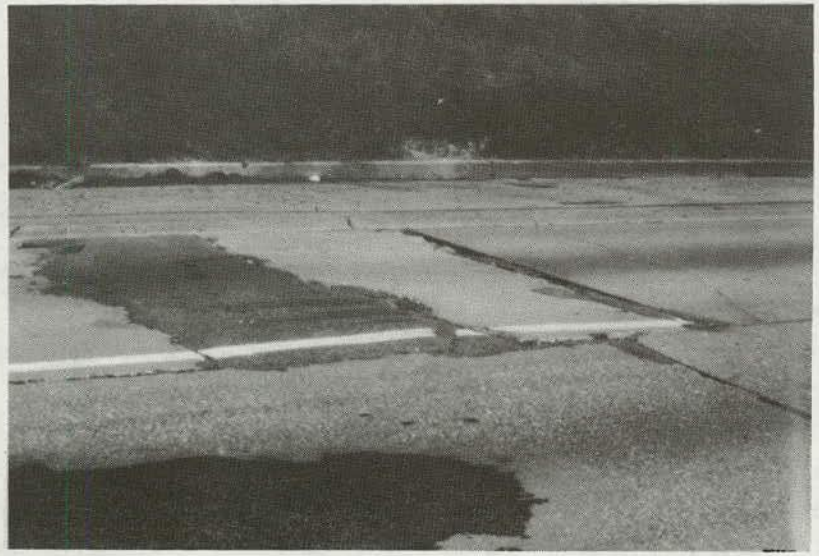


Figure 81. High-Severity Concrete Patch Deterioration.

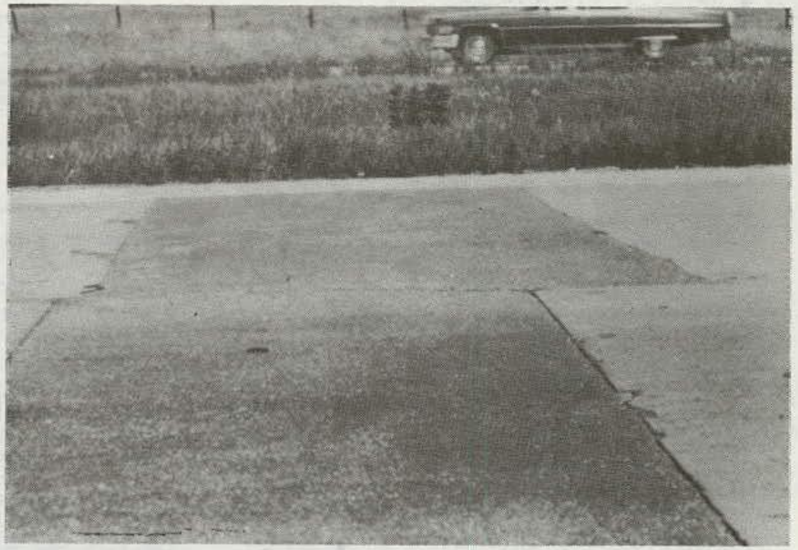


Figure 82. Low-Severity Asphalt Patch Deterioration.

Name of Distress:	Patch Adjacent Slab Deterioration
Description:	Deterioration of the original concrete slab adjacent to the permanent patch is given the above name. This may be in the form of spalling of the slab/patch joint, "D" cracking of the slab adjacent to the patch, or a corner break in the adjacent slab.
Severity Levels:	No levels of severity are defined. If patch adjacent slab deterioration occurs, it is counted.
How to Measure:	The number of patched joints with distress in the original slab adjacent to the patch(es) at each distress level (i.e., corner break, "D" cracking, spalling) will be counted and recorded separately.

Figure 83. Patch Adjacent Slab Deterioration (Corner Break).

Figure 84. Patch Adjacent Slab Deterioration ("D" Cracking).

Figure 85. Patch Adjacent Slab Deterioration (Spalling and "D" Cracking).

Name of Distress: Pumping and Water Bleeding

Description: Pumping is the movement of material by water pressure beneath the slab when it is deflected under a heavy moving wheel load. Sometimes the pumped material moves around beneath the slab, but often it is ejected through joints and/or cracks (particularly along the longitudinal lane/shoulder joint with an asphalt shoulder). Beneath the slab there is typically particle movement counter to the direction of traffic across a joint or crack that results in a buildup of loose materials under the approach slab near the joint or crack. Many times some fine materials (silt, clay, sand) are pumped out leaving a thin layer of relatively loose clean sand and gravel beneath the slab, along with voids causing loss of support. Pumping occurs even in pavement sections containing stabilized subbases. The erosion of the top of the stabilized subbase often occurs, and also a pumping of the foundation material from beneath the stabilized subbase is common.

Water bleeding occurs when water seeps out of joints and/or cracks. It many times drains out over the shoulder in low areas.

Severity Levels:

L - No fines can be seen on the surface of the traffic lanes or shoulder. However, there is evidence that water is forced out of a joint or crack when trucks pass over the joints or cracks. One evidence of water pumping is the existance of small "blowholes" in the asphalt shoulder adjacent to a transverse joint. The asphalt surface may have settled some indicating a loss of material beneath the surface. Another evidence of low severity pumping is the bleeding of water from the longitudinal lane/shoulder joint.

M - A small amount of pumped material can be observed near some of the joints or cracks on the surface of the traffic lane or shoulder. Blow holes may exist.

H - A significant amount of pumped materials exist on the pavement surface of the traffic lane or shoulder along the joints or cracks.

How to Measure: If pumping or water bleeding exists anywhere in the sample unit it is counted as occurring at highest severity level as defined above.

Figure 86. Low-Severity Pumping (Water Bleeding).

Figure 87. Medium-Severity Pumping (pumped material like this occurs only at a few of the joints and cracks).

Name of Distress:	Reactive Aggregate Distress
Description:	Reactive aggregates either expand in alkaline environments or develop prominent siliceous reaction rims in concrete. It may be an alkali-silica reaction or an alkali-carbonate reaction. As expansion occurs, the cement matrix is disrupted and cracks. It appears as a map cracked area; however, the cracks may go deeper into the concrete than in normal map cracking. It may affect most of the slab or it may first appear at joints and cracks.
Severity Levels:	L - Joint and or slab shows pressure and map cracking. Pavement may be discolored, but scaling and spalling of joints does not exist. M - Joints are spalled and or scaling exists. White fines may exist along cracks and joints. H - Joint spalling and or scalling exists to the extent that a tire damage or safety hazard exists. A significant amount of white fines may exist on the pavement surface.
How to Measure:	Reactive aggregate distress is measured as the percent of area of the sample unit which exhibits this distress at each severity level.

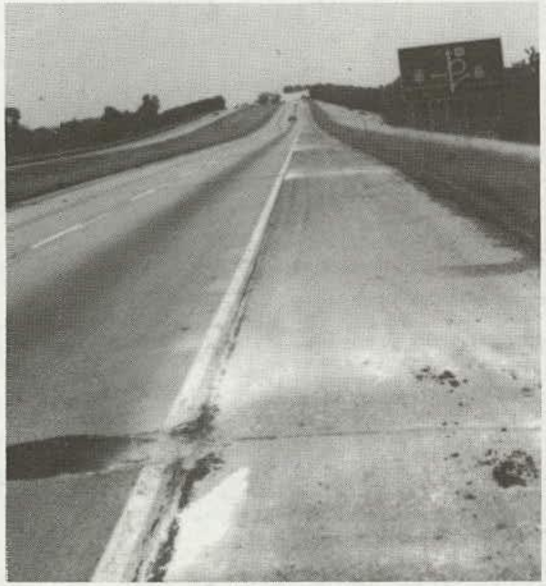


Figure 88. High-Severity Pumping.

Figure 89. Medium-Severity Reactive Aggregate Distress (Photo for Jointed Plain Concrete Pavement).

Name of Distress: Scaling and Map Cracking or Crazing

Description: Scaling is the deterioration of the upper 1/8-1/2 inch (3-13 mm) of the concrete slab surface. Map cracking or crazing is a series of fine cracks that extend only into the upper surface ot the slab surface. Map cracking or crazing is usually caused by over-finishing of the slab and may lead to scaling of the surface. Scaling can also be caused by reinforcing steel being too close to the surface.

Severity Levels:

L - Crazing or map cracking exists over a majority of the slab area; the surface is in good condition with no scaling.

M - Less than 10% of any slab exhibits scaling.

H - More than 10% of any slab exhibits scaling.

How to Measure: Scaling and map cracking or crazing are rated according to the highest severity level found in a sample unit.

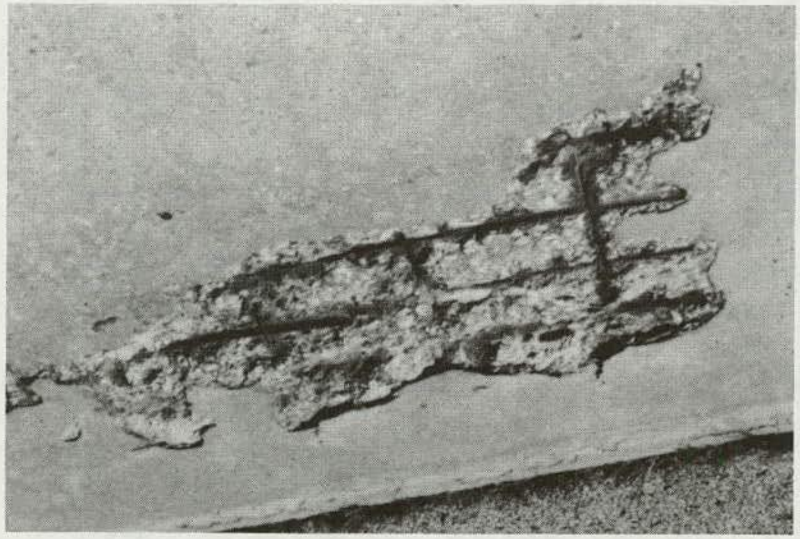


Figure 90. Scaling.

Figure 91. Scaling.

Name of Distress: Spalling (Transverse and Longitudinal Joint/Crack)

Description: Spalling of cracks and joints is the cracking, breaking, or chipping (or fraying) of the slab edges within 2 ft. (0.6 m) of the joint/crack. A spall usually does not extend vertically through the whole slab thickness, but extends to intersect the joint at an angle. Spalling usually results from (1) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion, (2) disintegration of the concrete from freeze-thaw action of "D" cracking, (3) weak concrete at the joint (caused by honeycombing), (4) poorly designed or constructed load transfer device (misalignment, corrosion), and/or (5) heavy repeated traffic loads.

Severity Levels:

L - The spall or fray does not extend more than 3 ins. (8 cm) on either side of the joint or crack. No temporary patching has been placed to repair the spall.

M - The spall or fray extends more than 3 ins. (8 cm) on either side of the joint or crack. Some pieces may be loose and/or missing but the spalled area does not present a tire damage or safety hazard. Temporary patching may have been placed because of spalling.

H - The joint is severly spalled or frayed to the extent that a tire damage or safety hazard exists.

How to Measure: Spalling is measured by counting and recording separately the number of joints with each severity level. If more than one level of severity exists along a joint, it well be recorded as containing the highest severity level present. Although the definition and severity levels are the same, spalling of cracks should not be recorded. The spalling of cracks is included in rating severity levels of cracks. Spalling of transverse and longitudinal joints will be recorded separately. Spalling of the slab edge adjacent to a permanent patch will be recorded as patch adjacent slab deterioration. If spalling is caused by "D" cracking, it is counted as both spalling and "D" cracking at appropriate severity levels.

Figure 92. Low-Severity Spalling (Fray).

Figure 93. Low-Severity Spalling.

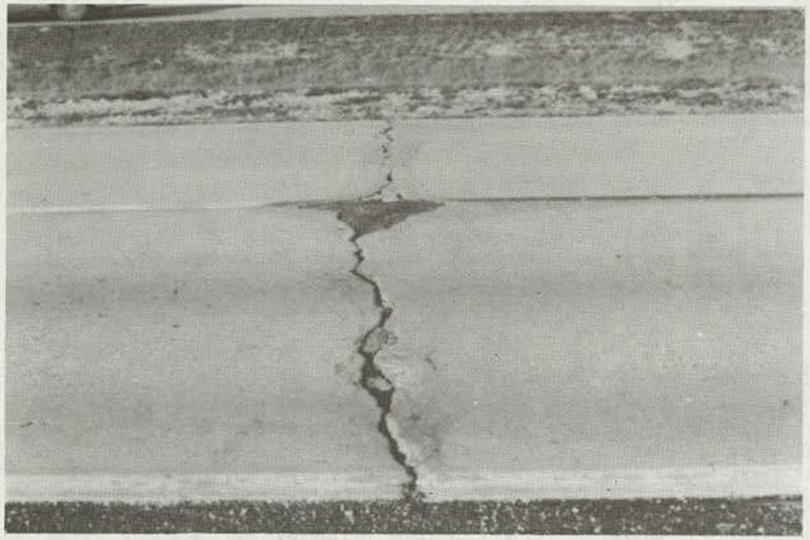


Figure 94. Medium-Severity Spalling.

Figure 95. High-Severity Spalling.

Figure 96. High-Severity Spalling.

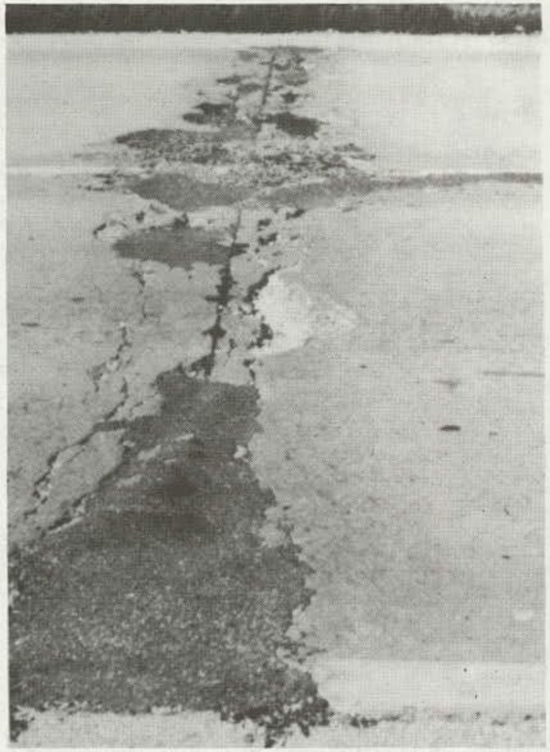


Figure 97. High-Severity Spalling.

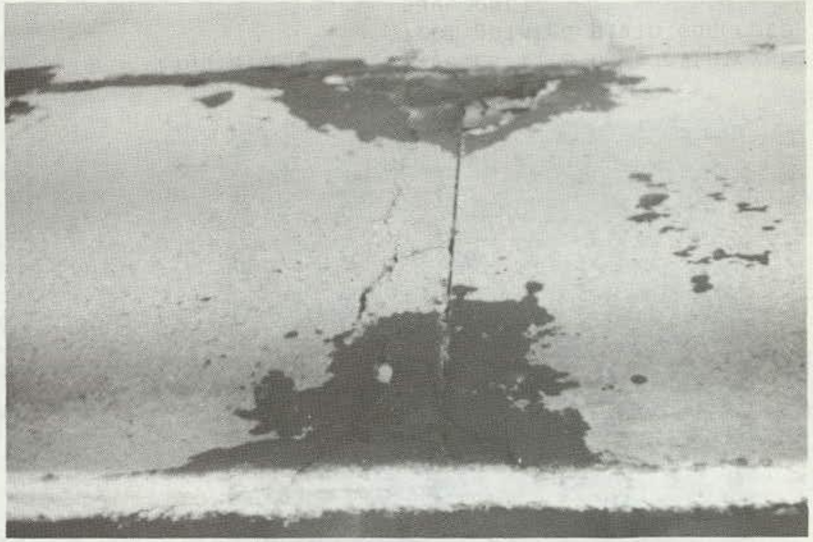


Figure 98. High-Severity Spalling.

Figure 99. High-Severity Spalling.

Figure 100. High-Severity Spalling.

Name of Distress:	Studded Tire Damage
Description:	Studded tire damage is a pavement wear caused or aggravated by the initial action of studded tires. Removal of or damage to the surface of the pavement exposing coarse aggregate can be observed in the wheel paths. Studded tire damage is not to be confused with scaling and crazing which can occur anywhere on the pavement.
Severity Levels:	No level of severity is defined. If studded tire damage occurs anywhere in the sample unit it is counted.
How to Measure:	If studded tire damage occurs anywhere in the sample unit, it is counted.

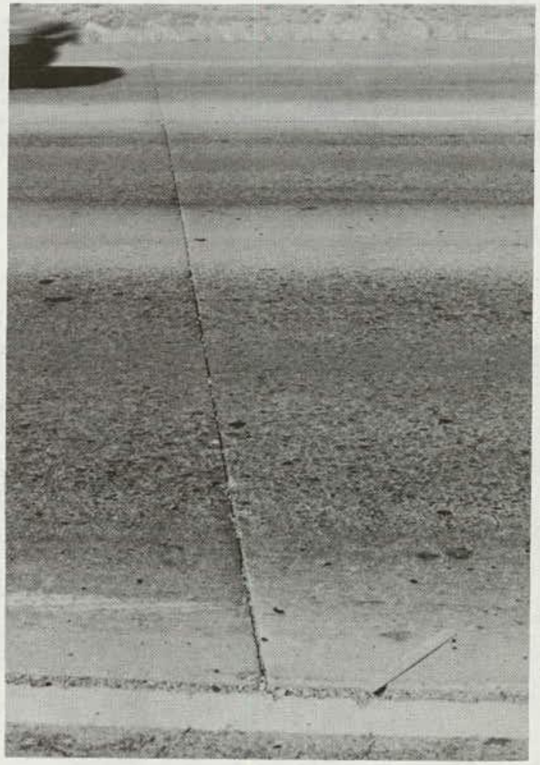


Figure 101. Studded Tire Damage (picture from jointed plain concrete pavement).

Name of Distress: Swell

Description: A swell is an upward movement or heave of the slab surface resulting in a sometimes sharp wave. The swell is usually accompanied by slab cracking. It is usually caused by frost heave in the subgrade or by an expansive soil. Swells can often be identified by oil droppings on the surface as well as riding over the pavement in a vehicle.

Severity Levels:

L - Swell causes a distinct bounce of the vehicle which creates no discomfort.

M - Swell causes significant bounce of the vehicle which creates some discomfort.

H - Swell causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: The number of swells within the uniform section are counted and recorded by severity level. Severity levels are determined by riding in a mid- to full-sized sedan weighing approximately 3000-38000 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

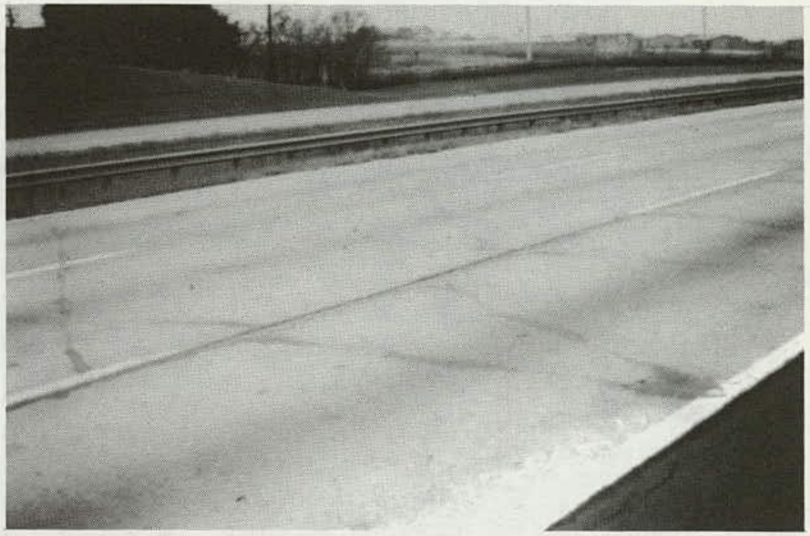


Figure 103. Swell Due to Expansive Soil.

Figure 102. Swell Due to Frost Heave.

Name of Distress: Transverse and Diagonal Cracks

Description: Linear cracks are caused by one or a combination of the following: heavy load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high severity cracks are working cracks and are considered major structural distresses. (Note: hairline cracks that are less than 6 feet (1.8 m) long are not rated).

Severity Levels:

- L - Hairline (tight) crack with no spalling or faulting, a well sealed crack with no visible faulting or spalling.
- M - Working crack with low to medium severity level of spalling, and/or faulting less than 1/2 inch (13 mm). Temporary patching may be present.
- H - A crack with width of greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.

How to Measure: Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded. Cracks in patches are recorded under patch deterioration.

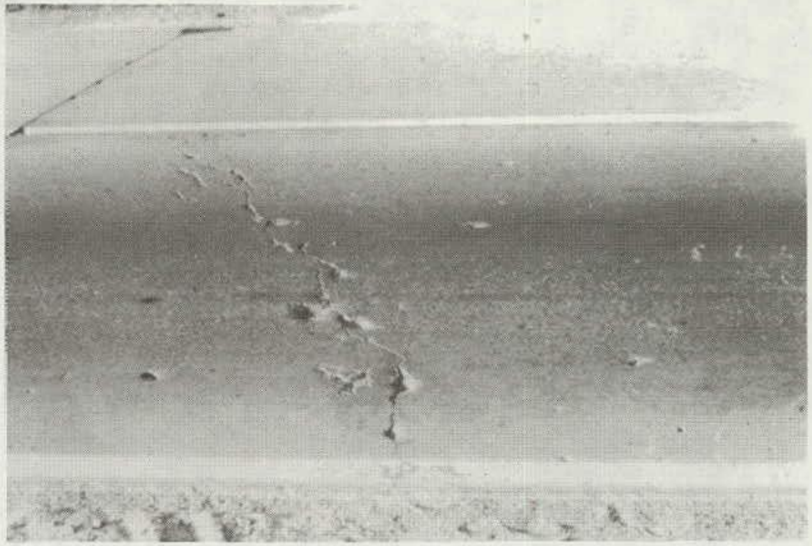


Figure 105. Medium-Severity Diagonal Crack (crack is tight even though it has some low spalling)

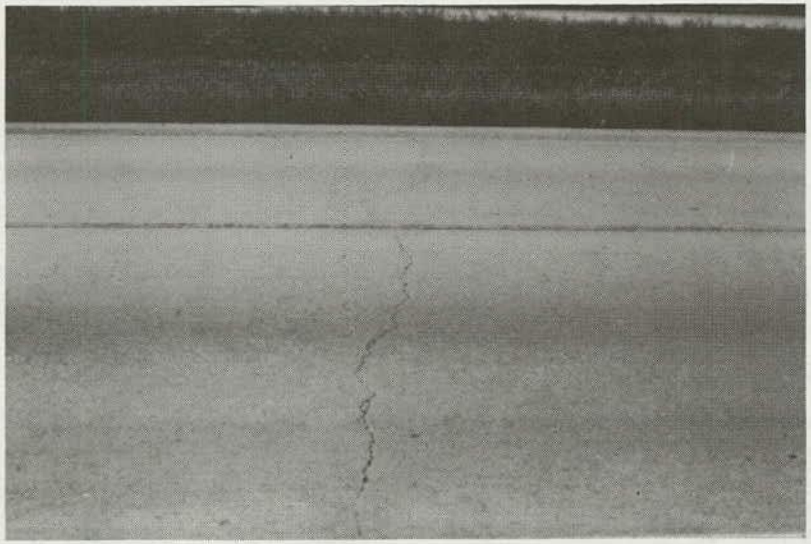


Figure 104. Low-Severity Transverse Crack.

Figure 106. Medium-Severity Transverse Crack.

Figure 107. High-Severity Transverse Crack.

Figure 108. High-Severity Transverse Crack.

CONTINUOUSLY REINFORCED CONCRETE DISTRESS

Name of Distress: Blow-up

Description: Blow-ups are caused by a combination of thermal and moisture expansive forces which exceed the pavement system's ability to absorb, in conjunction with a pavement discontinuity. Blow-ups occur at construction joints or at wide transverse cracks at which the steel has previously ruptured. The result is a localized upward movement of the slab at the edges of the crack or construction joint accompanied by shattering of the concrete in that area.

Severity Levels:

L - Blow-up has occurred, but only causes some bounce of the vehicle which creates no discomfort.

M - Blow-up causes a significant bounce of the vehicle which creates some discomfort. Temporary patching may have been placed because of a blow-up.

H - Blow-up causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: The number of blow-ups with each severity level in the sample unit will be counted and recorded separately. Severity levels are determined by riding in a mid- to full-sized sedan weighing approximately 3000-2800 lbs. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Figure 109. High-Severity Blow-up.

Figure 110. High-Severity Blow-up at Wide Transverse Crack.

Name of Distress: Construction Joint Deterioration

Description: Construction joint distress is a breakdown of the concrete or steel at a CRCP construction joint. It often results in a series of closely spaced transverse cracks near the construction joint or a large number of interconnecting cracks. These cracks can, in time, lead to spalling and breakup of the concrete. If an inadequate steel lap or a steel rupture occurs at a construction joint, the result is often spalling and disintegration of the surrounding concrete, and a possible punchout. This can also lead to a readily accessible entrance for water. The primary causes of construction joint distress are poorly consolidated concrete and inadequate steel content or placement.

Severity Levels:

L - Only closely spaced tight cracks with no spalling or faulting occurring within 10 ft (3 m) of each side of construction joint.

M - Some low severity spalling of cracks, or a low severity punchout exists within 10 ft (3 m) of either side of the construction joint. Temporary patching may have been placed.

H - Significant deterioration and breakup exists within 10 ft. (3 m) of the construction joint that requires patching.

How to Measure: The number of construction joints at each severity level is noted and recorded.

Figure 111. High-Severity Construction Joint Deterioration.

Figure 112. High-Severity Construction Joint Deterioration.

Name of Distress: Depression

Description: Depressions in concrete pavements are localized settled areas. There is generally significant slab cracking in these areas due to uneven settlement. The depressions can be located by stains caused by oil droppings from vehicles, and by riding over the pavement. Depressions can be caused by settlement or consolidation of the foundation soil or can be "built in" during construction. They are frequently found near culverts. This is usually caused by poor compaction of soil around the culvert during construction. Depressions cause slab cracking, roughness, and hydroplaning when filled with water of sufficient depth.

Severity Levels:

L - Depression causes a distinct bounce of vehicle which creates no discomfort.

M - Depression causes significant bounce of the vehicle which creates some discomfort.

H - Depression causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Depressions are measured by counting the number that exists in each uniform section. Each depression is rated according to its level of severity. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Figure 113. Depression.

Name of Distress: Durability ("D") Cracking

Description: "D" cracking is a series of closely spaced crescent-shaped hairline cracks that appear at a PCC pavement slab surface adjacent and roughly parallel to transverse and longitudinal joints, transverse and longitudinal cracks, and the free edges of pavement slab. The fine surface cracks often curve around the intersection of longitudinal joints/cracks and transverse joints/cracks. These surface cracks often contain calcium hydroxide residue which causes a dark coloring of the crack and immediate surrounding area. This may eventually lead to disintegration of the concrete within 1-2 ft. (0.30-0.6 m) or more of the joint or crack, particularly in the wheelpaths. "D" cracking is caused by freeze-thaw expansive pressures of certain types of coarse aggregates and typically begins at the bottom of the slab which disintegrates first. Concrete durability problems caused by reactive aggregates are rated under "Reactive Aggregate Distress."

Severity Levels:

L - The characteristic pattern of closely spaced fine cracks has developed near joints, cracks, and/or free edges; however, the width of the affected area is generally <12 in. (30 cm) wide at the center of the lane in transverse cracks and joints. The crack pattern may fan out at the intersection of transverse cracks/joints with longitudinal cracks/joints. No joint/crack spalling has occurred, and no patches have been placed for "D" cracking.

M - The characteristic pattern of closely spaced cracks has developed near the crack, joint or free edge and: (1) is generally wider than 12 in. (30 cm) at the center of the lane in transverse cracks and/or joints; or (2) low or medium severity joint/crack or corner spalling has developed in the affected area; or (3) temporary patches have been placed due to "D" cracking induced spalling.

H - The pattern of fine cracks has developed near joints or cracks and (1) a high severity level of spalling at joints/cracks exists and considerable material is loose in the affected area; or (2) the crack pattern has developed generally over the entire slab area between cracks and/or joints.

How to Measure: "D" cracking is measured and recorded in linear feet (or meters) of cracks and free edges affected. Different severity levels are counted and recorded separately. "D" cracking adjacent to a patch is rated as patch-adjacent slab deterioration. "D" cracking should not be counted if the fine crack pattern has not developed near cracks, joints and free edges. Popouts and discoloration of joints, cracks and free edges may occur without "D" cracking.

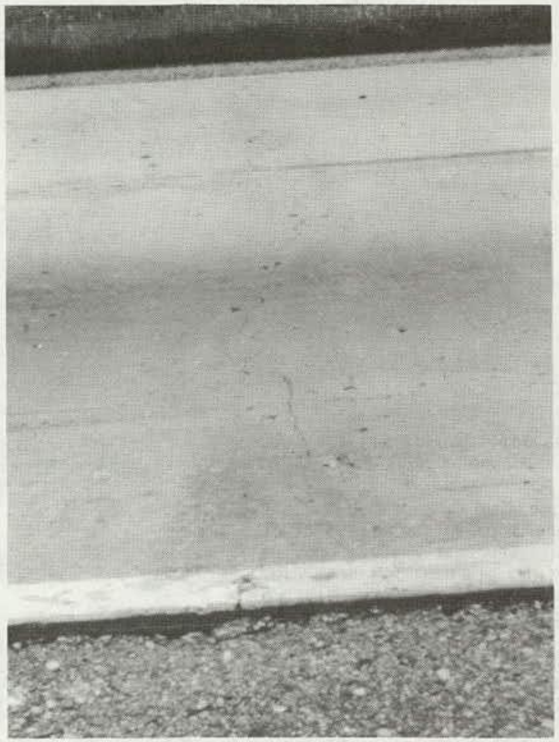


Figure 114. Low-Severity "D" Cracking.

Figure 115. Medium-Severity "D" Cracking.

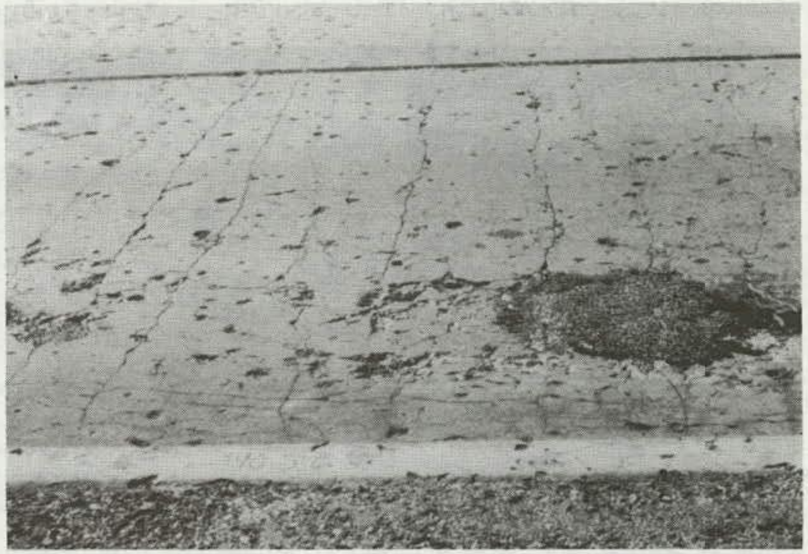


Figure 116. High-Severity "D" Cracking.

Name of Distress: Edge Punchout

Description: An edge punchout is first characterized by a loss of aggregate interlock at one or two closely spaced cracks (i.e., usually less than 48 in. (122 cm) apart) near the edge joint. The crack or cracks begin to fault and spall slightly which causes the portion of the slab between the closely spaced cracks to act essentially as a cantilever beam. As heavy truck load applications continue, a short longitudinal crack forms between the two transverse cracks about 24-60 in. (61-152 cm) from the pavement edge. Eventually the transverse cracks breakdown further, the steel ruptures and the pieces of concrete punch downward under load into the subbase and subgrade. There is generally evidence of pumping near edge punchouts, and sometimes extensive pumping. The distressed area will expand in size to adjoining cracks and develop into a very large area if not repaired. The edge punchout is the major structural distress of CRCP.

Severity Levels:

L - A longitudinal crack develops between two closely spaced transverse cracks. The longitudinal and transverse cracks are failry tight and only slight faulting or spalling is present.

M - The transverse and/or longitudinal cracks have begun to widen and spall with faulting or punching down of the concrete less than 1/2 inch (13 mm).

H - The concrete within the boundary of the punchout is breaking up, has been punched down into the subbase more than 1/2 inch (13 mm) and/or has an asphalt patch on top. If the area has been patched with asphalt it is still considered a punchout and not an asphalt patch since this is only a temporary patch.

How to Measure: The number of edge punchouts and their level of severity are recorded for each sample unit.

Figure 117. High-Severity "D" Cracking (note exposed edge of slab at bottom of photo).

Figure 118. Low-Severity Edge Punchout (Note: a fine longitudinal crack has developed between the two closely spaced transverse cracks).

Figure 119. Medium-Severity Edge Punchout (this photo is same edge punchout as Figure 118 after one year).

Figure 120. Medium-Severity Edge Punchout.

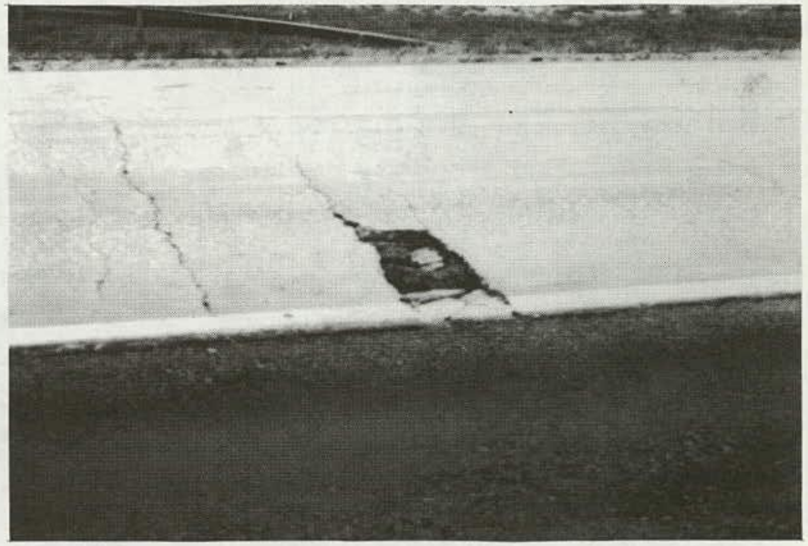


Figure 121. High-Severity Edge Punchout.

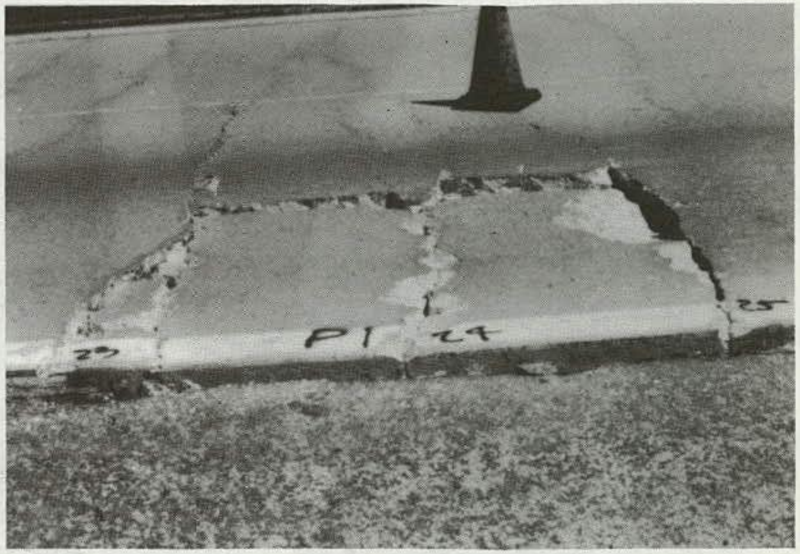


Figure 122. High-Severity Edge Punchout.

Name of Distress: Lane/Shoulder Joint Separation

Description: Lane/shoulder joint separation is the widening of the joint between the traffic lane and the shoulder generally due to movement in the shoulder. If the joint is tightly closed or well sealed so that water cannot easily infiltrate, then lane/shoulder joint separation is not considered a distress.

Severity Level:

L - A tight joint (sealed) with a mean opening up to 0.12 inch (3 mm).

M - More than 0.12 inch (3 mm) but equal to or less than 0.4 inch (10 mm) opening.

H - More than 0.4 (10 mm) opening. Gravel or sod shoulders are rated as high.

How to Measure: Lane/shoulder joint separation is measured and recorded in inches (or mm) at approximately every 100 feet. The mean separation is used to determine the severity level.

Figure 123. Medium-Severity Lane/Shoulder Joint Separation (asphalt shoulder).

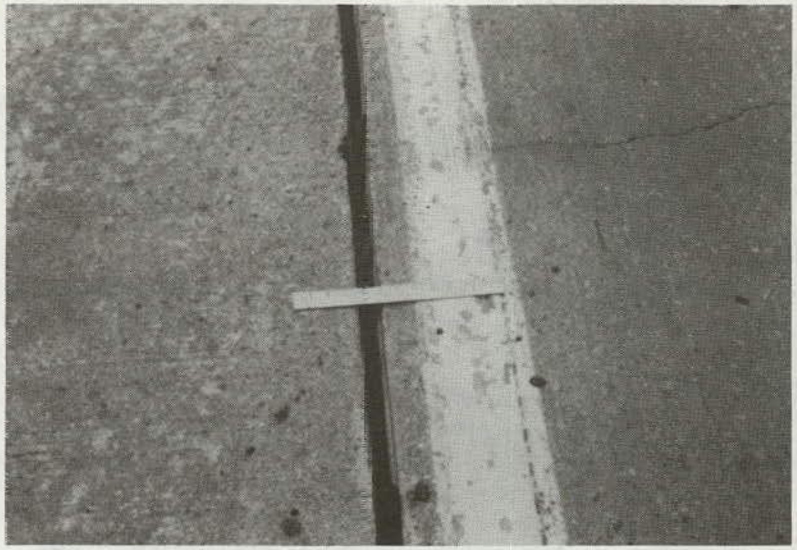


Figure 124. High-Severity Lane Shoulder Joint Separation (concrete shoulder).

Name of Distress: Localized Distress

Description: A localized area of slab where the concrete has broken up into pieces or spalled. The localized distress takes many shapes and forms. Many times it occurs within an area between intersecting, Y-shaped or closely spaced cracks. Localized distress can occur anywhere on the slab surface, but is frequently located in the wheelpaths. Inadequate consolidation of concrete is often a primary cause of localized distress. This is primarily considered to be caused by a construction deficiency, whereas the Edge Punchout is primarily load associated.

Severity Levels:

L - A low severity spalling or breakup of the concrete has occurred.

M - A moderate amount of spalling or breakup of the concrete has developed, or temporary patching has been placed because of the localized distress.

H - High severity spalling and/or settlement of the concrete has developed resulting in a definite safety hazard.

How to Measure: The number of localized distress areas are counted and recorded at each severity level in the uniform section.

Figure 125. Medium-Severity Localized Distress.

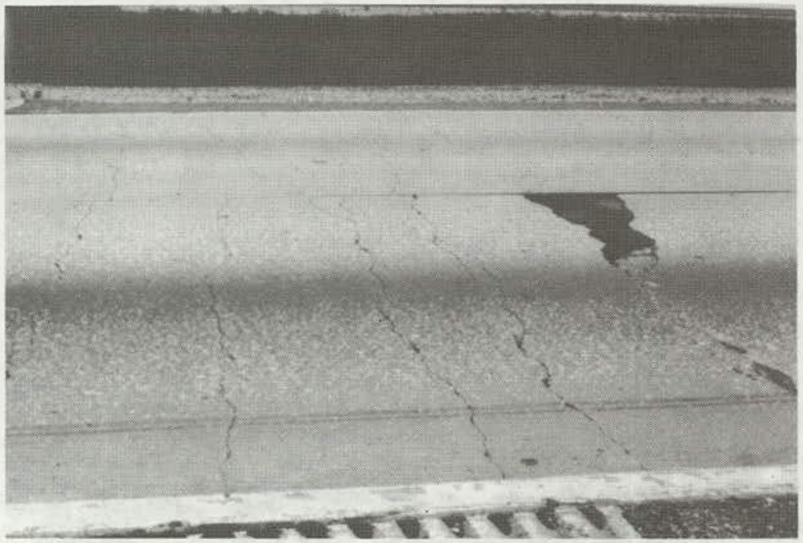


Figure 126. Medium-Severity Localized Distress.

Figure 127. Medium-Severity Localized Distress.

Figure 128. Medium-Severity Localized Distress.

Figure 129. Medium-Severity Localized Distress.

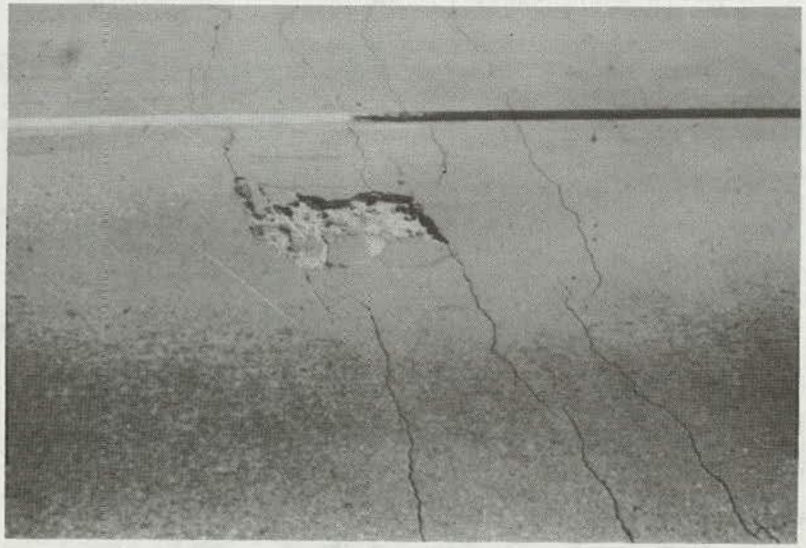


Figure 130. High-Severity Localized Distress.

Name of Distress:	Longitudinal Cracks
Description:	Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints, or by a combination of heavy load repetition, loss of foundation support, and thermal and moisture gradient stresses.
Severity Levels:	L - Hairline (tight) crack with no spalling or faulting, or a well sealed crack with no visible faulting or spalling. M - Working crack with a moderate or less severity spalling and/or faulting less than 1/2 inch (13 mm). H - A crack with width greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.
How to Measure:	Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded.

Figure 131. Medium-Severity Longitudinal Crack.

Name of Distress: Longitudinal Joint Faulting

Description: Longitudinal joint faulting is a difference in elevation of two traffic lanes measured at the longitudinal joint. It is caused primarily by heavy truck traffic and settlement of the foundation.

Severity Levels: No levels of severity are defined.

How to Measure: If the maximum longitudinal joint faulting is greater than 1/2 inch (13 mm), it is recorded as a distressed area.

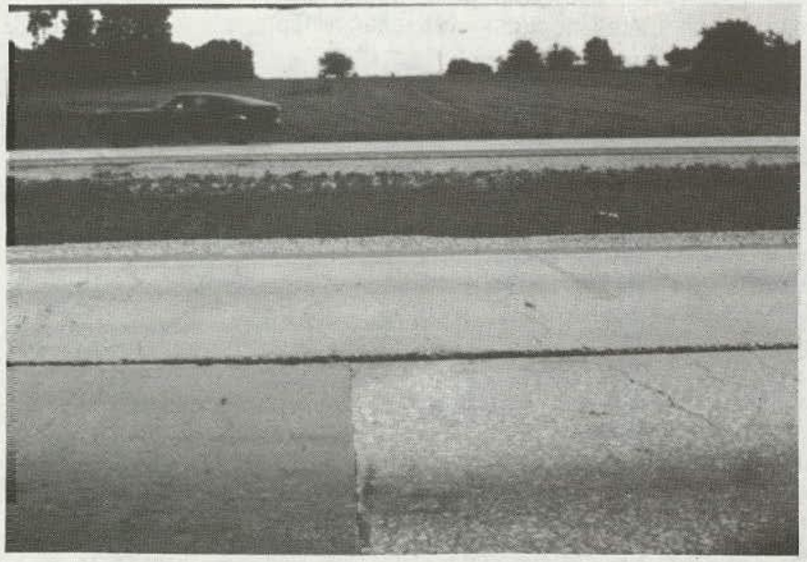


Figure 132. Longitudinal Joint Faulting.

Name of Distress: Patch Deterioration

Description: A patch is an area where a portion or all of the original concrete slab has been removed and replaced with a permanent type of material (e.g., concrete, epoxy, hot mix asphalt/aggregate mixture). Only permanent patches should be considered.

Severity Levels:

L - Patch has little or no deterioration. Cracks and edge joints are tight. Low severity spalling or ravelling may exist. No faulting or settlement has occurred. Patch is rated low severity even if it is in excellent condition.

M - Patch is somewhat deteriorated. Settlement < 1/2 inch (13 mm), cracking, rutting, or shoving has occurred in an asphalt patch; concrete patch may exhibit spalling and/or faulting up to 1/2 inch (13 mm) around the edges and/or cracks.

H - Patch is badly deteriorated either by cracking, faulting, spalling, rutting or shoving to a condition which requires replacement. Patch may present tire damage potential.

How to Measure: The number of patches at each severity level within the sample unit are counted and recorded. Patching is measured in square feet (or square meters) of area.

Figure 133. Low-Severity Asphalt Patch Deterioration.

Figure 134. Medium-Severity Asphalt Patch Deterioration (same patch as Figure 133 after 2 years).

Figure 135. High-Severity Asphalt Patch Deterioration.

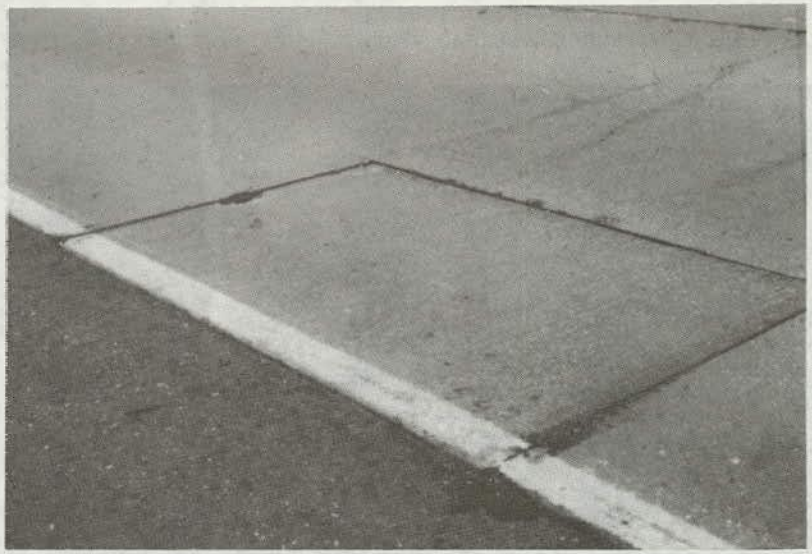


Figure 136. Medium-Severity Concrete Patch Deterioration.

Figure 137. Medium-Severity Concrete Patch Deterioration.

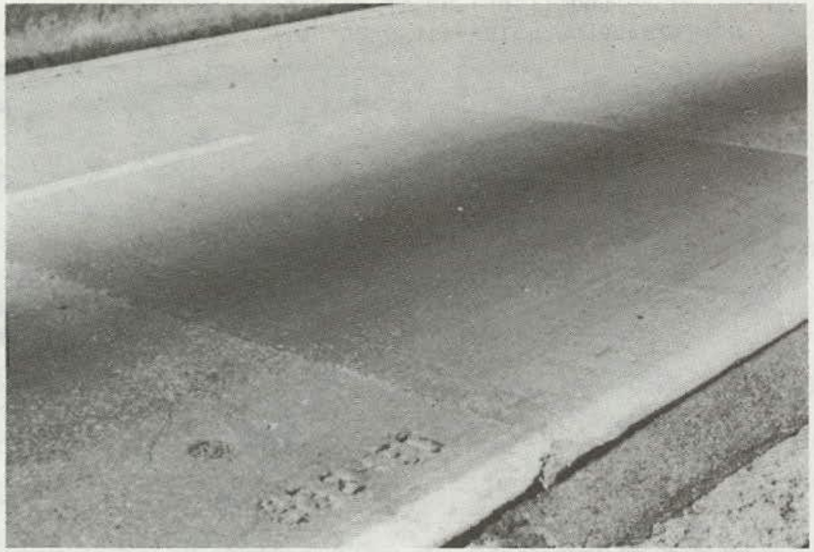


Figure 138. Low-Severity Concrete Patch Deterioration.

Name of Distress:	Patch Adjacent Slab Deterioration
Description:	Deterioration of the original concrete slab adjacent to the permanent patch is given the above name. This may be in the form of spalling of the slab/patch joint, "D" cracking of the slab adjacent to the patch, or a corner break (or edge punchout) in the adjacent slab.
Severity Levels:	No levels of severity are defined. If patch adjacent slab deterioration occurs, it is counted.
How to Measure:	The number of permanent patches with distress in the original slab adjacent to the patch at each distress level (i.e., corner break, "D" cracking, spalling) will be counted and recorded separately.

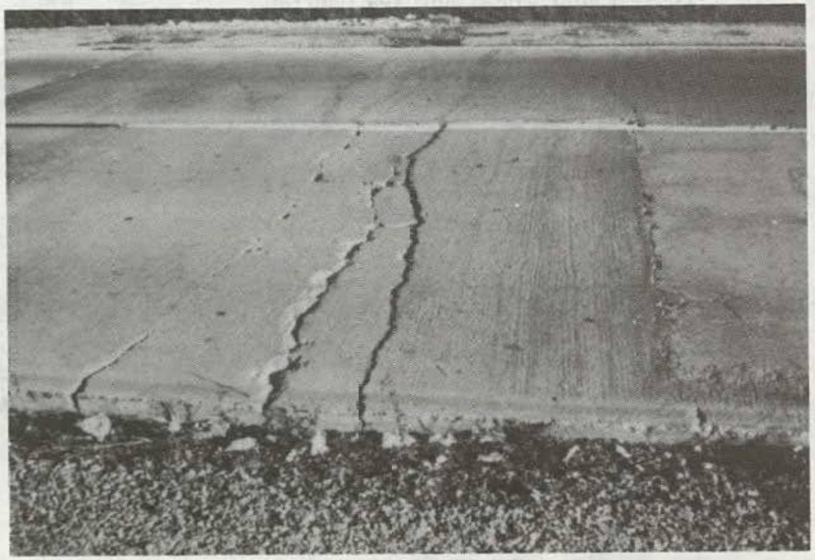


Figure 139. High-Severity Concrete Patch Deterioration.

Figure 140. Patch Adjacent Slab Deterioration (spalling).

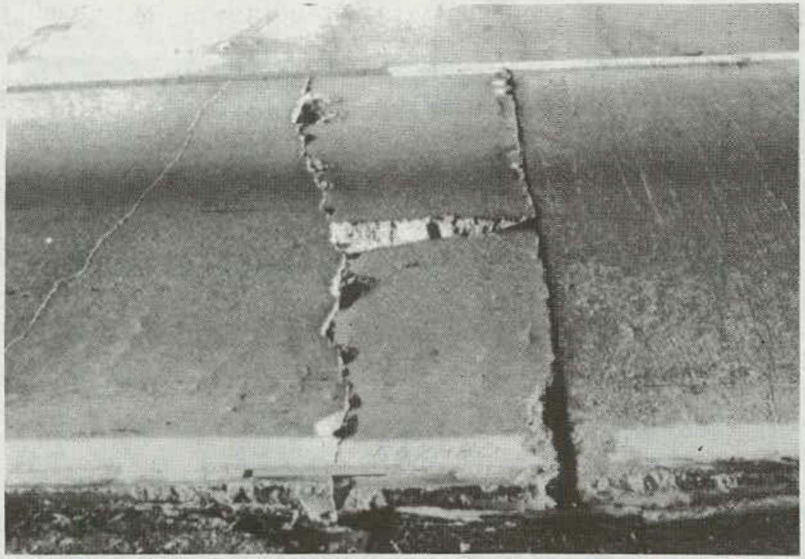


Figure 141. High-Severity Patch Adjacent Slab Deterioration (edge punchouts).

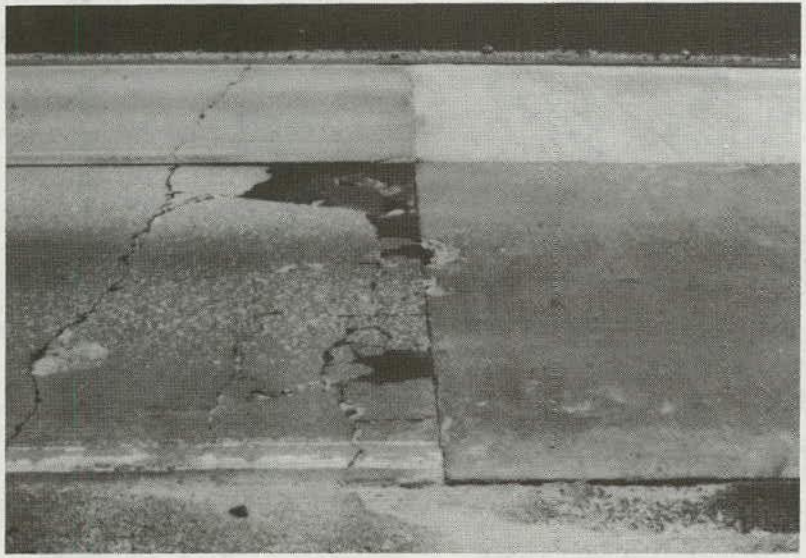


Figure 142. High Severity Patch Adjacent Slab Deterioration (spalling).

Name of Distress: Pumping and Water Bleeding

Description: Pumping is the movement of material by water pressure beneath the slab when it is deflected under a heavy moving wheel load. Sometimes the pumped material moves around beneath the slab, but often it is ejected through joints and/or cracks (particularly along the longitudinal lane/shoulder joint with an asphalt shoulder). Beneath the slab there is typically particle movement counter to the direction of traffic across a joint or crack that results in a buildup of loose materials under the approach slab near the joint or crack. Many times some fine materials (silt, clay, sand) are pumped out leaving a thin layer of relatively loose clean sand and gravel beneath the slab, along with voids causing loss of support. Pumping occurs even in pavement sections containing stabilized subbases. The erosion of the top of the stabilized subbase often occurs, and also a pumping of the foundation material from beneath the stabilized subbase is common.

Water bleeding occurs when water seeps out of joints and/or cracks. It many times drains out over the shoulder in low areas.

Severity Levels:

L - No fines can be seen on the surface of the traffic lanes or shoulder. However, there is evidence that water is forced out of a joint or crack when trucks pass over the joints or cracks. One evidence of water pumping is the existance of small "blowholes" in the asphalt shoulder adjacent to a transverse joint. The asphalt surface may have settled some indicating a loss of material beneath the surface. Another evidence of low severity pumping is the bleeding of water from the longitudinal lane/shoulder joint.

M - A small amount of pumped material can be observed near some of the joints or cracks on the surface of the traffic lane or shoulder. Blow holes may exist.

H - A significant amount of pumped materials exist on the pavement surface of the traffic lane or shoulder along the joints or cracks.

How to Measure: If pumping or water bleeding exists anywhere in the sample unit it is counted as occurring at highest severity level as defined above.

Figure 143. Low-Severity Pumping (water ejected out of transverse crack under truck wheel).

Figure 144. Low-Severity Pumping (water ejected out of longitudinal joint under truck wheel).

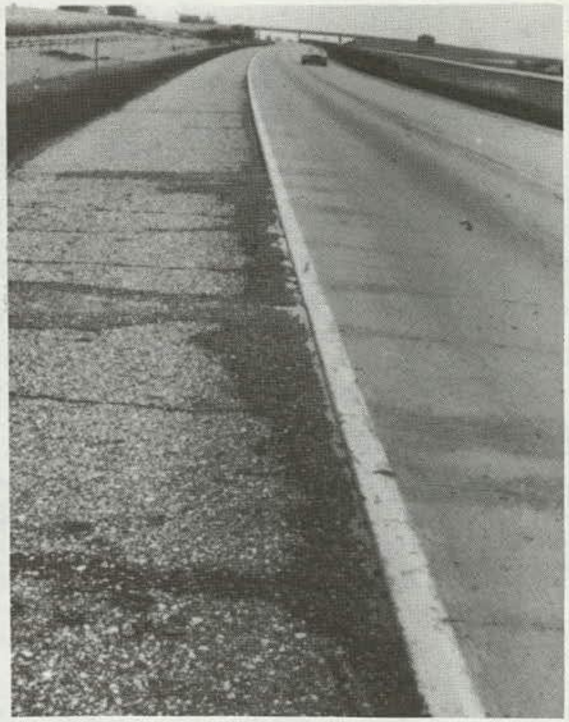


Figure 145. Low-Severity Water Bleeding.

Figure 146. Medium-Severity Pumping of Fines.

Figure 148. High-Severity Pumping of Fines.

Figure 147. Medium-Severity Pumping of Fines.

Figure 149. Very-High-Severity Pumping of Fines.

Name of Distress: Reactive Aggregate Distress

Description: Reactive aggregates either expand in alkaline environments or develop prominent siliceous reaction rims in concrete. It may be an alkali-silica reaction or an alkali-carbonate reaction. As expansion occurs, the cement matrix is disrupted and cracks. It appears as a map cracked area; however, the cracks may go deeper into the concrete than in normal map cracking. It may affect most of the slab or it may first appear at joints and cracks.

Severity Levels:

L - Joint and or slab shows pressure and map cracking. Pavement may be discolored, but scaling and spalling of joints does not exist.

M - Joints are spalled and or scaling exists. White fines may exist along cracks and joints.

H - Joint spalling and or scalling exists to the extent that a tire damage or safety hazard exists. A significant amount of white fines may exist on the pavement surface.

How to Measure: Reactive aggregate distress is measured as the percent of area of the sample unit which exhibits this distress at each severity level.

See Figure 89

Name of Distress: Scaling and Map Cracking or Crazing

Discription: Scaling is the deterioration of the upper 1/8-1/2 inch (3-13 mm) of the concrete slab surface. Map cracking or crazing is a series of fine cracks that extend only into the upper surface ot the slab surface. Map cracking or crazing is usually caused by over-finishing of the slab and may lead to scaling of the surface. Scaling can also be caused by reinforcing steel being too close to the surface.

Severity Levels:

L - Crazing or map cracking exists over a majority of the slab area; the surface is in good condition with no scaling.

M - Less than 10% of any slab exhibits scaling.

H - More than 10% of any slab exhibits scaling.

How to Measure: Scaling and map cracking or crazing are rated according to the highest severity level found in a sample unit.

Figure 150. Low-Severity Map Cracking or Crazing.

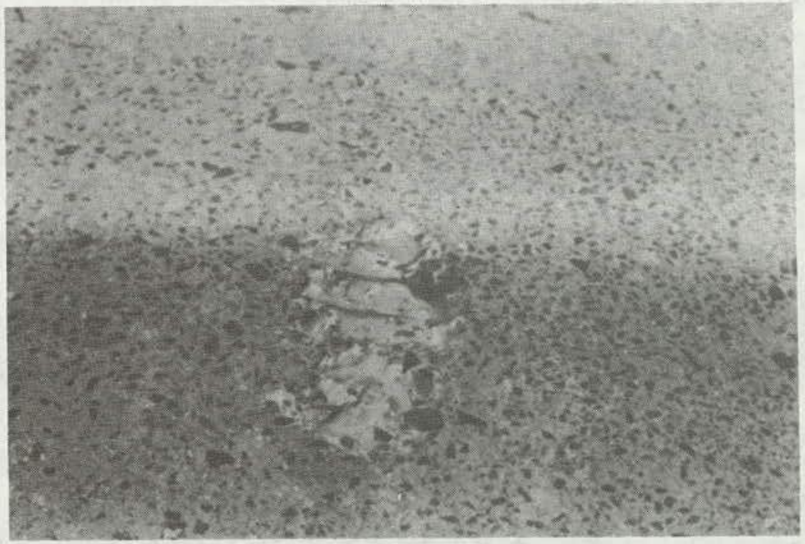


Figure 151. Medium-Severity Scaling (steel close to surface).

Name of Distress: Spalling

Description: Spalling of cracks and joints is the breakdown or fraying of the slab edges within 2 ft. (0.6 m) of the crack or joint. A spall usually does not extend vertically through the whole slab thickness, but extends to intersect the crack or joint at an angle. Spalling usually results from (1) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion, (2) disintegration of the concrete from durability problems, (3) weak concrete at the surface (caused by overworking or honeycombing), or (4) a keyed longitudinal joint failure.

Severity Levels:

L - The spall or fray does not extend more than 3 ins. (8 cm) on either side of the joint or crack. No temporary patching has been placed to repair the spall.

M - The spall or fray extends more than 3 ins. (8 cm) on either side of the joint or crack. Some pieces may be loose and/or missing but the spalled area does not present a tire damage or safety hazard. Temporary patching may have been placed because of spalling.

H - The joint is severly spalled or frayed to the extent that a tire damage or safety hazard exists.

How to Measure: Spalling of CRCP pavements is recorded under 5 distress types. Spalling of construction joints will be recorded under "Construction Joint Deterioration." Spalling of longitudinal and transverse joints and cracks are recorded under "Longitudinal Joint Spalling", "Transverse Cracks", and "Longitudinal Cracks". Spalling of the slab edge adjacent to a permanent patch will be recorded as "Patch Adjacent Slab Deterioration." If more than one level of severity exists along a crack or joint, it will be recorded at the highest severity level present.

Figure 152. Low-Severity Spalling of Transverse Cracks.

Figure 153. Low-Severity Spalling of Transverse Cracks (these cracks are tight beneath the spalled surface).

Figure 154. Low-Severity Spalling of Transverse Cracks.

Figure 156. Medium-Severity Spalling of Longitudinal Joint.

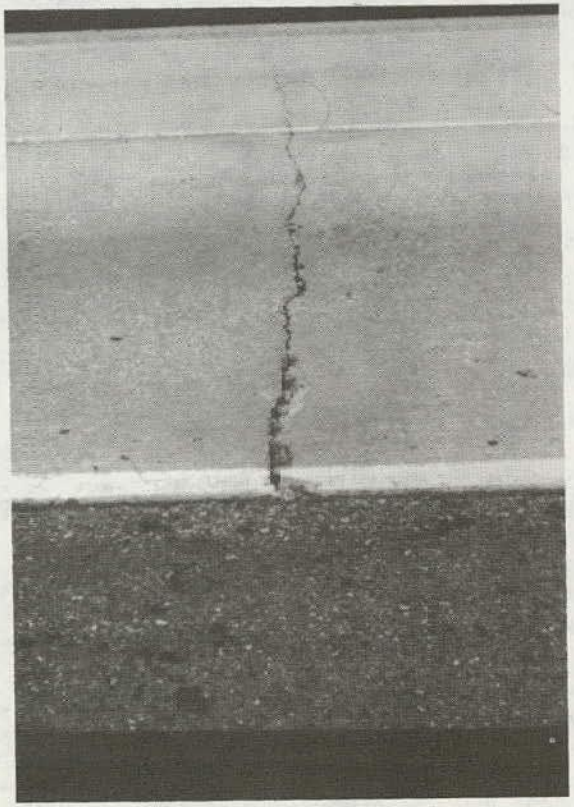


Figure 155. Medium-Severity Spalling of Transverse Cracks.

Figure 157. High Severity Spalling of Transverse Crack (Note: see Figure 112 for an example of high severity construction joint spalling).

Name of Distress: Studded Tire Damage

Description: Studded tire damage is a pavement wear caused or aggravated by the initial action of studded tires. Removal of or damage to the surface of the pavement exposing coarse aggregate can be observed in the wheel paths. Studded tire damage is not to be confused with scaling and crazing which can occur anywhere on the pavement.

Severity Levels: No level of severity is defined. If studded tire damage occurs anywhere in the sample unit it is counted.

How to Measure: If studded tire damage occurs anywhere in the sample unit, it is counted.

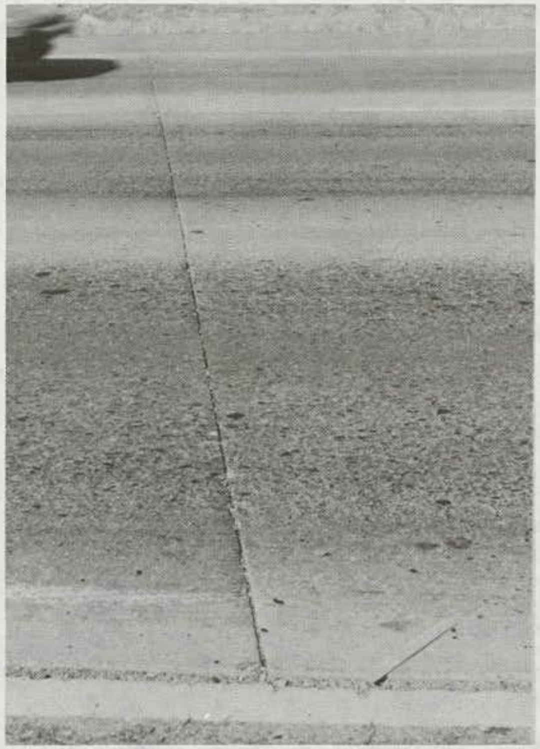


Figure 158. Studded Tire Damage. (Picture taken of a Jointed Plain Concrete Pavement.)

Name of Distress: Swell

Description: A swell is an upward movement or heave of the slab surface resulting in a sometimes sharp wave. The swell is usually accompanied by slab cracking. It is usually caused by frost heave in the subgrade or by an expansive soil. Swells can often be identified by oil droppings on the surface as well as riding over the pavement in a vehicle.

Severity Levels:

L - Swell causes a distinct bounce of the vehicle which creates no discomfort.

M - Swell causes significant bounce of the vehicle which creates some discomfort.

H - Swell causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: The number of swells within the uniform section are counted and recorded by severity level. Severity levels are determined by riding in a mid- to full-sized sedan weighing approximately 3000-38000 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Figure 159. Swell Caused by Frost Heave (located behind truck)

Figure 160. Swell Caused by Frost Heave.

Figure 161. Swell Caused by Expansive Soil.

Name of Distress: Transverse Cracking

Description: Transverse cracking of continuously reinforced slabs is a normal occurrence and is not in itself considered to be a distress. As soon as the slab is placed and begins to harden, drying shrinkage of the concrete occurs. Reinforcement in the slab and subbase friction oppose the shrinkage and cracks soon form. After about 2-4 years, the crack spacing becomes constant. The purpose of the steel is to hold these random spaced transverse cracks tightly together so that load transfer across the crack will be obtained through aggregate interlock. If the steel ruptures or shears, load transfer across the crack is lost and the crack becomes a potential location for major distress. When deicing salts and water infiltrate through a wide crack, the reinforcing steel is subjected to corrosion, and the effective diameter of the steel begins to decrease. When the stresses due to temperature changes and loading are greater than the strength of the steel, the reinforcing bar ruptures. Indicators of sheared or decreased diameter reinforcing bars are faulted and/or widened spalled cracks. Some cracks may have widened substantially after steel rupture. (Note: sometimes the transverse cracks run diagonally across the pavement and intersect. Hairline cracks that are less than 6 feet long are not rated.

Severity Levels: Severity levels of transverse cracking are determined by crack spalling and faulting.

L - Tight (hairline) cracks with no faulting, steel rupture, or spalling.*

M - A crack with no steel rupture, faulting less than or equal to 0.2 inch (5 mm) and/or low severity spalling.*

H - Faulting greater than 0.2 inch (5 mm), or steel rupture, or medium to high severity spalling.*

How to Measure: Faulting is determined by measuring elevation difference across transverse cracks one foot from the slab edge. Any cracks wider than 1/8 inch (3 mm) can be assumed to have some or all steel ruptured. Thus, all cracks in the inspection unit will be identified as L, M, or H, and the linear feet (or meters) of each is recorded. Cracks having a length less than six feet are not considered. All cracks within the sample unit are sketched with severity levels indicated.

*See definition provided under "Spalling."

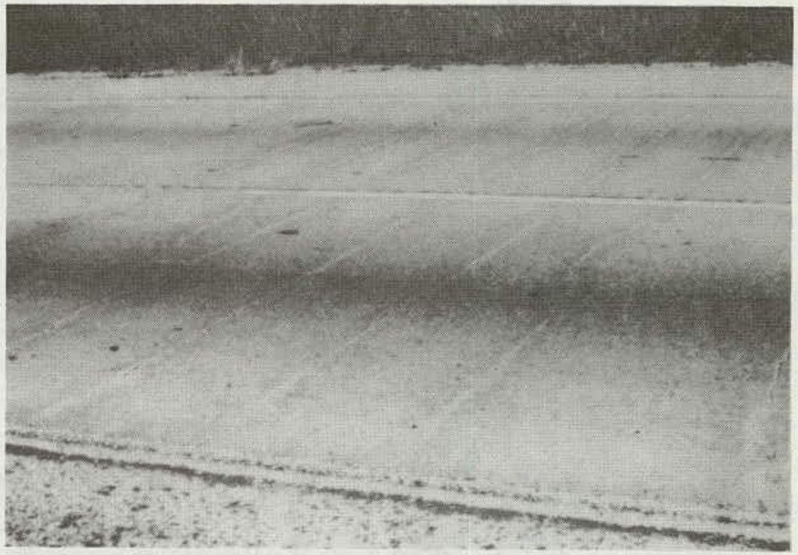


Figure 162. Low-Severity Transverse Cracks.

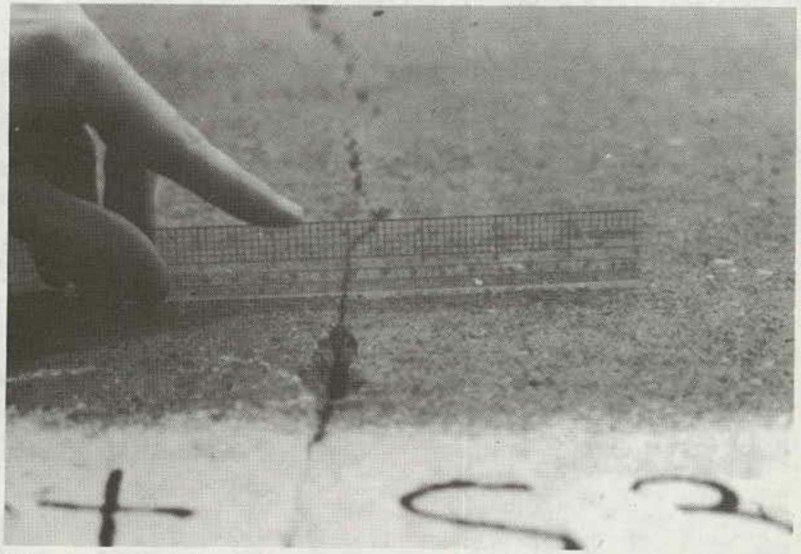


Figure 163. Medium-Severity Transverse Crack (note faulting).

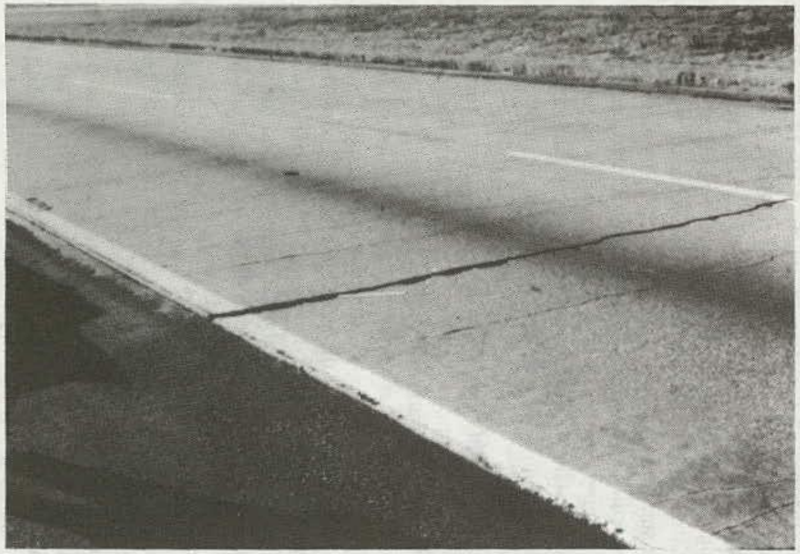


Figure 164. High-Severity Transverse Crack.

Figure 165. High-Severity Transverse Crack.

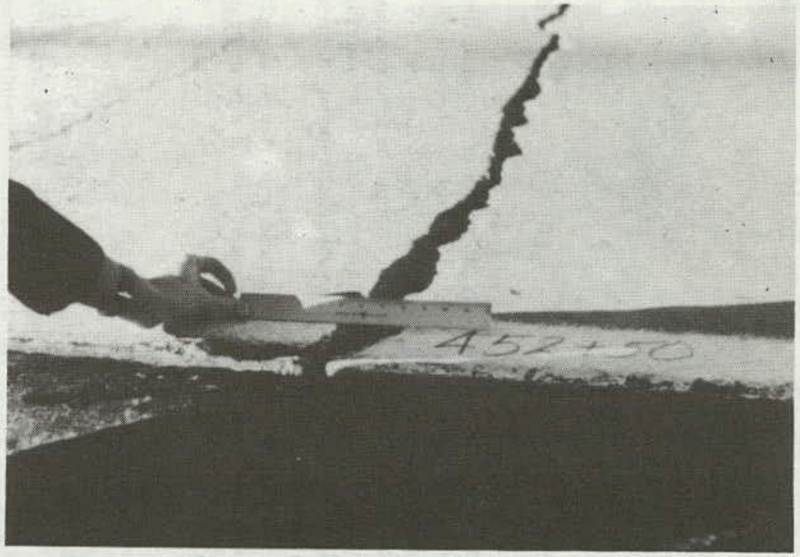


Figure 166. High-Severity Transverse Crack.

CHAPTER THREE

COPES DATA STORAGE AND RETRIEVAL

INTRODUCTION

This chapter describes the data input, storage and retrieval of COPES. The reader should become familiar with COPES as described earlier in the text of this report before reading this chapter.

Large amounts of data must be collected and processed by COPES. For a typical state highway network, data must be collected and input must be stored and retrieved, not only at the uniform section level but also at the sample unit level. Moreover, the amount of data needed is greatly increased for the nationwide evaluation of data from many states. Thus, the use of automatic data processing (ADP) was determined to be essential for the successful and efficient operation of the system.

It is important to recognize, however, that COPES is not intended to be a system that fully encompasses all day-to-day activities required for overall pavement management. COPES provides data for many uses including planning and design, but it is primarily an evaluation system, and thus the data storage and retrieval capabilities are not as demanding as for a comprehensive pavement management system (PMS). The data processing procedures recommended for use in COPES are widely used and generally available to state transportation agencies. Also, any agency can expand the capabilities of COPES to a larger computerized PMS to handle a wider variety of activities. COPES provides an excellent basis on which to develop a comprehensive PMS, or to interface with existing data storage systems used by the agency.

This chapter first describes data input and storage, and then data retrieval.

DATA INPUT AND STORAGE

The major data processing procedures used in COPES are shown in Figure 167. These include data collection, input, storage, and retrieval for analysis purposes.

Data Collection

The field and historical data for each uniform section are recorded on a set of 23 sheets. The sheets are applicable to all conventional concrete pavements: jointed reinforced, jointed plain, and continuously reinforced. Thus, if desired, a given state could include its entire concrete pavement network in the COPES data management system.

The field and historical data collection sheets include space for over 700 variables for each uniform section as specified in Chapter One.

Manual Storage of Data Sheets

Each set of 23 data collection sheets for a *given uniform section* is stored along with slides and any other data in a separate file folder in a file cabinet. The folders should be appropriately labeled and grouped by highway number (e.g., I-70, I-280, US-60). Within each highway group, they should be sequenced as they are in the field from, say, east to west and south to north. This will make it easy to locate the data sheets for any desired uniform section in the future.

Data sheets for future surveys can also be filed easily in each folder. Thus, the manual file system can become a permanent storage for the original raw data sheets.

Keypunching and Input of Raw Data

The data sheets are specifically prepared for direct keypunching onto computer cards or other media. The first design data sheet is shown in Figure 168, and two field data sheets in Figures 169 and 170. The small numbers down the right-hand side are the specific columns in which the data will be located on the card. The first nine columns of each card are for identification purposes: Record Number, State Code, Project ID, and Uniform Section Number. There are seven different "Records" or groupings of data, which are explained later. The particular sheet shown in Figure 168 has data in columns 10–74; 75–78 are blank as denoted by 75–78/BK. The 79–80/01 indicates that 0 and 1 are to be punched into columns 79 and 80, respectively. This designates the sequence number of the punched card. The second card would therefore have 02 punched in columns 79 and 80 as shown in Figure 170, and so forth. Thus, each punched card is specifically numbered. The "Dup" shown for columns 1–12 on Figure 170 means that the keypuncher should simply duplicate the same 12 characters from the preceding card (e.g., the identification, time sequence, and sample unit sequence variables).

After the raw data have been keypunched onto cards, they are read into the computer on disk files. The disk files are then loaded into the computerized database.

Each data element is given a specific alphanumeric name that is keyed to the data sheets. Consider the Design Data Sheet shown in Figure 169 and the variable labeled "State Highway Department (SHD) District Number." This variable is named "D1" in the database, where the "D" indicates that the variable is located in the Design Record, and the "1" indicates that the variable is the first item on the data sheet.

Variables contained on the field data sheets are named similarly. Figure 169 shows the uniform section field data sheet 2F. The variable "U3. Depth of Typical Cut" is labeled "U3" in the database. This particular sheet is for the Uniform Section and also provides for a "Time Sequence" as part of the identification code. Thus any number of time sequences of data from 01 to 99 can be added into the data bank.

Figure 170 shows one of the Sample Unit data sheets. Here,

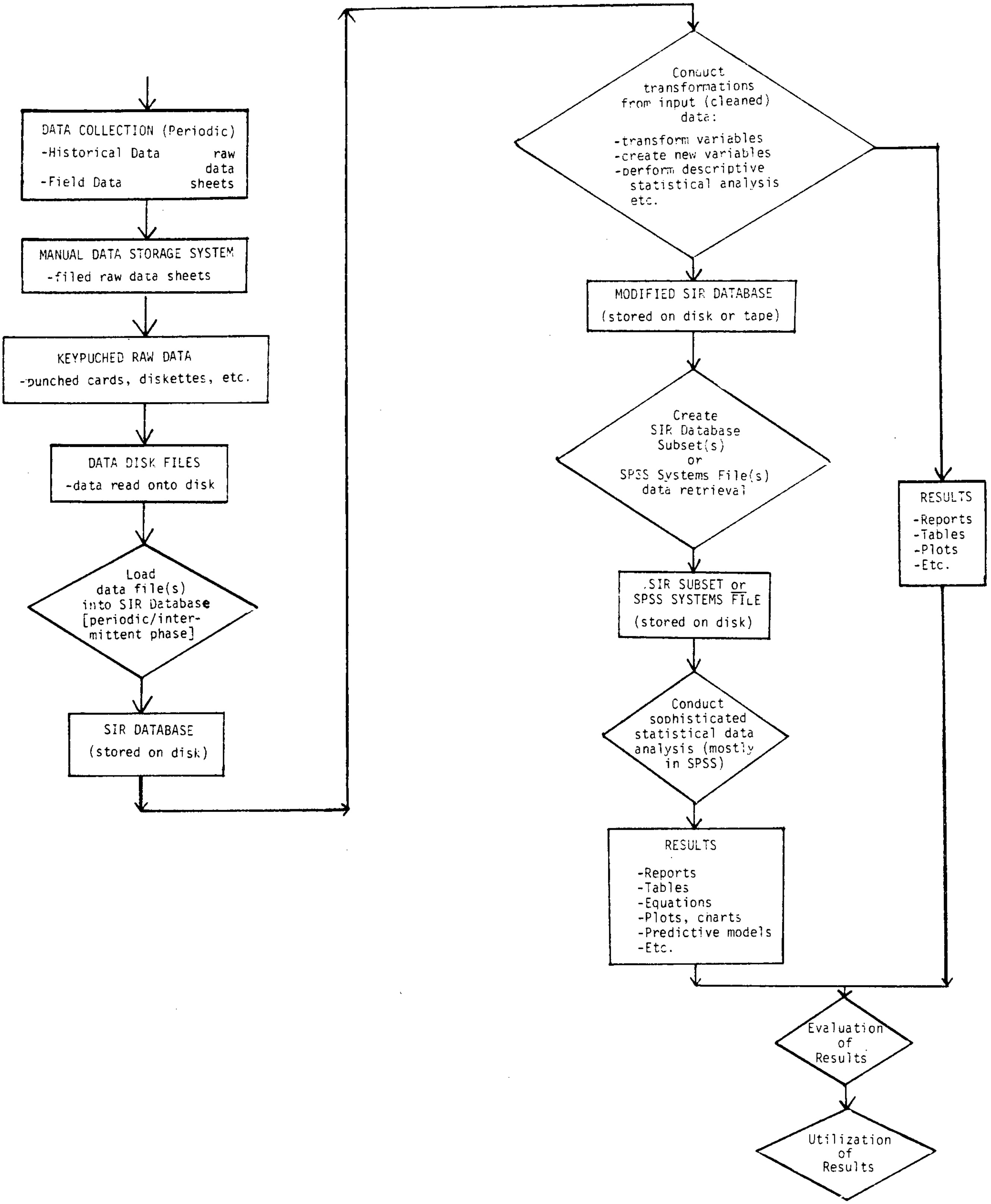
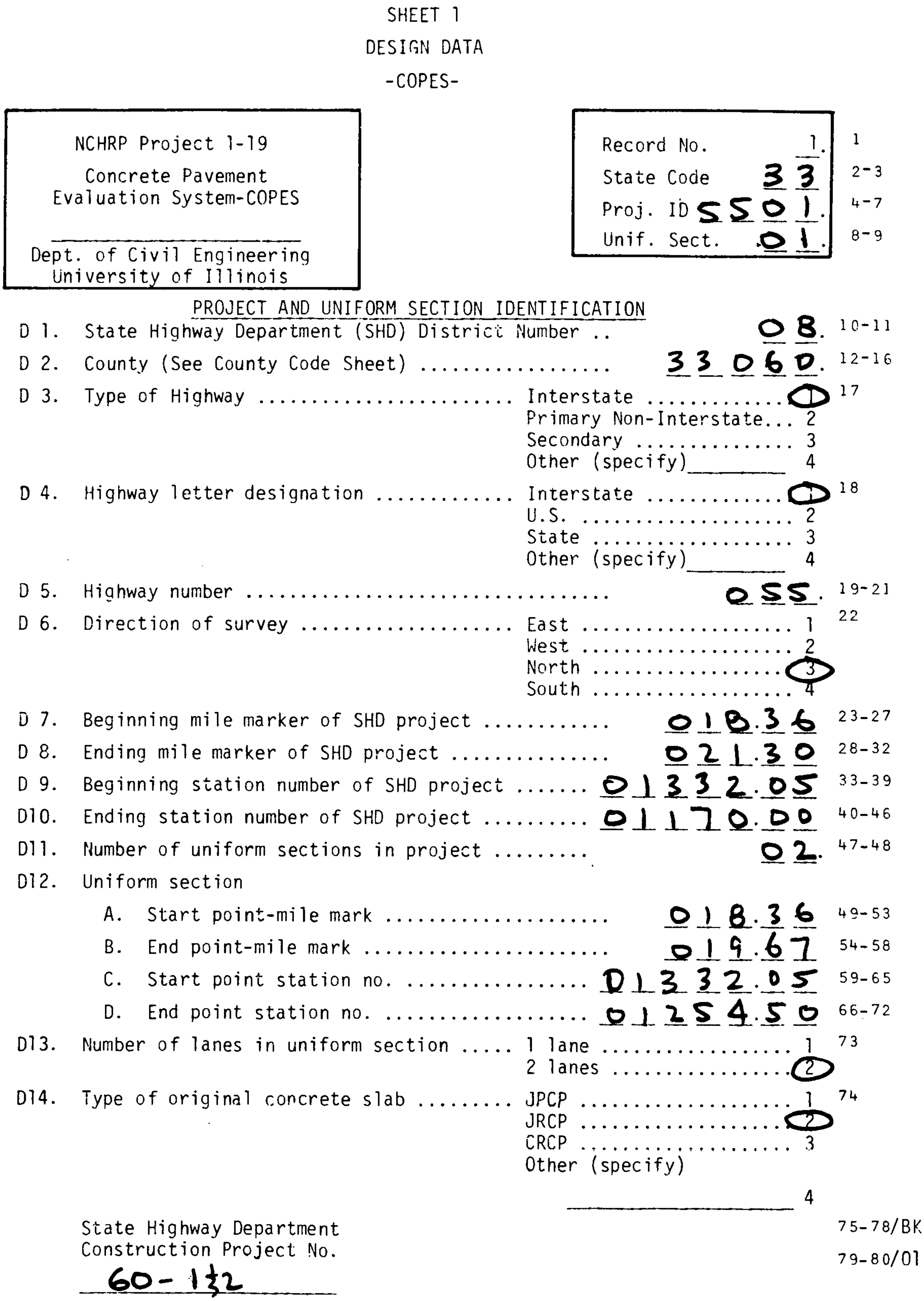


Figure 167. Flowchart of the entire data processing operation.



SHEET 1
DESIGN DATA
-COPES-

NCHRP Project 1-19
Concrete Pavement
Evaluation System-COPES

Dept. of Civil Engineering
University of Illinois

Record No. 1. 1
State Code 33 2-3
Proj. ID 5501. 4-7
Unif. Sect. 01. 8-9

PROJECT AND UNIFORM SECTION IDENTIFICATION

D 1. State Highway Department (SHD) District Number .. 08. 10-11

D 2. County (See County Code Sheet) 33060. 12-16

D 3. Type of Highway 17
- [✓ Interstate .... 1]
- Primary Non-Interstate... 2
- Secondary 3
- Other (specify)________ 4

D 4. Highway letter designation 18
- [✓ Interstate .... 1]
- U.S. 2
- State 3
- Other (specify)________ 4

D 5. Highway number 055. 19-21

D 6. Direction of survey 22
- East 1
- West 2
- [✓ North .... 3]
- South 4

D 7. Beginning mile marker of SHD project 018.36 23-27

D 8. Ending mile marker of SHD project 021.30 28-32

D 9. Beginning station number of SHD project 01332.05 33-39

D10. Ending station number of SHD project 01170.00 40-46

D11. Number of uniform sections in project 02. 47-48

D12. Uniform section

A. Start point-mile mark 018.36 49-53

B. End point-mile mark 019.67 54-58

C. Start point station no. 01332.05 59-65

D. End point station no. 01254.50 66-72

D13. Number of lanes in uniform section 73
- 1 lane 1
- [✓ 2 lanes .... 2]

D14. Type of original concrete slab 74
- JPCP 1
- [✓ JRCP .... 2]
- CRCP 3
- Other (specify) ________________ 4

State Highway Department
Construction Project No.
60-132

75-78/BK
79-80/01

Figure 168. Design data sheet 1.

SHEET 2F

UNIFORM SECTION FIELD DATA
-COPES-

Record No.	6.	1
State Code	33.	2-3
Proj. ID	5501.	4-7
Unif. Sect.	01.	8-9
Time Sequence	01.	10-11

UNIFORM SECTION SURVEY

Uniform Section Location:

Start Pt. Mile Mark 18.36

End Pt. Mile Mark 19.67

Start Pt. Station No. 1332+05

End Pt. Station No. 1254+50

U 1. Date Surveyed (day/month/year):

15/08/82 12-17

U 2. Foundation:

[✓ Majority at grade .... 1] 18
Majority in cut 2
Majority in fill 3

U 3. Depth of Typical Cut:

[✓ 5 ft. or less .... 1] 19
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. 4

Record the number of occurances for each lane at each severity level.

	Distress Type/ Location	Left Lane Severity			
		L	M	H	
U6L.	Depressions	02.	00.	00.	20-25
U7L.	Swells	00.	00.	00.	26-31

		Left Lane	
U8L.	Mean Panel PSR	3.8	32-33

U 4. Typical surface drainage in cut or at grade:

H* less than 2 ft. ..1 34
[✓ H between 2-5 ft. ..2]
H greater than 5 ft..3
Tied Concrete Curb ..4

Other _______________5

*H=Distance from top of slab to bottom of side ditch or natural ground if no ditch.

U 5. Height of typical fill:

[✓ 5 ft. or less .....1] 35
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. .4

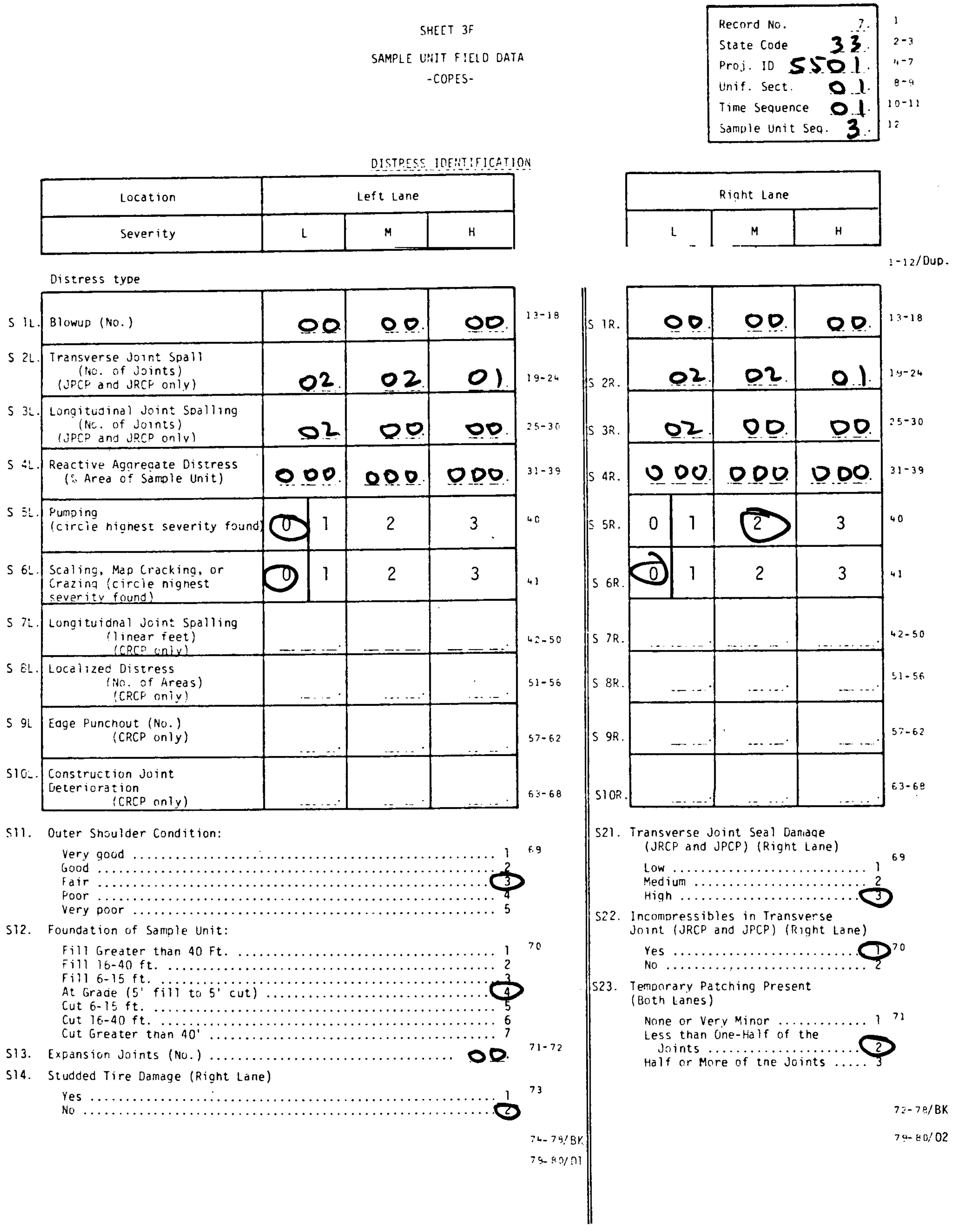
36/BK

	Right Lane Severity			
	L	M	H	
U6R.	02.	01.	00.	37-42
U7R.	01.	00.	00.	43-48

	Right Lane	
U8R.	3.2	49-50

51-78/BK
79-80/01

Figure 169. Uniform section field data sheet 2F.



SHEET 3F

SAMPLE UNIT FIELD DATA

-COPES-

Record No.	7	1
State Code	33	2-3
Proj. ID	5501	4-7
Unif. Sect.	01	8-9
Time Sequence	01	10-11
Sample Unit Seq.	3	12

DISTRESS IDENTIFICATION

	Location	Left Lane			
	Severity	L	M	H	
	Distress type				
S 1L.	Blowup (No.)	00	00	00	13-18
S 2L.	Transverse Joint Spall (No. of Joints) (JPCP and JRCP only)	02	02	01	19-24
S 3L.	Longitudinal Joint Spalling (No. of Joints) (JPCP and JRCP only)	02	00	00	25-30
S 4L.	Reactive Aggregate Distress (% Area of Sample Unit)	000	000	000	31-39
S 5L.	Pumping (circle highest severity found)	[✓ 0] 1	2	3	40
S 6L.	Scaling, Map Cracking, or Crazing (circle highest severity found)	[✓ 0] 1	2	3	41
S 7L.	Longituidnal Joint Spalling (linear feet) (CRCP only)				42-50
S 8L.	Localized Distress (No. of Areas) (CRCP only)				51-56
S 9L	Edge Punchout (No.) (CRCP only)				57-62
S10L.	Construction Joint Deterioration (CRCP only)				63-68

	Right Lane			
	L	M	H	
				1-12/Dup.
S 1R.	00	00	00	13-18
S 2R.	02	02	01	19-24
S 3R.	02	00	00	25-30
S 4R.	000	000	000	31-39
S 5R.	0 1	[✓ 2]	3	40
S 6R.	[✓ 0] 1	2	3	41
S 7R.				42-50
S 8R.				51-56
S 9R.				57-62
S10R.				63-68

S11. Outer Shoulder Condition: (69)

- Very good 1
- Good 2
- Fair .... [✓ 3]
- Poor 4
- Very poor 5

S12. Foundation of Sample Unit: (70)

- Fill Greater than 40 Ft. 1
- Fill 16-40 ft. 2
- Fill 6-15 ft. 3
- At Grade (5' fill to 5' cut) .... [✓ 4]
- Cut 6-15 ft. 5
- Cut 16-40 ft. 6
- Cut Greater than 40' 7

S13. Expansion Joints (No.) 00 (71-72)

S14. Studded Tire Damage (Right Lane) (73)

- Yes 1
- No .... [✓ 2]

74-78/BK

79-80/01

S21. Transverse Joint Seal Damage (JRCP and JPCP) (Right Lane) (69)

- Low 1
- Medium 2
- High .... [✓ 3]

S22. Incompressibles in Transverse Joint (JRCP and JPCP) (Right Lane) (70)

- Yes .... [✓ 1]
- No 2

S23. Temporary Patching Present (Both Lanes) (71)

- None or Very Minor 1
- Less than One-Half of the Joints .... [✓ 2]
- Half or More of the Joints 3

72-78/BK

79-80/02

Figure 170. Sample unit field data sheet 3F.

the identification code is again expanded to include a "Sample Unit Sequence No." Up to nine sample units can be included in any given Uniform Section. Again, each variable is identified by a alphanumeric name such as "S2RB," (S2 = sample unit item 2, Transverse Joint Spall, R = right lane, B = medium severity). All of these variables are defined in the Schema Definitions subsequently described.

Computerized Database Management System

Because of the large size, scope, and characteristics of the information handled by COPES, it was concluded that a database management system was required (DBMS). One system well suited for the job was the *S*cientific *I*nformation *R*etrieval or SIR (*1*). SIR is a hierarchical database management system. The variables in the database are grouped in records, where each record contains, or owns, many other records in a tree-like structure. The first version of COPES developed in 1979 used SIR 1.1. The final version of COPES uses SIR 2.0.

The data in the system developed for COPES have been arranged so that there are two levels of records: uniform section records and sample unit records. Each uniform section may contain (or "own") up to 10 sample unit records. A conceptual scheme of the data hierarchy design is shown in Figure 171. The SIR package is a very efficient means of data storage and retrieval because of the hierarchical relationship built into the data bank.

SIR provides for the description and input of missing data and rejection of invalid and out-of-range values as they are input. Relevant errors are detected in a very intelligent fashion; thus, the data are automatically cleaned as they are loaded into the system.

Another important function of SIR is the protection of the integrity and security of the data. Confidential information is protected from being accessed by unauthorized individuals or being accidentally altered during the retrieval and analysis phases.

The database is organized into seven "records" or "groups of data items":

1. Design Data.
2. Roughness, Skid, and PSI Data.
3. Axle Load Data.
4. Traffic Volume Data.
5. Maintenance Data.
6. Uniform Section Field Data.
7. Sample Unit Field Data.

The specific data sheets contained in each record are indicated beneath each record in Figure 171. This scheme of data storage in the SIR system was used for the purpose of efficiency in storage and retrieval. It should be noted here that for each uniform section of "case" in the database, there is one data set for Record I—Design. A case is defined as all data contained for a given uniform section. Records 2, 3, 4, 5, 6, and 7 can contain up to 99 different sets of time sequence data for each uniform section. Record 7 can contain up to nine sample units for each uniform section and time sequence. This arrangement allows great flexibility and capability in data storage.

Although different data types are stored in different records, variables from these records can be used together in any given retrieval and analysis operation of the user's discretion, by creating rectangular data sets.

The COPES data may be entered at any time during the study, retrieved in different runs as the need arises, and deleted

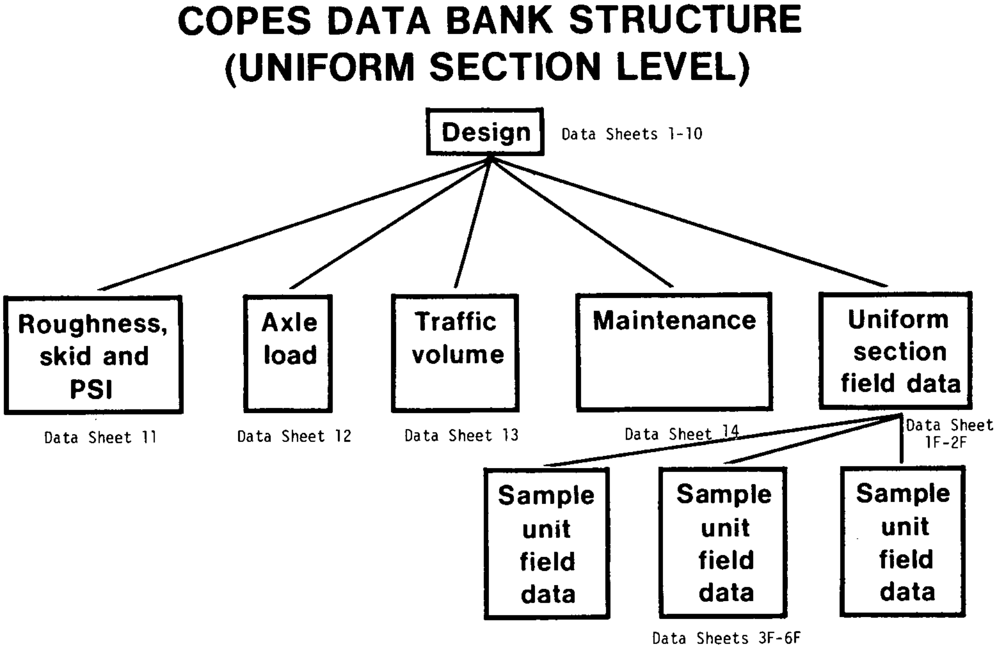


Figure 171. Conceptual scheme of data hierarchy.

or modified at the user's discretion. Updated files may be retained for future processing. The system thus provides for an automatic file management capability. The added advantages of such a DBMS are the absence of redundancy of data input and the security and integrity of the data.

The cleaned raw data read in from the computerized data files are subjected to automatic processing within SIR to accomplish a variety of tasks, as illustrated in Figure 167 by the diamond-shaped figure in the upper right-hand corner. Thus, the data are manipulated to create many new computed variables within the database. For instance, the cumulative number of 18-kip equivalent single-axle loads is automatically computed from the traffic data, and the Thornthwaite Moisture Index is calculated from the given climatic data stored in the database. These are typically performed by using special programs developed mostly in SIR.

Complete details of the SIR data management system are provided in the SIR User's Manual (*1*).

It is important to note that the data collected for COPES could also be entered into other computerized data management and statistical analysis systems. If the alternative system does not have the major capabilities of SIR, some difficulties may be expected because of the large size of the database. Also, the cost of the data storage, retrieval, and analysis may be greater. However, it is important to realize that the COPES data could be used even if the SIR system is not available through use of other data management and analysis systems.

Creation of the Database

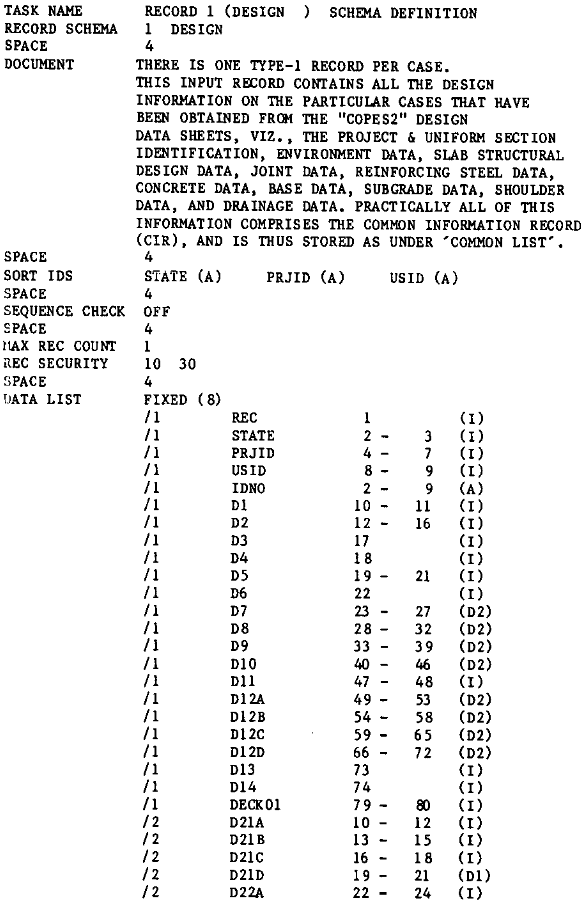
The COPES database is created by the "Schema Definition Program." The Schema Definition describes the database and the types of records contained therein. A few pages of the Schema Definition program are shown in Figure 172. The entire program includes about 39 pages similar to these pages, or a total of 2,386 lines of print. The Schema Definition may subsequently be easily modified as necessary. A detailed description of the Schema Definition is found in the SIR User's Manual (*1*).

DATA RETRIEVAL

An organized and well-documented database will facilitate the retrieval of information. The capabilities of SIR account for the efficient storage, retrieval, and statistical data analysis. By using SIR the user should be able to perform both simple and highly complex retrievals in a reasonably straightforward manner. The Retrieval Task lets the user extract data from one or more of the records. Specifically, the Retrieval Task can be used to:

1. Perform simple statistical procedures.
2. Create an SPSS or BMDP data file (which can then be used for detailed analysis).
3. Create a new SIR database.
4. Automatically produce a complete report.
5. Write out data contained in any Record.

The importance of checking out the database contents cannot be overstated. The contents should be printed out and carefully observed for errors in data.



```
TASK NAME       RECORD 1 (DESIGN  )  SCHEMA DEFINITION
RECORD SCHEMA   1  DESIGN
SPACE           4
DOCUMENT       THERE IS ONE TYPE-1 RECORD PER CASE.
               THIS INPUT RECORD CONTAINS ALL THE DESIGN
               INFORMATION ON THE PARTICULAR CASES THAT HAVE
               BEEN OBTAINED FROM THE "COPES2" DESIGN
               DATA SHEETS, VIZ., THE PROJECT & UNIFORM SECTION
               IDENTIFICATION, ENVIRONMENT DATA, SLAB STRUCTURAL
               DESIGN DATA, JOINT DATA, REINFORCING STEEL DATA,
               CONCRETE DATA, BASE DATA, SUBGRADE DATA, SHOULDER
               DATA, AND DRAINAGE DATA. PRACTICALLY ALL OF THIS
               INFORMATION COMPRISES THE COMMON INFORMATION RECORD
               (CIR), AND IS THUS STORED AS UNDER 'COMMON LIST'.
SPACE           4
SORT IDS        STATE (A)     PRJID (A)     USID (A)
SPACE           4
SEQUENCE CHECK  OFF
SPACE           4
MAX REC COUNT   1
REC SECURITY    10  30
SPACE           4
DATA LIST       FIXED (8)
                /1        REC            1         (I)
                /1        STATE          2 -    3  (I)
                /1        PRJID          4 -    7  (I)
                /1        USID           8 -    9  (I)
                /1        IDNO           2 -    9  (A)
                /1        D1            10 -   11  (I)
                /1        D2            12 -   16  (I)
                /1        D3            17         (I)
                /1        D4            18         (I)
                /1        D5            19 -   21  (I)
                /1        D6            22         (I)
                /1        D7            23 -   27  (D2)
                /1        D8            28 -   32  (D2)
                /1        D9            33 -   39  (D2)
                /1        D10           40 -   46  (D2)
                /1        D11           47 -   48  (I)
                /1        D12A          49 -   53  (D2)
                /1        D12B          54 -   58  (D2)
                /1        D12C          59 -   65  (D2)
                /1        D12D          66 -   72  (D2)
                /1        D13           73         (I)
                /1        D14           74         (I)
                /1        DECK01        79 -   80  (I)
                /2        D21A          10 -   12  (I)
                /2        D21B          13 -   15  (I)
                /2        D21C          16 -   18  (I)
                /2        D21D          19 -   21  (D1)
                /2        D22A          22 -   24  (I)
```

Figure 172. Example listings from the SIR schema definition of the COPES data bank.

Retrieval Methods

Data retrieval and analysis is easily accomplished using SIR in either *batch mode* (e.g., card decks) or *interactive mode* using a computer terminal. For convenience, the terminal can be located in the user's office and connected to the computer by means of telephone lines. The user sitting at a computer terminal can input and execute a set of SIR commands, retrieve data files in any desired format, conduct many kinds of analyses on the data, and print out the results. An example of a complete retrieval using the interactive mode from a terminal is given in this article.

Statistical Analysis Packages

The SIR system itself has the capability to perform several basic, descriptive statistical analyses such as mean, variance, standard deviation, coefficient of variation, histogram, and cross-tabulation. SIR also provides for direct interface with two widely used statistical packages: the Statistical Package for the Social Sciences (SPSS) (*2, 3, 4*) and the Bio-Med Computer Program, P-Series (BMDP). This allows the user to easily and quickly perform almost any type of statistical analysis, as described in the text of this report.

```
D32B          AVG MAX DAILY TEMP,DEG.C./
D32C          AVG MIN DAILY TEMP,DEG.C./
D32D          NORMAL MO PRECIP,CMS./
DMOIST        THORNTHWAITE MOISTURE INDEX/
D36           LATITUDE,DEGREES/
D37           FREEZING INDEX(32 DEG.F.-CE MTHD)/
D38           AVG # FREEZE-THAW CYCLES/
D39           ELEVATION, FT ABOVE SEA LEVEL;
              D40 MEAN CA. CHL.,TONS<LN-MI>YR/
D41           SLAB THKNESS,INS./
D42           LANE WIDTH,FT./
D43           SLAB CONSTR CMPLT,MO.-YR./
D44           OPENED TO TRAFFIC,MO.-YR./
D51           CONTRACTION JT SPACING,FT./
D52           EXPANSION JT SPACING,FT./
D53           JT SKEWNESS,FT. PER LANE/
D54           TRNSVRS CONTR JT LD TRANS/
D55           DOWEL DIA.,INS./
D56           DOWEL SPACING,INS./
D57           DOWEL LENGTH,INS./
D58           DOWEL COATING/
D59           METHOD TO INSTALL DOWELS/
D70           MTHD TO FORM JTS/
D71           JT SEALANT TYPE/
D72A          TRNSVRS JT SEAL RESERVOIR,WIDTH,INS./
D72B          TRNSVRS JT SEAL RESERVOIR,DEPTH,INS./
D73           LONGTDNL JT TYPE/
D74           TIE BAR DIA.,INS./
D75           TIE BAR LENGTH,INS./
D76           TIE BAR SPACING,INS./
D77           SHLDR-TRAFF LANE JT TYPE/
D78           S-T LN JT TIE BAR DIA.,INS./
D79           S-T LN JT TIE BAR LGTH,INS./
D80           S-T LN JT TIE BAR SPCNG,INS./
D81           REINFORCING TYPE/
D82           TRNSVRS BAR DIA.,INS./
D83           TRNSVRS BAR SPCNG,INS./
D84           LNGTDNL BAR DIA.,INS./
D85           LNGTDNL BAR SPCNG,INS./
D86           REINFORCING YIELD STRNGTH,KSI/
D87           DEPTH OF REINFORCEMENT,INS./
D88           MTHD TO PLACE REBAR/
D89           STL LAP LGTH ^5CONSTR JT,INS.(CRCP)/
D101A         MIX<COARSE AGGR>,# PER CU.YD./
D101B         MIX<FINE AGGR>,# PER CU.YD./
D101C         MIX,# PER CU.YD./
D101D         MIX,# PER CU.YD./
D102A         28-DAY MOD RUPT,PSI/
```

```
TASK NAME        RECORD 4 (TRAFFIC )  SCHEMA DEFINITION
RECORD SCHEMA    4  TRAFFIC
SPACE            4
DOCUMENT        THIS INPUT RECORD CONTAINS ALL THE
                TRAFFIC VOLUME DATA FOR BOTH THE PAST AND
                PRESENT.  THERE IS ONE TYPE-4 RECORD FOR
                EACH TIME SEQUENCE PER UNIFORM SECTION.
                THE DATA IS COLLECTED ON THE UNIFORM SECTION LEVEL.
SPACE            4
SORT IDS         STATE (A)     PRJID (A)     USID (A)      YEAR (A)
SPACE            4
SEQUENCE CHECK   OFF
SPACE            4
MAX REC COUNT    50
REC SECURITY     10  30
SPACE            4
DATA LIST        FIXED (1)
                 /1         REC            1          (I)
                 /1         STATE          2 -    3   (I)
                 /1         PRJID          4 -    7   (I)
                 /1         USID           8 -    9   (I)
                 /1         IDNO           2 -    9   (A)
                 /1         YEAR          10 -   11   (I)
                 /1         T1            12 -   16   (I)
                 /1         T2            17 -   21   (I)
                 /1         T3L           22 -   23   (D2)
                 /1         T3R           24 -   26   (D2)
                 /1         T4            27 -   30   (D3)
                 /1         T5            31          (I)
                 /1         TESALL        32 -   40   (D4)
                 /1         TESALR        41 -   49   (D4)
                 /1         TCUML         50 -   58   (D2)
                 /1         TCUMR         59 -   67   (D2)
                 /1         DECK01        79 -   80   (I)
SPACE            4
MISSING VALUES   STATE      ( BLANK  )/
                 PRJID      ( BLANK  )/
                 USID       ( BLANK  )/
                 IDNO       ( BLANK  )/
                 YEAR       ( BLANK  )/
                 T1         ( BLANK  )/
                 T2         ( BLANK  )/
                 T3L        ( BLANK  )/
                 T3R        ( BLANK  )/
                 T4         ( BLANK  )/
                 T5         ( BLANK  )/
                 TESALL     ( BLANK  )/
                 TESALR     ( BLANK  )/
                 TCUML      ( BLANK  )/
                 TCUMR      ( BLANK  )/
                 DECK01     ( BLANK  )/
```

```
VALID VALUES    REC         ( 4  )/
                DECK01      ( 1  )/
SPACE           4
VAR LABELS      REC            RECORD #/
                STATE          STATE #/
                PRJID          PROJECT #/
                USID           UNIF. SECT. #/
                YEAR           YEAR #/
                T1             ONE WAY ADT/
                T2             ONE WAY ADTT/
                T3L            ONE WAY LANE DISTRIBUTION/
                T3R            ONE WAY LANE DISTRIBUTION/
                T4             ONE WAY LOAD DISTRIBUTION FACTOR/
                T5             NUMBER OF LANES/
                TESALL         EQUIVALENT SINGL AXLE LOADS-LEFT LANE/
                TESALR         EQUIVALENT SINGL AXLE LOADS-RIGHT LANE/
                TCUML          CUMULATIV EQUIVLNT SINGL AXLE LOAD-LEFT;
                               LANE/
                TCUMR          CUMULATIV EQUIVLNT SINGL AXLE LOAD-RIGHT;
                               ;
                               ;
                               LANE/
```

Figure 172. Continued

Example Data Retrieval

Once all of the pavement data have been input, cleaned, etc., and the modified SIR database has been obtained as shown in Figure 167, retrievals of data can begin. A complete example retrieval is provided to illustrate the process. Evaluation and use of the retrieved data are discussed in earlier in the text.

The first step is to decide what data are to be retrieved for the specific problem under consideration. Assume that a retrieval is desired that provides uniform section identification and data on location, traffic, and selected distresses. These data are to be analyzed in general for the engineer to obtain a general indication of their characteristics.

A retrieval program is written to extract the desired data from the SIR database (Fig. 173). The retrieval program can be entered into the computer using a terminal in the user's office. This program not only extracts data from the database, but also computes means, sums, and the like, of several variables. It makes available data from each record through the PROCESS REC command. The COMPUTE and IF commands select and assign data to the given variable names. The final command is to create an SPSS file (called EXAMPLE) that contains all the data plus the assigned variables names.

The next step is to analyze the data contained in EXAMPLE. This is accomplished by preparing an SPSS program (as shown in Fig. 174), wherein a variety of statistical analyses are accom-

```
RUN NAME        EXAMPLE RETRIEVAL FOR REPORT
OLD FILE        COPES
PASSWORD        MICHAEL
SECURITY        MIKE,DARTER
RETRIEVAL
EXCLUDE         YR,T
PROCESS CASES   ALL
PROCESS REC     1
IFNOT           (STATE EQ 48) NEXT CASE
END PROCESS REC
MOVE VARS       D5,D41
COMPUTE         IDNUM=NUMBR(IDNO);
                SUMPREC=SUM(D21D,D22D,D23D,D24D,D25D,D26D,
                           D27D,D28D,D29D,D30D,D31D,D32D);
                USMILE=ABS(D12A-D12B)
PROCESS REC     6
MOVE VARS       TSEQ,U8R
COMPUTE         T=TSEQ;
                SWELDEP=SUM(U6RB,U6RC,U7RB,U7RC)/USMILE;
                AGE=(U1-D43)/365.0
IFTHEN          (TSEQ EQ 0)
.   SET T1,TCUMR (0)
ELSE
.   COMPUTE     YR=NUMBR(DATEC(U1,'YY'))
.   PROCESS REC 4
IFNOT             (YR EQ YEAR)NEXT RECORD
.   MOVE VARS   T1,TCUMR
.   EXIT RECORD
.   END PROCESS REC
ENDIF
.   PROCESS REC 7
IFNOT           (T EQ TSEQ)NEXT RECORD
COMPUTE         DETJT=MEANR(SUM(S1RA,S1RB,S1RC,S2RB,S2RC,S62RA,S62RB,S62RC,
                          S64RA,S64RB,S64RC)/S31)*5280.
IFTHEN          (D14 EQ 1)
COMPUTE         CRACKS=MEANR(SUM(S36RA,S36RB,S36RC,S37RA,S37RB,
                           S37RC,6.*S38R,20.*SUM(S66RA,S66RB,
                           S66RC,S68RA,S68RB,S68RC))/S31)*5280.
ELSEIF          (D14 EQ 2)
COMPUTE         CRACKS=MEANR(SUM(S36RB,S36RC,S37RB,S37RC)/S31)*5280.
ELSE
COMPUTE         CRACKS=1/0.
ENDIF
COMPUTE         R40R=MEANR(S40R)
.   END PROCESS REC
PERFORM PROCS
END PROCESS REC
END PROCESS CASES
MISSING VALUES  SUMPREC,SWELDEP,R40R,USMILE,AGE,DETJT,CRACKS (-99)
SPSS SAVE FILE FILENAME=EXAMPLE/
                VARIABLES=IDNUM D5 USMILE SUMPREC D41 T1 TCUMR AGE
                SWELDEP U8R DETJT CRACKS R40R/
                SORT = IDNUM TSEQ/
FINISH
```

Figure 173. Retrieval program to extract various data from the SIR database, calculate additional variables, and store all data in a file called EXAMPLE.

```
GET FILE        EXAMPLE
VAR LABELS      IDNUM COPES IDENTIFICATION NUMBER/
                D5 HIGHWAY NO./
                SUMPREC TOTAL AVERAGE ANNUAL PRECIPITATION, CM/
                D41 SLAB THICKNESS, INS./
                U8R PRESENT SEVICEABILITY RATING/
                SWELDEP MEAN SWELLS AND DEPRESSIONS PER MILE/
                AGE TIME IN YEARS BETWEEN CONSTRUCTION AND SURVEY/
                T1 ONE-WAY AVERAGE ANNUAL DAILY TRAFFIC COUNT/
                TCUMR TOTAL EQUIVALENT SINGLE AXLE LOADS IN RIGHT LANE/
                DETJT MEAN NO. OF DETERIORATED JOINTS PER MILE/
                CRACKS MEAN NO. OF CRACKS - FT. PER MILE/
                R40R TRANSVERSE JOINT FAULTING, INS./
LIST CASES      CASES=200/VARIABLES=IDNUM,D5,SUMPREC,AGE,T1,TCUMR,U8R,
                SWELDEP,DETJT,CRACKS,R40R
PRINT FORMATS   U8R(1),SWELDEP(1),DETJT(1),R40R(2),TCUMR(2)
CONDESCRIPTIVE SUMPREC,D41,TCUMR,SWELDEP,U8R,CRACKS,R40R,DETJT
STATISTICS      ALL
*SELECT IF      (U8R GT 0 AND LT 4.5)
*RECODE         U8R(0 THRU 0.9=0)(1.0 THRU 1.9=1)(2.0 THRU 2.9=2)
                (3.0 THRU 3.4=3)(3.5 THRU 3.9=4)
                (4.0 THRU 4.9=5)
FREQUENCIES     INTEGER=U8R(0,5)
PEARSON CORR    SUMPREC,TCUMR,AGE,SWELDEP,U8R,DETJT,CRACKS,R40R
STATISTICS      ALL
SCATTERGRAM     U8R(0,5) WITH TCUMR(0,40)
STATISTICS      ALL
*SELECT IF      (AGE GT 15 AND U8R GT 3.5)
LIST CASES      CASES=200/VARIABLES=IDNUM,AGE,U8R
PRINT FORMATS   AGE(1),U8R(1)
CONDESCRIPTIVE AGE
FINISH
```

Figure 174. SPSS program to analyze data contained in file EXAMPLE.

plished. Again, this program is easily entered at the computer terminal. The user's manual of the SPSS (*2*) should be consulted for information on the various statistical programs.

A brief description of the results obtained from the SPSS program run in Figure 174 is given. The first command is "LIST CASES" which lists out all data for selected variables (IDNUM, D5, SUMPREC, etc.), as shown in Figure 175.

For example, Case 8 is I-5 located in California. The average annual precipitation (SUMPREC) is 37 cm; the one-way ADT (TI) is 69,500; the total equivalent 18-kip single-axle loads in the outer lane to date is 31,160,000; its age is 27 years; there are no swells or depressions; the PSR (U8R) is 2.9; there are no deteriorated joints; there are 168 ft of slab cracking per mile (L+M+H); and the mean transverse joint faulting is 0.14 inch. Hundreds of other pieces of information could be printed out about this uniform section if needed.

The next command is "CONDESCRIPTIVE," which computes general statistics for each variable requested, as shown in Figure 176. For example, the variable D41 is the slab thickness in inches. It ranges from 8 to 11.4 inches, with a mean of 8.4 inches. There are 106 cases.

The "FREQUENCIES" command produces the results in Figure 177 for the variable 48R (or PSR) in the outer lane. For example, the percentage of sections having a PSR rating between 2.0 and 2.9 (fair rating) is 5.5.

The correlation of the variables can be studied using several methods. Here the PEARSON CORR and SCATTERGRAM command results are shown in Figures 178 and 179. For example, the correlation coefficient between TCUMR (18-kip equivalent single-axle loads in the outer lane) and PSR (present serviceability rating in the outer lane) is −0.8073 based on 101 cases, and the significance level is 0.1 percent. The scattergram plot of TCUMR versus PSR is shown in Figure 179.

Many types of data sorting can be accomplished. For example, using the "SELECT IF" command, the computer selects all cases having an age greter than 15 years and a PSRO greater than 3.5, and lists them out using the LIST CASES command in Figure 180.

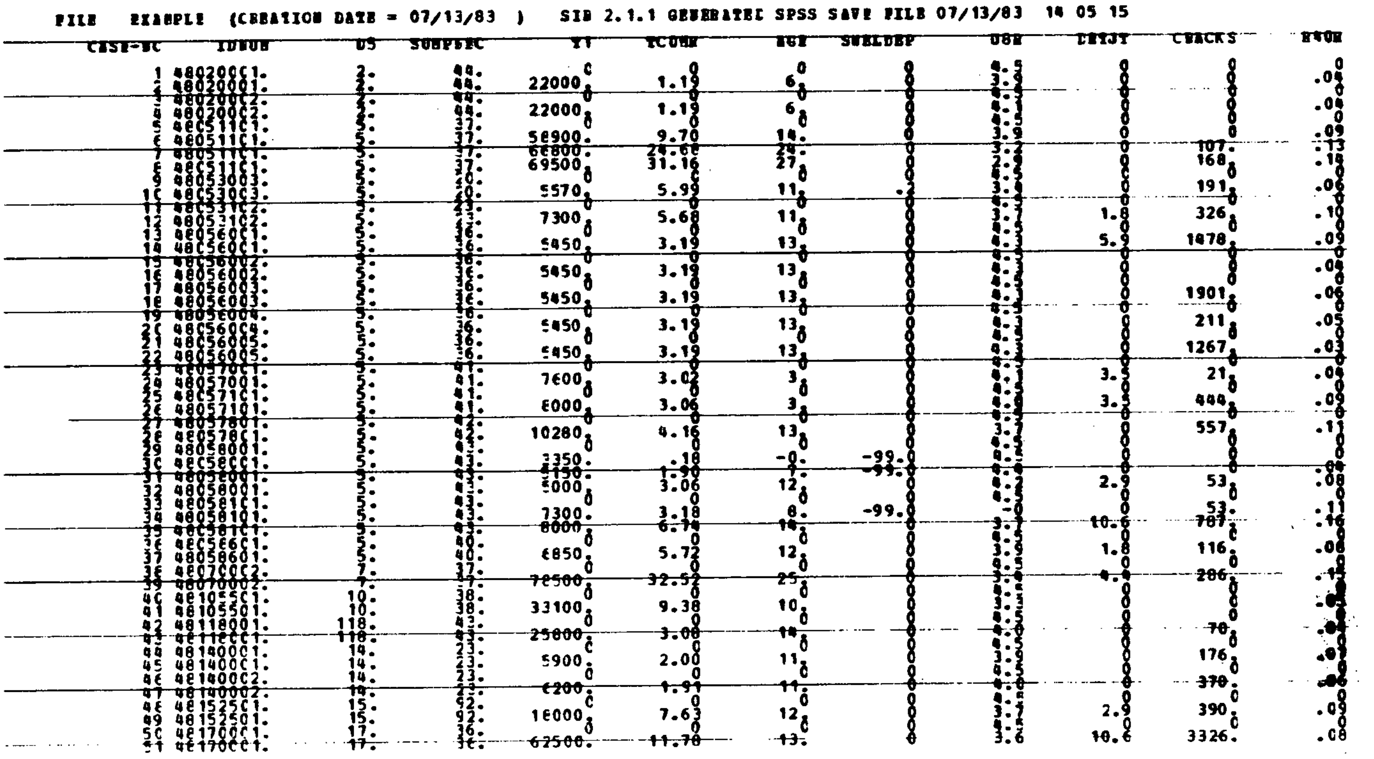
Many additional statistical commands can be used to analyze the data. One of the most important is the REGRESSION command that permits the development of multiple regression equations. Regression can be used, for example, as a powerful tool for determining which variables affect the occurrence of any distress type, and to develop a regression equation that could be used for structural design of the pavement.

The capabilities of the SIR database coupled with the SPSS (or BMPD) statistical packages to analyze and evaluate pavement performance data are virtually unlimited. Use of the interactive mode of running the programs provides almost instantaneous turnaround time for programs.

Computer costs are relatively small for both SIR and SPSS. The computer cost for retrieving the data from the SIR data bank and running the SPSS analysis program for the example found on the preceding pages was less than $5.00.

Report Generation

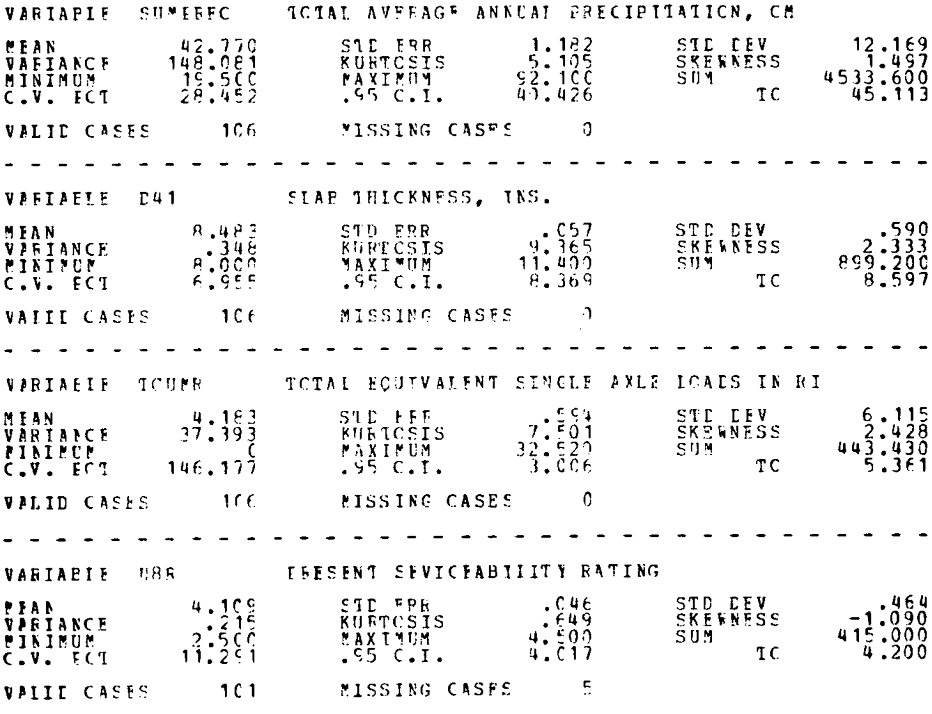
SIR has a flexible report generation capability whereby reports for management can be automatically produced whenever desired. A few pages of an example automated design report prepared by the Minnesota DOT is shown in Figure 181. Another



```
FILE   EXAMPLE  (CREATION DATE = 07/13/83  )   SIB 2.1.1 GENERATED SPSS SAVE FILE 07/13/83  14 05 15
```

(Hwy.) (Prec.) (ADT) (ESAL) (AGE) (Swells & Dep.)(PSR)(J. Det.) (Fault)

Figure 175. List of selected data for the first 51 cases contained in file EXAMPLE.



```
VARIABLE  SUMPREC     TOTAL AVERAGE ANNUAL PRECIPITATION, CM

MEAN          42.770      STD ERR        1.182      STD DEV        12.169
VARIANCE     148.081      KURTOSIS       5.105      SKEWNESS        1.497
MINIMUM       19.500      MAXIMUM       92.100      SUM          4533.600
C.V. PCT      28.452      .95 C.I.      40.426                TO   45.113

VALID CASES      106      MISSING CASES      0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

VARIABLE  D41         SLAB THICKNESS, INS.

MEAN           8.483      STD ERR         .057      STD DEV          .590
VARIANCE        .348      KURTOSIS       9.365      SKEWNESS        2.333
MINIMUM        8.000      MAXIMUM       11.400      SUM           899.200
C.V. PCT       6.955      .95 C.I.       8.369                TO    8.597

VALID CASES      106      MISSING CASES      0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

VARIABLE  TCUMR       TOTAL EQUIVALENT SINGLE AXLE LOADS IN MI

MEAN           4.183      STD ERR         .594      STD DEV         6.115
VARIANCE      37.393      KURTOSIS       7.501      SKEWNESS        2.428
MINIMUM            0      MAXIMUM       32.520      SUM           443.430
C.V. PCT     146.177      .95 C.I.       3.006                TO    5.361

VALID CASES      106      MISSING CASES      0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

VARIABLE  U8R         PRESENT SEVICEABILITY RATING

MEAN           4.109      STD ERR         .046      STD DEV          .464
VARIANCE        .215      KURTOSIS        .649      SKEWNESS       -1.090
MINIMUM        2.500      MAXIMUM        4.500      SUM           415.000
C.V. PCT      11.291      .95 C.I.       4.017                TO    4.200

VALID CASES      101      MISSING CASES      5
```

Figure 176. Output from CONDESCRIPTIVE command for variables SUMPREC, SLAB THICKNESS, TCUMR, and PSR.

```
UPR          PRESENT SEVICEABILITY RATING

                                            RELATIVE    ADJUSTED       CUM
                                ABSOLUTE      FREQ        FREQ         FREQ
CATEGORY LABEL    PSR   CODE      FREQ       (PCT)       (PCT)        (PCT)
               2.0-2.9     2         3         5.5         5.5          5.5
               3.0-3.4     3         9        16.4        16.4         21.8
               3.5-3.9     4        21        38.2        38.2         60.0
               4.0-4.9     5        22        40.0        40.0        100.0
                               -------     -------     -------
                         TOTAL      55       100.0       100.0

VALID CASES      55        MISSING CASES
```

Figure 177. Output from FREQUENCIES command for variable PSR in the outer lane.

```
- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - -

          SUMFREC    ICUMR      AGE        SWELDEP    UPR        DETJT      CRACKS     R40R

SUMFREC    1.0000      .0202      .0636      .0995     -.0202      .0703     -.0374      .0468
          (     0)   (  106)   (  106)   (   99)   (  101)   (  106)   (  106)   (  106)
          P=******   P= .418   P= .255   P= .164   P= .420   P= .237   P= .352   P= .317

ICUMR       .0202     1.0000      .8450      .1467     -.8073      .3415      .4021      .7675
          (  106)   (     0)   (  106)   (   99)   (  101)   (  106)   (  106)   (  106)
          P= .418   P=******   P= .001   P= .074   P= .001   P= .001   P= .001   P= .001

AGE         .0636      .8450     1.0000      .2773     -.8614      .4003      .5096      .8880
          (  106)   (  106)   (     0)   (   99)   (  101)   (  106)   (  106)   (  106)
          P= .259   P= .001   P=******   P= .003   P= .001   P= .001   P= .001   P= .001

SWELDEP     .0995      .1467      .2773     1.0000     -.3786     -.0075      .0920      .1922
          (   99)   (   99)   (   99)   (     0)   (   99)   (   99)   (   99)   (   99)
          P= .164   P= .074   P= .003   P=******   P= .001   P= .471   P= .183   P= .028

UPR        -.0202     -.8073     -.8614     -.3786     1.0000     -.3688     -.4378     -.8372
          (  101)   (  101)   (  101)   (   99)   (     0)   (  101)   (  101)   (  101)
          P= .420   P= .001   P= .001   P= .001   P=******   P= .001   P= .001   P= .001

DETJT       .0703      .3415      .4003     -.0075     -.3688     1.0000      .6026      .3660
          (  106)   (  106)   (  106)   (   99)   (  101)   (     0)   (  106)   (  106)
          P= .237   P= .001   P= .001   P= .471   P= .001   P=******   P= .001   P= .001

CRACKS     -.0374      .4021      .5096      .0920     -.4378      .6026     1.0000      .5171
          (  106)   (  106)   (  106)   (   99)   (  101)   (  106)   (     0)   (  106)
          P= .352   P= .001   P= .001   P= .183   P= .001   P= .001   P=******   P= .001

R40R        .0468      .7675      .8880      .1922     -.8372      .3660      .5171     1.0000
          (  106)   (  106)   (  106)   (   99)   (  101)   (  106)   (  106)   (     0)
          P= .317   P= .001   P= .001   P= .028   P= .001   P= .001   P= .001   P=******

(COEFFICIENT / CASES / SIGNIFICANCE)      (99.0000 MEANS UNCOMPUTABLE)
```

Figure 178. Output from PEARSON CORR command for eight variables.

example of a Traffic Report is shown in Figure 182. This aspect has not been fully developed in COPES, but if the system is to be used by an agency for pavement management, specific reports could be designed as for Minnesota. These could include the following, for example:

CONDITION OF PROJECT—Outputs a condition history for a given project or several projects

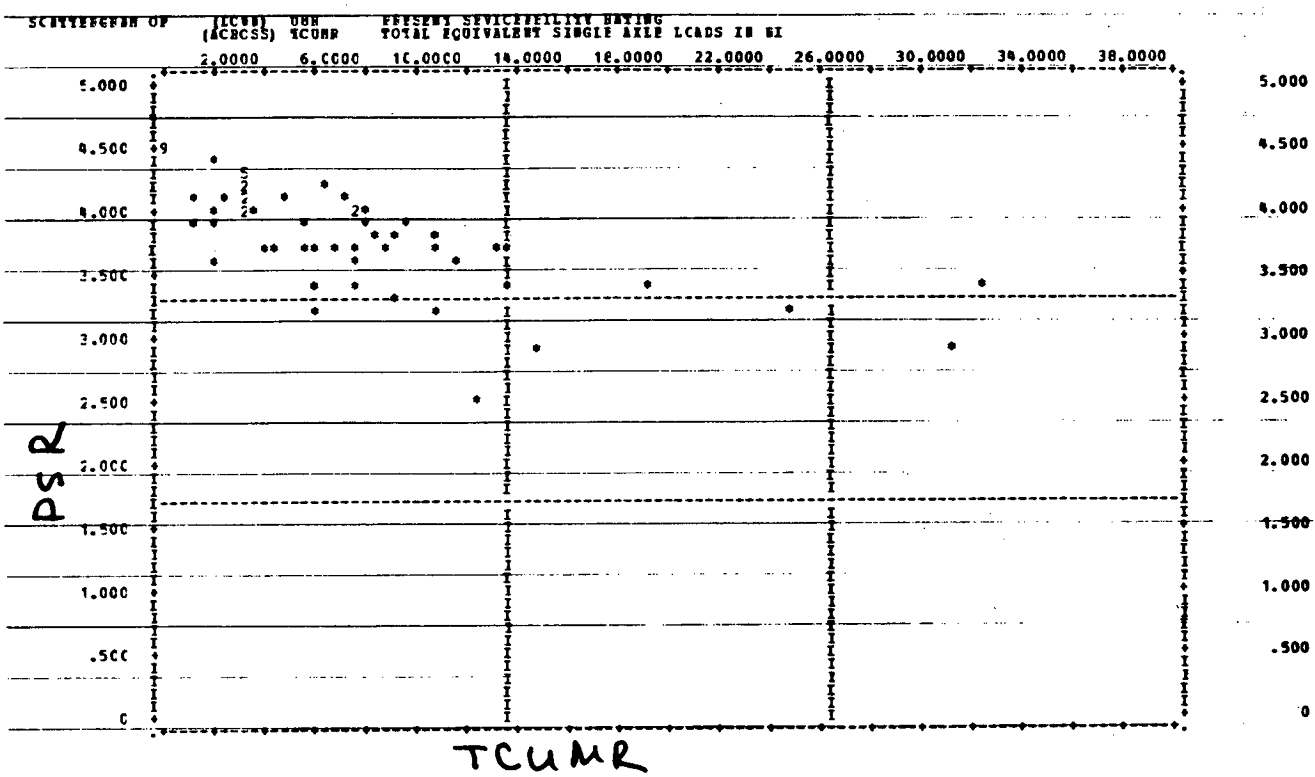
CONDITION SUMMARY—Outputs condition data for a given highway, district, or state

PHYSICAL FACILITY DATA—Describes the design and materials for a given project or several projects

MAINTENANCE—Provides a summary of all major maintenance and rehabilitation work performed on a given project or several projects.

TRAFFIC—Provides ADT, ADTT, lane truck distribution, average truck load distribution factor and equivalent 18-kip single axle loads for a given project

OTHERS—The agency can design any report desired



```
CORRELATION (R) -      -.80732      R SQUARED       -      .65176     SIGNIFICANCE R -      .00001
STD ERR OF EST  -       .27518      INTERCEPT (A)   -     4.36575     STD ERROR OF A -      .03325
SIGNIFICANCE A  -       .00001      SLOPE (B)       -     -.06000     STD ERROR OF B -      .00441
SIGNIFICANCE B  -       .00001

PLOTTED VALUES -     101    EXCLUDED VALUES -      0    MISSING VALUES -      5

******** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

Figure 179. Output from the SCATTERGRAM command for variables TCUMR and PSR for a selected state.

```
FILE    EXAMPLE  (CREATION DATE = 07/13/83  )    SIF 2.1.1 GENERATED SPSS SAVE FILE 07/13/83
  CASE-NO        IDNUM           AGE          PSR

        1 48660301.         26.0          3.7
        2 48807701.         22.0          3.7
        3 48808001.         16.6          3.8
        4 48999001.         26.6          3.7
```

Figure 180. Output from SELECT IF command that requested only those cases where AGE was greater than 15 Years and PSR was greater than 3.5.

```
+   +   +   +   +   +   +   +   +   +   +   +   +
+  MINNESOTA DEPARTMENT OF TRANSPORTATION S  +
+ (CO)NCRETE (P)AVEMENT (E)VALUATION (S)YSTEM +
+          C     O     P     E     S          +
+            PROJECT INFORMATION              +
                    FOR
+           CASE NUMBER 29494301              +
+   +   +   +   +   +   +   +   +   +   +   +   +

PROJECT AND UNIFORM SECTION IDENTIFICATION

D1    STATE HIGHWAY DEPARTMENT DISTRICT NUMBER.......5

D2    COUNTY.......................................HENNEPIN

D3    TYPE OF HIGHWAY..................................

D4    HIGHWAY LETTER DESIGNATION....................INTERSTATE
D5    HIGHWAY NUMBER................................494

D6    DIRECTION OF SURVEY...........................WEST
D7    BEGINNING MILE MARKER OF PROJECT..............    1.60
D8    ENDING    MILE MARKER OF PROJECT..............    7.85
D9    BEGINNING STATION NUMBER......................********
D10   ENDING    STATION NUMBER......................********

D11   NUMBER OF UNIFORM SECTIONS....................3
D12   UNIFORM SECTION A.  START POINT-MILE MARK......   1.60
                      B.  END   POINT-MILE MARK......   2.80
                      C.  START POINT-STATION........********
                      D.  END   POINT-STATION........********

D13   NUMBER OF LANES IN UNIFORM SECTION............2

D14   TYPE OF ORIGINAL CONCRETE SLAB................JRCP

ENVIRONMENTAL DATA

               AVG       AVG MAX     AVG MIN       AVG
             MONTHLY      DAILY       DAILY       PRECIP
             TEMP  C     TEMP  C     TEMP  C     CMS H20
D21   JAN      -12          -7         -17          1.8
D22   FEB       -9          -4         -14          2.0
D23   MAR       -3           2          -7          4.3
D24   APR        7          13           1          5.1
D25   MAY       13           0           7          8.6
D26   JUN       19          25          13          9.9
D27   JUL       22          27          16          9.4
D28   AUG       21          27          15          7.9
D29   SEP       15          21           9          6.9
D30   OCT       10          16           3          4.6
D31   NOV        0           5          -5          3.0
D32   DEC       -8          -3         -12          2.3

D36   LATITUDE (DEGREES)............................44

D37   FREEZING INDEX (32 DEG. F-CE METHOD)..........1567

D38   AVERAGE NUMBER OF ANNUAL FREEZE-THAW CYCLES....8

D39   ELEVATION (FEET ABOVE SEA LEVEL)..............834

D40   AVERAGE YEARLY DEICING SALT (TON/LANE MILE)....0
```

```
SLAB STRUCTURAL DESIGN

D41   SLAB THICKNESS (IN)............................10.0

D42   LANE WIDTH (FT)................................12

D43   DATE SLAB CONSTRUCTION COMPLETED (MO/YR).......10/59

D44   DATE OPENED TO TRAFFIC (MO/YR).................10/59

JOINT DATA

D51   AVERAGE CONTRACTION JOINT SPACING (FT:......... 39.3

D52   BUILT-IN EXPANSION JOINT SPACING (FT)..........0

D53   SKEWNESS OF JOINT (FT/LANE)....................0.0

D54   TRANSVERSE CONTRACTION JOINT (LOAD TRANSFER)...DOWELS

D55   DOWEL DIAMETER (INCHES).............  .........1.25

D56   DOWEL SPACING  (INCHES)........................12

D57   DOWEL LENGTH   (INCHES)........................18

D58   DOWEL COATING..................................PAINT>GREASE

D59   METHOD USED TO INSTALL DOWELS..................PREPLACED ON BASKETS

D70   METHOD USED TO FORM TRANSVEERSE JOINTS.........OTHER

D71   JOINT SEALANT TYPE USED IN TRANSVERSE JOINTS...RUBBER ASPHALT<OLD>

D72   TRANSVERSE JOINT SEALANT RESERVOIR
                         (A) WIDTH (INCHES)........... .38
                         (B) DEPTH (INCHES)...........2.5

D73   TYPE OF LONGITUDINAL JOINT (BETWEEN LANES).....SAWED WK PLANE

D74   TIE BAR DIAMETER (INCHES)...................... .63

D75   TIE BAR LENGTH   (INCHES)......................36

D76   TIE BAR SPACING  (INCHES)......................24

D77   TYPE OF SHOULDER-TRAFFIC LANE JOINT............BUTT

D78   SHOULDER-TRAFFIC LANE JOINT TIE BAR (DIA(IN))..0.00

D79   SHOULDER-TRAFFIC LANE JOINT TIE BAR (LEN(IN))..0

D80   SHOULDER-TRAFFIC LANE JOINT TIE BAR (SPC(IN))..0
```

Figure 181. Example automated report developed by Minnesota DOT for a given project in the data bank.

```
REINFORCING STEEL DATA

D81  TYPE OF REINFORCING............................WELDED WIRE FABRIC

D82  TRANSVERSE BAR DIAMETER (INCHES)............... .23

D83  TRANSVERSE BAR SPACING  (INCHES)...............12.0

D84  LONGITUDINAL BAR DIAMETER (INCHES)............. .16

D85  LONGITUDINAL BAR SPACING  (INCHES)............. 6.0

D86  YIELD STRENGTH OF REINFORCING (KSI)............70.0

D87  DEPTH TO REINFORCEMENT (INCHES)................2.5

D88  METHOD USED TO PLACE REBAR.....................BETN CONCRETE LAYERS

D89  LENGTH OF STEEL LAP AT CONSTR JOINT (INCHES)...0

CONCRETE DATA

D101 MIX DESIGN (#/CU.YD.)  (A) COARSE AGGREGATE....2328
                           (B) FINE   AGGREGATE....892
                           (C) CEMENT..............530
                           (D) WATER...............210

D102 STRENGTH (MODULUS OF RUPTURE) (A) MEAN.........5684
                                   (B) RANGE........1391

D104 SLUMP (INCHES)                (A) MEAN.........1.5
                                   (B) RANGE........1.0

D105 TYPE CEMENT USED...............................TYPE I

D106 ALKALI CONTENT OF CEMENT (%)................... 0.0

D107 ENTRAINED AIR (%)             (A) MEAN.........5.5
                                   (B) RANGE........5.5

D108 ADDITIVES OTHER THAN AIR-ENTRAINERS............

D109 MAXIMUM SIZE OF COARSE AGGREGATE (INCHES)......2.0

D110 TYPE OF COARSE AGGREGATE.......................<CRUSHED>GRAVEL

D111 SOURCE OF COARSE AGGREGATE (A) SOURCE I........119001
                                (B) SOURCE II.......*
                                (C) SOURCE III......*

D112 TYPE OF FINE AGGREGATE.........................NATURAL>CRUSHED SAND

D113 SOURCE OF FINE AGGREGATE   (A) SOURCE I........119001
                                (B) SOURCE II.......*
                                (C) SOURCE III......*
```

```
D114 TYPE OF AGGREGATE DURABILITY TEST USED.........SHTO T104,ASTM C88
D115 RESULT OF DURABILITY TEST IN ITEM D114.........0

D116 TYPE OF PAVER USED.............................SLIP FORM

D117 METHOD USED TO CURE CONCRETE...................WHT PLYETHLNE SHT

D118 METHOD USED TO FINISH CONCRETE.................BURLAP DRAG

D119 GEOLOGIC CLASSIFICATION OF COARSE AGGREGATE....OTHER

BASE DATA

D131 TYPE OF BASE...................................GRAVEL

D132 STABILIZED BASE LAYER THICKNESS (INCHES).......0.0

D133 STRENGTH TEST USED FOR STABILIZED BASE.........
D134 RESULT OF STRENGTH TEST IN ITEM D133...........*

D135 MATERIAL PASSING NO. 200 SIEVE (%).............7

D136 NON-STABILIZED BASE LAYER THICKNESS (INCHES)...3.0

D137 STRENGTH TEST USED FOR NON-STABILIZED BASE.....OTHER
D138 RESULT OF STRENGTH TEST IN ITEM D137...........52

SUBGRADE DATA

D151 AASHTO SOIL CLASSIFICATION.....................A-4

D152 STRENGTH TEST USED ON SUBGRADE.................SHTO T190,ASTM D2844
D153 TEST RESULT FROM ITEM D152.....................43

D154 TEST USED TO PREDICT SWELL POTENTIAL...........
D155 TEST VALUE FROM ITEM D154......................*****

D156 TEST USED TO PREDICT FROST SUSCEPTIBILITY......
D157 TEST VALUE FROM ITEM D156......................*****

D158 OPTIMUM LAB DRY DENSITY (PCF)..................100

D159 OPTIMUM LAB MOISTURE CONTENT (%)...............21

D160 TEST USED TO MEASURE DRY DENSITY...............OTHER
D161 MEAN MEASURED DRY DENSITY IN SITU (% OPT)......111
D162 MEAN MEASURED MOISTURE CONTENT IN SITU (% OPT).0

D163 PLASTICITY INDEX...............................5

D164 LIQUID LIMIT...................................20
```

```
SHOULDER DATA

D181 SHOULDER SURFACE TYPE..........................ASPHALT CONCRETE

D182 SHOULDER BASE TYPE.............................GRAVEL

D183 SHOULDER WIDTH (FEET)..........................10

D184 SHOULDER SURFACE THICKNESS (INCHES)............ 2.0

D185 SHOULDER BASE THICKNESS (FEET).................11.0

DRAINAGE DATA

D186 SUBSURFACE DRAINAGE TYPE.......................

D187 DIAMETER OF LONGITUDINAL DRAINPIPES (INCHES)...***

D188 SUBSURFACE DRAINAGE LOCATION...................

ROUGHNESS, FRICTION & PSI DATA
                                LEFT LANE (L)   RIGHT LANE (R)

R1   CALCULATED PSI...........      ***             ***
R2   INSPECTION DATE (PSI).....********        ********

R3   FRICTION NUMBER (WET).....     ***             ***
R4   INSPECTION DATE (FN)......********        ********
R5   EQUIPMENT USED TO MEASURE FN...................*

R6   ROUGHNESS INDEX (RI)......     ***             ***
R7   INSPECTION DATE (RI)......********        ********
R8   EQUIPMENT USED TO MEASURE RI...................*

AXLE LOAD DATA


   SINGLE AXLE LOAD    %         TANDEM AXLE LOAD     %
A1    UNDER <  3,000   0.00    A21    UNDER <  6,000   0.00
A2    3,000 -  6,999   6.04    A22    6,000 - 11,999   0.00
A3    7,000 -  7,999   3.17    A23   12,000 - 17,999   2.47
A4    8,000 - 11,999  27.23    A24   18,000 - 23,999  20.85
A5   12,000 - 15,999  39.48    A25   24,000 - 29,999    .76
A6   16,000 - 17,999   0.00    A26   30,000 - 31,999   0.00
A7   18,000 - 18,499   0.00    A27   32,000 - 32,499   0.00
A8   18,500 - 19,999   0.00    A28   32,500 - 33,999   0.00
A9   20,000 - 21,999   0.00    A29   34,000 - 35,999   0.00
A10  22,000 - 23,999   0.00    A30   36,000 - 37,999   0.00
A11  24,000 - 25,999   0.00    A31   38,000 - 39,999   0.00
A12  26,000 - 29,999   0.00    A32   40,000 - 41,999   0.00
A13  30,000 >    OVER  0.00    A33   42,000 - 43,999   0.00
                               A34   44,000 - 45,999   0.00
                               A35   46,000 - 49,999   0.00
A14 AVE # AXLE/TRUCK 3.306     A36   50,000 >    OVER  0.00
```

Figure 181. Continued

```
UNIFORM SECTION SURVEY

U1   DATE SURVEYED..........................................18/05/82

U2   FOUNDATION.............................................MAJORITY IN CUT

U3   DEPTH OF TYPICAL CUT...................................16-40 FT.

U4   TYPICAL SURFACE DRAINAGE IN CUT........................2<=H<=5 *FT.*

U5   HEIGHT OF TYPICAL FILL.................................

     DISTRESS TYPE  LEFT  LANE SEVERITY
       LOCATION      L     M    H

U6L   DEPRESSIONS    0     0    0
U7L     SWELLS       10     0    3
U8L    PANEL PSR          8.3

     DISTRESS TYPE  RIGHT LANE SEVERITY
       LOCATION      L     M    H

U6R   DEPRESSIONS    20     0    0
U7R     SWELLS       0     0    0
U8R    PANEL PSR          3.8


DESTRESS IDENTIFICATION

      DISTRESS TYPE          LOCATION        SEVERITY
                                        LOW  MEDIUM  HIGH
S1L   BLOW UP (#)             LT....... 0      0      0
S1R                           RT....... 0      0      0

S2L   TRANSVERSE SPALLS       LT....... 5      6      0
S2R   (JPCP & JRCP #-JOINTS)  RT....... 7      6      0

S3L   LONGITUDINAL SPALLS     LT....... 0      0      0
S3R   (JPCP & JRCP #-JOINTS)  RT....... 3      0      0

S4L   REACTIVE AGGREGATE      LT......  0      0      0
S4R   (% AREA SAMPLE UNIT)    RT......  0      0      0

S7L   LONGITUIDNAL SPALLING   LT......***    ***    ***
S7R   (LINEAR FT CRCP ONLY)   RT......***    ***    ***

S8L   LOCALIZED DISTRESS      LT.......**     **     **
S8R   (#-AREA CRCP ONLY)      RT.......**     **     **

S9L   EDGE PUNCHOUTS          LT.......**     **     **
S9R   (CRCP ONLY)             RT.......**     **     **

S10L CONSTRUCTION JOINT       LT.......**     **     **
S10R (DISTRESS CRCP ONLY)     RT.......**     **     **

S5L   PUMPING                 LT...........LOW
S5R                           RT...........LOW

S6L   SCALING, MAP CRACKING   LT...........LOW
S6R       OR CRAZING          RT...........LOW

S11   OUTER SHOULDER CONDITION.............FAIR

S12   FOUNDATION OF SAMPLE UNIT............AT GRADE,+-5 FT.

S13   EXPANSION JOINTS.....................

S14   STUDDED TIRE DAMAGE..................YES

S21   TRANSVERSE JOINT SEAL DAMAGE.........LOW

S22   INCOMPRESSIBLES IN TRANSVERE JOINT...NO

S23   TEMPORARY PATCHING PRESENT...........LT HALF JTS
```

```
CRACKING AND FAULTING DATA

S31  SAMPLE UNIT LENGTH (FEET)............600
S32  SAMPLE UNIT START PT (MILE POINT)....    2.00
S33  SAMPLE UNIT START PT (STATION NO)....********

     DISTRESS TYPE            LOCATION     SEVERITY
                                   LOW  MEDIUM  HIGH
S34L LONGITUDINAL "D" CRACKING LT...  0     0      0
S34R (LINEAR FEET)             RT...  0     0      0

S35L TRANSVERSE "D" CRACKING   LT...  0     0      0
S35R (LINEAR FEET)             RT...  0     0      0

S36L LONGITUDINAL CRACKING     LT...  0     0      0
S36R (LINEAR FEET)             RT...  0     0      0

S37L TRANSVERSE CRACKING       LT...  0    12     24
S37R (LINEAR FEET)             RT...  0    25     12

S38L CORNER BREAKS             LT.........0
S38R (NUMBER)                  RT.........0

S39L CRACKING DUE TO JOINT     LT.........0
S39R (NUMBER)                  RT.........0

S40L TRANSVERSE JOINT FAULTING LT.........*
S40R (MEAN INCHES)             RT......... .030

S41L LONGITUDNAL FAULTS        LT.........1
S41R (NUMBER OF AREAS)         RT.........0

S42R LANE/SHOULDER SEPARATIONS............LOW
```

```
      TYPE OF PATCH         LOCATION      SEVERITY
                                    LOW  MEDIUM  HIGH
S61L  TOTAL ASPHALT PATCH     LT...... 21     0      0
S61R  AT JOINT (SQ. FEET)     RT......  7     0      0

S62L  NO. OF JOINTS PATCHED   LT......  7     0      0
S62R  AT JOINT (ASPHALT)      RT......  4     0      0


S63L  TOTAL PCC PATCH         LT......  0     0      0
S63R  AT JOINT (SQ. FEET)     RT......  0     0      0

S64L  NO. OF JOINTS PATCHED   LT......  0     0      0
S64R  AT JOINT (PCC)          RT......  0     0      0


S65L  TOTAL ASPHALT PATCH     LT......  0     0      0
S65R  NOT AT JOINT (SQ. FEET) RT......  0     0      0

S66L  NO. OF JOINTS PATCHED   LT......  0     0      0
S66R  NOT AT JOINT (ASPHALT)  RT......  0     0      0


S67L  PCC PATCHES NOT AT      LT......  0     0      0
S67R  JOINT (SQ. FEET)        RT......  0     0      0

S68L  PCC PATCHES             LT......  0     0      0
S68R  (NUMBER)                RT......  0     0      0


S69L  CORNER BREAKS   (#)     LT...........0
S69R  WITH ADJACENT SLAB DET  RT...........1

S70L  "D" CRACKING    (#)     LT...........0
S70R  WITH ADJACENT SLAB DET  RT...........0

S71L  SPALLING        (#)     LT...........4
S71R  WITH ADJACENT SLAB DET  RT...........3
```

Figure 181. Continued

Year	1-Way ADT	1-Way ADTT*	1-Way Lane*** Dist. (Trucks) L-Lane	R-Lane	Factor**	1-Way No. of Lanes	Yearly ESAL L.L.	R.L.	Cum. ESAL L.L.	R.L.
60	14500	1500	.28	.65	.770	3	.1	.3	.1	.3
61	14520	1500	.28	.65	.807	3	.1	.3	.2	.6
62	14600	1510	.28	.65	.844	3	.1	.3	.4	.9
63	14800	1520	.28	.65	.881	3	.1	.3	.5	1.2
64	15300	1530	.28	.65	.917	3	.1	.3	.7	1.5
65	16175	1530	.28	.64	.954	3	.1	.3	.8	1.8
66	17000	1535	.29	.64	.991	3	.2	.4	1.0	2.2
67	18400	1560	.29	.63	1.000	3	.2	.4	1.1	2.6
68	19300	1590	.30	.63	1.000	3	.2	.4	1.3	2.9
69	20250	1600	.30	.62	1.000	3	.2	.4	1.5	3.3
70	21000	1650	.30	.62	1.000	3	.2	.4	1.7	3.7
71	21400	1700	.31	.62	1.000	3	.2	.4	1.8	4.0
72	21600	1740	.31	.62	1.000	3	.2	.4	2.0	4.4
73	21800	1780	.31	.62	1.005	3	.2	.4	2.2	4.8
74	22200	1800	.31	.62	1.040	3	.2	.4	2.5	5.3
75	22700	1860	.31	.61	1.080	3	.2	.4	2.7	5.7
76	23400	1930	.31	.61	1.150	3	.3	.5	2.9	6.2
77	24300	2030	.32	.61	1.240	3	.3	.6	3.2	6.8
78	25500	2200	.32	.60	1.305	3	.3	.6	3.6	7.4
79	27000	2350	.32	.60	1.370	3	.4	.7	3.9	8.1
80	27900	2500	.33	.60	1.430	3	.4	.8	4.4	8.9
81	28500	2600	.33	.60	1.490	3	.5	.8	4.9	9.7
82	28500	2660	.33	.60	1.540	3	.5	.9	5.3	10.6

* Excluding Pickups and Panels
** Ave. 18-kip ESAL/Truck
*** Est. using COPES Truck Lane Distribution Models

ESAL L.L.: Equivalent Single Axle Load L-Lane (Millions)
ESAL R.R.: Equivalent Single Axle Load R-Lane (Millions)
Cum. ESAL: Cumulative Equivalent Single Axle Load (Millions)

Figure 182. Example automated report for a given project traffic volume and ESAL.

REFERENCES

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2. Nie, N. H., Hull, C. H., Jenkins, J. G., Stienbrenner, K., and Bent, D. H., "Statistical Package for the Social Sciences (SPSS). Second edition, McGraw-Hill Book Company, New York, N. Y. (1975).
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APPENDIX A

BLANK COPES DATA COLLECTION SHEETS

The blank data collection sheets provided in the remainder of this appendix were designed to assist the user in identifying and recording the information needed to implement COPES on a similar type system.

SHEET 1
DESIGN DATA
-COPES-

NCHRP Project 1-19
Concrete Pavement
Evaluation System-COPES

Dept. of Civil Engineering
University of Illinois

Record No. 1. 1
State Code __ __ 2-3
Proj. ID __ __ __ __. 4-7
Unif. Sect. __ __. 8-9

PROJECT AND UNIFORM SECTION IDENTIFICATION

D 1. State Highway Department (SHD) District Number .. __ __. 10-11

D 2. County (See County Code Sheet) .... __ __ __ __ __. 12-16

*D 3. Type of Highway .... Interstate 1 17
Primary Non-Interstate... 2
Secondary 3
Other (specify)________ 4

*D 4. Highway letter designation .... Interstate 1 18
U.S. 2
State 3
Other (specify)________ 4

*D 5. Highway number .... __ __ __. 19-21

*D 6. Direction of survey .... East 1 22
West 2
North 3
South 4

*D 7. Beginning mile marker of SHD project .... __ __ __.__ __ 23-27

*D 8. Ending mile marker of SHD project .... __ __ __.__ __ 28-32

D 9. Beginning station number of SHD project ...... __ __ __ __ __.__ __ 33-39

D10. Ending station number of SHD project .... __ __ __ __ __.__ __ 40-46

D11. Number of uniform sections in project .... __ __. 47-48

D12. Uniform section

* A. Start point-mile mark .... __ __ __.__ __ 49-53

* B. End point-mile mark .... __ __ __.__ __ 54-58

C. Start point station no. .... __ __ __ __ __.__ __ 59-65

D. End point station no. .... __ __ __ __ __.__ __ 66-72

*D13. Number of lanes in uniform section ..... 1 lane 1 73
2 lanes 2

*D14. Type of original concrete slab .... JPCP 1 74
JRCP 2
CRCP 3
Other (specify)
________________ 4

State Highway Department 75-78/BK
Construction Project No. 79-80/01

____

*Variables that were found to be highly important

SHEET 2

DESIGN DATA
-COPES-

Record No. 1. 1-9/Dup.
State Code ___ ___.
Proj. ID ___ ___ ___ ___.
Unif. Sect. ___ ___.

ENVIRONMENTAL DATA

		Avg. Monthly Temp., °C (A)	Avg. Max. Daily Temp., °C (B)	Avg. Min. Daily Temp., °C (C)	Avg. Monthly Precip., CMS of Water (D)	
*D 21	January	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	10-21
*D 22	February	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	22-33
*D 23	March	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	34-45
*D 24	April	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	46-57
*D 25	May	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	58-69
*D 26	June	___ ___.	___ ___.	___ ___.	___ ___.___	70-78
						79-80/02 1-9 /Dup.
*D 27	July	___ ___.	___ ___.	___ ___.	___ ___.___	10-18
*D 28	August	___ ___.	___ ___.	___ ___.	___ ___.___	19-27
*D 29	September	___ ___.	___ ___.	___ ___.	___ ___.___	28-36
*D 30	October	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	37-48
*D 31	November	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	49-60
*D 32	December	___ ___ ___.	___ ___ ___.	___ ___ ___.	___ ___.___	61-72

73-78/BK
79-80/03
1-9 /Dup.

*D 36. Latitude (degrees) .... ___ ___. 10-11

*D 37. Freezing Index (32°F -- CE Method) .... ___ ___ ___ ___. 12-15

D 38. Average No. of Annual Freeze-Thaw Cycles ...... ___ ___ ___. 16-18

D 39. Elevation (feet above sea level) .... ___ ___ ___ ___ ___. 19-23

D 40. Avg. Annual Deicing Salt ($CaCl_2$) Application (ton/lane mile/year) .... ___ ___. 24-25

*Variables that were found to be highly important.

SHEET 3

DESIGN DATA
-COPES-

Record No. 1.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

SLAB STRUCTURAL DESIGN

*D 41. Slab thickness (in).. .... __ __.__ 26-28

*D 42. Lane width (ft) .... __ __. 29-30

*D 43. Date slab construction completed (month/year) __ __/__ __ 31-34

*D 44. Date opened to traffic (month/year) .... __ __/__ __ 35-38

39-44/BK

JOINT DATA

*D 51. Average contraction joint spacing (ft) __ __ __.__ 45-48

(Random joint spacing, if any: ____________________)

*D 52. Built-in expansion joint spacing (ft)..... __ __ __ __. 49-52

*D 53. Skewness of joint (ft/lane) .... __.__ 53-54

*D 54. Transverse contraction joint load transfer system 55
- Dowels 1
- No mechanical load transfer device 2
- Other (specify) ____________________ 3

*D 55. Dowel diameter (in.) .... __.__ __ 56-58

*D 56. Dowel spacing (in.) .... __ __. 59-60

*D 57. Dowel length (in.) .... __ __. 61-62

D 58. Dowel coating 63
- Paint and/or grease 1
- Plastic 2
- Monel 3
- Stainless steel 4
- Epoxy 5
- Other (specify) ____________________ 6

D 59. Method used to install dowels 64
- Preplaced on baskets ...1
- Mechanically installed .2
- Other (specify) ____________________ 3

65-78/BK

79-80/04

*Variables that were found to be highly important.

SHEET 4

DESIGN DATA

-COPES-

Record No. 1. 1-9/Dup.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

JOINT DATA

(continued from sheet 3)

*D 70. Method used to form transverse joints 10
- Sawed 1
- Plastic insert 2
- Metal insert (i.e., Uni-tube) 3
- Other (specify)

D 71. Joint sealant type used in transverse joints (as built) 11
- No joint sealant 0
- Preformed (open web) 1
- Asphalt 2
- Rubberized asphalt (old type) 3
- Rubberized asphalt (new type) 4
- Silicone 5
- Other (e.g., closed neoprene) (specify) ________________________ 6

D 72. Transverse joint sealant reservoir (as built)
- (A) Width (in.) __.__ __ 12-14
- (B) Depth (in.) __.__ 15-16

D 73. Type of longitudinal joint (between lanes) 17
- Butt 1
- Keyed 2
- Sawed weakened plane 3
- Insert weakened plane 4
- Other (specify) ________________________ 5

D 74. Tie bar diameter (in.) .... __.__ __ 18-20

D 75. Tie bar length (in.) .... __ __. 21-22

D 76. Tie bar spacing (in.) .... __ __. 23-24

D 77. Type of shoulder-traffic lane joint 25
- Butt 1
- Keyed 2
- Sawed weakened plane 3
- Insert weakened plane 4
- Tied concrete curb 5
- Other (specify) ________________________ 6

D 78. Shoulder-traffic lane joint tie bar diameter (for concrete shoulder) (in.)............ __.__ __ 26-28

D 79. Shoulder-traffic lane joint tie bar .... __ __. 29-30
length in inches (for concrete shoulder)

D 80. Shoulder-traffic lane joint tie bar .... __ __. 31-32
spacing (for concrete shoulder)(in.)

SHEET 5

DESIGN DATA

-COPES-

Record No. 1.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

REINFORCING STEEL DATA

* D 81. Type of reinforcing .... No reinforcing 0 33
Deformed bars 1
Welded wire fabric 2
Other (specify)
______________________ 3

D 82. Transverse bar diameter (in.) .... __.__ __ 34-36

D 83. Transverse bar spacing (in.) .... __ __.__ 37-39

*D 84. Longitudinal bar diameter (in.) .... __.__ __ 40-42

*D 85. Longitudinal bar spacing (in.) ... . __ __.__ 43-45

D 86. Yield strength of reinforcing (ksi) .... __ __.__ 46-48

D 87. Depth to reinforcement from slab surface .... __.__ 49-50
(in.)

D 88. Method used to place rebar .... Preset on chairs 1 51
Mechanically 2
Between layers of concrete. 3
Other (specify)
______________________ 4

D 89. Length of steel lap at construction ....
joint (CRCP only) (in.): __ __. 52-53

54-78/BK

79-80/05

*Variables that were found to be highly important.

SHEET 6

DESIGN DATA

-COPES-

Record No. 1. 1-9/Dup.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

CONCRETE DATA

D101. Mix design (lb/yd^3)............... (A) Coarse aggregate __ __ __ __. 10-13
(B) Fine aggregate __ __ __ __. 14-17
(C) Cement .... __ __ __ __. 18-21
(D) Water .... __ __ __ __. 22-25

* D102. Strength (28-day modulus of rupture)(psi)(based on 3rd point loading) (A) Mean .... __ __ __ __. 26-29
(B) Range .... __ __ __ __. 30-33

Note: If data specified above is not available, please provide any available data below:

Type of Test ____________________ (see Test Type Code) 34-42/BK
Age of Concrete (days) ____________
Mean ____________________
Range ____________________

D104. Slump (in.) .... (A) Mean .... __.__ 43-44
(B) Range .... __.__ 45-46

D105. Type cement used (see Cement Type Codes) .... __ __. 47-48

D106. Alkali content of cement,(%)......................... __ __.__ 49-51

*D107. Entrained air,(%)................. (A) Mean .... __.__ 52-53
(B) Range .... __.__ 54-55

D108. Additives other than air-entrainers (see Cement Additive Code) .... __ __. 56-57

D109. Maximum size of coarse aggregate (in.) .... __.__ 58-59

*D110. Type of coarse aggregate 60
Crushed stone 1
Gravel or crushed gravel 2
Crushed slag 3
Blend crushed stone/gravel 4
Blend crushed stone/slag 5
Blend Gravel/slag 6
Other (specify)
______________________________ 7

*Variables that were found to be highly important.

SHEET 7

DESIGN DATA

-COPES-

Record No. 1.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

CONCRETE DATA

(continued from Sheet 6)

D111. Source of coarse aggregate (Source code number obtained from a State list of sources and producers of aggregates for highway construction)	(A) Source I __ __ __ __ __ __.	61-66
	(B) Source II __ __ __ __ __ __.	67-72
	(C) Source III__ __ __ __ __ __.	73-78
D112. Type of fine aggregate	Natural or crushed sand 1	79-80/06
	Manufactured sand (from crushed gravel or stone) ... 2	1-9 /Dup. 10
	Other (specify) ______________________________ 3	
D113. Source of fine aggregate (Source code number obtained from a State list of sources and producers of aggregates for highway construction)	(A) Source I __ __ __ __ __ __.	11-16
	(B) Source II __ __ __ __ __ __.	17-22
	(C) Source III__ __ __ __ __ __.	23-28
D114. Type of aggregate durability test used (see Durability Test Type Code)	__ __.	29-30
D115. Result of durability test in item D114	__ __.__	31-33
D116. Type of paver used	Slip form 1	34
	Side form 2	
D117. Method used to cure concrete	Membrane curing compound 1	35
	Burlap curing blankets 2	
	Waterproof paper blankets 3	
	White Polyethylene sheeting .. 4	
	Burlap-polyethylene blanket .. 5	
	Cotton mat curing 6	
	Hay 7	
	Other (specify) ______________________________ 8	

SHEET 8

DESIGN DATA
-COPES-

Record No. 1.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

CONCRETE DATA
(continued from Sheet 7)

*D118. Method used to finish concrete .... Tine 1 36
Broom 2
Burlap drag 3
Grooved float 4
Astro turf 5
Other (specify)
________________________ 6

D119. Geologic classification of coarse crushed stone concrete aggregate (see Geologic Classification Code) .... __ __. 37-38

BASE DATA
39-46/BK

*D131. Type of base (see Base Type Code) .... __ __. 47-48

*D132. Stabilized base layer thickness (in.) .... __.__ 49-50

D133. Type strength test used for stabilized base layer (see Test Type Code) .... __ __. 51-52

D134. Result of strength test in Item D133 .... __ __ __ __. 53-56

D135. Percent material passing No. 200 sieve (for granular base only) .... __ __. 57-58

*D136. Non-stabilized (granular) base layer thickness (in.) .... __.__ 59-60

D137. Type strength test used for nonstabilized base layer thickness (see Test Type Code) .... __ __. 61-62

D138. Result of strength test in Item D137 .... __ __. 63-64

65-78/BK
79-80/07

*Variables that were found to be highly important.

SHEET 9

DESIGN DATA
-COPES-

Record No. 1. 1-9/Dup.
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

SUBGRADE DATA

*D151. AASHTO soil classification .... __ __. 10-11
(see Soil Type Code)

*D152. Strength test used on subgrade .... __ __. 12-13
(see Test Type Code)

*D153. Test result from Item D152 .... __ __ __. 14-16

D154. Test used to predict swell potential .... __ __. 17-18
(see Test Type Code)

D155. Test value from Item D154 .... __ __ __.__ 19-22

D156. Test used to predict frost susceptibility .... __ __. 23-24
(see Test Type Code)

D157. Test value from Item D156 .... __ __ __.__ 25-28

D158. Optimum lab dry density (pcf) .... __ __ __. 29-31

D159. Optimum lab moisture content (%) .... __ __. 32-33

D160. Test used to measure dry density 34

No test performed	0
Standard Proctor (T-99)	1
Modified Proctor (T-180).....	2
Other (specify) ______________	3

D161. Mean measured dry density insitu (% optimum) .... __ __ __. 35-37

D162. Mean measured moisture content in situ .... __ __ __. 38-40
(% optimum)

D163. Plasticity index .... __ __. 41-42

D164. Liquid limit .... __ __. 43-44

45-59/BK

*Variables that were found to be highly important.

SHEET 10

DESIGN DATA

-COPES-

Record No. 1.
State Code ___ ___.
Proj. ID ___ ___ ___ ___.
Unif. Sect. ___ ___.

SHOULDER DATA

*D181. Shoulder surface type	Turf	1	60
	Granular	2	
	Asphalt concrete	3	
	Concrete	4	
	Other (specify) ______________	5	
*D182. Shoulder base type (see Base Type Code)		___ ___.	61-62
*D183. Shoulder width (ft)		___ ___.	63-64
D184. Shoulder surface thickness (in.)		___.___	65-66
D185. Shoulder base thickness (in.)		___ ___.___	67-69

DRAINAGE DATA

*D186. Subsurface drainage type	No subsurface drainage	1	70
	Longitudinal drains	2	
	Transverse drains	3	
	Drainage blanket	4	
	Well system	5	
	Drainage blanket with longitudinal drains	6	
	Other (specify) ______________	7	
D187. Diameter of longitudinal drainpipes (in.)		___.___	71-72
D188. Subsurface drainage location	Continuous along project	1	73
	Intermittent	2	
			74-78/BK
			79-80/08

*Variables that were found to be highly important.

Record _2_. 1
State Code __ __. 2-3
Proj. ID __ __ __ __. 4-7
Unif. Sect. __ __. 8-9
Year __ __. 10-11
Roughness Seq. __ __. 12-13

SHEET 11

ROUGHNESS, SKID AND PSI DATA

-COPES-

	Left Lane (L).	Right Lane (R).	
R 1. Calculated PSI from roughness/distress measurements ...	__.__	__.__	14-17
R 2. Inspection date (day/month/year) for PSI	__ __/__ __/__ __	__ __/__ __/__ __	18-29
*R 3. Skid number (SN) (wet)	__ __.	__ __.	30-33
*R 4. Inspection date (day/month/year) for SN	__ __/__ __/__ __	__ __/__ __/__ __	34-45
*R 5. Equipment used to measure SN (left and right lanes)			
- Trailer (locked wheel with ASTM E274 standard tire)	....	 1	46
- Mu meter	....	 2	
- Other (specify) ______________________________ .	....	 3	
*R 6. Roughness Index (RI)	__ __ __.	__ __ __.	47-52
*R 7. Inspection date (day/month/year) for RI	__ __/__ __/__ __	__ __/__ __/__ __	53-64
*R 8. Equipment used to measure RI (left and right lanes)			
- BPR Roughometer (in/mile)	....	 1	65
- May's Ride Meter (in/mile)	....	 2	
- PCA Roughometer (in^2/mile)	....	 3	
- Profilograph (in/mile)	....	 4	
- GM Profilometer	....	 5	
- Other (specify) ______________________________	....	 6	66-78/BK 79-80/01

*Variables that were found to be highly important.

SHEET 12

* AXLE LOAD DATA

-COPES-

Record No.	3.	1
State Code	__ __.	2-3
Proj. ID	__ __ __ __.	4-7
Unif. Sect.	__ __.	8-9
Year	__ __.	10-11

1-11/Dup.

	SINGLE AXLE LOAD	%	
A 1.	Under 3,000	__ __.__ __	12-15
A 2.	3,000 - 6,999	__ __.__ __	16-19
A 3.	7,000 - 7,999	__ __.__ __	20-23
A 4.	8,000 - 11,999	__ __.__ __	24-27
A 5.	12,000 - 15,999	__ __.__ __	28-31
A 6.	16,000 - 17,999	__ __.__ __	32-35
A 7.	18,000 - 18,499	__ __.__ __	36-39
A 8.	18,500 - 19,999	__ __.__ __	40-43
A 9.	20,000 - 21,999	__ __.__ __	44-47
A10.	22,000 - 23,999	__ __.__ __	48-51
A11.	24,000 - 25,999	__ __.__ __	52-55
A12.	26,000 - 29,999	__ __.__ __	56-59
A13.	30,000 or over	__ __.__ __	60-63
	* Total SA =	________	
A14.	Average No. of Axles per Truck .... (single and tandem)	__.__ __	64-67
			68-78/BK
			79-80/01

	TANDEM AXLE LOAD	%	
A21.	Under 6,000	__ __.__ __	12-15
A22.	6,000 - 11,999	__ __.__ __	16-19
A23.	12,000 - 17,999	__ __.__ __	20-23
A24.	18,000 - 23,999	__ __.__ __	24-27
A25.	24,000 - 29,999	__ __.__ __	28-31
A26.	30,000 - 31,999	__ __.__ __	32-35
A27.	32,000 - 32,499	__ __.__ __	36-39
A28.	32,500 - 33,999	__ __.__ __	40-43
A29.	34,000 - 35,999	__ __.__ __	44-47
A30.	36,000 - 37,999	__ __.__ __	48-51
A31.	38,000 - 39,999	__ __.__ __	52-55
A32.	40,000 - 41,999	__ __.__ __	56-59
A33.	42,000 - 43,999	__ __.__ __	60-63
A34.	44,000 - 45,999	__ __.__ __	64-67
A35.	46,000 - 49,999	__ __.__ __	68-71
A36.	50,000 or over	__ __.__ __	72-75
	* Total TA =	________	
	* Note: % SA + % TA = 100.00		
			76-78/BK
			79-80/02

*Variables that were found to be highly important.

SHEET 13

TRAFFIC VOLUME DATA

-COPES-

Record No. _4_. 1
State Code __ __. 2-3
Proj. ID __ __ __ __. 4-7
Unif. Sect. __ __. 8-9

	YEAR (YEAR)	ONE-WAY ADT (*T1)	ONE-WAY ADTT[a] (*T2)	ONE-WAY LANE DISTRIBUTION[b] (TRUCKS[a]) LEFT LANE (*T3L)	RIGHT LANE (*T3R)	ONE-WAY LOAD DISTRIBUTION FACTOR[a] (*T4)	ONE-WAY NUMBER OF LANES ACROSS HIGHWAY (*T5)	
	__ __.	__ __ __ __ __.	__ __ __ __ __.	.__ __	__.__ __	__.__ __ __	__.	10-31 32-78/BK 79-80/01
1-9/Dup.	__ __.	__ __ __ __ __.	__ __ __ __ __.	.__ __	__.__ __	__.__ __ __	__.	10-31 32-78/BK 79-80/01
1-9/Dup.	__ __.	__ __ __ __ __.	__ __ __ __ __.	.__ __	__.__ __	__.__ __ __	__.	10-31 32-78/BK 79-80/01
1-9/Dup.	__ __.	__ __ __ __ __.	__ __ __ __ __.	.__ __	__.__ __	__.__ __ __	__.	10-31 32-78/BK 79-80/01
1-9/Dup.	__ __.	__ __ __ __ __.	__ __ __ __ __.	.__ __	__.__ __	__.__ __ __	__.	10-31 32-78/BK 79-80/01
1-9/Dup.	__ __.	__ __ __ __ __.	__ __ __ __ __.	.__ __	__.__ __	__.__ __ __	__.	10-31 32-78/BK 79-80/01

a Excluding Pickup and Panel Trucks, and 2 axle/4 tire Trucks.

b Distribution across lanes must sum to 1.00 for 2 lane highways in one direction, and must sum to less than 1 for highways of 3 lanes or more in one direction. Right Lane Distribution factor must equal 1.00 for highways of one lane in one direction.

* Variables that were found to be highly important.

SHEET 14

MAINTENANCE DATA
-COPES-

Record No. _5_. 1
State Code __ __. 2-3
Proj. ID __ __ __ __. 4-7
Unif. Sect. __ __. 8-9

	YEAR (YEAR)	MAINTENANCE SEQUENCE NO. (MSEQ)	WORK TYPE (CODE) (M1)	LOCATION ON PAVEMENT (CODE) (M2)	MAINTENANCE MATERIAL (CODE) (M3)	WORK QUANTITY (M4)	THICKNESS (INCHES) (M5)	
	__ __.	__ __.	__ __.	__ __.	__ __.	__ __ __ __ __.	__ __.__	10-27 28-78/BK 79-80/01
1-9/Dup.	__ __.	__ __.	__ __.	__ __.	__ __.	__ __ __ __ __.	__ __.__	10-27 28-78/BK 79-80/01
1-9/Dup.	__ __.	__ __.	__ __.	__ __.	__ __.	__ __ __ __ __.	__ __.__	10-27 28-78/BK 79-80/01
1-9/Dup.	__ __.	__ __.	__ __.	__ __.	__ __.	__ __ __ __ __.	__ __.__	10-27 28-78/BK 79-80/01
1-9/Dup.	__ __.	__ __.	__ __.	__ __.	__ __.	__ __ __ __ __.	__ __.__	10-27 28-78/BK 79-80/01
1-9/Dup.	__ __.	__ __.	__ __.	__ __.	__ __.	__ __ __ __ __.	__ __.__	10-27 28-78/BK 79-80/01

SHEET 1F

FIELD DATA

-COPES-

NCHRP Project 1-19
Concrete Pavement
Evaluation System-COPES

Dept. of Civil Engineering
University of Illinois

State Code __ __.
Proj. ID __ __ __ __.

CONSTRUCTION PROJECT REFERENCE DATA

Construction Project Locations:

Start Pt. Mile Mark ____________

End Pt. Mile Mark ____________

Start Pt. Station No. ____________

End Pt. Station No. ____________

Construction Project Length (Miles) ____

Highway No. ____________

Direction of Survey:

East 1
West 2
North 3
South 4

Surveyor Initials ____________

Uniform Section Locations:

Uniform Section No.	Uniform Section Start Point		Number of Lanes	Location of Lanes
	Mile Marker	Station Number		
01			1 2	Outer 2
02				Outer 2
03				Outer 2
04				Outer 2
05				Outer 2
06				1st Inner 2
07				1st Inner 2
08				1st Inner 2
09				1st Inner 2
10				1st Inner 2
11				2nd Inner 2
12				2nd Inner 2
13				2nd Inner 2
14				2nd Inner 2
15				2nd Inner 2

SHEET 2F

UNIFORM SECTION FIELD DATA
-COPES-

Record No.	6.	1
State Code	__ __.	2-3
Proj. ID	__ __ __ __.	4-7
Unif. Sect.	__ __.	8-9
Time Sequence	__ __.	10-11

UNIFORM SECTION SURVEY

Uniform Section Location:

Start Pt. Mile Mark ____________

End Pt. Mile Mark ____________

Start Pt. Station No. ____________

End Pt. Station No. ____________

*U 1. Date Surveyed (day/month/year):

__ __/__ __/__ __ 12-17

*U 2. Foundation:

Majority at grade 1 18
Majority in cut 2
Majority in fill 3

*U 3. Depth of Typical Cut:

5 ft. or less 1 19
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. 4

Record the number of occurances for each lane at each severity level.

	Distress Type/ Location	Left Lane Severity			
		L	M	H	
U6L.	Depressions	__ __.	__ __.	__ __.	20-25
U7L.	Swells	__ __.	__ __.	__ __.	26-31

		Left Lane	
*U8L.	Mean Panel PSR	__.__	32-33

*Variables that were found to be highly important.

U 4. Typical surface drainage in cut or at grade:

H* less than 2 ft. ..1 34
H between 2-5 ft. ...2
H greater than 5 ft..3
Tied Concrete Curb ..4

Other ____________5

*H=Distance from top of slab to bottom of side ditch or natural ground if no ditch.

U 5. Height of typical fill:

5 ft. or less 1 35
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. .4

36/BK

	Right Lane Severity			
	L	M	H	
U6R.	__ __.	__ __.	__ __.	37-42
U7R.	__ __.	__ __.	__ __.	43-48

	Right Lane	
U8R.	__.__	49-50

51-78/BK
79-80/01

SHEET 3F

SAMPLE UNIT FIELD DATA

-COPES-

Record No.	7.	1
State Code	__ __.	2-3
Proj. ID	__ __ __ __.	4-7
Unif. Sect.	__ __.	8-9
Time Sequence	__ __.	10-11
Sample Unit Seq.	__.	12

DISTRESS IDENTIFICATION

	Location	Left Lane			
	Severity	L	M	H	
	Distress type				
S 1L.	Blowup (No.)	__ __.	__ __.	__ __.	13-18
S 2L.	Transverse Joint Spall (No. of Joints) (JPCP and JRCP only)	__ __.	__ __.	__ __.	19-24
S 3L.	Longitudinal Joint Spalling (No. of Joints) (JPCP and JRCP only)	__ __.	__ __.	__ __.	25-30
S 4L.	Reactive Aggregate Distress (% Area of Sample Unit)	__ __ __.	__ __ __.	__ __ __.	31-39
S 5L.	Pumping (circle highest severity found)	0 1	2	3	40
S 6L.	Scaling, Map Cracking, or Crazing (circle highest severity found)	0 1	2	3	41
S 7L.	Longituidnal Joint Spalling (linear feet) (CRCP only)	__ __ __.	__ __ __.	__ __ __.	42-50
S 8L.	Localized Distress (No. of Areas) (CRCP only)	__ __.	__ __.	__ __.	51-56
S 9L	Edge Punchout (No.) (CRCP only)	__ __.	__ __.	__ __.	57-62
S10L.	Construction Joint Deterioration (CRCP only)	__ __.	__ __.	__ __.	63-68

S11. Outer Shoulder Condition:

Very good 1 69
Good 2
Fair 3
Poor 4
Very poor 5

S12. Foundation of Sample Unit:

Fill Greater than 40 Ft. 1 70
Fill 16-40 ft. 2
Fill 6-15 ft. 3
At Grade (5' fill to 5' cut) 4
Cut 6-15 ft. 5
Cut 16-40 ft. 6
Cut Greater than 40' 7

S13. Expansion Joints (No.) .... __ __. 71-72

S14. Studded Tire Damage (Right Lane)

Yes 1 73
No 2

74-78/BK
79-80/01

	Right Lane			
	L	M	H	1-12/Dup.
S 1R.	__ __.	__ __.	__ __.	13-18
S 2R.	__ __.	__ __.	__ __.	19-24
S 3R.	__ __.	__ __.	__ __.	25-30
S 4R.	__ __ __.	__ __ __.	__ __ __.	31-39
S 5R.	0 1	2	3	40
S 6R.	0 1	2	3	41
S 7R.	__ __ __.	__ __ __.	__ __ __.	42-50
S 8R.	__ __.	__ __.	__ __.	51-56
S 9R.	__ __.	__ __.	__ __.	57-62
S10R.	__ __.	__ __.	__ __.	63-68

S21. Transverse Joint Seal Damage (JRCP and JPCP) (Right Lane) 69

Low 1
Medium 2
High 3

S22. Incompressibles in Transverse Joint (JRCP and JPCP) (Right Lane)

Yes 1 70
No 2

S23. Temporary Patching Present (Both Lanes)

None or Very Minor 1 71
Less than One-Half of the Joints 2
Half or More of the Joints 3

72-78/BK

79-80/02

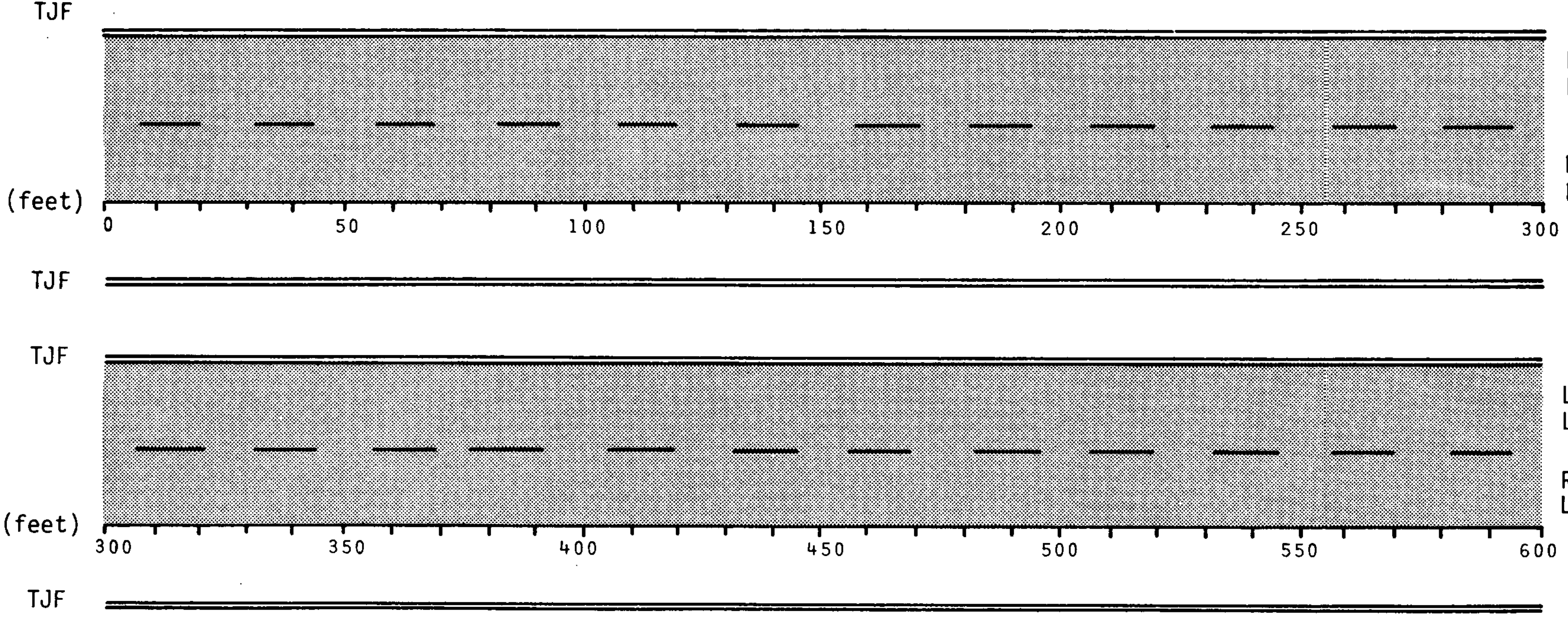
State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.
Time Sequence __ __.
Sample Unit Seq. __.

SHEET 4F

SAMPLE UNIT FIELD DATA
-COPES-

CRACKING AND FAULTING DATA

Start Pt. Mile Mark ____________ Start Pt. Station No. ____________



1. Record crack pattern (indicate Medium (M) and High (H) severity; "D" Cracking severity as D_L, D_M, D_H
2. Measure Transverse Joint Faulting (TJF) at 1 foot in from pavement edge.
3. Also record corner breaks and cracking from improper joint construction.
4. Data from this sheet to be tabulated on Sheet 5F.
5. Mean Lane Shoulder Separation (inches) ____________________.

Record No.	7.	1-12/Dup.
State Code	__ __.	
Proj. ID	__ __ __ __.	
Unif. Sect.	__ __.	
Time Sequence	__ __.	
Sample Unit Seq.	__.	

SHEET 5F

SAMPLE UNIT FIELD DATA

-COPES-

CRACKING AND FAULTING DATA

(Tabulated from Sheet 4F)

S31. Sample Unit Length (feet) __ __ __ __. 13-16

S32. Sample Unit Start Pt. - Mile Mark __ __ __.__ __ 17-21

S33. Sample Unit Start Pt. - Station No. __ __ __ __ __.__ __ 22-28

Location	Left Lane			
Severity	L	M	H	
Distress Type				
S34L. Longitudinal "D" Cracking (linear ft.)	__ __ __ __.	__ __ __ __.	__ __ __ __.	29-40
S35L. Transverse "D" Cracking (linear ft.)	__ __ __.	__ __ __.	__ __ __.	41-49
S36L. Longitudinal Cracking (linear ft.)	__ __ __ __.	__ __ __ __.	__ __ __ __.	50-61
S37L. Transverse Cracking (linear ft.)	__ __ __ __.	__ __ __ __.	__ __ __ __.	62-73
S38L. Corner Breaks (No.) (low, medium and high)	__ __.			74-75

76-78/BK

79-80/03

1-12/Dup

S39L. Cracking from Improper Joint Construction (linear ft.)(low, med. & high)	__ __ __ __.	13-16
S40L. Transverse Joint Faulting (mean, inches) (JRCP/JPCP only)	__.__ __	17-19
S41L. No. of Longitudinal Joint Faulting Areas	__.	20
Lane/Shoulder Separation (Circle Mean Severity Found)	▨	

21-31/BK

	Right Lane			
	L	M	H	
S34R.	__ __ __ __.	__ __ __ __.	__ __ __ __.	32-43
S35R.	__ __ __.	__ __ __.	__ __ __.	44-52
S36R.	__ __ __ __.	__ __ __ __.	__ __ __ __.	53-64
S37R.	__ __ __ __.	__ __ __ __.	__ __ __ __.	65-76
S38R.	__ __.			77-78

79-80/04

1-12/Dup

S39R	__ __ __ __.			13-16
S40R	__.__ __			17-19
S41R	__.			20
S42R	1	2	3	21

22-78/BK

79-80/05

SHEET 6F-R

SAMPLE UNIT FIELD DATA

-COPES-

Record No. 7. 1-12/Dup
State Code
Proj. ID
Unif. Sect.
Time Sequence
Sample Unit Seq.

PERMANENT PATCH DETERIORATION

(Reinforced Pavements)

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	

JRCP Permanent Patch at each Transverse Joint (slab replacement excluded)

	Total Asphalt Patch Area at a Joint ** (square feet)									
S61L.	Total Asphalt Patch (sq. feet)				13-24	S61R.				37-48
S62L.	No. of Joints Patched (asphalt)				25-30	S62R.				49-54
	Total PCC Patch Area at a Joint ** (square feet)									
S63L.	Total PCC Patch (sq. feet)				31-42	S63R.				55-66
S64L.	No. of Joints Patched (PCC)				43-48	S64R.				67-72

** Each cell represents one joint.

73-78/BK
79-80/07
1-12/Dup

JRCP Permanent Patch Not at a transverse joint, including slab replacement or CRCP Permanent Patch at any location.

	Asphalt Patch(es)* (square feet)									
S65L.	Total Asphalt Patch (sq. feet)				49-60	S65R.				13-24
S66L.	Asphalt Patch (No.)				61-66	S66R.				25-30
	PCC Patch(es)* (square feet)				67-78/BK 79-80/06 1-12/Dup					
S67L.	Total PCC Patch (sq. feet)				13-24	S67R.				31-42
S68L.	PCC Patches (No.)				25-30	S68R.				43-48

* Each cell represents one patch.

No. of Patches with Patch Adjacent Slab Deterioration (JRCP and CRCP)

S69L.	Corner Break		31-32	S69R.		49-50
S70L.	"D" Cracking		33-34	S70R.		51-52
S71L.	Spalling		35-36	S71R.		53-54

55-78/BK
79-80/ 08

SHEET 6F-P

SAMPLE UNIT FIELD DATA

-COPES-

Record No. 7. 1-12/Dup.
State Code _ _.
Proj. ID _ _ _ _.
Unif. Sect. _ _.
Time Sequence _ _.
Sample Unit Seq. _.

PERMANENT PATCH DETERIORATION

(Plain Jointed Pavements)

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	

JPCP Permanent Small Patches (entire patch within 3 ft. of original joint) placed at a joint to repair joint deterioration.

	Total Asphalt Patch Area at a Joint * (square feet)									
S61L.	Total Asphalt Patch (square feet)	_ _ _ _.	_ _ _ _.	_ _ _ _.	13-24	S61R.	_ _ _ _.	_ _ _ _.	_ _ _ _.	37-48
S62L.	No. of Joints Patched (asphalt)	_ _.	_ _.	_ _.	25-30	S62R.	_ _.	_ _.	_ _.	49-54
	Total PCC Patch Area at a Joint* (square feet)									
S63L.	Total PCC Patch (square feet)	_ _ _ _.	_ _ _ _.	_ _ _ _.	31-42	S63R.	_ _ _ _.	_ _ _ _.	_ _ _ _.	55-66
S64L.	No. of Joints Patched (PCC)	_ _.	_ _.	_ _.	43-48	S64R.	_ _.	_ _.	_ _.	67-72

73-78/BK
79-80/07
1-12/Dup.

JPCP Permanent Large Patches and Slab Replacements placed to repair slab failure.

	Asphalt Patch(es)* (square feet)									
S65L.	Total Asphalt Patch (square feet)	_ _ _ _.	_ _ _ _.	_ _ _ _.	49-60	S65R.	_ _ _ _.	_ _ _ _.	_ _ _ _.	13-24
S66L.	Asphalt Patch (No.)	_ _.	_ _.	_ _.	61-66	S66R.	_ _.	_ _.	_ _.	25-30
	PCC Patch(es)* (square feet)				67-78/BK 79-80/06 1-12/Dup.					
S67L.	Total PCC Patch (square feet)	_ _ _ _.	_ _ _ _.	_ _ _ _.	13-24	S67R.	_ _ _ _.	_ _ _ _.	_ _ _ _.	31-42
S68L.	PCC Patch (No.)	_ _.	_ _.	_ _.	25-30	S68R.	_ _.	_ _.	_ _.	43-48

*Each cell represents one patch.

31-36/BK

49-78/BK
79-80/08

SHEET 7F

FIELD DATA

-COPES-

State Code __ __.

Proj. ID __ __ __ __.

TRUCK LANE DISTRIBUTION DATA

	Mile-Post (approximate) E, W, N, S	TIME			TRUCK DISTRIBUTION* (excluding pick-ups and panels)
		Begin Count t_0	End Count t_1	Δt t_1-t_0 (min)	Far Right Lane Far Left Lane
Σ					
%					**

APPROX. ADTT = 1440 * (Σ trucks ÷ ΣΔt) = ________________

*Data to be taken for trucks traveling in direction opposite that of the direction of the pavement survey.

**Distribution across lanes must sum to 100%.

SHEET 8F
UNIFORM SECTION FIELD DATA
-COPES-

State Code __ __.
Proj. ID __ __ __ __.
Unif. Sect. __ __.

SAMPLE UNIT LAYOUT DATA

210	180	150	120	90	60	30	Sample Unit No.
209	179	149	119	89	59	29	
208	178	148	118	88	58	28	
207	177	147	117	87	57	27	
206	176	146	116	86	56	26	
205	175	145	115	85	55	25	
204	174	144	114	84	54	24	
203	173	143	113	83	53	23	
202	172	142	112	82	52	22	
201	171	141	111	81	51	21	
200	170	140	110	80	50	20	
199	169	139	109	79	49	19	
198	168	138	108	78	48	18	
197	167	137	107	77	47	17	
196	166	136	106	76	46	16	
195	165	135	105	75	45	15	
194	164	134	104	74	44	14	
193	163	133	103	73	43	13	
192	162	132	102	72	42	12	
191	161	131	101	71	41	11	
190	160	130	100	70	40	10	
189	159	129	99	69	39	9	
188	158	128	98	68	38	8	
187	157	127	97	67	37	7	
186	156	126	96	66	36	6	
185	155	125	95	65	35	5	
184	154	124	94	64	34	4	
183	153	123	93	63	33	3	
182	152	122	92	62	32	2	
181	151	121	91	61	31	1	Start

Instructions: Identify start and end of uniform section, and also start of each sample unit to be surveyed with a station no. or mile post. Circle each sample unit to be surveyed. Sample Unit to consist of a 10% sample, i.e. 0.1 mile sample unit per 1 mile of uniform section.

APPENDIX B

COPES DATA CODE SHEETS

STATE CODE

	Code
Alabama	20
Alaska	53
Arizona	45
Arkansas	38
California	48
Colorado	41
Connecticut	07
Delaware	11
District of Columbia	12
Florida	19
Georgia	18
Hawaii	49
Idaho	43
Illinois	33
Indiana	25
Iowa	27
Kansas	35
Kentucky	23
Louisiana	37
Maine	05
Maryland	13
Massachusetts	02
Michigan	26
Minnesota	29
Mississippi	22
Missouri	34
Montana	32
Nebraska	36
Nevada	47

	Code
New Hampshire	04
New Jersey	08
New Mexico	46
New York	09
North Carolina	16
North Dakota	31
Ohio	24
Oklahoma	39
Oregon	51
Pennsylvania	10
Rhode Island	03
South Carolina	17
South Dakota	30
Tennessee	21
Texas	40
Utah	44
Vermont	06
Virginia	14
Washington	52
West Virginia	15
Wisconsin	28
Wyoming	42
FHPD	56
American Samoa	54
Guam	50
Puerto Rico	01
Virgin Islands	01

COUNTY CODE

(Illinois)
(Question D2.)

Adams	33001
Alexander	33002
Bond	33003
Boone	33004
Brown	33005
Bureau	33006
Calhoun	33007
Carroll	33008
Cass	33009
Champaign	33010
Christian	33011
Clark	33012
Clay	33013
Clinton	33014
Coles	33015
Cook	33016
Crawford	33017
Cumberland	33018
De Kalb	33019
De Witt	33020
Douglas	33021
Du Page	33022
Edgar	33023
Edwards	33024
Effingham	33025
Fayette	33026
Ford	33027
Franklin	33028
Fulton	33029
Gallatin	33030
Greene	33031
Grundy	33032
Hamilton	33033
Hancock	33034
Hardin	33035
Henderson	33036
Henry	33037
Iroquois	33038
Jackson	33039
Jasper	33040
Jefferson	33041
Jersey	33042
Jo Daviess	33043
Johnson	33044
Kane	33045
Kankakee	33046
Kendall	33047
Knox	33048
Lake	33049
La Salle	33050
Lawrence	33051

Lee	33052
Livingston	33053
Logan	33054
Mc Donough	33055
Mc Henry	33056
Mc Lean	33057
Macon	33058
Macoupin	33059
Madison	33060
Marion	33061
Marshall	33062
Mason	33063
Massac	33064
Menard	33065
Mercer	33066
Monroe	33067
Montgomery	33068
Morgan	33069
Moultrie	33070
Ogle	33071
Peoria	33072
Perry	33073
Piatt	33074
Pike	33075
Pope	33076
Pulaski	33077
Putman	33078
Randolph	33079
Richland	33080
Rock Island	33081
Saline	33082
Sangamon	33083
Schuyler	33084
Scott	33085
Sheby	33086
Stark	33087
Stephenson	33088
St. Clair	33089
Tazewell	33090
Union	33091
Vermilion	33092
Wabash	33093
Warren	33094
Washington	33095
Wayne	33096
White	33097
Whiteside	33098
Will	33099
Williamson	33100
Winnebago	33101
Woodford	33102

CEMENT TYPE CODE

(Question D105.)

	Code
Type I	01
Type II	02
Type III	03
Type IV	04
Type V	05
Type IS	06
Type ISA	07
Type IA	08
Type IIA	09
Type IIIA	10
Type IP	11
Type IPA	12
Type N	13
Type NA	14
Other (specify)____________________	15

CEMENT ADDITIVE CODE

(Question D108.)

	Code
Retarding Admixture	01
Water-reducing Admixture	02
Accelerating Admixture	03
Fly Ash	04
Coloring Admixtures	05
Dampproofing Agents	06
Water-reducing and Retarding Admixture	07
Water-reducing and Accelerating Admixture	08
Other (specify)____________________________	09

AGGREGATE DURABILITY TEST TYPE CODE

(Question D114.)

	AASHTO	ASTM	Code
Abrasion of Stone and Slag by Use of the Deval Machine	T3	--	01
Abrasion of Gravel by Use of Deval Machine	T4	--	02
Specific Gravity and Absorption of Fine Aggregate	T84	C128	03
Specific Gravity and Absorption of Coarse Aggregate	T85	C127	04
Resistance to Abrasion of Small Size Coarse Aggregate by Use of Los Angeles Machine	T96	C131	05
Soundness of Aggregate by Freezing and Thawing	T103	--	06
Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate	T104	C88	07
Resistance to Abrasion of Large Size by Use of Los Angeles Machine	--	C535	08
Potential Volume Change of Cement-Aggregate Combinations	--	C342	09
Scratch Hardness of Coarse Aggregate Particles	T189	C851	10
Evaluation of Frost Resistance of Coarse Aggregates in Air-Entrained Concrete by Critical Dilution Procedures		C682	11
Concrete Aggregates	M80	C33	12
Potential Alkali Reactivity of Cement Aggregate Combinations	--	C227	13
Potential Reactivity of Aggregates	--	C289	14
Test for Clay Lumps and Friable Particles in Aggregates	--	C142	15
Recommended Practice for Petrografic Examination of Aggregates for Concrete	--	C295	16
Test for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates	--	C586	17
Other (Specify)__________________________			18

GEOLOGIC CLASSIFICATION CODE

(Question D119.)

Igneous:	
Granite	01
Syenite	02
Diorite	03
Gabbro	04
Peridotite	05
Felsite	06
Basalt	07
Diabase	08
Sedimentary:	
Limestone	09
Dolomite	10
Shale	11
Sandstone	12
Chert	13
Conglomerate	14
Breccia	15
Metamorphic:	
Gneiss	16
Schist	17
Amphibolite	18
Slate	19
Quartzite	20
Marble	21
Serpentine	22
Other (specify) ______________________________	23

BASE TYPE CODE

(Questions D131 and D182.)

	Code
No base (slab placed directly on subgrade)	01
Gravel (uncrushed)	02
Crushed stone or gravel or slag	03
Sand	04
Soil aggregate (predominantly soil)	05
Bituminous treated soil-aggregate	06
Bituminous aggregate mixture (plant mix)	07
Asphalt concrete hot mix	08
Open graded asphalt treated	09
Thin asphalt concrete layer over granular material	10
Soil cement	11
Cement-aggregate mixture (gravel and crushed stone)	12
Cement-aggregate mixture over granular material	13
Lean concrete mixture	14
Recycled concrete mixture	15
Lime soil	16
Pozzolanic-aggregate mixture	17
Other (Specify)______________________________	18

TEST TYPE CODE

(Questions D133, D137, D152, D154, and D156.)

	AASHTO	ASTM	Code
Resistance "R" Value	T 190	D 2844	01
CBR California Bearing Ratio	T 193	D 1883	02
Unconfined Compressive Strength	T 208	D 2166	03
Repetitive Static Place Load Test	T 221	D 1195	04
Non Repetitive Static Plate Load Test	T 222	D 1196	05
Vane Shear Test	T 223	D 2573	06
Triaxial Compression Test	T 234	D 2850	07
Penetration Test of Concrete	T 206	D 1586	08
Compressive Strength of Bituminous Mix	T 167	D 1074	09
Marshall Stability	T 245	D 1559	10
Resistance to Deformation and Cohesion of Bituminous Materials - Hveem Apparatus	T 246	D 1560	11
Resistance to Plastic Flow by Means of the Hubbard-Field Apparatus		D 1138	12
Dynamic Modulus of Asphalt Mix		D 3497	. . .13
Penetration Test of Bituminous Mixture	T 49	D 3	14
Flexural Strength of Concrete Using Beam with Third-Point Loading	T 97	C 78	15
Splitting Tensile Strength	T 98	C 496	16
Compressive Strength of Concrete	T 22	C 39	17
Static Modulus of Elasticity		C 469	18
Resistance of Concrete to Freezing and Thawing	T 161	C 666	19
Test for Compressive Strength of Soil-Cement		D 1633	20
Test for Flexural Strength of Soil-Cement		D 1635	21
Wetting and Drying Test of Soil-Cement	T 135	D 559	22

TEST TYPE CODE

(continued)

	AASHTO	ASTM	Code
Freezing and Thawing Test of Soil-Cement	T 136	D 560	23
Fly Ash and Other Pozzolans for Use with Lime		D 593	24
Determination of the Strength of Soil-Lime Mix	T 220		25
Determining Expansive Soils and Remedial Actions	T 258		26
Soil-Aggregate Subbase, Base and Surface Courses	M 147	D 1241	27
Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes	M 145	--	28
Terms Relating to Subgrade, Soil Aggregate, and Fill Materials	M 146	--	29
Potential Volume Change of Cement Aggregate Combinations	--	C 342	30
Evaluation of Frost Resistance of Coarse Aggregate in Air-Entrained Concrete by Critical Solution Procedures	--	C 682	31
Other (specify) ________________			32

SOIL TYPE CODE

(Question D151.)

AASHTO Soil Classification

	Code
A-1-a	01
A-1-b	02
A-3	03
A-2-4	04
A-2-5	05
A-2-6	06
A-2-7	07
A-4	08
A-5	09
A-6	10
A-7-5	11
A-7-6	12

MAINTENANCE AND REHABILITATION WORK CODES

(Question M1.)

	Code
Crack Sealing (linear ft.)	01
Transverse Joint Sealing (linear ft.)	02
Lane-Shoulder Longitudinal Joint Sealing (linear ft.)	03
Full Depth Transverse Joint Repair Patch (sq. ft.)	04
Full Depth Slab Patching Other Than Joint (sq. ft.)	05
Slab Replacement (sq. ft.)	06
Longitudinal Subdrainage (linear ft.)	07
Shoulder Replacement (sq. yards)	08
Overlay (sq. ft.)	09
Grinding Surface (sq. ft.)	10
Grooving Surface (sq. ft.)	11
Pothole Repair (sq. ft.)	12
Seal Coat (sq. yds)	13
Pressure Grout to Fill Voids (no. of holes)	14
Slab Jacking Depressions (no. of depressions)	15
Asphalt Undersealing (no. of holes)	16
Spreading of Sand or Aggregate (sq. yards)	17
Reconstruction (Removal and Replacement) (sq. yards)	18
Other (specify) ________________	19

MAINTENANCE LOCATION ON PAVEMENT CODE

(Question M2.)

Entire Uniform Section

Traffic Lanes	
Both Lanes	10
Left Lane only	20
Right Lane only	30
Shoulder	40
Curb and Gutter	50
Side Ditch	60
Culvert	70
Other (specify) ______________	80

Sample Unit Y Only *

Traffic Lanes	
Both Lanes	1Y
Left Lane only	2Y
Right Lane only	3Y
Shoulder	4Y
Curb and Gutter	5Y
Side Ditch	6Y
Culvert	7Y
Other (specify) ______________	8Y

* Where Y is the sample unit sequence number.

MAINTENANCE MATERIALS TYPE CODE

(Question M3.)

	Code
Preformed Joint Fillers	01
Hot-poured Joint and Crack Sealer	02
Cold-poured Joint and Crack Sealer	03
Portland Cement Concrete (JPCP)	04
Portland Cement Concrete (JRCP)	05
Portland Cement Concrete (CRCP)	06
Portland Cement Concrete Prestressed	07
Portland Cement Concrete Fibrous	08
Asphalt Concrete	09
Cold Mix Bituminous Material	10
Sand Asphalt	11
Surface Treatment Single Layer	12
Surface Treatment Double Layer	13
Surface Treatment Three or More Layers	14
Sand Seal	15
Slurry Seal	16
Fog Seal	17
Prime Coat	18
Tack Coat	19
Dust Layering	20
Treated or Stabilized Materials	21
Cement Grout	22
Aggregate (Gravel, Crushed Stone or Slag)	23
Sand	24
Longitudinal Drains	25
Transverse Drains	26
Drainage Blankets	27
Well System	28
Drainage Blankets with Longitudinal Drains	29
Diamond Grinding of Surface	30
Other (specify) ______________	31

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