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16. Abstract

In order to explain observations of significantly different performances for many of the rigid pavements in Texas, a quantitative evaluation was required to relate distress mechanisms to distress manifestation and to develop better predictors of performance. In theory, if all variables influencing the performance of a pavement structure could be correctly evaluated in all possible combinations of their magnitude, duration, and probability of occurrence, it would be possible to predict their effects upon the pavement and thus produce an ideal design.

Methods previously used for the design and analysis of rigid pavements originated from concepts which were severely limited by the broad assumptions on which they were based. The CTR staff had previously derived underlying principles concerning the mechanistic behavior of composite materials. This report describes how these principles were used in the development of improved concrete pavement and overlay design procedures. Maintenance and rehabilitation studies were performed concurrently using information collected from condition survey and surface profile measurements. This information was analyzed in depth in the development of distress prediction models and suitable criteria for use in rehabilitation decision making. The implementation of several innovative rehabilitation techniques is also described.

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SUMMARY AND RECOMMENDATIONS FOR THE IMPLEMENTATION OF RIGID PAVEMENT DESIGN, CONSTRUCTION AND REHABILITATION TECHNIQUES

by

B. F. McCullough
W. R. Hudson
C. S. Noble

Research Report Number 177-22F

Development and Implementation of the Design, Construction
and Rehabilitation of Rigid Pavements

Research Project 3-8-75-177

conducted for

Texas
State Department of Highways and Public Transportation

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

by the

CENTER FOR TRANSPORTATION RESEARCH

BUREAU OF ENGINEERING RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

March 1981

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

PREFACE

This is the final in the series of 22 reports describing the work done in the project entitled "Development and Implementation of the Design, Construction, and Rehabilitation of Rigid Pavements." The project has been conducted at the Center for Transportation Research, The University of Texas at Austin, as part of the Cooperative Highway Research Program sponsored by the State Department of Highways and Public Transportation and the Federal Highway Administration.

This final report has been prepared in a Summary format to provide the State Highway Department and Public Transportation a guide to tie the wide range of research efforts that were conducted as a part of this project. The report summarizes the basic findings in a given area, then gives specific references to previous project reports so that a reader, so desiring, may pursue a specific area in more detail. We have included in the Appendices several proposed sections to be included in the Texas State Highway Department and Public Transportation design and operation manuals. We attempted to develop these in a format so that with a minimal effort the departmental personnel can edit and revise to include in the appropriate manuals if they so desire.

The principal investigators extend their special thanks to all members of the staff, graduate students, and other faculty members that contributed to the activities during the project's duration. Their very valuable input, effort, ideas, follow-up, etc. made this project a success and a contribution to the Department's operation. We also wish to thank those individuals at the State Highway Department and Public Transportation for their assistance; especially Gerald Peck for his guidance and interaction which permitted us to be responsive to the departmental needs. Also thanks go to many others who worked with the project personnel at various time, including Billy Bannister (D-9), Richard Rogers (D-8), Bob Mikulin (D-8), and Bob Guinn (D-18).

B. Frank McCullough
W. R. Hudson
C. S. Noble

March 1981

LIST OF REPORTS

Report No. 177-1, "Drying Shrinkage and Temperature Drop Stresses in Jointed Reinforced Concrete Pavement," by Felipe R. Vallejo, B. Frank McCullough, and W. Ronald Hudson, describes the development of a computerized system capable of analysis and design of a concrete pavement slab for drying shrinkage and temperature drop. August 1975.

Report No. 177-2, "A Sensitivity Analysis of Continuously Reinforced Concrete Pavement Model CRCP-1 for Highways," by Chypin Chiang, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this model, the relative importance of the input variables of the model and recommendations for efficient use of the computer program. August 1975.

Report No. 177-3, "A Study of the Performance of the Mays Ride Meter," by Yi Chin Hu, Hugh J. Williamson, B. Frank McCullough, and W. Ronald Hudson, discusses the accuracy of measurements made by the Mays Ride Meter and their relationship to roughness measurements made with the Surface Dynamics Profilometer. January 1977.

Report No. 177-4, "Laboratory Study of the Effect of Non-Uniform Foundation Support on CRC Pavements," by Enrique Jiminez, B. Frank McCullough, and W. Ronald Hudson, describes the laboratory tests of CRC slab models with voids beneath them. Deflection, crack width, load transfer, spalling and cracking are considered. Also used is the SLAB 49 computer program that models the CRC laboratory slab as a theoretical approach. The physical laboratory results and the theoretical solutions are compared and analyzed, and the accuracy is determined. August 1977.

Report No. 177-6, "Sixteenth Year Progress Report on Experimental Continuously Reinforced Concrete Pavement in Walker County," by Thomas P. Chesney and B. Frank McCullough, presents a summary of data collection and analysis over a 16-year period. During that period, numerous findings resulted in changes in specifications and design standards. These data will be valuable for shaping guidelines and for future construction. April 1976.

Report No. 177-7, "Continuously Reinforced Concrete Pavement: Structural Performance and Design/Construction Variables," by Pieter J. Strauss, B. Frank McCullough, and W. Ronald Hudson, describes a detailed analysis of design, construction, and environmental variables that may have an effect on the structural performance of a CRCP. May 1977.

Report No. 177-9, "CRCP-2, An Improved Computer Program for the Analysis of Continuously Reinforced Concrete Pavements," by James Ma and B. Frank McCullough, describes the modification of a computerized system capable of analysis of a continuously reinforced concrete pavement based on drying shrinkage and temperature drop. August 1977.

Report No. 177-10, "Development of Photographic Techniques for Performance Condition Surveys," by Pieter J. Strauss, James Long, and B. Frank McCullough, discusses the development of a technique for surveying heavily trafficked highways without interrupting the flow of traffic. May 1977.

Report No. 177-11, "A Sensitivity Analysis of Rigid Pavement-Overlay Design Procedure," by F. C. Nayak, B. Frank McCullough, and W. Ronald Hudson, gives a sensitivity analysis of input variables of Federal Highway Administration computer-based overlay design procedure RPOD1. June 1977.

Report No. 177-12, "A Study of CRCP Performance: New Construction versus Overlay," by James I. Daniel, B. Frank McCullough, and W. Ronald Hudson, documents the performance of several continuously reinforced concrete pavements (CRCP) in Texas. April 1978.

Report No. 177-13, "A Rigid Pavement Overlay Design Procedure for Texas SDHPT," by Otto Schnitter, B. Frank McCullough, and W. Ronald Hudson, describes a procedure recommended for use by the Texas SDHPT for designing both rigid and flexible overlays on existing rigid pavements. The procedure incorporates the results of condition surveys to predict the existing pavements remaining life, field and lab testing to determine material properties, and elastic layer theory to predict the critical stresses in the pavement structure. May 1978.

Report No. 177-15, "Precast Repair of Continuously Reinforced Concrete Pavement," by Gary E. Elkins, B. Frank McCullough, and W. Ronald Hudson, describes an investigation into the applicability of using precast slabs to repair CRCP, presents alternate repair strategies, and makes new recommendations on installation and field testing procedures. May 1979.

Report No. 177-16, "Nomographs for the Design of CRCP Steel Reinforcement," by C. S. Noble, B. F. McCullough, and J. C. M. Ma, presents the results of an analytical study undertaken to develop regression equations and nomographs for use as a supplementary tool in the design of steel reinforcement in continuously reinforced concrete pavement by the Texas State Department of Highways and Public Transportation. August 1979.

Report No. 177-17, "Limiting Criteria for the Design of CRCP," by B. Frank McCullough, J. C. M. Ma, and C. S. Noble, presents a set of criteria which limits values of a set of variables to be used in the design of CRCP. These criteria are to be used in conjunction with Report No. 177-16. August 1979.

Report No. 177-18, "Detection of Voids Underneath Continuously Reinforced Concrete Pavemtnts," by John Birkhoff and B. Frank McCullough, presents the results of an investigation in which three methods for detecting voids underneath CRC pavements (deflection, pumping and vibration) are evaluated with respect to reliability of successful void detection. August 1979.

Report No. 177-19, "Manual for Condition Survey of Continuously Reinforced Concrete Pavement," by Arthur Taute and B. Frank McCullough, presents the condition survey method used during the 1978 statewide CRCP condition survey. In addition, proposals for a condition survey procedure for jointed concrete pavement are presented. February 1981.

Report No. 177-20, "Summary Report for 1978 CRCP Condition Survey in Texas," by Manuel Gutierrez de Velasco and B. Frank McCullough, presents a qualitative analysis of the distress condition of CRCP in the State of Texas using field data collected in 1974 and 1978. Also, criteria are developed in order to weight the different distress manifestations in deciding when to overly a CRCP. January 1981.

Report No. 177-21, "Distress Prediction Models for CRCP," by C.S. Noble and B. Frank McCullough, describes a detailed analysis of the condition survey data collected in 1974 and 1978, and presents distress prediction models developed from this data. Recommendations are made for the establishment of an overall rigid pavement evaluation system. March 1981.

Report No. 177-22F, "Summary and Recommendations for the Implementation of Ridig Pavement Design, Construction and Rehabilitation Techniques," by B. Frank McCullough, W. R. Hudson and C. S. Noble. March 1981.

ABSTRACT

In order to explain observations of significantly different performances for many of the rigid pavements in Texas, a quantitative evaluation was required to relate distress mechanisms to distress manifestation and to develop better predictors of performance. In theory, if all variables influencing the performance of a pavement structure could be correctly evaluated in all possible combinations of their magnitude, duration, and probability of occurrence, it would be possible to predict their effects upon the pavement and thus produce an ideal design.

Methods previously used for the design and analysis of rigid pavements originated from concepts which were severely limited by the broad assumptions on which they were based. The CFTR staff had previously derived underlying principles concerning the mechanistic behavior of composite materials. This report describes how these principles were used in the development of improved concrete pavement and overlay design procedures. Maintenance and rehabilitation studies were performed concurrently using information collected from condition survey and surface profile measurements. This information was analyzed in depth in the development of distress prediction models and suitable criteria for use in rehabilitation decision making. The implementation of several innovative rehabilitation techniques is also described.

KEY WORDS: Rigid pavements, performance, distress, evaluation, design, overlay, maintenance, rehabilitation, condition survey, surface profile, prediction models, criteria.

SUMMARY

Preliminary design and analysis techniques for rigid pavements have been previously developed on several Center for Transportation Research Projects. This report describes how a more exact determination of relevant relationships was made during this study. A reliable simulation of field conditions was achieved, and appropriate CRCP performance prediction models developed. Also, suitable CRCP condition survey data collection, storage analysis, and updating procedures were established. Subsequently, reliable rigid pavement performance evaluation, design, maintenance, rehabilitation and overlay methods were recommended and implemented. Finally, procedures were recommended where these methods could eventually be incorporated into a comprehensive rigid pavement evaluation and design system. For any specific locality this system can be used to select an optimum rigid pavement design, based on minimum overally cost considerations.

IMPLEMENTATION STATEMENT

It is anticipated that the procedures and models established in this project will be implemented by the Texas SDHPT within the near future. Specific recommendations concerning the Texas SDHPT Operations and Procedures Manual have been summarized in the conclusions of this report, therefore are not repeated here.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Since World War II, many miles of rigid pavements have been constructed in the State of Texas, and many of these pavements are now near the end of their projected design lives. Some of these pavements are still providing a satisfactory performance, while others are not. To explain the difference in the performance of these pavements, a quantitative evaluation is required to relate the mechanisms of distress to distress manifestation and to develop better predictors of performance. In theory, if all variables influencing the performance of a pavement structure could be correctly evaluated in all possible combinations of their magnitude, duration, and probability of occurence, it would be possible to predict their effects upon the pavement and thus produce an ideal design. With this as an overall goal for the research project, specific objectives were defined as discussed in the following sections.

OBJECTIVES OF THE PROJECT

Preliminary design and analysis techniques for rigid pavements had been previously developed on several Center for Transportation Research projects. Unfortunately, several inputs required for the use of these analysis methods were not available. Thus, a need existed for a more exact determination of some of these inputs so that a reliable simulation of field conditions could be achieved and appropriate CRCP performance predication models developed. Once this was done, suitable CRCP condition survey data collection, storage, analysis, and updating procedures could be established. This would then allow reliable rigid pavement performance evaluation, design, maintenance, rehabilitation, and overlay methods to be recommended and implemented. These methods could eventually be incorporated into a comprehensive rigid pavement evaluation and design system which for any specific locality could be used to select an optimum rigid pavement design, based on minimum overall cost considerations.

The methods previously used to determine both slab thickness and percent reinforcement for the various types of rigid pavements originated from concepts which were severely limited by the broad assumptions on which they were based. The CTR staff had previously derived underlying principles concerning the mechanistic behavior of composite materials. It was thus decided that this information could be used as the initial basis for determining suitable inputs into an improved concrete pavement design procedure. Then, with this as a starting point, the investigation could proceed to realize the objectives as summarized below.

The primary objectives throughout this study were to

(1) develop and implement rehabilitation design procedures and techniques for rigid pavements,

(2) implement the research results accomplished to optimize the design and rehabilitation of rigid pavements, and

(3) continue the performance study made of concrete pavements in Texas in order to establish design criteria and to confirm the reliability and significance of available models.

For the purposes of this report, these objectives have been divided into four general areas:

(1) development of improved rigid pavement design procedures,

(2) development of innovative rehabilitation techniques and incorporation into suitable maintenance programs,

(3) development of an improved overlay design method, and

(4) evaluation of rigid pavement perforamnce by

  (a) profile measurements

  (b) condition survey of CRC pavements in Texas.

SCOPE

Originally, the scope of this project encompassed a research program directed towards the development and implementation of reliable procedures for the design, construction, and overlay of rigid pavements.

In March 1975, the scope of the project was expanded at the request of the sponsors to include research which would entail two additional problem areas. These were (1) the development of new,innovative methods of rehabilitating concrete pavement and (2) the development of methods for measuring structural condition of concrete pavements.

In March 1976, the scope of the project was further broadened to include more emphasis on rehabilitation techniques other than overlays. This was a consequence of the fact that during the final years of the project a substantial amount of the available highway monies was spent for rehabilitation and that this trend was considered likely to continue into the forseeable future. During the final year, the study was completed and appropriate reports were published.

Therefore, the scope of this report extends to a summary of all the above investigations, which have been classified into four general areas, as shown in Fig 1.1. Chapters 2 and 4 describe the improved design and overlay techniques, respectively. The results of the maintenance and rehabilitation studies are summarized in Chapter 3. In Chapter 5, the condition survey and profile measurement studies are discussed. Finally, a summary of the significant conclusions and recommendations arising out of the whole study is presented in Chapter 6. The entire study is best described with reference to the 22 different research reports which have been written and submitted for publication. Consequently, this report adopts this approach throughout Chapters 2-6. A complete list of these reports,in order of publication, has been included on pages iv-vi, while a breakdown according to the four areas discussed above is presented in Fig 1.1.

(1) Design

Reports: 177-1

(2) Maintenance

Reports: 177-15
177-18

(3) Overlay Design

Reports: 177-11
177-12
177-13
177-14*

(4) Performance Evaluation

(a) Profile Measurements

Reports: 177-3
177-5*

(b) Condition Survey

Reports: 177-6
177-8*
177-10
177-19
177-20
177-21

Final Summary**

Report: 177-22F

*These reports were not published in final form

**Titles of all reports may be obtained by referring to the "List of Reports" on page iv.

Fig 1.1. List of Project 177 Reports, according to research area.

CHAPTER 2. DEVELOPMENT OF IMPROVED DESIGN METHODS FOR RIGID PAVEMENTS

PRELIMINARY DEVELOPMENTS

In 1972, an NCHRP study was conducted at the University of Texas at Austin. It consisted of a review of design and construction variables, theoretical studies, field surveys, and laboratory investigations. The fundamental philosophy of this review was that, through a combination of field observations and laboratory studies, reliable procedures could be achieved to develop mathematical models that simulate field performance of CRCP. Based on these mathematical models, the CRCP-1 computer program was developed to calculate the stresses in concrete and steel, the crack width, and the crack spacing resulting from concrete volume changes due to temperature and shrinkage (Ref 1). Historically then, it was this particular study which formed the starting point for the development of the comprehensive rigid pavement design procedure which has evolved under Project 177 and which is discussed in more detail in this chapter.

DESIGN OF JOINTED REINFORCED CONCRETE PAVEMENT

As the introductory study discussed above was being completed, so was the first investigation into rigid pavement design procedures under Project 177. The results were published in Report No. 177-1 (Ref 2), entitled "Drying Shrinkage and Temperature Drop Stresses in Jointed Reinforced Concrete Pavement," by Felipe R. Vallejo, B. Frank McCullough, and W. Ronald Hudson. This report describes the development of a computerized system capable of analysis and design of a concrete pavement slab allowing for drying shrinkage and temperature drop. During the course of the project, this computer program (JRCP-1) has undergone considerable improvement. The latest revision resulted in the version entitled JRCP-2, which has been documented in Ref 3. Charts for use in the design of JRCP at a specific feasibility level were prepared during the final stages of the project. These were based upon the computer program JRCP-2 and are summarized in Ref 4. It should be noted that the design procedures do not at this stage consider the effect of external load. It is proposed to modify the computer program and associated design charts as part of a separate research program now being conducted under CTR Project 249 as a continuation of the project being discussed in this report.

DESIGN OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

Comprehensive Design Procedure. Following the completion of the NCHRP study discussed under "Previous Developments," one of the major areas which was investigated during the course of Project 177 was the development of a comprehensive CRCP design procedure.

Generally, the engineer is encouraged to design each pavement for the soil conditions, traffic, materials, etc. present at the site and to be wary of inappropriate boundary values and practices. However, in order to cover such a wide variety of input variables, he needs a large-scale experiment to anticipate the effects of the individual variations of the variables and the variations in groups. Thus, a sensitivity analysis of the behavior of CRCP using the CRCP-1 model was conducted for the Texas SDHPT, as reported in CTR Report No. 177-2 (Ref 5). From the results of this study, the relative importance of about 15 input variables was determined in order to investigate the effect of changes in values of these variables on the CRCP behavior. The list of the input variables includes the steel properties, the concrete properties, the friction-movement relationships, and temperature variations. In addition to establishing relative importance, the study revealed several inconsistencies of the initial model at extreme boundary conditions that resulted in modification of the computer program.

The next step in the development was to include the effect of wheel load stresses on crack spacing history. The NCHRP 1-15 Study, "Design of Continuously Reinforced Concrete Pavements for Highways," found that heavy volumes of 18-kip single axle loads resulted in reduced crack spacings (Ref 1). The study of the effect of wheel load stress on pavement behavior and its interaction with the other input variables is discussed in CTR Report 177-9 (Ref 6), which describes the development of the CRCP-2 model. This development process is outlined in flowchart form in the upper part of Fig 2.1. Notice from Fig 2.1 that the models for external load, which

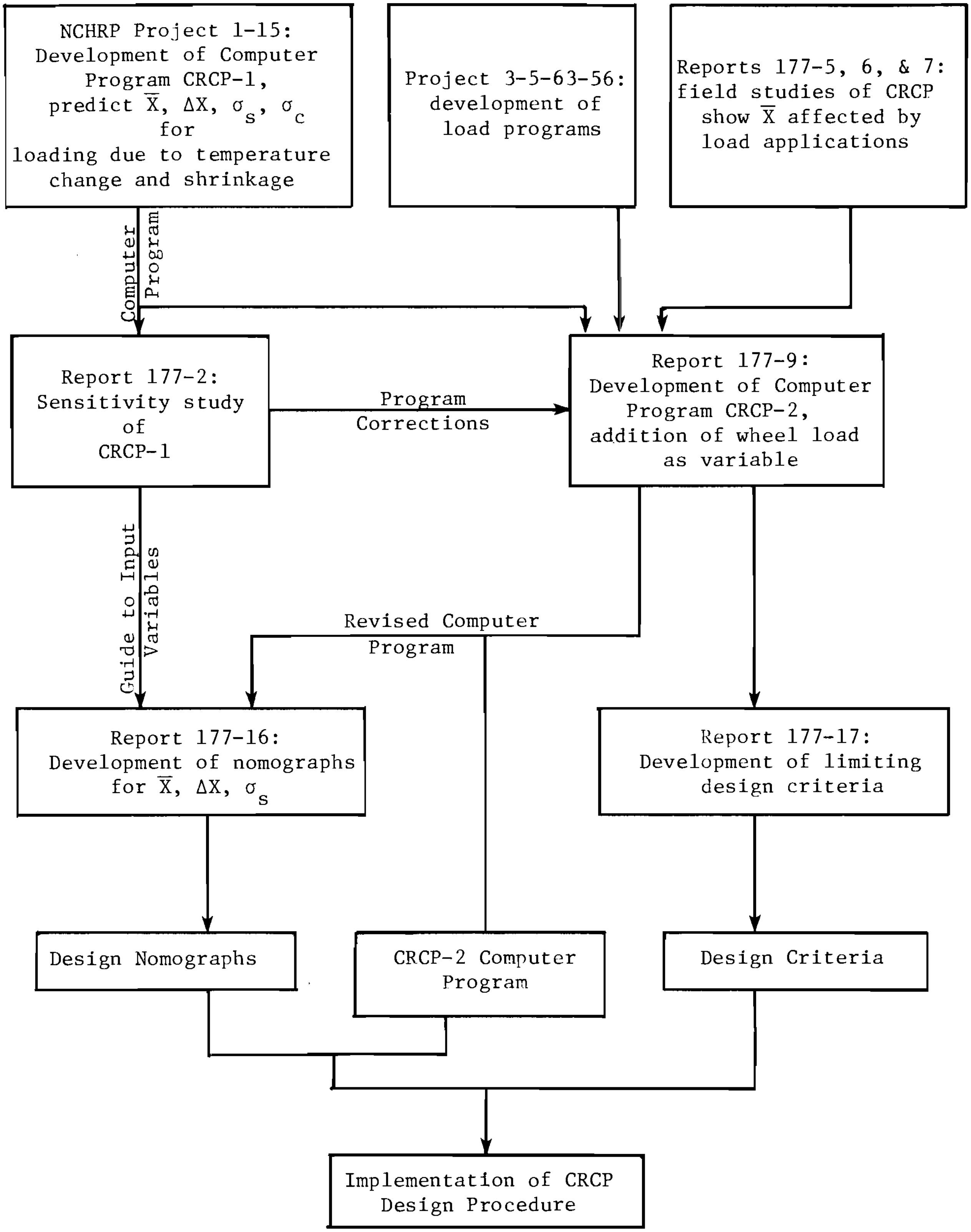

Fig 2.1. Development of CRCP design procedure - flowchart.

were developed in CTR Study 3-5-63-56 (Ref 7), were combined in the program CRCP-2. Also the results of the separate field studies showing the effects of traffic and other load variables on crack spacing were described in Report Nos. 177-5, 6, and 7 (Refs 8, 9, 10) and incorporated into the final version of CRCP-2, as described in Report No. 177-9 (Ref 6). During the final year of Project 177, some minor improvements were made to CRCP-2 with regard to bond development length. These changes and others have been documented in Ref 11. Reports 177-16 and 17 (Refs 12, 13) describe the preparation of a series of design charts along with the deviation of appropriate limiting criteria for use with the charts. These two reports should be used together as a supplementary (to the CRCP-2 computer program) tool for the design of CRCP at a specific feasibility level. Finally, these design techniques have been implemented in a series of CRCP highway projects. The results of these case studies will be documented under CTR Project 249. The following pages present some of the significant details of the total procedure in terms of two major aspects: reinforcement and thickness.

Reinforcement Design. Report No. 177-2 (Ref 5) summarizes the earliest CRCP study completed under the project. This was a sensitivity analysis of CRCP-1 for the major variables affecting CRCP behavior. From this study, the relative importance of these variables with regard to reinforcement and thickness was established. Specifically, Report No. 177-2, "A Sensitivity Analysis of Continuously Reinforced Concrete Pavement Model CRCP-1 for Highways," by Chypin Chiang, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this model and the relative importance of the input variables of the model and makes recommendations for efficient use of the computer program. It was published in August 1975. The next relevant investigation completed is summarized in Report No. 177-4 (Ref 14). This describes the results of an experiment to investigate the effects of subbase or subgrade support loss on slab deflection distress manifestations and load transfer. Although the results of this study are closely related to slab thickness design, variations in the subgrade and subbase support have an indirect effect on the amount of reinforcing steel required. As such, the findings from this investigation became important for further developmental work which took place towards the end of the project.

Historically, the next significant development was recorded in Report No. 177-6 (Ref 9), which reports case studies showing that higher percentages of reinforcement gave better performance with regard to failure. Specifically, CTR Report No. 177-6, "Sixteenth Year Progress Report on Experimental Continuously Reinforced Concrete Pavement in Walker County," by Thomas P. Chesney and B. Frank McCullough, presents a summary of data collection and analysis over a 16-year period. During that period, numerous findings resulted in changes in specifications and design standards. These data were subsequently used for shaping guidelines and for future construction. The report was published in April 1976.

A better understanding of the important variables in reinforcement design was obtained following the work described in Report No. 177-7 (Refs 10, 15); however, the next significant advance was not documented until the publication of Report No. 177-9 (Ref 6). This report summarizes the procedure for treatment of detailed CRCP reinforcement design as incorporated into the computer program CRCP-2. A user's guide and a typical output for the program CRCP-2 have been included in this report as Appendix A. This program has been functional on the Texas SDHPT computer since May 1979. Report No. 177-9, "CRCP-2, An Improved Computer Program for the Analysis of Continuously Reinforced Concrete Pavements," by James Ma and B. Frank McCullough, describes the modification of a computerized system capable of analysis of a continuously reinforced concrete pavement based on drying shrinkage and temperature drop. This report was published in August 1979. During the final two years of the project, minor improvements were made to the CRCP-2 program where required.

Finally, the latest developments in CRCP reinforcement design have been documented in Report Nos. 177-16 and 177-17 (Refs 12, 13). Report No. 177-16, "Nomographs for the Design of CRCP Steel Reinforcement," by C. S. Noble, B. F. McCullough, and J. C. M. Ma, presents the results of an analytical study undertaken to develop regression equations and nomographs. These are to be used as supplementary (to CRCP-2) tools in the design of steel reinforcement in continuously reinforced concrete pavement by the Texas State Department of Highways and Public Transportation at the feasibility study level. CRCP-2 should be used for detailed design. Report No. 177-16 was published in August 1979. These nomographs and regression equations have been included as Appendix B of this report. An allied study was also finished in August 1979. Report No. 177-17, "Limiting Criteria for the Design of CRCP," by J. C. M. Ma, B. F. McCullough, and C. S. Noble, presents a set of criteria which limits values of a set of variables to be used in the design of CRCP. These criteria are to be used in conjunction with Report No. 177-16.

Finally, the major recommendation to be made with regard to CRCP reinforcement design is that both the charts discussed in Report No. 177-16 and the limiting criteria presented in Report 177-17 should be inserted in the Texas SDHPT Highway Design Division Operations and Procedures Manual, Part IV, Appendix F (Ref 16), in the appropriate section (F-108).

Thickness Design. Following the preliminary work done on the development of CRCP-1 and during the associated sensitivity study, the next significant advances with regard to thickness design were made as part of the study described in Report No. 177-4, which was published in August 1977. This report, "Laboratory Study of the Effect of Non-Uniform Foundation Support of CRC Pavements," by Enrique Jiminez, B. Frank McCullough, and W. Ronald Hudson, describes the laboratory tests of CRC slab models with voids beneath them. Deflection, crack width, load transfer, spalling, and cracking were considered. Also described is the SLAB 49 computer program that models the CRC laboratory slab as a theoretical approach. Physical laboratory test results and corresponding theoretical solutions are compared and analyzed, and estimates of prediction accuracy are determined. The major findings of the above study were essentially that voids beneath rigid pavements have an important influence on performance and that a thicker pavement is needed in areas where voids probably exist. These would typically be over subgrades where swelling clays are present or differential settlement has been seen to occur. During the course of this investigation, it was also shown that CRCP slab performance can be adequately modelled using the SLAB 49 program.

Contemporary with the above study, work was continuing on a thorough investigation of the influence of different variables on performance with particular emphasis on thickness. Report No. 177-7, "Continuously Reinforced Concrete Pavement: Structural Performance and Design/Construction Variables," by Peter J. Strauss, B. Frank McCullough, and W. Ronald Hudson, describes a detailed analysis of the effect of design, construction, and environmental variables on the structural performance of a CRCP. The performances of pavements using different aggregates and different thicknesses were compared. This report was published in May 1977.

Recommendations for the design of slab thickness were then initially made for use with the CRCP-2 computer program (Ref 5, 6). It should be noted, however, when using the CRCP reinforcement design equations and nomographs described previously, that slab thickness is not specifically treated in these equations, although a slab thickness must be selected. A detailed treatment of the process involved in this selection is given in Ref 13. Thus a designer can confidently design CRCP reinforcement and thickness by using either Report Nos. 177-16 and 177-17 or the CRCP-2 computer program. Finally, it is necessary to point out that the initial work showing the influence of voids on CRCP performance has been supplemented by a study completed during the last year of the project. Report No. 177-18 (Ref 17) describes a procedure for void detection. It should be noted that the conclusions regarding the relative importance of several different variables on CRCP performance were confirmed by the results of the 1978 condition survey and subsequent analysis. This may be seen with reference to Report Nos. 177-19, 177-20, and 177-21 (Refs 18, 19, 20), all of which were published in December 1979.

CHAPTER 3. MAINTENANCE AND MINOR REHABILITATION OF RIGID PAVEMENTS

INTRODUCTION

Innovations and new developments with regard to the maintenance and minor rehabilitation of CRCP have been achieved in three separate studies conducted during the course of this project. Appropriate recommendations have been made in the relevant reports as discussed below.

PRECAST REPAIR OF CRCP (Ref 21)

With regard to innovations in minor repair techniques, Report No. 177-15, "Precast Repair of Continuously Reinforced Concrete Pavement," by Gary E. Elkins, B. Frank McCullough, and W. Ronald Hudson, describes an investigation into the applicability of using precast slabs to repair CRCP. It also presents alternate repair strategies and makes new recommendations on installation and field testing procedures. It was published in May 1979. Field implementation of these techniques is currently being carried out on several Texas SDHPT projects throughout the state.

VOID DETECTION AND REPAIR

As discussed in Chapter 2, the effect of the presence of voids on pavement performance was shown to be significant during the early years of the project. Therefore, a study was completed in the final year of the project to develop procedures for the detection of voids and for their subsequent correction. Report No. 177-18, "Detection of Voids Underneath Continuously Reinforced Concrete Pavements," by John Birkhoff and B. Frank McCullough, presents the results of an investigation in which three methods for detecting voids underneath CRC pavement (deflection, pumping, and vibration) are evaluated with respect to reliability of successful void detection. This report was published in August 1979.

MAINTENANCE RECOMMENDATIONS

The problem of decision making with regard to frequency, level, and utility of maintenance effort has been treated more completely in two other areas of this project. Clearly, maintenance recommendations must be related to the condition of the pavement at the time of decision as well as to the availability of funds and the value of the benefits of the maintenance. Chapter 5 of Report 177-21 (Ref 20) discusses the relationships between these variables and in Chapter 6, appropriate recommendations are made as to when to apply which level of maintenance. Finally, the decision process for choosing when to apply major maintenance in the form of overlaying a pavement has also been discussed in Chapter 7 of Report 177-21. Chapter 4 of this report treats the overlay design process itself in detail.

CHAPTER 4. RIGID PAVEMENT OVERLAY DESIGN

SIGNIFICANT VARIABLES IN OVERLAY DESIGN

The need for a uniform procedure for the design of pavement overlays to meet the growing demand for rehabilitation of U. S. highways has become increasingly apparent. To satisfy this need, a structural design procedure based on layered theory was developed by Austin Research Engineers, Inc., under a Federal Highway Administration contract. The computerized overlay design procedure for rigid pavements is called RPOD1. There are as many as 17 input variables, which include the moduli of elasticity, the thicknesses and Poisson's ratios for different layers of existing pavement, bond breaker, and overlay. The response of the program is the thickness in inches of the overlay which is required for the projected traffic. Following this study, it was decided that during the course of Project 177, major emphasis should be given to the improvement and subsequent implementation of this overlay design procedure at the Texas SDHPT.

The initial objectives of this particular study were to determine the reliability of the model and to establish the relative significance of each of the input variables to the computer program RPOD1 for use by the Texas SDHPT. The results of this initial study were presented in Report No. 177-11, published in June 1977 (Ref 22). This report, entitled "A Sensitivity Analysis of Rigid Pavement-Overlay Design Procedure," by B. C. Nayak, B. Frank McCullough, and W. Ronald Hudson, gives a sensitivity analysis of input variables to the Federal Highway Administration computer-based overlay design procedure RPOD1.

CASE STUDIES: EVALUATION OF OVERLAY PERFORMANCE

The next step taken with regard to the development of an up-to-date overlay design procedure was to perform a study of the comparative behavior of newly constructed overlaid pavements.

The performance of a pavement is a measure of how well it serves traffic over a period of time. A pavement which had low serviceability during much of its life would not have performed its function of serving traffic as well as one which had high serviceability during most of its life, even though both ultimately reached the same state of distress simultaneously. The performance of a pavement is also a function of riding quality and pavement distress. The ride quality and distress manifestations are subjectively measured in the field by a condition survey. With the analysis of these condition survey data, the present serviceability of the pavement structure can be determined, along with the subsequent determination of the relative pavement performance when compared with an adjoining pavement of a different construction. In this study, the pavement performance of a new CRCP construction was determined as being either better or worse than the performance of a CRCP overlay constructed over an older JCP. Thus, Report No. 177-12, published in April 1978, "A Study of CRCP Performance: New Construction versus Overlay," by James I. Daniel, B. Frank McCullough, and W. Ronald Hudson, documents the performance of several (new and overlayed) continuously reinforced concrete pavements (CRCP) in Texas (Ref 23). This report was the first step in the documentation of pavement performance. This documentation was considered necessary for subsequent progress in pavement and overlay design and rehabilitation. Through such field investigations, CTR personnel were able to gain the knowledge necessary for the improvement of existing design methods.

DEVELOPMENT OF A TOTAL PAVEMENT OVERLAY DESIGN PROCEDURE

The development of an improved overlay design program was successfully completed in the second to last year of the study. The CTR Report No. 177-13, "A Rigid Pavement Overlay Design Procedure for the Texas SDHPT," by Otto Schnitter, B. Frank McCullough, and W. Ronald Hudson, describes a procedure recommended for use by the Texas SDHPT for designing both rigid and flexible overlays in existing rigid pavements (Ref 24). The procedure incorporates the results of condition surveys to predict the existing pavement's remaining life, field and lab testing to determine material properties, and elastic layer theory to predict the critical stresses in the pavement structure.

The report was published in May 1978. In summary, this is a pavement design method consisting of fatigue and reflection cracking subsystems. The fatigue cracking subsystem considers remaining life of the existing pavement, uses fatigue principles, and determines the required overlay thickness for a specific design life. Miner's linear damage hypothesis is used in the process. The reflection cracking subsystem provides a rational way of analyzing an overlay for the possible occurrence of reflection cracking.

This design procedure was developed by adapting, through evaluation, modification, improvement, and simplification, the previously developed FHWA overlay design procedure for rigid pavements. Revisions made to the FHWA procedure include modifications to

(1) computer programs,
(2) the input guides for the computer programs, and
(3) materials characterization procedures.

This procedure provides a means to design a wide variety of overlays on rigid pavements in a rational way. Input guides for the program RPOD-2 have been included as Appendix C.

CALCULATION OF OPTIMUM TIME TO OVERLAY

The final study performed during the project with regard to the rehabilitation of rigid pavements, was an investigation into the development of a procedure for determining the best (optimum) time to overlay any given pavement, in relation to total overall utility. Report No. 177-14*, "A Methodology to Determine an Optimum Time to Overlay," by James I Daniel, B. Frank McCullough, and W. Ronald Hudson, describes the development of a mathematical model for predicting the optimum time to overlay an existing rigid pavement (Ref. 25). Specifically, the report presents a methodology for determining the optimum time to make one or more overlays, based on total cost of the strategy over the entire design period. The method employs several modelling procedures for predicting the cost of the overlay(s), maintenance costs and the cost to the user. Detailed descriptions of each model are presented

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*Not published in final form.

in the report. The final chapter of the report employs the methodology in developing models for the optimization of time to overlay for two specific cases. Computer program listings and user manuals for both maintenance and user's cost determinations are found in the Appendices of the report. The computer program for the determination of the overlay thickness is found in other reports.

COMPREHENSIVE OVERLAY DESIGN METHOD: STRATEGY SELECTION

Completion of the task of developing and implementing a comprehensive rigid pavement rehabilitation method which will provide optimum designs was not achieved during the course of Project 177. This task has, however, become the primary objective of the subsequent CTR Project 249. This task is being achieved through modification (to include strategy selection, reliability, and other improvements), simplification, and field application of the design procedure described above. Implementation of the complete method, with all improvements incorporated, is anticipated during 1980.

CHAPTER 5. EVALUATION OF RIGID PAVEMENT PERFORMANCE

INTRODUCTION

Essential to the process of the design, maintenance and rehabilitation of rigid pavements is some rational procedure for evaluating their performance. Accordingly a significant portion of the effort on this project has been devoted to the establishment of a rigid pavement performance evaluation system. Two aspects have been investigated in detail: pavement roughness has been studied using profile (deflection) measurements (Refs 8, 17, 26, 27, 28, 29, and the condition of pavements across the state has been rated by visual survey techniques (Refs 9, 16, 18, 19, 20, 30). Separate studies have been completed and documented in both these areas. Recommendations have also been made concerning the role which performance measurements should play in pavement evaluation techniques which are to be incorporated into the overall design process (Refs 18, 20). Included in the recommended system are a series of performance (distress) prediction models developed using the data collected during the study (Ref 20), along with procedures for updating these data on a regular (annual), statewide basis (Ref 19). Also included is a technique for deciding upon the level of maintenance which a particular pavement would require, given its condition.

PROFILE AND ROUGHNESS MEASUREMENTS

The earliest work completed under the project concerning pavement evaluation techniques was an investigation into the feasibility of using the recently developed Mays Ride Meter to obtain a measure of the road roughness. Published in January 1977, this early CFHR Report was No. 177-3. Entitled "A Study of the Performance of the Mays Ride Meter," by Yi Chin Hu, Hugh J. Williamson, B. Frank McCullough, and W. Ronald Hudson, the report discusses the accuracy of measurements made by the Mays Ride Meter and their relationship to roughness measurements made with the Surface Dynamics Profilometer. A contemporary study, published in March 1976, Report No. 177-5*, "A Comparison of Two Inertial Reference Profilometers Used to Evaluate Airfield and Highway Pavements," by Chris Edward Doepke, B. Frank McCullough, and W. Ronald Hudson, describes a United States Air Force owned profilometer developed for measuring airfield runway roughness. This is compared with the Surface Dynamics Profilometer. Plotted profiles and mean roughness amplitude data from each profilometer are compared and evaluated. From these two studies, it was concluded that the Surface Dynamics Profilometer (SDP) is very capable of obtaining an accurate roughness evaluation of the road. However, the equipment itself and its operation are expensive. The Mays Ride Meter (MRM), a device which measures the serviceability indices of the road sections (as does the SDP), is less expensive to operate, but it is not so accurate and it does not provide as much roughness information. It was shown that the MRM is responsive primarily to short waves, while the SDP is capable of measuring roughness with a wide range of wavelengths. In view of the repeatability of the MRM and the agreement between the measurements made by different MRM's, however, these conclusions do not reduce the value of the MRM as a profile measuring tool. However, the MRM should be thought of as a device which reacts to short waves only.

Since these results have been documented, the Texas State Department of Highways and Public Transportation has employed the measurements of a Surface Dynamics Profilometer to calibrate its fleet of Mays Road Meters. In early 1978, a simple profile statistic, whose components relate to the physical concept of vertical acceleration, was devised to predict an SI based on the response of a typical Mays Meter trailer. It has since proved to be a more effective calibration standard than the previous SI (Ref 29).

CONDITION SURVEY OF RIGID PAVEMENTS

Statewide, visual condition surveys for sections of CRC highway throughout Texas were performed under Project 177 in both 1974 and 1978. A photographic condition survey of the same sections was also performed in 1976 (Ref 30). Data from all these surveys have been stored in computer file format and analyzed. A series of reports have been prepared based on these data and the analyses, and relevant recommendations are now being implemented

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*This has not been published as a final report.

by the Texas SDHPT. Updating of these data banks, analyses, and recommendations is anticipated on a regular (annual) basis following the conclusion of Project 177.

The initial condition survey investigations performed under Project 177 were documented in CTR Report No. 177-6, "Sixteenth Year Progress Report on Experimental Continuously Reinforced Concrete Pavement in Walker County," by Thomas P. Chesney and B. Frank McCullough. This report presents a summary of data collection and analysis over a 16-year period. During that period, numerous findings resulted in changes in specifications and design standards. It was clear at that time that these data would be valuable for shaping guidelines for future construction. This report was published in April 1976.

The next study conducted was described in CTR Report No. 177-8*, "Continuously Reinforced Concrete Pavement: Prediction of Distress Quantities," by John P. Machado, B. Frank McCullough, and Hugh J. Williamson. Here, a general analysis of enviornmental design, construction, and historic pavement behavior conditions and their effects on future performance was carried out. This analysis was based on a statewide CRCP Condition Survey which was conducted in 1974. The report was published in November 1977.

Next, a photographic condition survey was completed and documented in Report No. 177-10, "Development of Photographic Techniques for Performance Condition Surveys," by Pieter Strauss, James Long, and B. Frank McCullough. The development of a technique for surveying heavily trafficked highways without interrupting the flow of traffic is reported here. The report was published in December 1977.

Finally, in 1978, a second statewide visual CRCP condition survey was completed. The data were summarized and analyzed and the relevant conclusions documented in a series of reports which are described below.

First, data summary reports for the 1974 and 1978 surveys were prepared for all 12 Texas districts which were involved in the surveys, and subsequently distributed to appropriate Texas SDHPT district offices. A collection of summary sheets from these reports has been included here in Appendix D.

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*Not published as a final report.

CTR Report No. 177-19, "Manual for Condition Survey of Continuously Reinforced Concrete Pavements," by Arthur Taute and B. F. McCullough was published in December 1979. This manual suggests guidelines for condition survey procedures and frequency of surveys. Copies of the appropriate, recommended rating forms have been included in Appendix D.

Also published in December 1979 was Report No. 177-20, entitled "Summary Report for 1978 CRCP Condition Survey in Texas" by Manuel Gutierrez de Velasco and B. F. McCullough. This report covers the overall 1978 condition survey and makes comparisons with the 1974 data. The results are presented with very little analysis. Except that, included in this report, are the results of an analysis which establishes the terms of the distress condition of the pavement at any given time.

Finally, a detailed analysis of the data collected in both 1974 and 1978 surveys was completed in December 1979. This work has been documented in Report No. 177-21, entitled "Distress Prediction Models for CRCP" by C. S. Noble and B. F. McCullough, and published in December 1979. This analysis includes a comparison of actual distress measurements and values computed from early prediction models, as well as improvements to those prediction models, and an analysis of the effects of important construction and environmental variables on performance. Also included is a series of recommendations concerning the establishment and operation of an overall rigid pavement evaluation system (RPES). Using this system a designer would, on the basis of real data, be able to evaluate the need for either an overlay, a minor repair, or some routine maintenance activity, as required, for any pavement in Texas, at any given time in the pavement's life. These decisions would be based on the pavement's condition, likely deterioration rate, and the increased utility associated with each of the maintenance or rehabilitation activities. A summary of the Pavement Utility Equation is given in Report 177-21.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

The major conclusions and recommendations based on the results of all the investigations completed during the course of this research project are outlined below.

(1) Detailed design of CRCP should be performed using the CRCP-2 computer program which is now available on computers at the Center for Transportation Research and the Texas SDHPT in Austin. A copy of the input guide and an example output are included in Appendix A. Reference should also be made to CTR Report Nos. 177-2 and 177-9.

(2) Similar detailed design of JRCP can now be performed for temperature and shrinkage loads, using the JRCP-2 computer program which is also available on the CTR and Texas SDHPT computers in Austin. Detailed procedures for the design against traffic loads will be established during the course of Project 249, which continues at least through 1983.

(3) Design charts (nomographs) and design equations have been prepared, along with limiting criteria on relevant distress variables, for the complete design of CRCP (reinforcement and slab thickness) at a specific feasibility level. The entire procedure is discussed in CTR Report Nos. 177-16 and 177-17. Associated preliminary studies are described in CTR Report Nos. 177-1, 177-4, and 177-7. These design charts and equations are included here in Appendix B. It is strongly recommended that these design charts be included in the appropriate section of the Texas SDHPT Operations and Procedures Manual (Part IV, Design) (Ref 16).

(4) A CRCP overlay design procedure which was developed at the CTR should be incorporated into Ref 16 and implemented where appropriate as soon as possible. This procedure involves the use of the computer program RPOD-2, which is available on both the CTR and Texas SDHPT computers. The program is discussed in full in CTR Report No. 177-13. A copy of the user's manual has been included as Appendix C to this report. Following completion of preliminary investigations which were reported in CTR Report Nos. 177-11 and 177-12, a procedure was developed which enables

the designer to calculate the optimum time to overlay a given rigid pavement (CTR Report No. 177-14*). Accordingly, optimum (with respect to minimum cost) overlay strategy selection is being incorporated into a comprehensive rigid pavement overlay design procedure still being developed at the CTR (under Project 249). Implementation of this procedure has already been initiated successfully using several projects in Texas and its use is strongly recommended wherever overlays to rigid pavements are required.

(7) Following the completion of the studies described in CTR Report Nos. 177-3 and 177-5, procedures were developed for the reliable, yet economical measurement of highway profiles. Also, information obtained with the Profilometer and the Mays Ride Meter concerning the profile of any rigid pavement can now be related to an evaluation of the distress condition of that pavement and hence to its maintenance needs at any time during its life. The continued use of these instruments, to monitor the profile of all rigid pavements in Texas on a regular basis, is recommended here. This is being accomplished under Project 251.

(8) Visual condition surveys of CRCP in Texas were completed in 1974, 1976 (photographic), and 1978, as described in CTR Report Nos. 177-6, 177-10, and 177-20. The resulting distress measurements have since been used in the development of distress prediction models, as described in CTR Report Nos. 177-8* and 177-21. It is recommended that the condition surveys be implemented by the Texas SDHPT on a regular basis using the procedures established during this study, as outlined in CTR Report No. 177-19 (CRCP and JRCP) and CTR Technical Memorandum No. 177-72 (Overlay). Copies of these recommended rating forms have been included in Appendix D to this report.

(9) Finally, it is recommended that the distress prediction models, along with a data bank based upon the results of the regular condition survey, should be used in a comprehensive rigid pavement evaluation system for the calculation of pavement utility. This should be done for any rigid pavement in Texas, at any time, such that the resulting utility function could be used in the decision making process with regard to the distribution of funds for pavement maintenance and rehabilitation. Accordingly, it is recommended

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*Not published in final form.

that the evaluation system and decision criteria (as discussed in CTR Report Nos. 177-20 and 177-21) be incorporated into the appropriate section of the Texas SDHPT Operations and Procedures Manual and implemented as soon as possible.

In summary, the reader's attention is also directed to Research Project 249 at the Center for Transportation Research. Reports emanating from that project will supplement the work which has been completed and reported in Project 177.

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APPENDIX A

CRCP-2 COMPUTER PROGRAM

USER'S MANUAL AND TYPICAL OUTPUT

APPENDIX A. CRCP-2 USER'S MANUAL AND TYPICAL OUTPUT

This appendix contains a detailed guide for the use of computer program CRCP-2 for the design of continuously reinforced concrete pavement. The program has been available for use on the Texas SDHPT computer since June 1979. All detailed CRCP designs to be implemented in Texas should be made using this program.

All card types must be present for each problem unless otherwise stated except type 1, which must be present once and only once.

TYPE 1

Description of Run

1.1 *AN1 - Run comments
(Two cards)

TYPE 2

Description of Problem

2.1 *NPROB - Problem number

2.2 *AN2 - Problem comments

*Any combination of letters and/or numbers

TYPE 3
Steel Properties

3.1 ITYPER - Type of reinforcement = 1 for deformed bar = 2 for deformed wire fabric										5
3.2 P - Percent steel reinforcement	11	12	13	14	15	16	• 17	18	19	20
3.3 DIA - Reinforcing bar diameter (inches)	21	22	23	24	25	• 26	27	28	29	30
3.4 FY - Yield stress (psi)	31	32	33	34	35	36	37	38	39	• 40
3.5 ES - Elastic modulus (psi)	41	42	43	44	45	46	47	48	49	• 50
3.6 *ALPHAS - Thermal coefficient of steel	51	52	• 53	54	55	56	E 57	- 58	0 59	60
3.7 BHIGH - Transverse wire spacing (inches) (omit if deformed bar is used)	61	62	63	64	65	• 66	67	68	69	70

*See explanation on page 37.

TYPE 4
Concrete Properties

4.1 THICK - Slab thickness (inches)

							•		
11	12	13	14	15	16	17	18	19	20

4.2 **ALPHAC - Thermal coefficient of concrete

		•				E	-	0	
21	22	23	24	25	26	27	28	29	30

4.3 ***ZTOT - Drying shrinkage strain (inches/inches)

		•				E	-	0	
31	32	33	34	35	36	37	38	39	40

4.4 UNWT - Unit weight of concrete (pcf)

								•	
41	42	43	44	45	46	47	48	49	50

4.5 FPC - 28-day compressive strength (psi) (Omit if user provides age-tensile strength relationship)

								•	
51	52	53	54	55	56	57	58	59	60

4.6 ****STRNMUL - Used with FPE by the program to generate age-tensile strength relationship. (Omit if user provide age-tensile strength relationship) (STRNMUL must be $\leq$1.0) (DEFAULT value is 1.0)

		•	
61	62	63	64

4.7 NSTRN - Number of points in the age-tensile strength relationship

= 0 if program generates relationship ($0 \leq NSTRN \leq 20$)

65	66

4.8 IFY - Number of points in the slab-base friction relationship (See type 10)

= 1 - user supplies one point, program will generate a straight line curve

= 2 - user supplies one point, program will generate a parabolic curve (in the above cases, the point should be the maximum value, beyond that sliding occurs)

\>2 - user defines the curve with IFY points (The first point must be 0.0, 0.0) (default value is 2)

69	70

, *, ****See explanation on page 37.

3.6 *ALPHAS - Thermal coefficient of steel

Various values of coefficient of thermal expansion are listed in Table A.1 for different steels. A normal range of 5×10^{-6} to 7×10^{-6} (in./in./°F) is commonly used.

4.2 **ALPHAC - Thermal coefficient of concrete (in./in./°F)

The thermal expansion and contraction of concrete vary with factors such as richness of mix, water-cement ratio, temperature range, concrete age, and relative humidity. However, the main factor affecting the thermal properties of concrete is the minalogic composition of the aggregate. Fig A.1 shows some experimental values of thermal coefficient of linear expansion for neat cements and for mortars and concretes with different kinds of aggregates. The coefficient appears to be very much influenced by the type of coarse aggregate, being highest for quartz, followed by sandstone, granite, basalt, and limestone. Gravel may vary considerably in its minerological composition, having a thermal coefficient of about five to seven millionths (in./in./°F).

4.3 ***ZTOT - Drying shrinkage strain (in./in.)

Drying shrinkage of concrete is one of the principal causes of cracking. Upon exposure to drying conditions, moisture slowly diffuses from the interior mass of the concrete to the surface, tending to reduce the effect of moisture loss by surface evaporation. There are many factors that influence the magnitude of drying shrinkage, such as: water content, type of aggregate, type of cement, moisture, temperature conditions, sizes of pavement slabs, and duration of moist curing. The drying shrinkage varies commonly from 0.0002 to 0.0006 inches/inches. The single largest factor that influences shrinkage is its water content and this relationship is shown in Fig A.2 (made by the Bureau of Reclamation).

4.6 ****STRNMUL - Used with FPC by program to generate age-tensile strength

With 28-day compressive strength (FPC) given by the user, the program will calculate the flexural strength using the following equation:

$$\text{flexural strength } f_u = \frac{3000}{3 + \frac{12000}{\text{FPC}}}$$

The tensile strength is then generated by multiplying the flexural strength with a coefficient "STRNMUL."

$$\text{tensile strength } (f_t) = f_u \times \text{STRNMUL}$$

"STRNMUL" varies from 0.5 to 1.0. Table A.2 and Fig A.3 provide some guidance to the designer for choosing an appropriate flexural-tensile factor (STRNMUL).

TABLE A.1

Material	Coefficient of Thermal Expansion α $10^{-6}/°F$
Cast iron, ductile, as cast	7.5
Steel, 0.2 percent C, hot-rolled	6.7
Steel, 0.2 percent C, cold-rolled	6.7
Steel, 1.0 percent C, hot-rolled	7.3
Steel, 1.0 percent C, hardened and tempered at 800°F	---
Steel, AISI 4640, hardened and tempered at 800°F	---
Stainless steel, type 302, cold-rolled	8.9

Material	Thermal Expansion, in./in./°F, at 68°F
Silver (sterling)	10×10^{-6}
Steel (1020)	6.5×10^{-6}
Steel (1040)	6.3×10^{-6}
Steel (1080)	6.0×10^{-6}
Steel (k8Cr-8Ni stainless)	5×10^{-6}

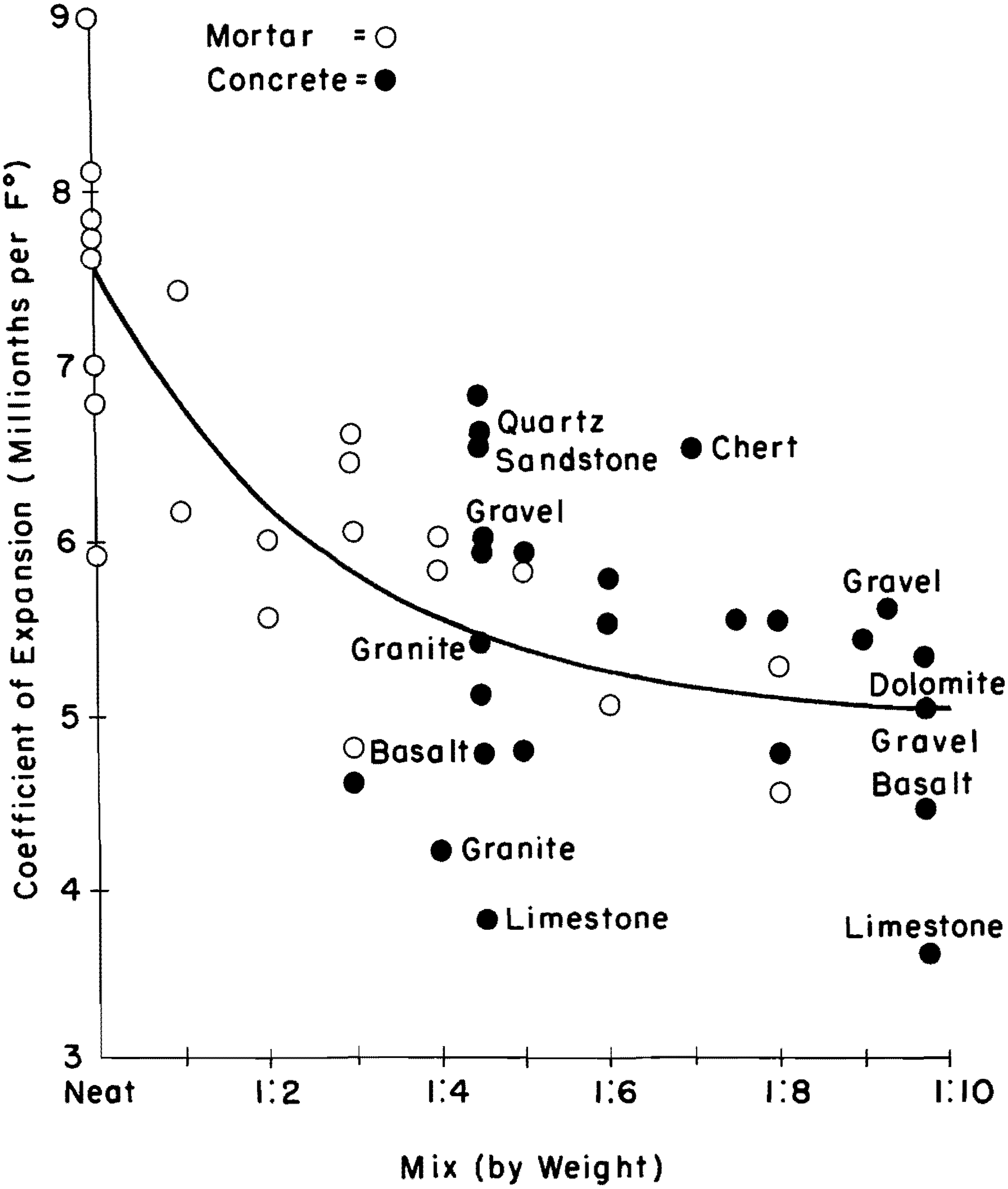

Fig A.1. Thermal coefficients of expansion of neat cement, mortar, and concrete. (Ref 5)

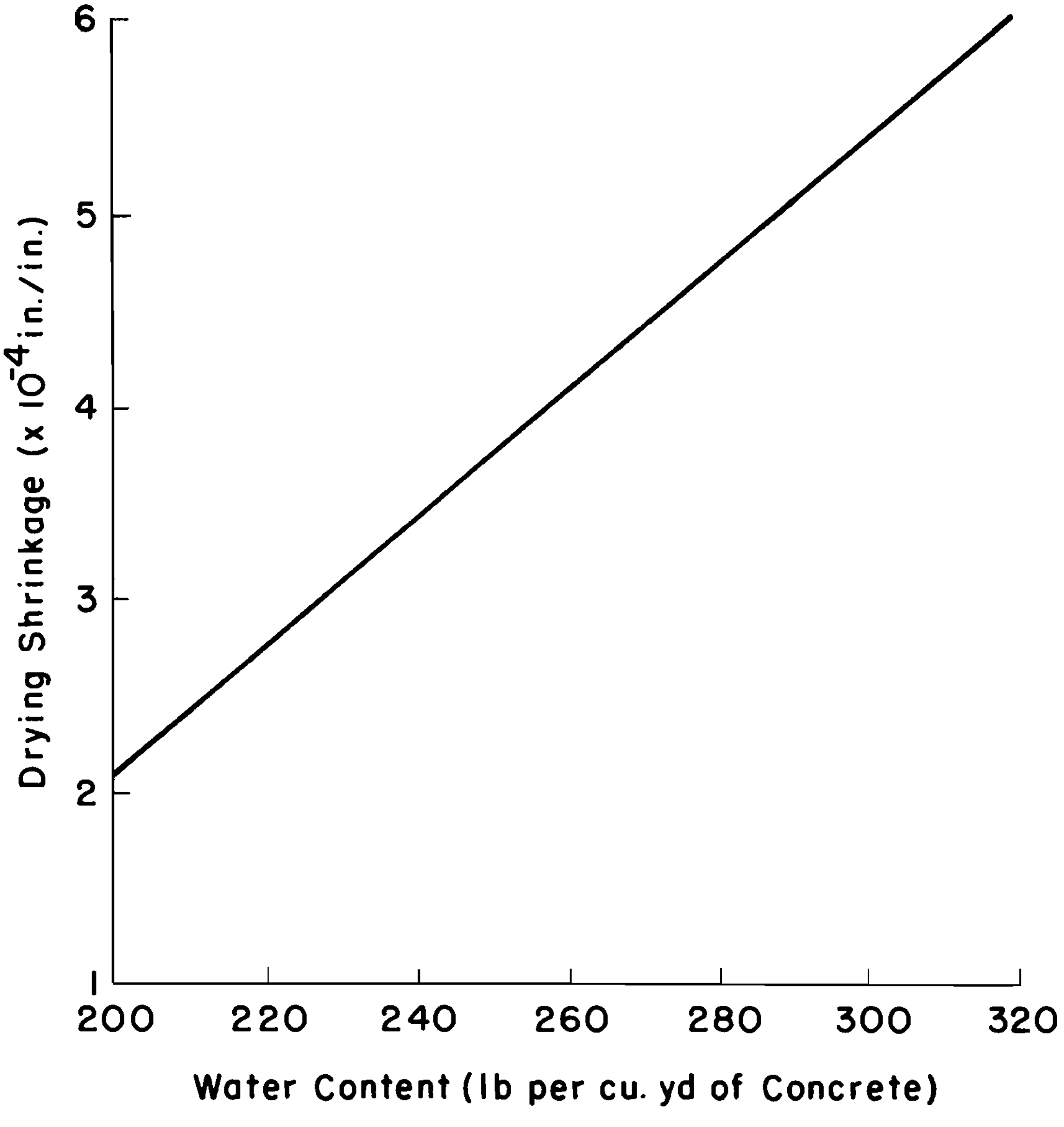

Fig A.2. Typical effect of water content on drying shrinkage. (Ref 5)

TABLE A.2

Concrete	Split-tensile Strength Flexural Strength
Gravel	5/8
Linestone	2/3
Light-weight aggregate	3/4

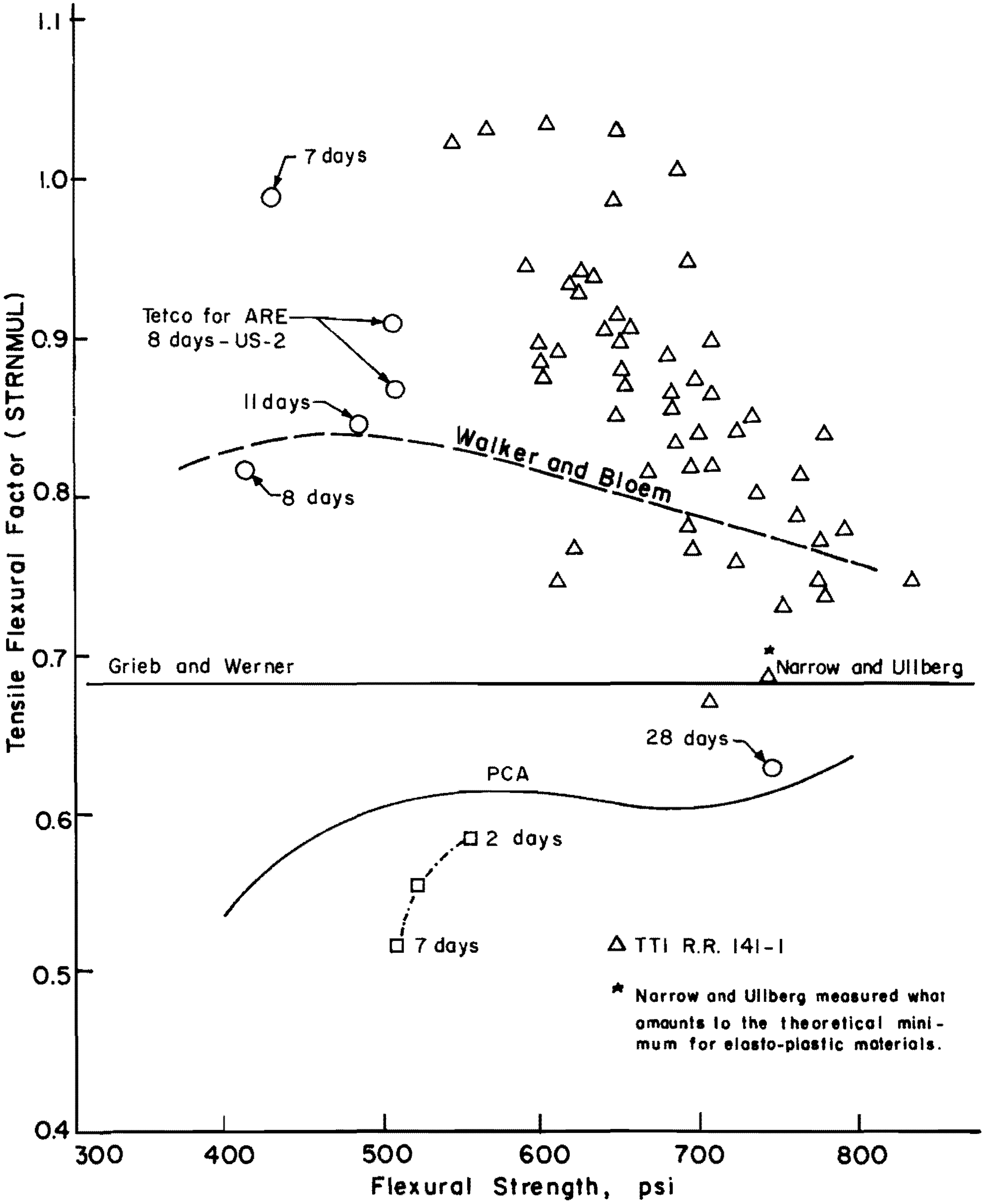

Fig A.3. Concrete tensile strength as a function of flexural strength.

TYPE 5

Environmental Inputs

5.1 *CURTEMP - Curing Temperature (°F)

							•		
1	2	3	4	5	6	7	8	9	10

5.2 *NTEMP - Number of days before concrete gains full strength. NTEMP should equal NSTRN if NSTRN = 28 ($0 \leq NTEMP \leq 50$)

11	12	13	14	15

5.3 *DELTATM - Minimum temperature expected after concrete gains full strength (°F)

							•		
21	22	23	24	25	26	27	28	29	30

5.4 *COLDTM - Number of days after concrete is set before minimum temperature DELTATM occurs (e.g., first cold season) (Omit if run is program CRCP-1) ($COLDTM \geq 28.0$) (DEFAULT value is 28.0)

				•
36	37	38	39	40

TYPE 6

Environmental Input Continue

(more than one card may be needed)

6.1 *DT(1) - Minimum daily temperature (°F)

			•	
1	2	3	4	5

6.2 *DT(2)

			•	
6	7	8	9	10

.
.
.
DT(NTEMP)

---

*See explanation on the following page.

*TYPE 5 and TYPE 6 - Concrete gains strength most rapidly during the first few days. As much as 30 percent or more can be lost if premature drying or enormous temperature drop were permitted during that period. The maintenance of proper conditions when the slab is first placed is termed as "CURTEMP", or the curing temperature. This temperature is used to compare with "DT", which is a record of daily temperatures from the time when the slab was placed to "NTEMP" (14th or 28th day, depending on the type of cement), when substantial concrete strength was reached. From then on, concrete gains strength at a much slower pace. If the minimum temperature were to occur a few months after the pavement had been built, for example, the first winter, that period of time, counted in number of days would be "COLDTM" (Fig A.4).

It is intended in the program that all temperatures be the slab temperatures at mid-depth. If these are unavailable, air temperature may be used as an approximation since the daily changes of air temperature are generally reflected as similar slab temperature changes.

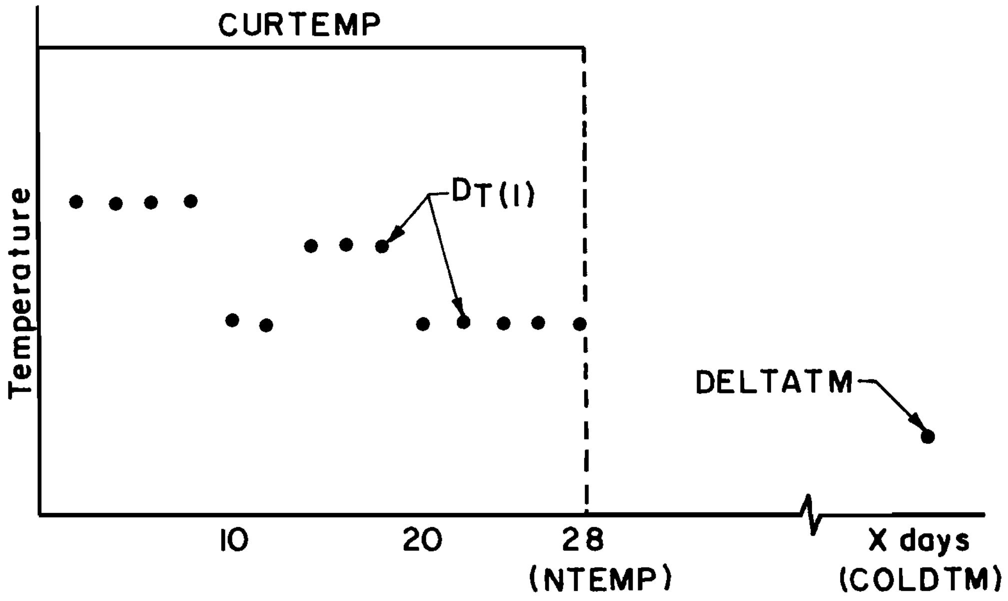

Fig A.4. Age (days)

TYPE 7

External Loads and Stresses
(Omit this card if run is program CRCP-1)

7.1 TMLOD - Number of days after concrete is set before wheel load is applied (DEFAULT value is 0.0)

			•	
6	7	8	9	10

7.2 *WHLOAD - Wheel load (lb) (DEFAULT value is 0.0)

= blank if user supplies WHLSTR

							•		
11	12	13	14	15	16	17	18	19	20

7.3 WHBASE - Wheel base radius (in.)

= blank if user supplies WHLSTR

							•		
21	22	23	24	25	26	27	28	29	30

7.4 SOILK - Modulus of subgrade (psi)

= blank if user supplies WHLSTR

							•		
31	32	33	34	35	36	37	38	39	40

7.5 *WHLSTR - Wheel load stress (psi)

= blank if user supplies WHLOAD

							•		
41	42	43	44	45	46	47	48	49	50

---

*An option is provided here so that the user can either choose to input wheel load stress WHLSTR directly or let the program generate the tensile stress using Westergaard's equation by inputting WHLOAD, WHBASE, and K.

TYPE *8

Print and Plot Option
(Do not omit this card even if print and plot are not used)

8.1 *TOL - Relative closure tolerance
(percent)
(DEFAULT value is 5.0)

			•	
1	2	3	4	5

8.2 LONGPR - Flag to print intermediate steps

= YES if desired

= blank if not desired

8	9	10

8.3 NPRINT - Rate of subsampling used in printing intermediate results (e.g., 101 points are calculated in each iteration. If NPRINT = 20 and LONGPR = YES then, for each iteration, values at points 1, 21, 41, 61, 81, 101 will be printed) (DEFAULT value is 20)

11	12	13	14	15

8.4 IPLOT - Flag for plot of temperature drop versus time

= YES if desired

= blank if not desired

18	19	29

8.5 TMSCALE - Number of inches/day to be plotted

	21	22	23	24	25	26	27
•							
28	29	30	31	32	33	34	35

8.6 FINAL - Number of days to be plotted

			•	
36	37	38	39	40

---

*TOL - Recommended 1.0 percent for CRCP-2

Recommended 5.0 percent for CRCP-1

TYPE 9

Age-Tensile Strength Relationship
(This card type must be omitted if NSTRN = 0)

9.1	AGEU (1) - Age of concrete (days)				•	
		1	2	3	4	5
9.2	TENSION (1) - Tensile strength (psi)				•	
		6	7	8	9	10
9.3	AGEU (2)				•	
		11	12	13	14	15
9.4	TENSION (2)				•	
		16	17	18	19	20

9.5 AGEU (3)

9.6 AGEU (3)
AGEU (NSTRN)
TENSION (NSTRN)

TYPE 10

Slab-base Friction Relationship
(Force-Displacement)

10.1 *FEXP (1) - Frictional force per area (psi)

1	2	3	4	5	6	7	8	9	10

10.2 *YEXP (1) - Slab movement (inches)

11	12	13	14	15	16	17	18	19	20

10.3 *FEXP (2)

10.4 *YEXP (2)

.

.

.

.

FEXP (IFY)

YESP (IFY)

10.1 *FEXP (1) - Frictional force for per area (psi), where I - 1 to IFY

10.2 *YEXP (1) - Slab movement (inches) corresponding to the frictional force, I - 1 to IFY

From the NCHRP Research Project Report 1-15, the following slab-base friction relationships are recommended.

Fig A.5 shows force-displacement curves of various subbase materials.

Figs A.6 - A.9 shows force-displacement curves for various concrete thicknesses.

Figs A.10 - A.13 show the same curves but grouped into special categories (bond breaking on very smooth surface, five granular materials, coarse granular material, and cohesive material.

No friction curves for stabilized subbases are given because data is not available.

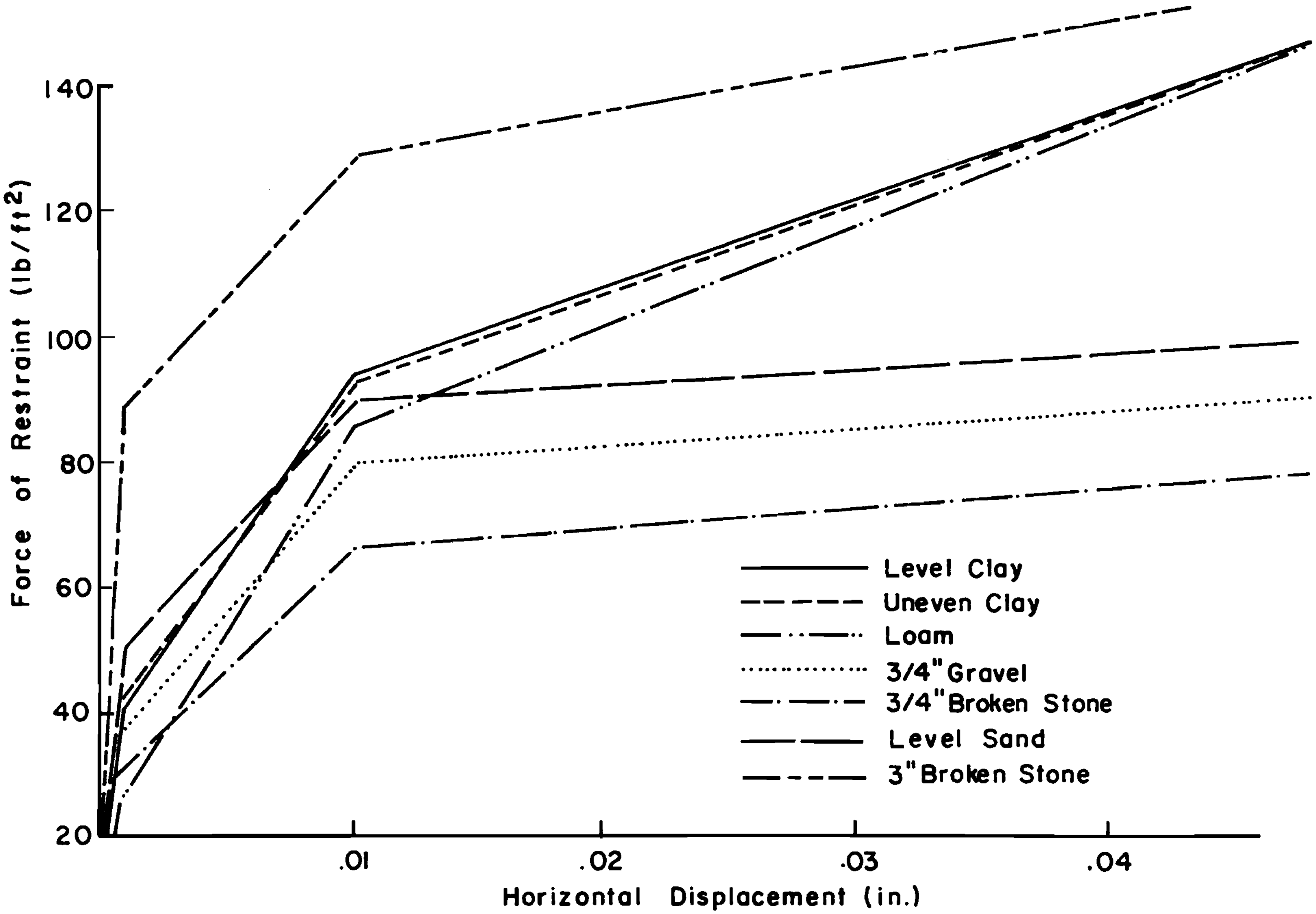

Fig A.5. Force/displacement curves for various subbase layers for slab that is 2' X 6' X 6". Unit weight of concrete = 145 pcf.

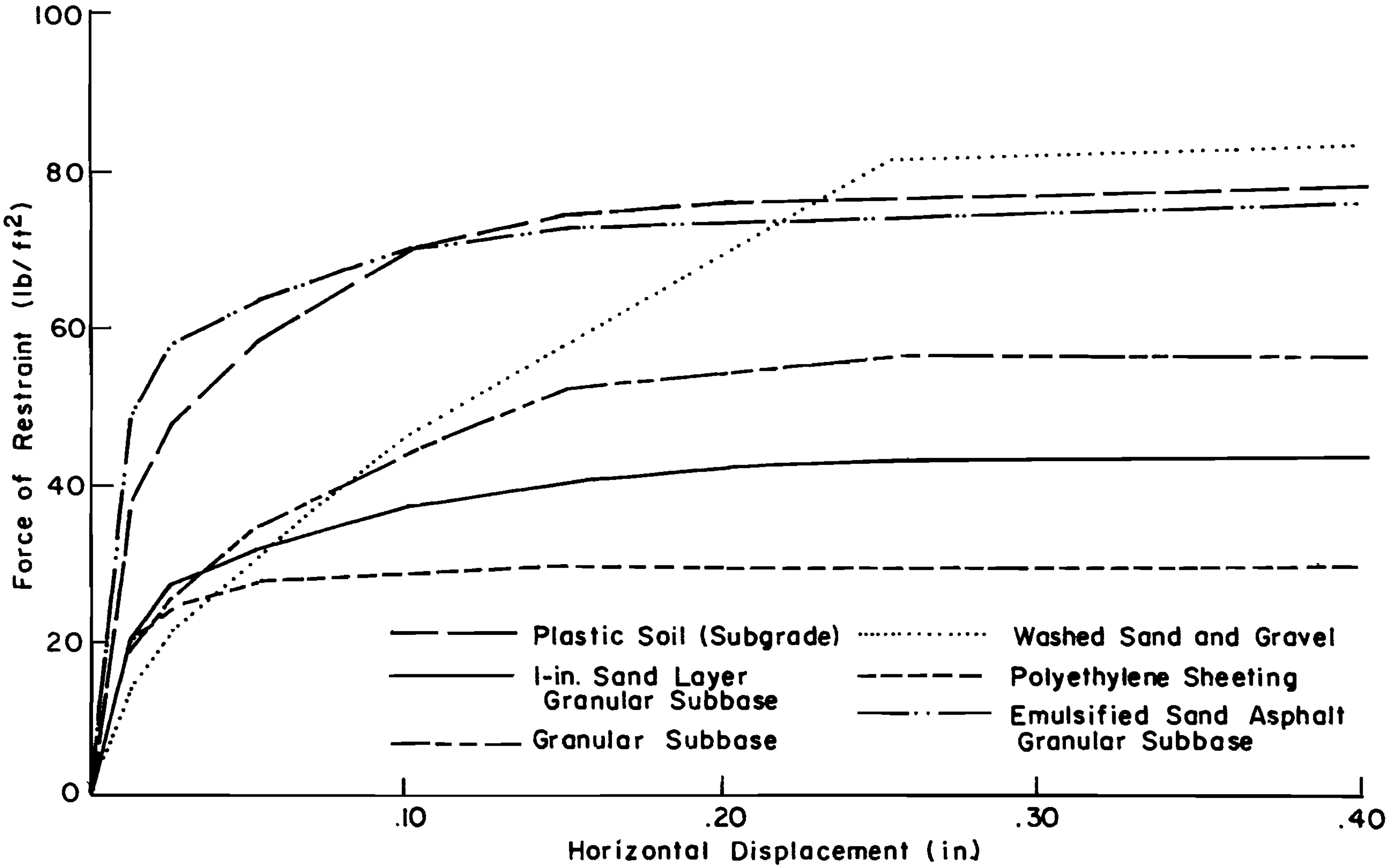

Fig A.6. Force/displacement curves for various base layers for a slab that is 6' X 6' X 5", assuming unit weight of concrete equals 144 pcf.

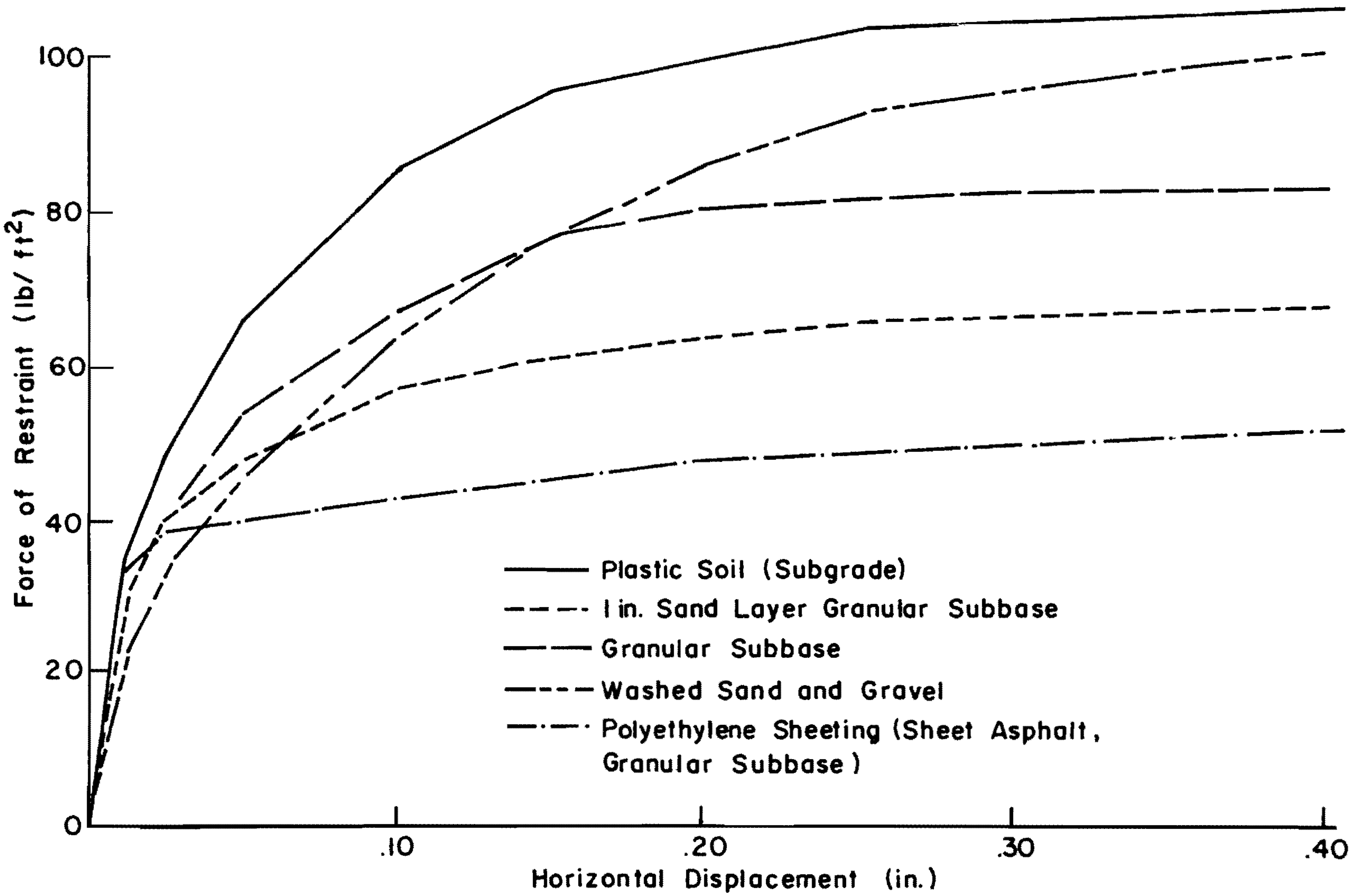

Fig A.7. Force/displacement curves for various conditions of a 6' X 6' slab with 8" thickness, assuming unit weight of concrete = 144 pct.

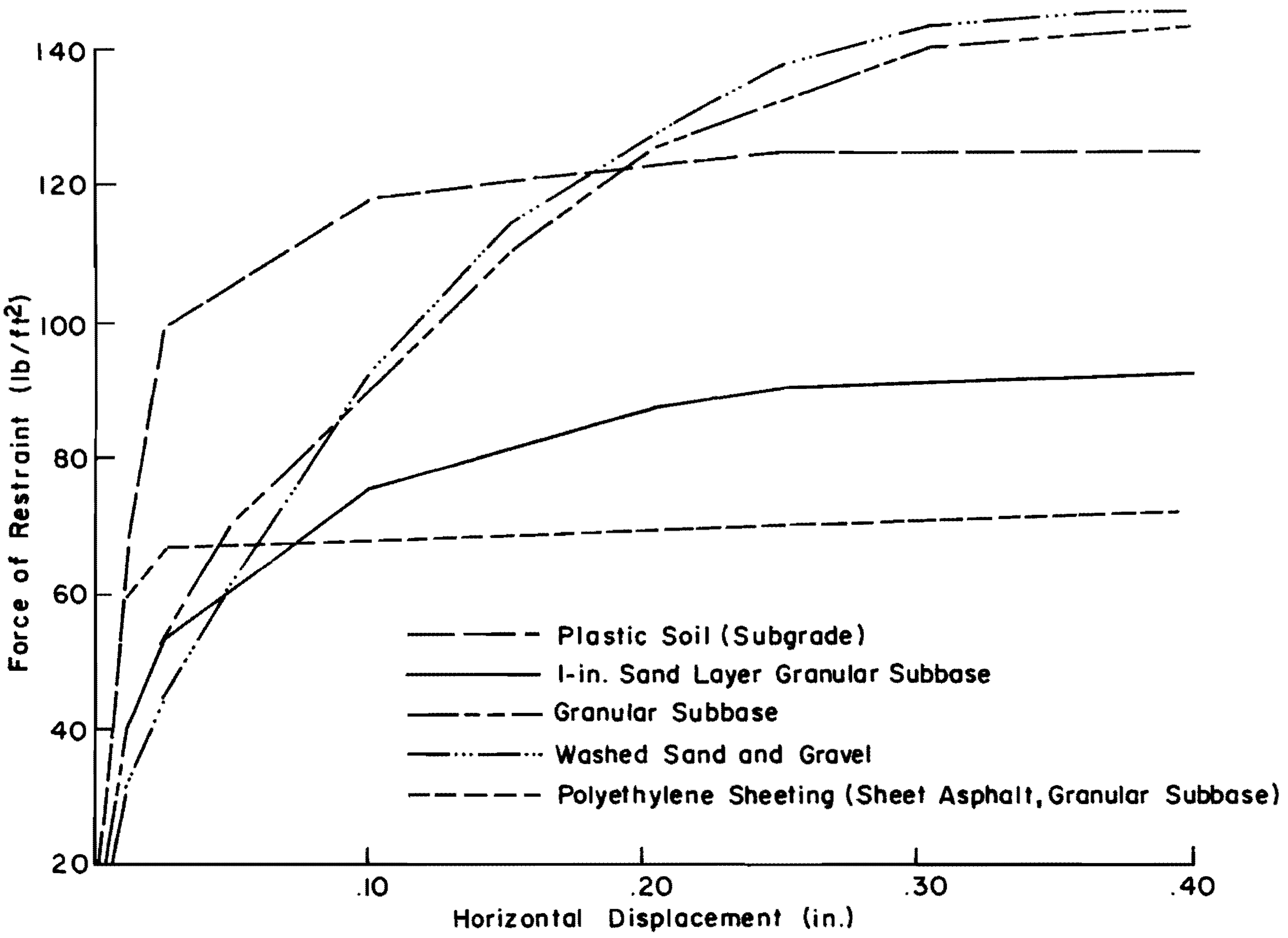

Fig A.8. Force/displacement curves for various conditions of a 6' X 6' X 11" slab, assuming unit weight = 144 pcf.

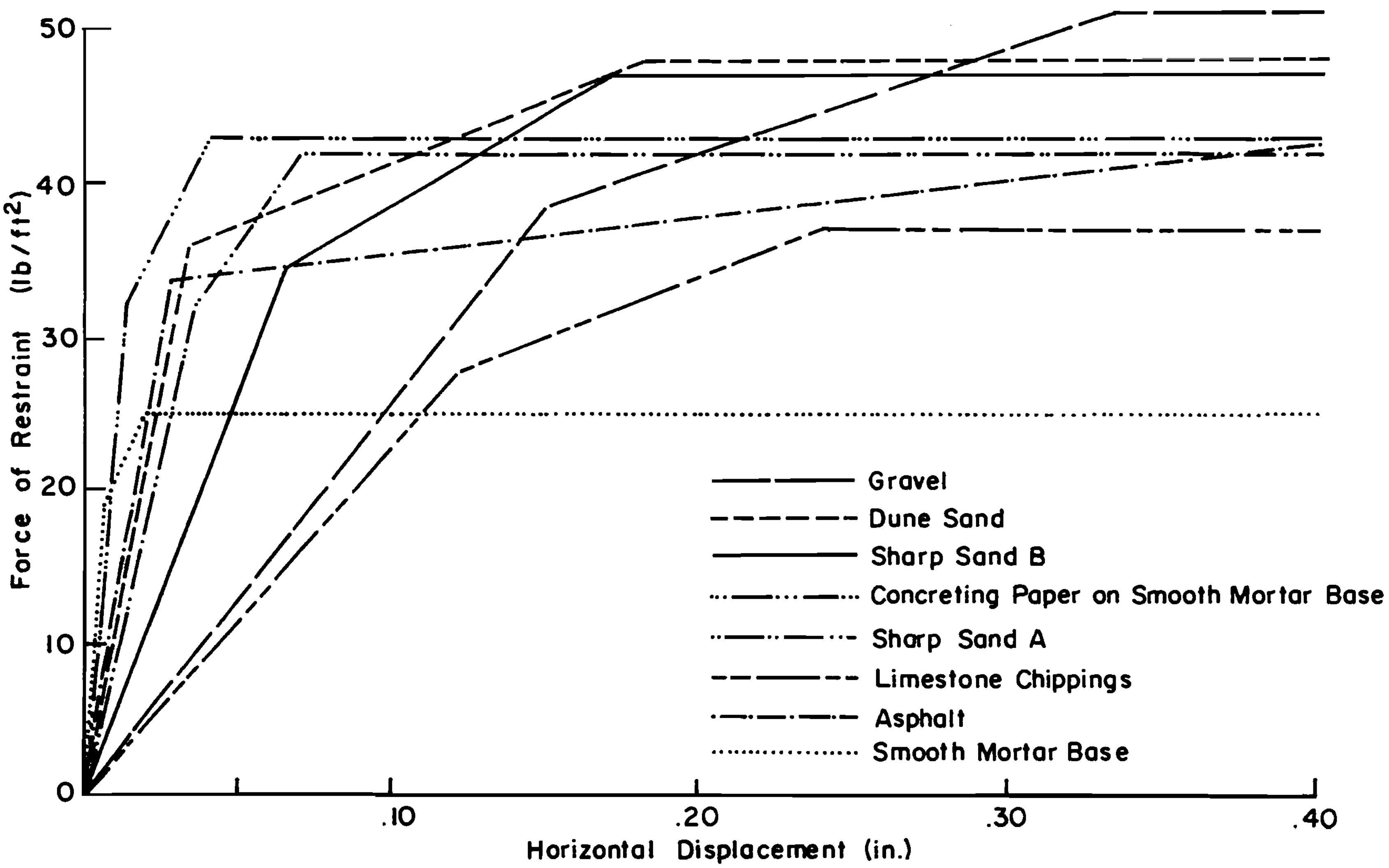

Fig A. 9. Force/displacement curves for various base layers for a slab that is 4' X 6' X 6".

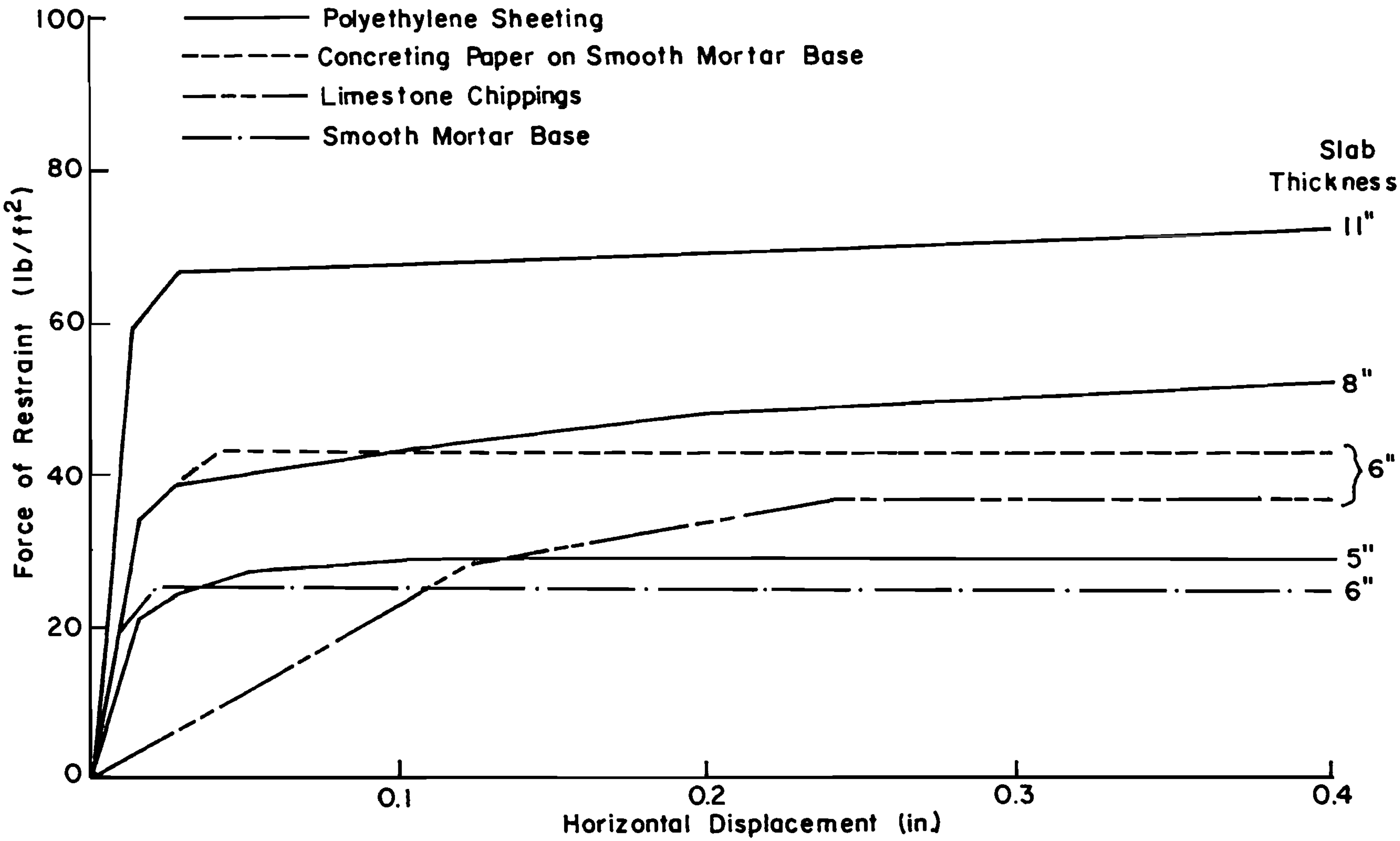

Fig A.10. Force/displacement curves for very smooth base or bond breaking material for various slab thicknesses.

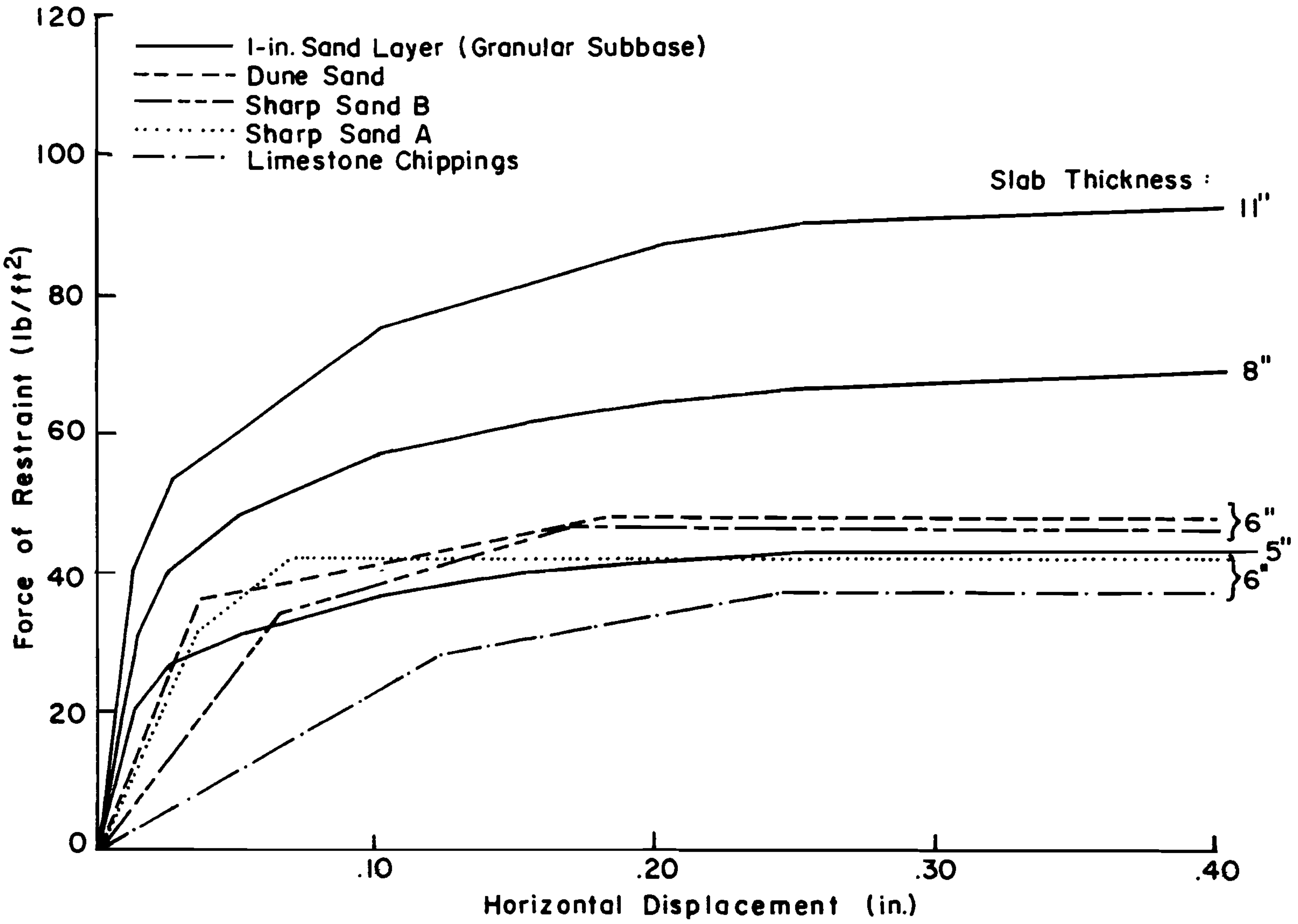

Fig A. 11. Force/displacement curves for fine granular materials or cohesiveless soil for various slab thicknesses.

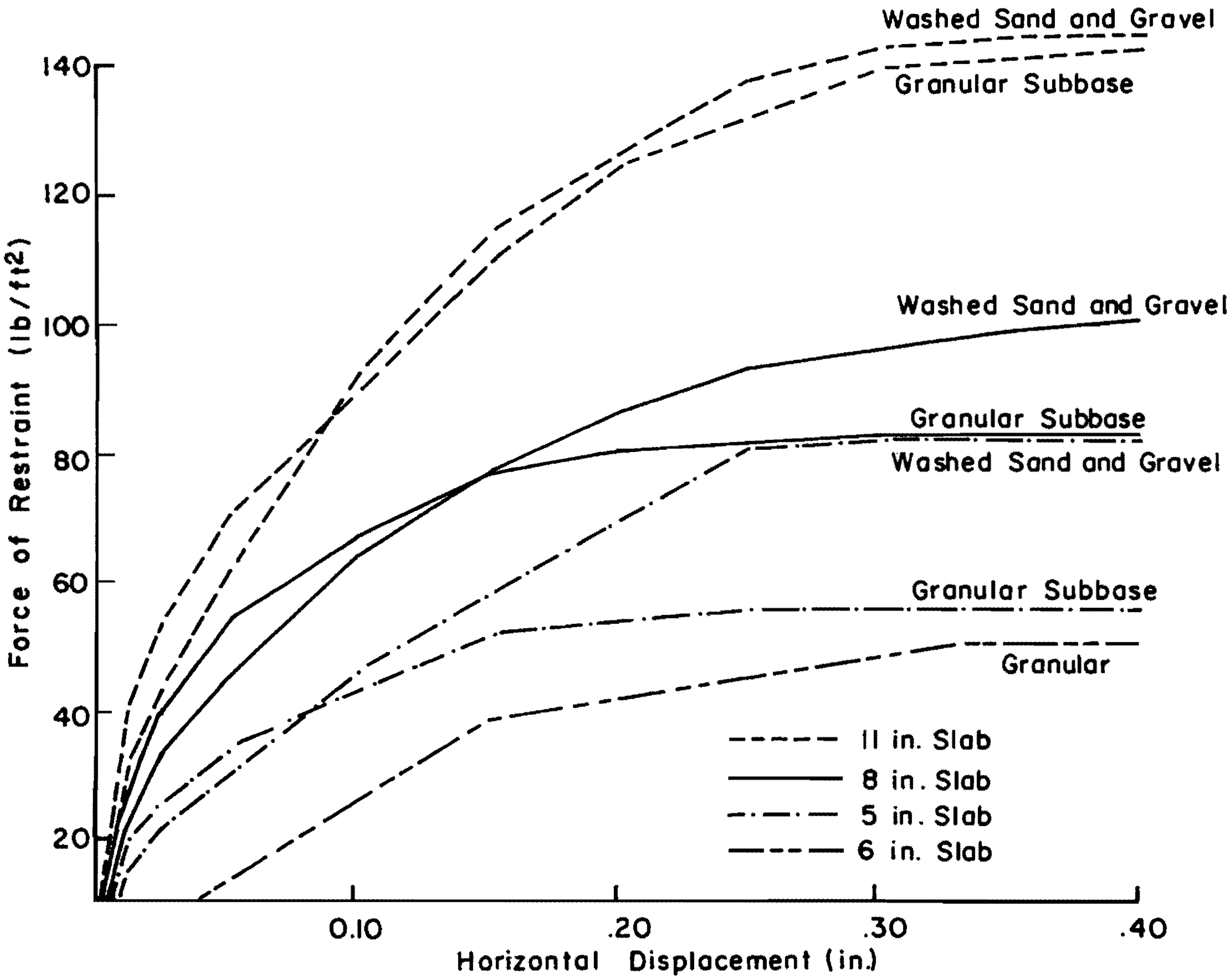

Fig A.12. Force/displacement curves for cohesiveless soils or coarse granular materials.

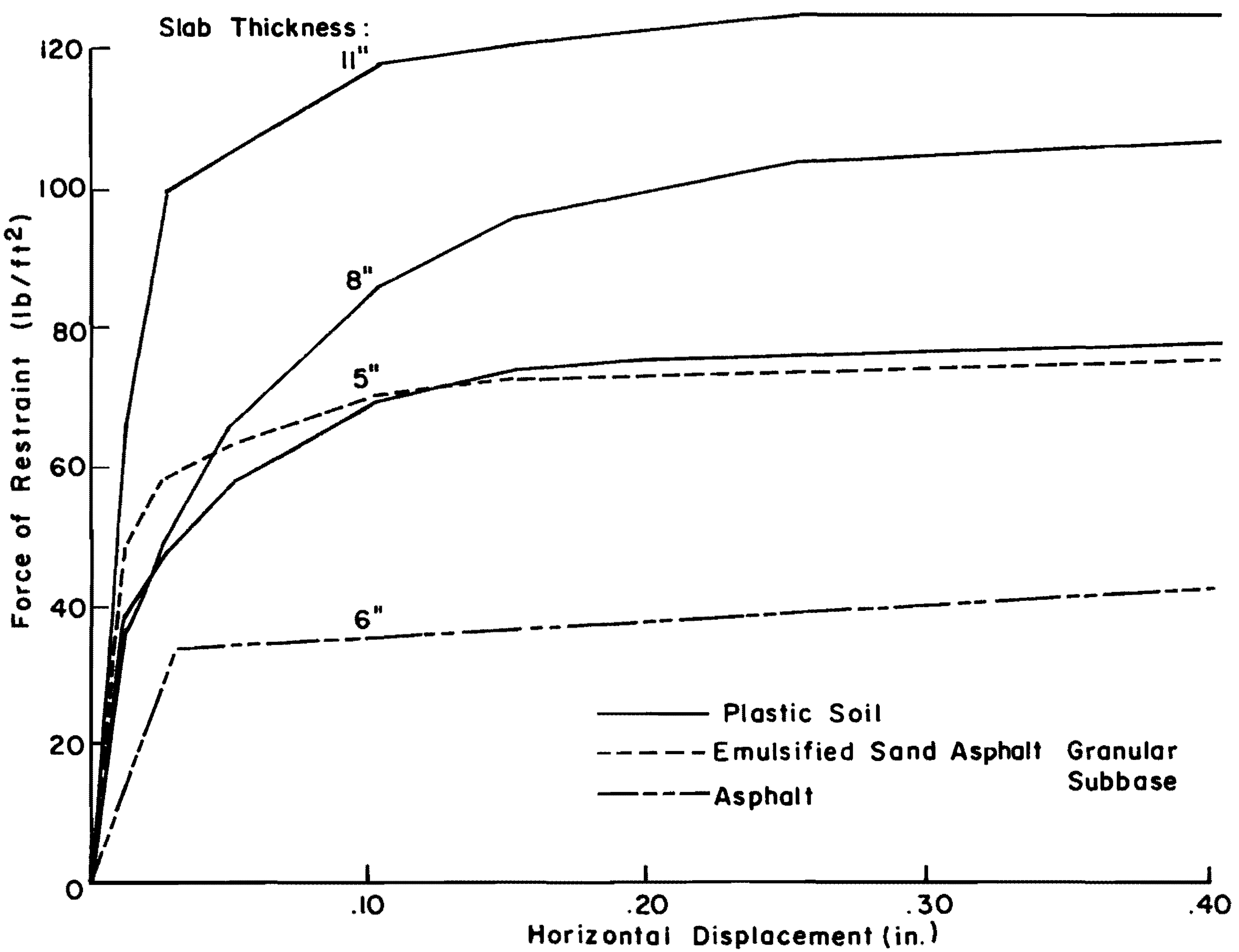

Fig A.13. Force/Displacement curves for cohesive materials for various soil thicknesses.

```
PROB
   1        F = 15. Y=-.1

        ********************************************
        *                                          *
        *              STEEL PROPERTIES            *
        *                                          *
        ********************************************


             TYPE OF LONGITUDINAL REINFORCEMENT IS
                        DEFORMED BARS


             PERCENT REINFORCEMENT = 7.000E-01
             BAR DIAMETER          = 6.000E-01
             YIELD STRESS          = 6.000E+04
             ELASTIC MODULUS       = 2.900E+07
             THERMAL COEFFICIENT   = 5.000E-06


        ********************************************
        *                                          *
        *             CONCRETE PROPERTIES          *
        *                                          *
        ********************************************


             SLAB THICKNESS       = 1.000E+01
             THERMAL COEFFICIENT = 5.000E-06
             TOTAL SHRINKAGE     = 4.000E-04
             UNIT WEIGHT CONCRETE= 1.500E+02
             COMPRESSIVE STRENGTH= 3.000E+03


            TENSILE STRENGTH DATA
            *********************

             NO TENSILE STRENGTH DATA IS INPUT BY USER
             THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
             IS USED WHICH IS BASED ON THE RECOMMENDATION
             GIVEN BY U.S. BUREAU OF RECLAMATION

             AGE,  TENSILE
            (DAYS) STRENGTH

              0.0     0.0
              1.0   159.1
              3.0   253.2
              5.0   299.1
              7.0   326.1
             14.0   372.0
             21.0   398.3
             28.0   410.8
```

```
************************************************
*                                              *
*      SLAB-BASE FRICTION CHARACTERISTICS      *
*              F-Y RELATIONSHIP                *
*                                              *
************************************************

     TYPE OF FRICTION CURVE IS A STRAIGHT LINE

      MAXIMUM FRICTION FORCE=   15.0000
      MOVEMENT AT SLIDING   =    -.1000


******************************
*                            *
*      TEMPERATURE DATA      *
*                            *
******************************


     CURING TEMPERATURE= 70.0


          MINIMUM      DROP IN
DAY     TEMPERATURE  TEMPERATURE

  1         50.0         20.0
  2         50.0         20.0
  3         50.0         20.0
  4         50.0         20.0
  5         50.0         20.0
  6         50.0         20.0
  7         50.0         20.0
  8         50.0         20.0
  9         50.0         20.0
 10         50.0         20.0
 11         50.0         20.0
 12         50.0         20.0
 13         50.0         20.0
 14         50.0         20.0
 15         50.0         20.0
 16         50.0         20.0
 17         40.0         30.0
 18         40.0         30.0
 19         40.0         30.0
 20         40.0         30.0
 21         40.0         30.0
 22         40.0         30.0
 23         40.0         30.0
 24         40.0         30.0
 25         40.0         30.0
```

```
26          40.0          30.0
27          40.0          30.0
28          40.0          30.0

  MINIMUM TEMPERATURE EXPECTED AFTER
  CONCRETE GAINS FULL STRENGTH        =  0.0 DEGREES FAHRENHEIT
  DAYS BEFORE REACHING MIN. TEMP.     = 28.0 DAYS
```

```
************************************************
*                                              *
*                EXTERNAL LOAD                 *
*                                              *
************************************************


      WHEEL LOAD (LBS)          = 1.800E+04
      WHEEL BASE RADIUS (IN) = 6.000E+00
      SUBGRADE MODULUS (PSI) = 1.500E+02
      CONCRETE MODULUS (PSI) = 3.321E+06
      LOAD APPLIED AT           =  28. TH DAY
      CALC.LOAD STRESS (PSI) = 2.440E+02




************************************************
*                                              *
*        ITERATION AND TOLERANCE CONTROL       *
*                                              *
************************************************


 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   60

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

```
          TESTING


PROB
   1       F = 15. Y=-.1
                                                                    MAXIMUM
  TIME    TEMP     DRYING    TENSILE  CRACK      CRACK        CONCRETE    STRESS IN
 (DAYS)   DROP   SHRINKAGE   STRGTH   SPACING    WIDTH         STRESS     THE STEEL

   .33    10.0   6.092E-12    91.9     409.0  8.829E-04     3.600E+01   6.476E+03
   .50    20.0   2.458E-09   112.5     409.0  3.748E-03     8.475E+01   1.448E+04
  1.50    20.0   7.326E-06   187.1     409.0  5.994E-03     1.440E+02   2.254E+04
  2.50    20.0   3.629E-05   233.3     409.0  1.042E-02     2.158E+02   3.207E+04
  3.50    20.0   7.204E-05   265.4     230.0  1.323E-02     2.580E+02   3.751E+04
  4.50    20.0   1.054E-04   288.3      86.3  9.973E-03     2.314E+02   3.266E+04
  5.50    20.0   1.344E-04   306.0      86.3  1.200E-02     2.623E+02   3.638E+04
  6.50    20.0   1.589E-04   319.5      86.3  1.376E-02     2.875E+02   3.939E+04
  7.50    20.0   1.797E-04   329.5      86.3  1.526E-02     3.079E+02   4.180E+04
  8.50    20.0   1.975E-04   336.4      86.3  1.655E-02     3.243E+02   4.370E+04
  9.50    20.0   2.127E-04   343.2      86.3  1.767E-02     3.387E+02   4.538E+04
 10.50    20.0   2.259E-04   349.8      43.1  1.073E-02     2.654E+02   3.397E+04
 11.50    20.0   2.374E-04   356.3      43.1  1.119E-02     2.738E+02   3.486E+04
 12.50    20.0   2.475E-04   362.6      43.1  1.160E-02     2.814E+02   3.568E+04
 13.50    20.0   2.565E-04   368.9      43.1  1.197E-02     2.884E+02   3.644E+04
 14.50    20.0   2.645E-04   373.9      43.1  1.230E-02     2.945E+02   3.709E+04
 15.50    20.0   2.716E-04   377.8      43.1  1.259E-02     2.995E+02   3.762E+04
 16.37    20.0   2.772E-04   381.1      43.1  1.283E-02     3.029E+02   3.795E+04
 16.50    30.0   2.781E-04   381.6      43.1  1.483E-02     3.258E+02   4.138E+04
 17.50    30.0   2.839E-04   385.4      43.1  1.509E-02     3.288E+02   4.163E+04
 18.50    30.0   2.892E-04   389.1      43.1  1.533E-02     3.315E+02   4.186E+04
 19.50    30.0   2.941E-04   392.8      43.1  1.556E-02     3.340E+02   4.207E+04
 20.50    30.0   2.985E-04   396.5      43.1  1.576E-02     3.363E+02   4.226E+04
 21.50    30.0   3.026E-04   399.2      43.1  1.595E-02     3.384E+02   4.243E+04
 22.50    30.0   3.064E-04   401.0      43.1  1.611E-02     3.402E+02   4.258E+04
 23.50    30.0   3.099E-04   402.8      43.1  1.627E-02     3.419E+02   4.272E+04
 24.50    30.0   3.131E-04   404.6      43.1  1.641E-02     3.434E+02   4.284E+04
 25.50    30.0   3.161E-04   406.4      43.1  1.655E-02     3.449E+02   4.296E+04
 26.50    30.0   3.190E-04   408.1      43.1  1.667E-02     3.463E+02   4.307E+04
 27.50    30.0   3.216E-04   409.9      43.1  1.679E-02     3.475E+02   4.318E+04
```

```
 AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING       = 7.301E-01 FEET
CRACK WIDTH         = 6.355E-03 INCHES
MAX CONCRETE STRESS= 4.077E+02 PSI
MAX STEEL STRESS    = 2.183E+04 PSI,
CONC.TENS.STRENGTH = 4.108E+02 PSI


STA-   DIS-    CONCRETE      FRICTION     CONCRETE      STEEL
TION  TANCE    MOVEMENT       FORCE        STRESS       STRESS

  1     0.0    0.000E+00    0.000E+00    1.637E+02   -1.532E+03
  2      .0   -3.071E-05    4.606E-03    1.620E+02   -1.298E+03
  3      .1   -6.144E-05    9.216E-03    1.604E+02   -1.065E+03
  4      .1   -9.219E-05    1.383E-02    1.587E+02   -8.311E+02
  5      .2   -1.230E-04    1.844E-02    1.571E+02   -5.974E+02
  6      .2   -1.538E-04    2.306E-02    1.555E+02   -3.638E+02
  7      .3   -1.846E-04    2.769E-02    1.538E+02   -1.301E+02
  8      .3   -2.154E-04    3.231E-02    1.522E+02    1.035E+02
  9      .4   -2.463E-04    3.694E-02    1.506E+02    3.371E+02
 10      .4   -2.771E-04    4.157E-02    1.489E+02    5.708E+02
 11      .4   -3.080E-04    4.621E-02    1.473E+02    8.044E+02
 12      .5   -3.390E-04    5.085E-02    1.456E+02    1.038E+03
 13      .5   -3.699E-04    5.549E-02    1.440E+02    1.272E+03
 14      .6   -4.009E-04    6.013E-02    1.424E+02    1.505E+03
 15      .6   -4.319E-04    6.478E-02    1.407E+02    1.739E+03
 16      .7   -4.629E-04    6.943E-02    1.391E+02    1.973E+03
 17      .7   -4.939E-04    7.409E-02    1.375E+02    2.206E+03
 18      .7   -5.250E-04    7.874E-02    1.358E+02    2.440E+03
 19      .8   -5.560E-04    8.341E-02    1.342E+02    2.674E+03
 20      .8   -5.871E-04    8.807E-02    1.326E+02    2.907E+03
 21      .9   -6.182E-04    9.274E-02    1.309E+02    3.141E+03
 22      .9   -6.494E-04    9.741E-02    1.293E+02    3.374E+03
 23     1.0   -6.805E-04    1.021E-01    1.276E+02    3.608E+03
 24     1.0   -7.117E-04    1.068E-01    1.260E+02    3.842E+03
 25     1.1   -7.429E-04    1.114E-01    1.244E+02    4.075E+03
 26     1.1   -7.742E-04    1.161E-01    1.227E+02    4.309E+03
 27     1.1   -8.054E-04    1.208E-01    1.211E+02    4.543E+03
 28     1.2   -8.367E-04    1.255E-01    1.195E+02    4.776E+03
 29     1.2   -8.680E-04    1.302E-01    1.178E+02    5.010E+03
 30     1.3   -8.993E-04    1.349E-01    1.162E+02    5.244E+03
 31     1.3   -9.306E-04    1.396E-01    1.146E+02    5.477E+03
 32     1.4   -9.620E-04    1.443E-01    1.129E+02    5.711E+03
 33     1.4   -9.933E-04    1.490E-01    1.113E+02    5.944E+03
 34     1.4   -1.025E-03    1.537E-01    1.096E+02    6.178E+03
 35     1.5   -1.056E-03    1.584E-01    1.080E+02    6.412E+03
 36     1.5   -1.088E-03    1.631E-01    1.064E+02    6.645E+03
 37     1.6   -1.119E-03    1.679E-01    1.047E+02    6.879E+03
 38     1.6   -1.151E-03    1.726E-01    1.031E+02    7.113E+03
 39     1.7   -1.182E-03    1.773E-01    1.015E+02    7.346E+03
 40     1.7   -1.214E-03    1.820E-01    9.983E+01    7.580E+03
```

```
41      1.8   -1.245E-03     1.868E-01     9.819E+01     7.814E+03
42      1.8   -1.277E-03     1.915E-01     9.655E+01     8.047E+03
43      1.8   -1.308E-03     1.962E-01     9.492E+01     8.281E+03
44      1.9   -1.340E-03     2.010E-01     9.328E+01     8.515E+03
45      1.9   -1.372E-03     2.057E-01     9.164E+01     8.748E+03
46      2.0   -1.403E-03     2.105E-01     9.001E+01     8.982E+03
47      2.0   -1.435E-03     2.152E-01     8.837E+01     9.215E+03
48      2.1   -1.467E-03     2.200E-01     8.673E+01     9.449E+03
49      2.1   -1.498E-03     2.247E-01     8.510E+01     9.683E+03
50      2.1   -1.530E-03     2.295E-01     8.346E+01     9.916E+03
51      2.2   -1.562E-03     2.343E-01     8.183E+01     1.015E+04
52      2.2   -1.594E-03     2.390E-01     8.019E+01     1.038E+04
53      2.3   -1.625E-03     2.438E-01     7.855E+01     1.062E+04
54      2.3   -1.657E-03     2.486E-01     7.692E+01     1.085E+04
55      2.4   -1.689E-03     2.534E-01     7.528E+01     1.108E+04
56      2.4   -1.721E-03     2.581E-01     7.364E+01     1.132E+04
57      2.5   -1.753E-03     2.629E-01     7.201E+01     1.155E+04
58      2.5   -1.785E-03     2.677E-01     7.037E+01     1.179E+04
59      2.5   -1.817E-03     2.725E-01     6.873E+01     1.202E+04
60      2.6   -1.849E-03     2.773E-01     6.710E+01     1.225E+04
61      2.6   -1.881E-03     2.821E-01     6.546E+01     1.249E+04
62      2.7   -1.913E-03     2.869E-01     6.382E+01     1.272E+04
63      2.7   -1.945E-03     2.917E-01     6.219E+01     1.295E+04
64      2.8   -1.977E-03     2.965E-01     6.055E+01     1.319E+04
65      2.8   -2.009E-03     3.013E-01     5.891E+01     1.342E+04
66      2.8   -2.041E-03     3.061E-01     5.728E+01     1.365E+04
67      2.9   -2.073E-03     3.110E-01     5.564E+01     1.389E+04
68      2.9   -2.105E-03     3.158E-01     5.400E+01     1.412E+04
69      3.0   -2.137E-03     3.206E-01     5.237E+01     1.436E+04
70      3.0   -2.169E-03     3.254E-01     5.073E+01     1.459E+04
71      3.1   -2.202E-03     3.303E-01     4.910E+01     1.482E+04
72      3.1   -2.234E-03     3.351E-01     4.746E+01     1.506E+04
73      3.2   -2.266E-03     3.399E-01     4.582E+01     1.529E+04
74      3.2   -2.298E-03     3.448E-01     4.419E+01     1.552E+04
75      3.2   -2.331E-03     3.496E-01     4.255E+01     1.576E+04
76      3.3   -2.363E-03     3.544E-01     4.091E+01     1.599E+04
77      3.3   -2.395E-03     3.593E-01     3.928E+01     1.622E+04
78      3.4   -2.428E-03     3.641E-01     3.764E+01     1.646E+04
79      3.4   -2.460E-03     3.690E-01     3.600E+01     1.669E+04
80      3.5   -2.492E-03     3.739E-01     3.437E+01     1.693E+04
81      3.5   -2.525E-03     3.787E-01     3.273E+01     1.716E+04
82      3.5   -2.557E-03     3.836E-01     3.109E+01     1.739E+04
83      3.6   -2.590E-03     3.885E-01     2.946E+01     1.763E+04
84      3.6   -2.622E-03     3.933E-01     2.782E+01     1.786E+04
85      3.7   -2.655E-03     3.982E-01     2.618E+01     1.809E+04
86      3.7   -2.687E-03     4.031E-01     2.455E+01     1.833E+04
87      3.8   -2.720E-03     4.080E-01     2.291E+01     1.856E+04
88      3.8   -2.752E-03     4.128E-01     2.127E+01     1.879E+04
89      3.9   -2.785E-03     4.177E-01     1.964E+01     1.903E+04
90      3.9   -2.818E-03     4.226E-01     1.800E+01     1.926E+04
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  91      3.9   -2.850E-03     4.275E-01     1.637E+01     1.950E+04
  92      4.0   -2.883E-03     4.324E-01     1.473E+01     1.973E+04
  93      4.0   -2.915E-03     4.373E-01     1.309E+01     1.996E+04
  94      4.1   -2.948E-03     4.422E-01     1.146E+01     2.020E+04
  95      4.1   -2.981E-03     4.471E-01     9.819E+00     2.043E+04
  96      4.2   -3.014E-03     4.520E-01     8.183E+00     2.066E+04
  97      4.2   -3.046E-03     4.570E-01     6.546E+00     2.090E+04
  98      4.2   -3.079E-03     4.619E-01     4.910E+00     2.113E+04
  99      4.3   -3.112E-03     4.668E-01     3.273E+00     2.136E+04
 100      4.3   -3.145E-03     4.717E-01     1.637E+00     2.160E+04
 101      4.4   -3.178E-03     4.766E-01     0.000E+00     2.183E+04
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APPENDIX B

CRCP SUPPLEMENTARY SUBBASE, SLAB THICKNESS, REINFORCEMENT AND OVERLAY DESIGN PROCEDURE

APPENDIX B. CRCP SUPPLEMENTARY SUBBASE, SLAB THICKNESS, REINFORCEMENT, AND OVERLAY DESIGN PROCEDURE

This appendix presents material recommended as replacements in total for the appropriate sections of Appendix F of the Texas SDHPT Highway Design Division Operations and Procedures Manual in the format set out in the following pages:

Specifically,

Section B.1 should replace Section F-105

Section B.2 should replace Section F-106(b)

Section B.3 should replace Section F-106(a)

Section B.4 should replace Section F-108

Section B.5 should replace Section F-109

Figure B.1 is a Design Input Summary Sheet that lists all the input parameters required to design the subbase, the slab thickness, and the reinforcement for a CRCP. In the following pages, details are given for obtaining these parameters and for the design of the components of a CRCP. Further reference will be made to this figure.

A traffic analysis similar to the one shown in Fig B.2 should be obtained from D-10 using a standard request form similar to the one shown in Fig B.3. Note that the D-10 traffic data is given for one direction; that is, they consider a directional distribution factor of 0.5. Then, twice the estimate of the 18-k ESAL obtained from D-10 should be multiplied by a directional distribution factor and a lane distribution factor to define the design lane traffic:

$$W_D = W_{18\text{-}k} \, (DD)(LD)$$

where W_D = design lane traffic, 18-k ESAL highway over design period;

W18-k = accumulated 18-k ESAL both directions of the highway over design period

DD = directional distribution factors, and

LD = lane distribution factor.

The directional distribution factor for several highways and locations in the state (taken from Ref 20), are shown in Table B.1. In this reference,

SUBBASE DESIGN

Subbase Materials	Elastic Modulus (psi)	Support Loss Factor	Alternate Trial Thicknesses

SLAB THICKNESS DESIGN

Design K-Values on Top of Subbase (pci)

Subbase Alternatives				
1	2	3	4	5

Design 18-kip ESAL Applications __________

Allowable Flexural Working Stress in Concrete __________(psi)

Concrete Modulus of Elasticity __________(psi)

LONGITUDINAL REINFORCEMENT DESIGN

Rebar Diameter __________

Wheel Load Stress __________(psi)

Concrete Shrinkage __________(in/in)

Design Temperature Drop __________(°F)

Concrete Tensile Strength __________(psi)

Thermal Coefficient Ratio α_s/α_c __________

TRANSVERSE REINFORCEMENT DESIGN

Total Width of Slab __________(in)

Subbase Friction Factor __________

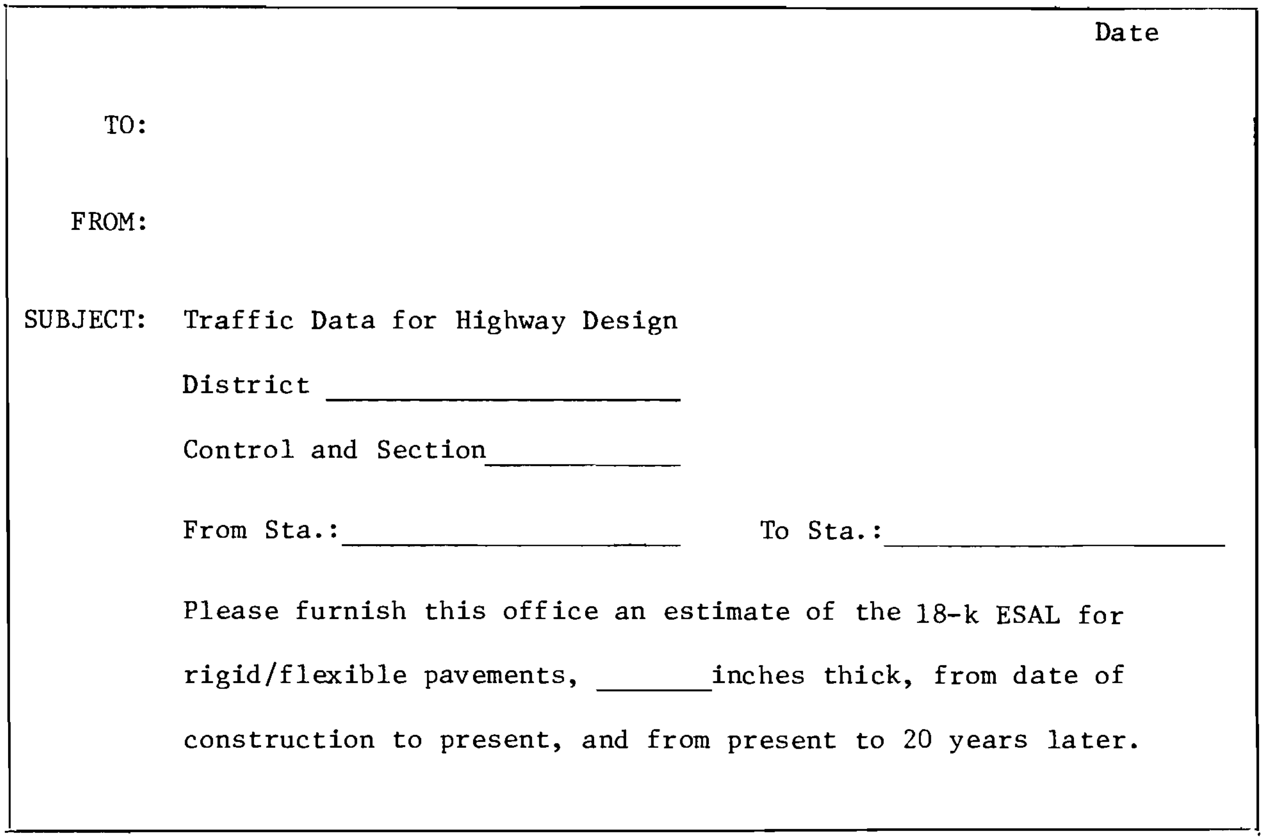
Allowable Working Stress in Steel __________(psi)

Cross-Sectional Area of Rebar __________(in^2)

Fig B.1. Design input summary sheet.

Description of Location	Average Daily Traffic		Directional Distribution Factor	Design Hourly Volume	Percent Trucks		Anticipated Annual Rate of Growth	ATHWLD	Percent Tandem Axles in ATHWLD	Total Number of Equivalent 18K Single Axle Load Applications One Direction Expected for a 20-Year Design Period (19 to 19)	
	1975	1995			ADT	DHV				Flexible Pavement	Rigid Pavement
1. West Loop Freeway (IH 610) North of Southwest Freeway (US 59)	168,000	263,000	57-43%	10.9%	8.0	5.0	2.8%	14,500	10	55,619,000	81,655,000
2. South Freeway (SH 288) North of South Loop Freeway (IH 610)	40,000	130,000	65-35%	14.1%	4.7	2.9	11.2%	14,500	10	11,879,000	17,566,000

Fig B.2. Traffic analysis for highway design.



Date

TO:

FROM:

SUBJECT: Traffic Data for Highway Design

District ______________________

Control and Section____________

From Sta.:_____________________ To Sta.:______________________

Please furnish this office an estimate of the 18-k ESAL for rigid/flexible pavements, _______inches thick, from date of construction to present, and from present to 20 years later.

Fig B.3 Request form to D-10 for traffic data.

TABLE B.1. ESTIMATED DIRECTION DISTRIBUTION FACTORS FOR CRCP IN TEXAS* (FROM REF 20)

Highway Section	District	% Traffic	
		EB or NB	WB or SB
IH 10	13	30	70
	20	31	69
	24	34	66
IH 20	10	57	43
IH 30	1	49	51
	19	58	42
IH 35	9	37	63
IH 45	17	22	78

*This data may change with time as the direction of heavy loads may shift due to changing conditions.

a relationship between percent of highway defects and percent of traffic to be assigned to each direction of the highway was developed; this relationship was used to define the DD factors. If no data are available, a DD factor of 0.5 may be assumed.

The lane distribution factor relates the number of 18-k ESAL moving in the heaviest traveled lane to the number moving in the same direction. For two-lane roadways (both directions), this factor is simply 1.00. For highways with more than one lane in each direction, this factor may vary between .8 to 1.0 for two lanes in a single direction and .6 to .8 for 3 or more lanes in each direction. A conservative value (high) should be used if the lane distribution information is not known.

SUBBASE DESIGN

Subgrade [To Replace F106 (b)]

The modulus of support or reaction k-value must be evaluated for the existing material. This value can be determined with plate load tests or through correlation with other soil tests such as presented in Ref 33.

Evaluation for modulus of subgrade, k, by the plate-load test, is too cumbersome to be repeated often enough to account for variation within any new location project. Generally, the Engineer's experience and knowledge of local material is the best source of information. Soil surveys and laboratory tests will aid the Engineer in his estimate. For evaluation of existing pavements the Dynaflect has given useful data. It has been common practice to lime-stabilize clay subgrades to provide an all-weather working table to promote faster construction. Lime stabiliation has also been used to reduce potential swelling problems. In general, lime-stabilized subgrade does not provide significant structural support for the concrete slab. Asphalt or portland cement stabiliazation of sandy soild has been used infrequently for special problems, and, because of the lack of performance experience with this type design, it should not be considered as having additional structural value unless experience can be documented.

Subbase*

A subbase is defined as a foundation course placed between the subgrade and the concrete pavement. The primary function of a subbase is to improve the foundation for the pavement so that the foundation can withstand the effect of large amounts of water that infiltrate the concrete pavement. Secondary functions include providing a working table for construction traffic and strengthening the foundation so that a lesser slab is required. A subbase achieves its primary function by being either erosion-resistant or a drainage layer in an overall drainage system that rapidly carries away the infiltrating water so that high pore pressures under load do not develop. The value of the subbase as a part of the load-carrying structure depends on its strength or modulus of elasticity as compared to the strength or modulus of the pavement slab. A stress analysis should be performed if consideration is to be given to the structural value of the subbase.

The three types of materials that have proven most successful as water-resistant (non-pumping) subbases are: (1) durable, lean concrete; (2) erosion resistant soil cement; and (3) moisture resistant (non-stripping) bituminous mixtures.

1. A lean portland cement concrete base of four inches or greater may be used if a bond breaker is provided to prevent cracks in the base from reflecting into the concrete pavement. It appears that the concrete base can have a relatively low cement factor if a good entrained air system can be achieved to provide adequate workability and sufficient durability. The optimum cement and air contents for the material to be used should be determined in the laboratory.
2. Enough cement should be used in the soil cement base to assure an erosion resistant material. The Portland Cement Association recommends an increase in cement content for soil cement base to resist erosion where this material is used as riprap on dams. Bases under concrete pavement should have the same consideration since they are subject to similar or greater erosive action due to pumping. A bond breaker is needed to prevent the cracks in the soil cement from reflecting through the concrete surface.

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*Taken from Appendix F of the "Texas SDHPT Operations and Procedures Manual," without change.

3. To provide erosion resistance in bituminous mixtures, relatively high asphalt content (low air voids) and either non-stripping aggregates or anti-stripping agents are required. Recent observations have indicated that the benefits of a bituminous subbase may be reduced by the bonding of the concrete pavement to the subbase and the resultant reflection cracking of the pavement joints down through the subbase.

After providing materials that will satisfy the primary function of being non-erosive, the designer must be assured that these materials are of quality and quantity such that will provide an adequate working table for construction equipment and for foundation improvement (if this is a consideration in design).

Stabilized subbases will be required under all concrete pavement except for the following three cases:

1. In areas where other materials have given satisfactory performance for a similar design and traffic.
2. In areas where the cost of subbase approaches the cost of the concrete slabs and where there are concrete curbs or concrete shoulders or where concrete slab extends a minimum of 3 feet beyond the shoulder line, the subbase may be deleted by increasing the slab thickness a minimum of 3 inches. A cost analysis will be necessary to justify the extra slab thickness in lieu of a design with a subbase.
3. Where the contractor elects to place the subbase with the concrete pavement in one pass, the material specified for the pavement will be used for the entire depth. This would probably be economical in only a few locations and where the design is non-reinforced or lightly reinforced slabs. In this type design the dowel bars remain the same size but reinforcing steel and tie bars will have to be increased in size to keep the area of the steel at approximately the same percentage of the slab's cross-sectional area.

Subbase Design [To be inserted in Section F106 between Sections (c) and (d)]

There are two important factors to be considered in evaluating the strength of the proposed subbase-on-subgrade combination. These are (a) improved support strength of the layered system and (b) the capability of a layered system to maintain its strength and integrity under heavy highway traffic loadings in the presence of moisture or marginal drainage conditions.

The effect of the composite k-value due to the layered effect of the pavement structure may be accounted for as described below under "Effect of Layered System." In using this approach, the designer assumes the material does not lose its integrity due to water erosion. Since most unstabilized materials and some stabilized materials lose part of their integrity during their service life due to pumping, consolidation, erosion, etc., this effect must be considered in design.

Effect of Layered System. The design chart for evaluating the effect of the layers in the structure is shown in Fig B.4. The material parameters required in this analysis are the stiffness of the subbase material and the modulus of subgrade reaction. The designer begins with a trial or preselected subbase thickness and projects the corrected k-value at the top of the subbase.

If more than one material is being used for the subbase layer, the designer may take this into account by applying this procedure for each layer. The first time through gives the corrected support value at the top of the first layer. With this value and the thickness and stiffness of the next layer, a new k-value at the top of the next layer is determined. The process is repeated until the k-value immediately below the concrete pavement is obtained. This procedure may be used to determine the structural contribution of a drainage layer if it is provided.

Correction for Erodability and/or Loss of Support. The influence of material erodability and support loss on the long-range characteristics of subbase support may be evaluated by using Fig B.5. The composite k-value from Fig B.4 is projected from the horizontal axis to the appropriate support loss factor of the subbase material. The design k-value will always be equal to or less than the layered k-value, with the reduction depending on the material quality and its ability to resist erosion and movement.

A "support loss factor" (LF) is assigned to subbase materials to account for support loss over the life of the pavement. This factor ranges from 0 to 3, with 0 representing no erosion of the subbase and 3 representing the erosion of a highly erosion-susceptible material.

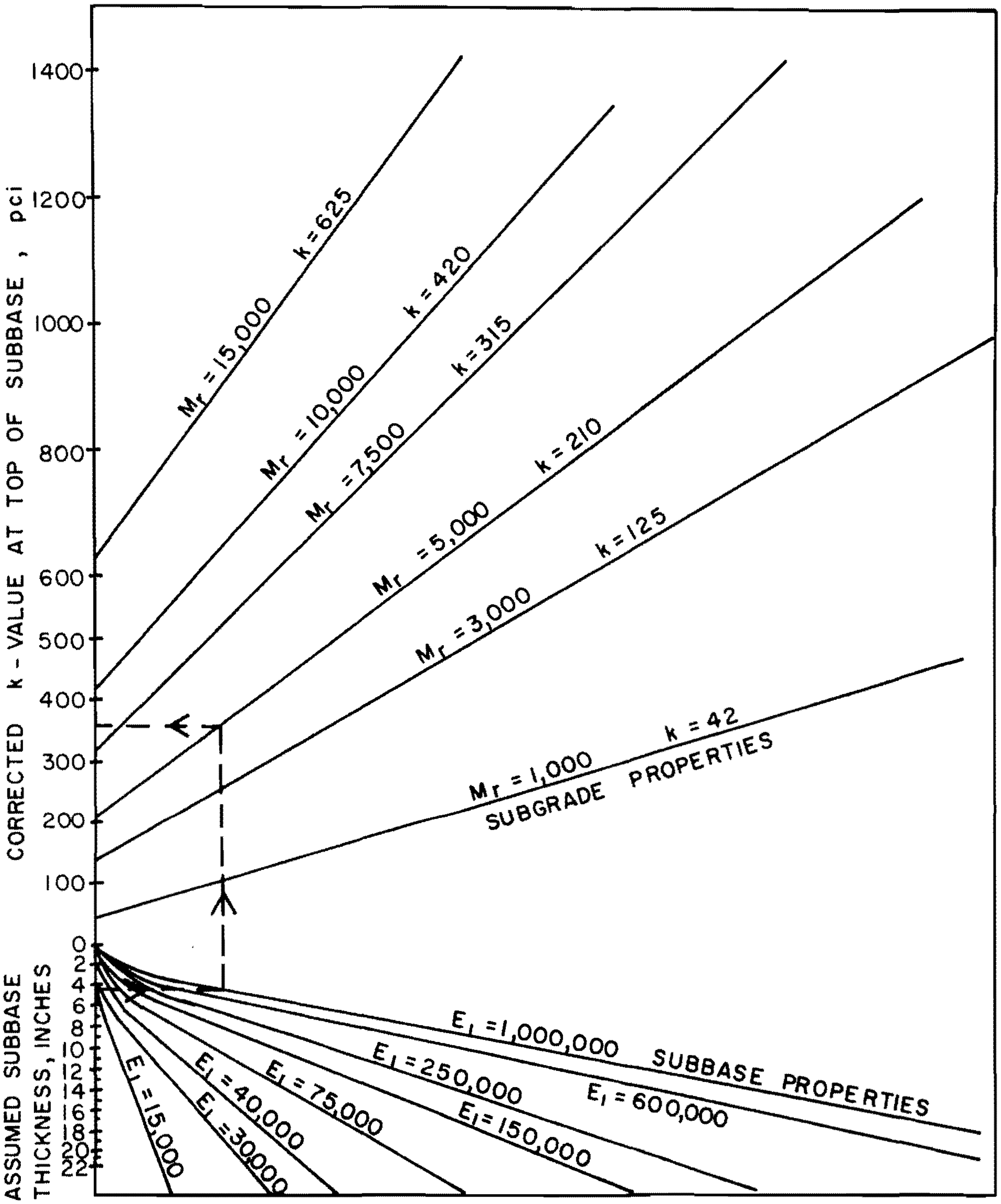


Fig B.4 Chart for adjusting k-value for effect of subbase layers

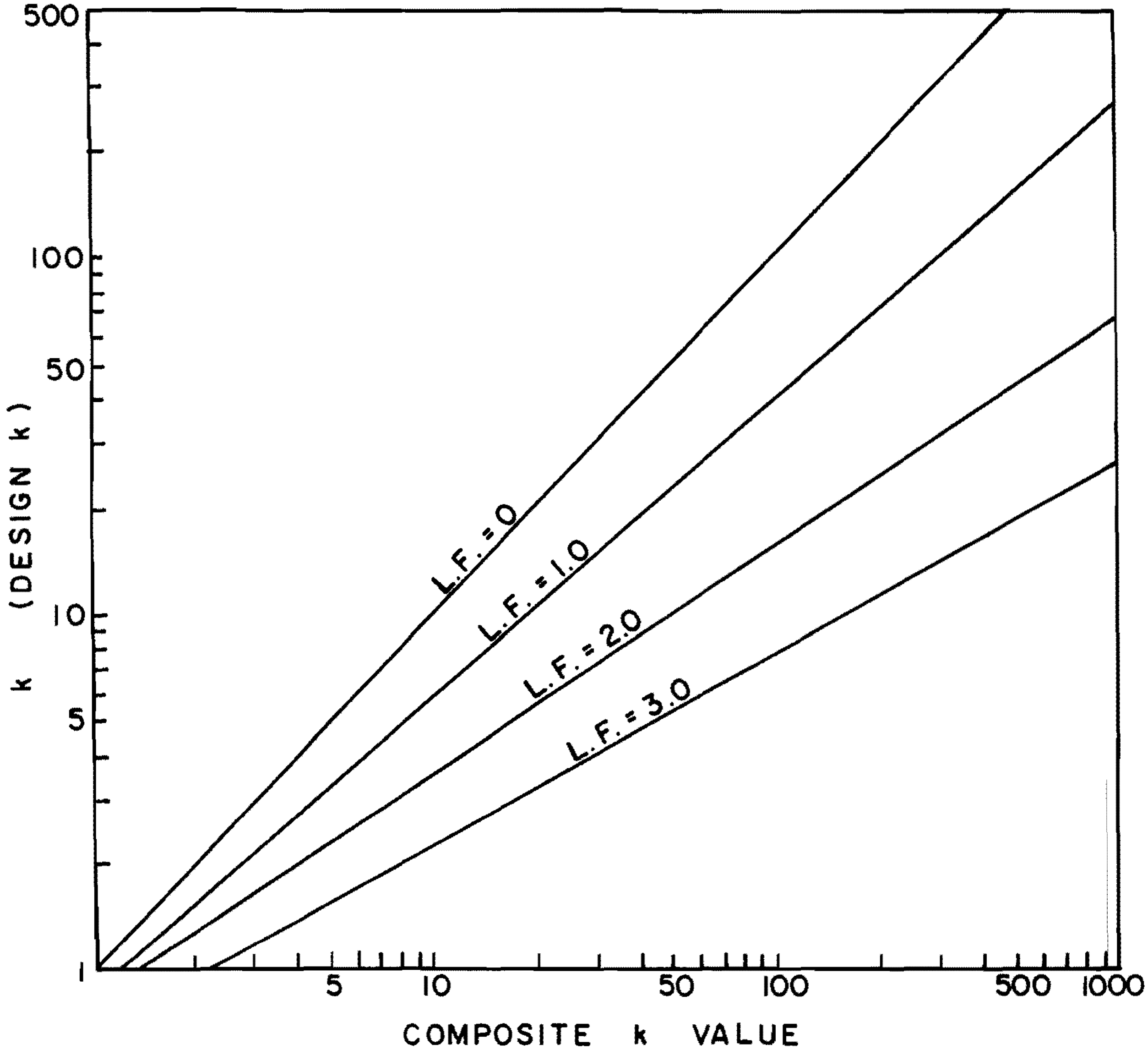


Fig B.5. Correction of k-value for subbase loss.

At the present time, no tests are available that may be used to directly determine this factor. Suggested values for several categories of subbase systems are presented in Table B.2.

SLAB THICKNESS DESIGN [To Replace Section F106(a)]

The slab thickness design is based on the revised AASHTO rigid pavement design equation which relates the number of 18-kip ESAL applications to a selected level of serviceability. The effect of voids between the concrete slab and subbase is incorporated in this equation indirectly through the K-value due to their effects on serviceability at the AASHO Road Test. A correction may also be applied to the composite k-value on top of the subbase for soils that have high differential expansive or settlement characteristics since voids may be produced. For these conditions, a support loss factor of 1 to 3 is suggested. The effects of tied concrete shoulders and adjacent lanes are incorporated into the design deducting one inch in thickness from the value given by the nomograph, if experience has shown that the resulting thickness will be satisfactory.

The following input quantities to the thickness design should be recorded on the input summary sheet in Fig B.1:

(1) number of 18-kip ESAL applications expected over the design period in the design lane (Section F105);

(2) the allowable working flexural stress in the concrete;

(3) the concrete modulus of elasticity; and

(4) the design modulus of reaction (k-value) on top of the subbase [Section F106(b)].

The nomograph for easy solution of the design equation is shown in Fig B.6. The design thickness is found by first making the appropriate input values on the various scales. Then, starting at the far left on the traffic scale, a line is constructed passing through the values on the traffic scale and working stress and intersecting turning line 1. Next, a similar line is constructed through the design values on the k-value and modulus of elasticity scales and projected to turning line 2. The thickness is then located by constructed lines and the two turning lines. The thickness may be estimated to the nearest tenth of an inch.

TABLE B.2. TYPICAL SUPPORT LOSS FACTORS OF SUBBASE MATERIALS

	Support Loss Factor	
Material	Stable Subgrage	Unstable Subgrade
Lean concrete base	0	1 - 2
Cement aggregate mixtures	0 - 1	1 - 2
Asphalt treated base	0 - 1	1 - 2
Bituminous stabilized mixtures	0 - 1	1 - 2
Lime stabilized materials	1 - 2	2 - 3
Unbound granular materials	1 - 3	2 - 3
Fine grained materials	2 - 3	2 - 3

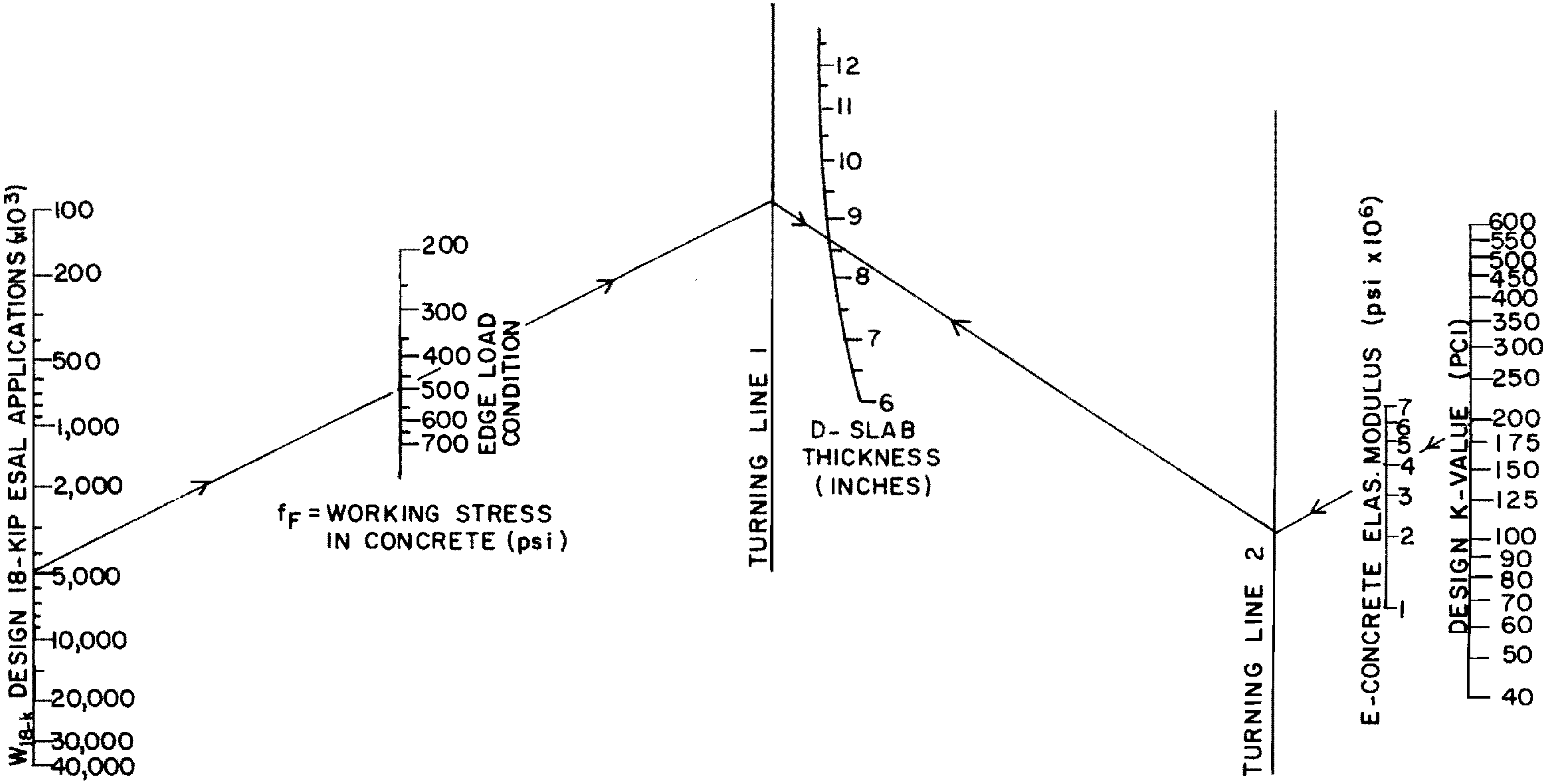


Fig B.6. Thickness design nomograph for CRC pavements.

REINFORCEMENT DESIGN [To Replace Section F108]

The principal reinforcement in CRCP is the longitudinal steel which is essentially continuous throughout the length of the pavement. Transverse reinforcement is provided to a lesser degree in some pavements. Other reinforcement is used at terminal anchorages, construction joints, and edges of pavements with tied shoulders. These other types of reinforcement are discussed elsewhere.

The longitudinal reinforcement is used to control cracks which form in the pavement due to volume change in the concrete. It is the restraint of the concrete due to the steel reinforcement and subbase friction which causes the concrete to fracture. A balance between the properties of the concrete and the reinforcement must be achieved to cause the pavement to respond in a satisfactory manner. It is the evaluation of this interaction which forms the basis of this reinforcement design.

The purpose of transverse reinforcement in a CRC pavement is to control the width of any longitudinal cracks which may form. Transverse reinforcement is not required for CRC pavements in which no longitudinal cracking is likely to occur. However, if longitudinal cracking does occur, transverse reinforcement will restrain lateral movement and minimize the deleterious effects of a free edge.

Longitudinal Reinforcement

The design procedure presented here may be systematically performed using Worksheet 1 (Fig B.7). Space is provided for entering the appropriate design inputs, intermediate results, and calculations for determining the required amount of longitudinal steel reinforcement. The design inputs may be taken from the completed input summary sheet in Fig B.1. A separate worksheet, i.e., Worksheet 2 (Fig B.8), is provided for design revisions.

Limiting Design Criteria. To determine levels of steel reinforcement for a CRC pavement, limits on acceptable levels of crack spacing, crack width, and steel stress are established which minimize distress manifestations common to this pavement type. These levels are based on theoretical considerations and field performance studies. These limiting levels are then used

Input Variable	Value	Input Variable	Value
Rebar Diameter	in	Wheel Load Stress	psi
Concrete Shrinkage	in/in	Design Temp Drop	°F
Concrete Tensile Strength	psi	Thermal Coefficient Ratio α_s/α_c	

	Crack Spacing	Crack Width	Steel Stress	Design Steel Range
Value of Limiting Criteria	Min: 3.5 ft Max 8.0 ft	in	psi	
Minimum Required Steel Percentage				P^*_{min}
Maximum Required Steel Percentage		☒	☒	P^*_{max}

*Enter the largest percentage across line

If $P_{max} < P_{min}$ then reinforcement criteria are in conflict.
Use Worksheet 2 if reinforcement Criteria are in conflict.

Fig B.7. Worksheet 1. Longitudinal reinforcement design.

	Change in Value from Previous Trial					
Parameter	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	
Rebar Diameter (2)						
Concrete Shrinkage						
Concrete Tensile Strength (2)						
Wheel Load Stress						
Design Temperature Drop (1)						
Crack Width Criterion						
Steel Stress Criterion						
Required Steel % for Crack Spacing						minimum
						maximum
Required Steel % for Crack Width						
Required Steel % for Steel Stress						
Minimum % Reinforcement P_{min}						
Maximum % Reinforcement P_{max}						

1. Change in this parameter will affect crack width criterion.
2. Change in this parameter will affect crack stress criterion.

Fig B.8. Worksheet 2. Revised Longitudinal reinforcement design.

to estimate the required level of reinforcement which will cause the pavement to satisfactorily respond to the anticipated environmental and vehicular loading conditions.

Crack Spacing. Limits placed on crack spacing are derived from consideration of spalling and punchouts. A maximum desirable crack spacing is derived from a correlation between crack spacing and incidence of spalling (Ref 13). A maximum crack spacing limit for use in design of 8.0 feet is recommended (Ref 13). A minimum desirable crack spacing is derived from consideration of the effect of slab length on the formation of punchouts. A limiting value on the minimum crack spacing of 3.5 feet is recommended for use in this design procedure. These criteria may be adjusted for effects of slab thickness, experience, and other considerations, as presented in Ref 13.

Crack Width. The magnitude of the crack width influences spalling and water infiltration into the pavement. Water infiltration is controlled by limits on the permanent crack width, which is related to permanent deformation of the reinforcing steel. This will be covered under the design criteria for steel stress.

The limiting criteria on crack width is derived from consideration of spalling (Ref 13). The primary spalling mechanism has been attributed to the combination of stresses resulting from environmental and vehicular loading. Crack width, which is a function of temperature dependent horizontal stresses, has been correlated with spalling.

The limiting crack width is determined with Fig B.9, using the selected design temperature drop. A vertical line is projected from the design temperature drop to the turning line. A horizontal line is projected from this intersection to the crack width scale. The limiting crack width is then read off this scale. The limiting criteria increase with temperature drop, reflecting the fact that the support conditions freeze at low temperatures, thus reducing deflection.

Steel Stress. Limiting criteria are placed on steel stresses to guard against steel fracture and excessive permanent deformation. To guard against steel fracture, a limiting stress of 3/4 the ultimate tensile strength is set. The conventional limit on steel stress is 3/4 the yield point so that the steel does not undergo any plastic deformation. Based on past experience, many miles of CRC pavement have performed satisfactorily even though the

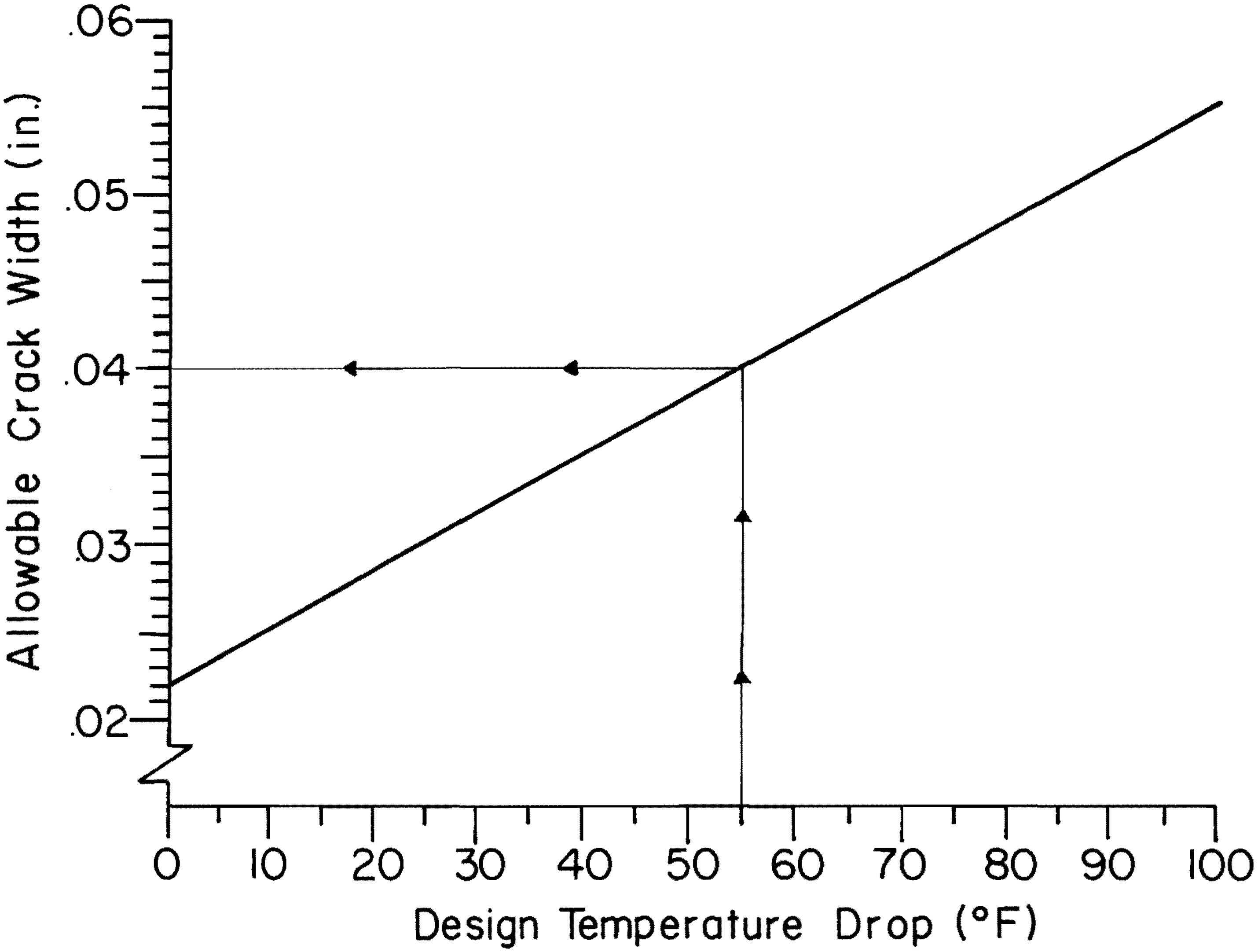


Fig B.9. Limiting crack width for design temperature drop.

steel stress was predicted to be above the yield point. This led to reconsideration of these criteria and allowance for a small amount of permanent deformation (Ref 13).

Values of allowable steel stress for use in this design procedure are listed in Table B.3 as a function of rebar size and concrete strength. The indirect tensile strength should be that determined using Ref 13. The limiting steel stresses are for 60 ksi steel meeting ASTM A 615 specifications. Guidance for determination of allowable steel stress for other types of steel is provided in Ref 13.

Design Charts. The longitudinal steel design for CRC pavements is based upon the estimated steel percentage required to satisfy the limiting criteria on crack spacing, crack width, and steel stress. This estimate is made using the three design charts presented in Fig B.10, B.11, and B.12. These design charts are based on a regression analysis of a fractional factorial study of computer program CRCP2 reported in Ref 12. A design chart is provided for each of the limiting criterion developed in the previous section. It is recommended that the designer use the computer program CRCP-2 for special or unusual conditions.

The following inputs described in Ref 32 listed on Fig B.1 are used to determine the required steel reinforcement percentage:

f_t = concrete indirect tensile strength, psi.

σ_w = wheel load stress: Fig B.13 may be used to estimate this stress.

Z = concrete shrinkage at 28 days, in./in.

ϕ = reinforcing bar diameter, in.

a_s/a_c = ratio of thermal coefficients of steel to concrete.

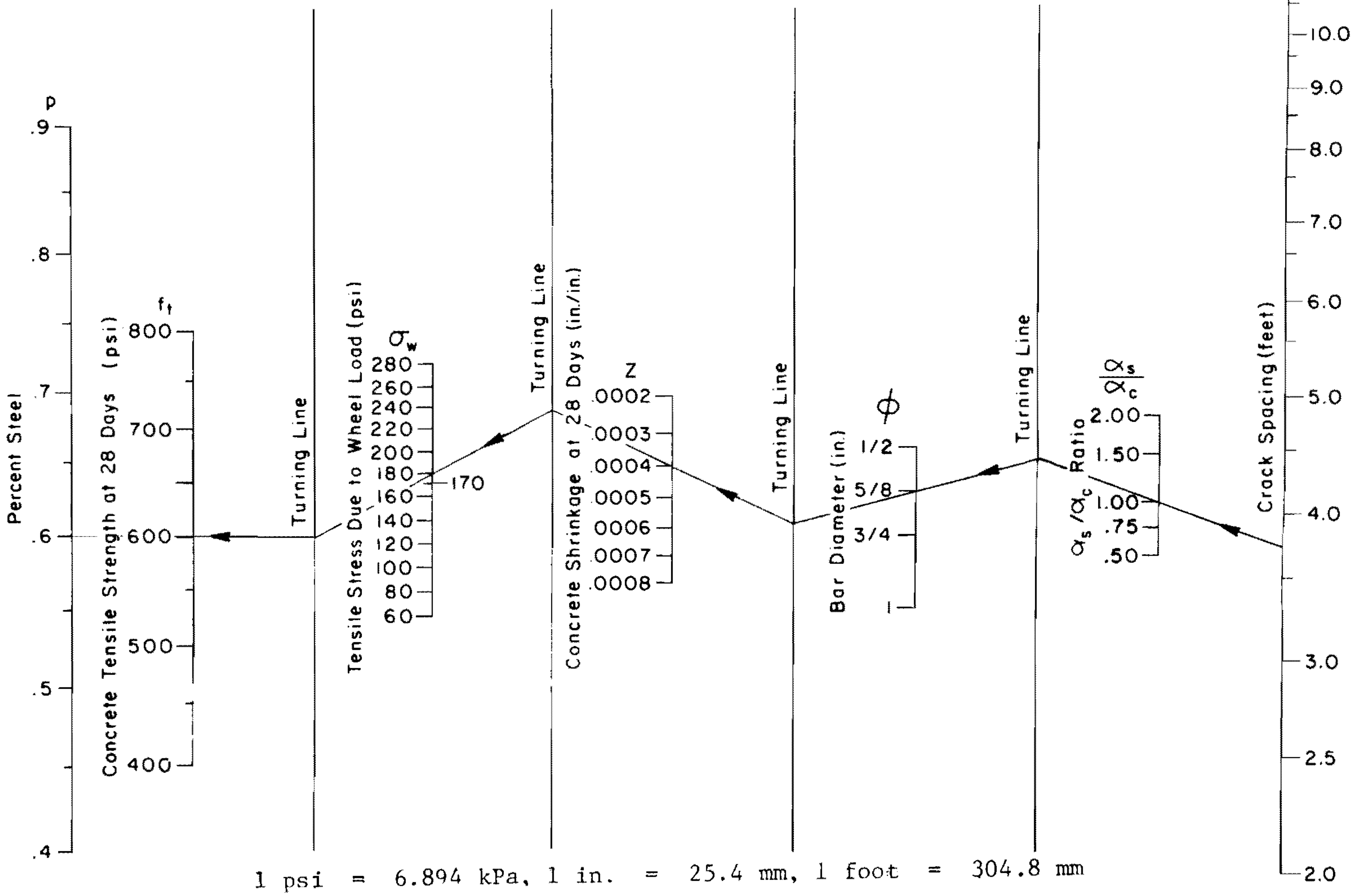
T_D = design temperature drop, F.

Recommended values of concrete properties and design temperature drops are given on Tables B.4 and B.5. It is important to note, in Table B.1, that different properties should be considered for the PC concrete depending on the aggregate type used in the mix. Suggested temperature drops to use in some parts of the state are given on Table B.5. These values are only guidlines and should be replaced if better information is available.

TABLE B.3 ALLOWABLE STEEL STRESS, KSI (After Red 13)

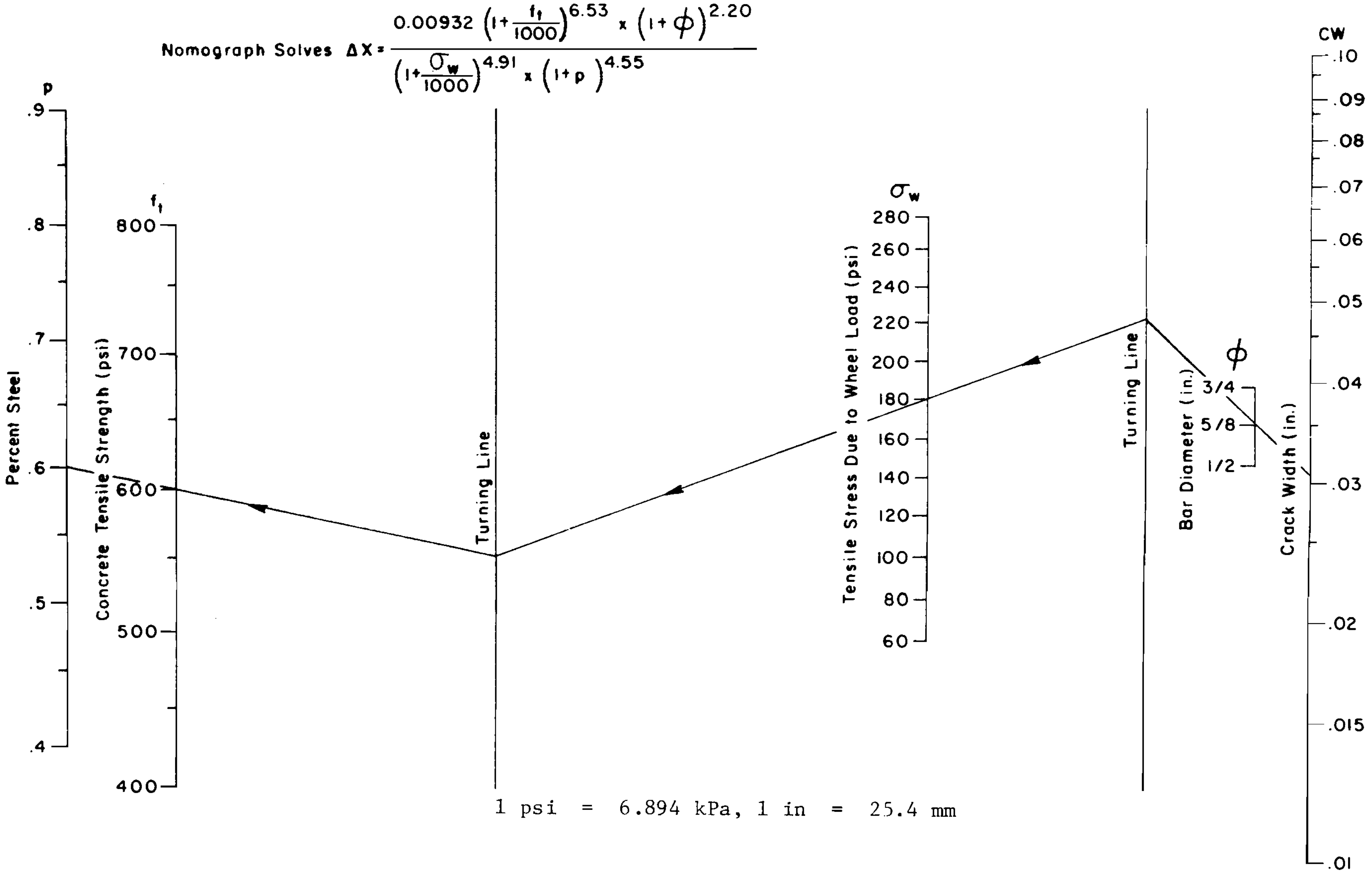
Indirect Tensile Strength of Concrete at 28 days, psi	Rebar Size		
	#4	#5	#6
≤300	65	57	54
400	67	60	55
500	67	61	56
600	67	63	58
700	67	65	59
≥800	67	67	60

Nomograph Solves $\bar{X} = \dfrac{1.32\left(1+\frac{f_t}{1000}\right)^{6.70} \times \left(1+\frac{\alpha_s}{2\alpha_c}\right)^{1.15} \times \left(1+\phi\right)^{2.19}}{\left(1+\frac{\sigma_w}{1000}\right)^{5.20} \times \left(1+p\right)^{4.60} \times \left(1+1000Z\right)^{1.79}}$



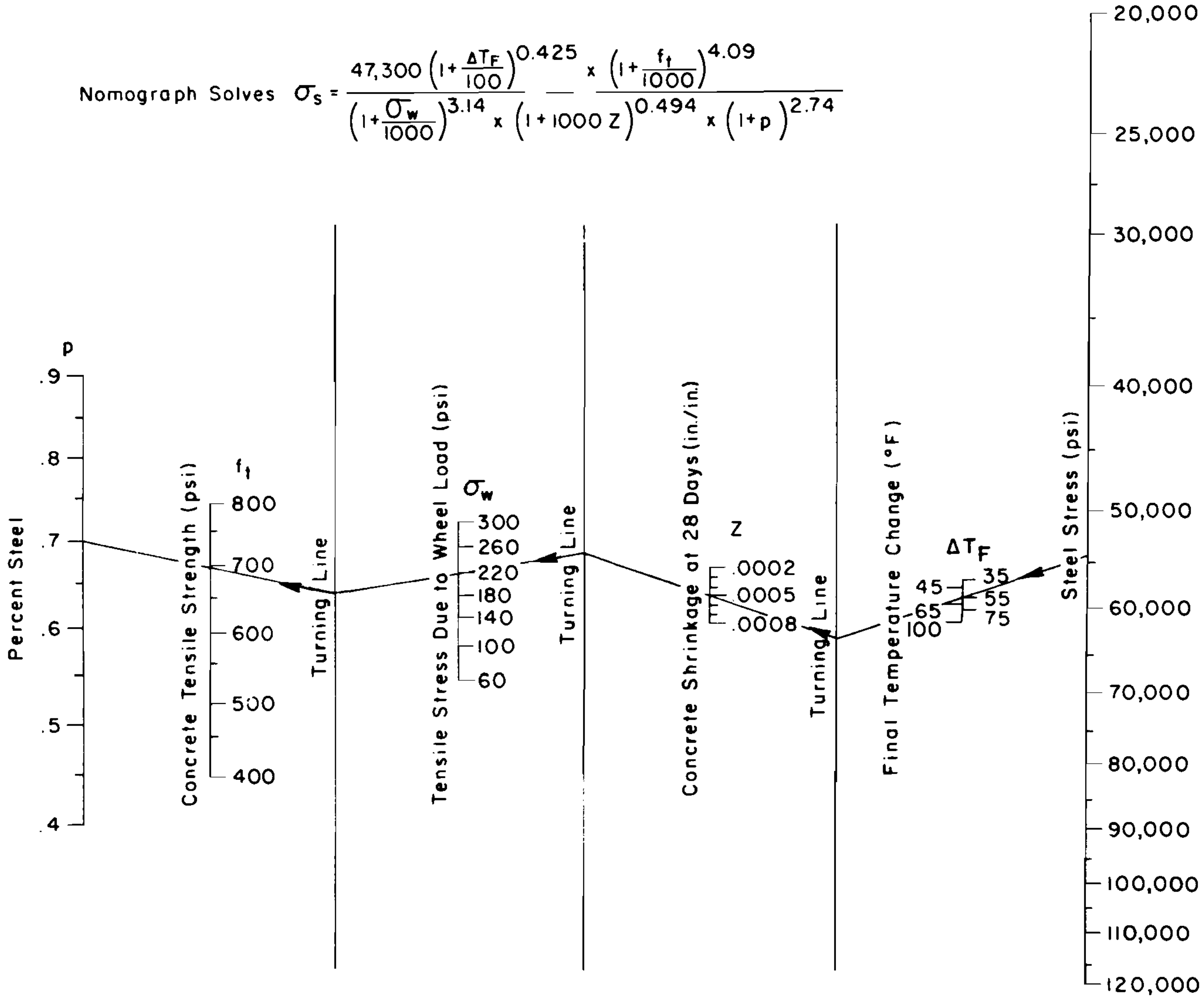
1 psi = 6.894 kPa, 1 in. = 25.4 mm, 1 foot = 304.8 mm

Fig B.10. Nomograph for prediction of crack spacing.



1 psi = 6.894 kPa, 1 in = 25.4 mm

Fig B.11. Nomograph for prediction of crack width.



Nomograph Solves $\sigma_s = \dfrac{47{,}300\left(1+\frac{\Delta T_F}{100}\right)^{0.425} \times \left(1+\frac{f_t}{1000}\right)^{4.09}}{\left(1+\frac{\sigma_w}{1000}\right)^{3.14} \times \left(1+1000\,Z\right)^{0.494} \times \left(1+p\right)^{2.74}}$

1 psi = 6.894 kPa, 1 F° = 0.556 C°

Fig B.12. Nomograph for prediction of steel stress.

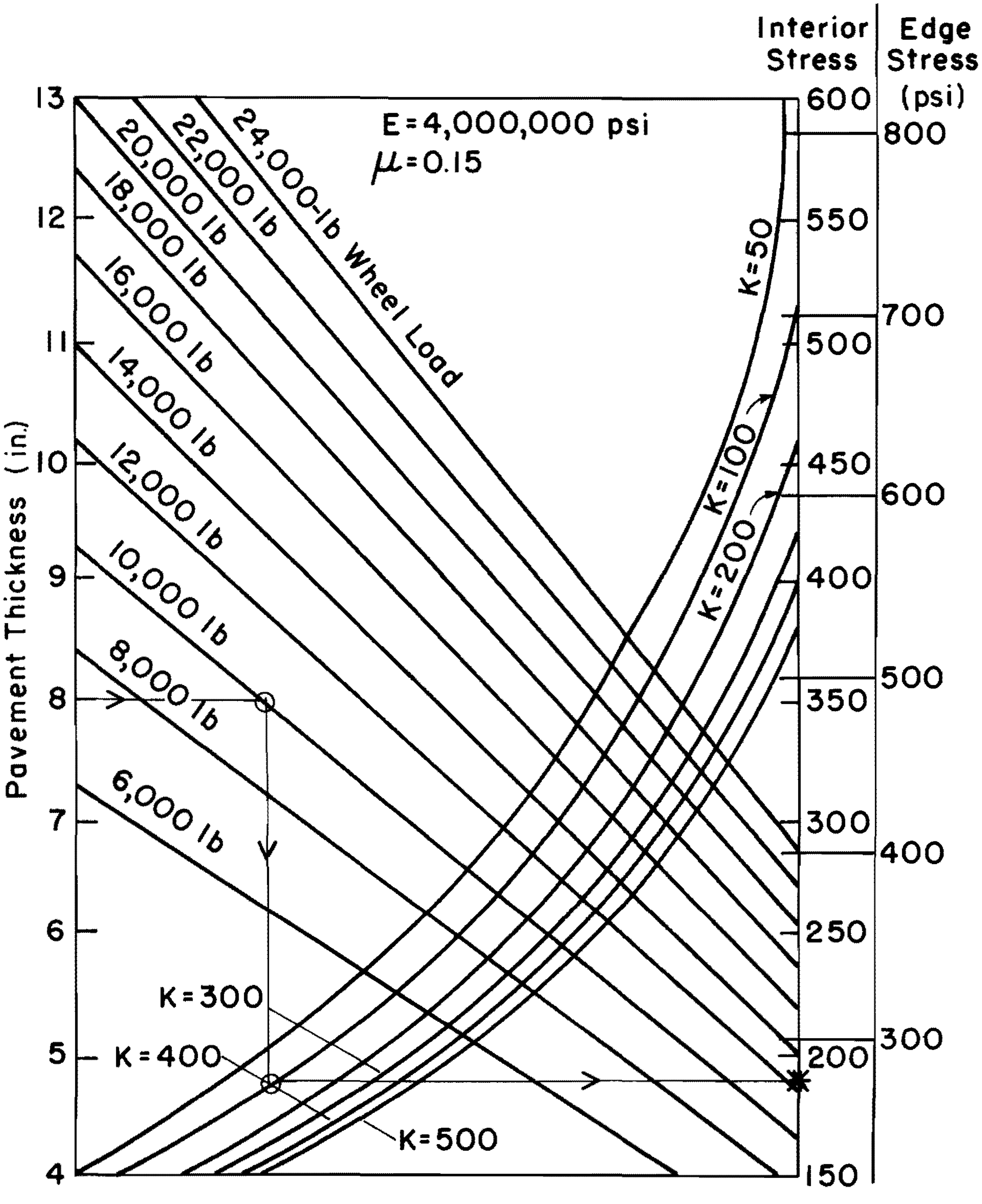


Fig B.13. Wheel load tensile stress nomograph (edge and interior condition).

TABLE B.4. RECOMMENDED VALUES OF CONCRETE PROPERTIES FOR THE DESIGN OF CRCP

	Concrete Coarse Aggregate	
	Limestone	Siliceous
Modulus of elasticity, psi	4.5×10^6	6.0×10^6
Tensile strength factor*	0.67	0.63
Shrinkage, in/in	0.0005	0.0003
Thermal coefficient ratio α_s/α_c**	1.70	1.35

*The tensile strength factor (FST) is used to determine the concrete tensile strength (f) from the allowable working flexural stress in the concrete (f_F), by means of the equation:

$$f = TSF \times f_F$$

**This thermal coefficient ratio (α_s/α_c) was calculated using a thermal coefficient of steel (α_s) of 6×10^{-6}/°F.

TABLE B.5. RECOMMENDED VALUES FOR THE DESIGN TEMPERATURE DROP* TO BE USED FOR THE DESIGN OF CRCP

Location	ΔT
Amarillo	85
Austin	80
Dallas-Ft. Worth	80
El Paso	85
Galveston	65
Houston	65
Lubbock	90
Port Arthur	65
San Antonio	80
Victoria	65
Waco	80
Wichita Falls	85

*The design temperature drop (ΔT) is defined as the algebraic difference between the expected temperature at the time of placing the concrete and the minimum expected temperature during the life time of the pavement.

The design charts are used by constructing a continuous line across the chart intersecting the appropriate design values on the various scales. The design charts are constructed with the limiting criterion scale on the right. This allows the designer to begin with the limiting criterion and working to the left, to solve for the required steel percent.

The design charts may also be used to predict the response of a CRC pavement by starting with the steel percentage and working backwards, to the left, to the estimated crack spacing, crack width, or steel stress. This procedure may be used to check the appropriateness of a final design.

Design Procedure. The following procedure may be used to determine the amount of longitudinal reinforcement.

(1) List design input values and limiting criteria in the appropriate spaces on Worksheet 1 (Fig B.7).

(2) Solve for the required amount of steel reinforcement to satisfy each limiting criterion using the design charts in Figs B.10, B.11, and B.12. Record the resulting steel percentages in the provided spaces on Worksheet 1.

(3) If $P_{max} \geq P_{min}$, go to step 4. If $P_{max} < P_{min}$,

   (a) Review the design inputs and decide which input to revise.

   (b) Indicate the revised design inputs on Worksheet 2 (Fig B.8). corresponding change in the limiting criteria as influenced by the change in design parameter and record this on Worksheet 2. Check to see if the revised inputs affect the subbase and slab thickness design. It may be necessary to reevaluate the subbase and slab thickness design.

   (c) Rework the design nomographs and enter the resulting steel percentages on Worksheet 2.

   (d) If $P_{max} \geq P_{min}$, to to step 4. If $P_{max} < P_{min}$, repeat this step using the space provided on Worksheet 2 for additional trials.

(4) Determine the range in the number of rebars required:

$$N_{min} = .01273 \frac{P_{min} W_s D}{\phi^2} \qquad \text{(B.3.1)}$$

$$N_{max} = .01273 \frac{P_{max} W_s D}{\phi^2} \qquad (B.3.2.)$$

where

N_{min} = minimum required number of rebars,

N_{max} = maximum required number of rebars,

P_{min} = minimum required percent steel,

P_{max} = maximum required percent steel,

W_s = total width of pavement section, in.,

D = thickness of concrete layer, in., and

ϕ = rebar diameter, in.

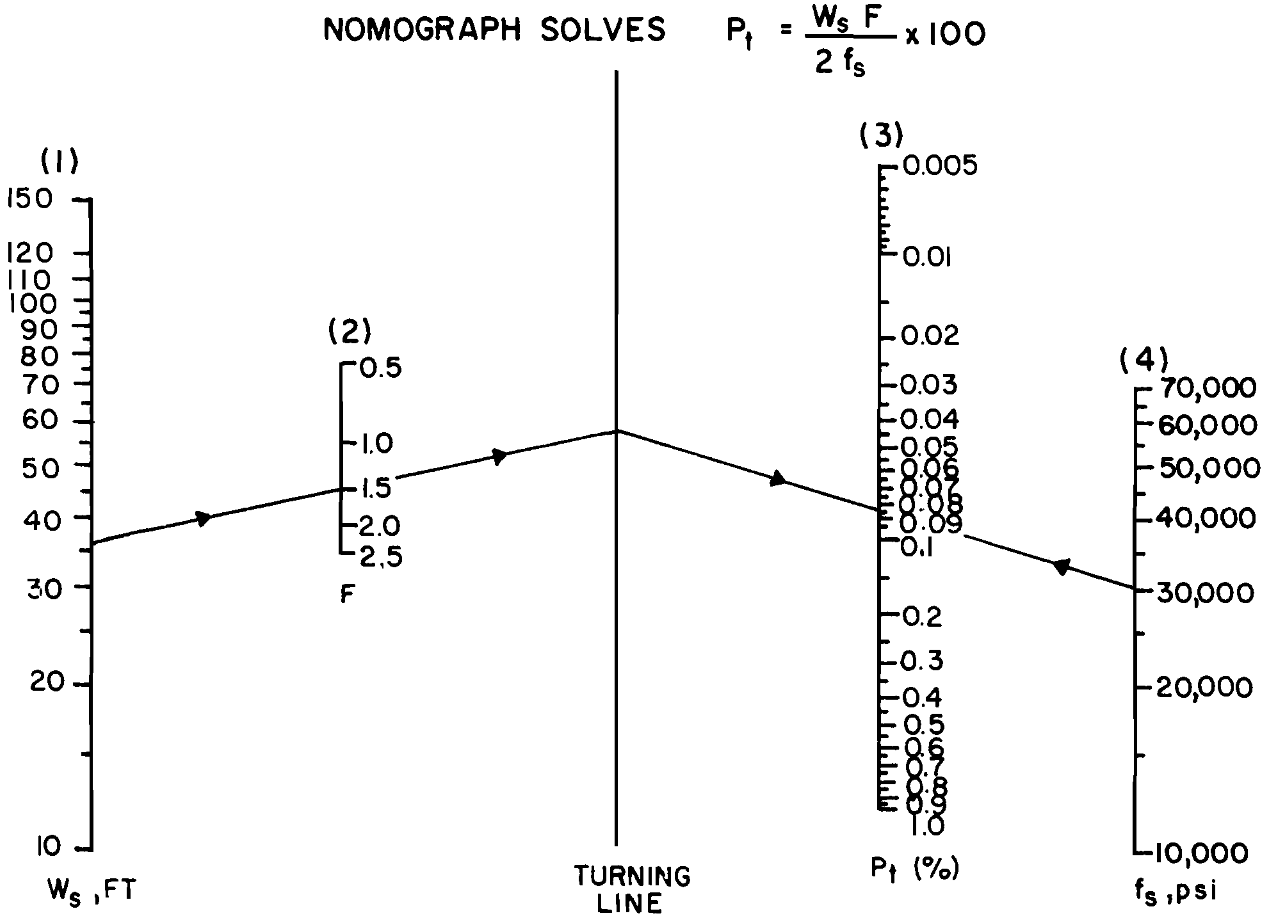
(5) Determine the final steel design by selecting the total number of rebars in the final design section, N_{Design}, such that N_{Design} is a whole integer number between N_{min} and N_{max}.

Transverse Reinforcement Design

The design of transverse reinforcement and tie bars is based on the subgrade drag theory similar to the method in Ref 34. The inputs to determine the required steel percentage are the total width of the pavement section, subbase friction factor, and the allowable stress in the steel. The total width of the pavement section should include the width of tied shoulders if present.

The solution for the required amount of transverse steel may be obtained with the nomograph in Fig B.14. The steel percentage is determined by constructing a line starting at the pavement width on scale 1, passing through the subbase friction factor on scale 2, and intersecting the turning line. A line is then constructed from this point on the turning line through the allowable steel stress on scale 4. The steel percentage is then read off of scale 3 at the intersection with the previously constructed line.

The required percent transverse steel may also be determined by evaluating the equation indicated at the top of Fig B.14.



Example Problem:

W_s = 36 ft.

F = 1.5

f_s = 30,000 psi

Solution:

P_t = .085%

Scale:

P_t = Transverse steel, %

W_s = Slab width, feet

F = Subbase friction factor

f_s = Allowable working stress in steel, psi (.75 yield strength)

Fig B.14. Transverse steel reinforcement design chart.

The required percent steel determined above is based on a concrete unit weight of 144 lb/ft. This percentage may be adjusted for concretes of differing unit weights as follows:

$$P_{tc} = P_t \frac{W_t}{144}$$

where

P_{tc} = corrected percent transverse stee,

P_t = percent transverse steel computed above, and

W_t = unit weight of concrete, lb/ft^3.

Determination of the unit weight of concrete is covered under ASTM C 138-75 and AASHTO T 121 test specifications.

The steel percentage determined above is the amount of the reinforcement required to keep a longitudinal crack which forms in the center of the pavement closed. The amount of transverse reinforcement may be reduced toward the edges of the pavement as illustrated in Fig B.15.

The percent transverse steel may be converted to spacing between reinforcing bars as follows:

$$Y = \frac{A_b}{P_t D} \times 100$$

where

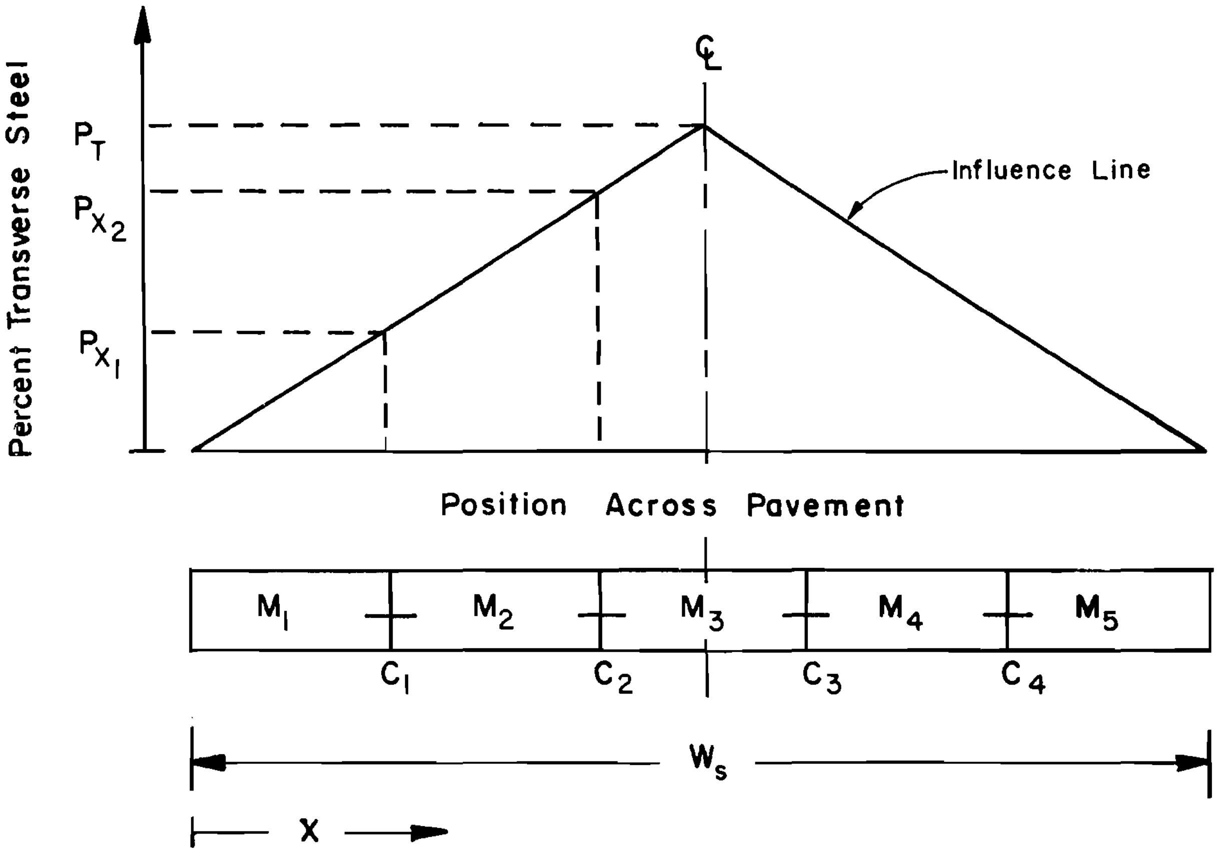
Y = transverse steel spacing, in.,

A_b = cross-sectional area of transverse reinforcing steel, in.,

P_t = percent transverse steel, and

D = pavement thickness, in.

Some continuously reinforced concrete pavements have been designed without transverse reinforcement. These pavements should perform satisfactorily unless longitudinal cracking occurs. It is recommended that all CRC pavements contain transverse reinforcement, especially in areas where frost-susceptible or expansive soils exist. If longitudinal cracking does occur, the transverse reinforcement will restrain lateral movement and eliminate the deleterious effects of free edges.



$$P_X = 2\ P_T\ \frac{W}{W_s}$$

where

P_T = Design percent steel in center of pavement,

W_s = Total width of pavement slab,

X = Distance from a free edge to the most interior point of the area under consideration,

P_X = Reduced percent transverse steel at location X,

M_X = Concrete placement module.

Fig B.15. Reduction of transverse steel across pavement.

OVERLAY [To Replace Section F109]

The design of an overlay is unique to each particular project. The most common practice is the use of asphaltic concrete pavement to restore serviceability. This may also, for a time, reduce joint maintenance and improve drainage characteristics, but it does not provide long-term solution to most problems. Considerable thickness of asphaltic concrete is needed to provide structural value and to postpone reflection cracking. A detailed study of the existing surface and a thorough analysis of the expected results should be performed in the consideration of an asphaltic concrete pavement overlay.

A limited amount of experience is available in the use of relatively thin continuously reinforced overlays. A minimum thickness of 6 inches has given satisfactory performance. Experience in other states indicates that thinner, more economical overlays may be appropriate in some cases. A thorough analysis of existing conditions and possible solutions should be performed for each project.

The computer program RPOD2 (Ref 25) can be used for the detailed analysis; this program is available on the Texas SDHPT computer and a copy of the input guide has been included in Appendix C of this report. The program will output a thickness-traffic relationship for the specific conditions of the project which the designer uses with his known traffic to obtain the design thickness. A typical curve for a recent overlay project has been included as Fig B.16. The total equivalent 18-kip ESAL single axle load expected in the design lane from Section F105 is used to enter the graph for determining the overlay thickness.

Deciding When to Overlay. An equation has been developed using past condition survey data in the state to decide when to overlay a CRCP (Ref 19).

The equation is

$$z = 2.113 - 0.138F - 0.032MS - 0.020SS$$

where

z = overlay decision index;

F = failures per mile;

MS = minor spalling, percent; and

SS = severe spalling percent.

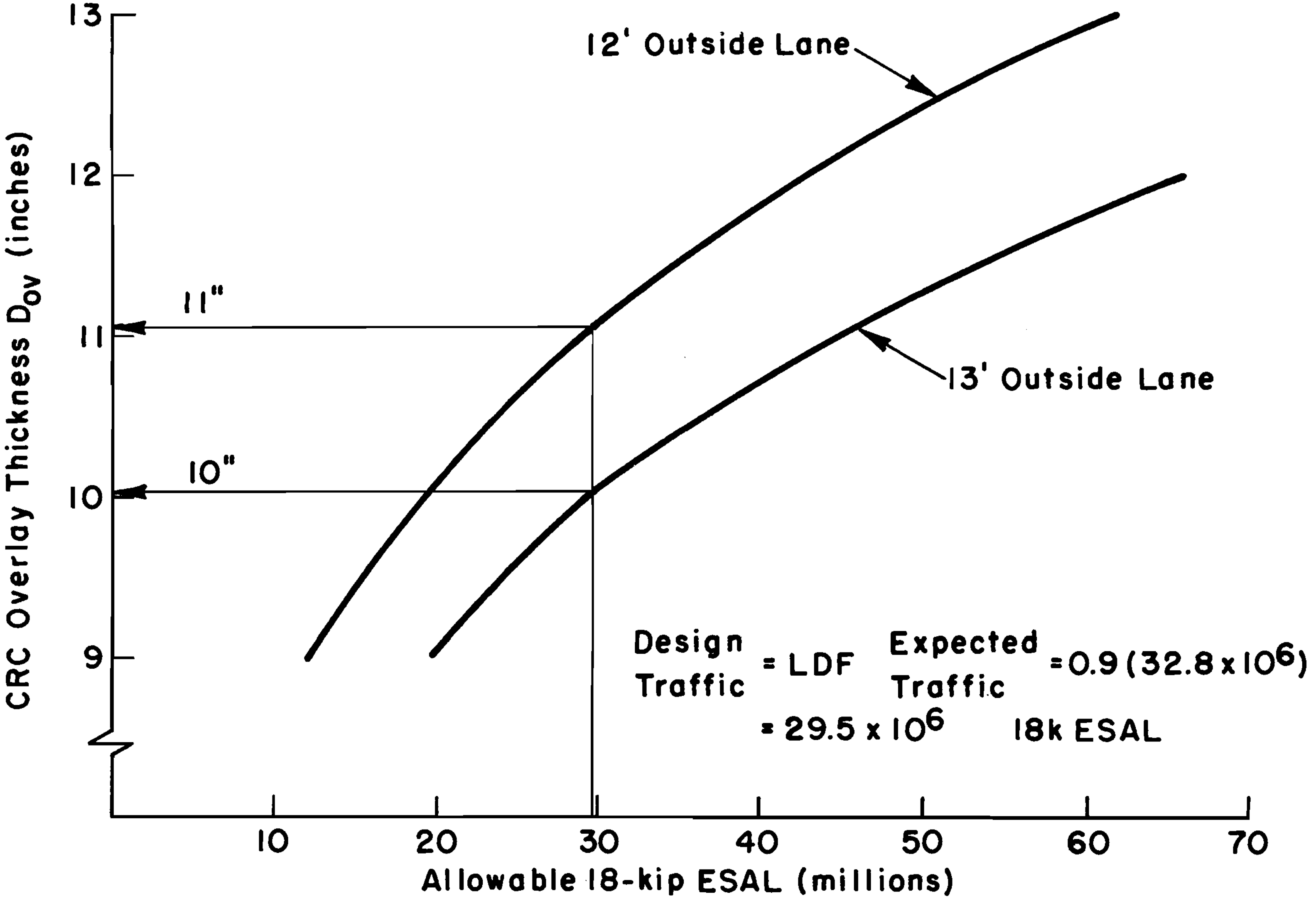


Fig B.16. Typical CRCP overlay thickness design curves (Project IH-10, Hudspeth County, Texas, 1979).

For any given pavement section, the input parameters have to be obtained by surveying the distress condition of the road. These parameters are substituted in the equation to obtain the z value. If the z value is smaller than zero, the pavement is a candidate to be overlayed. If the z value is positive, the pavement is in good condition; the higher the z value, the better the condition of the pavement.

APPENDIX C

RPOD2 INPUT GUIDES

RIGID PAVEMENT OVERLAY DESIGN PROGRAM (RPOD2) INPUT GUIDES

This appendix presents two input guides for use with RPOD2; a random order input guide recommended for most users and a fixed order input guide intended to be a user's manual. If the user desires a more detailed description of the procedure, he is directed to the Center for Transportation Research Report 177-13, by Otto Schnitter, W. R. Hudson, and B. F. McCullough. The two input guides presented herein are excerpts from that report.

RPOD2

RANDOM ORDER INPUT GUIDE

INPUT GUIDE

INSTRUCTIONS TO THE PROGRAM ARE SUPPLIED IN THE FORM OF DIRECTIVES. A DIRECTIVE OCCUPIES EITHER THE FIRST OR SECOND HALF OF A CARD (COLUMNS 1-40 OR 41-80). THE FIRST EIGHT CHARACTERS OF EACH DIRECTIVE CONTAIN A KEYWORD IDENTIFYING THE TYPE OF INFORMATION BEING ENTERED. ALL KEYWORDS MAY BE ABBREVIATED TO THEIR FIRST FOUR CHARACTERS; THE REST OF THE IDENTIFIER IS IGNORED. IF THE FIRST FOUR CHARACTERS OF A DIRECTIVE ARE BLANK, THEN THE WHOLE DIRECTIVE IS SKIPPED, AND READING CONTINUES WITH THE NEXT DIRECTIVE. THIS MEANS THAT ALL DIRECTIVES MAY BEGIN IN COLUMN ONE AT THE OPTION OF THE USER.

MORE THAN ONE PROBLEM MAY BE SOLVED IN A SINGLE EXECUTION OF THE PROGRAM. EACH PROBLEM IS PREFACED WITH A *PROBLEM* DIRECTIVE AND THE LAST PROBLEM OF A RUN IS TERMINATED BY AN *END* DIRECTIVE. ALL RELEVANT INFORMATION MUST BE SUPPLIED FOR THE FIRST PROBLEM OF A RUN VIA THE VARIOUS DIRECTIVES WHICH ARE EXPLAINED BELOW. SUBSEQUENT PROBLEMS IN THE SAME RUN NEED ONLY SPECIFY DIRECTIVES WHICH ARE TO BE CHANGED; ALL OTHER VALUES WILL BE RETAINED FROM THE PRECEDING PROBLEM, WITH THE EXCEPTION OF THE CORNER DIRECTIVE, WHICH APPLIES ONLY TO THE CURRENT PROBLEM. ALL DATA ON A SINGLE DIRECTIVE MUST BE SUPPLIED, HOWEVER, EVEN IF ONLY ONE NUMBER IS BEING CHANGED.

ALL DIRECTIVES SHARE A COMMON FORMAT, BUT THE MEANINGS OF THE FIELDS DIFFER DEPENDING ON THE KEYWORD IDENTIFIER. THESE SPECIFIC MEANINGS ARE DESCRIBED BELOW UNDER THE HEADINGS OF THE APPROPRIATE KEYWORDS. THE GENERAL FORMAT IS AS FOLLOWS:

FIELD NAME	COLUMN NUMBERS	TYPE OF VALUE	FORMAT USED
KEYWORD	1-8	CHARACTER	2A4
IVL	9-10	INTEGER	I2
VAL(1)	11-20	REAL	F10.0
VAL(2)	21-25	REAL	F5.0
VAL(3)	26-30	REAL	F5.0
ITYPE(1)	31-34	CHARACTER	A4
ITYPE(2)	35-38	CHARACTER	A4

ADDING 40 TO THE COLUMNS LISTED ABOVE GIVES THE CORRESPONDING COLUMN NUMBER FOR A DIRECTIVE WHICH IS PUNCHED IN THE SECOND HALF OF THE CARD.

SOME DIRECTIVES REQUIRE FURTHER VALUES FROM CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE CARD ON WHICH THE DIRECTIVE APPEARS. THESE CARDS WILL BE READ IN 8F10.0 FORMAT. AS MANY CARDS AS ARE NEEDED TO HOLD THE NUMBER OF VALUES TO BE INPUT SHOULD BE SUPPLIED. IF TWO SUCH DIRECTIVES ARE PUNCHED ON A SINGLE CARD, THE EXTRA CARDS FOR THE DIRECTIVE IN COLUMNS 1 THROUGH 40 SHOULD PRECEDE THOSE REQUIRED FOR THE ONE IN COLUMNS 41 THROUGH 80.

KEYWORD DICTIONARY

BOND BKR

THIS DIRECTIVE IS NEVER REQUIRED. IF IT DOES NOT APPEAR, THEN THE DEFAULT VALUES FOR THE BOND BREAKER LAYER WILL BE USED. DEFAULT VALUES WILL ALSO BE SUPPLIED FOR ANY FIELD ON THE DIRECTIVE WHICH IS LEFT BLANK.

NOTE THAT A BOND BREAKER LAYER IS ONLY USED IF THE ≠UNBD≠ OPTION IS SELECTED ON THE OVERLAY DIRECTIVE, INDICATING THAT AN UNBONDED OVERLAY IS TO BE BUILT (SEE COMMENTS FOR OVERLAY DIRECTIVE BELOW). IF THIS OPTION IS NOT SPECIFIED, THEN THE BOND BREAKER DESCRIPTION WILL BE IGNORED, ALTHOUGH THE VALUES SUPPLIED WILL STILL BE AVAILABLE TO SUBSEQUENT PROBLEMS.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF BOND BREAKER LAYER IN PSI.
(DEFAULT IS 100000.0)
VAL(2) = THICKNESS OF BOND BREAKER LAYER IN INCHES.
(DEFAULT IS 1.0)
VAL(3) = POISSON/S RATIO FOR BOND BREAKER LAYER
(DEFAULT IS 0.3)

CORNER

THIS DIRECTIVE IS NEVER REQUIRED. IT IS USED ONLY WITH JCP EXISTING PAVEMENT, AND PROVIDES A MEASURED RATIO OF CORNER DEFLECTION TO INTERIOR DEFLECTION FOR A GIVEN PAVEMENT SECTION. THIS RATIO IS USED TO OBTAIN THE LOAD LOCATION (STRESS ADJUSTMENT) FACTOR FOR THE DETERMINATION OF REMAINING LIFE AND, FOR JCP OVERLAYS, OF ESTIMATED OVERLAY LIFE. THE LOAD LOCATION FACTOR IS DETERMINED USING INTERPOLATION IN A CURVE OF STRESS RATIO VS. DEFLECTION RATIO. THIS DIRECTIVE APPLIES ONLY TO THE PROBLEM WITH WHICH IT WAS READ. DEFAULT VALUE OF THE LOAD LOCATION FACTOR FOR JCP EXISTING PAVEMENT AND JCP/JCP OVERLAYS IS 1.5.

FIELD DEFINITIONS:

VAL(1) = RATIO OF DEFLECTION MEASURED AT A CORNER (JCP)
TO THAT MEASURED AT AN INTERIOR POINT.

DEFLECT

THIS DIRECTIVE IS REQUIRED TO DESIGNATE THE MAGNITUDE OF THE DESIGN DEFLECTION. ITS LOCATION (IN CARTESIAN COORDINATES) WITH RESPECT TO THE LOAD WHEELS OF THE DEFLECTION MEASURING DEVICE IS X = 0.0, Y = 0.0.

IF THE LOADS DIRECTIVE IS LEFT OUT, THEN THE DYNAFLECT IS ASSUMED TO BE THE DEFLECTION MEASURING DEVICE AND ONLY THE DESIGN DEFLECTION (DETERMINED FROM MEASUREMENTS BETWEEN THE DYNAFLECT LOAD WHEELS) IS REQUIRED.

IF THIS DIRECTIVE AND THE LOADS DIRECTIVE BOTH ARE LEFT OUT, THEN THE MODULUS READ ON THE SUBGRADE LAYER DIRECTIVE WILL BE USED FOR BOTH EXISTING PAVEMENT AND OVERLAY LIFE CALCULATIONS.

FIELD DEFINITIONS:

VAL(1) = DESIGN DEFLECTION IN INCHES. THIS DEFLECTION SHOULD BE REPRESENTATIVE OF THE MORE DISTRESSED PORTIONS OF THE PAVEMENT, HENCE A MINIMUM CONFIDENCE LEVEL OF 90 PERCENT IS RECOMMENDED.

END

THIS DIRECTIVE INFORMS THE PROGRAM THAT NO MORE PROBLEMS ARE TO BE EXECUTED IN THIS RUN. EVERY INPUT DECK MUST CONTAIN AN END DIRECTIVE, EVEN IF ONLY ONE PROBLEM IS TO BE ANALYZED. THIS DIRECTIVE HAS NO PARAMETERS.

LAB DATA

THIS DIRECTIVE IS REQUIRED IF THE LOAD UNDER WHICH THE DEFLECTION MEASUREMENTS WERE TAKEN DIFFERS SIGNIFICANTLY FROM THE 18-KIP SINGLE AXLE DESIGN LOAD. THIS DATA IS USED TO DETERMINE THE SLOPE OF THE SUBGRADE RESILIENT MODULUS VS. DEVIATOR STRESS CURVE. TWO OPTIONS ARE AVAILABLE FOR INPUTTING THIS DATA.

OPTION 1. THE USER CAN INPUT THE ACTUAL DATA POINTS (FROM LAB TESTS OF SUBGRADE SAMPLES DETERMINING RESILIENT MODULUS AS A FUNCTION OF DEVIATOR STRESS) AND THE PROGRAM WILL COMPUTE THE SLOPE OF THE CURVE. THE NUMBER OF DATA POINTS TO BE READ IS SPECIFIED ON THE DIRECTIVE CARD. PAIRED VALUES OF RESILIENT MODULUS AND CORRESPONDING DEVIATOR STRESS ARE READ FROM CARDS IMMEDIATELY FOLLOWING THIS DIRECTIVE IN 8F10.0 FORMAT. A MINIMUM OF TWO POINTS AND A MAXIMUM OF 10 MAY BE SUPPLIED. NOTE THAT FOUR POINTS CAN BE PUNCHED ON A SINGLE CARD, THAT NO FIELDS CAN BE SKIPPED AND THAT AS MANY CARDS AS ARE NECESSARY TO READ THE DATA MUST BE PROVIDED.

OPTION 2. THIS OPTION ALLOWS THE USER TO INPUT THE SLOPE OF THE LAB DATA CURVE. IT IS IMPORTANT TO NOTE THAT THE SLOPE REPRESENTS A CHANGE IN THE LOG OF THE RESILIENT MODULUS OVER A CHANGE IN THE LOG OF THE DEVIATOR STRESS. SLOPES GREATER THAN OR EQUAL TO ZERO ARE NOT ALLOWED. TO INPUT THIS SLOPE, THE USER MUST SET IVL = 1 (UNDER THE FIELD DEFINITIONS BELOW) AND ENTER VAL(1) = SLOPE.

FIELD DEFINITIONS:

IVL = NUMBER OF LAB DATA POINTS TO BE READ.
VAL(1) = SLOPE OF LAB DATA CURVE (READ ONLY IF IVL = 1).

LAYER

THIS DIRECTIVE DEFINES THE PROPERTIES OF A SINGLE LAYER OF THE EXISTING PAVEMENT. A LAYER DIRECTIVE IS REQUIRED FOR EACH LAYER DOWN TO AND INCLUDING THE SUBGRADE. AFTER THE FIRST PROBLEM IT IS POSSIBLE TO CHANGE THE VALUES FOR A SINGLE LAYER WITHOUT ALTERING THE OTHERS BY INCLUDING A LAYER DIRECTIVE FOR THAT LAYER ONLY. A MAXIMUM OF FOUR LAYERS ARE PERMITTED, UNLESS A BOND BREAKER LAYER IS TO BE USED (SEE OVERLAY DIRECTIVE) IN WHICH CASE ONLY THREE EXISTING LAYERS ARE ALLOWED. IF THE THICKNESS OF THE SUBGRADE LAYER IS INPUT AS ZERO, THEN IT IS ASSUMED TO BE SEMI-INFINITE. OTHERWISE THE PROGRAM WILL SIMULATE THE PRESENCE OF BEDROCK AT THE INDICATED DEPTH BELOW THE TOP OF THE SUBGRADE WHEN PERFORMING DEFLECTION CALCULATIONS.

FIELD DEFINITIONS:

IVL = LAYER NUMBER. LAYERS ARE NUMBERED FROM THE TOP DOWN.
  0 < IVL < 5
  (NO DEFAULT VALUE)
VAL(1) = MODULUS OF ELASTICITY FOR LAYER MATERIAL IN PSI.
  (NO DEFAULT VALUE)
VAL(2) = LAYER THICKNESS IN INCHES (ZERO IF INFINITE).
  (NO DEFAULT VALUE UNLESS SUBGRADE)
VAL(3) = POISSON/S RATIO FOR LAYER MATERIAL.
  (DEFAULT VALUE BASED ON MATERIAL TYPE)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
  ≠AC ≠ - ASPHALTIC CONCRETE,
  ≠CRCP≠ - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT,
  ≠GRAN≠ - GRANULAR BASE MATERIAL,
  ≠JCP ≠ - JOINTED CONCRETE PAVEMENT,
  ≠STAB≠ - STABALIZED BASE MATERIAL,
  ≠SUBG≠ - SUBGRADE LAYER.
  (MUST BE JCP OR CRCP IF TOP LAYER)
ITYPE(2) = RIGID BASE INTERFACE TYPE (REQUIRED IF RIGID BASE REQUESTED):
  ≠FF ≠ - FULL FRICTION INTERFACE,
  ≠NF ≠ - NO FRICTION INTERFACE.
  (NO DEFAULT VALUE)

LOADS

THIS DIRECTIVE DESCRIBES THE LOAD GEOMETRY OF THE DEFLECTION MEASURING DEVICE WITH RESPECT TO THE LOCATION OF THE DEFLECTION MEASUREMENTS, X = 0.0, Y = 0.0. IF THIS DIRECTIVE IS LEFT OUT, THEN THE DYNAFLECT IS ASSUMED TO BE THE DEFLECTION MEASURING DEVICE (SEE DEFLECT DIRECTIVE).

FROM ONE TO FOUR UNIFORM CIRCULAR LOADS MAY BE MODELED WITH THIS DIRECTIVE. A SINGLE LOAD FORCE AND PRESSURE ARE INPUT FOR ALL OF THE LOADS. AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE LOCATIONS OF EACH OF THE LOADS AS PAIRS OF X AND Y COORDINATES (IN 8F10.0 FORMAT).

FIELD DEFINITIONS:

IVL = NUMBER OF LOADS (0 < IVL < 5).
VAL(1) = DEFLECTION LOAD FORCE IN POUNDS.
VAL(2) = DEFLECTION LOAD PRESSURE IN PSI.

OVERLAY

THIS DIRECTIVE DEFINES THE TYPE OF OVERLAY TO BE BUILT. WITH IT THE DESIGNER SPECIFIES THE MATERIAL TO BE USED, ITS PROPERTIES, AND THE PRESENCE OR ABSENCE OF A BOND BREAKER LAYER. IT IS IMPORTANT TO NOTE THAT THE INCLUSION OF A BOND BREAKER LAYER (VIA THE ≠UNBD≠ OPTION) REDUCES THE MAXIMUM NUMBER OF EXISTING PAVEMENT LAYERS FROM FOUR TO THREE. AN OVERLAY DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF OVERLAY MATERIAL IN PSI.
(NO DEFAULT VALUE)
VAL(2) = POISSON/S RATIO FOR OVERLAY MATERIAL.
(DEFAULT VALUE BASED ON MATERIAL TYPE)
VAL(3) = CONCRETE FLEXURAL STRENGTH FOR PCC OVERLAY, IN PSI.
(DEFAULT = 690.0)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
≠AC≠ - ASPHALTIC CONCRETE OVERLAY,
≠CRCP≠ - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT,
≠JCP≠ - JOINTED CONCRETE PAVEMENT.
ITYPE(2) = BOND BREAKER CONDITION AS FOLLOWS:
= BLANK IF AC OVERLAY,
= ≠BOND≠ IF BONDED PORTLAND CEMENT OVERLAY,
= ≠UNBD≠ IF UNBONDED PCC OVERLAY.
(BOND BREAKER LAYER WILL BE USED)

PAVEMENT

THIS DIRECTIVE DESCRIBES THE CONDITION OF THE EXISTING PAVEMENT. IT IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. NOTE THAT LAYER DIRECTIVES ARE ALSO REQUIRED FOR EACH LAYER INCLUDING THE TOP ONE.

FIELD DEFINITIONS:

IVL = NUMBER OF LAYERS IN EXISTING PAVEMENT DOWN TO AND INCLUDING THE SUBGRADE. AT LEAST ONE AND NOT MORE THAN FOUR LAYERS MAY BE SPECIFIED (THREE IF BOND BREAKER LAYER SPECIFIED ON OVERLAY DIRECTIVE).
(NO DEFAULT VALUE)

VAL(1) = NUMBER OF 18 KIP EQUIVALENT SINGLE AXLE WHEEL LOADS APPLIED TO DATE (PUNCHED WITH DECIMAL POINT).
(DEFAULT IS 1.)

VAL(2) = CONCRETE FLEXURAL STRENGTH FOR EXISTING PAVEMENT, IN PSI.
(DEFAULT IS 690.0)

ITYPE = 8-CHARACTER FIELD SPECIFYING PAVEMENT CONDITION:

```
BLANK       - NO CRACKING OR VOIDS PRESENT.
≠VOID    ≠  - VOIDS PRESENT BUT NO CRACKING.
≠TYPE 1,2≠  - TYPE 1 OR 2 CRACKING PRESENT.
≠VOID 1,2≠  - TYPE 1 OR 2 CRACKING WITH VOIDS PRESENT.
≠TYPE 3,4≠  - TYPE 3 OR 4 CRACKING PRESENT.
≠MECH BKN≠  - PAVEMENT WILL BE MECHANICALLY BROKEN
              PRIOR TO OVERLAY.
```

PROBLEM

THIS DIRECTIVE SIGNALS THE BEGINNING IF A GROUP OF DIRECTIVES THAT DESCRIBE A SINGLE PROBLEM FOR WHICH SOLUTIONS OF ALLOWABLE TRAFFIC AS A FUNCTION OF OVERLAY THICKNESS ARE DESIRED. IT PERMITS THE USER TO SPECIFY A TITLE AND A PROBLEM NUMBER WHICH WILL APPEAR IN THE PRINTED OUTPUT AND CAN BE USED TO IDENTIFY THE RESULTS. IF A NON-ZERO DIGIT APPEARS ANYWHERE BETWEEN COLUMNS 11 AND 20 OF THIS DIRECTIVE, THEN AN 80-CHARACTER TITLE IS READ FROM AN EXTRA CARD WHICH IMMEDIATELY FOLLOWS THE PROBLEM DIRECTIVE. THIS TITLE WILL REMAIN IN EFFECT UNTIL ANOTHER IS PROVIDED.

FIELD DEFINITIONS:

IVL = PROBLEM NUMBER (IVL < 100).
(DEFAULT IS 1 IF FIRST PROBLEM, PREVIOUS PROBLEM NUMBER PLUS ONE OTHERWISE)

VAL(1) = 0 IF NO TITLE CARD,
> 0 IF TITLE CARD FOLLOWS.

TRAFFIC

THIS DIRECTIVE IS NEVER REQUIRED. IT PROVIDES UP TO 5 DESIGN TRAFFIC VALUES, FOR WHICH OVERLAY THICKNESSES ARE OBTAINED BY INTERPOLATION IN THICKNESS AS A FUNCTION OF LOG(PREDICTED APPLICATIONS TO FAILURE). CONSERVATIVE OVERLAY THICKNESSES ARE CALCULATED IF THE SPECIFIED FATIGUE LIFE IS LESS THAN THAT FOR THE RECOMMENDED MINIMUM OVERLAY THICKNESS.

AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE DESIGN TRAFFIC VALUES IN 5F10.0 FORMAT.

FIELD DEFINITIONS:

IVL = NUMBER OF DESIGN TRAFFIC VALUES (LESS THAN OR EQUAL TO 5) (DEFAULT: 0)

RPOD2

FIXED ORDER INPUT GUIDES

Appendix C. RPOD2 FIXED ORDER INPUT GUIDES

Card Type 1: New Problem Card

1.1 Directive

P	R	O	B	L	E	M	
1	2	3	4	5	6	7	8

1.2 Problem Number

9	10

1.3 Title Card Switch
If this value is greater than zero, the entire 80 columns of the following card will be read as a title card.

									•
11	12	13	14	15	16	17	18	19	20

Card Type 2: Title Card

1		80

(Any combination of letters and/ or numbers).
Note: present this card only if 1.3 is greater than zero.

Card Type 3: Existing Pavement Card

3.1 Directive

P	A	V	E	M	E	N	T
1	2	3	4	5	6	7	8

3.2 Number of layers in existing pavement structure.
This must include the subgrade.
At least one and not more than four layers may be specified.
If a bondbreaker is used only three layers may be specified here. This value also designates how many of Card Type 4 (Layer Cards) are to be expected.

9	10

3.3 Number of 18-kip equivalent single axle wheel loads applied to date. This value must be non-zero; therefore, default value = 1.

									•
11	12	13	14	15	16	17	18	19	20

3.4 Existing pavement concrete flexural strength, psi
Default value = 690 psi

				•
21	22	23	24	25

3.5 Existing pavement condition
(any combination of letters and/
or numbers).
Blank - No cracking or voids present
"VOID" - Voids present, but no cracking
"TYPE 1,2" - Type 1 or 2 cracking present
"VOID 1,2" - Type 1 or 2 cracking with voids present
"TYPE 3,4" - Type 3 or 4 cracking present
"MECH BKN" - Pavement will be mechanically broken prior to overlay.

31	32	33	34	35	36	37	38

Card Type 4: Layer Card

This card defines the properties of the existing pavement and is required for each layer, down to and including the subgrade. The layers are numbered from the top down and a maximum of four layers is permitted unless a bondbreaker is specified, in which case only three layers are permitted. If the thickness of the subgrade is zero, the program will assume it semi-infinite. If the thickness of the subgrade is not zero, the program will assume the presence of bedrock beneath the subgrade layer when performing deflection calculations. The variable definitions are;

4.1 Directive

L	A	Y	E	R			
1	2	3	4	5	6	7	8

4.2 Layer Number
(right justify)

9	10

4.3 Elastic modulus of layer in 4.2, psi. Note: If card type 7 is provided, the subgrade requires only an approximate value to start iteration.

									•
11	12	13	14	15	16	17	18	19	20

4.4 Thickness of layer in 4.2, inches

			•	
21	22	23	24	25

4.5 Material type of layer in 4.2
(any combination of letters and/
or numbers)
"AC" - asphaltic concrete,
"CRCP" - continuously reinforced concrete pavement,
"GRAN" - granular base material,
"JCP" - jointed concrete pavement,
"STAB" - stabilized base material,
"SUBG" - subgrade layer.
(top layer must be either JCP or CRCP)

31	32	33	34

4.6 Rigid base interface type
(required if rigid base is required)
"FF" - full friction interface
"NF" - no friction interface
(no default value)
Note: A fixed value for Poisson's ratio for a specific material type is being used. For more information on the values being used as well as how to use other values, see the supplement to this guide.

35	36	37	38

Card Type 5: Lab Data Designation Card

This card is required if the load under which the deflection measurements are taken differs significantly from the 18 kip equivalent axle load. Laboratory tests must be made to determine elastic modulus as a function of deviator stress for the subgrade.

As an alternative this function can be expressed as the slope of the log resilient modulus versus log deviator stress relationship, which might be determined by approximate ways discussed in Appendix 4.

5.1 Directive

L	A	B		D	A	T	A
1	2	3	4	5	6	7	8

5.2 Number of pairs of lab data points
(right justify)
Lab data required are elastic modulus versus corresponding deviator stress. A minimum of two points and a maximum of ten may be specified.
If this value is provided, card Type 6 must follow this card. If 1 is entered in this field, 5.3 must be provided.

9	10

5.3 Slope of the log resilient modulus versus log deviator stress line.
This program can handle only negative values for this slope. Zero slopes must be input as a slight negative value, say -0.0001. In this case, the number of pairs of lab data points (5.2) must be 1.

					•				
11	12	13	14	15	16	17	18	19	20

Card Type 6: Lab Data Card

If 5.2 is not zero or one, this card type must be provided to designate the value of elastic modulus versus deviator stress for each lab data point (read in consecutive 10-column fields, four pairs of values per card). A minimum of ten sets of data are to be provided.

6.1 Elastic modulus for data point 1, psi

									●
1	2	3	4	5	6	7	8	9	10

6.2 Deviator stress for data point 1, psi
etc.

						●			
11	12	13	14	15	16	17	18	19	20

Card Type 7: Design Deflection Card

This card designates the magnitude of the design deflection. The deflection load is assumed to be the Dynaflect load. If deflections other than Dynaflect deflections are to be used, see the supplement to this input guide.

7.1 Directive

D	E	F	L	E	C	T	
1	2	3	4	5	6	7	8

7.2 Design deflection, inches
This value should be representative of the more distressed portion of the particular pavement section, hence a minimum confidence level of 90 percent is recommended. Interior deflections are to be used in this procedure. If Card Type 7 is not provided, the value of the subgrade modulus (read from a Card Type 4) will be used in the calculations.

	●								
11	12	13	14	15	16	17	18	19	20

Card Type 8: Corner to Interior Stress Ratio Card

This card is not required. It is used with JC existing pavements, and provides a measured ratio of corner deflection to interior deflection for a given pavement section. This ratio is used to obtain the stress adjustment factor for the determination of remaining life and, for JCP overlays, of estimated overlay life. The default value of the stress adjustment factor is 1.5.

8.1 Directive

C	O	R	N	E	R		
1	2	3	4	5	6	7	8

8.2 Ratio of the deflection measured at a corner (of a JC existing pavement) to that measured at an interior point

					•				
11	12	13	14	15	16	17	18	19	20

Card Type 9: Overlay Card

This card defines the type of overlay to be used. With it, the designer specifies the material type and properties of the overlay and also the presence or absence of a bondbreaker layer.

9.1 Directive

O	V	E	R	L	A	Y	
1	2	3	4	5	6	7	8

9.2 Modulus of overlay, psi

									•
11	12	13	14	15	16	17	18	19	20

9.3 Overlay concrete flexural strength, psi
Default value 690 psi
Leave blank if AC overlay.

				•
26	27	28	29	30

9.4 Overlay material type as follows:
"AC" - asphaltic concrete overlay
"CRCP" - continuously reinforced concrete overlay
"JCP" - jointed concrete overlay

31	32	33	34

9.5 Bonding condition as follows:
Blank - AC overlay
"BOND" - bonded PCC overlay
"UNBD" - unbonded PCC overlay
(If bondbreaker will be used, reduce the maximum allowable number of layers in existing pavement from four to three.)
Note: A fixed value for Poisson's ratio for a specific material type is being used. For more information on the values being used as well as how to use other values, see the supplement to this guide.

35	36	37	38

Card Type 10: Bondbreaker Card

This card is never required. If it does not appear, default values for the bondbreaker layer will be used. Default values will be supplied for any field on the directive which is left blank.

A bondbreaker will be used only if specified through 11.5 or for PCC overlays on pavements without remaining life.

10.1 Directive

B	O	N	D		B	K	R
1	2	3	4	5	6	7	8

10.2 Modulus of bondbreaker, psi
Default value: 100,000 psi

									●
11	12	13	14	15	16	17	18	19	20

10.3 Thickness of bondbreaker, inches
Default value: 1.0 inch
A default value of 0.3 is being used for Poisson's ratio of bondbreaker. For information on how to use other values see the supplement to this guide.

		●		
21	22	23	24	25

Card Type 11: Traffic Designation Card

This directive is never required. It provides up to five design traffic values, for which overlay thicknesses are obtained by interpolation from the overlay thickness versus pavement life curve calculated by the program.

This card designates the number of design traffic values to be read and used for interpolation.

If this card is used, it must be followed by Card Type 14.

11.1 Directive

T	R	A	F	F	I	C	
1	2	3	4	5	6	7	8

11.2 Number of design traffic values
(right justify)

9	10

Card Type 12: Traffic Card

This card designates the magnitudes of design traffic values specified in 13.2.

12.1 Traffic i

									●
10(i-1)+ 1	10(i-1)+ 2	10(i-1)+ 3	10(i-1)+ 4	10(i-1)+ 5	10(i-1)+ 6	10(i-1)+ 7	10(i-1)+ 8	10(i-1)+ 9	10(i-1)+10

Card Type 13: End

This card informs the program that no more problems are to be executed in this run. Every input deck must contain one of this type of cards at the end of the data, even if only one problem is to be analyzed.

13.1 Directive

E	N	D					
1	2	3	4	5	6	7	8

Note: More than one problem may be solved in a simple execution of the program. Each problem is prefaced with a "PROBLEM" directive. All relevant information must be supplied for the first problem of a run as explained above. Subsequent problems in the same run need only specify directives which are changed. All other values will be retained from the preceding problem, with the exception of the corner directive, which applies only to the current problem. All data on a single directive must be supplied, however, even if only one number is being changed.

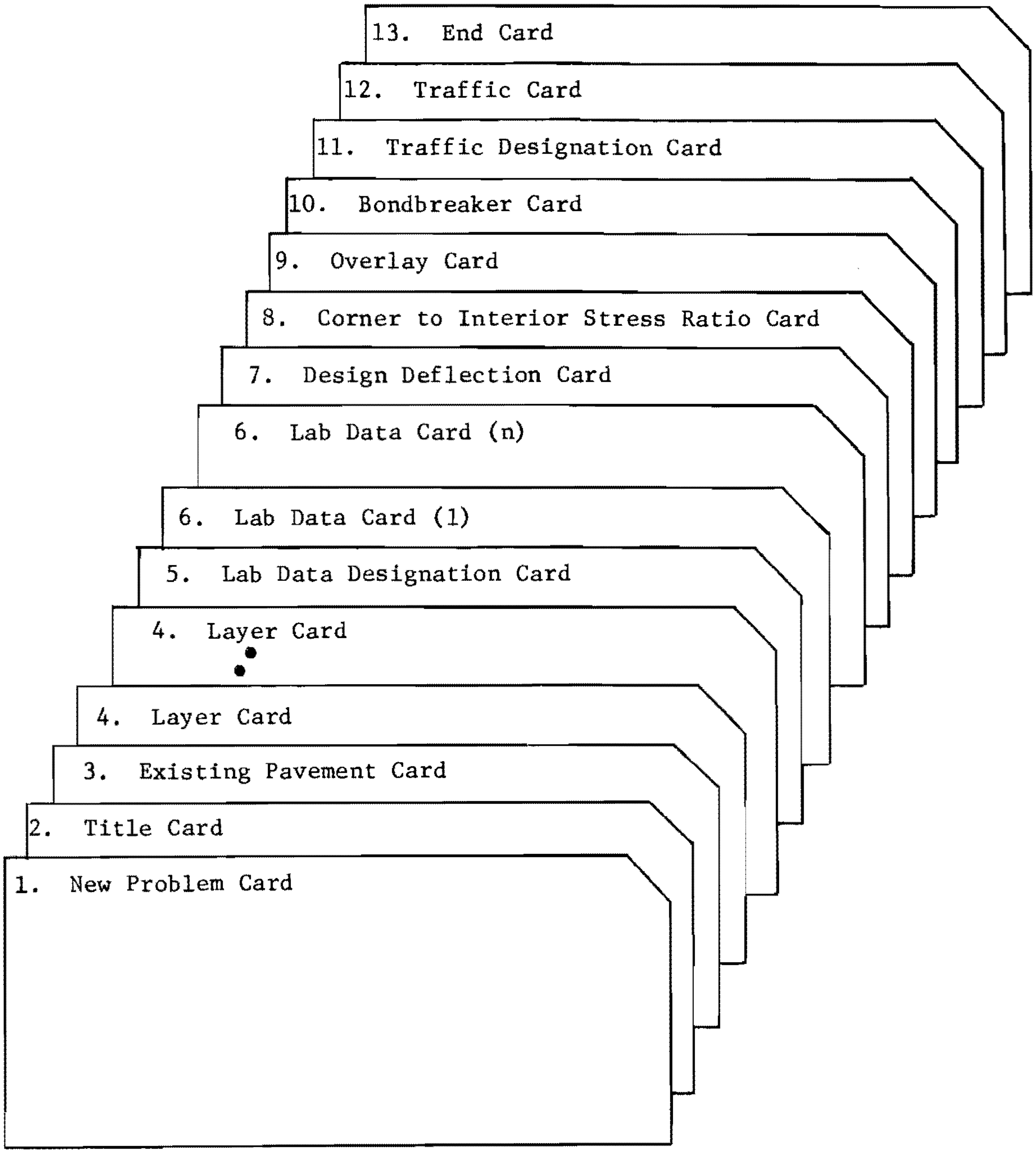


Fig C.1. Assembly of RPOD2 data
General Input Guide

SUPPLEMENT TO RPOD2 GENERAL INPUT GUIDE

The purpose of this supplement is to enable the user to change the following "fixed" variables:

(1) Poisson's ratio of existing pavement layers,
(2) Poisson's ratio of overlay,
(3) Poisson's ratio of bondbreaker layer, and
(4) Deflection loads to other than Dynaflect loads.

The following values are used for Poisson's ratio in the RPOD2 program if the general input guide is used:

portland cement concrete	0.15
asphaltic concrete	0.30
stabilized subbases	0.20
granular subbases	0.40
subgrade	0.45

Poisson's Ratio of Existing Pavement Layers

Poisson's ratio values of existing pavement layers can be specified on Card Type 4 if values other than the fixed values are desired, as follows:

Poisson's ratio for layer in 4.2

	●			
26	27	28	29	30

Poisson's Ratio of Overlay

The value of Poisson's ratio of overlay can be specified on Card Type 9 if another value than the fixed value is desired, as follows:

Poisson's ratio for overlay

	●			
21	22	23	24	25

Poisson's Ratio of Overlay

The value of Poisson's ratio of the bondbreaker can be specified on Card Type 10 if another value than the fixed value is desired as follows:

Poisson's ratio for bondbreaker layer

	●			
26	27	28	29	30

Deflection Loads

Dynaflect load magnitude, pressure, and load geometry are automatically fixed in RPOD2 if the general input guide is used.

It is, however, possible to use any other deflection measuring device and to input the load magnitudes, load pressure, and load geometry.

Card Type 7a: Deflection Load Magnitude Card

This card describes the load magnitude of the deflection measuring device. If this card is not provided, Dynaflect loads will be assumed. From one to four circular loads of equal magnitude may be specified.

7a.1 Directive

L	O	A	D	S			
1	2	3	4	5	6	7	8

7a.2 Load magnitude, pounds

									●
11	12	13	14	15	16	17	18	19	20

7a.3 Load pressure, psi

				●
21	22	23	24	25

Card Type 7b: Deflection Load Geometry Card

If card 8 is provided it must be followed by this card type. To describe the load geometry, it is necessary to select a cartesian coordinate system, in such a way that the locations of the deflection measurements are centered at the origin. The load geometry is described by determining x and y coordinates for each load.

7b.1 x - coordinate for load 1

								●	
1	2	3	4	5	6	7	8	9	10

7b.2 y - coordinate for load 1

								●	
11	12	13	14	15	16	17	18	19	20

.

.

.

7b.7 x - coordinate for load 4 ____

								●	
61	62	63	64	65	66	67	68	69	70

7b.8 y - coordinate for load 4 ____

								●	
71	72	73	74	75	76	77	78	79	80

Figure C.2 indicates the assembly of the RPOD2 input guide if other loads than Dynaflect loads are used.

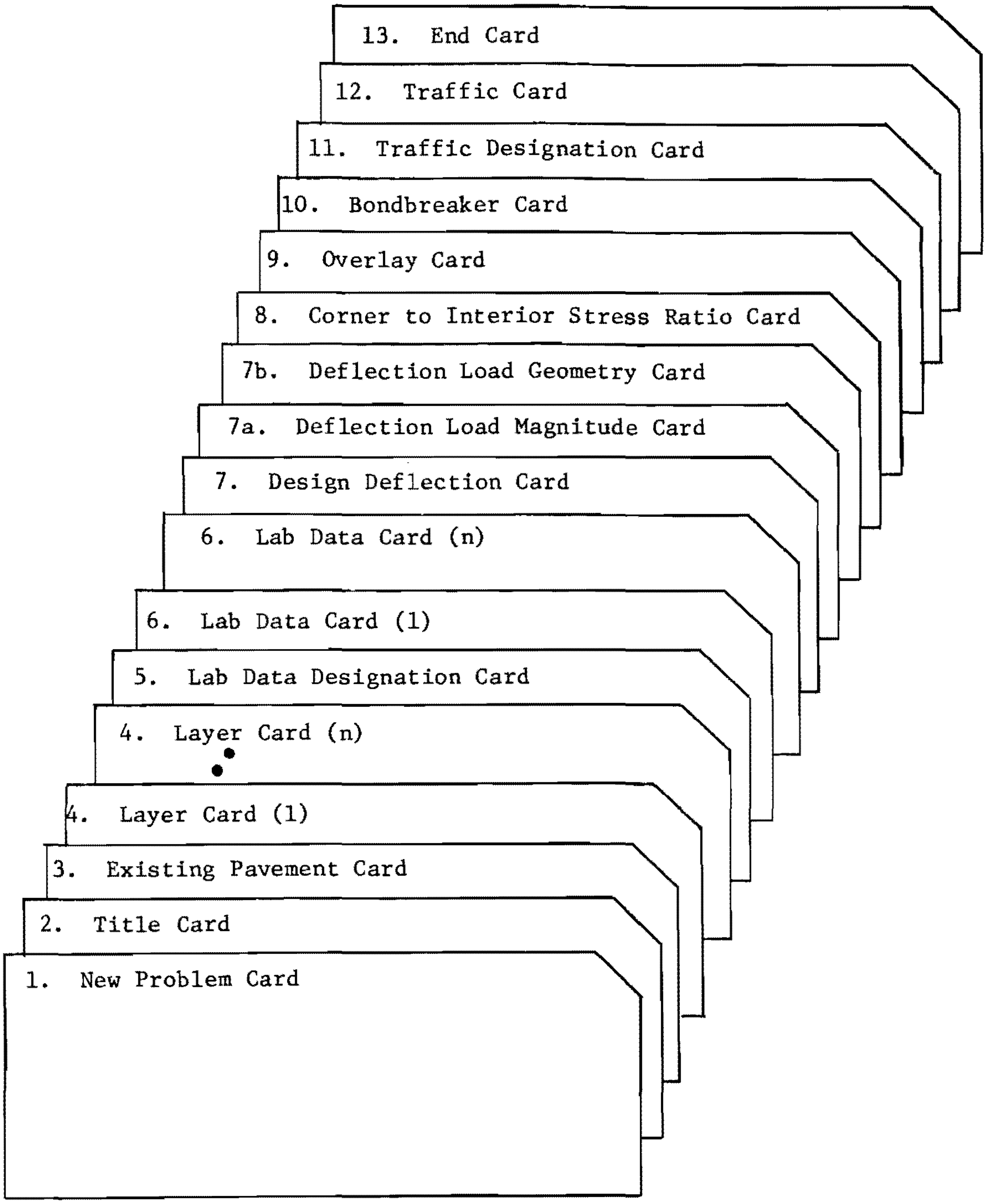


Fig C.3. Assembly of RPOD2 data
Special Input Guide

APPENDIX D

CONDITION SURVEY RATING FORMS

LIST OF CONDITION SURVEY FORMS

Title		Page
CRCP	Condition Survey Rating Form	138
CRCP	Condition Survey Summary Forms	139
CRCP	Condition Survey Rating Form for Small Sections	142
CRCP	Condition Survey Summary Form for Small Sections	143
JRCP	Condition Survey Rating Form	144
ACP Overlay	Condition Survey Rating Form	145
ACP Overlay	Condition Survey Summary Form	146
ACP Overlay	Condition Ride Quality Survey Rating Form	147
ACP Overlay	Condition Roughness Survey Summary Form	148

```
                    PROJECT IDENTIFICATION INFORMATION
                               DISTRICT 10

*****************************************************************
CFHR      HWY     COUNTY      CTRL  SEC   JOB   LENGTH  AGE    SURVEY
 NO.                                                    (YRS)   DATE
*****************************************************************

1006 EB  IH-20   VAN ZANDT   495  2     5       5.2    12.9   6-21-78
      ( KAUFMAN COUNTY LINE TO 5.24 MI EAST)

1007 EB  IH-20   VAN ZANDT   495  2     7       4.8    12.9   6-21-78
      ( 5.2 MI E OF KAUFMAN CO LINE TO NEAR ST 64)

1001 EB  IH-20   VAN ZANDT   495  2     3       4.0    15.2   6-20-78
      ( NEAR ST 64 TO 5.2 MI EAST)

1005 EB  IH-20   VAN ZANDT   495  3     3       8.2    13.8   6-20-78
      ( NEAR JCT 19 E TO 1.6 MI WEST OF FM 773)

1004 EB  IH-20   VAN ZANDT   495  3     4       8.0    14.6   6- 8-78
      ( 1.6 MI WEST FM 773 TO SMITH COUNTY LINE)

1002 EB  IH-20   SMITH       495  4     3       6.6    15.0   6- 7-78
      ( VAN ZANDT COUNTY LINE TO 6.6 MI EAST)

1003 EB  IH-20   SMITH       495  4     4       6.2    14.6   6- 6-78
      ( 6.6 MI EAST OF VAN ZANDT C.L. TO  .44 MI EAST US 69)

1009 EB  IH-20   SMITH       495  4     3       7.8    12.5   6- 6-78
      ( .4 MI EAST OF US 69 TO 8.1 MI EAST OF US 69)

1010 EB  IH-20   SMITH       495  5     5       7.4    12.3   6- 9-78
      (8.1 MI EAST OF US 69------ TO NEAR US 271)

1014 EB  IH-20   SMITH       495  6     1       8.2    12.4   6- 8-78
      (US271 TO GREGG CT LINE)

1008 EB  IH-20   GREGG       495  7     1       4.8    12.8   6-20-78
      (SMITH CT LINE TO 4.829 MI E)

1011 EB  IH-20   GREGG       495  7     2       4.0    11.9   6-20-78
      (4.8 MI EAST OF SMITH CO LINE TO 0.5 MI WEST OF US 259)

1012 EB  IH-20   GREGG       495M 7     3       6.4    11.3   6-21-78
      (0.5 WEST OF US 259 TO 1.8 MI EAST OF SABINE R)

1013 EB  IH-20   GREGG       495  7     6       1.8    11.3   6-21-78
      (1.8 MI EAST OF SABINE R TO HARRISON CL)

1012 WB  IH-20   GREGG       495  7     3       6.4    11.3   6-21-78
      (1.8 MI. E SABINE RIVER TO 0.5 MI W OF US 259)
```

CRCP CONDITION SURVEY

DISTRICT | CONTROL | SECT. | HIGHWAY | AGE (F10.0) | DIR | COUNTY | JOB | CFHR NO. | MO DAY YEAR

LOCATION FROM

TO

MILE POST	MILE POINT	COMMENTS [BRIDGES OVERLAYS LANDMARKS]	SPALLING		PUMPING		PUNCH OUTS				REPAIR PATCHES		RIDING QUALITY
							MINOR		SEVERE		ASPHALT CONCRETE	P.C. CONCRETE	
			MINOR NO. OF CRACKS	SEVERE NO. OF CRACKS	MINOR %	SEVERE %	<20FT	>20FT	<20FT	>20FT	NO. OF OCCURRENCES	NO. OF OCCURRENCES	
1 2 3 4 5	6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	29 30 31 32	33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52	53 54 55 56	57 58 59 60	61 62 63 64 65 66 67 68	69 70 71 72 73 74 75 76	77 78 79 80
1 2 3 4 5	6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	29 30 31 32	33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52	53 54 55 56	57 58 59 60	61 62 63 64 65 66 67 68	69 70 71 72 73 74 75 76	77 78 79 80

```
                         PROJECT SUMMARY SHEET
                              DISTRICT 10

****************************************************************
CFHR NO.1006    HIGHWAY IH-20   EB
****************************************************************

MILE POST:                           513.5    514.5    515.5    516.5

MILE POINT:                          0.000    1.082    2.082    3.082

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

LENGTH (MILES):                          1.0      1.0      1.0

LENGTH OVERLAYED SINCE 1970:             0.0      0.0      0.0

SERVICEABILITY INDEX (1978):             2.9      3.0      3.2

CRACK SPACING (FEET)

   MEAN:                                  -        -        -

   STANDARD DEVIATION:                    -        -        -

PERCENT SPALLING

   MINOR:                                 -        -        -

   SEVERE:                                -        -        -

PERCENT PUMPING

   MINOR:                                 .4       .4      2.8

   SEVERE:                               0.0      0.0      0.0

NUMBER OF SPALLING CRACKS

   MINOR:                                360      370      415

   SEVERE:                                45       25       25

NUMBER OF PUNCHOUTS

   MINOR  - L.T. 20 FT:                   10       22       15

          - G.T. 20 FT:                    0        0        0

   SEVERE - L.T. 20 FT:                    1        0        0

          - G.T. 20 FT:                    0        0        0

A.C. REPAIR PATCHES:                      11        6        4

P.C.C. REPAIR PATCHES:                     0        0        3

****************************************************************
```

FAILURE SUMMARY FOR DISTRICT 10

CFHR NO.	AGE	LENGTH	REPAIR PATCHES (NO./MILE) A.C. 1974/1978	REPAIR PATCHES (NO./MILE) P.C.C. 1974/1978	PUNCHOUTS (NO./MILE) 1974/1978	FAILURES (NO./MILE) 1974/1978	FAILURES (TOTAL) 1974/1978
1006 FR	12.9	5.2	3.5 / 6.2	.2 / 1.7	.4 / .6	4.0 / 8.5	21 / 44
1007 FR	12.9	4.8	4.8 / 6.3	1.0 / 4.8	1.0 / .4	6.9 /11.5	33 / 55
1001 FR	15.2	4.0	3.0 / .8	1.3 /10.3	.8 / .5	5.0 /11.5	20 / 46
1005 FR	13.8	8.2	1.2 / .6	.1 / .6	.1 / .1	1.5 / 1.3	12 / 11
1004 FR	14.6	8.0	1.6 /15.4	.6 / 2.9	.2 / 1.0	2.4 /18.4	20 / 147
1002 FR	15.0	6.6	0.0 / 1.7	.5 / .8	0.0 / .2	.5 / 2.6	3 / 17
1003 FR	14.6	6.2	1.5 / 3.9	2.1 / 3.9	0.0 / 1.9	3.5 / 9.7	22 / 60
1009 FR	12.5	7.8	.6 / .8	.4 / .8	0.0 / 3.7	1.0 / 5.3	8 / 41
1010 FR	12.3	7.4	3.5 / .3	2.3 / 3.2	.8 / 7.3	6.6 /10.8	49 / 80
1014 FR	12.4	8.2	5.1 / 1.2	1.8 / 5.2	1.0 /16.0	7.9 /22.4	66 / 184
1008 FR	12.8	4.9	3.3 / 2.9	.9 / 4.0	1.0 / 9.6	5.2 /16.5	25 / 79
1011 FR	11.9	4.0	.3 / 1.5	.3 / 1.0	0.0 / 1.3	.5 / 3.8	2 / 15
1012 FR	11.3	6.4	.3 / .6	.3 / .8	.5 / 1.2	1.1 / 2.7	7 / 17
1013 FR	11.3	1.8	0.0 / 0.0	0.0 / 0.0	0.0 / .6	0.0 / .6	0 / 1
1012 WR	11.3	6.4	.9 / 1.1	.4 / 1.6	.5 / 1.2	1.8 / 3.9	10 / 25

RIDING QUALITY SUMMARY
DISTRICT 10

CFHR NO.		HWY	AGE (YRS)	LENGTH (MILES)	MEAN SERVICEABILITY INDEX 1974	1978
1006	EB	IH-20	12.9	5.2	3.1	3.2
1007	EB	IH-20	12.9	4.8	3.1	3.1
1001	EB	IH-20	15.2	4.0	3.1	3.1
1005	EB	IH-20	13.8	8.2	3.0	3.1
1004	EB	IH-20	14.6	8.0	2.9	3.1
1002	EB	IH-20	15.0	6.6	3.3	3.4
1003	EB	IH-20	14.6	6.2	3.1	3.2
1009	EB	IH-20	12.5	7.8	3.4	3.8
1010	EB	IH-20	12.3	7.4	3.1	3.3
1014	EB	IH-20	12.4	8.2	3.2	3.1
1008	EB	IH-20	12.8	4.8	3.5	3.6
1011	EB	IH-20	11.9	4.0	3.4	3.7
1012	EB	IH-20	11.3	6.4	3.4	3.8
1013	EB	IH-20	11.3	1.8	3.4	3.8
1012	WB	IH-20	11.3	6.4	3.4	3.8
1011	WB	IH-20	11.9	4.0	3.3	3.6
1008	WB	IH-20	12.8	4.8	3.5	3.8
1014	WB	IH-20	12.4	8.0	3.2	I
1013	WB	IH-20	11.3	1.8	3.3	I
1010	WB	IH-20	12.3	7.4	3.1	I
1009	WB	IH-20	12.5	7.8	3.4	I
1003	WB	IH-20	14.6	6.2	3.2	I

CRC PAVEMENT CONDITION SURVEY FORM FOR SMALL SECTIONS

DISTRICT	CONTROL	SECTION	JOB Nº	CFTR #	HIGHWAY AND DIRECTION	COUNTY	DATE

LOCATIONS		COMMENTS	DATE OF SURVEY	NUMBER OF CRACKS	NUMBER OF SPALLED CRKS		PUNCHOUTS				PATCHES		PUMPING	
FROM	TO				MINOR	SEVERE	MINOR		SEVERE		A. C.	PCC	MINOR	SEVERE
							< 20'	> 20'	< 20'	> 20'				
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33	34 35 36 37 38 39 40	41 42 43 44 45 46	47 48 49 50	51 52 53 54	55 56 57	58 59 60	61 62 63	64 65 66	67 68 69	70 71 72	73 74 75 76	77 78 79 80
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33	34 35 36 37 38 39 40	41 42 43 44 45 46	47 48 49 50	51 52 53 54	55 56 57	58 59 60	61 62 63	64 65 66	67 68 69	70 71 72	73 74 75 76	77 78 79 80

```
                    SMALL SECTIONS CONDITION SURVEY
                    -------------------------------
 CONDITION SURVEY OF SMALL SECTION ALONG IH-10 NEAR COLUMBUS
 TO CHECK ON THE EFFECTIVENESS OF AN EDGE DRAIN.


************************************************************************
DIST:    13 CNTR NO:  1303  HIGHWAY: IH-10FR         COUNTY: COLORADO
SECT:     1 CONTROL:   271   JOB NO:      1    REPORT DATE:  18 JUN 80
************************************************************************

  SEGMENTS -

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

  FR:   0+ 0      LENGTH:  600 FT
  TO:   6+ 0      COMMENTS: WITH DRAIN

      SURVEYS -                      JAN.75      MAR.77       JUN.79

      CRACKS   /NO.PER MI:      116/1020.8  119/1047.2  136/1196.8
      MIN SPALL/NO.PER MI:        0/   0.0    0/   0.0    3/  26.4
      SEV SPALL/NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      MPO. <20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      MPO. >20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      SPO. <20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      SPO. >20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      AC. PATCH/NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      PCC PATCH/NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      MINOR PUMPING  FEET:             0           0            0
      SEVERE PUMPING FEET:             0           0            0

      FAILURES /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
************************************************************************

  FR:   6+ 0      LENGTH:  600 FT
  TO:  12+ 0      COMMENTS: W/O  DRAIN

      SURVEYS -                      JAN.75      MAR.77       JUN.79

      CRACKS   /NO.PER MI:      115/1012.0  117/1029.6  127/1117.6
      MIN SPALL/NO.PER MI:        0/   0.0    0/   0.0    2/  17.6
      SEV SPALL/NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      MPO. <20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      MPO. >20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      SPO. <20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      SPO. >20 /NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      AC. PATCH/NO.PER MI:        0/   0.0    0/   0.0    0/   0.0
      PCC PATCH/NO.PER MI:        0/   0.0    0/   0.0    1/   8.8
      MINOR PUMPING  FEET:             0           0            0
      SEVERE PUMPING FEET:             0           0            0

      FAILURES /NO.PER MI:        0/   0.0    0/   0.0    1/   8.8
************************************************************************
```

JOINTED CONCRETE PAVEMENT CONDITION SURVEY

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

LOCATION FROM

TO

MILE POST	MILE POINT	COMMENTS [OVERLAYS BRIDGES RAMPS LANDMARKS]	SLAB ASSOCIATED DISTRESS						JOINT ASSOCIATED DISTRESS						
			TRANSVERSE CRACKS			ASPHALT PATCHES [N°]	PCC PATCHES [N°]	EDGE PUMPING [FT]	SPALLED JOINTS [N°]	FAULTED JOINTS [N°]	CRACKING AT JOINTS [N°]	ASPHALT PATCHES [N°]	PCC PATCHES [N°]	BAD JOINT SEALANT [N°]	JOINT PUMPING [N°]
			N°	N° SPALLED	N° FAULTED										
1 2 3 4 5	6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24	25 26 27	28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75	76 77 78 79 80
1 2 3 4 5	6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24	25 26 27	28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75	76 77 78 79 80

ACP OVERLAY CONDITION SURVEY RATING FORM

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

1									
2									
3	DIST.	CONTROL	SECT.	JOB #	CFHR #	HWY. and DIR.	COUNTY	DATE	
4									

5–8	LIMITS		OVERLAY THICKNESS INCHES	% STEEL	CONC PLACEMENT TEMP (±)	TRANSITION YES or NO	DATE SURVEY MADE	REFL. CRACKS	PATCHES	FAILURES	BOND FAILURES	RUT DEPTH	COMMENTS	
	FROM	TO												
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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                         ACP OVERLAY CONDITION SURVEY
                         ----------------------------
    EXPERIMENT CONSIDERING OVERLAY THICKNESS, PERCENT STEEL, AND
                      CONCRETE PLACEMENT TEMPERATURE


*********************************************************************
DIST: 17   CFHR NO: 1701   HIGHWAY: IH 45 SBL      COUNTY: WALKER
SECT: 07   CONTROL: 675     JOB NO: 4        REPORT DATE: 02/19/79
*********************************************************************

OVERLAY SEGMENTS -

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

FR: 602+23     LENGTH: 3796 FT   THICKNESS: 2.5 IN   TRANSITION: NO
TO: 564+27     PERCENT STEEL:  .6     PLACEMENT TEMPERATURE: <90 F.

  SURVEYS -                     OCT 74     OCT 76     APR 79     APR 81

  REFL.CRKS/NO.PER MI:        0/  0.0    1/  1.4   10/ 13.9   12/ 16.7
  PATCHES  /NO.PER MI:        7/  9.7    0/  0.0    2/  2.8    3/  4.2
  FAILURES /NO.PER MI:        2/  2.8    2/  2.8    4/  5.6    4/  5.6
  LOSS OF BOND FAILURES:            0          0          0          0
  MEAN RUT DEPTH (IN):           0.00        .01        .08        .12

  COMMENTS:                     NO OVL
  -------------------------------------------------------------------

  SURVEYS (CONT.) -             MAY 83

  REFL.CRKS/NO.PER MI:        13/ 18.1
  PATCHES  /NO.PER MI:         4/  5.6
  FAILURES /NO.PER MI:         5/  7.0
  LOSS OF BOND FAILURES:             1
  MEAN RUT DEPTH (IN):             .13

  COMMENTS:
*********************************************************************

FR: 564+27     LENGTH: 8127 FT   THICKNESS: 2.5 IN   TRANSITION: NO
TO: 483+ 0     PERCENT STEEL:  .6     PLACEMENT TEMPERATURE: >90 F.

  SURVEYS -                     OCT 74     OCT 76     APR 79

  REFL.CRKS/NO.PER MI:        0/  0.0    2/  1.3   10/  6.5
  PATCHES  /NO.PER MI:       28/ 18.2    0/  0.0    4/  2.6
  FAILURES /NO.PER MI:       25/ 16.2    0/  0.0    3/  1.9
  LOSS OF BOND FAILURES:            0          0          0
  MEAN RUT DEPTH (IN):           0.00        .01        .05

  COMMENTS:                     NO OVL
*********************************************************************
```

ACP OVERLAY RIDE QUALITY SURVEY RATING FORM

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

1									
2									
3	DIST.	CONTROL	SECT.	JOB #	CFHR#	HWY. and DIR.	COUNTY	DATE	
4									

5 6 7 8	LIMITS FROM	TO	OVERLAY THICKNESS INCHES	% STEEL	CONC. PLACE-MENT TEMP (±)	TRAN-SITION YES or NO	DATE SURVEY MADE	SERVICEABILITY INDICES 4-10'	10-25'	25-50'	50-100'	SIV	MRM	COMMENTS	
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															
21															
22															
23															
24															
25															
26															
27															
28															

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

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                       ACP OVERLAY ROUGHNESS SURVEY
                       ----------------------------
  CONDITION SURVEY OF SMALL SECTION ALONG IH-10 NEAR COLUMBUS
  TO CHECK ON THE EFFECTIVENESS OF AN EDGE DRAIN.
----------------------------------------------------------------------
DIST:     13 CFHR NO:  1303 HIGHWAY: IH-10EB         COUNTY: COLORADO
SECT:      1 CONTROL:   271  JOB NO:      1     REPORT DATE:  18 JUN 80
----------------------------------------------------------------------

OVERLAY SEGMENTS -

**********************************************************************
FR:    0+00      LENGTH: 1040 FT    THICKNESS: WIT IN    TRANSITION:
TO:    6+00      PERCENT STEEL:H DRA      PLACEMENT TEMPERATURE:  IN F.

  ROUGHNESS INDICES -           JAN.75    MAR.77    JUN.79

  SI (4-10 FT):                   1.00      1.00      1.00
  SI (10-25 FT):               1600.00   1900.00   3600.00
  SI (25-50 FT):                 -0.00     -0.00    300.00
  SI (50-100 FT):                -0.00     -0.00     -0.00
  SIV:                           -0.00     -0.00     -0.00
  MRM (IN/MILE):                 -0.00     -0.00     -0.00

  COMMENTS:
**********************************************************************
FR:    6+00      LENGTH: 1040 FT    THICKNESS: W/O IN    TRANSITION:
TO:   12+00      PERCENT STEEL:  DRA      PLACEMENT TEMPERATURE:  IN F.

  ROUGHNESS INDICES -           JAN.75    MAR.77    JUN.79

  SI (4-10 FT):                   1.00      1.00      1.00
  SI (10-25 FT):               1500.00   1700.00   2700.00
  SI (25-50 FT):                 -0.00     -0.00    200.00
  SI (50-100 FT):                -0.00     -0.00     -0.00
  SIV:                           -0.00     -0.00     -0.00
  MRM (IN/MILE):                 -0.00     -0.00     -0.00

  COMMENTS:                                          1
**********************************************************************
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THE AUTHORS

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B. Frank McCullough is a Professor of Civil Engineering at The University of Texas at Austin. He has strong interests in pavements and pavement design and has developed design methods for continuously reinforced concrete pavements currently used by the State Department of Highways and Public Transportation, U. S. Steel Corporation, and others. He has also developed overlay design methods now being used by the FAA, U. S. Air Force, and FHWA. During nine years with the State Department of Highways and Public Transportation he was active in a variety of research and design activities. He worked for two years with Materials Research and Development, Inc., in Oakland, California, and for the past eight years for The University of Texas at Austin. He participates in many national committees and is the author of over 100 publications that have appeared nationally.

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