ANNUAL REPORT ON IMPORTANT 1970-71 PAVEMENT RESEARCH NEEDS

TO

AREA III RESEARCH ADVISORY COMMITTEE

by

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Research Report 123-7

A System Analysis of Pavement Design
and Research Implementation

Research Project 1-8-69-123

conducted

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PREFACE

This report fulfills one of the primary objectives of Project 123, to provide a systematic plan of research for continued development of a pavement design system. Project 123 is a cooperative research study involving the Texas Highway Department, the Center for Highway Research at The University of Texas at Austin, and the Texas Transportation Institute at Texas A&M University. The long-range objective of this project is "to develop for the Texas Highway Department a rational pavement design and management system for all pavement types and, furthermore, to provide for continued input of the latest research developments and findings into this system."

The Texas Highway Department Research Area III Pavement Design Advisory Committee functions in an advisory capacity for the research studies in the general area of pavement design. The committee anticipates and recommends research needs in this area and assists in the dissemination and implementation of the study results.

This report is the list of important pavement research needs for the year 1970-71 submitted by the principal investigators of the project to the Research Area III Advisory Committee for a continually improving pavement design system. It is expected that this report will be revised, updated, and resubmitted annually.

INTRODUCTION

One of the primary objectives of Project 123, as stated in the Project Proposal (Ref 1), is as follows:

> Delineate additional profitable areas of research in design, construction, maintenance, and economics of pavements.

The intent of this objective is to provide a systematic plan of research for continued development of a pavement design system (PDS) in order to provide for optimum utilization of funds and personnel. This objective corresponds to and is inherent in the Texas Highway Department concept of continually improving pavement design systems. It was emphasized in an earlier report that attainment of such a "rational design system" would be a step-by-step process over a period of time (Ref 2). Therefore, the areas recommended for research and discussed herein are those in which initiating and correlating development will be the most beneficial in improving the PDS.

Present Status of PDS

During the first two years of the project activities, the primary effort has been aimed at developing operational pavement design systems, using the best state-of-the-art information. The result of these activities to date is a set of pavement design models in the form of computer programs designated FPS (Flexible Pavement System, Ref 2) and RPS (Rigid Pavement System, Ref 3). These design systems encompass as many variables in terms of materials properties, environment, load, and economics as could be characterized with research information available during the period of inception (1968 to March 1971). Thus, utilization of state-of-the-art information permitted early development of a working PDS. The principal investigators fully recognized that not all possible variables were included and furthermore that improvement was needed immediately; for example, in the method of characterizing certain variables.

One immediate need is for more rational models to describe the pavement structure's response to loads. Several of the suggested research areas therefore pertain to the development of better models for predicting the load-stress relationships. As a first step in this direction, a changeover to elastic theory has been initiated (Ref 4).

The FPS computer program was implemented on a trial basis in several Texas Highway Department districts, and detailed sensitivity studies were performed on several versions of this program (Ref 5). These two activities provided the principal investigators a key to the weak areas of the design system. In some of these areas, the Project 123 personnel have already developed new or improved methods for treating the variables. These include improved models for considering skid resistance (Ref 6) and characterizing swelling clay (Ref 7), identification of insensitive variables in the current programs (Ref 8), and up-dating of economic data and models (Ref 9). However, the long-range concept of developing successive, improved generations of design systems requires the coordinated effort of all the pavement researchers and their colleagues in the field.

RECOMMENDED RESEARCH AREAS

Based on the trial implementation, sensitivity studies, and the preliminary selection of design models, the project staff has established that the following research is important to future improvements in pavement design. A complete description of the items is given in the next section.

(1) Determination of the relationship between pavement distress and a performance failure wear-out function

(2) Characterization of Texas paving materials for use in linear elastic models

(3) Development of a general stochastic analysis procedure for the pavement design system

(4) Identification of the distress state in pavements, determination of the corrective action applied to each type of distress, and measurement of the effects of such correction on Serviceability Index

(5) Improved traffic projection methods

(6) Development of better economic data and models

DESCRIPTION OF IMPORTANT RESEARCH NEEDS

In the following paragraphs, a detailed problem statement is given for each of the research areas listed in the previous section, to provide the researcher a guideline for submitting research proposals. Research conducted in this framework can be injected into the PDS immediately.

(1) Determination of the Relationship Between Pavement Distress and a Performance Failure Wear-out Function

There is no truly mechanistic way to relate pavement distress to pavement failure except for specific conditions (e.g., excessive rutting levels related to safety). Objective measurements of roughness and distress or subjective ratings must be used to bridge this gap and thus to establish a way of defining pavement unserviceability and failure which involve various levels of combined distress modes in terms of the pavement's function and the road user.

Studies must define important distress factors involved in pavement failure as well as weighting functions for these factors and must define them in terms of time, traffic, or other, pseudo-time, factors. In changing from empirical to mechanistic methods, it is essential that this gap be bridged. Some way must be found to relate stress, strain, and deformation to serviceability and performance through some estimate of distress and its relation to behavior, or the ability to predict stress and strain is of no value.

(2) Characterization of Texas Paving Materials for Use in Linear Elastic Models

In brief, the FPS computer program chooses a trial design, computes its surface deflection from an empirical equation, and from the computed deflection predicts the life of the pavement. The empirical relationships used in FPS do not permit the computation of stresses and strains in the pavement. In this sense, the method differs from practically all other structural design procedures in engineering. This difference in FPS becomes especially important when stabilized materials subjected to tensile strain and fatigue are present in the structure.

It is felt that the state-of-the-art of flexible pavement design has advanced to the point where an attempt should be made to employ the theory of elasticity, the theory that permits the estimation of stresses and strains anywhere within a structure, in FPS. One of the first steps in this direction is the development of practical, reliable, and economical methods for obtaining estimates of the elastic constants, Young's modulus and Poisson's ratio, of flexible pavement materials, as well as their tensile strengths, compressive strengths, and hydro-thermal volume change properties as they exist in the roadway. Furthermore, variations in these quantities from point to point in the structure, from one season to another, and from one location in the state to another should be studied so that suitable design values can be selected.

The relationships in RPS utilize some of these elastic constants, and thus the preceding comments are also apropos here. Figure 1 has been prepared to give potential researchers preliminary guidelines for selecting test methods. Many additional guidelines will ultimately be required.

In the selection of strength testing methods, consideration must be given to the concept of fatigue testing. Numerous studies have indicated the need for considering this concept, since pavements seldom fail under a single load. Therefore, procedures must be developed for establishing fatigue life under a range of stress levels representative of those experienced in the field. The duration of loading as well as the stress cycling levels must simulate field loadings.

It is expected that appropriate laboratory tests must be developed and means found for correlating the laboratory values with those measured or estimated by other independent means in the field. The researcher needs to consider whether the materials must be characterized on a project basis or in general categories.

It is anticipated that each of the material categories in Fig 1 will be a separate work item, with the researcher considering all factors, e.g., elastic properties, strengths, and fatigue, to provide a compatible system. The priority items in this area are surface and foundation materials.

	Surface		Base and Subbase Materials			
Factor	Concrete	ACP	Granular Material	Chemically-Treated Material	Subgrade Soils	Foundation
Loading						
(1) Type	Tensile or flexural	Tensile or flexural	Triaxial compression	Tensile or flexural	Triaxial compression	Triaxial compression
(2) Dynamic or static	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic
(3) Representative stresses	100-300 psi	100-200 psi	20-80 psi	100-300 psi	2-10 psi	2-10 psi
(4) Representative load duration	Simulate vehicular speed	Simulate vehicular speed	Simulate vehicular speed	Simulate vehicular speed	Simulate vehicular speed	Simulate vehicular speed
(5) Representative frequency	Simulate traffic frequency	Simulate traffic frequency	Simulate traffic frequency	Simulate traffic frequency	Simulate traffic frequency	Simulate traffic frequency
Sample composition						
(1) Moisture	N/A	N/A	SFC	AC	SFC	SFC
(2) Density	AC	AC	SFC	AC	SFC	SFC
(3) Size	Representative	Representative	Representative	Representative	Representative	Representative

SFC - Simulate history of field conditions

AC - As constructed

Fig 1. Guidelines for materials characterization.

(3) Development of a General Stochastic Analysis Procedure for the Pavement Design System

Most current design procedures are deterministic in nature, using exact values of input and presenting the results as exact values. However, properties and performance of actual pavements are subject to considerable random or stochastic variations. Stochastic mathematical models are required to take into account these random variations. These may be inserted into the FPS and RPS programs to give more realistic simulated field performance.

A parallel phase of this study is to determine the actual variation of properties experienced in real pavements. The variations and types of distributions must be established for each of the more important variables.

(4) Identification of the Distress State in Pavements, Determination of the Corrections Applied to Them, and Measurement of the Effects of Such Corrections

The overall need in this project is for better performance information about Texas pavements. The project will supply the interim or short-term solution to the following research needs:

(a) identification of distress manifestations present in Texas pavements and the methods of treatment used for the various types of distress;

(b) the modeling in PDS of the effects of various types of pavement rehabilitation (maintenance, reconstruction, or overlaying); and

(c) the measurement of the effects (immediate and with respect to time) of various types of maintenance and rehabilitation on the serviceability index and performance trends.

The first part of the research problem is to identify the predominant distress manifestations present on the primary pavement types in Texas and the mechanisms producing them. Figure 2, developed by others (Ref 12) could be used as a guideline for conducting this study. Typical of the distress manifestations to be considered are rutting, shoving, transverse cracking, longitudinal cracking, raveling, spalling, stripping, edge failures, and heaving. Additionally, pumping, blowups, joint faulting, and shoulder distress of concrete pavements may be found. The state-wide distribution and magnitude of the distress as well as the type of pavement, its age, and a

Distress Model	Distress Manifestation	Examples of Distress Mechanism*
Fracture	Cracking	Excessive loading Repeated loading (i.e., fatigue) Thermal changes Moisture changes Slippage (horizontal forces) Shrinkage
	Spalling	Excessive loading Repeated loading (i.e., fatigue) Thermal changes Moisture changes
Distortion	Permanent Deformation	Excessive loading Time-dependent deformation (e.g., creep) Densification (i.e., compaction) Consolidation Swelling
	Faulting	Excessive loading Densification (i.e., compaction) Consolidation Swelling
Disintegration	Stripping	Adhesion (i.e., loss of bond) Chemical reactivity Abrasion by traffic
	Raveling and scaling	Adhesion (i.e., loss of bond) Chemical reactivity Abrasion by traffic Degradation of aggregate Durability of binder

* Not intended to be a complete listing of all possible distress mechanisms.

Fig 2. Categories of pavement distress (after Ref 12).

judgment of the amount of traffic are needed. Identification of the methods of treatment on the distressed pavements forms the next phase of the research problem and the immediate need of the researchers who are modeling such pavements. Additionally, any quantitative or even qualitative estimates of the effectiveness of these treatments would be valuable.

In modeling the effects of various types of pavement rehabilitation, the identified methods of treatment will be used as a first step. In modeling pavement performance over long periods of time, it is necessary to model not only the performance of the initial pavement but the performance of the maintained, or reworked, or overlaid pavement. While mechanistic approaches are being developed that may predict distress and the resulting loss of serviceability on new pavements, very little information is available or will be available in the near future to form the basis for predicting the performance of the maintained pavement. Yet most pavements are in this category. For the present, it becomes necessary, therefore, to rely almost entirely on empirical models for this type of performance. The modeling in PDS of performance of the rehabilitated pavements will become an iterative procedure which will use the information developed in the next research item and the feedback data system developed in Project 123.

The measurement of the immediate change in Serviceability Index of the rehabilitated pavement (e.g., did the maintenance level-up the road or roughen it and if so, how much?) will become possible as soon as the identification of the various types of maintenance has been accomplished. These immediate effects will be measured with a roughness measurement device by simply measuring roughness before and after the rehabilitation. The effects of each type of rehabilitation on serviceability trends (e.g., did sealing the cracks reduce the rate of loss of serviceability which was occurring on the road?) will be much more difficult to ascertain. It is believed that information such as may be obtained from the proposed Texas Highway Department Pavement Data System will be necessary. Such information will probably have to be obtained over a broad data base and kept "living." For instance, as new pavement types and new maintenance methods are developed, new data will be required to update the information.

(5) Improved Traffic Projection Methods

A comprehensive pavement system analysis and design must include the computations and evaluation of the system responses (stresses, strains, deflections, and surface properties) generated by a load or a group of loads applied on the system. These load-associated responses of a pavement structure are functions of vehicle speed, load magnitudes, frequency of loading, total applications within each category, and load distribution with respect to placement.

Accuracy of pavement system analysis is therefore dependent on our ability to project traffic. Accurate predictions of traffic are relatively difficult due to the many physical, seasonal, social, and economic environments acting on the flow of traffic.

Thus, in order to work toward an improved pavement design system, we must have the following:

(a) improved traffic projection (number, magnitude, frequency, duration) during the life of the facility and its distribution in space and time; and

(b) information on the accuracy of such projections.

(6) Development of Better Economic Data and Models

The present economic analysis in PDS is based on the first version of the cost models, which are inadequate and for which the input data is generally based on value judgments for making estimates. The following three phases of the economic analysis should be improved by a research project:

(a) material values,

(b) user cost analysis, and

(c) economic optimization models.

Material values entail research in such general areas as cost of materials, the statistical distributions of such costs, and the salvage values of these materials as functions of pavement life, analysis period, material and road types, and other variables. Development of better models would probably include the consideration of the overall highway system and not just the pavement system.

User cost analysis is a wide area of research and will include, for immediate application into PDS, such specific areas as consideration of accident costs, extension of user cost computations to cover such situations as maintenance, rehabilitation, and seal coats, and development of additional models to handle traffic flows at the time of such situations.

Economic optimization models is another need in the development of PDS. Currently, the optimization involved in PDS is with respect to overall cost of alternative pavement strategies (initial construction plus overlay). Further optimization within the economic models is possible, for example, in such specific areas as optimization with regard to traffic handling at the time of system corrections and optimization within overlays, seal coats, and maintenance subsystems to take into account their interrelationships.

REFERENCES

1. Research Study Renewal for Project 1-8-69-123, "A System Analysis of Pavement Design and Research Implementation," for fiscal year 1970-71, prepared jointly by the Project staff, April 1, 1970.

2. Hudson, W. Ronald, B. Frank McCullough, F. H. Scrivner, and James L. Brown, "A Systems Approach Applied to Pavement Design and Research," Research Report No. 123-1, published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, December 1969.

3. Kher, Ramesh K., W. Ronald Hudson, and B. Frank McCullough, "A Systems Analysis of Rigid Pavement Design," Research Report No. 123-5, published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, November 1970.

4. Scrivner, F. H., C. H. Michalak, and W. M. Moore, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections," Research Report No. 123-6, to be published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, in progress.

5. Kher, Ramesh K., B. Frank McCullough, and W. Ronald Hudson, "A Sensitivity Analysis of the Flexible Pavement System FPS-2," Research Report No. 123-8, to be published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, in progress.

6. Steitle, David, and B. Frank McCullough, "Skid Resistance Considerations in the Flexible Pavement System," Research Report No. 123-9, to be published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, in progress.

7. Witt, Arthur W., III, and B. Frank McCullough, "Characterization of the Swelling Clay Parameter Used in the Pavement Design System," Research Report No. 123-3, published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, August 1970.

8. Brown, James L., Larry J. Buttler, and Hugo E. Orellana, "A Recommended Texas Highway Department Pavement Design System User's Manual," Research Report No. 123-2, published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, March 1970.

9. McFarland, W. F., "New Economic Data and Models for the Pavement Design System," Research Report No. 123-10, to be published jointly by Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, The University of Texas at Austin, in progress.

10. Hudson, W. R., and B. F. McCullough, "Systems Formulation: Development of SAMP - An Operational Pavement Design System," Final Report, NCHRP Project 1-10 and 1-10/1, Materials Research and Development, Inc., December 1970.