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16. Abstract

One of the most important needs in a pavement design program is for an established relationship between pavement distress and pavement performance. Many mechanistic models have been developed for use in the prediction of stresses, strains, deflections, etc., but these models provide no way to predict the performance of a pavement. This report presents initial research directed toward the goal of relating pavement distress to pavement performance. To explore the use of condition surveys in solving the problem, 26 condition surveys were conducted on two-tenths-mile-long pavement sections. Distress manifestations were recorded on data sheets and photographs were taken. To explore the use of pavement profile studies in solving the problem, the Surface Dynamics Profilometer was used to collect data on four of the pavement sections on which condition surveys had been conducted. The profilometer was also used to collect data for determining the serviceability index of the sections on which the condition surveys had been conducted. To explore the use of maintenance studies in helping to solve the problem of relating stress to performance, information about the Texas Highway Department maintenance procedures was obtained from a Texas Highway Department Maintenance Engineer. It is recommended that a research plan using the research presented here as a guide be designed for condition surveys, profile studies, and maintenance studies. It is thought that information gained from conducting research within these areas can be combined to develop a performance or failure function that will aid in the accomplishment of the ultimate goal - the prediction of the performance of pavements.

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USE OF CONDITION SURVEYS, PROFILE STUDIES, AND MAINTENANCE STUDIES IN RELATING PAVEMENT DISTRESS TO PAVEMENT PERFORMANCE

by

Robert Phillip Smith
B. Frank McCullough

Research Report Number 123-19

A System Analysis of Pavement Design
and Research Implementation

Research Project 1-8-69-123

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The Texas Highway Department

in cooperation with the
U. S. Department of Transportation
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Highway Design Division
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Texas Transportation Institute
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May 1974

PREFACE

This report presents work accomplished from 1972 to 1973 in introducing and beginning initial work directed toward the relation of pavement distress to pavement performance. It includes a description of the research area, results of condition surveys performed in Texas Highway Department District 14, results of profile studies in District 14, and results of maintenance procedure studies in District 14. Recommendations for future research that will be helpful to the Texas Highway Department are given.

This is the nineteenth in a series of reports that describes the work accomplished in the project entitled "A Systems Analysis Applied to Pavement Design and Research Implementation." The project is a long-range research program to develop a system analysis of pavement design and management. The project is conducted in cooperation with the Federal Highway Administration Department of Transportation.

Special thanks and appreciation are extended to Dr. W. Ronald Hudson for a critical review of the report; to Dr. Ramesh Kher, Dr. Roger Walker, and Mr. Frank Carmichael for their help; to Mrs. Marie Fisher for typing and other help with the report; and to Mr. Arthur Frakes for editing the manuscript.

Robert P. Smith
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May 1974

LIST OF REPORTS

Report No. 123-1, "A Systems Approach Applied to Pavement Design and Research," by W. Ronald Hudson, B. Frank McCullough, F. H. Scrivner, and James L. Brown, describes a long-range comprehensive research program to develop a pavement systems analysis and presents a working systems model for the design of flexible pavements. March 1970

Report No. 123-2, "A Recommended Texas Highway Department Pavement Design System Users Manual," by James L. Brown, Larry J. Buttler, and Hugo E. Orellana, is a manual of instructions to Texas Highway Department personnel for obtaining and processing data for flexible pavement design system. March 1970

Report No. 123-3, "Characterization of the Swelling Clay Parameter Used in the Pavement Design System," by Arthur W. Witt, III, and B. Frank McCullough, describes the results of a study of the swelling clays parameter used in pavement design system. August 1970

Report No. 123-4, "Developing A Pavement Feedback Data System," by R. C. G. Haas, describes the initial planning and development of a pavement feedback data system. Februar 1971.

Report No. 123-5, "A Systems Analysis of Rigid Pavement Design," by Ramesh K. Kher, W. R. Hudson, and B. F. McCullough, describes the development of a working systems model for the design of rigid pavements. November 1970

Report No. 123-6, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections," by F. H. Scrivner, C. H. Michalak, and William M. Moore, describes a computer program which will serve as a subsystem of a future Flexible Pavement System founded on linear elastic theory. March 1971

Report No. 123-6A, "Calculation of the Elastic Moduli of a Two Layer Pavement System from Measured Surface Deflections, Part II," by Frank H. Scrivner, Chester H. Michalak, and William M. Moore, is a supplement to Report No. 123-6 and describes the effect of a change in the specified location of one of the deflection points. December 1971

Report No. 123-7, "Annual Report on Important 1970-71 Pavement Research Needs," by B. Frank McCullough, James L. Brown, W. Ronald Hudson, and F. H. Scrivner, describes a list of priority research items based on findings from use of the pavement design system. April 1971

Report No. 123-8, "A Sensitivity Analysis of Flexible Pavement System FPS2," by Ramesh K. Kher, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this system, the relative importance of the variables of the system and recommendations for efficient use of the computer program. August 1971

Report No. 123-9, "Skid Resistance Considerations in the Flexible Pavement Design System," by David C. Steitle and B. Frank McCullough, describes skid resistance consideration in the Flexible Pavement System based on the testing of aggregates in the laboratory to predict field performance and presents a nomograph for the field engineer to use to eliminate aggregates which would not provide adequate skid resistance performance. April 1972

Report No. 123-10, "Flexible Pavement System - Second Generation, Incorporating Fatigue and Stochastic Concepts," by Surendra Prakash Jain, B. Frank McCullough, and W. Ronald Hudson, describes the development of new structural design models for the design of flexible pavement which will replace the empirical relationship used at present in flexible pavement systems to simulate the transformation between the input variables and performance of a pavement. January 1972

Report No. 123-11, "Flexible Pavement System Computer Program Documentation," by Dale L. Schafer, provides documentation and an easily updated documentation system for the computer program FPS-9. April 1972

Report No. 123-12, "A Pavement Feedback Data System," by Oren G. Strom, W. Ronald Hudson, and James L. Brown, defines a data system to acquire, store, and analyze performance feedback data from in-service flexible pavements. May 1972

Report No. 123-13, "Benefit Analysis for Pavement Design System," by Frank McFarland, presents a method for relating motorist's costs to the pavement serviceability index and a discussion of several different methods of economic analysis.

Report No. 123-14, "Prediction of Low-Temperature and Thermal-Fatigue Cracking in Flexible Pavements," by Mohamed Y. Shahin and B. Frank McCullough, describes a design system for predicting temperature cracking in asphalt concrete surfaces. August 1972

Report No. 123-15, "FPS-11 Flexible Pavement System Computer Program Documentation," by Hugo E. Orellana, gives the documentation of the computer program FPS-11, October 1972. April 1972

Report No. 123-16, "Fatigue and Stress Analysis Concepts for Modifying the Rigid Pavement Design System, " by Piti Yimprasett and B. Frank McCullough, describes the fatigue of concrete and stress analyses of rigid pavement. October 1972

Report No. 123-17, "The Optimization of a Flexible Pavement System Using Linear Elasticity," by Danny Y. Lu, Chia Shun Shih and Frank H. Scrivner, describes the integration of the current Flexible Pavement System computer program and Shell Oil Company's program BISTRO, for elastic layered systems, with special emphasis on economy of computation and evaluation of structural feasibility of materials. March 1973

Report No. 123-18, "Probabilistic Design Concepts Applied to Flexible Pavement System Design," by Michael I. Darter and W. Ronald Hudson, describes the development and implementation of the probabilistic design approach and its incorporation into the Texas flexible pavement design system for new construction and asphalt concrete overlay. May 1973

Report No. 123-19, "The Use of Condition Surveys, Profile Studies, and Maintenance Studies in Relating Pavement Distress to Pavement Performance," by Robert P. Smith and B. Frank McCullough, introduces the area of relating pavement distress to pavement performance, presents work accomplished in this area and gives recommendations for future research. May 1974

ABSTRACT

One of the most important needs in a pavement design system is for an established relationship of pavement distress to pavement performance. Many mechanistic models have been developed for use in the prediction of stresses, strains, deflections, etc., but these models provide no way to predict the performance of a pavement. This need has been expressed by experts in the field of pavement design as perhaps the most needed research area at the present time. Initial research directed toward relating pavement distress to pavement performance is presented in this report.

It is difficult to describe the problem of relating distress to performance and what research work actually is involved in the establishment of this relation. However, it is thought that pavement condition surveys, pavement profile studies, and pavement maintenance studies are specific areas that will add much to the relation.

To explore the use of condition surveys in solving the problem, 26 condition surveys were conducted on two-tenths-mile-long pavement sections in Texas Highway Department District 14. The survey procedure used consisted of recording distress manifestations on data sheets and taking photographs of these distress manifestations. The results are presented as percents of the pavement areas that were distressed and rankings of the distress manifestations according to prominence of occurrence. It is recommended that future condition surveys be conducted to collect data that will be useful in relating pavement distress to performance.

To explore the use of pavement profile studies in solving the problem, the Surface Dynamics Profilometer was used to collect data. The profilometer was run on four of the pavement sections on which condition surveys had been conducted. The distress manifestations encountered in the condition surveys were correctly scaled and positioned on the profilometer strip charts for the four sections. The purpose of doing this was hopefully to correlate a specific profile pattern with a specific distress manifestation. The data obtained do not allow this to be done in its present form. However, it is thought that

with more detailed use of the profilometer capabilities, such as various filters and wavelength analyses, this can be done.

The profilometer also was used to collect data for determining the serviceability index of the sections on which the condition surveys had been conducted. The results compare the serviceability index values with the amount of distress present in the pavement sections.

To explore the use of maintenance studies in helping to solve the problem of relating distress to performance, an interview was conducted with the District 14 Maintenance Engineer to obtain information about the Texas Highway Department maintenance procedures. It was learned that the resident foremen inspect the pavements and make recommendations to the District Maintenance Engineer on which pavements need improvements and what improvements should be made. The final decision usually rests with the maintenance engineer. More detailed studies on maintenance and its effect on performance need to be conducted with the help of highway department personnel.

It is thought that very useful and meaningful information was gained in the pilot research of the areas discussed. It is recommended that a thorough research plan, using the research presented here as a guide, be designed for condition surveys, profile studies, and maintenance studies. After conducting research within these areas, it is sincerely thought that the information gained can be combined to develop a performance or failure function that will enable the accomplishment of the ultimate goal - the prediction of the performance of pavements.

KEY WORDS: pavement distress, pavement performance, condition survey, profile study, maintenance study, distress manifestation, profilometer, Mays Ride Meter, serviceability index.

SUMMARY

It has been said by several experts in the field of pavement design that one of the largest deficiencies in a well-organized pavement design system is the lack of a relation of pavement distress to performance. With this need in mind, a description of the problem of relating distress to performance is presented along with pilot research in three areas: (1) condition surveys, (2) profile studies, and (3) maintenance studies. It is recommended that the research presented in this study be carried forward with other research projects directed toward the ultimate goal of prediction of the performance of pavements.

IMPLEMENTATION STATEMENT

The purpose of this study is primarily to introduce research areas which when expanded can be implemented into highway design with the result being a much improved design system. Future research in this area with specific intentions of implementing the results into the design system can lead to accomplishment of the highly desired goal of prediction of the performance of pavements.

Some initial work has been done already in one area of proposed research in this study. The Surface Dynamics Profilometer has been used to study profile pattern wavelengths of certain areas and has given promising results. The various capabilities of the profilometer should be utilized to further this study and the areas of condition surveys and maintenance studies should be expanded with the intention of implementing the results into the design system.

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CHAPTER 1. INTRODUCTION

It has been stated by many in the field of pavement design that one of the largest deficiencies in a well-organized pavement design system is the absence of a good relationship of pavement distress to pavement performance (Ref 4). At the present time, little organized research is in progress that is directed specifically towards relating pavement distress to pavement performance. With this in mind it was decided to explore the meaning of this relationship, examine any past work that had been done in this area, and outline and begin some initial research directed toward the establishment of a relationship between pavement distress and performance. Four areas were studied: the relation of pavement distress to pavement performance, pavement condition surveys, pavement profiles and pavement maintenance. Presentations of the work conducted in these four areas are given in the remaining chapters of this study.

The second chapter includes an introduction to the meaning of relating pavement distress to performance, the need for research in this area, background work that has been accomplished, and research plans that might be considered for future efforts in this area.

The third chapter includes the role that pavement condition surveys play in relating distress to performance. Pavement condition surveys were conducted on 26 pavement sections in Texas Highway Department District 14. The survey procedure used and the results obtained are given in Chapter 3.

The fourth chapter includes the role of pavement profile studies in relating distress to performance. The Surface Dynamics Profilometer (Ref 15) was used to collect data from some of the pavement sections on which condition surveys were conducted. The results obtained and possible future research are presented. The profilometer also was used to determine the serviceability index for some of the sections on which condition surveys were conducted. The results obtained from this are also presented in Chapter 4.

The fifth chapter presents information on the role of pavement maintenance studies in relating distress to performance. The Texas Highway Department maintenance procedures were discussed with the District 14 Maintenance Engineer. The results of this discussion along with proposed future work in this area are presented in Chapter 5.

Chapter 6 contains the conclusions that were drawn from the initial research performed in the four areas.

It must be remembered that the purpose of this work was to explore research areas that might contribute to relating distress to performance. It is realized that much more thorough and detailed research needs to be conducted before the relationship of pavement distress to pavement performance can be satisfactorily accomplished.

CHAPTER 2. RELATION OF PAVEMENT DISTRESS TO PAVEMENT PERFORMANCE

In the field of pavement research many feel that the lack of a sound basis for relating pavement distress to pavement performance is the most critical deficiency in the development of a complete pavement design system (Ref 16). Careful research must be conducted that will lead toward the realization of the ultimate goal - prediction of the performance history of a pavement from the input variables.

To begin work in this area, one must understand the meaning of performance. A highway is a driver-vehicle-pavement system that must perform in the best way possible in order to serve its purpose: the transportation of people and goods. The performance of this system is measured by what the user feels. What the user feels is the combined effect of several factors such as surface roughness, skid resistance, surface texture, geometric design, striping, signing, illumination, and esthetics. If the user is satisfied when he utilizes the system, it has performed well. If he is dissatisfied, it has performed poorly.

When one or more of the above mentioned factors fail to perform as well as required, the overall performance of the highway is adversely affected. For example, the riding surface may be smooth, but there may be poor skid resistance, or the riding surface and skid resistance may be good, but the geometric alingment may make the user seem unsafe. Thus it is desirable that all the factors that affect the performance of the highway be optimized in order to provide a highway that will have the desired level of performance.

The pavement designer is interested in that part of the performance that is conveyed from the pavement to the automobile wheels to the driver and it is primarily he that must solve the problem of the roughness that is conveyed to the rider. He must design a pavement that performs well and maintains an adequately smooth and safe surface.

To do this there must be a sound method for measuring and/or predicting the performance of a pavement. The AASHO Road Test was the pioneer effort in developing such a method (Ref 1). It led to rating the serviceability of a pavement to the pavement structure by the development of the serviceability index equation, which includes slope variance, rut depth, cracking and patching. This was the first model that related distress to performance.

This was a decisive beginning; however the model has its shortcomings. The four variables included are not enough to define serviceability. More thorough and detailed insight into the problem is needed by considering additional variables.

There are many mechanistic models available to predict distress in a binomial form, i.e., yes or no, such as stress, strain and deflection analyses, along with strength data. The equstions immediately arise. What can be done with all these tools? Of what ultimate value are they? They are somewhat useless unless they can be used to predict a real distress and eventually performance. Figure 2.1 shows part of the pavement design system, a block diagram relating distress to performance. There needs to be a sound way of combining primary and limiting responses to fill the block and thus enable prediction of pavement performance, perhaps as a function of a distress index. Very little work has been done in this block and the purpose of this study is to define the problem, state the needs, and outline a work plan to initiate research that will enable it to be completed.

Definition of Performance

Before the problem of relating distress to performance can be defined and described, it is necessary to understand the meaning of performance and distress. An excerpt from an article by Nakamura and Michael in Highway Research Record 40, 1963, will help to define performance (Ref 2).

> Several years ago D. C. Greer, State Highway Engineer of Texas, made the statement that highways are for the comfort and convenience of the traveling public. This simple statement implies that the purpose of any road or highway pavement is to serve the highway user and that a good highway pavement is one on which the traveling public has a comfortable ride. But what is a comfortable ride? And how can the comfort and convenience provided by a highway pavement be measured? These are some of the unanswered questions which plague the highway authority when the final decision as to which highways to improve must be made.
>
> For many years state highway departments have developed reconstruction and maintenance programs on the basis of the personal knowledge of members of their staffs relative to the needs of their highway systems. However, highway personnel usually have different amounts of information on the condition of each highway within the highway system and, thus,

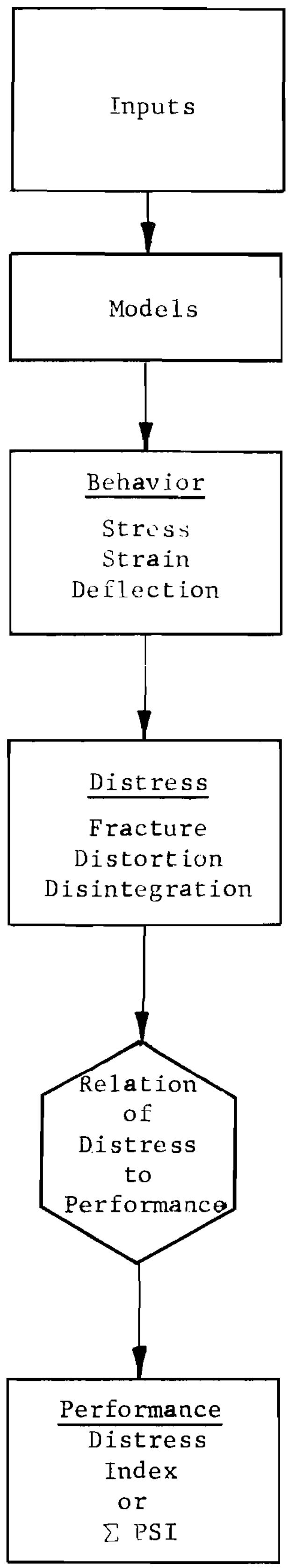


Fig 2.1. Flow Chart for deriving pavement performance.

their evaluation of the serviceability of a specific highway pavement may be heavily biased. It is also typical that a poor highway pavement to one engineer might mean that a pavement has a few cracks, whereas to another, it might mean that a large number of cracks and patches are present. One engineer might classify a highway pavement with 10-foot lanes as excellent, whereas another might classify only highway pavements with 12-foot lanes as excellent category. As a result, it is difficult to compare evaluations made by different personnel, and almost impossible to develop optimum reconstruction amd maintenance programs on the basis of such evaluations of highway pavement serviceability.

Such an evaluation procedure might be one which would utilize an objective measurement or measurements and which would have a close correlation with the subjective human judgment of the total traveling public. Such a procedure should also provide an indication of the performance of a pavement throughout its life if evaluated periodically, be applicable to all roads, and be usable as a tool in developing final highway improvement programs.

Many studies have been devoted to the problem of the evaluation of highway pavement serviceability and/or performance. Various evaluation procedures have resulted from these studies and are being used by state highway departments throughout the country. These procedures may be classified into three general types: (a) evaluation of sufficiency rating systems, (b) evaluation by surface riding quality indicators, and (c) evaluation by subjective serviceability ratings.

Karl Pister, in a state-of-the-art paper published in Highway Research Board Special Report 126, 1971 (Ref 3), also provides some insight into the question.

> Serviceability, which embodies the function of a pavement, is the ability of a pavement to serve traffic with safety and comfort and with a minimum of detrimental effects to either vehicle or pavement.
>
> The present serviceability index, which is the current (present) measure of the effectiveness of the pavement, is a numerical index of the ability of a pavement in the present condition to serve traffic.
>
> Performance is the measure of the accumulated service provided by a pavement, i.e., the adequacy with which a pavement fulfills its purpose. Performance implicitly includes 'service per dollar' or some other type of economic measure.

W. R. Hudson in a Highway Research Board Special Report 126 paper (Ref 5) used the following definition of performance:

> Performance is a measure of the accumulated service provided by a facility, i.e., the adequacy with which a pavement fulfills its purpose. Performance is often specified by a performance index as suggested by Carey and Irick in HRB Bulletin 250 (Ref 1). As such, it is a direct function of the serviceability history of the pavement.

It can be seen from these varying statements by persons who are working in the pavement field that there is no clear-cut "dictionary" definition of pavement performance. For the purposes of this paper, the above definition of pavement performance given by W. R. Hudson will be used.

Definition of Distress

Distress is not easily defined in succinct terms. It is generally thought of, however, as a condition that causes a loss in serviceability of the pavement. This loss in serviceability is usually felt by the user as a rough pavement. But as already stated in the definition of performance, one must be careful in defining distress or failure. To some persons any type of crack at all might be considered a distress, whereas to others some cracks are not considered distress because they do not reduce the serviceability of the pavement. For the purposes here, distress will be thought of as that condition that causes or will cause a reduction in serviceability. Distress modes will be defined in one of these three categories: fracture, distortion, and disintegration. These are shown in Table 2.1 along with the manifestations of each mode and the probable causes (mechanism) (Ref 6).

Thus, if it is known that distress is what causes or will cause a loss in serviceability, and it is known that performance is the accumulated serviceability as determined by the user and if this performance can be described and measured, then this is a beginning in relating distress to performance.

Background Work

Before further work can be done toward relating distress to performance, the previous accomplishments in this area should be studied and described. Developments for use on the AASHO Road Test (Ref 1) were pioneer efforts. The following brief description taken from NCHRP Report 7 (Ref 7) will clarify this initial progress:

> One of the most significant findings of the AASHO Road Test dealt with serviceability of pavements and methods of measuring pavement condition. Specifically, serviceability has been referred to as the Present Serviceability Index (PSI).
>
> Briefly stated, the concepts were constructed on the premise that the road user should determine whether or not a pavement is satisfactory. Thus, the Present Serviceability Index was obtained by correlating user opinions with measurements of road roughness

TABLE 2.1 MODES, MANIFESTATIONS, AND MECHANISMS OF TYPES OF DISTRESS

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.

(as measured by the AASHO slope profilometer) and the extent of cracking patching and rutting.

The Present Serviceability Index was established from regression equations which related user opinions with objective measurements. A panel drove over selected pavements and rated the pavements using an appropriate scale. The rating scale for this study ran from 0 to 5. A rating of zero denoted an impassable pavement whereas a rating of 5 indicated a perfectly smooth pavement. The raters were asked to mark on the scale the number which indicated their opinion of the road at the time that it was rated. In addition, the raters were asked to give their opinions relative to the objective features (i.e., rutting and cracking) of the pavement which influenced their rating and were asked to state whether the road was acceptable for Interstate traffic.

Ratings vary because of human nature and differences of opinion; thus, the rating numbers assigned to a pavement by panel members were averaged and designated the Present Serviceability Index.

Thus it can be seen that this was the first model that related distress in the forms of slope variance, cracking, patching, and rut depth, to performance, in the form of a serviceability index.

However, there are shortcomings in this model. The use of only four distress variables seems to fall short of a thorough expression of distress. The use of a present serviceability index to describe performance is inadequate or perhaps erroneous as explained in the following excerpt from HRB Record 40 (Ref 8) by W. N. Carey:

Some of my fellow committee members and others seem to have missed one point about the AASHO Road Test serviceability concept. That is this: no one has made any claim for the present serviceability index as a device by which one can predict future performance. The work "present" is part of the name of this index to circumvent this misunderstanding. Although no one made any direct criticism of the concept, there was criticism by inference in some of the remarks to the effect that the concept falls short because it does not predict future performance. It is not intended to - it never was. Our definition of performance, which you have heard a thousand times, is the "trend" of serviceability with time or with load applications. We do not call performance "serviceability" nor vice versa. It is the trend with time and load applications that we call performance.

We have no argument with those who want to look at things in the small; that is, to find out why one part of a pavement fails. We know that this has to be done. We recognize this requires measurements of the individual compoents of a structure and clear understanding of drainage and all of these things, but it was never the intention of the Road Test performance concept to do this. The

Road Test performance concept was intended to compare designs in the large - over miles, not over one-quarter mile or over one square yard. We think that this can be done rapidly over wide mileages. Please don't accuse us of forgetting those things that influence performance in the small or accuse us of saying that present serviceability, today, by itself, has anything to do with "future" performance. It has to be looked at over a period of time before we can begin to predict future performance.

Need for Research

Because of the inadequacy of the AASHO PSI equations to relate distress to performance and because of the lack of research performed in this area, there has been a definite requirement for additional research. The opinions of some of those attending a workshop held December 7-10, 1970, in Austin, Texas, in structural design of asphalt concrete pavement systems verify this need for research. The following list contains ten major research items selected by the Advisory Committee from the deliberations of the nine discussion groups and endorsed by the consensus of the workshop attendees. Ranking by importance was established by vote of the Advisory Committee (Ref 9):

(1) relationship between pavement distress and a performance or failure function,

(2) applicability of linear theories to predict stresses, strains, deflections, and fatigue and rutting distress in pavements,

(3) mechanical characterization of granular materials,

(4) effect of environment on pavement system condition and response,

(5) pavement design as a stochastic process,

(6) fracture mechanisms,

(7) mechanical characterization of pavement materials (other than granular),

(8) loading variables,

(9) methods of predicting reflection cracking, and

(10) development of proper feedback information data for the pavement system.

As can be seen, the first ranking need is that of relating distress to performance. The Advisory Committee report made these further comments on the problem:

Relationship between pavement distress and a performance or failure function - The mechanistic approach to pavement analysis and design can at best yield predictions of the nature and extent of pavement distress (e.g., the extent of rutting and nature and extent of cracking). There is an urgent need for a technique whereby such structural distress and its objective measurement (including, for example, measurements of roughness) can be related to the functional performance and perhaps to ultimate failure of the pavement. It seems apparent at this time that the only feasible way to relate distress to performance is through a statistical analysis of serviceability-performance information (most probably subjective in nature) and objective distress predictions or evaluations. Such an analysis must (a) define important distress factors involved in pavement nonserviceability and failure, (b) establish suitable weighting functions to judge the relative importance of various levels of combined distress modes, (c) identify suitable limiting levels of distress occurring separately or in combination, and (d) develop or adopt suitable measures of performance or serviceability."

Since its original development, the Present Serviceability Index concept has been adopted by many user groups. Specifically, several state highway departments have adopted these concepts for setting up maintenance programs, road life studies and priority ratings.

The present serviceability index equations mentioned above are as follows:

Flexible Pavements

$$p = 5.3 - 1.91 \log (1 + \overline{SV}) - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2 \qquad (2.1)$$

Rigid Pavements

$$p = 5.41 - 1.78 \log(1 + \overline{SV}) - 0.09 \sqrt{C + P} \qquad (2.2)$$

where

p = present serviceability index,

$\overline{SV}$ = mean slope variance, a summary statistic of wheelpath roughness,

C = area of detrimental cracking per 1000 square feet,

P = area of patching per 1000 square feet, and

$\overline{RD}$ = average rut depth in the wheelpath, inches.

Performance can be expressed as a function of the above present serviceability equations. This expression as used by McCullough in a Highway Research Board Special Report 126 paper (Ref 6) is as follows:

$$P(\underline{x},t) = \underset{s=0}{\overset{s=t}{F}} [p(\underline{x}, s)]$$

where

$P(\underline{x},t)$ = performance as a function of space and time,

t = time, and

$\underline{x}$ = position vector of a point referred to a coordinate system

The FHA responded to the Advisory Committee's number one need as follows (Ref 10):

> The task of relating pavement performance or a failure function to pavement distress is a major problem area that has yet to be solved. The pavement serviceability performance concept of Carey and Irick used at the AASHO Road Test does not use a mechanistic approach to pavement evaluation. It is a correlation of quantifiable measurements on the pavement to represent the subjective opinions of the user as to whether the pavement is functioning as intended.

Harry Smith made the following comments on the workshop sessions (Ref 11):

> The designer must predict the performance of a pavement that is to be subjected to the complex interaction of load, environment, and time variables. Until there is a suitable procedure for relating predicted pavement behavior and distress to pavement performance in the real world, I cannot see how the solution to boundary value problems will be useful to highway pavement designers.

William Carey made the following introductory remarks (Ref 12):

> I still hear clever doctoral dissertations on how to predict stress in an element of a homogeneous elastic slab on an idealized foundation. No one has ever suggested how knowledge of such stress relates to the performance of pavements in the real world.

Karl Pister made the following comment (Ref 3):

> ... performance is the real goal of design and operation (through proper management) of the system. Yet, relatively little

information concerning pavement behavior, in which performance is the dependent variable, can be found in the literature. This is of course understandable because performance is somewhat ambiguous to define, in spite of its conceptual importance.

W. R. Hudson in his state-of-the-art paper for the workshop made this statement (Ref 5):

> It is recommended that, as research effort continues toward the development of a better pavement design method, adequate attention be given to combining various pavement behavior and distress factors into an overall performance function because it only through adequate definition of this function that the pavement problem will ultimately be solved.

As stated before, the purpose of this study is to respond to these expressed needs by initiating research that will lead to the fulfillment of these needs. It is hoped that a well-organized plan can be devised that outlines the research pieces that later can be put together to develop the desired performance function.

Description of Problem

The phrase "relating distress to performance" must be understood before any research can be conducted that will be useful. Many pavement engineers have expressed the need for relating distress to performance, yet this is as far as they go. None have explained what it means or what good will be accomplished if this is done. There must be some reasons and objectives for relating distress to performance and there must be some description of what the phrase "relating distress to performance" actually means. Until these things are brought into the light and discussed and outlined, no meaningful research can be begun. Thus, an attempt will be made here to describe the problem.

Figure 2.2 which is more detailed and enlarged than Fig 2.1, attempts to describe what is meant by "relating distress to performance." At present, pavement design progresses from the inputs (block 1) to performance in the form of accumulated serviceability (block 4) by use of design models (block 5) and the PSI equations (block 6). Doing this overlooks pavement behavior (block 2) and pavement distress (block 3). It is desirable to include the knowledge that has been accumulated in these two areas in pavement design in progressing from inputs to performance, but a step in the process is missing. This step involves the progression from distress to performance. Various mechanistic

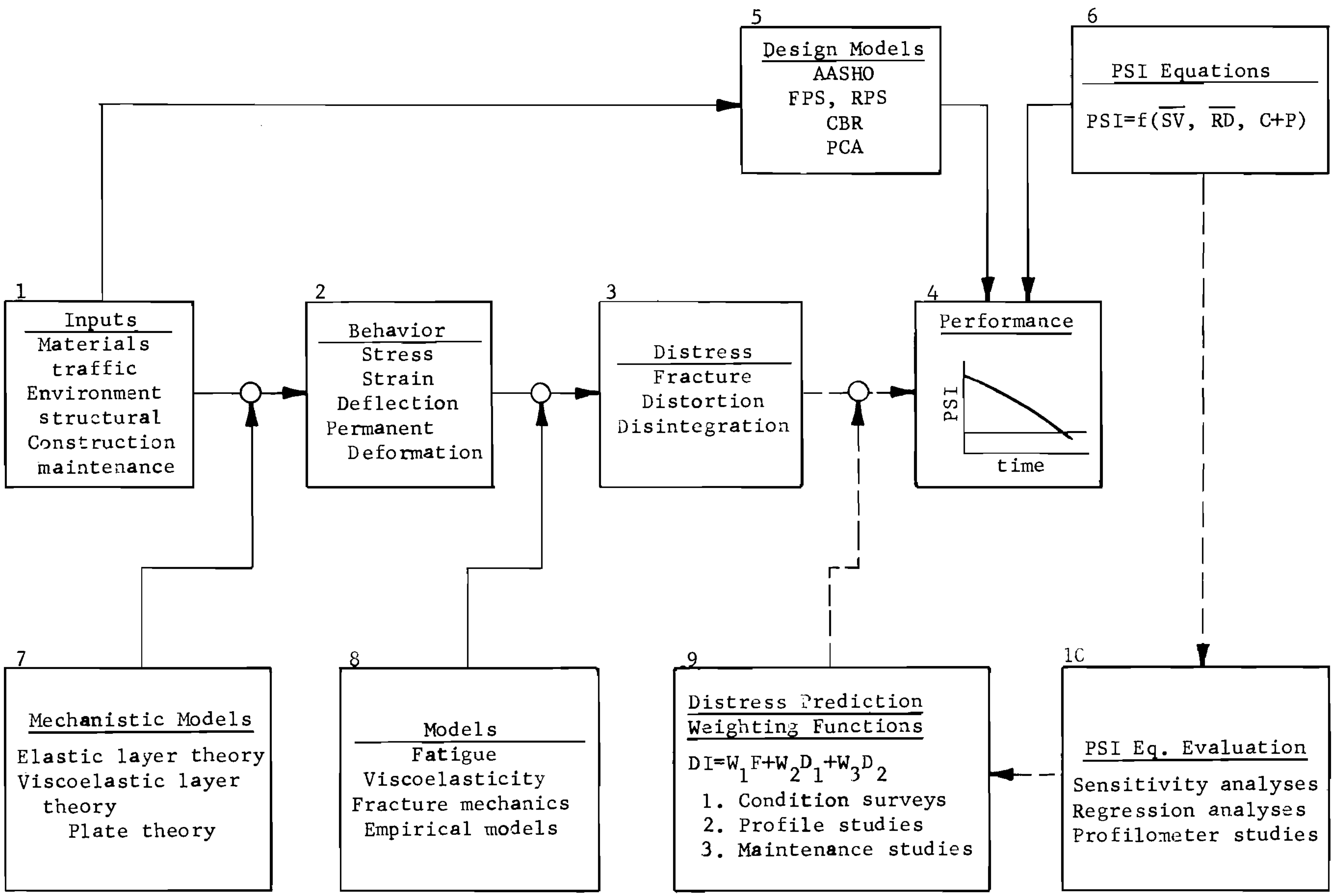


Fig 2.2. Distress-performance relationship with use of models.

models exist (block 7) which can determine to a fairly accurate degree the pavement behavior given certain inputs; and models also exist (block 8) which can determine to a less accurate degree pavement distress, given certain pavement behavior. However, no models and very limited knowledge exists which allows the progression from pavement distress (block 3) to pavement performance (block 4). Thus, information that will allow this progression, perhaps in the form of distress weighting functions (block 9) used in prediction models, is what is meant by relating distress to performance. By use of a well-designed research plan and by use of continued evaluation of the PSI equation and its terms (block 10), perhaps enough information can be obtained to determine these distress weighting functions and prediction models.

Research Plan

It is felt that research conducted toward relating distress to performance should first consist of the determination of the various distress manifestations (cracking, spalling, faulting, scaling, etc.), their magnitudes, their effect on serviceability, and methods of correcting them. This can primarily be done by condition surveys, profile studies, and maintenance studies.

The various distress manifestations then need to be associated with distress mechanism. This is more difficult to do than the first step of the research plan, but can be done within a detailed work plan. These distress mechanisms, when determined, can then be ranked according to priority.

Continued evaluation of the present serviceability model should be conducted to see that it contains each of the occurring distress manifestations with the best weighting function.

Then improvements in the model can be made or new models can be developed for predicting the ultimate goal - the performance of pavements.

It would be wise to look at a second proposed research plan that differs somewhat from the first as outlined in Fig 2.2. This plan can be visualized by referring to Fig 2.3, which is a similar but more simplified version of Fig 2.2. The proposed research plan is indicated by the bold curved lines. Instead of progressing straight through from inputs to behavior to distress and finally to performance by the use of mathematical models, a simpler and possibly faster method can be employed as shown.

The behavior of existing pavements can be described by measuring deflections, etc. and then the inputs can be found from existing past records of

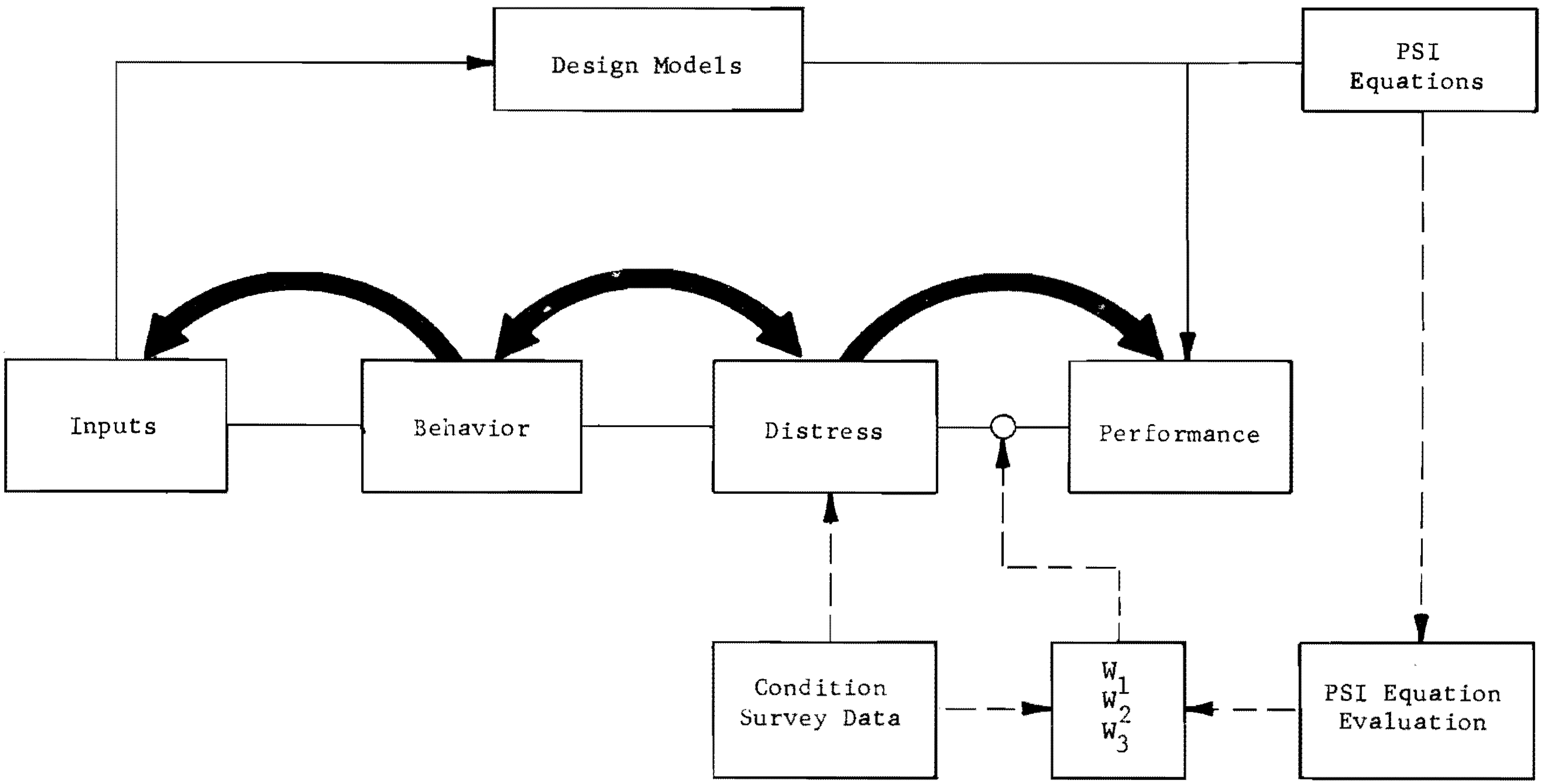


Fig 2.3. Distress-performance relationship without use of models.

materials, thicknesses, etc., thus relating inputs and behavior without the use of mathematical prediction models.

Pavement distress information can be compiled from condition surveys and then compared with the behavior measurements, thus relating behavior and distress without the use of mathematical models, very few of which exist.

Then the pavement distress data can be compared to performance by the collection of data using the profilometer and Mays Meter, thus bridging the gap between distress and performance.

This method of relating distress to performance would perhaps be much faster than the first proposed method, which could take several years, but may not be quite as accurate as the first. However, it might accomplish the objective of providing a relationship between distress and performance at least on a cursory basis.

CHAPTER 3. PAVEMENT CONDITION SURVEYS

Before a relationship can be established between pavement distress and pavement performance, it is necessary to determine the types of distress that actually occur in pavements with information sufficiently detailed to differentiate the various types of distress. Thus, the decision was made to conduct a detailed inspection condition survey to provide information on distress for further use in establishing the distress-performance relationship.

The following objectives were established for the condition survey:

(1) determination of the distress types that occur on pavements, along with their relative frequency of occurrence,

(2) determination of the amount of distressed area in pavements, and

(3) establishment of a more suitable method for performing condition surveys.

Method of Sample Selection

After consideration of travel distance and available time, money, and manpower, the decision was made to conduct a preliminary condition survey on flexible pavements within Texas Highway Department District 14, which is shown in Fig 3.1.

Interstate highways were eliminated because of the problems that would occur in surveying due to the high traffic volume and lack of manpower available. Thus the survey was conducted on primary and secondary flexible pavements in District 14.

For this pilot study a group of pavements already scheduled for maintenance were selected, since they obviously contained distress. Subsequent studies will be needed for distress at various stages of development.

It must be kept in mind that the distress data are biased due to the method of selection and are not representative of the overall highway system in the district. All pavements except two were chosen from two Texas Highway Department project lists dated February 1973.

These lists give proposed projects, their location, and the type of work to be done. For aid in determining the best survey procedure to use, two sections

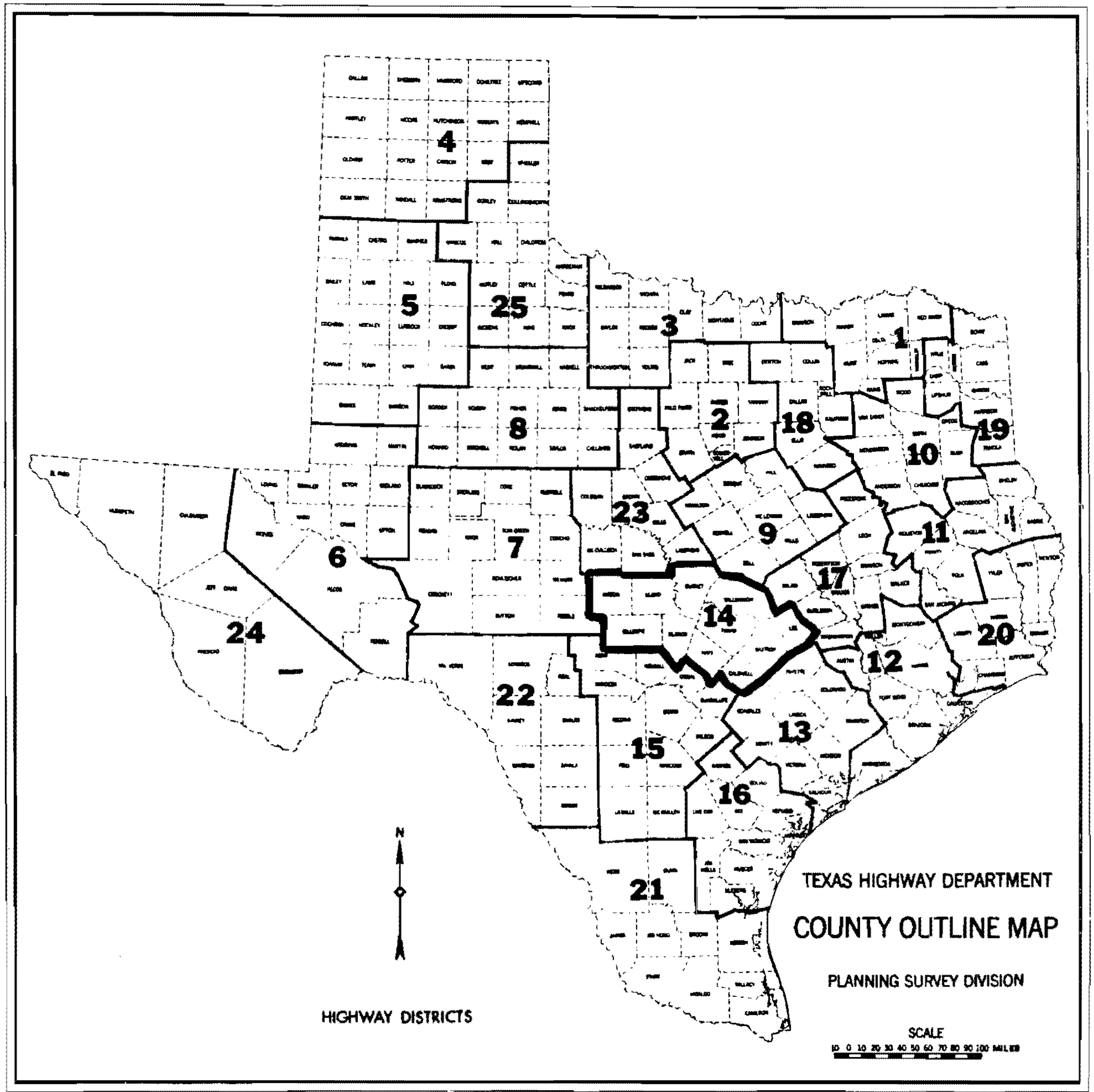


Fig 3.1. Texas Highway Department Districts.

were selected very near Austin as trial sections: (a) one being on Loop 360 west of Austin, and (b) the other on Pleasant Valley Road in Austin. Table 3.1 is a list of pavements studied and the number of sample sections chosen from each pavement. Figure 3.2 shows these pavements on a District 14 map.

In order to insure a consistent method of sampling, one two-tenths-mile section was selected from each three miles of pavement studied to give the desired number of sample sections based on the amount of time available for surveying. This procedure was used to the extent possible, but there are some deviations, mainly on SH 80 in Caldwell County and FM 621 in Hays County, from which more than one section per three miles was chosen.

The sample section length was chosen to be two-tenths of a mile because it is a common length used to obtain serviceability index data which are also included in this study.

Table 3.2 lists the 26 sections that were surveyed and includes section number, highway number, county, and control-section number. A detailed location of each section is given in Appendix 1.

Field Survey Procedure

Through the years many different types of condition survey methods have been used. The method described below was chosen to begin this study based on the requirements of the study.

The following equipment was used in conducting the surveys:

(1) survey data sheets, clipboard, pencils,
(2) spray paint,
(3) distance measuring wheel,
(4) camera, numbered pieces of cardboard for picture identification, and
(5) map for location of section to survey.

A District Control-Section map was used to locate each section to be surveyed. Effort was made to locate the beginning of a section at an easily identified point such as a city limit, county line, highway intersection, etc. This beginning point was marked by spray painting a strip approximately eight inches wide and four inches long extending from the pavement edge. Information required on the first data sheet shown in Fig 3.3 was recorded, including an adequate location of the section and any pertinent comments.

TABLE 3.1. PAVEMENTS SCHEDULED FOR RECONDITIONING IN THD STATUS OF PROJECTS MANUALS

County	Highway Number	Control Section	Length (miles)	Limits of Segment	Type of Work	Number of .2-Mile Sample Sections for Survey
Bastrop	SH 71	265-3	7.9	Red Gully to 2 mi. w. of Bastrop	Gr. strs. surf. for add'l lanes	2
Bastrop	SH 71	265-5	14.4	E. c/l of Bastrop E. to Fayette Co. line	Gr. strs. surf.	5
Caldwell	SH 80	286-2	4.2	Hays c/l to FM 1979 at Martindale	Wdn. surf.	2
Gillespie	US 290	112-2	8.2	8.6 mi. w. of Fredericksburg west	Wdn. gr. strs. surf.	3
Gillespie	US 290	112-2	8.7	Kimble Co. line to 16.8 mi. w of Fredericksburg	Reconst. gr. strs. surf.	2
Gillespie	US 87	71-6	0.5	Mason c/l to N. Cherry Springs	Wdn. gr. strs. surf.	0
Gillespie	SH 16	290-3	0.9	.9 mi. N of US 290 in Fredericksburg N	Wdn. gr. strs. surf.	0
Hays	SH 80	286-1	1.2	Blanco Rv. bridge to Caldwell c/l	Recond. and wdn. surf.	0
Hays	FM 621	987-3	2.9	SH 123 to Guadalupe c/l	Wdn. gr. strs. surf.	2
Mason	US 87	71-5	11.1	1.3 mi. S of Beaver Cr. to Gillespie c/l	Gr. strs. surf.	4

(Continued)

TABLE 3.1. (Continued)

County	Highway Number	Control Section	Length (miles)	Limits of Segment	Type of Work	Number of .2-mile Sample Sections for Survey
Travis	MH	3385-1	1.2	In City of Austin on Riverside Dr. from IH 35 SE to Pleasant Valley Road	Wdn. gr. strs. surf.	0
Travis	PH	3357-1	0.4	City of Austin on Pleasant Valley Rd. from 7th St. N. to Webberville Road	Gr. strs. surf.	0
Williamson	FM 971	2690-1	10.1	Weir E. to SH 95 in Granger	Add'l base & surf.	4

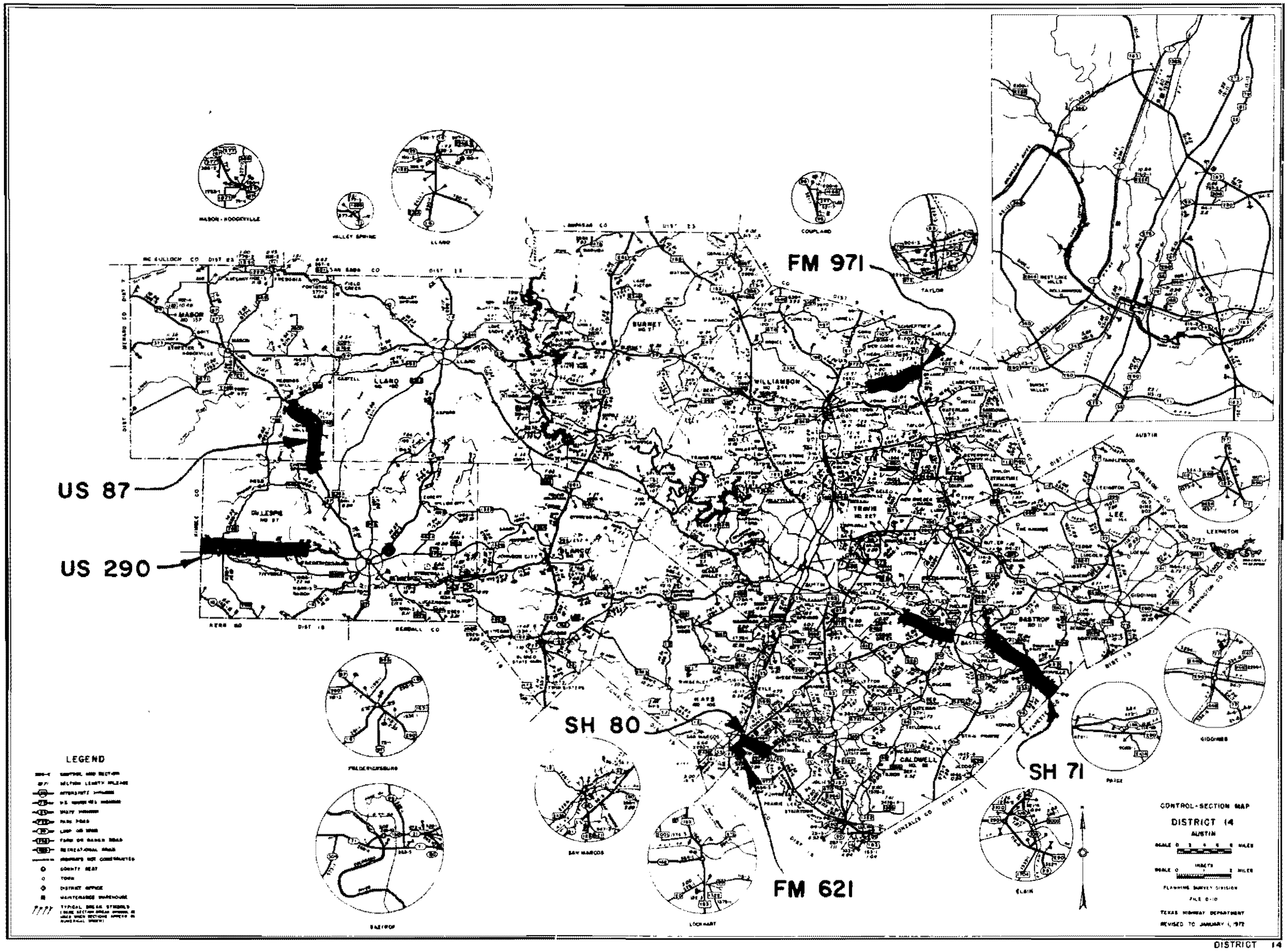


Fig 3.2. District 14 pavements scheduled for improvements.

TABLE 3.2. LIST OF SECTIONS SURVEYED

Section Number	Highway Number	County	Control-Section
P-1	SH 71	Bastrop	265-4
P-2	L 360	Travis	113-13
P-3	Pleasant Valley Rd.	Travis	---
1	FM 621	Hays	987-3
2	FM 621	Hays	987-3
3	SH 80	Caldwell	286-2
4	SH 80	Caldwell	286-2
5	SH 71	Bastrop	265-6
6	SH 71	Bastrop	265-6
7	SH 71	Bastrop	265-5
8	SH 71	Bastrop	265-5
9	SH 71	Bastrop	265-5
10	SH 71	Bastrop	265-3
11	FM 971	Williamson	2690-1
12	FM 971	Williamson	2690-1
13	FM 971	Williamson	2690-1
14	FM 971	Williamson	2690-1
15	US 87	Mason	71-5
16	US 87	Mason	71-5
17	US 87	Mason	71-5
18	US 87	Mason	71-5
19	US 290	Gillespie	112-2
20	US 290	Gillespie	112-2
21	US 290	Gillespie	112-2
22	US 290	Gillespie	112-2
23	US 290	Gillespie	112-2

IDENTIFICATION OF PAVEMENT DISTRESS MANIFESTATIONS

DATA SHEET

Highway No.	SH 71 Bastrop Co.	Sample Section No.	5
Control-Section	265-6	Survey Party	Phil Smith
Highway Type	Primary	Date	3/6/73
Pavement Type	Flexible		
Native Soil	Br. Cl. Sa.		
Cut or Fill	At grade		

Location of Sample Section:

Begins at Bastrop-Fayette county line and proceeds West in West bound lane.

Comments:

2 lane highway with 12' wide lanes and 8' wide paved shoulder.

There is a longitudinal construction crack on the center stripe for almost the entire section.

Block cracking is fairly prominent and there are several transverse cracks.

Fig 3.3. Sample data sheets.

(Continued)

Sample Section No. 5

Highway No. SH 71

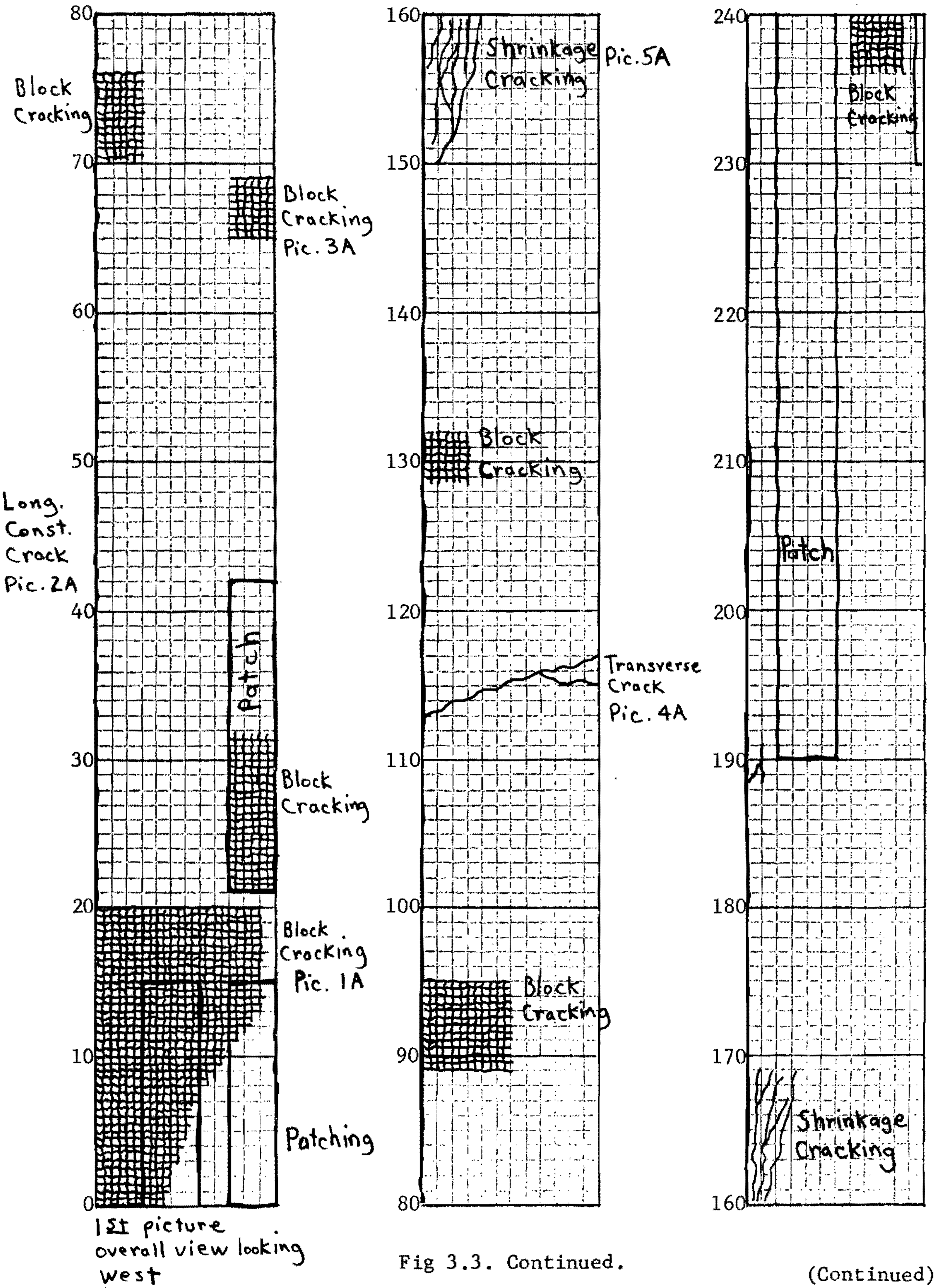


Fig 3.3. Continued.

(Continued)

Sample Section No. 5

Highway No. SH 71

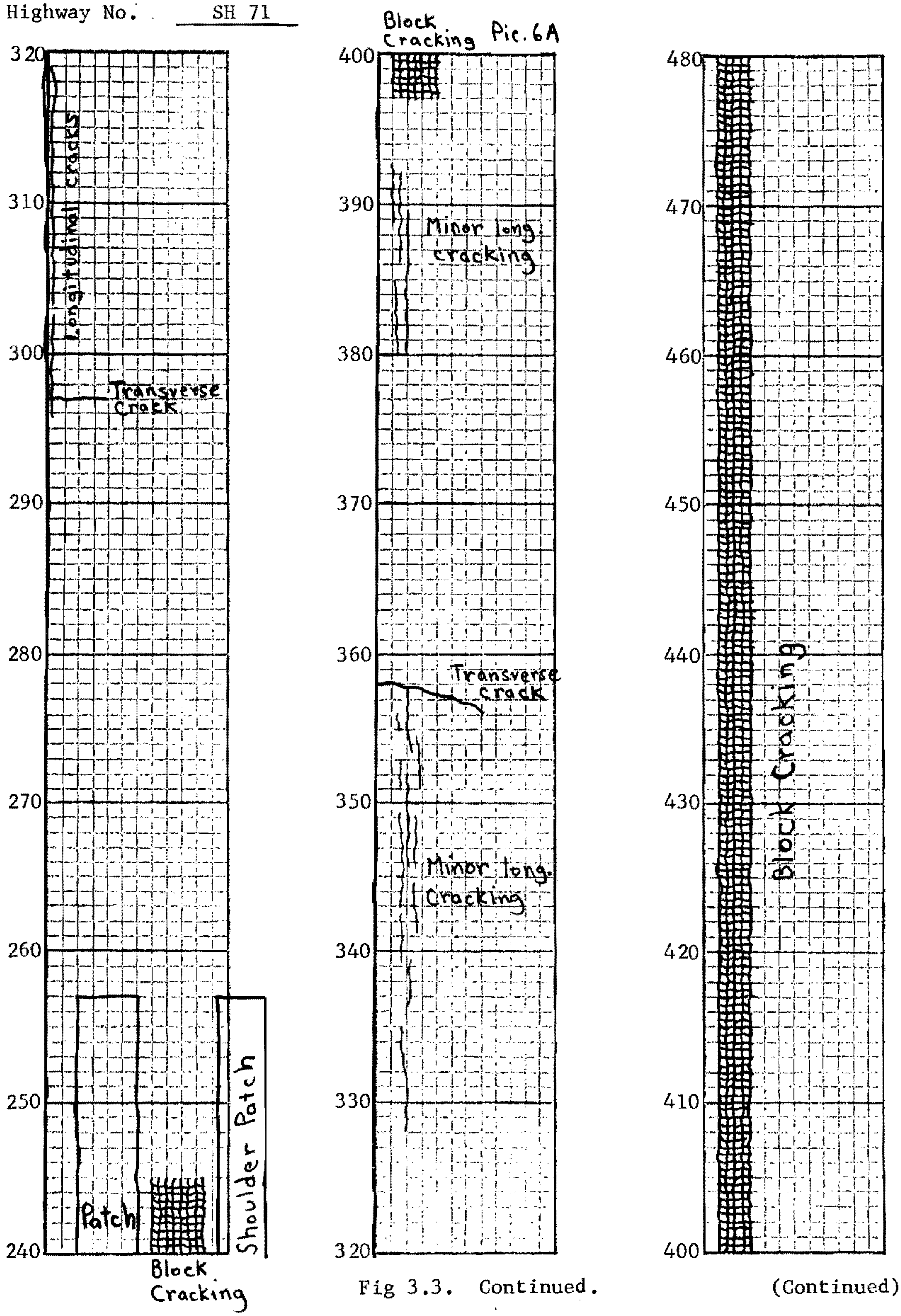


Fig 3.3. Continued. (Continued)

Sample Section No. 5

Highway No. SH 71

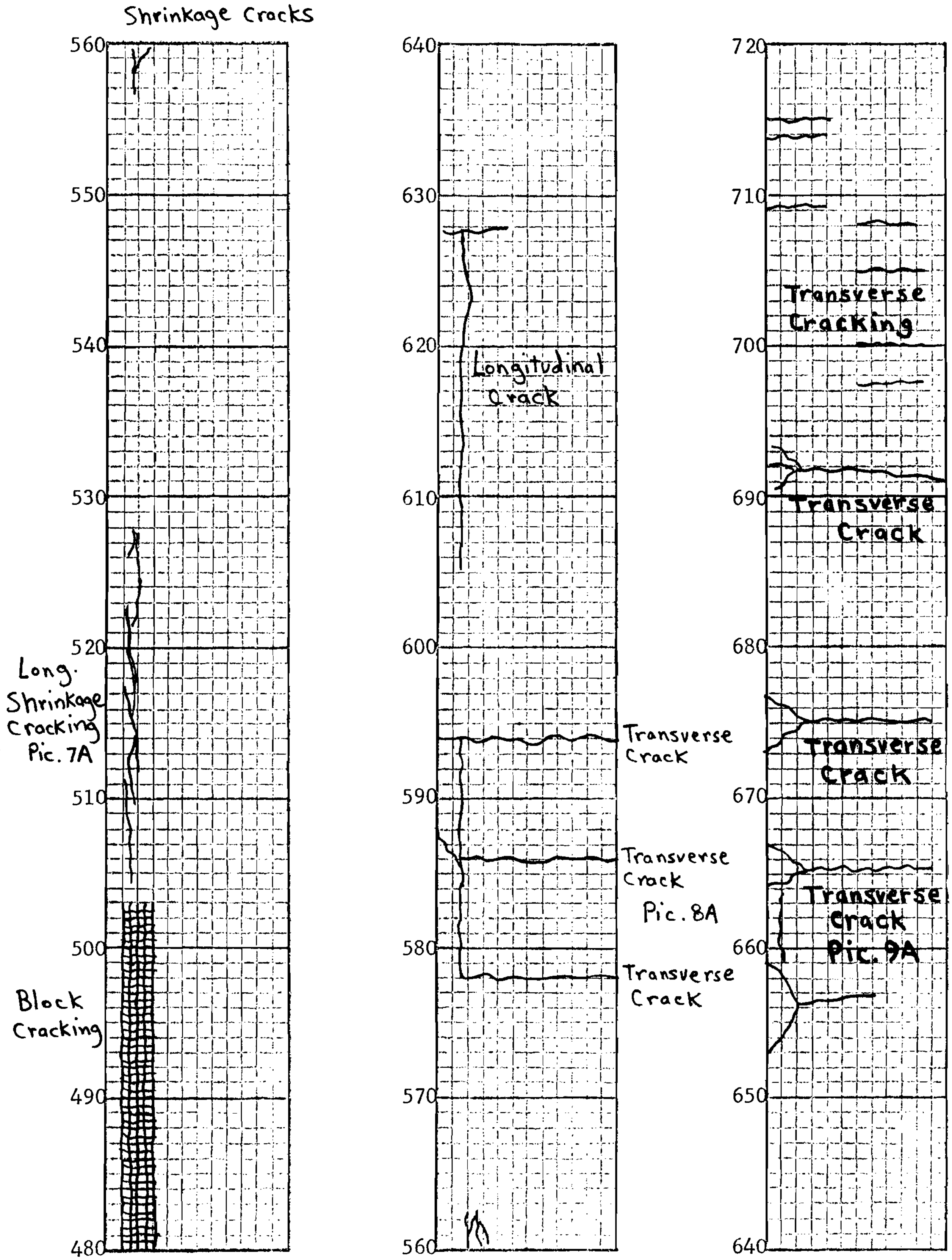


Fig 3.3. Continued.

(Continued)

Sample Section No. 5

Highway No. SH 71

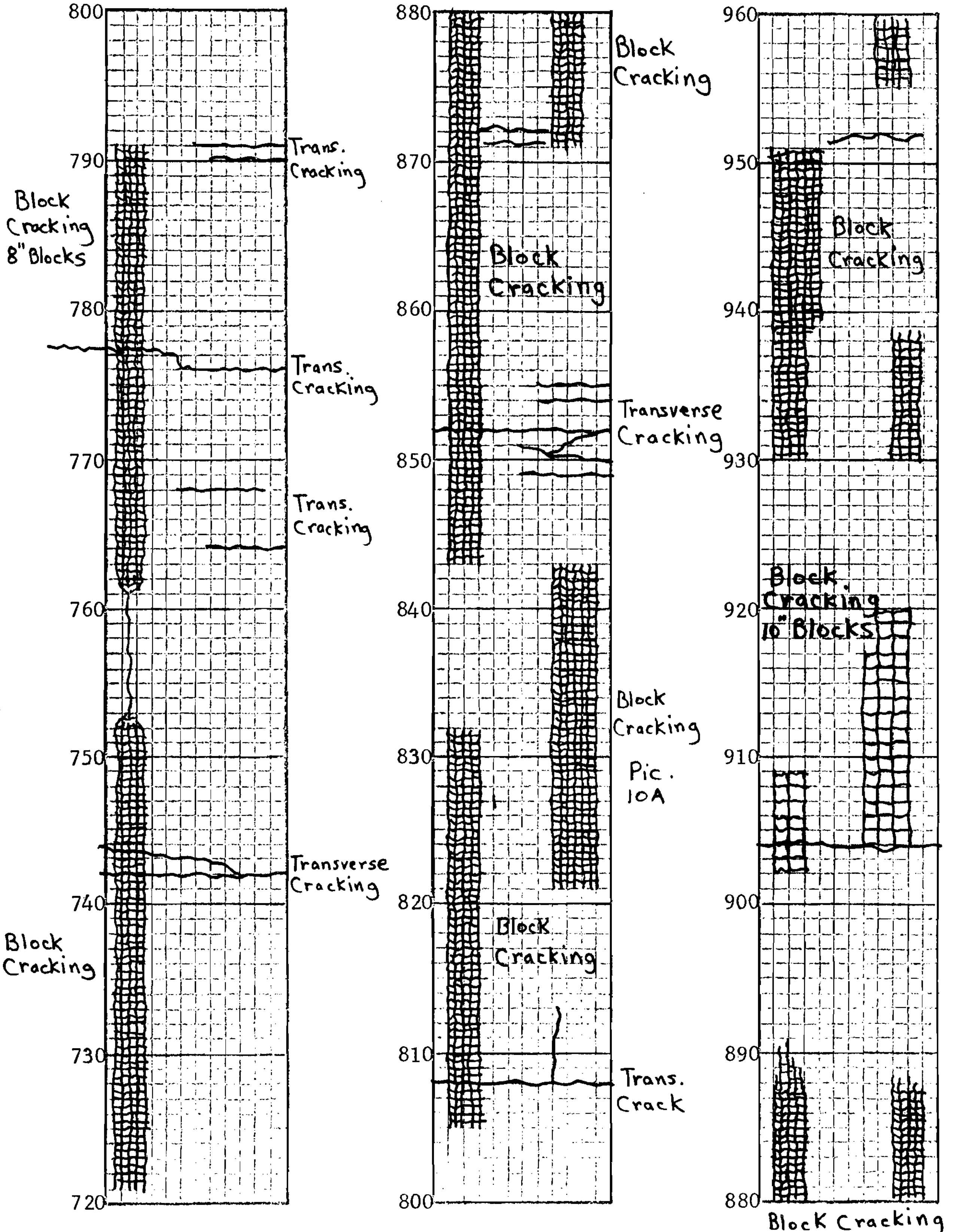


Fig 3.3. Continued.

(Continued)

Sample Section No. 5

Highway No. SH 71

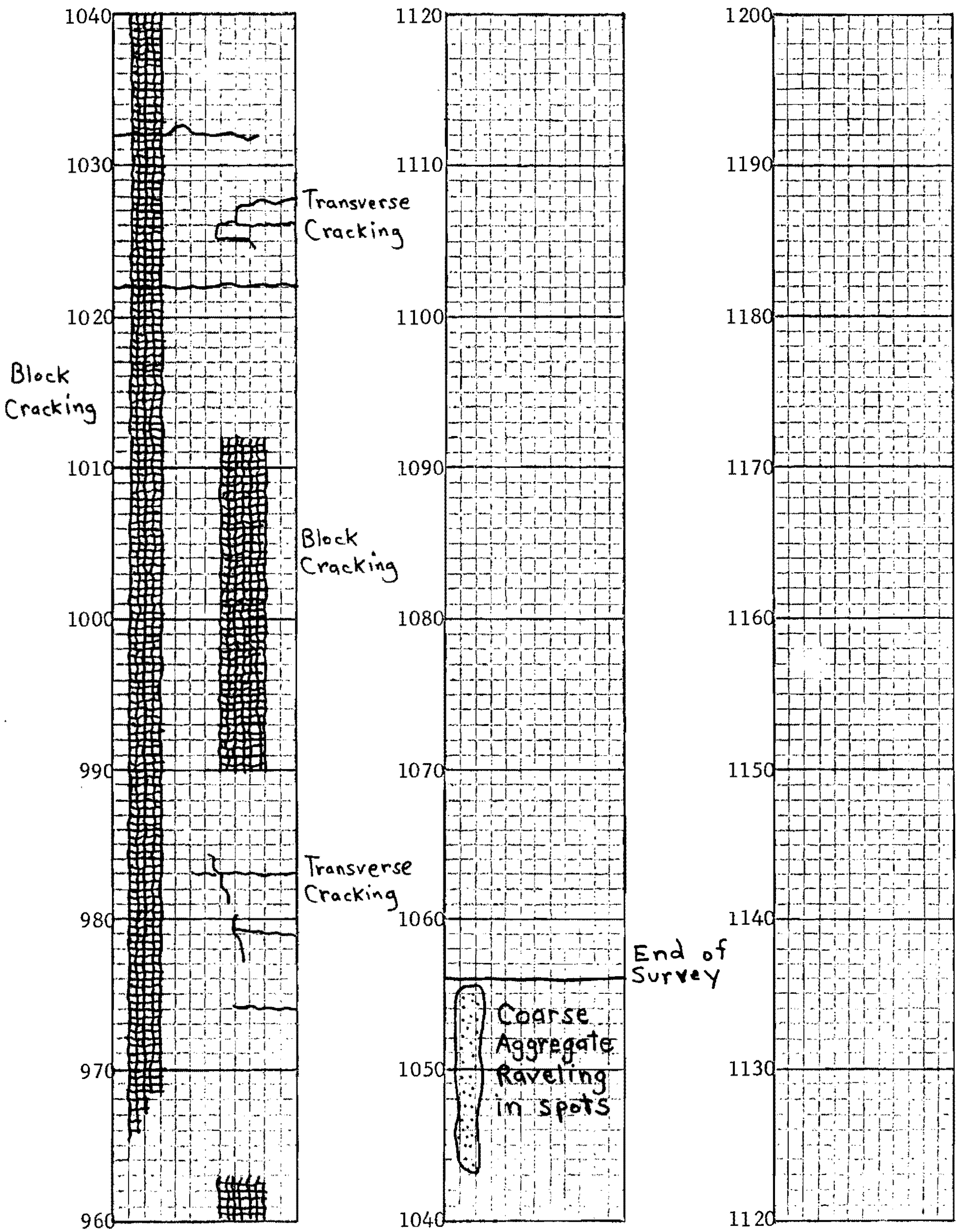


Fig 3.3. Continued.

(Continued)

A picture was taken which gave an overall view of the section as shown in Fig 3.4(a). The distance measuring wheel was set to zero and placed at the painted strip for beginning the distance measurement.

The last five sheets of the data set (Fig 3.3) consist of grids which represent the pavement lane to be surveyed. The lane is divided into 1 × 1-foot grids and is shown to be 12 feet wide. The numbers beside the grid represent linear distance along the pavement lane. The outside lane was chosen for survey on four-lane highways.

The measuring wheel was rolled linearly along the pavement until a crack or other distress was encountered. The distance reading was noted in feet and the distress manifestation was drawn on the data sheet at the corresponding linear distance and identified. Effort was made to draw the distress manifestation as nearly as possible to the correct scale using the 1 × 1-foot grid as a guide.

A 2 × 2-inch numbered cardboard square was placed near the distress on the pavement and a photograph was taken. The number on the cardboard was recorded on the data sheet at the point the distress occurred. Thus, photographs are available which give an even more accurate description of the distress than the scaled drawing on the grid data sheet. Figures 3.4(a) to 3.4(1) are photographs of the various types of distress manifestations encountered in the condition survey shown in Figure 3.3.

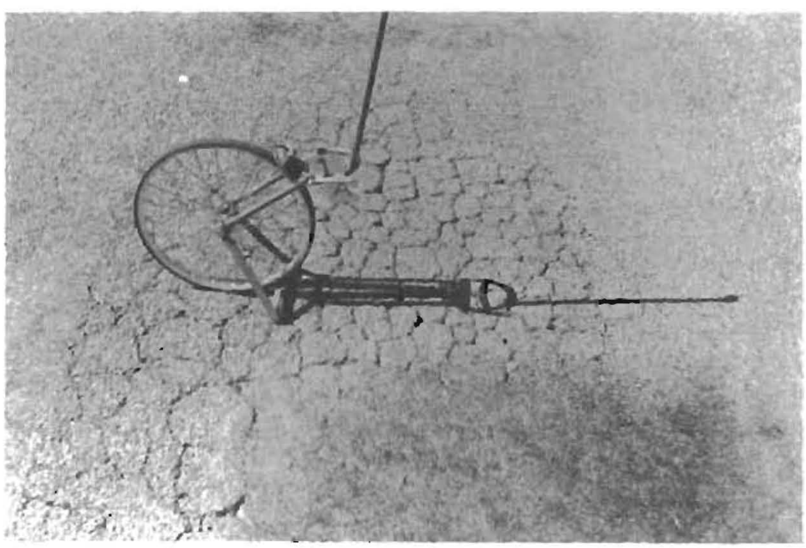
The measuring wheel was then rolled forward until the next distress manifestation was encountered and the procedure was repeated. This method was continued, making scaled drawings and taking photographs, until the distance measuring wheel had measured 1056 feet, which is two-tenths of a mile. The data set included is for a section surveyed on SH 71 in Bastrop County.

After completion of the condition survey on the two-tenths-mile section, the end point was marked with spray paint just as the beginning had been. The beginning and end points were marked so the section could be located easily if desired at a later date.

The guide or standard used for identifying the distress manifestations was Highway Research Board Special Report 113 (Ref 14), which gives pictures, definitions, descriptions, and probable causes of various pavement distresses.

It is thought that the type of data sheets used gives a better, clearer description of the pavement than ones which record only the amount and severity of distress in a table. With the information collected in this form, it is

(a) Overall view of section looking west.

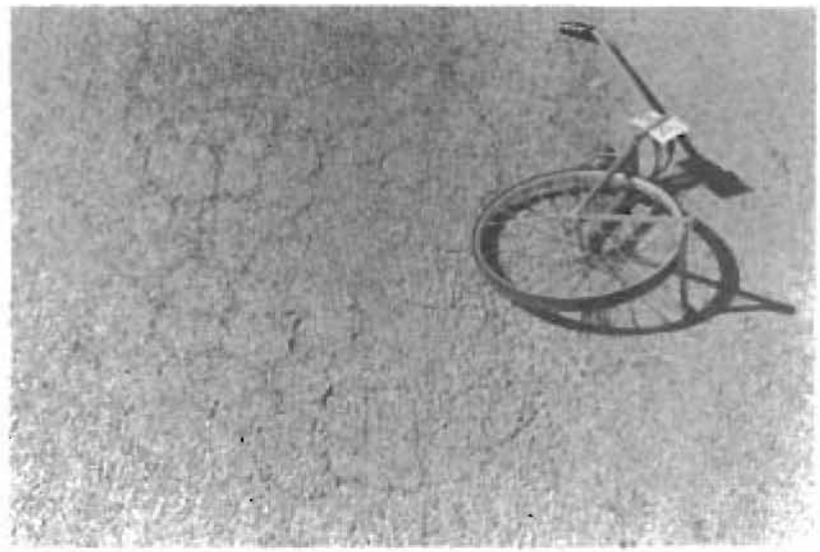


(b) Block cracking.

Fig 3.4 Condition survey photographs.

(Continued)

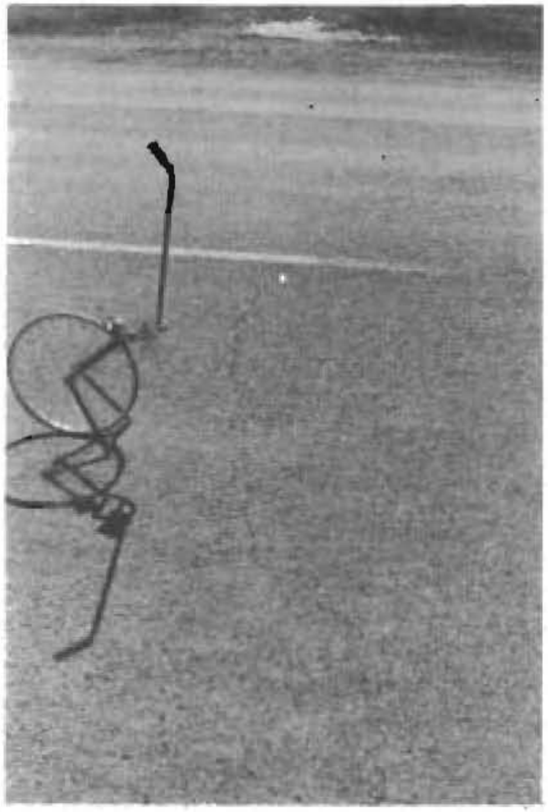
(c) Longitudinal construction crack.



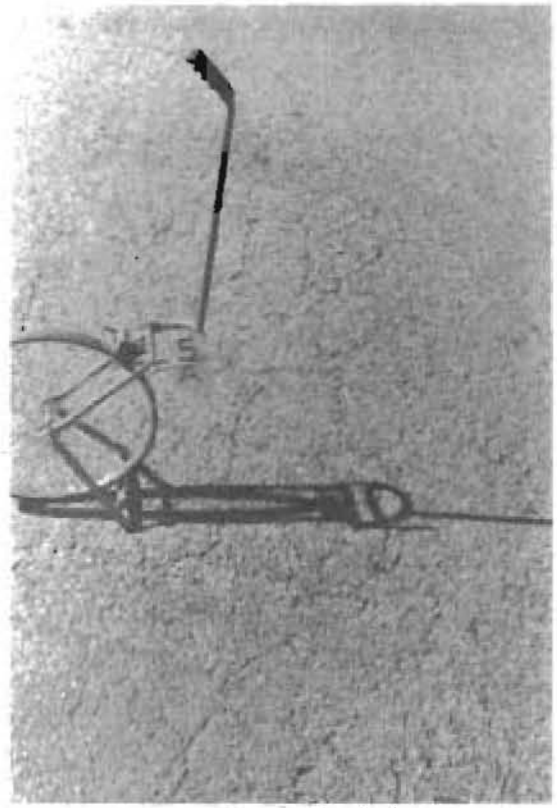
(d) Block cracking.

Fig 3.4. Continued.

(Continued)



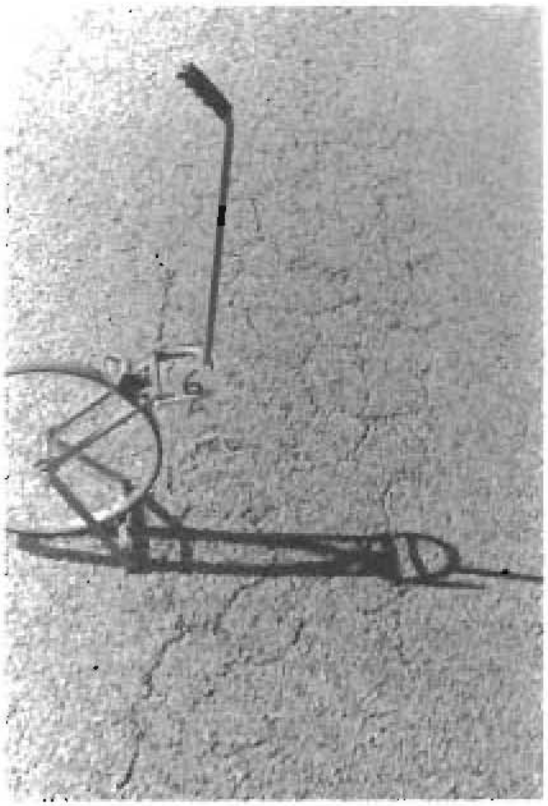
(e) Transverse cracking.



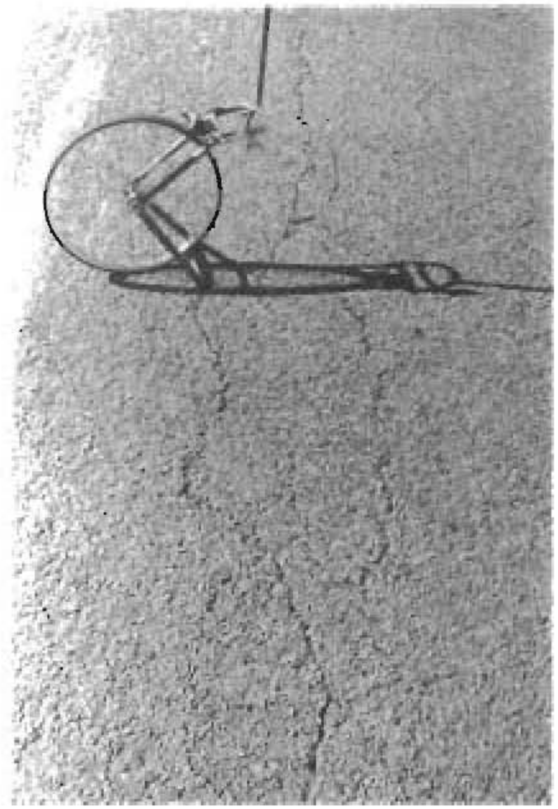
(f) Shrinkage cracking.

Fig 3.4. Continued.

(Continued)



(g) Block cracking.



(h) Longitudinal shrinkage cracking.

Fig 3.4. Continued.

(Continued)

(i) Transverse cracking

(j) Transverse cracking.

Fig 3.4. Continued.

(Continued)

(k) Block cracking.

(l) Raveling of aggregate.

Fig 3.4. Continued.

fairly easy to convert to any other form if desired. One of the objectives of this survey was to determine the amount of distressed area on the pavements and it was thought that this could be done more easily with this type of form than with some others that were considered.

Summary of Results

The previously described procedure was used in performing condition surveys on the 26 two-tenths-mile sections which included eight different highways and seven counties within District 14. The data sheets and pictures for each of the sections were filed in a notebook for convenience when reducing the data and summarizing the results. Because of the large volume of data sheets and pictures, not all are included in this summary. Some examples of data sheets and photographs for a typical section are summarized in Figs 3.3 and 3.4. Photographs of the various distress manifestations encountered in District 14, along with the description and probable cause are included in Appendix 2.

As might be expected, the sections on the secondary roads were more heavily distressed than those on the primary roads. The sections in the eastern part of the district were more heavily cracked than those in the hill country in the western part of the district. This probably is due to the difference in the geological soil formations, the eastern part having sand, silt, and clay soils and the western part having rocky limestone soil.

The most frequently encountered distress manifestation was patching. Fatigue cracking, mostly in the form of longitudinal and block cracking, was encountered fairly often. The rutting that occurred was, generally speaking, fairly minor except on some of the secondary road sections. Edge deterioration was somewhat common in pavements with no paved shoulder. Bleeding was encountered often, but usually it was not severe enough to cause any problems. Raveling was fairly common but usually not in a severe stage.

In classifying the distress according to the modes (fracture, distortion, and disintegration) it was found that by far the majority of the distress manifestations were fracture. The only distortion to speak of was rutting. No noticeable transverse distortion was present. There was very little, if any, swelling or settlement that could be detected visually. The major forms of disintegration were raveling and breakage of the pavement edge.

Not all of the sections experienced all the types of distress manifestations. Table 3.3 gives the number of sections in which each manifestation was present and the percent of the total sections in which each was present.

Table 3.4 lists the distress manifestations encountered in the condition surveys and the measurement units of each that were used in reducing the data from the field data sheets.

These units were chosen based upon experience gained while performing the condition surveys. Table 3.5 gives a summary of the amount of each distress manifestation encountered in each section surveyed using the units of measure indicated. Table 3.6 gives the total amount for each distress type encountered for District 14 in order of occurrence measured in square feet and linear feet.

Reporting the distress summary as in Table 3.6 leads to problems because the distress manifestations are not expressed in the same units. This has always been a problem in summarizing condition survey data.

One of the objectives of performing the condition surveys was to collect data that would enable the ranking of the distress manifestations according to their relative frequency of occurrence and the determination of the percent of the highway that has various types of distress manifestations. In order to do this, all the occurring distresses must be described by the same unit of measure. It is thought that the best unit to use is a unit of area, the most logical being square feet. Thus, all of the above distress manifestations not in units of square feet must be changed.

It is realized that there is no accurate, exact way of doing this, but it is felt that this can be done with enough reliability for the purpose of this comparison as follows:

Edge Cracking. Almost all of the edge cracking that occurred was within one foot of the pavement edge. Thus, it is assumed that when edge cracking occurs, the part of the pavement that is distressed is a one-foot-wide strip on the edge. Then the edge cracking that was reported as linear feet can be changed to square feet simply by multiplying by 1.0.

Longitudinal Cracking. The distress reported as longitudinal cracking was isolated cracks. It is assumed that a 6-inch-wide area along the length of the crack is the area of pavement that experiences the distress. Thus, the amount of distress reported as linear feet can be changed to square feet

TABLE 3.3. NUMBER AND PERCENT OF SECTIONS IN WHICH EACH TYPE OF DISTRESS MANIFESTATION WAS PRESENT

Distress Manifestation	Number of Sections in which Present	Percent of Sections in which Present
Patching	22	85
Raveling	15	58
Longitudinal Fatigue Cracking	13	50
Bleeding	13	50
Edge Cracking	12	46
Longitudinal Cracking	12	46
Rutting	10	38
Edge Deterioration	9	35
Transverse Cracking	7	27
Block Fatigue Cracking	6	23
Indentations	6	23
Shrinkage Cracking	5	19
Construction Cracking	4	15
Potholes	3	12
Alligator Fatigue Cracking	2	8
Streaking	2	8
Depression	1	4

TABLE 3.4. DISTRESS MANIFESTATION TYPES AND UNITS OF MEASURE

Distress Manifestation	Unit of Measurement
Block Fatigue Cracking	Square feet
Alligator Fatigue Cracking	Square feet
Longitudinal Fatigue Cracking	Square feet
Shrinkage Cracking	Square feet
Edge Cracking	Linear feet
Longitudinal Cracking	Linear feet
Transverse Cracking	Linear feet
Construction Cracking	Linear feet
Raveling	Square feet
Bleeding	Square feet
Patching	Square feet
Rutting	Linear feet
Streaking	Linear feet
Potholes	each
Indentations	Linear feet
Edge Deterioration	Linear feet
Depression	Square feet

TABLE 3.5. SUMMARY OF DISTRESS MANIFESTATIONS FROM FIELD DATA SHEET

Section number	Highway number	County	Block fatigue cracking	Alligator fatigue cracking (square feet)	Longitudinal fatigue cracking (square feet)	Raveling (square feet)	Bleeding (square feet)	Patching (square feet)	Rutting (linear feet)	Edge cracking (linear feet)	Longitudinal cracking (linear feet)	Shrinkage cracking (square feet)	Transverse cracking (linear feet)	Construction cracking (linear feet)	Streaking (linear feet)	Potholes	Indentations (linear feet)	Shoving (square feet)	Depression (square feet)	Edge deterioration (linear feet)
P-1	SH 71	Bastrop				2	4				36		20	79	83					
P-2	L 360	Travis				504					44					1	1			
P-3	P.V.R.	Travis	666	1872	1132			1453	36	45	20	220				2			37	
1	FM 621	Hays			1240	130	400	5760	320	30										
2	FM 621	Hays				285	134	5200		450	20			78		2	34			1000
3	SH 80	Caldwell			50	102		1328	32	27	8						21			1056
4	SH 80	Caldwell	220		110	2			70	30	20									1000
5	SH 71	Bastrop	1272		84	20		448			20	92	318	1000						
6	SH 71	Bastrop					234	3251						1056						
7	SH 71	Bastrop					430	4			676	20	8				2			
8	SH 71	Bastrop			110		140	1419			26	20	77							
9	SH 71	Bastrop					178	799			14									
10	SH 71	Bastrop						80			42		86							
11	FM 971	Williamson			320			28			95						10			52
12	FM 971	Williamson			930	50		52		120										230
13	FM 971	Williamson	460		3290	300	36	2858	720	40		30					50			17
14	FM 971	Williamson			930	900		541		230					800					50
15	US 87	Mason				90	619	1339	160											250
16	US 87	Mason				500														1
17	US 87	Mason				180	2590	600	170											
18	US 87	Mason				460	240	90												
19	US 290	Gillespie	272		310		840	5190	500				34							
20	US 290	Gillespie	50	40	60			7405	40	60			8							
21	US 290	Gillespie			80			2380	200	80										
22	US 290	Gillespie						1970		60										
23	US 290	Gillespie				20	1120	1070		100										
TOTALS			2940	1912	8646	3545	6965	43,265	2248	1272	1021	382	551	2213	883	5	118		37	3656

TABLE 3.6. SUMMARY OF DISTRESS FOR TOTAL DISTRICT

Distress Manifestation	Unit	Amount
Patching	Square feet	43,265
Longitudinal Fatigue Cracking	Square feet	8,646
Bleeding	Square feet	6,965
Raveling	Square feet	3,545
Block Fatigue Cracking	Square feet	2,940
Alligator Fatigue Cracking	Square feet	1,912
Shrinkage Cracking	Square feet	382
Depressions	Square feet	37
Edge Deterioration	Linear feet	3,656
Rutting	Linear feet	2,248
Longitudinal Construction Cracking	Linear feet	2,213
Edge Cracking	Linear feet	1,272
Longitudinal Cracking	Linear feet	1,021
Streaking	Linear feet	883
Transverse Cracking	Linear feet	551
Indentations	Linear feet	118

by multiplying the numerical value by 0.5. The criterion for using the 6-inch area is the knowledge gained after observing the cracks during the condition survey.

Transverse Cracking. This distress is the most difficult one to describe by area. However, it is felt that the best way to do so is the same as with longitudinal cracking, i.e., assume that the distressed area is a 6-inch-wide strip along the length of the crack. Thus, the amount of transverse cracking that was reported as linear feet can be changed to square feet by multiplying by 0.5.

Construction Cracking. The construction cracks that occurred were along longitudinal joints at the edge of the lane being surveyed. It will once again be assumed that the construction crack affects a 6-inch-wide strip along the length of the crack. The area of the surveyed lane that is affected is then a 3-inch-wide strip along the length of the crack, the other three inches being the adjacent lane. The amount of distress reported as construction carcking in linear feet can then be changed to square feet by multiplying by 0.25.

Rutting. The amount of distorted pavement in the rutted sections was observed to be generally a 2-foot-wide strip along the length of the rutting. Thus the amount of rutting reported in linear feet can be changed to square feet by multiplying by 2.0.

Streaking. The streaking that was observed had no apparent effect on the pavement serviceability other than causing aggregate raveling and thus is not included in the distress summary. Any distress that occurs in the streaked area is reported as raveling.

Potholes. Only five potholes were encountered in all the surveyed section and thus are not included in the distress summary due to their negligible effect.

Indentations. Only a few indentations were encountered and they were of such minor consequence that they are not included in the distress summary.

Edge Deterioration. The edge deterioration that was encountered generally occurred within a one-foot-wide strip along the pavement edge. Thus, the edge deterioration reported as linear feet can be changed to square feet by multiplying by 1.0.

It must be recognized that patching is actually covering some type of distress, but this can only be recorded as area of patching, since there is no way to determine exactly what distress was present before patching.

It is realized that there is no theoretical reasoning behind the above adjustments, but it is also felt that logical judgement was used based upon knowledge gained while conducting the condition surveys. It should also be pointed out that in a few cases more than one distress manifestation occurred in the same area. This was taken into account when reporting the amount of distressed area.

The most common occurrence of this was the presence of edge cracking and edge deterioration in the same area. When both were present in a section, the larger of the two values was used to compute the amount of distressed area.

Based upon these adjustments the data summary can be presented in ways that are more meaningful toward realization of the objectives. Table 3.7 gives a summary of the distress manifestations encountered in each section, expressed in units of square feet.

By considering that the total area of each section is given by multiplying the 12-foot lane width by the two-tenths-mile length and knowing the amount of distress area in each section, the percent area distressed can be computed. These percents are given for each section along with a mean value in Table 3.8. It is noted that 22 percent of the area surveyed was experiencing some type of distress.

Perhaps a more meaningful result toward accomplishment of the objectives that were set forth is a ranking of the distress manifestations according to their contribution to the total distressed area. This ranking is given in Table 3.9.

This table includes patching as a distress manifestation. There is no argument that a patch indicates a previously distressed area, but a patched area itself may not be a distress when thinking in terms of a distress being that which causes a loss in serviceability or performance. With this in mind Table 3.10 is presented and gives the percent distress contributed by each type excluding patching.

Discussion of Distress Manifestations

The ranking of the distress manifestations according to occurrence has no explicit connection with ranking them according to their effect upon the

TABLE 3.7. SUMMARY OF DISTRESS MANIFESTATIONS EXPRESSED IN SQUARE FEET

Section Number	Highway Number	County	Block fatigue cracking	Alligator fatigue cracking	Longitudinal fatigue cracking	Shrinkage cracking	Transverse cracking	Longitudinal cracking	Construction cracking	Edge cracking	Edge deterioration	Raveling	Bleeding	Rutting	Patching	Area distressed	Area of section	Percent distressed
P-1	SH 71	Bastrop					10	18	20			2	4			54	12,672	0.4
P-2	L 360	Travis						22				504				526	"	4.2
P-3	P.V.R.	Travis	666	1872	1132	220		10		45				72	1453	5470	"	43.2
1	FM 621	Hays			1240					30		130	400	640	5760	8200	"	64.7
2	FM 621	Hays						10	19	450	1000	285	134		5200	6648	"	52.5
3	SH 80	Caldwell			50			4		27	1056	102		64	1328	2604	"	20.5
4	SH 80	Caldwell	220		110			10		30	1000	2		140		1482	"	11.7
5	SH 71	Bastrop	1272		84	92	159	10	250			20			448	2335	"	18.4
6	SH 71	Bastrop							264				234		3251	3749	"	29.6
7	SH 71	Bastrop				20	4	338					430		4	796	"	6.3
8	SH 71	Bastrop			110	20	39	13					140		1419	1741	"	13.7
9	SH 71	Bastrop						7					178		799	984	"	7.8
10	SH 71	Bastrop					43	21							80	144	"	1.1
11	FM 971	Williamson			320			48			52				28	448	"	3.5
12	FM 971	Williamson			930					120	230	50			52	1262	"	10.0
13	FM 971	Williamson	460			30				40	17	300	36	1440	2858	5164	"	40.8
14	FM 971	Williamson								230	50	900			541	1671	"	13.2
15	US 87	Mason									250	90	619	320	1339	2618	"	20.7
16	US 87	Mason									1	500				501	"	4.0
17	US 87	Mason										180	2590	340	600	3710	"	29.3
18	US 87	Mason										460	240		90	790	"	6.2
19	US 290	Gillespie	272		310		17						840	1000	5190	7629	"	60.2
20	US 290	Gillespie	50	40	60		4			60				80	7405	7699	"	60.8
21	US 290	Gillespie			80					80				400	2380	2940	"	23.2
22	US 290	Gillespie								60					1970	2030	"	16.0
23	US 290	Gillespie								100		20	1120		1070	2310	"	18.2
TOTALS - AREA			2940	1912	4426	382	266	501	553	1272	3656	3545	6965	4496	43,265	73,505	329,472	22.3
Percent of Total Distress			4.0	2.6	6.0	0.5	0.4	0.7	0.8	0.9	4.9	4.8	9.5	6.1	58.9	100		
Percent of Total excluding Patching			9.7	6.3	14.6	1.2	1.0	1.7	1.9	2.2	11.9	11.7	23.1	14.8		100		

TABLE 3.8. PERCENT OF AREA DISTRESSED IN EACH SECTION AND TOTAL AREA SURVEYED

Section Number	Highway Number	County	Percent of Area Distressed
P-1	SH 71	Bastrop	0.4
P-2	L 360	Travis	4.2
P-3	P.V.R.	Travis	43.2
1	FM 621	Hays	64.7
2	FM 621	Hays	52.5
3	SH 80	Caldwell	20.5
4	SH 80	Caldwell	11.7
5	SH 71	Bastrop	18.4
6	SH 71	Bastrop	29.6
7	SH 71	Bastrop	6.3
8	SH 71	Bastrop	13.7
9	SH 71	Bastrop	7.8
10	SH 71	Bastrop	1.1
11	FM 971	Williamson	3.5
12	FM 971	Williamson	10.0
13	FM 971	Williamson	40.8
14	FM 971	Williamson	13.2
15	US 87	Mason	20.7
16	US 87	Mason	4.0
17	US 87	Mason	29.3
18	US 87	Mason	6.2
19	US 290	Gillespie	60.2
20	US 290	Gillespie	60.8
21	US 290	Gillespie	23.2
22	US 290	Gillespie	16.0
23	US 290	Gillespie	18.2
Mean			22.3

TABLE 3.9. PERCENT OF TOTAL DISTRESS CONTRIBUTED BY EACH TYPE INCLUDING PATCHING

Distress Manifestation	Percent Contributed to Total Distress
Patching	59.9
Bleeding	9.4
Rutting	6.1
Longitudinal Fatigue Cracking	6.0
Edge Deterioration	4.9
Raveling	4.8
Block Fatigue Cracking	4.0
Alligator Fatigue Cracking	2.6
Edge Cracking	0.9
Construction Cracking	0.8
Longitudinal Cracking	0.7
Shrinkage Cracking	0.5
Transverse Cracking	0.4
Total	100.0

TABLE 3.10. PERCENT OF TOTAL DISTRESS CONTRIBUTED BY EACH TYPE EXCLUDING PATCHING

Distress Manifestation	Percent Contributed to Total Distress
Bleeding	23.0
Rutting	14.8
Longitudinal Fatigue Cracking	14.6
Edge Deterioration	11.9
Raveling	11.7
Block Fatigue Cracking	9.7
Alligator Fatigue Cracking	6.3
Edge Cracking	2.2
Construction Cracking	1.9
Longitudinal Cracking	1.7
Shrinkage Cracking	1.2
Transverse Cracking	1.0
Total	100.0

serviceability or performance of a pavement, but should be helpful in doing so. This can be proved by noting that bleeding ranks at the top of the list according to occurrence, but obviously should not rank at the top of the list according to effect upon serviceability or performance. The determination of this is a much broader area, which is the theme of this study.

The objectives of determining the distresses present, frequency of occurrence, and amount of area distressed were accomplished. It should be kept in mind, however, that adjustments were made on the units of measure when the data were being summarized. The different rankings of distress manifestations found in various tables of this chapter can be useful in determining research priorities and in evaluation of serviceability equations. They can be helpful in studies of maintenance and overlay programs also.

Another objective was to establish a suitable method for performing condition surveys. The method used in this condition survey has a large plus factor with respect to the detailed information it provides. The data sheets used actually give the analyzer a scaled drawing of the pavement with distress manifestations that are present. The use of these data along with the photographs should give him enough information to summarize the data however he sees fit.

A disadvantage does exist, however, with respect to the amount of time required to conduct the surveys. The detailed distress drawings and identification accompanied by picture taking are quite time consuming. Each two-tenths-mile section required approximately one-half to two hours for one person to complete. The time could be reduced if the survey party included more than one person.

It is thought that it would be good to consider the collection of similar type data in other Texas Highway Department Districts. Each district probably has some distress types that are unique to it and each may have differences in the prominence of various distresses. The publishing of a manual with pictures, descriptions and probable causes of each type of distress, such as in Appendix 2, could be very helpful to maintenance personnel in the district when determing the condition of pavements. This might lead to a more uniform and consistent method of rating pavement condition for scheduling of maintenance.

Another objective of performing the condition survey was to obtain more knowledge about pavements and pavement distresses. It is thought that this objective was also accomplished. General and detailed knowledge was gained about the appearance of distresses, their places of occurrence and patterns of occurrence, their frequency of occurrence and methods that are used to correct them.

Thus, the objectives that had been established before beginning the condition survey were all accomplished, some to a greater extent and accuracy than others. It is hopeful that the information gained can be used to improve and initiate other condition surveys in order to gain more knowledge that will lead toward the relationship of pavement distress to pavement performance.

Relating Distress Manifestations and Mechanisms

It is a very difficult task to relate each manifestation to a specific mechanism since a combination of mechanisms causes some of the manifestations. However, some discussion is given on relating the manifestations to mechanisms.

The distress manifestation most often encountered was patching, as shown in Table 3.9. This, of course, was to be expected. It is obvious that the patching cannot be related directly to a specific distress mechanism since the reasons for the patching are hidden beneath it.

Excluding patching, the most prominent manifestation encountered was bleeding, as shown in Table 3.10. This can be related to the type of surfaces on the sections surveyed, which were almost totally surface treatments. Bleeding, of course, is associated with surface treatments and thus on other pavement surface types it most likely would not rank as the most prominent distress manifestation.

The rutting that occurred cannot be tied down to any definite mechanism except perhaps in section number 13 in Williamson County. This section was fairly heavily distressed throughout and the cause was probably the subgrade material, which was a clay. This section experienced more distortion than any other section. Further data collection on the history of the pavements including subgrade types, base types and thicknesses, surface types, maintenance and traffic could give much more insight into relating the rutting as well as other manifestations to a more definite mechanism.

The edge distress that was encountered can be related to the shoulder condition. The sections with paved shoulders had very little, if any, edge distress. On the other hand, those sections with no paved shoulder or those that were eroded and loose had considerable edge distress.

It is difficult to relate each type of cracking to a mechanism, but an interesting pattern was observed for the cracking as a whole. The sections that were located in the western part of the district had overall less cracking. This indicates that the general soil formation - mostly limestone in the west and clays, silts, sands in the east - has a definite effect on the amount of cracking that will occur.

Some of the transverse cracking in Bastrop County appeared to be reflection cracking from underlying pavement. Other than this, it was difficult to relate the types of cracking to specific mechanisms. Most seemed to be associated with combinations of traffic, soil support, and surface condition.

A much more detailed study of the pavement history of the sections including traffic, materials, and maintenance would give very useful information in relating distress manifestations and distress mechanisms.

CHAPTER 4. PAVEMENT PROFILE STUDIES

The most important characteristic used to judge the condition of a pavement is its roughness. To the user the degree of roughness stands out above all the other characteristics including skid resistance, appearance, texture, and width. If he were asked to rate the performance of a highway his rating would be based on how rough his rides had been. The fact that roughness is considered so important led to the development of very useful profile measurement oriented equipment. It is thought that some of this equipment can be very helpful in the problem area of relating pavement distress to pavement performance.

The Surface Dynamics Profilometer is a profile measuring and recording system that gives output in the form of a profile versus distance plot for a pavement (Ref 15). The profilometer was used in connection with this work to collect data that hopefully will initiate more thorough and detailed research using the profilometer. This data collection and recommended future research using the profilometer are presented in this chapter.

Concepts for Use of Profilometer

After discussions with Dr. Roger Walker on the uses and capabilities of the profilometer, it was decided that a good possibility existed of using it to collect information about relating pavement distress to pavement performance. Most of the previous use of the profilometer has not been connected closely with specific pavement distresses, but with the general profile of the pavement. Thus, it was decided to attempt to relate the profilometer output to specific pavement distresses determined in condition surveys.

Some of the initial ideas and objectives that were outlined are as follows:

(1) determine how cracking changes the pavement profile by obtaining profile data on pavements with few or no cracks and on pavement with heavy cracking;

(2) determine wavelengths and amplitudes of various crack patterns and relate the amount and type of cracking to the profile change using a conceptual experiment design such as shown in Fig 4.1; and

(3) classify or characterize the various types of cracking according to types of distribution such as χ^2, normal, or F distribution using a concept such as shown in Fig 4.2.

It was thought that research directed toward the accomplishment of these objectives might lead to more detailed methods of describing or predicting pavement distresses and their relation to performance. The following equation is an idea of what might result from this research:

$$Cr = B_0 + B_1 A_1 + B_2 A_2 + B_3 A_3$$

where

Cr = amount or type of cracking,

B = numerical constants,

A = amplitude, wavelength, or distribution of cracks.

With these initial concepts and ideas in mind, some beginning information was obtained for this research idea. Since detailed information on types and locations of distresses was obtained in the condition surveys given in Chapter 3, profilometer data were collected on some of these sections and the results compared to the condition survey.

Profilometer Data Collection and Analysis

Four two-tenths-mile sections, Nos. 11, 12, 13, and 14 on FM 971 in Williamson County, were chosen for profile study. The locations of these sections are given in Chapter 3 and Appendix 1.

The profilometer was run on these sections at a speed of 20 mph. The strip charts with the profiles of both wheel paths were then analyzed for any profile amplitude or wavelength patterns that occurred. The distress manifestations from the condition survey data sheets, such as shown in Chapter 3, were indicated on the profile strip charts by scaling off horizontal distance from the beginning mark of the section. By doing this, the profile pattern for an exact location or a specific distress manifestation could be studied.

Wavelength	Amplitude	Type or amount of cracking					
		A	B	C	D	E	F
λ_1	A_1						
	A_2						
	A_3						
λ_2	A_1						
	A_2						
	A_3						
λ_3	A_1						
	A_2						
	A_3						

Fig 4.1. A conceptual experiment design for crack analysis using wavelength and wave amplitude.

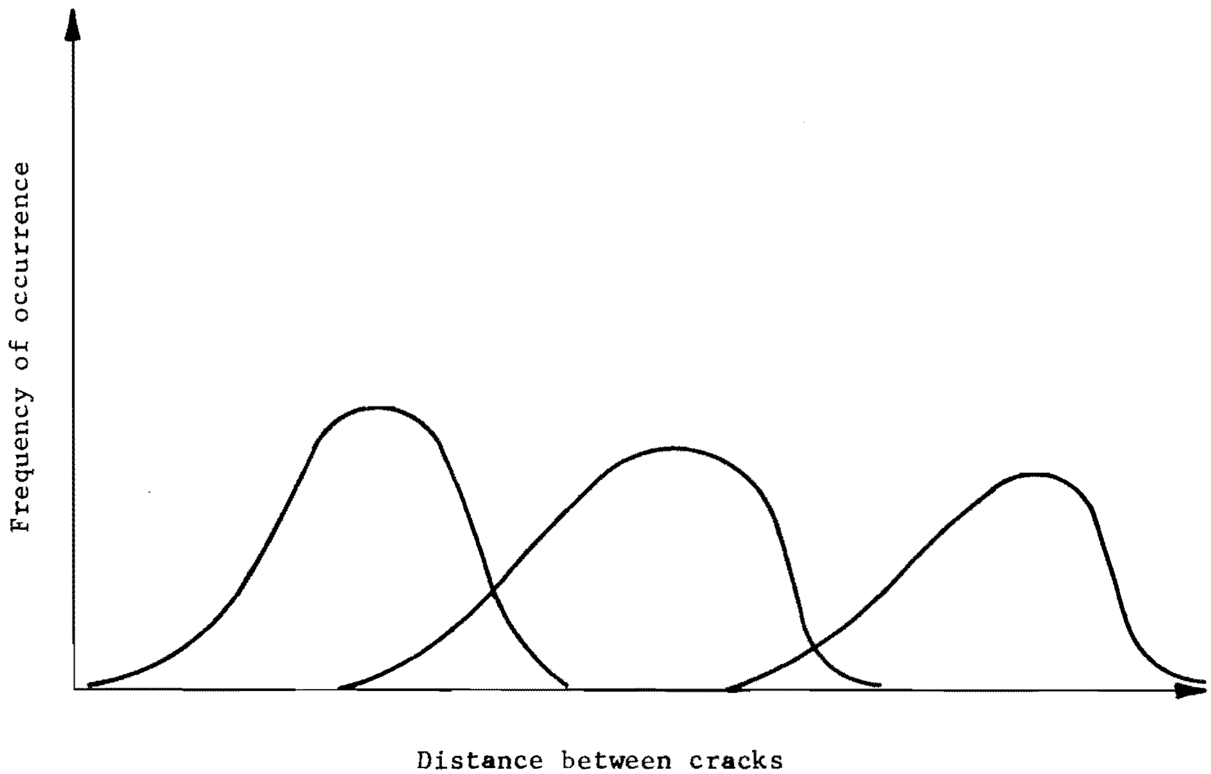


Fig 4.2. Crack analysis using type of distribution.

Portions of the strip charts on which this was done are shown in Figs 4.3 through 4.6. The horizontal scale is shown at the top of the figures and the vertical scale is shown on Fig 4.3. All figures have the same vertical scale.

Results show that generally where more distress occurs more profile change occurs as would obviously be expected. It seems that the main desired goal of relating specific distress types to specific profile amplitude and wavelength patterns cannot be accomplished from this form of data for only four pavement sections. However, some promise for future accomplishment is shown by the profile pattern of block cracking given in Fig 4.4, in that it has a somewhat definite pattern of small wave amplitude and length.

Serviceability Index Data Collection and Analysis

The profilometer was used to collect serviceability index values for the pavement sections on which condition surveys were performed. These values are shown in Table 4.1. Sections 11, 12, 13, and 14 are not included because the data were not in the correct form to obtain the serviceability indices for these sections. The values for Sections 4 and 6 should be discarded because they had some overlay work between the time of the condition survey and the serviceability index determination.

To analyze this serviceability index data, several plots were made with the SI as the dependent variable. Table 4.2 lists the data that are plotted. The amount of distress was taken from Table 3.7. The total area distressed is included as well as some of the more predominantly occurring distresses. These plots are shown in Figs 4.11 through 4.16. Generally, no meaningful correlation exists for the plots. The correlation in the plot of bleeding versus serviceability index seems to be in reverse of what might be expected. This plot shows increased bleeding results in a higher serviceability index. The collection of much more data needs to be done to develop more meaningful correlations for all of these plots.

It is interesting to note the serviceability index values that were obtained for the sections. The values range from 2.0 to 4.0 with a mean of 2.9. It is somewhat surprising that the mean is as high as 2.9. These values are terminal serviceability values since all of these sections were scheduled for rehabilitation. A mean value of 2.9 for a terminal serviceability is higher than the design terminal serviceability now being used by the Texas

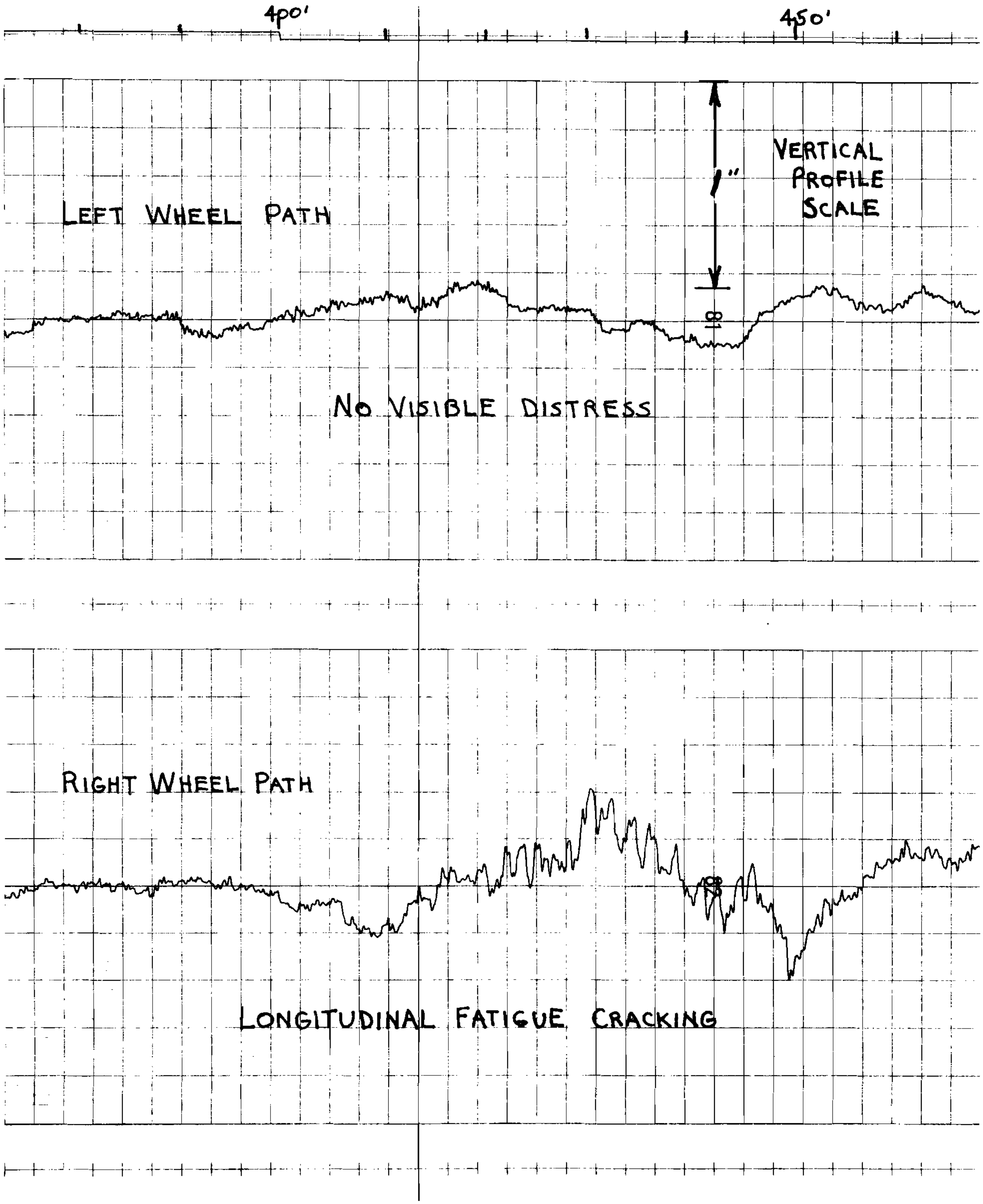


Fig 4.3. Section 11 - FM 971 - longitudinal fatigue cracking.

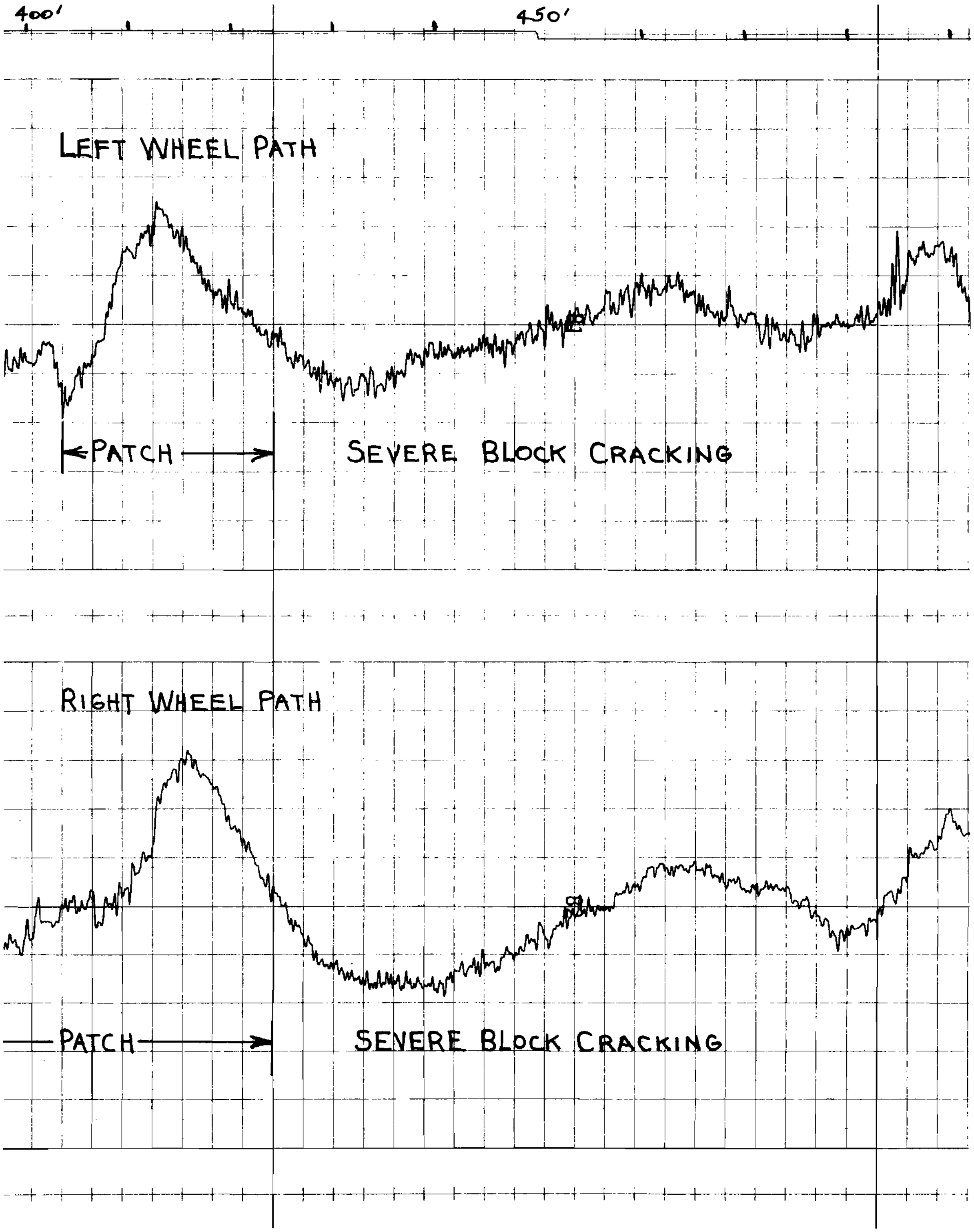


Fig 4.4. Section 13 - FM 971 - block cracking and patching.

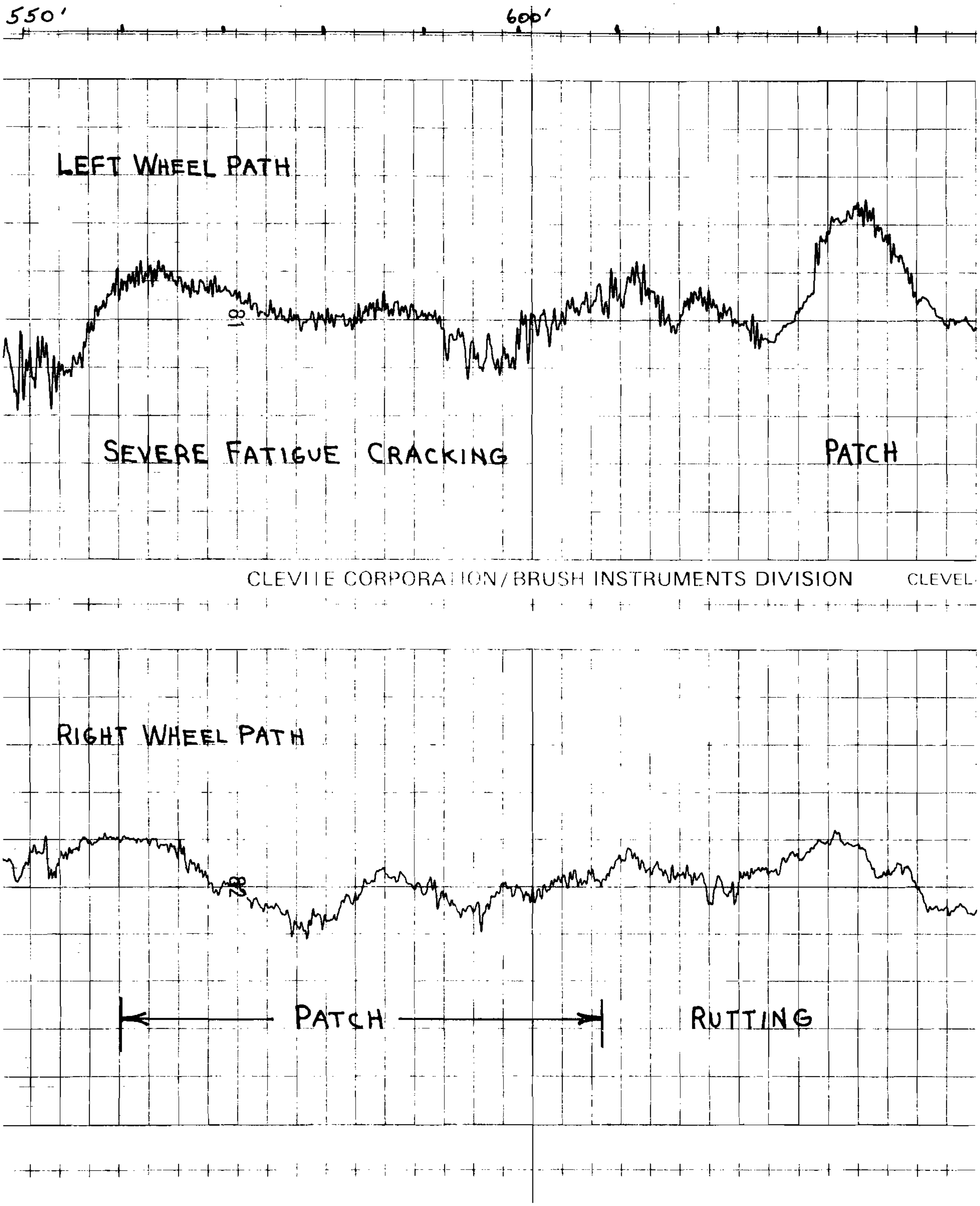


Fig 4.5. Section 13 - FM 971 - fatigue cracking, rutting, and patching.

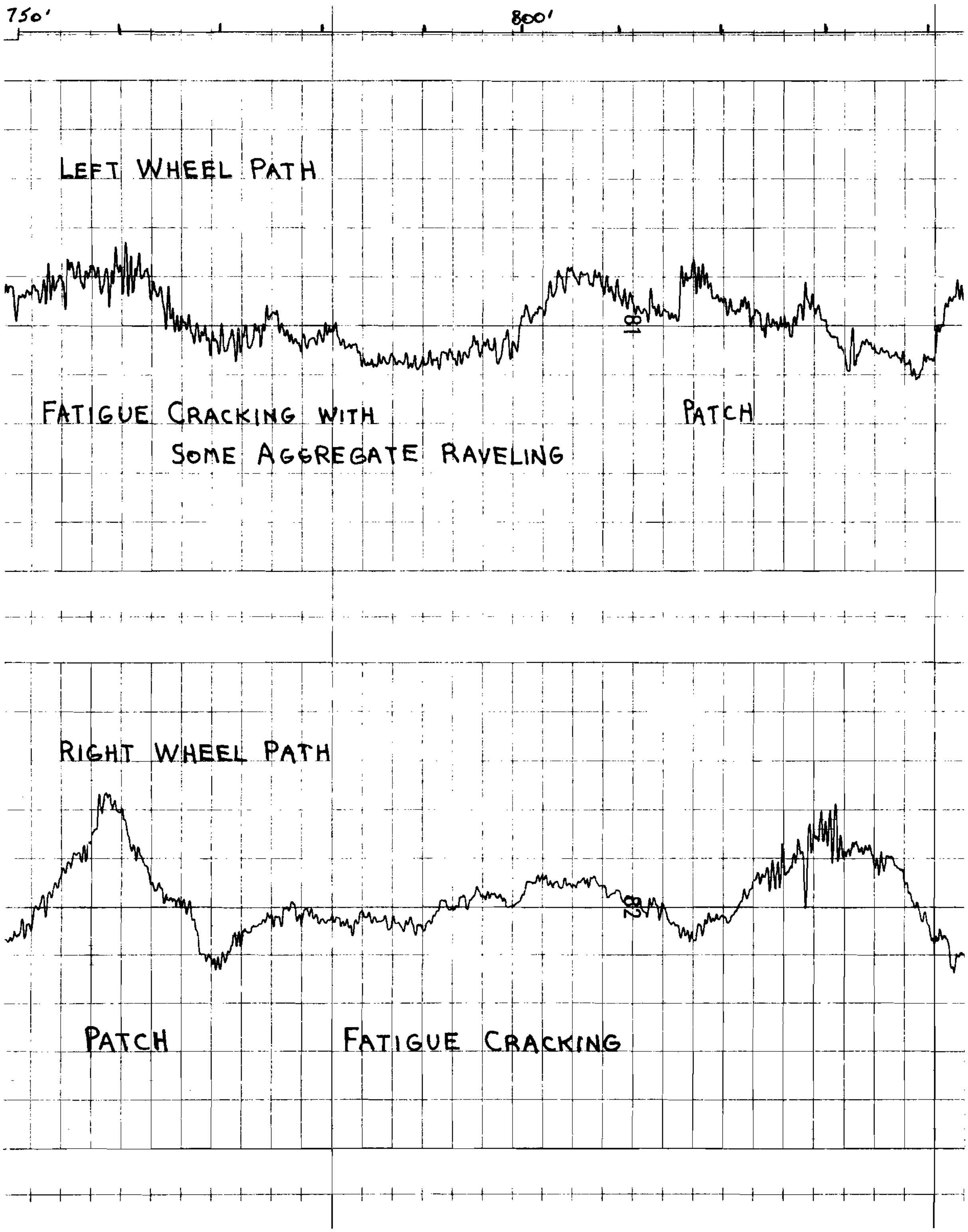


Fig 4.6. Section 13 - FM 971 - fatigue cracking, raveling, and patching.

TABLE 4.1. SERVICEABILITY INDEX VALUES

Section Number	Highway Number	County	Serviceability Index
P-1	SH 71	Bastrop	3.4
P-2	L 360	Travis	2.2
P-3	Pleasant Valley Rd.	Travis	2.0
1	FM 621	Hays	2.6
2	FM 621	Hays	2.3
3	SH 80	Caldwell	4.1
4	SH 80	Caldwell	3.2
5	SH 71	Bastrop	3.0
6	SH 71	Bastrop	2.8
7	SH 71	Bastrop	3.4
8	SH 71	Bastrop	2.4
9	SH 71	Bastrop	3.3
10	SH 71	Bastrop	3.4
15	US 87	Mason	2.8
16	US 87	Mason	3.8
17	US 87	Mason	3.2
18	US 87	Mason	3.3
19	US 290	Gillespie	2.9
20	US 290	Gillespie	2.9
21	US 290	Gillespie	3.5
22	US 290	Gillespie	3.7
23	US 290	Gillespie	3.5

TABLE 4.2. COMPARISON OF SERVICEABILITY INDEX AND AMOUNT OF DISTRESS

Section Number	Serviceability Index	Total Area Distressed (sq. feet)	Bleeding (sq. feet)	Raveling (sq. feet)	Longitudinal Fatigue Cracking (sq. feet)	Rutting (sq. feet)	Patching (sq. feet)
P-1	3.4	54	4	2			
P-2	2.2	526		504			
P-3	2.0	5470			1132	72	1453
1	2.6	8200	400	130	1240	640	5760
2	2.3	6648	134	285			5200
3	4.1	2604		102	50	64	1328
5	3.0	2335		20	84		448
7	3.4	796	430				4
8	2.4	1741	140		110		1419
9	3.3	984	178				799
10	3.4	144					80
15	2.8	2618	619	90		320	2618
16	3.8	501		500			501
17	3.2	3710	2590	180		340	3710
18	3.3	790	240	460			790
19	2.9	7629	840		310	1000	7629
20	2.9	7699			60	80	7699
21	3.5	2940			80	400	2940
22	3.7	2030					2030
23	3.5	2310	1120	20			2310

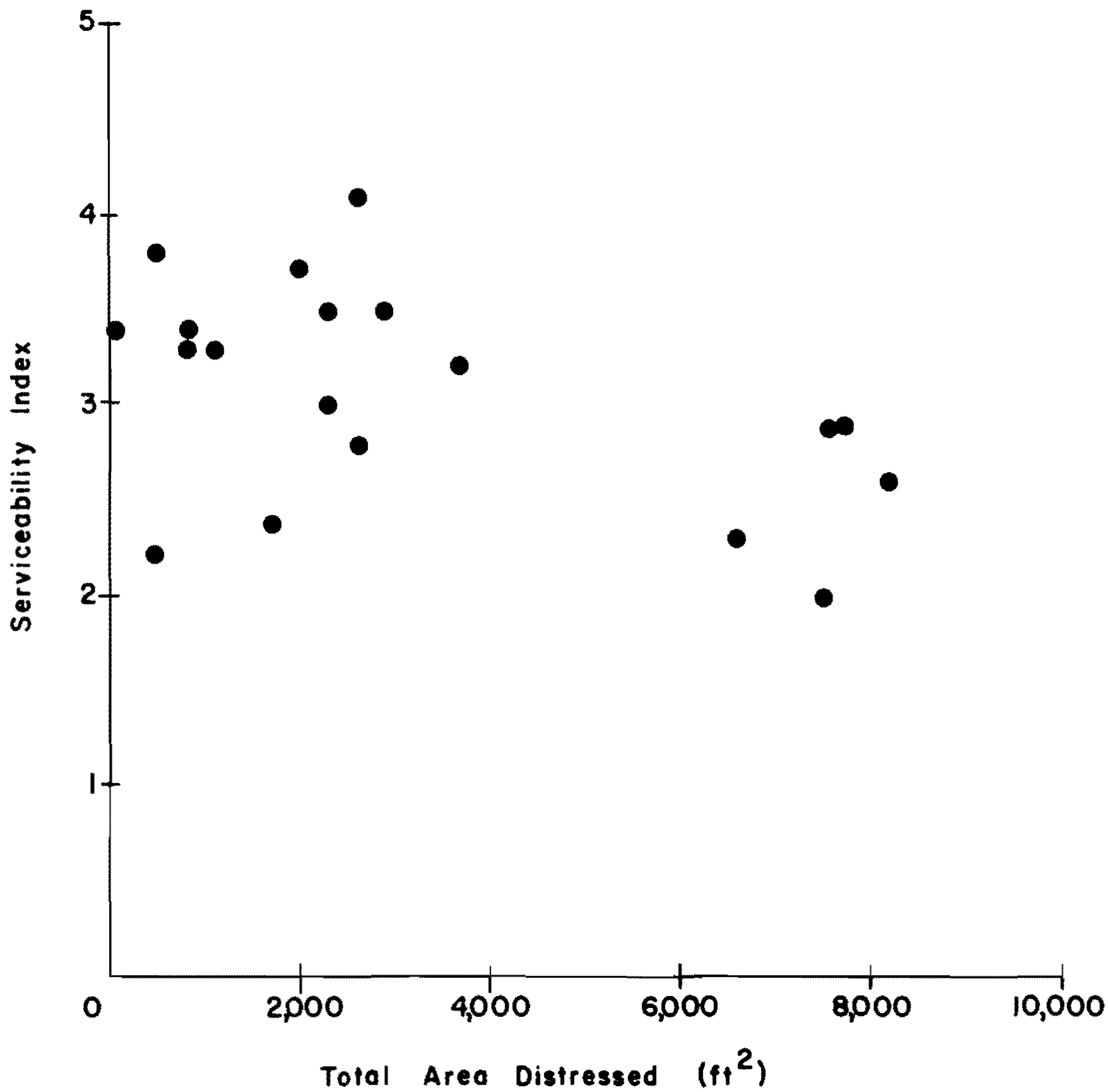


Fig 4.11. Total area distressed versus serviceability index.

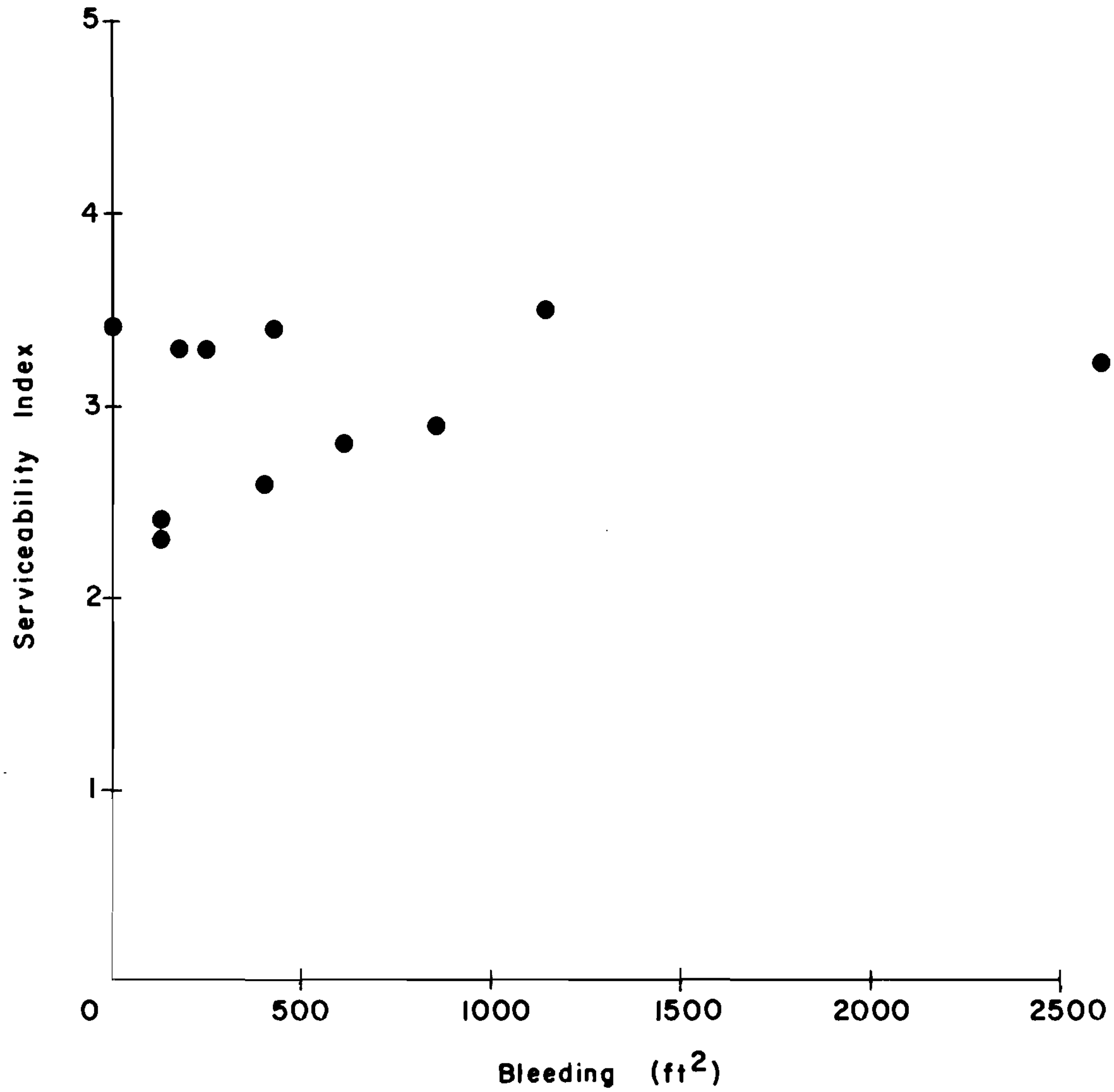


Fig 4.12. Bleeding versus serviceability index.

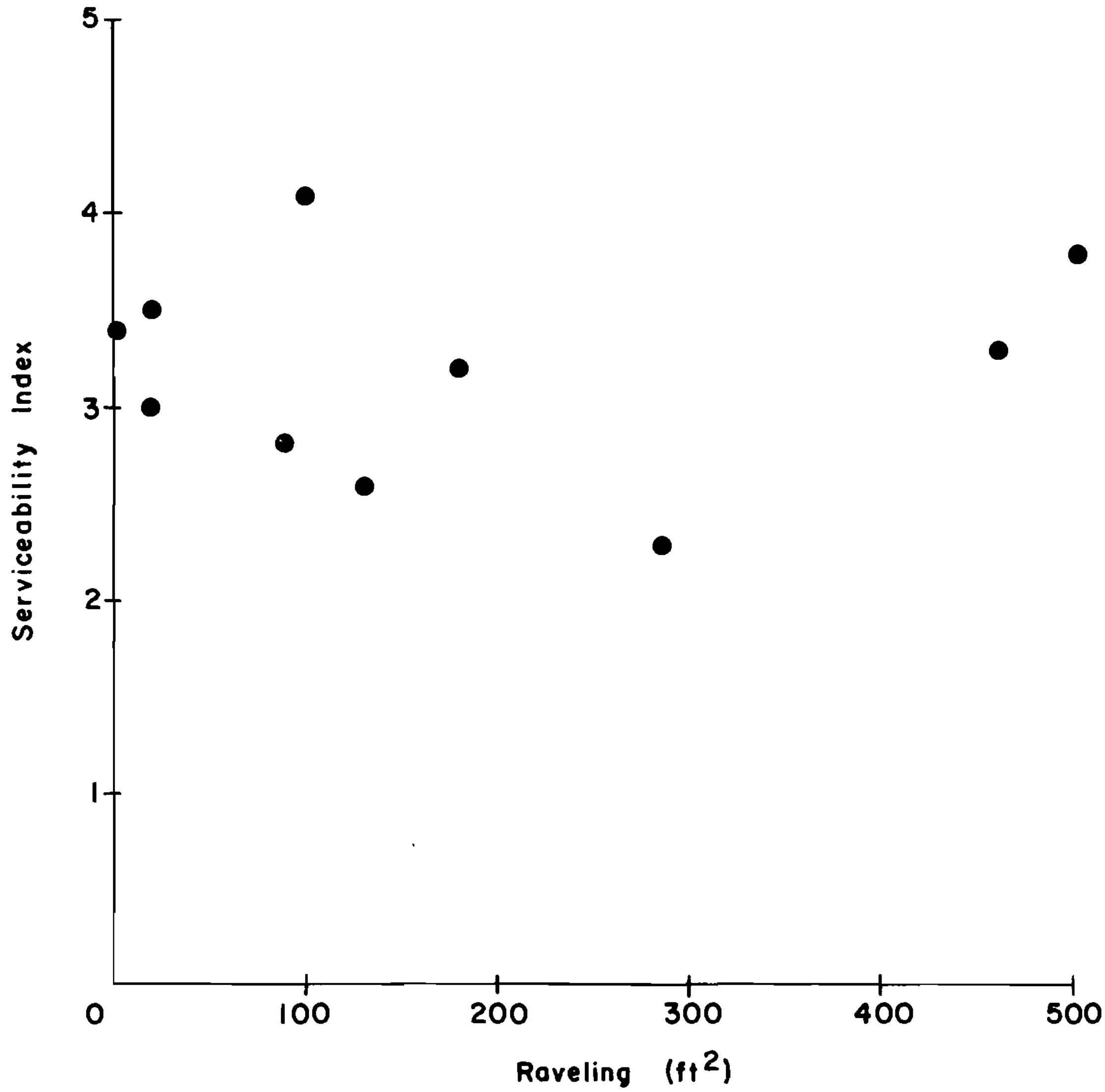


Fig 4.13. Raveling versus serviceability index.

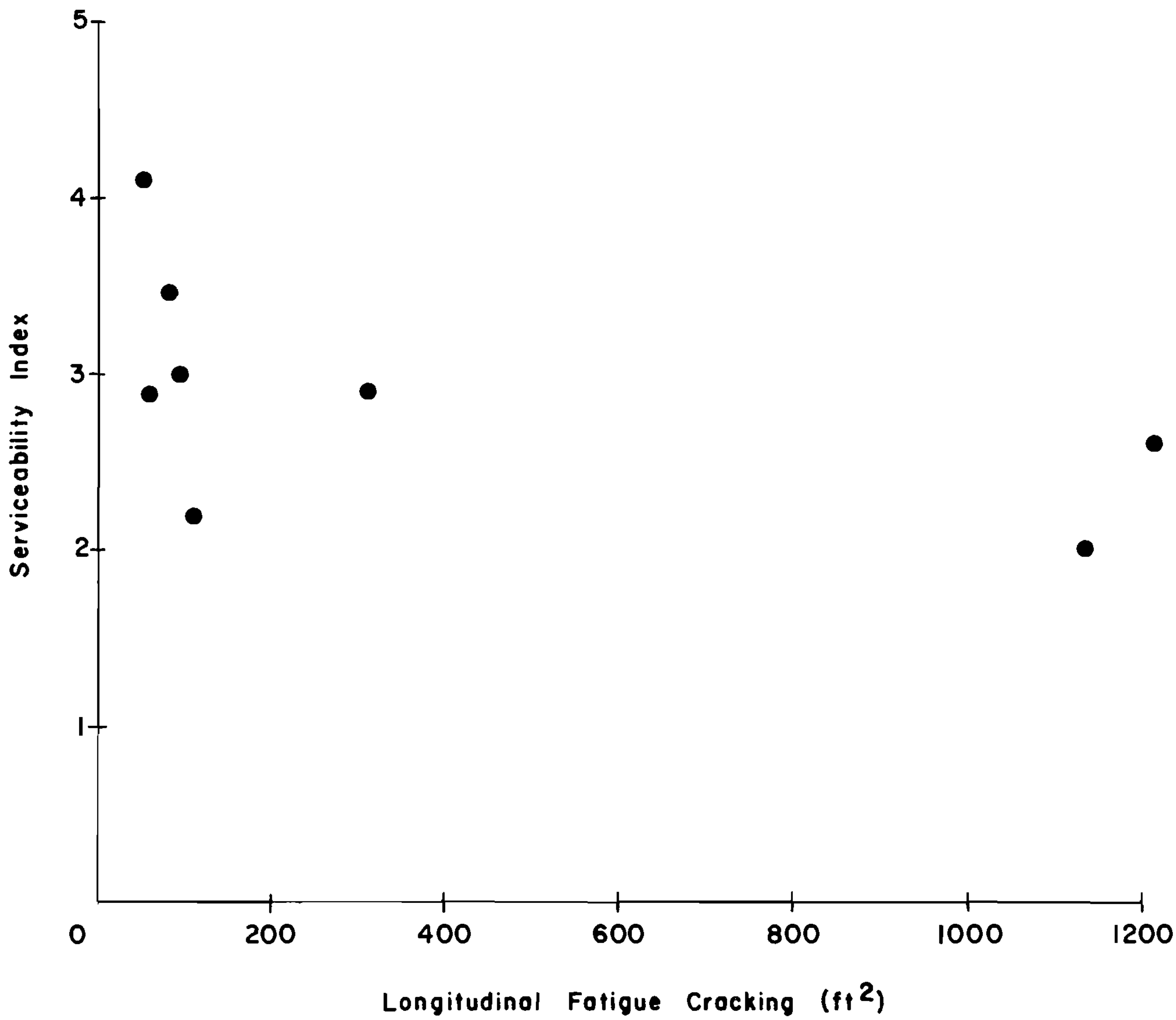


Fig 4.14. Longitudinal fatigue cracking versus serviceability index.

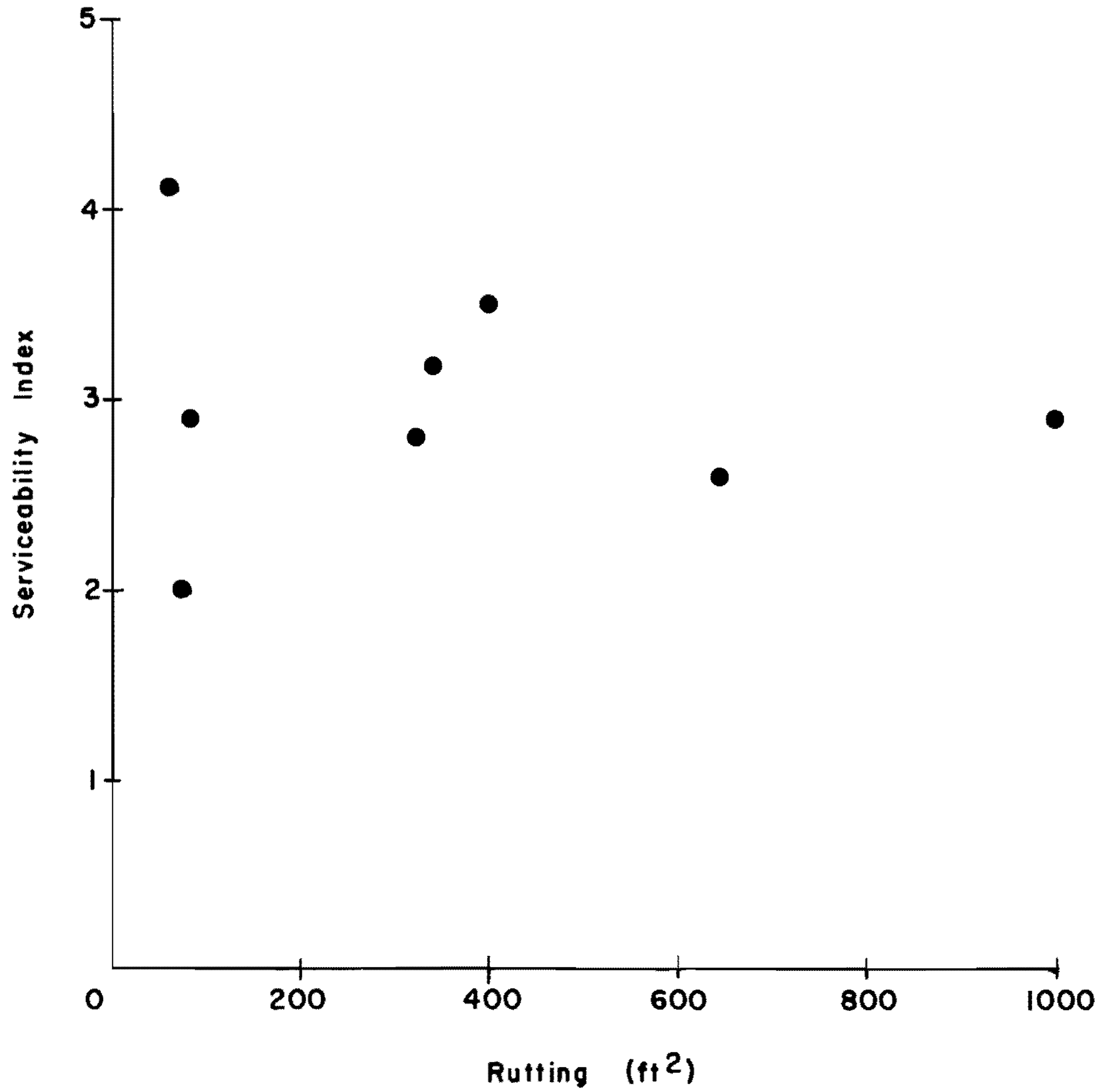


Fig 4.15. Rutting versus serviceability index.

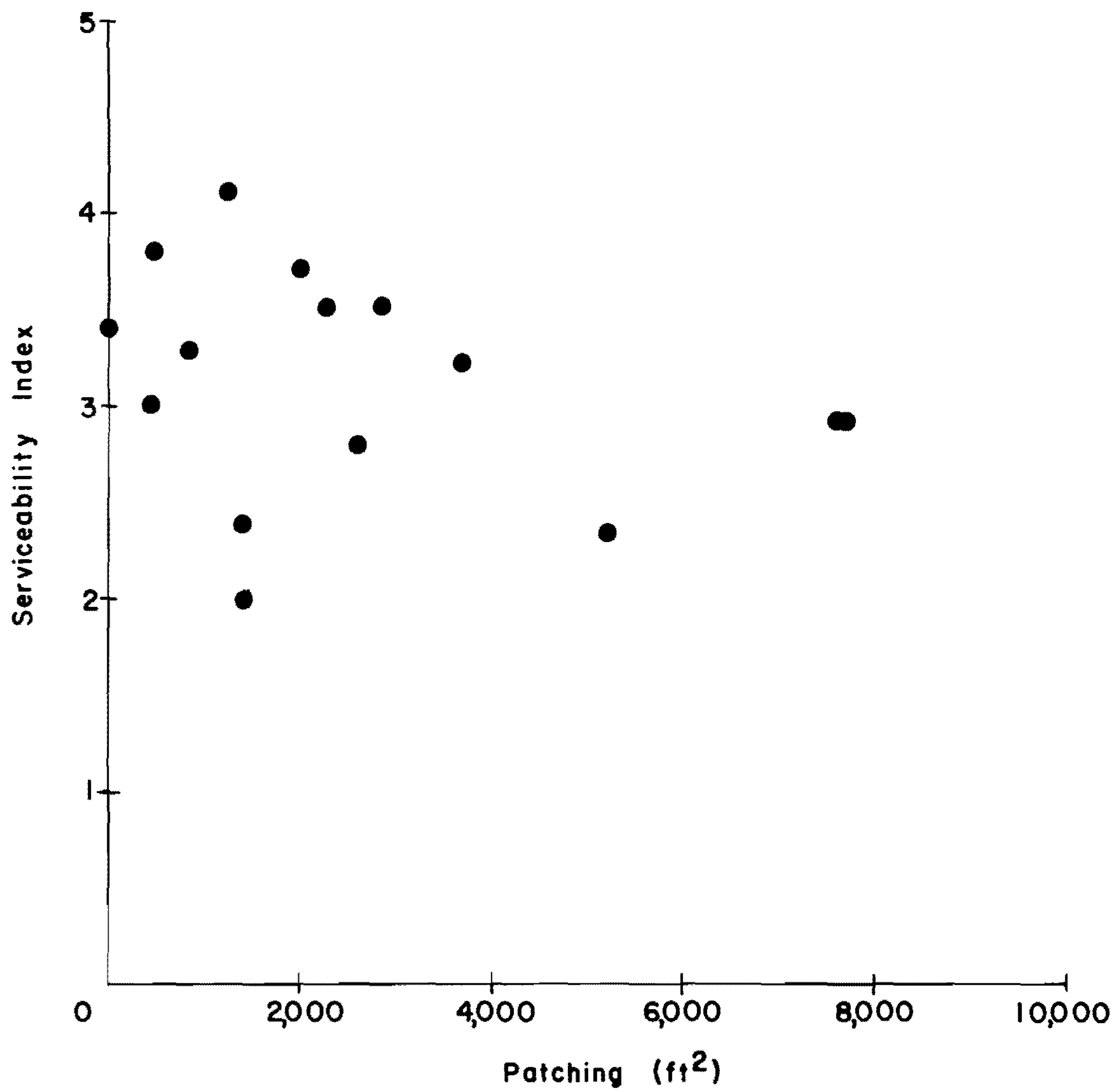


Fig 4.16. Patching versus serviceability index.

Highway Department. This indicates that the maintenance personnel who chose these highways for rehabilitation might tend to feel that a highway needs rehabilitation before it reaches the design terminal serviceability. Further study in this area might provide useful information on the best design terminal serviceability values to use.

Proposed Future Profilometer Use

It is realized that the collection of such a small amount of data does not provide enough information to accomplish the ultimate desired goals. However, the purpose of this research was to begin initial work and determine the possible usefulness of further research in this area. It is felt that this definitely was done and that highly promising results to initiate further research were gained.

It is recommended that future research be conducted on a larger data collection basis and more refined data analysis. Many miles of distressed pavement exists from which much profile data could be collected for comparison with specific distresses. The capabilities of the profilometer output were only touched on the surface in this initial research.

It is recommended that serious consideration be given in the future to use of various filters that are available with the profilometer and any other techniques that are available for analyzing the profile patterns to a finer degree. This could lead to the collection of much more detailed knowledge on distress in a much shorter time than can be done using field condition surveys.

It is thought that with concentrated effort and further use of the profilometer, this area of research could be the most profitable one yet in the attempt to relate pavement distress to pavement performance.

CHAPTER 5. MAINTENANCE STUDY

Due to various factors such as amount of traffic, materials, construction, subgrade properties, and environment, highway pavements become distressed. These distresses must bè corrected to the greatest extent possible if a high degree of serviceability and good performance is to be acquired. Thus, a study of the maintenance of pavements should be included in research directed toward relating pavement distress to pavement performance. A thorough study and analysis of pavement maintenance might lead to improved maintenance procedures, improved scheduling of maintenance, and predictions of the effect that various types of maintenance will have on performance of the pavement. The purpose here is to point out the importance of a maintenance study, what can be gained, and what future research might be helpful in this area.

Current Maintenance Procedure

It would be helpful to look at the current maintenance procedure used by the Texas Highway Department. Since the scope of the condition survey portion of this work was District 14, the maintenance procedure used in this district is given here. Of course, this is probably similar to the procedure used in all the districts in the state. The information given here on maintenance was provided by Mr. Jack Wilder, the District 14 Maintenance Engineer.

As a guide for obtaining the desired information on maintenance procedure, the following questions were formulated before talking with the maintenance engineer:

(1) Who is involved in determining when a pavement needs maintenance or reconditioning?

(2) What methods are used to determine this?

(3) Is a condition survey performed on pavements?

(4) If so, how is this done and how are the results reported?

(5) What specific pavement distress manifestations lead to the decision to do maintenance or overlay work?

(6) Who decides what type maintenance to use for certain distress and what are these types of maintenance?

It was thought that if these questions could be answered they would provide good beginning information on a study of highway maintenance procedure.

It was learned that the key personnel involved in maintenance decisions within the district are the maintenance foremen in the residency and the district maintenance engineer. Routine daily maintenance such as crack sealing and patching is determined by each residency and conducted by the personnel in the residency. However, for larger maintenance jobs such as scarifying, resurfacing, and overlays the final decisions usually rest with the maintenance engineer.

The maintenance foreman in the residency inspects the roads daily for the distress present on the pavements. Based upon his ability, experience, and past knowledge of the pavement such as type of surface, type of base, etc., he recommends to the district maintenance engineer the pavements he thinks need to be reconditioned and what work should be done on these pavements. The maintenance engineer along with the resident foreman then inspects the pavements and makes the final decision on which pavements are to be placed on the improvement fund list and what improvements are to be made.

The maintenance foremen make the pavement surveys as detailed as possible based on the number of miles of pavement they have to survey. Their report on the condition is based upon their ability and personal knowledge. Condition surveys similar to the ones made in District 14 for this work are not conducted by the Highway Department personnel. No detailed distinction between the various types of distresses such as block cracking, shrinkage cracking, transverse cracking, rutting, and raveling is made although some of these may be noted as occurring.

Mr. Wilder pointed out that most people, even those with no knowledge of pavements at all, can do a fairly good job of rating the condition of pavements according to the riding quality. He said he has been one of a group of persons, all with different backgrounds and experiences, who rated some pavements using a ride quality rating scale method. Each of these persons rated the pavement fairly close to the same. This type of rating has been done several times and each has shown that generally each person rates the pavement fairly close to the same rating number as far as ride and appearance are concerned.

After inspection of the pavements and the determination of which pavements need maintenance and the type maintenance they need, the decision must be made as to which ones can receive maintenance. Presently, the most severe constraint upon maintaining pavements is cost. This constraint prohibits the extent of maintenance that is desired. Based upon the amount of money available, the district maintenance engineer usually asks the resident maintenance foreman to choose from among the distressed pavements the ones that he feels need maintenance the most. If approved by the maintenance engineer, these pavements are then placed on the improvement fund program and then on the bid list for contractor bidding.

Mr. Wilder feels that the lack of needed maintenance money, which is more severe now than in the past, may be causing the Highway Department to lose gound on the maintenance of highways. Also, the snow and ice during the past winter caused extensive damage which could possibly require three to four years to overcome. Thus, the constraint of money seems to be putting an extra burden on the Texas Highway Department maintenance procedure.

Discussion of Observations

In conclusion, the Highway Department's maintenance procedure consists of inspection by the resident foremen of the pavements according to the maintenance procedure in the Maintenance Manual, recommendations to the district maintenance engineer, inspection by the maintenance engineer, and placement on the funding list for improvements. Routine daily maintenance is performed by resident personnel based upon their own decisions.

Based on information obtained in this initial study of maintenance procedures, it is recommended that future research in this area be conducted so that it will add to the attainment of the goal of relating pavement distress to pavement performance. The information learned to this point has been fairly general, so it is thought that more detailed and closer work with highway department personnel would result in very useful information.

Since the majority of the key personnel involved in maintenance decisions are the resident maintenance foremen, it is thought that interviews with some of these men about how they determine pavement condition and maintenance work would be of great help. Questions similar to those given in this chapter could be used as a guide. The district maintenance engineer would be helpful in formulating these questions. Consideration should be given to distributing a questionaire to persons involved in maintenance decisions. This was done in District 17 in January 1973. The questionaire was on criteria used to select highways for maintenance and asked for a rating of decision factors for various maintenance work. The results are shown in Table 5.1 and show the relative weights given to factors that distress pavements. Results are shown for engineers and maintenance forces. It was noted that the maintenance forces weight the factors of pavement cracking, surface roughness, and type of existing base higher than the highway engineers and that highway engineers stress raveling of aggregate, visible pavement deformation, skid values, and amount of traffic when considering pavements for maintenance. Other considerations, not shown on the original questionaire, were added by some of the maintenance and engineering personnel and are shown in Table 5.2. From results of the questionaire it was concluded that the selection of pavements for maintenance is still an art which improves with experience. Collection of information of this type in other districts would be very useful.

Appendix 2 contains pictures, descriptions, and probable causes of different types of distress manifestations that were encountered in the condition survey in District 14. It is thought that consideration should be given to distributing manuals with this information to personnel that are involved in determining the condition of pavements. This would be helpful to them in identifying distress to a higher degree of detail and would provide them with additional overall information on pavement distresses. Since each district contains different types of distress, a manual could be prepared for each district that includes the distress types that occur in that district. Perhaps with information of this type, the maintenance personnel will be oriented toward identifying more specifically the various distresses and what types of maintenance they require.

The use of the Surface Dynamics Profilometer and the Mays Ride Meter can add useful information on the effect that maintenance has on the performance of a pavement. These can be used to collect data on pavements before and after maintenance is performed and then analyzed to see what specific changes resulted due to the maintenance. Over a period of time it possibly can be determined whether or not one type of maintenance is better than others for upgrading the performance of pavements.

TABLE 5.1. RESULTS OF QUESTIONNAIRE ON RATING DECISION FACTORS

Decision Factors	Seal Coat		Level Up		Recom. Base		Comp. Rework	
	Engr.	Maint.	Engr.	Maint.	Engr.	Maint.	Engr.	Maint.
Raveling of aggregate	18.3	13.9	6.3	3.5	3.8	5.3	1.0	xx
Amount of cracking	14.6	24.6	8.3	12.8	7.9	7.3	1.7	xx
Type of cracking	9.6	11.2	4.2	5.8	8.1	7.2	0.9	xx
Roughness of surface	3.8	6.8	12.1	19.3	2.5	8.6	0.8	xx
Visible pavement deformation	4.2	3.3	19.6	7.7	13.3	10.6	6.3	xx
Skid values	15.6	7.1	11.3	5.3	1.3	1.0	0.8	xx
Deflection values	1.0	0.9	2.9	8.3	7.1	8.2	3.1	xx
Amount of traffic	24.5	17.3	22.9	16.8	23.3	16.2	29.1	xx
Type of existing base	2.2	7.3	5.6	7.6	17.9	21.0	5.7	xx
Other considerations	6.2	7.6	6.8	12.9	14.8	14.6	50.6	xx

TABLE 5.2. ADDITIONAL MAINTENANCE CONSIDERATIONS

1. Type of traffic and characteristics of the highway.
2. Speed zoning of highway.
3. Cross slope of roadway.
4. Drainage of roadway.
5. Accident record on the roadway.
6. Cost of additional right-of-way.
7. Capability of county to obtain additional right-of-way.
8. Existing pavement width and condition.
9. Bridge widths and condition.
10. Condition of existing base.
11. Excessive patching.
12. Available funds for maintenance.
13. Condition of the subgrade.
14. Importance of the highway to the system.

It is recognized that making pavement maintenance decisions is an art and that accumulation of experience cannot be replaced; however, it is felt that future research in this area such as outlined above can help make this a finer art and also provide information that will bring highway pavement researchers nearer the goal of relating pavement distress to pavement performance.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It was known before beginning this research that the goal of predicting the performance of pavements could not be reached within the scope of this effort. It was thought, however, that by introducing some areas of research and presenting some possible future research outlines, impetus might be given to others for carrying forward this research. These areas have been introduced and outlined in this work.

The major portion of this work consisted of the condition survey data collection and analysis. Goals were established before beginning the surveys and these goals have been accomplished, some with more satisfaction than others.

The first goal, the determination of the distress types that occur on pavements, along with their frequency of occurrence, was accomplished for the District 14 highways that were surveyed. This information is given in Table 3.9. The most frequently occurring distress manifestation is patchings, as would be expected for highways that are scheduled for resurfacing. The number two manifestation in order of occurrence is bleeding. This is because the highways that were surveyed had surface treatments, which tend to have more bleeding than other surface types. The number three manifestation is rutting which was generally not too severe where it did occur. Following, in order, are longitudinal fatigue cracking, edge deterioration, ravelling, and the other various types of cracking. Patching accounted for approximately 60 percent of the distress manifestations, bleeding for nine percent, rutting for six percent, longitudinal fatigue cracking for six percent, edge deterioration for five percent and ravelling for five percent. The other types of cracking accounted for the remainder. Of the total area surveyed, 22 percent was experiencing some type of distress. Generally speaking, the highways in the western part of the district experienced less distress, especially cracking, than those in the eastern part of the district. This is most likely due to the general limestone soil formation in the west, which gives less movement than the clays in the eastern part. The determination of the amount of distressed area accomplished the second goal.

The third goal was to establish a suitable method of performing condition surveys. The method presented in this work gives very good detailed information, including photographs, but is more time-consuming than is desired. There is room for improvement in this area.

The fourth goal was the attainment of knowledge of pavements by performing the condition surveys. This goal has also been accomplished, quite satisfactorily.

Another major area of this research was the profile data collection and analysis. Profilometer output data were used to determine the possible future usefulness of the profilometer in identifying distress types. The amount of data collected was not enough to draw any definite conclusions, but some promise is shown by some of the profile plots such as for an area that was experiencing block cracking. Also in this research area was the determination of values ranged from 2.0 to 4.1 with a mean of 2.9. It is interesting to note this average terminal serviceability index value of 2.9 is higher than would be expected for pavements scheduled for resurfacing. It is higher than the usual design value for terminal serviceability. Thus, perhaps the maintenance engineers feel that a pavement needs resurfacing before it reaches the design terminal serviceability.

Recommendations

It is recommended that detailed condition surveys, such as the one performed in this research, be performed in other districts within the state. Each district may have different distresses, both in occurrence and prominence. It is recommended that a manual be prepared for each district that includes the types of distress for that district, their causes, pictures, and types of maintenance needed. The distribution of this manual to the maintenance personnel, as well as others, could add to the development of improved maintenance procedures and increase knowledge of detailed distress types.

More study in comparing the design terminal serviceability to the actual terminal serviceability of pavements would also provide interesting and useful information regarding the proper design value for terminal serviceability.

In order to aid in relating distress manifestations and distress mechanisms it is recommended that a study be made of the history of pavements including design, materials, dimensions, surface types, etc. for comparison with the distress that is present on these pavements. This would provide information that would help in determining the cause of certain types of distress.

Thus, much more thorough and detailed research needs to be conducted within each of the areas presented here. Each area - pavement condition surveys, profile studies, and maintenance studies - can become the basis for a large-scale research project. After the collection of detailed information in those areas, it is sincerely thought that the information can be combined into a distress-performance relationship that will enable the ultimate goal to be reached - the prediction of the performance of pavements.

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APPENDIX 1

LOCATION OF SECTIONS

APPENDIX 1. LOCATION OF SECTIONS

Table A1.1 gives a detailed description of the location of each section. Figures A1.1 through A1.8 are portions of county maps with the sections located. The section number appears in a circle and an arrow points to the exact location.

TABLE A1.1. LOCATION OF SECTIONS

Section Number	Highway Number	County	Location of Section
P-1	SH 71	Bastrop	Begins at intersection of FM 20 with SH 71 approximately 2.5 miles west of Bastrop City limits at Colorado River and proceeds west in eastbound outside lane.
P-2	L 360	Travis	Begins at first crossover west of Lamar Blvd. overpass and proceeds east in westbound lane.
P-3	Pleasant Valley Road	Travis	Begins at intersection of South Lakeshore with Pleasant Valley Road just south of Longhorn Dam and proceeds north in outside southbound lane.
1	FM 621	Hayes	Begins at Hays-Guadalupe County line and proceeds east in westbound lane.
2	FM 621	Hayes	Begins at intersection of a paved county road with FM 621 approximately 0.6 mile west of Hays-Guadalupe County line and proceeds east in westbound lane.
3	SH 80	Caldwell	Begins at intersection of FM 1979 with SH 80 and proceeds toward west in westbound lane.
4	SH 80	Caldwell	Begins at Hays-Caldwell County line and proceeds east in eastbound lane.
5	SH 71	Bastrop	Begins at Bastrop-Fayette County line and proceeds west in westbound lane.
6	SH 71	Bastrop	Begins at intersection of Hill Road (small paved county road) with SH 71 approximately 2.3 miles west of Bastrop-Fayette County line and 0.5 mile east of Smithville and proceeds toward west in westbound outside lane.
7	SH 71	Bastrop	Begins at intersection of FM 153 with SH 71 approximately 1.4 miles west of Colorado River bridge and proceeds west in westbound outside lane.

(Continued)

TABLE A1.1. (Continued)

Section Number	Highway Number	County	Location of Section
8	SH 71	Bastrop	Begins at west end of Alum Creek bridge and proceeds west in westbound outside lane.
9	SH 71	Bastrop	Begins at eastern Bastrop city limits sign and proceeds east in eastbound outside land.
10	SH 71	Bastrop	Begins at intersection of FM 1209 with SH 71 approximately 23 miles east of Austin and proceeds west in westbound lane.
11	FM 971	Williamson	Begins at intersection of FM 1105 with FM 971 in Weir and proceeds east in eastbound lane.
12	FM 971	Williamson	Begins 3.7 miles east of Weir at M-K-T railroad crossing at Mozo and proceeds east in eastbound lane.
13	FM 971	Williamson	Begins at west city limits of Granger and proceeds west in westbound lane.
14	FM 971	Williamson	Begins 2.8 miles west of Granger City limits at M-K-T railroad crossing and proceeds west in westbound lane.
15	US 87	Mason	Begins 1.5 miles north of Cherry Spring at bottom of hill (approximately 0.4 mile north of Gillespie County line and 150' - 200' north of private road) and proceeds north in northbound lane.
16	US 87	Mason	Begins at northermost intersection of Ranch Road 2242 with US 87 approximately 7.3 miles north of Cherry Spring (2242 intersects US 87 twice) and proceeds north in northbound lane.
17	US 87	Mason	Begins 1.5 miles south of Beaver Creek at top of hill and proceeds south in southbound lane.

(Continued)

TABLE A1.1. (Continued)

Section Number	Highway Number	County	Location of Section
18	US 87	Mason	Begins at southernmost intersection of Ranch Road 2242 with US 87 (2242 intersects US 87 twice) and proceeds south in southbound lane.
19	US 290	Gillespie	Begins 8.6 miles west of Fredericksburg and proceeds west in westbound lane.
20	US 290	Gillespie	Begins 12.6 miles west of Fredericksburg (4.0 miles west of beginning of section 19) at west end of creek bridge and proceeds west in westbound lane.
21	US 290	Gillespie	Begins at Gillespie-Kimble County line and proceeds east in eastbound lane.
22	US 290	Gillespie	Begins at east Harper City limits approximately 4.0 miles east of Kimble County line and proceeds east in eastbound lane.
23	US 290	Gillespie	Begins at east end of creek bridge 5.7 miles east of Harper City limits and proceeds east in eastbound lane.

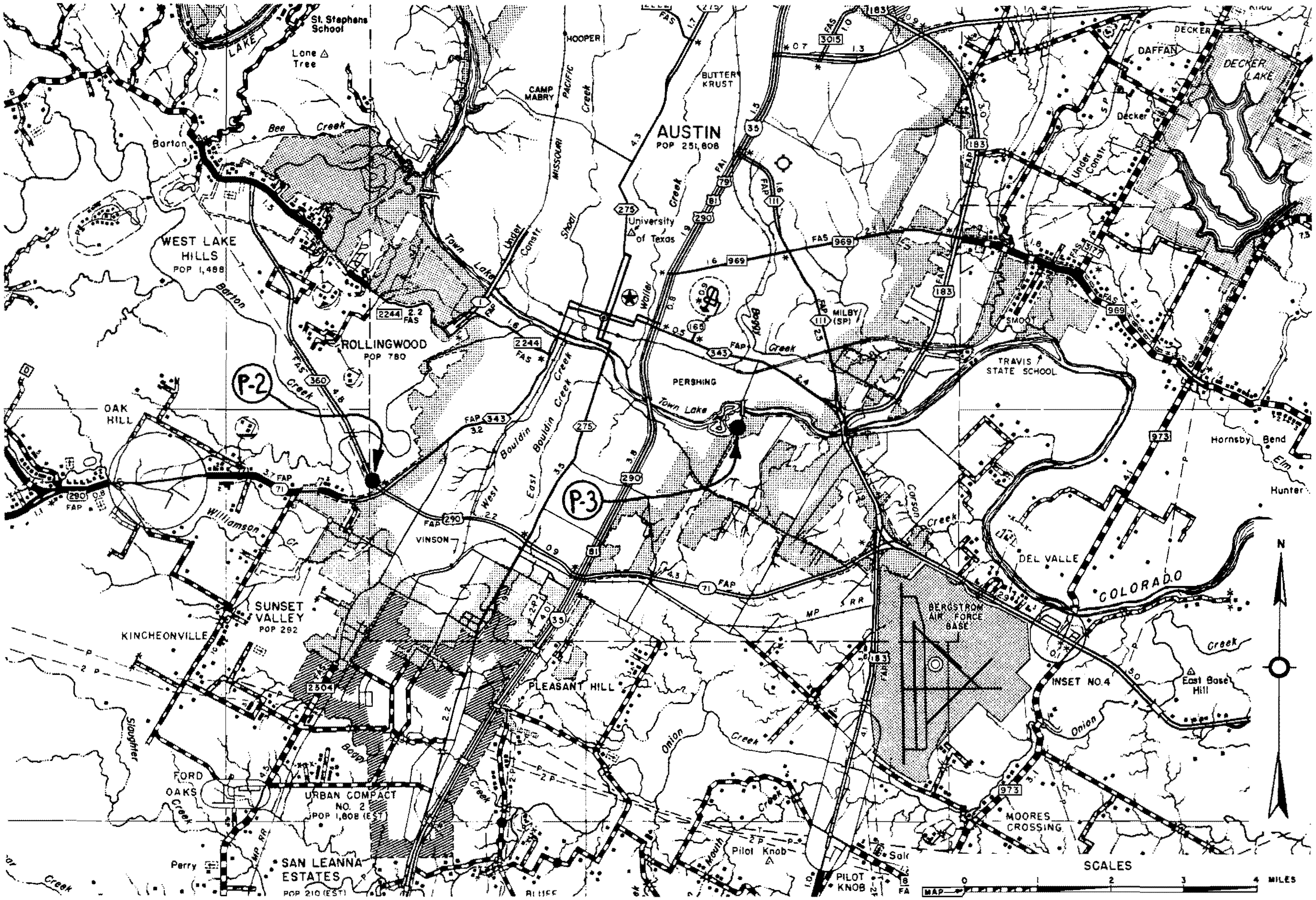


Fig Al.1. Travis County - Loop 360 and Pleasant Valley Road - Sections P-2 and P-3.

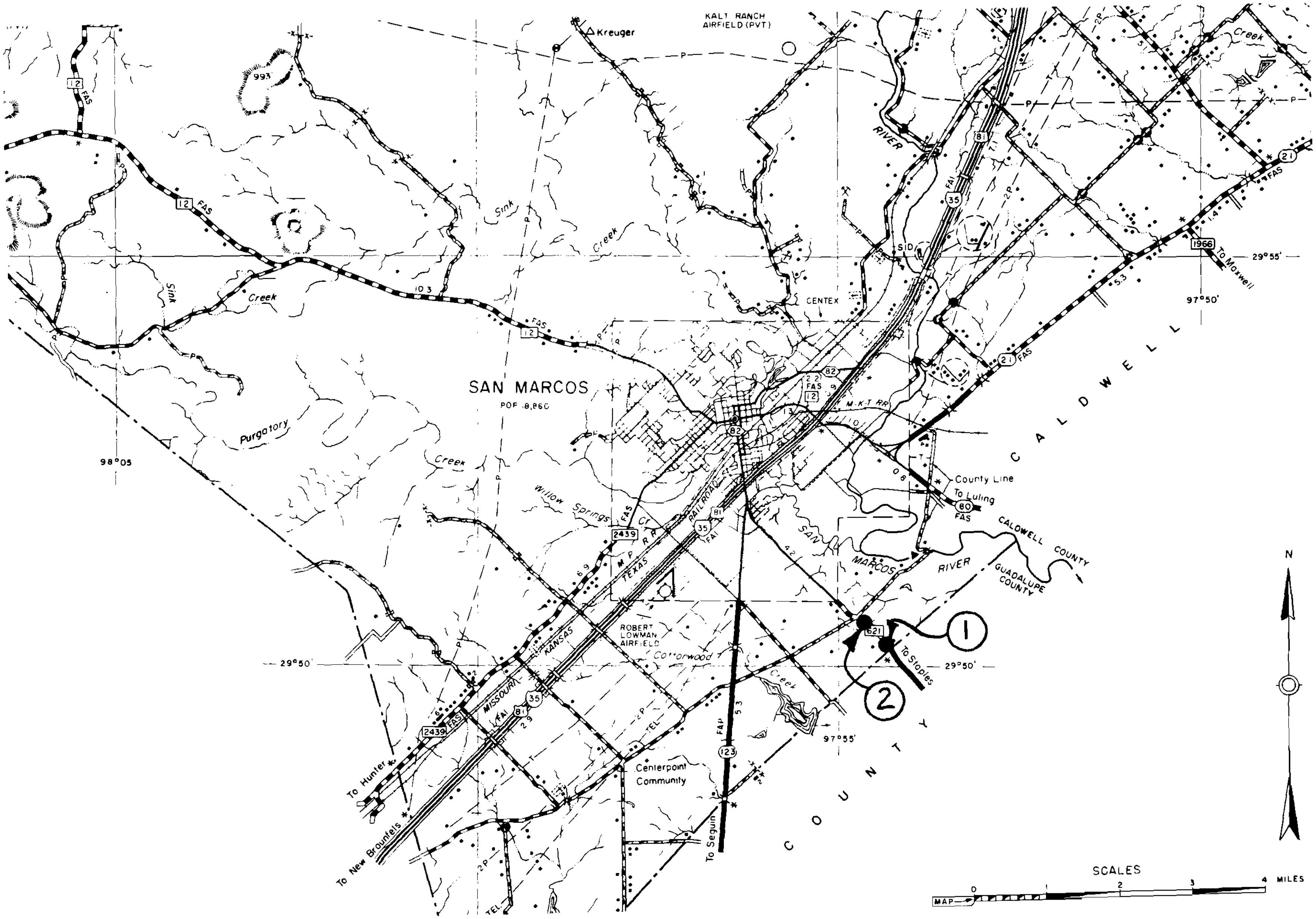


Fig A1.2. Hays County - FM 621 - Sections 1 and 2.

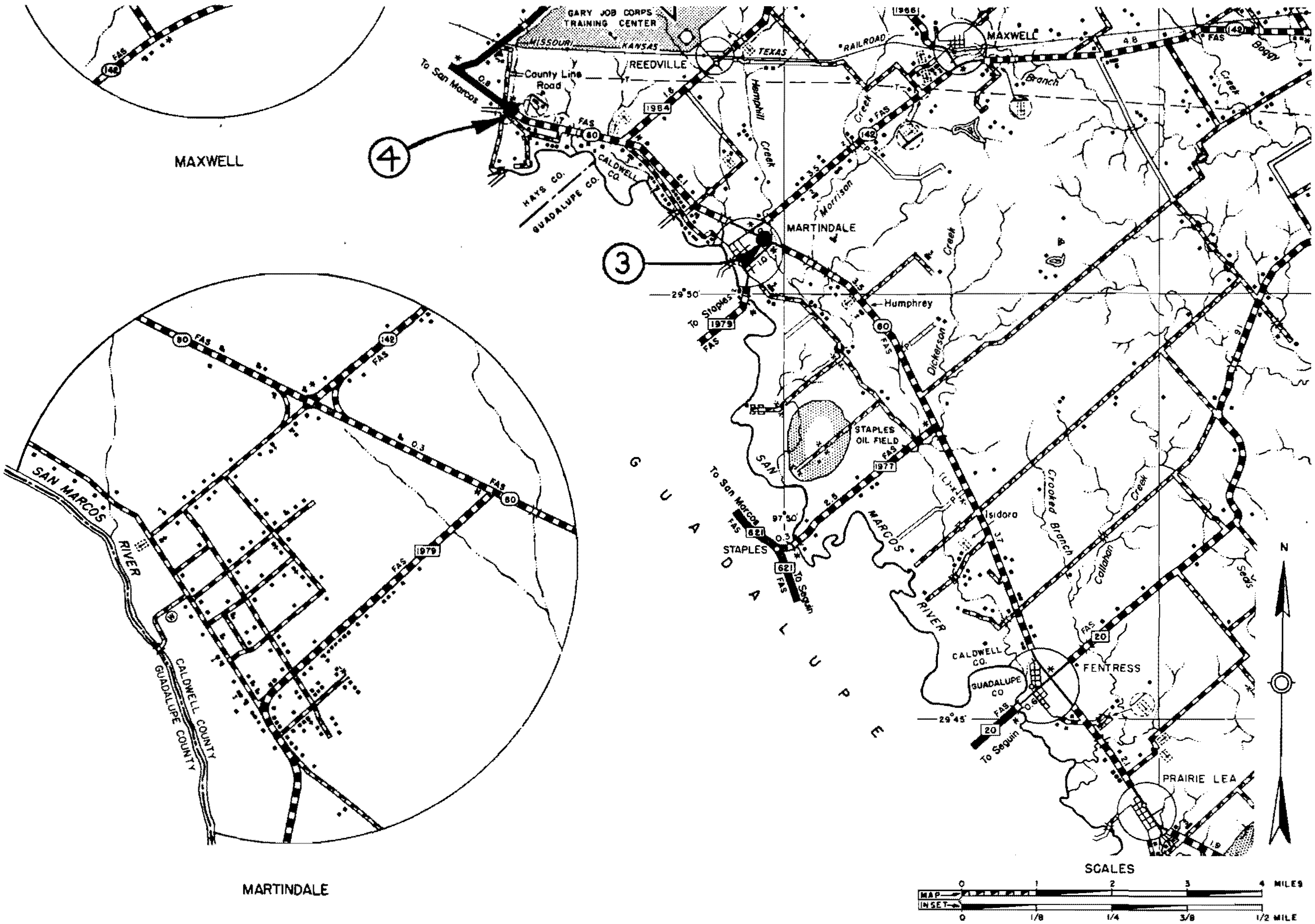


Fig A1.3. Caldwell County - SH 80 - Sections 3 and 4.

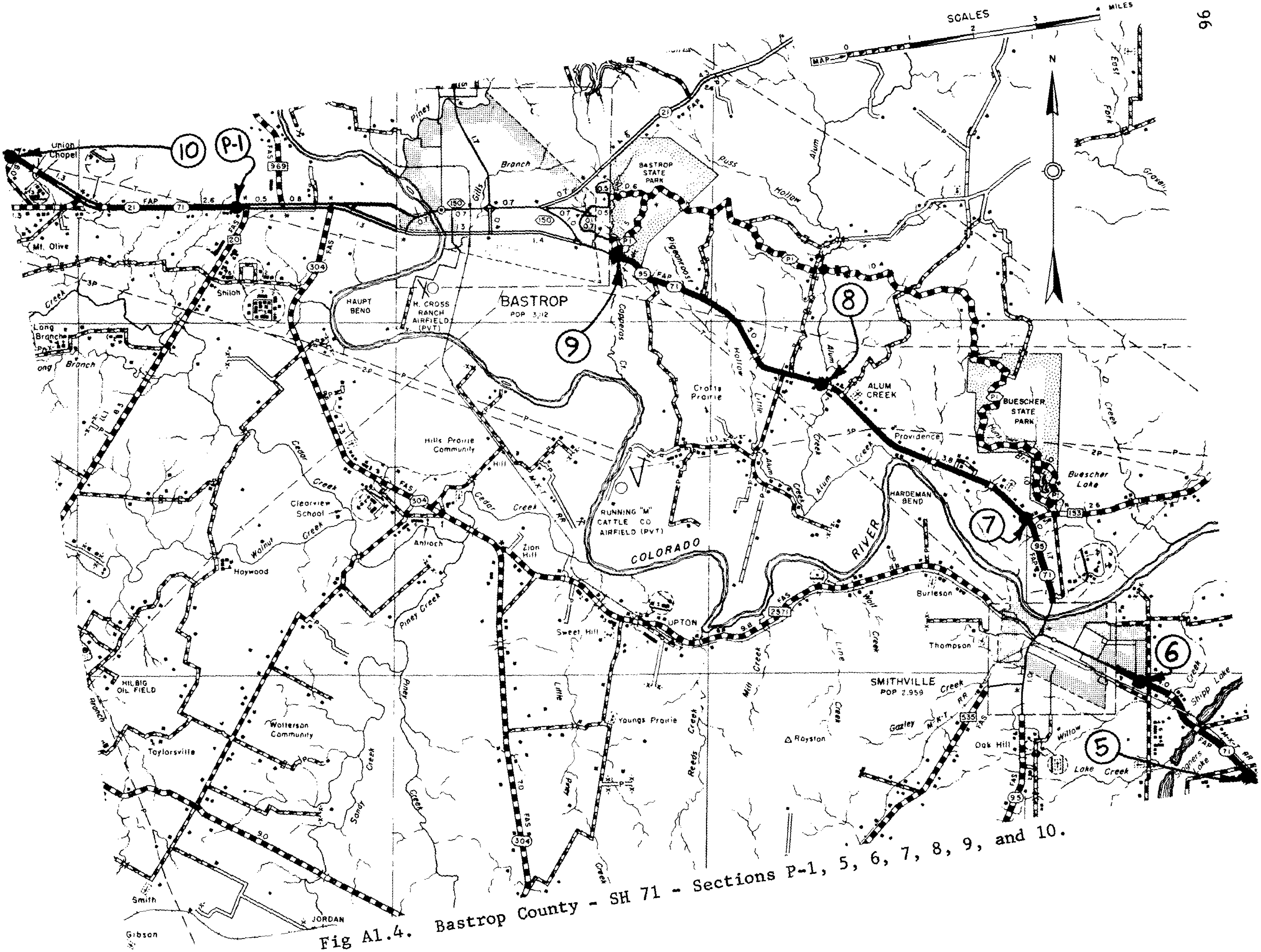


Fig A1.4. Bastrop County - SH 71 - Sections P-1, 5, 6, 7, 8, 9, and 10.

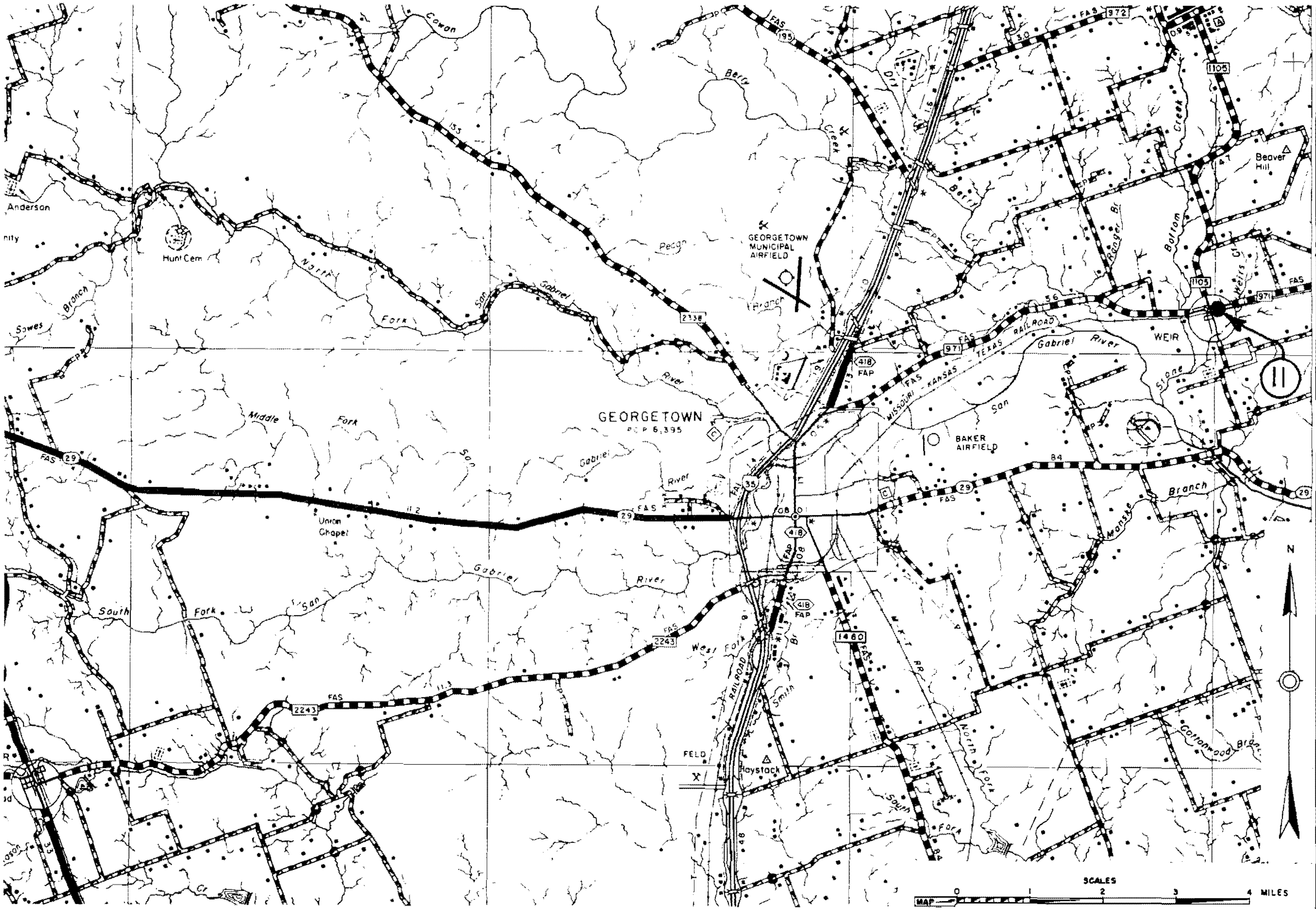


Fig A1.5. Williamson County - FM 971 - Section 11.

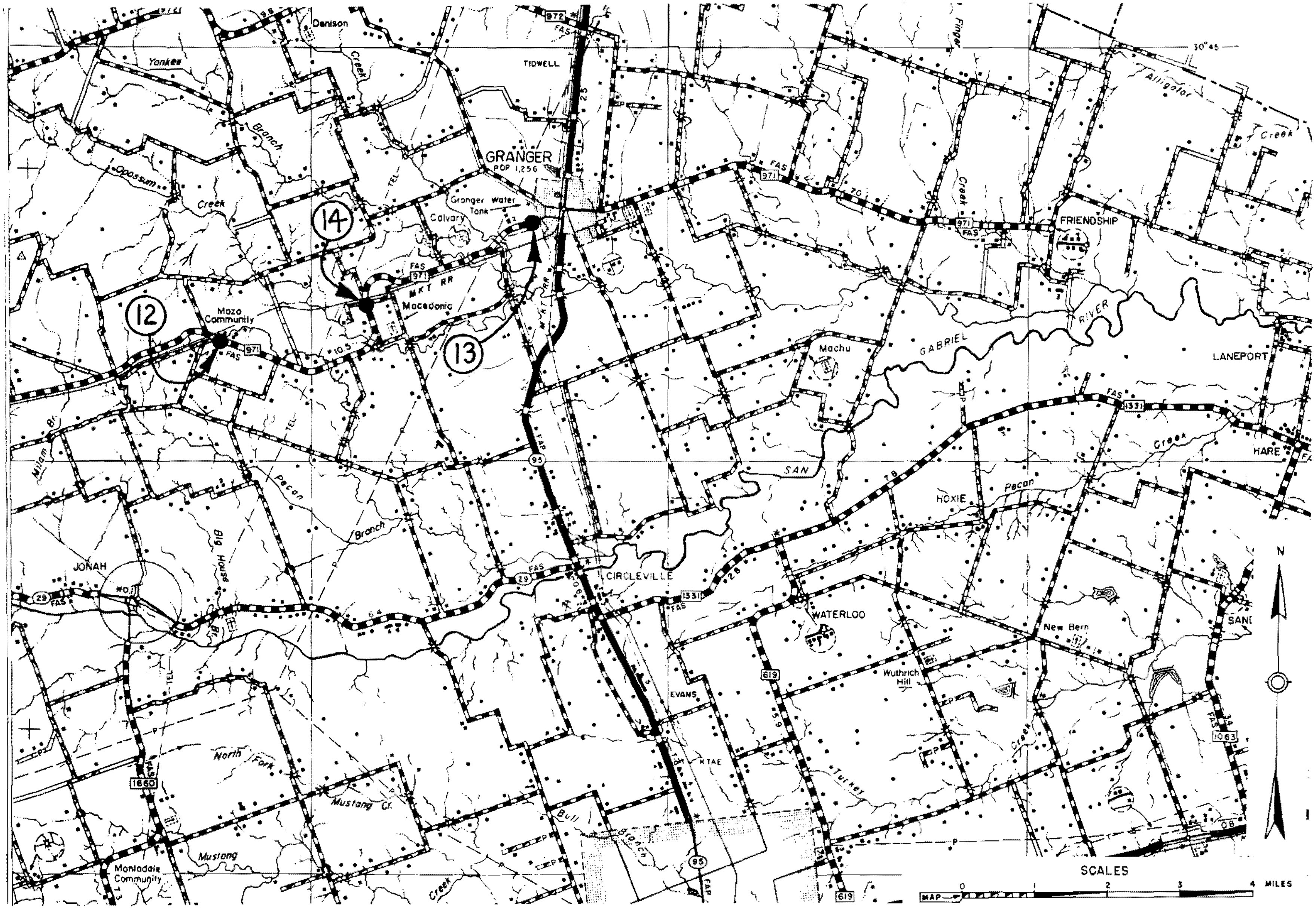


Fig A1.6. Williamson County - FM 971 - Sections 12, 13, and 14.

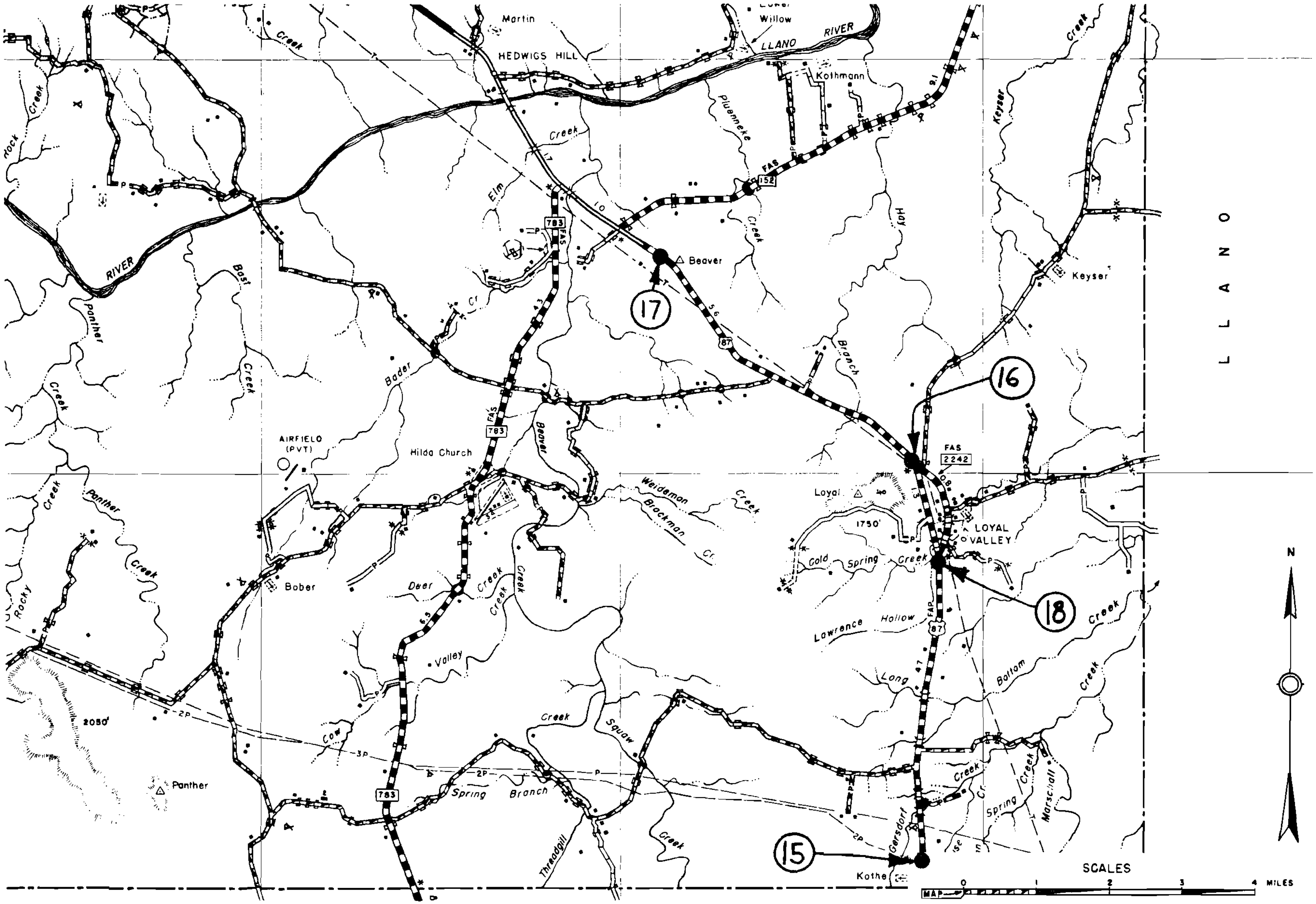


Fig A1.7. US 87 - Mason County - Sections 15, 16, 17, and 18.

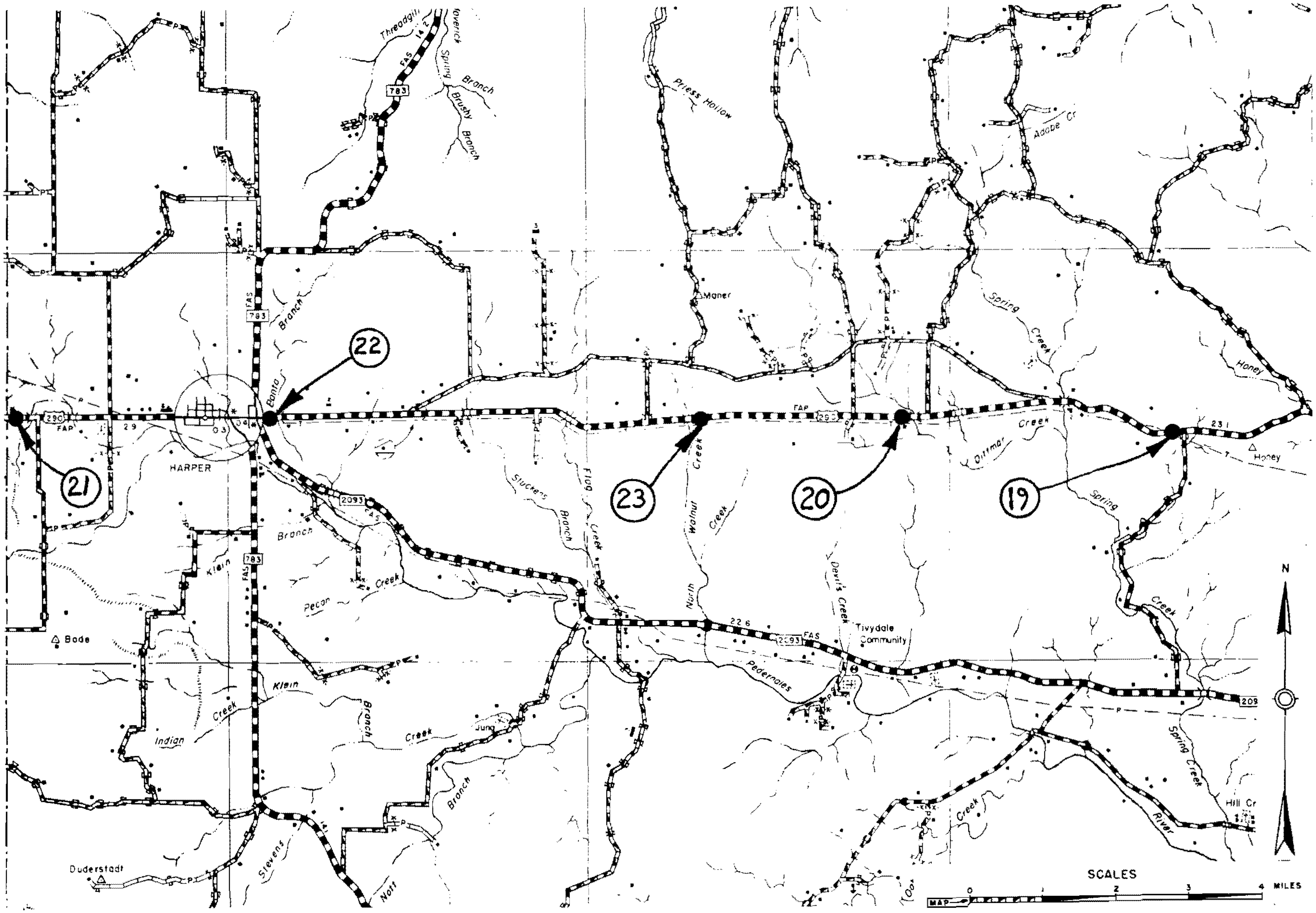


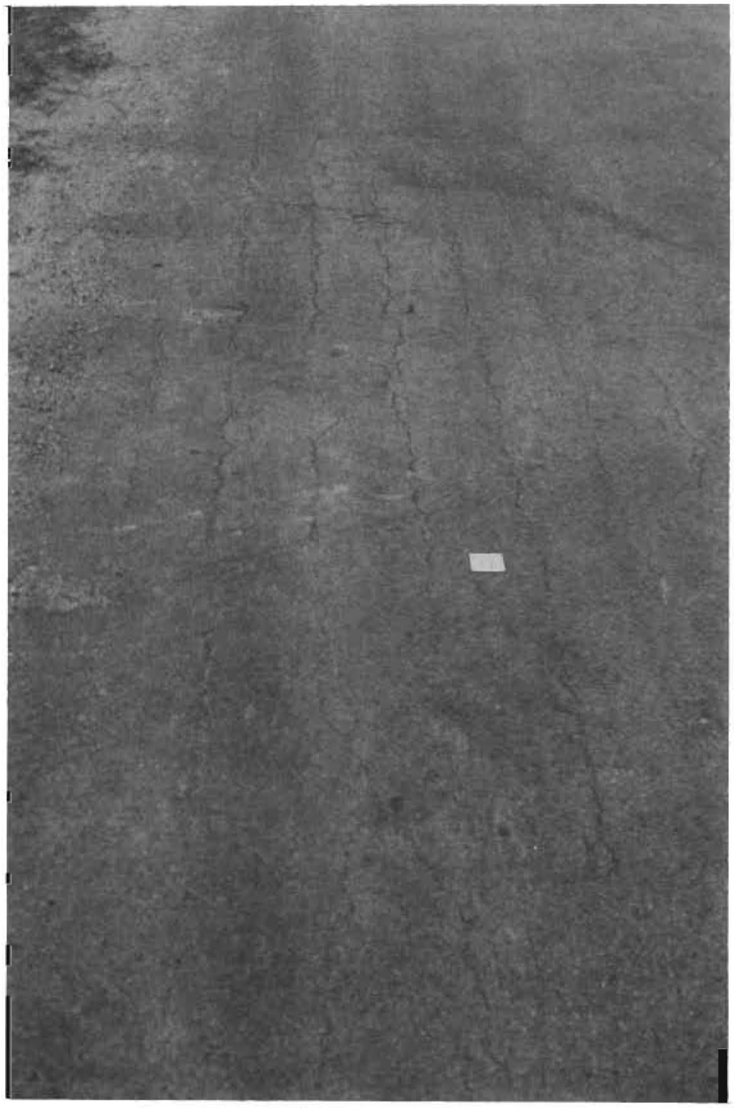
Fig A1.8. US 290 - Gillespie County - Sections 19, 20, 21, 22, and 23.

APPENDIX 2

PHOTOGRAPHS, DESCRIPTIONS, AND PROBABLE CAUSES OF DISTRESS MANIFESTATIONS

APPENDIX 2. PHOTOGRAPHS, DESCRIPTIONS, AND PROBABLE CAUSES OF DISTRESS MANIFESTATIONS

The following pages in this appendix consist of photographs of distress manifestations encountered during the condition surveys of District 14, along with their descriptions, and probable causes. Highway Research Board Special Report Number 114 (Ref 14) was used as a guide in writing the appendix.



Distress Manifestation: Longitudinal Fatigue Cracking

Description: Early stage of fatigue cracking; parallel longitudinal cracks in wheel path

Probable cause: Traffic applications; unstable base or subgrade

Distress Manifestation: Block Fatigue Cracking

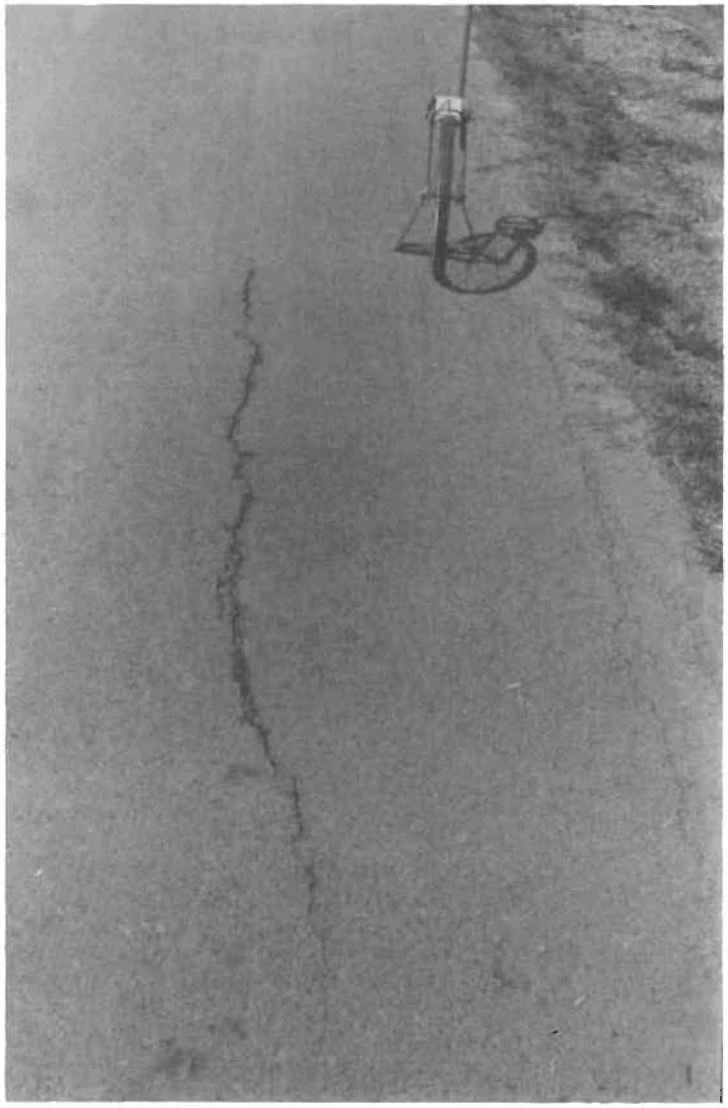
Description: More advanced stage of fatigue cracking; Interconnected cracks generally forming large blocks or polygons with sharp corners

Probable cause: Excessive traffic; unstable base or subgrade

Distress Manifestation: Alligator Fatigue Cracking

Description: Most advanced stage of fatigue cracking; interconnected cracks forming small blocks or polygons that resemble an alligator hide

Probable cause: Excessive traffic; unstable base or subgrade



Distress Manifestation: Longitudinal Cracking

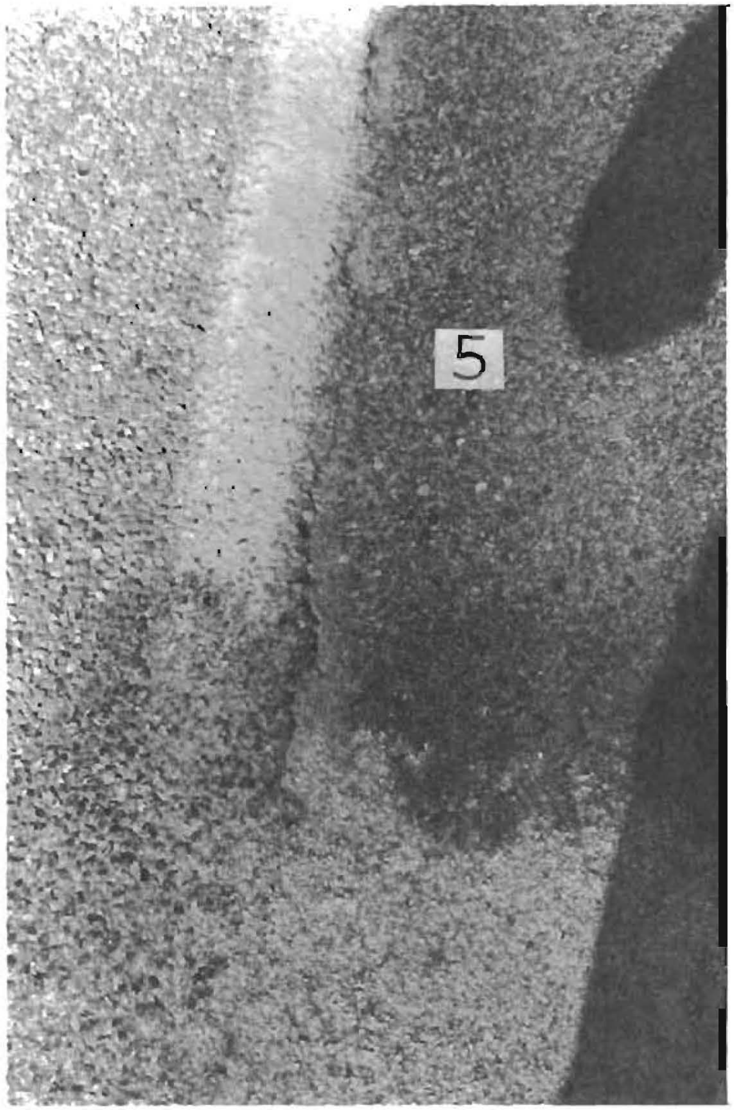
Description: Isolated cracks running parallel to direction of road

Probable cause: Loss of support; weak area in pavement

Distress Manifestation: <u>Shrinkage Cracking</u>

Description: Cracks forming a branch-like pattern

Probable cause: Shrinkage of pavement surface or underlying support



Distress Manifestation: Longitudinal Construction Cracking

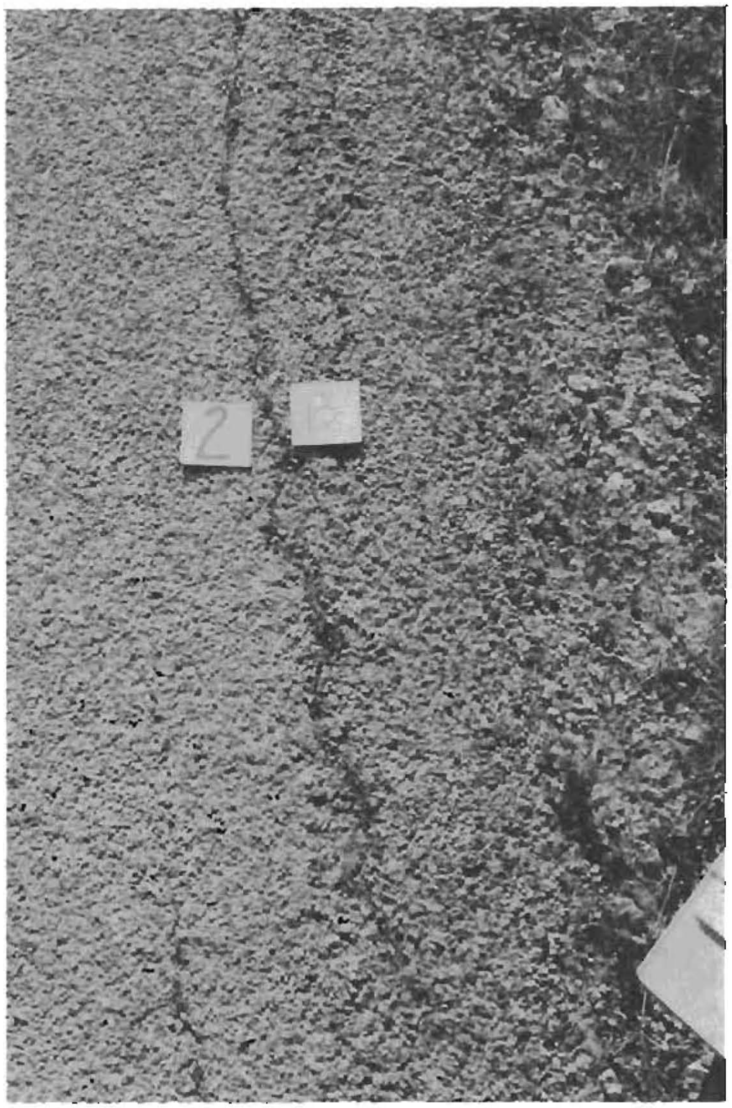
Description: A crack or break coinciding with pavement centerline or lane stripes

Probable cause: Cold or improperly constructed joint between pavement sections; settlement of roadbed under traffic

Distress Manifestation: Transverse Cracking

Description: Cracking approximately at right angles to the pavement centerline

Probable cause: Shrinking of the surface courses or pavement structure and possible traffic action; reflection of cracks or joints under the surface course



Distress Manifestation: Edge Cracking

Description: Longitudinal cracking near the edge of the pavement

Probable cause: Inadequate thickness of the pavement to support traffic; loss of support

Distress Manifestation: Raveling

Description: Surface disintegration by dislodgement of aggregate

Probable cause: Uneven distribution of asphalt from the spray bar; insufficient asphalt or binding agent in the surface; traffic action on a weak surface

Distress Manifestation: Bleeding

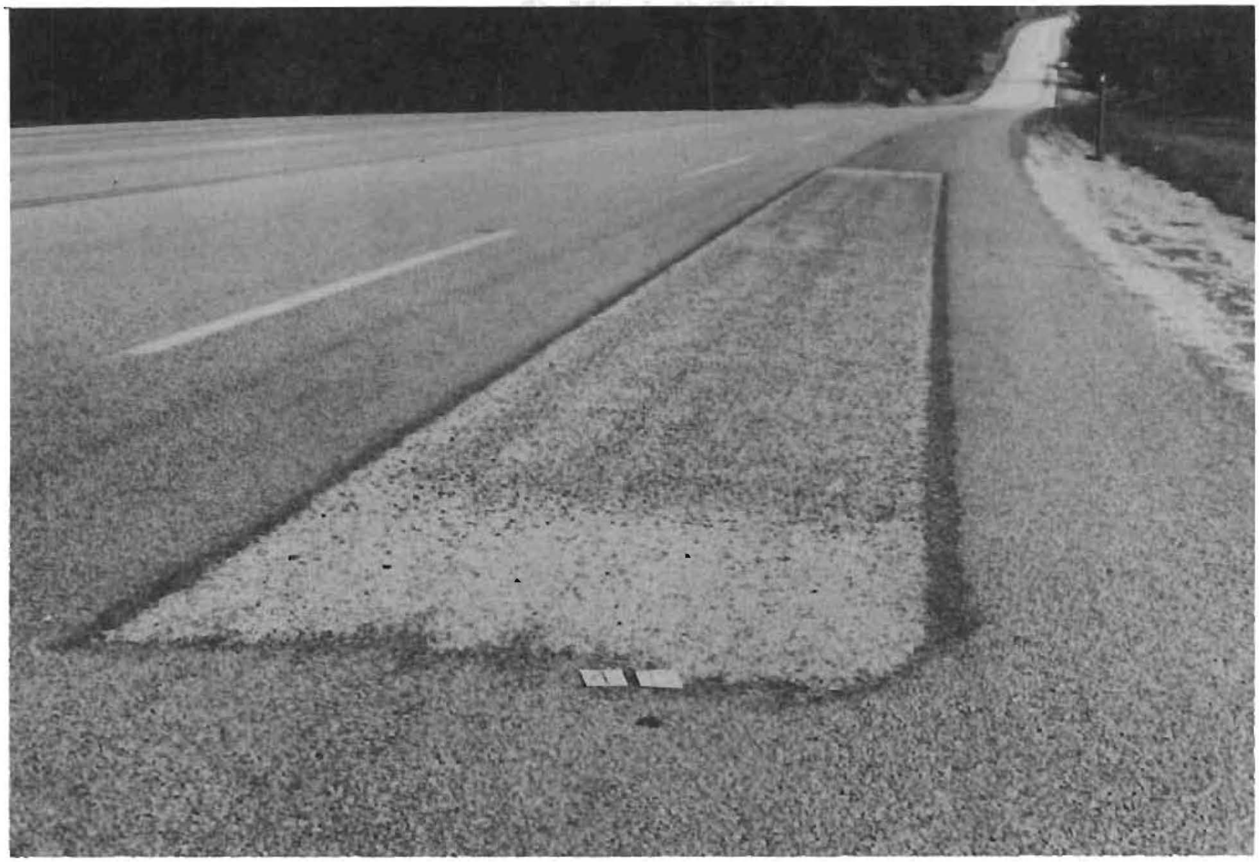
Description: Free asphalt on surface of pavement

Probable cause: Excess asphalt; rich application of asphalt with insufficient blotter

Distress Manifestation: Rutting

Description: Longitudinal depressions that form under traffic in the wheel paths and have a minimum length of approximately 20 feet

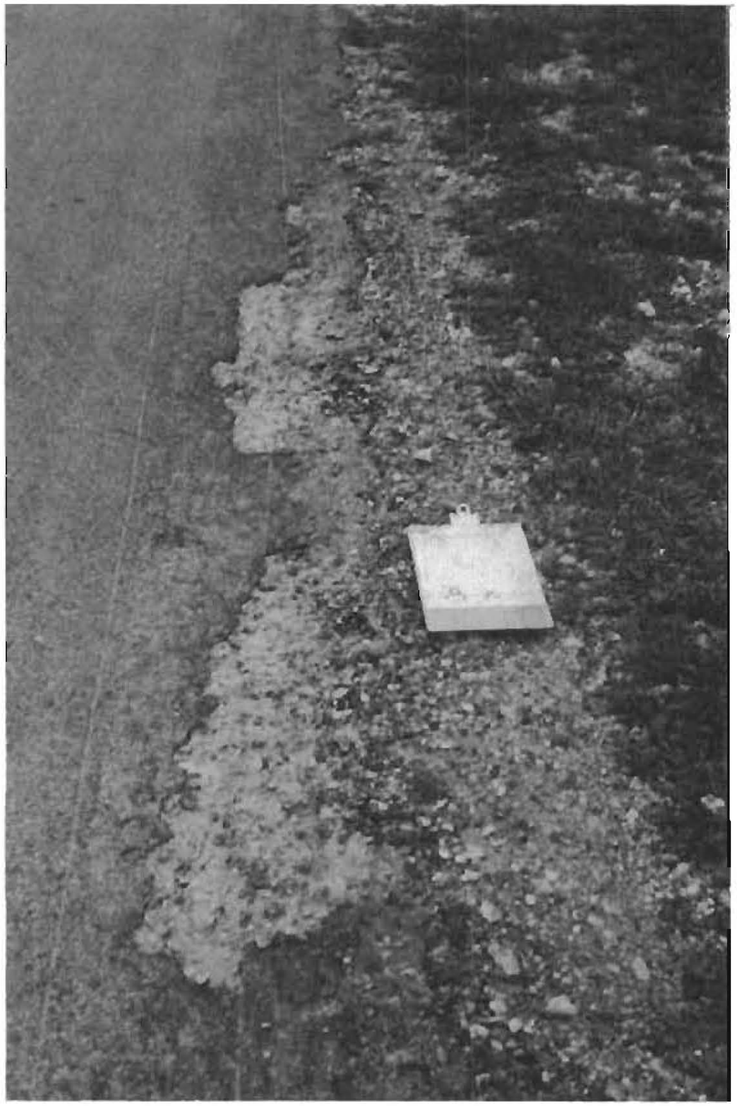
Probable cause: Localized and channeled wheel traffic over unstable pavement or foundation; traffic heavier than the design strength of the pavement structure



Distress Manifestation: Patching

Description: Replacement or covering of a part of the pavement that is experiencing distress

Probable cause: Distress of the pavement



Distress Manifestation: Edge Deterioration

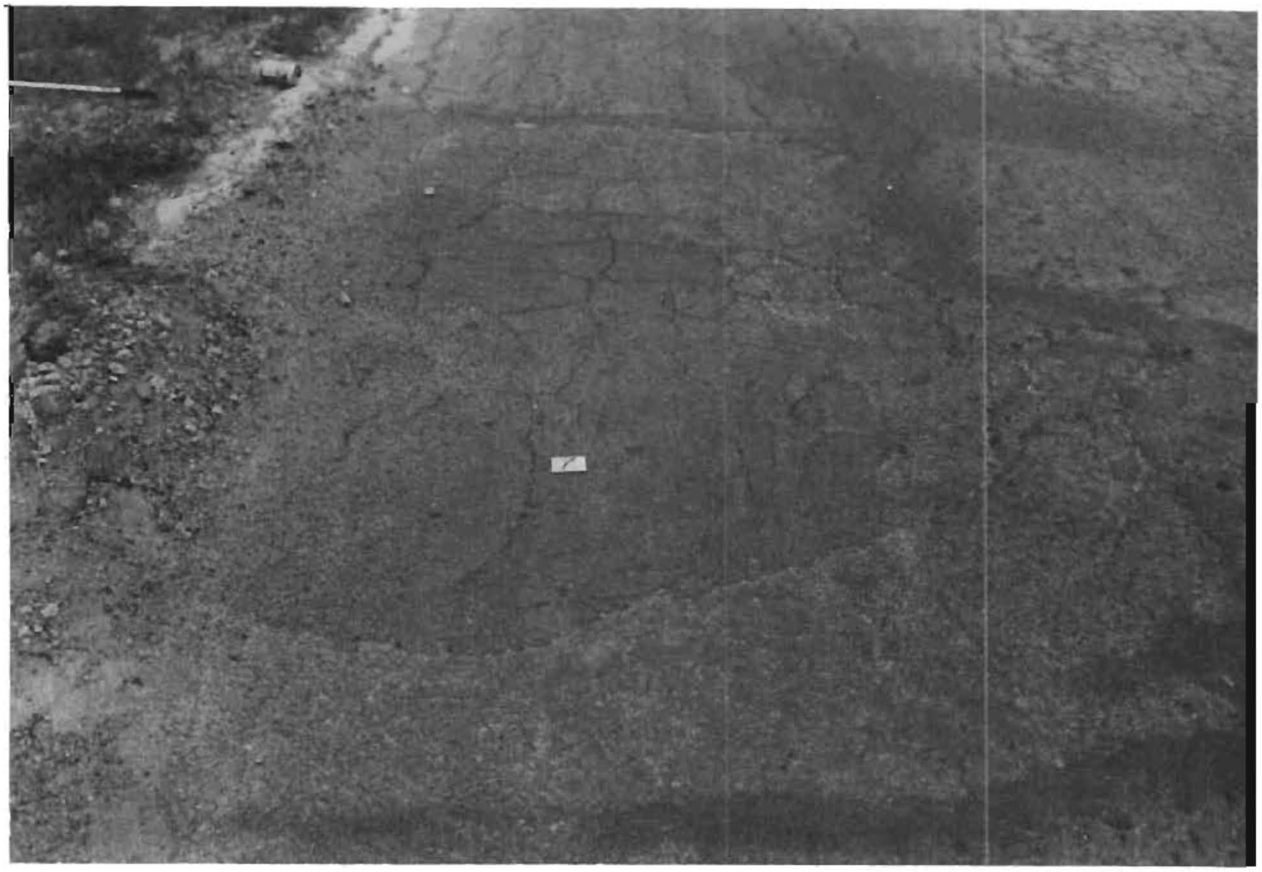
Description: Breaking-up of pavement edge

Probable cause: Unprotected or unsealed edge; insufficient pavement thickness to support traffic; loss of support under edge

Distress Manifestation: Streaking

Description: Alternate lean and heavy lines of asphalt running parallel to the pavement centerline

Probable cause: Clogged or improperly adjusted nozzles of the spray bar of the asphalt distributor during sealcoating



Distress Manifestation: <u>Depression</u>

Description: Localized pavement area with elevation lower than adjacent areas

Probable cause: Compression of roadbed materials; settlement of improperly compacted fill in trenches or patched roadbeds

Distress manifestation: Indentation

Description: Scarred or indented place on pavement

Probable cause: Wheel rims of blown tires, tractor cleats, sharp rimmed metal wheels, or sharp objects dragged over the surface