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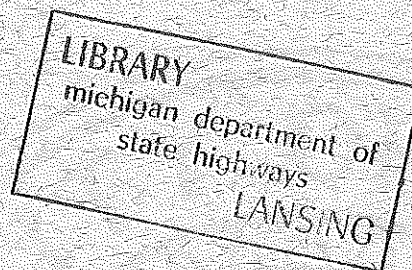
MICHIGAN PAVEMENT PERFORMANCE STUDY

Five Year Summary **Michigan Pavement Performance Study**

*Evaluation of Pavement Performance
as Related to
Design, Construction, Maintenance and Operation*

1957 - 1962

By
WILLIAM S. HOUSEL



Project of the

**Michigan Highway Planning Survey
Work Program HPS-1 (27)
In Cooperation With
U.S. Department of Commerce
Bureau of Public Roads**

December, 1962

*Stokstad
15 July 63*

OFFICE OF RESEARCH ADMINISTRATION • ANN ARBOR

UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

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EVALUATION OF PAVEMENT PERFORMANCE
AS RELATED TO
DESIGN, CONSTRUCTION, MAINTENANCE AND OPERATION

1957 - 1962

BY

WILLIAM S. HOUSEL
Research Consultant

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MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

ORGANIZATION

I Cooperating Agencies

- A. U. S. Department of Commerce - Bureau of Public Roads
- B. Michigan State Highway Department
- C. University of Michigan - Department of Civil Engineering
(Contractor)

II Sponsors

- A. 1957-1959
 - 1. Michigan Trucking Association
 - 2. American Trucking Associations, Inc.
 - 3. Automobile Manufacturers Association
- B. 1959-1962
 - 1. Michigan State Highway Department (Contractee)

III Sponsor Representatives and Advisory Personnel

- A. 1957-1959
 - 1. Wm. W. Johnston - Managing Director,
Michigan Trucking Association
 - 2. H. A. Mike Flanakin - Highway Engineer,
American Trucking Associations, Inc.
 - 3. R. A. Lill - Chief of Highway Engineering
American Trucking Associations, Inc.
 - 4. T. F. Creedon - Highway Engineering Advisor
Automobile Manufacturers Association
 - 5. John H. King - Manager, Motor Truck Division
Automobile Manufacturers Association

B. 1959-1962

1. Howard E. Hill - Managing Director,
Michigan State Highway Department
2. William W. McLaughlin - Testing and Research Engineer,
Michigan State Highway Department
3. O. L. Stokstad - Design Development Engineer,
Michigan State Highway Department
4. E. M. Noble - Highway Planning Survey Manager,*
Michigan State Highway Department

FINANCING

I Contracts and Expenditures

A. Trucking Associations' Sponsorship	\$ 109,737.41
University of Michigan Account 50824	
1 Sep 57 - 31 Aug 58 -- \$ 45,000.00	
1 Sep 58 - 30 Nov 58 -- 19,000.00	
1 Dec 58 - 31 Aug 59 -- 45,000.00	
(Overrun) -- 737.41	
B. Michigan State Highway Department Sponsorship	374,739.70
University of Michigan Account 03088	
1 Jul 59 - 31 Dec 59 -- \$ 29,061.56	
1 Jan 60 - 30 Jun 60 -- 26,908.50	
1 Jul 60 - 30 Jun 61 -- 140,577.64	
1 Jul 61 - 30 Jun 62 -- 142,196.27	
1 Jul 62 - 31 Dec 62 -- 35,995.73**	
	<hr/>
	\$ 484,477.11

* H. S. Bengry, 1959-60; A. C. Sherman, 1961

** December Estimate - \$6,500.00

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

PREFACE

It is the purpose of this five year summary to assemble and review without duplicating a large number and variety of reports that have been submitted during this period for the information and use of the Michigan State Highway Department and others who have had an interest in the study. The opening discussion is intended to present a resume which touches on the high points of the pavement performance study, its background, objectives, results obtained over the five year period, and their practical application to the design, construction, maintenance, and operation of a state highway system.

Three series of reports are included as an integral part of this five year summary. The published papers or those presented at meetings without publication in recognized proceedings have been assembled in their original form as a part of the review. The second series, Departmental Reports, with the few exceptions noted have had or are being given official distribution to those connected with the investigation in one way or another. Reports submitted as part of the five year summary have been bound separately to make them more readily available to those interested in the subject of any specific report.

The third series, listed as Supplementary Reports, represents miscellaneous dissemination of information in several forms including short letter-reports on problems of immediate interest and papers submitted for preliminary review which may or may not have been published in final form.

Some of this information may have had only limited departmental distribution and is not being included in this final assembly of reports other than by brief review.

Information given in the listed reports has been considered in preparing the review although specific reports may not be designated. In other cases, reference to specific reports may be made by number designation and the reader may go to the report itself for more detailed information. Finally, it may be pointed out that this review and those supplementary reports which have been given only limited distribution may be obtained by those who may so desire by application to the Michigan State Highway Department.

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

ACKNOWLEDGMENTS

During the five year period that this comprehensive study of pavement performance has been in progress there have been a number of agencies taking part in the joint effort and many individuals who have made important contributions to the project. Without their interest and support, it would have been impossible to carry this work to what it is hoped will be considered a successful conclusion. Preceding the text is an outline of project organization and financing; the supporting agencies and their representatives have been named and the magnitude of financial support of the project from several sources has been given.

The direct supervision of the project for the Michigan State Highway Department has been the responsibility of W. W. McLaughlin, Testing and Research Engineer. O. L. Stokstad, Design Development Engineer, has been a frequent advisor and co-worker whose efforts have been particularly valuable in applying the results of this research to the everyday problems and operations of the Highway Department. W. M. Aldous was Project Supervisor for the University of Michigan in 1957-1958; his initiative and ability played a large part in the planning and assembling of the project equipment and instrumentation. Henry W. Wallace, as Associate Research Engineer, has been Project Supervisor for the University of Michigan since 1959, and has been responsible for direct supervision and innumerable but important details of operation. John E. Allen, as Field Survey Supervisor, has been with the project from the beginning, and his

knowledge and experience with mechanical and electrical equipment as well as in supervision of field personnel has been invaluable to the project. Others on the research staff who have been engaged in the project work are too numerous to name individually, but it is their devotion to and interest in the work, beyond the basic requirements of their employment, that have been most important in accomplishing project objectives. Authorship of some of the supplementary reports will provide at least some recognition of their efforts.

From the standpoint of the University of Michigan, the project has provided the opportunity for a considerable number of graduate students whose field of interest was in soils and highway engineering to take part in productive research, gain practical experience, and supplement other sources of financial support for their education.

MICHIGAN PAVEMENT PERFORMANCE STUDY

FIVE YEAR SUMMARY

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 - 1. Routes and Mileage Surveyed
 - 2. Frost Sections
 - 3. Special Projects
 - 4. Pavement Inventory

- II List of Previous Reports
 - A. Publications and Papers
 - P-1 - "Pavement Profile Surveys to Correlate Michigan Design Practice with Service Behavior", Proceedings, Highway Research Board, Vol. 38, 1959. (Co-author, O. L. Stokstad)
 - P-2 - "Legal Weight Limitations on Motor Vehicles", Paper presented at 44th Annual Michigan Highway Conference, Grand Rapids, Michigan, March, 1959.
 - P-3 - "Service Behavior as a Criterion for Pavement Design", Paper presented at 48th Annual Meeting of Western Petroleum Refiners Association, San Antonio, Texas, March, 1960.
 - P-4 - "Cumulative Changes in Rigid Pavement with Age in Service", Highway Research Board Bulletin No. 328, 1962. (Paper presented at 41st Annual Meeting of Highway Research Board, Washington, D. C., January, 1962)
 - P-5 - "Design, Maintenance, and Performance of Resurfaced Pavements at Willow Run Airfield", Highway Research Board Bulletin No. 322, 1962. (Paper presented at 41st Annual Meeting of Highway Research Board, Washington, D. C., January, 1962)

P-6 - "The Michigan Pavement Performance Study for Design Control and Serviceability Rating", Proceedings, The International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1962.

B. Departmental Reports

- D-1 - Frost Displacement Profiles. September, 1959.
Revised, November, 1959.
- D-2 - Measurement of the Riding Quality of Bridge Decks.
November, 1959.
- D-3 - Cumulative Changes in Rigid Pavement with Age in Service. Preliminary Draft, January, 1960. Report Postponed to January, 1962.
- D-4 - A Special Report on Pavement Profiles of Ingham County Roads. December, 1959.
- D-5 - The Performance of US-31, Muskegon - Grand Haven Expressway, as Determined from Roughness Profiles. March, 1961.
- D-6 - The Performance of the Bay City - Midland Expressway as Determined from Roughness Profiles. March, 1961.
- D-7 - Load-Deflection Study of a Bituminous Pavement on M-55. April, 1961.
- D-8 - Bridge Deck Roughness Data for Grand Rapids Area Bridges. June, 1961.
- D-9 - Bridge Deck Roughness Data for Grand Blanc Area Bridges. October, 1961.
- D-10 - Performance of Detroit-Brighton Expressway on I-96 from Pleasant Valley Road to Novi Road as Determined from Roughness Profiles. December, 1962.
- D-11 - Special Roughness Profile Study - Fenton-Clio Expressway, US-23, and Battle Creek Bypass, I-94 (US-12). December, 1962.
- D-12 - The Performance of Benton Harbor - New Buffalo Expressway on I-94 from Stevensville to M-60 as Determined from Roughness Profiles. December, 1962.
- D-13 - The Performance of Muskegon - Grand Haven Expressway on US-31. (Special Study Project No. 1) December, 1962.

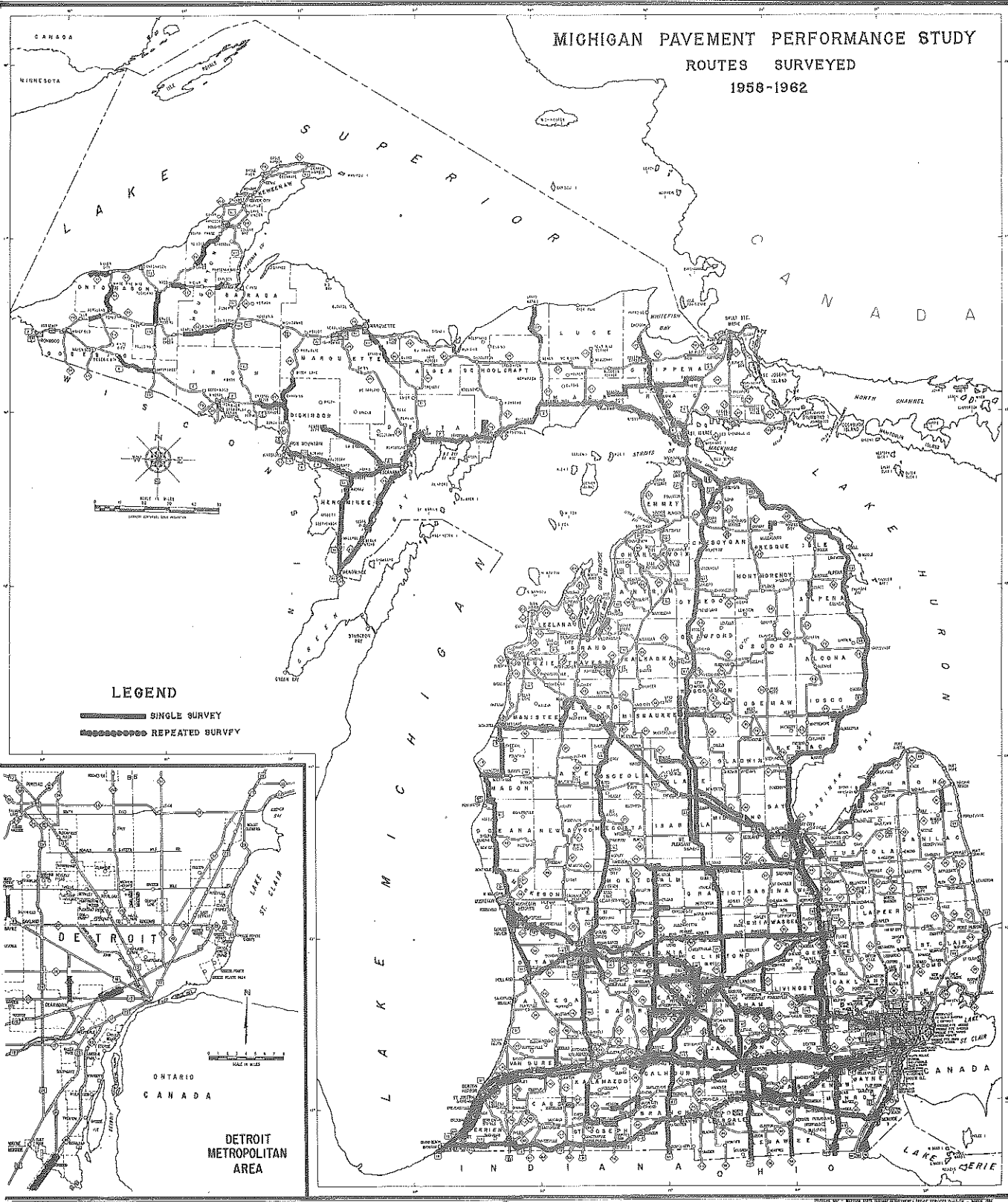
- D-14 - Load-Deflection Study of Selected Flexible Pavements (Special Study Projects No. 1, 3, and 5) December, 1962.
- D-15 - The Performance of Rockwood-Monroe Section - Detroit-Toledo Expressway, I-75, as Determined by Roughness Profiles. (Special Study Project No. 10) December, 1962.
- D-16 - Feasibility Study of Equipment for Recording Continuous Load-Deflection Profiles. December, 1962.
- D-17 - Comparative Performance of Reinforced Concrete Pavement and Plain Concrete Pavement with and without Bituminous Resurfacing - Special Sections on I-94, The Detroit Industrial Expressway. December, 1962.
- D-18 - Computer Program for Converting the Modified Michigan Roughness Profile to a True Surface Profile. December, 1962.
- D-19 - Manual for Operating and Servicing the Truck-Mounted Profilometer. December, 1962.
- D-20 - The Performance of I-96, Portland to M-66. (Special Study Project No. 12) December, 1962.

C. Supplementary Reports

- S-1 - Pavement Roughness on Concrete Bridge Decks. February 24, 1959.
- S-2 - Proposal for Continuation of Michigan Pavement Performance Study. December 9, 1959. Revised, December 23, 1959.
- S-3 - Summary of Pavement Profile Surveys, 1958-1960 - General Motors Proving Grounds, Milford, Michigan. November 23, 1960.
- S-4 - Progress Report and Present Status of Michigan Pavement Performance Study. December 14, 1960.
- S-5 - Riding Qualities of Bridge Decks - St. Joseph River Bridge on I-94 near Benton Harbor. January 9, 1961.
- S-6 - Fowlerville Automatic Scale - Truck Profilometer Profiles of March 4, 1961. March 7, 1961.
- S-7 - Road Classification and All-Season Trunkline. March 17, 1961.

- S-8 - Riding Qualities of Bridge Decks - I-96 Bridge over 28th Street, Grand Rapids, Michigan. March 23, 1961.
- S-9 - Fowlerville Automatic Scale - February 7, 1961 Truck Profilometer Data. March 27, 1961.
- S-10 - Riding Qualities of Bridge Decks - I-96 over Thornapple River. April 7, 1961.
- S-11 - Michigan Pavement Performance Study - Proposed Work Program for July, 1961 through June, 1962. April 15, 1961. Revised, May 1, 1961 and May 9, 1961.
- S-12 - Fowlerville Automatic Scale - May 5, 1961 Hand Profilograph Data. May 11, 1961.
- S-13 - Indiana Pavement Profiles - US-20. November 13, 1961.
- S-14 - Initial Profilometer Survey of December 20, 1961 - Southfield Expressway from Ford Road to Joy Road. December 27, 1961.
- S-15 - Profilometer Data on Bituminous Resurfacing Projects Fb 25011 C1-R and Mb 30062 C2-R. January 2, 1962.
- S-16 - Pavement Roughness - M-21 Exit Ramp to I-96. Hand Finish vs. Machine Finish. December 28, 1962.
- S-16B- M-21 Exit Ramp to I-96. Machine Finish vs. Hand Finish. July 13, 1962.
- S-17 - Cumulative Changes in Rigid Pavement with Age in Service. January 23, 1962. (Preprint copies of HRB Paper)
- S-18 - Design, Maintenance, and Performance of Resurfaced Pavements at Willow Run Airfield. February 14, 1962. (Preprint copies of HRB Paper)
- S-19 - Roughness of US-131 in Kent County, South of Grand Rapids. March 13, 1962.
- S-20 - The Michigan Pavement Performance Study for Design Control and Serviceability Rating. July 6, 1962. (Preprint copies of International Conference Paper)
- S-21 - Examples of Riding Quality of 1961 Bituminous Pavements - US-27 North of M-55; Control Sections 72014 C1 and 72014 C2, US-27. July 9, 1962.

MICHIGAN PAVEMENT PERFORMANCE STUDY
 ROUTES SURVEYED
 1958-1962



"The human understanding when it has once adopted an opinion . . . draws all things else to support and agree with it. And though there be a greater number and weight of instances to be found on the other side, yet these it either neglects and despises, or else by some distinction sets aside and rejects; in order that by this great and pernicious predetermination the authority of its former conclusions may remain inviolate."

Francis Bacon
(1561-1626)

"When you can measure that of which you speak, and express it in numbers, you know something about it."

Lord Kelvin
(1824-1907)

EVALUATION OF PAVEMENT PERFORMANCE
AS RELATED TO
DESIGN, CONSTRUCTION, MAINTENANCE, AND OPERATION

INTRODUCTION

Evaluation of pavement performance on a large scale by the procedures used in this investigation was undertaken in the belief that carefully controlled observations of existing pavement under actual service conditions and environment would provide the answers to some of the most perplexing problems facing the highway engineer. The first year, from September, 1957, through the first half of 1958, was devoted largely to selecting procedures and designing, planning, and assembling equipment. In spite of a disappointingly long shakedown period for the truck-mounted profilometer, considerable mileage of pavement profile was recorded in the first year and a half.

In the five years that the Michigan Pavement Performance Study has been in progress, almost 10,000 lane miles of profile have been recorded. The progress by years is shown in the following table; the routes surveyed are shown on the small scale map following the table of contents. On some of these routes only one lane has been surveyed, normally one of the traffic lanes. On a large part of the mileage, particularly on new construction and certain roads of special interest, all lanes, including both traffic and passing lanes, have been surveyed.

TOTAL MILEAGE OF RECORDED PAVEMENT PROFILE

1958	----	1,969.2
1959	----	2,128.2
1960	----	1,769.4
1961	----	2,366.8
1962	----	<u>1,535.6</u>
		9,769.2

This large mileage of recorded pavement profile and supplemental data represent a volume of basic information on pavement condition and performance, the value of which has been only partially utilized to date. This review and the accompanying supplementary reports will illustrate the use of this information in design, construction, maintenance, and operation of the Michigan trunk line system. However, its value as a pavement inventory and a foundation on which to build future applications of practical value can be realized only by its continued use and by keeping it up-to-date and growing as the highway system grows.

In the opening discussion of the Michigan Pavement Performance Study it is appropriate and useful to supply some background information as a matter of record. Condition surveys of existing pavements as a check on design and a basis for more effective utilization of natural conditions and materials in highway construction are not new. As pointed out in several of the published reports, this approach had been used for many years and was the fundamental basis for Michigan design of the roadway structure.

Prior to the current study, definite criteria for measuring pavement performance in a quantitative manner had been set up and put into practice under field conditions.^{1,2} The primary function of a pavement is

¹ W. S. Housel, "Report on the Evaluation of Service Behavior of Plain vs. Reinforced Concrete Pavement", University of Michigan Research Institute Report No. 2053-1-S, for Wire Reinforcement Institute, May, 1954.

² W. S. Housel, "Pavement Performance as Related to Design", Proceedings, Fortieth Annual Michigan Highway Conference, 1955.

to provide a smooth riding surface supplying safety, comfort, and economy to the highway user. Recognizing this, riding quality has been defined in terms of a Roughness Index (RI), expressing the cumulative or total inches of vertical displacement per mile measured from the recorded pavement profile.

It was also recognized that the structural properties of the pavement would control its ability to endure under the combined stresses of continuous load repetition and the rigors of its environment. It seemed logical that failure to survive or inadequacy as a structure would be reflected in cracking or loss of structural continuity even before riding quality was affected. Timely maintenance or corrective steps would depend on early identification of weakness, so a Continuity Ratio was adopted as an independent quantitative measure of structural adequacy. The continuity ratio was defined as the ratio of the uncracked slab length of a pavement divided by 15. The control length of 15 feet was selected as a measure of the normal subdivision of a rigid concrete slab due to shrinkage, warping, and curling under temperature, moisture, and other environmental influences. It was considered that such environmental effects did not reflect structural inadequacy; thus, slab lengths of 15 feet or more would not be considered evidence of structural weakness.

The adoption of these criteria and their application to condition surveys of existing pavements in 1957 at the beginning of the current survey was not a generally recognized approach, but definitely a minority viewpoint. Design committees of the Highway Research Board, as well as many others, had become committed to the road test approach. As a matter of fact, the first published paper, P-1, included in this report was presented by Mr. Stokstad and the writer by invitation in lieu of including

field surveys as an alternate to the satellite tests in the recommended procedures then being circulated by those committees to follow up the AASHO Road Test.

Having established criteria and general procedures for the pavement performance surveys, the truck-mounted profilometer with its electronic recording instrumentation was developed as the major piece of equipment. It was modeled after that designed by F. N. Hveem and used by the California Department of Highways. It was selected as the most practical under field conditions and state highway department operation to collect and record a large volume of pavement profile data. Many types of road roughometers have been described and used with varying success, but the choice had to be made from those which were readily available. There was little time to devote to devising and developing instrumentation, and the California machine was operating efficiently and, with some modifications, met the needs of the Michigan study.

Modifying the available provision for recording a continuous pavement profile in one wheel track, a double recording system was adopted which provided profiles in both the outer and inner wheel paths in one operation. Electronic integrating instrumentation was added to record the cumulative roughness in inches of vertical displacement for each quarter-mile. More details on the profilometer and its operation are given in the reports included as part of this summary.

USE OF PAVEMENT PROFILE SUMMARIES

The first objective of this review is to provide convenient access to the large volume of accumulated pavement performance data, the ultimate value of which will be realized only in proportion to its continued use.

Summary of Pavement Survey Data

The Control Section Log Records of all roads which have been surveyed during the past five years have been assembled to serve as the basic index to the Summary of Pavement Survey Data. These Control Section Log Records are the standard forms on which the history and present status of all contract sections in the Michigan trunkline system have been recorded. They are in fact a physical inventory of the state highway system and are in constant use by the Department in compiling highway statistics relating to the physical condition of Michigan roads and future needs.

These records, while somewhat voluminous, are the most convenient and readily available means of identifying and locating any particular section of state trunkline system and obtaining the essential facts concerning it. In the compilation of Control Section Log Records included in this review, all construction contracts for which pavement profiles have been recorded are shown with the mileage, number of lanes surveyed, the date or dates of surveys, and the chart roll number on which the pavement profile is recorded. There are 1700 rolls of pavement profile charts on file at the Willow Run Soils and Paving Laboratory, with a total of some 32 miles of chart covering 9,769 miles of recorded pavement profile. At the present time, these basic records are in the custody of the University and are adequately housed and readily available for reference as long as present space assignments are maintained.

The next step in utilization of the pavement profile data involves the use of the Summary of Pavement Survey Data. This summary is compiled in five sections, one for each of the five years from 1958 through 1962. In it are tabulated in detail all of the data gathered in connection with the pavement profile surveys. A typical data sheet is included in this review as

Appendix B. In 1959 this table was revised to its present form, in which the first five columns give the identification information, including route number, contract number, pavement type, year built, and district and control number. The next nine columns give corollary information for each profile survey, including roll number, date of survey, weather conditions, pavement condition, temperature of air, pavement, and subgrade, length of survey, and direction and lane number. The next four columns give the wheel path and its three roughness index values, in inches of cumulative vertical displacement per mile: the average for the contract section, and the minimum and maximum values for the smoothest and roughest quarter mile, respectively.

The next column gives the adequacy classification established for pavement evaluation or rating used in connection with the pavement performance study. (See Reports P-1, P-2, and P-3) The last three columns give the data on structural continuity of the pavement, including the continuity ratio of the original or "as built" pavement and the continuity ratio and cracking index at the time of the survey.

At the beginning of the tabulations for each year, a special listing has been compiled to serve as an index to the data sheets which follow. The routes surveyed are listed by number, e.g., US-2, M-21, etc., followed by page number and location where the particular section will be found. The tabulation also shows the month of the survey and the mileage surveyed for each route by month and the total for the year. In the index tables, the trunklines surveyed are assembled in three groups, designated as frost sections, special projects, and pavement inventory. This grouping was not completely established in the first several years, but has been followed in the tabulation of data since 1959. The tabulated pavement

survey data have been assembled under this same grouping system for the purpose of making more accessible the data related to specific subjects of interest.

The frost sections refer to projects included in special studies of frost displacement. Special projects are those selected by O. L. Stokstad in the last several years for special consideration because of design features of particular interest, as listed in Appendix A. Roads not falling in either of the first two categories are referred to simply as part of the pavement inventory involved in the long range use of pavement profile data. As in the index summaries at the beginning of each year's tabulation, the tabulations of detailed data are assembled in the numerical order of the route numbers.

UTILIZATION OF PAVEMENT PROFILE DATA

In the title of this review it is indicated that pavement performance data finds application in design, construction, maintenance, and operation of highways. It is not always recognized that a highway department actually has four major functions which may be so delineated in describing different phases of its operations. However, in planning this review of the pavement performance study, it did appear not only appropriate but necessary to so classify highway activities in order to accurately illustrate the usefulness of pavement profile data.

Design Correlation

The primary objective of the Michigan Pavement Performance Study was to provide more accurate and discerning techniques for checking pavement design and detecting weakness in service performance. It seemed

entirely logical that changes in the pavement surface or profile would reflect the integrated result of the various stresses and strains to which a pavement is subjected, originating from variations in the supporting subgrade below or from repeated load application and weather cycles above. While the uncontrolled variables of environment seem much more difficult to gauge than the more precise relationships of applied load and reaction in the pavement structure, they are nevertheless the influences under which pavements must endure. Every one of these variables, controlled or uncontrolled, has its effect on the pavement surface; whether or not they can be identified is a test of the observer and the methods of analysis brought to bear on the problem.

At first it was thought that an initial reference profile would have to be recorded and then, after a sufficient period of time had elapsed to produce a measurable change, a subsequent profile would measure the change. This meant that a period of years, perhaps many, would be required before definitive changes would become apparent. It came then as an unexpected bonus when, after a considerable volume of profile data had been accumulated, it turned out that roads which had been in service for varying periods of time under varying conditions of service and environment fell into definite patterns of behavior that could be defined in terms of pavement roughness, structural continuity, and related characteristics of the pavement. This discovery opened the door to a great storehouse of valuable data when it became apparent that the entire highway system was the final testing ground and that the many years these roads had already been subjected to traffic was the ultimate road test, which was merely awaiting analysis.

From the standpoint of pavement design, the reports which are a part of this review contain many examples in which the responsible factors in pavement performance have been clearly identified in terms which demonstrate them to be subject to design control. The overriding importance of soil conditions and drainage stands out in many of these examples and demonstrates the soundness of Michigan design, which follows the unspectacular but time-tried principle that it is the subgrade which "does, in fact, carry the road and the carriage also".

A few illustrations drawn from the supplementary reports and summarized briefly may be used for illustration. The following table lists the correlation between riding quality and drainage taken from Report P-1. It should be noted that drainage as listed includes internal drainage as controlled by soil texture and ground water level.

Route Number	Figure Number	Service Period Years	Roughness Index Inches per Mile		Drainage	Riding Quality
			OWP	IWP		
US-112	7A	32	72	75	Fair	Very Good
	7B	32	291	395	Poor	Prohibitive*
M-25	8A	28	91	66	Excellent	Good to Very Good
	8B	36	218	175	Poor	Very Poor
M-41	12A	22	383	365	Poor	Prohibitive*
	12B	22	73	75	Good	Very Good
M-36	16A	19	84	77	Excellent	Good
	16B	19	363	282	Poor	Prohibitive*

* Outside the tentative rating scale

Other design correlations presented in Report P-1 include the poor performance of short concrete slabs without load transfer at the joints (See Fig. 17), as compared to the performance of another road (See Fig. 12B), also having comparatively short slabs, but with load transfer provided. While there were other factors involved to some degree, the contrast in these two roads was so sharp that the comparison is still valid, with the first pavement becoming extremely rough in its period of service and the second maintaining very good riding quality over a considerably longer period of time.

The most interesting feature of the rough pavement in the preceding example is the characteristic saw-tooth pattern produced by tilting and faulting of the short slabs. This illustrates the unique value of an actual pavement profile which goes beyond the roughness index derived from it. Such a profile is a realistic picture of the pavement itself and a physical condition that has been produced by some specific factors among a variety of influences that may have been present. Such a profile is as individualistic as a signature, reflecting characteristics that can be fully appreciated only by examining the profile itself and the physical conditions associated with it in whatever detail is necessary to reading the pavement's past history.

This leads to perhaps the most important consideration in evaluating pavement performance from condition surveys. The roughness index or some other quantity derived from the pavement survey may adequately reflect the present riding quality or serviceability of the pavement. This in itself is an important consideration and may be useful in several respects. However, from the standpoint of pavement design one must know not only the extent to which a pavement has deteriorated or lost riding quality but why

it has reached that particular level of serviceability. This is the crux of the situation and the point at which the actual pavement profile shows its real value, as it may provide an insight into events in the past history of the pavement which have left no other clues. (See Fig. 13 and Page 17, Report No. P-6)

There are a number of other examples of the surprising consistency with which accurate pavement profiles and the quantitative criteria derived from them single out abnormalities in pavement behavior or unusual conditions which have affected pavement performance. For more complete study of all such information, reference should be made to the reports submitted as part of the five year summary.

The discussion of the evaluation of pavement performance as related to design may be concluded by summarizing some of the major findings on design correlation during the five year study.

1. Michigan's current design standards for rigid pavements carrying present legal axle loads are adequate for all-season service without load restriction. In thousands of miles of pavement profile surveys of concrete pavements which by design or natural conditions meet these standards, there has been no significant evidence of loss in serviceability over periods up to thirty years due to unlimited repetition of legal axle loads.
2. On the other hand, concrete pavements that have been designed and built to these standards suffer a cumulative increase in roughness of 4 to 5 inches per mile per year due to environmental and climatic factors. Chief among these deteriorating influences are the temporary pavement displacements caused by frost action and temperature differentials. Frost displacement appears to originate in the freezing of moisture which accumulates in the subgrade and granular bases and subbases immediately beneath the pavement surface. Temporary displacements, which reach a maximum in late winter, largely disappear in the summer but leave a residual roughness which is the primary source of the

cumulative loss in riding quality. (See Report P-4, Figs. 1 through 9)

3. Flexible pavements with bituminous surfaces built to equivalent all-season standards for present legal axle loads show comparable performance characteristics and evidence of cumulative changes of about the same order of magnitude. The mechanics of flexible pavement are such that cumulative loss of riding quality is not produced by the same type of residual roughness as in rigid pavements but, on the other hand, there is some evidence of measurable differentials in roughness due to traffic. These considerations and results from short time studies are inconclusive, although they give some promise that the loss in riding quality may proceed at a lesser rate than in rigid pavements. However, sufficient data over longer periods of service and comparable conditions are still to be accumulated to supplement the present study before these important questions can be answered. (Report P-6, Figs. 14 through 18 and Table 2)

Construction Practice and Pavement Performance

It has been stated that pavement performance surveys have shown that current design standards provide adequate load-supporting capacity. However, these same surveys show that in terms of potential riding quality, the benefits of adequate design are not being fully realized. Involved in this problem are plans and specifications and construction control which fail to achieve the maximum potential performance from well-designed pavements. This appears to fall largely in the field of construction practice so is being discussed under that heading. The accumulation of a large volume of pavement profile data has brought to light, or perhaps emphasized by supplying the figures, several deficiencies in construction practice.

Granting that the end product in building a pavement is riding quality, then current specifications and inspection procedures fail to

conserve or protect a considerable percentage of a pavement's potential life. "Built-in" roughness has become a common term only since pavement condition surveys have included accurately recorded profiles and the roughness index associated with them. One of the first observations that was somewhat surprising to those unaware of the problem was the sharp contrast between the roughness index of bridge decks and bridge approaches and that of the adjacent roadway pavements finished with conventional paving equipment. Another observation on "built-in" roughness is the almost universal characteristic of greater roughness in the outside wheel path or the edge of the pavement. This has been taken to indicate that irregularities in form setting were more completely reproduced close to the forms and damped out, to some degree, in the center of the concrete slab.

As data accumulated in considerable volume, they have been reported to the Department so that possible corrective measures could be studied. Departmental Reports D-2, D-8, and D-9 and Supplementary Reports S-1, S-5, S-8, and S-10 have all reported field survey data compiled on the roughness of bridge decks and bridge approaches. Summarizing of representative data from these reports shows roughness indexes ranging from about 100 to 300, averaging around 200 inches per mile. In terms of the tentative rating of riding quality, the average performance of bridge decks would be described as very poor to extremely rough. Bridge approaches fall in about the same classification.

Turning next to hand finishing of paving, which occurs in special cases where machine finishing is impossible or has been eliminated by special permission, the results are comparable to those obtained on bridge decks. Supplementary Reports S-16 and S-16B dealt with the roughness of hand finished pavement on the ramps of the grade separation at the

intersection of M-21 and I-96, near Grand Rapids. The roughness on the first ramp, reported in S-16, varied from 167 to 191 inches per mile, which would be rated from poor to very poor. The second ramp, reported in S-16B, showed a roughness index varying from 145 to 154, falling on the border line between acceptable and poor, but certainly not to be considered as high quality work.

Occasionally some unusual conditions come to light as pavement profiles are being analyzed which may be related to construction methods. Such a case has been described in Supplementary Report S-19, and also in Report P-6 (See Fig. 13 and Page 17). In this case, a comparatively new pavement on US-131 was reported by the Department as being extremely rough, and a pavement profile survey was requested. On the basis of the profile, this section was rated extremely rough, with a roughness index of 233 inches per mile and a saw-tooth pattern, particularly in the outer wheel path, almost identical to that caused by the tilting of short slabs previously reported on US-24A and Shown in Fig. 13A in Report P-6. The close comparison in terms of roughness index and profile was not repeated on the inner wheel path of the US-131 pavement, where the saw-tooth pattern was damped out and the roughness index dropped to 105 inches per mile. The sharp displacements in the outer wheel path were repeated at intervals of approximately 10 feet. Although there were no joints or cracks in the pavement to produce faulting at these intervals, spacing of these displacements did coincide with the 10 foot length of the sections of the paving forms. The evidence pointed to careless form setting and it was concluded that this was the source of this abnormal and unusual built-in roughness. Parenthetically, it may here be noted that the considerable effort devoted to grinding down high spots did not appear to have been particularly effective in producing improved riding quality.

Supplementary Report No. S-14 is of interest as an illustration of high built-in roughness resulting from a combination of conditions during construction, which may or may not be justified. Initial roughness ranged from 107 to 124 inches per mile, with an average of 115 for all lanes. This project was discussed with the project engineer who considered that the high roughness was due to inadequate equipment and inexperienced workmen.

The principal item of objectionable equipment was the "bull float" (longitudinal float) finishing machine which was also in poor condition. This type of equipment is not suited to finishing steep alternating grades (3 per cent) with short vertical curves and has been prohibited on subsequent work of this nature. The "bull float" has a 10-foot long straight float positioned at a slight angle to the center line. This oscillates longitudinally as it moves back and forth across the pavement and simultaneously advances. (See Fig. 24-11, Page 24-21, Wood's Highway Engineering Handbook). The front end tends to gouge into the slab going uphill and the rear gouges going down. The finished pavement surface passes the 10-foot straight edge test easily, but may still be rough riding.

In discussing examples where construction practice has resulted in abnormally high built-in roughness, it would distort the picture to ignore the equally numerous examples where high grade workmanship has produced superior riding quality. The fact that there are such examples is particularly significant because it demonstrates that it is within the range of common practice in pavement construction to produce such superior results. There is then all the more reason why poor workmanship and inferior riding quality need not be accepted.

Several examples of superior riding quality may be cited in both concrete pavements and asphalt pavements. In Fig. 1 in Report P-4 there are

identified a group of three concrete pavements, discussed on Page 13, built with roughness indexes of 50 inches or less per mile and five other projects which, allowing for normal increase in roughness, would have had "built-in" roughness of less than 50 inches per mile. It is significant that five of these eight projects were built by two contractors who had established a reputation for doing high quality work. Other illuminating examples were also cited in the same report in the discussion of quality of workmanship.

Other examples of excellent construction performance were given in Departmental Reports D-5 and D-6, where the contractors made a special effort to provide superior riding quality. On US-31, the Muskegon - Grand Haven Expressway, a heavy-duty asphaltic pavement, the initial roughness index values ranged from 20 to 40 inches per mile. On the Bay City - Midland Expressway, a concrete pavement, the average roughness index values ranged from 34 to 58 inches per mile. In terms of maximum and minimum for any quarter mile, roughness index values ranged from 20 to 84 inches per mile, indicating less uniformity in finishing than on the US-31 flexible pavement. Supplementary Report No. S-21 presents data on a number of contracts totalling more than 30 miles of bituminous expressway construction on I-75 or US-27 in which the job average of roughness index values ranged from 17 to 49 inches per mile, with only a few quarter mile maximum values above 50.

Other observations of direct correlation between pavement performance and construction conditions are given in several reports on special projects, some of which will be cited as examples to illustrate the more prevalent sources of poor performance which appear to be related to construction practice.

The Fenton - Clio Expressway on US-23, now I-75, discussed in Departmental Report No. D-11, has been the source of comment by a number of

observers reporting certain sections south of Flint which have shown abnormal increases in roughness and other signs of deterioration. Mr. Stokstad first called this to the attention of the Pavement Performance Study group in his memorandum of March 14, 1960. At that time he commented on the number of pop-outs and numerous transverse cracks; he suggested frost heaving, settlement, and perhaps inferior aggregates as possible contributing factors.

Subsequent surveys reported in D-11 confirm these observations and, as shown in Table III, there are significant differentials in both the roughness indexes and continuity ratios in the sections south of M-78, toward Fenton, and the sections north of Flint. In the same table, the grouping of contractors is indicative of their general performance on other projects and is further evidence that "built-in" roughness may be as much a reflection of the characteristics of the contractor as it is of physical conditions associated with the project.

On the other hand, it is equally important to identify the particular elements in pavement construction which provide the opportunity for poor workmanship and are thus a primary source of poor performance. Enough has been said of built-in roughness as an immediate result of careless finishing.

Attention may next be given to those factors which result in early and excessive deterioration in the pavement surface. Non-uniform compaction of granular bases and subbases and failure to provide uniform subgrade support for the pavement structure are the most familiar sources of poor pavement performance. An abnormal decrease in structural continuity shown by excessive crack development and deterioration of the pavement surface may be due to inferior concrete, non-uniform settlement of the supporting subgrade and bases, or a combination of these two basic deficiencies. There are a number of examples of this in the series of reports submitted in the course

of the pavement performance study and doubtless many more in the pavement profile data that have not yet been analyzed.

Several examples may be selected for illustration. Perhaps the most striking example is the rapid deterioration of the Detroit Industrial Expressway, from Willow Run to Detroit. Built during the war years, the sand subbase over clay was adequate in thickness; however, failure to provide adequate and uniform compaction through field density control, combined with the elimination of steel reinforcing and further complicated by poor control of concrete mixtures, made the poor performance inevitable. These conditions were clearly revealed by comprehensive investigations subsequently made by the Department. Regardless of whether or not these conditions could be excused as emergency construction, the results were nevertheless revealing as the consequence of poor construction practice.

After this pavement had been stress-conditioned through years of service under heavy traffic, it was rehabilitated by bituminous resurfacing to recover acceptable riding quality. It was hoped that it could then provide a period of years of improved service without rapid deterioration. The results presented in Departmental Report D-17 are rather fragmentary, but the abnormally high rate of increase in roughness of the plain concrete sections is not an encouraging indication. As shown in Table 1 and Fig. 4, the newer reinforced concrete pavement shows an average increase in roughness of 4.5 inches per mile per year, while the older plain concrete, resurfaced in 1955-56, shows an increase in roughness about three times as great.

Another of the "Special Projects" selected by Mr. Stokstad for close attention was on I-75, the Detroit-Toledo Expressway, and is briefly reported in Departmental Report No. 15. Again, the early results are not

encouraging, although it isn't clear as yet whether the excessive cracking is due to deficiencies in design or in construction. The increase in roughness index has not yet been sufficient to reveal lack of subgrade support and it may be some years before comparative results become definitive.

Application of Pavement Profile Data to Maintenance

Data from condition surveys of existing roads are of direct value in several phases of maintenance, with particular reference to the pavement structure. The rate of change in both roughness and structural continuity, when compared with normal cumulative changes, may reflect unfavorable physical conditions or weakness in design and construction that may be possible to correct. Cracking in concrete pavements due to environmental factors or load repetition or to the combination of both is a natural development; hence, joint and crack maintenance is accepted as normal and considered a routine operation in the early stages of pavement life. In older pavements or in those which for one reason or another are subject to excessive cracking, filling of joints and cracks may become ineffective or prohibitive. Such conditions may be the signal for resurfacing or early reconstruction, beyond the scope of maintenance.

In bituminous pavements, both roughness and loss of structural continuity have significance comparable to those in rigid concrete pavements, but the evidence of structural deterioration is not as easy to evaluate in quantitative terms. Identification and classification of cracking, patching, and other types of surface deterioration in bituminous pavements have been worked out by technical committees of the Highway Research Board and also in connection with the AASHO Road Test. The final reports from that test are perhaps the most readily available and the most authoritative for present use. Consequently, they will be considered in some detail.